Transportation Association of Canada

# Synthesis of Practices for Work Zone Speed Management

November 2005

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Transportation Association of Canada
2323 St. Laurent Blvd.
Ottawa, ON K1G 4J8
Tel. (613) 736-1350 ~ Fax (613) 736-1395
www.tac-atc.ca

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<tr><td colspan="2">Author(s)<br>Milton D. Harmelink<br>Rodney Edwards</td><td colspan="3">Corporate Affiliation (s)<br><br>Arges Training & Consulting</td></tr>
<tr><td colspan="2">Sponsoring/Funding Agencies and Addresses<br><br>Transportation Association of Canada (TAC)<br>2323 St. Laurent Blvd.<br>K1G 4J8</td><td colspan="3">Performing Agencies Names and Addresses<br><br>Arges Training & Consulting<br>106 Hollyrood Hts. Dr<br>Mississauga, ON<br>L5G 2H4</td></tr>
<tr><td colspan="4">Abstract<br><br>Speeding in work zones is one of the most common traffic violations as observed by road builders and road maintenance crews. The practice creates an unsafe situation for road crews and all types of road users.<br><br>The Synthesis of Practices for Work Zone Speed Management reviews work zone speed management efforts in Canada and the United States. The report provides an overview of technologies and methods for managing speed in work zones, with topics ranging from posted speed limit reductions and narrowing lanes to portable variable message signs and enforcement. In addition to work zone management, the report discusses other methods for speed management, including merge control, driver and worker education, and real-time traffic information systems. The report also provides a number of conclusions and recommendations based on the synthesis, which identify some of the key problems and solutions.</td><td>Keywords<br><br>Traffic Control<br>Construction Site<br>Speed Limit<br>Driver Information<br>Electronic Driving Aid<br>Speed Control (struct elem)</td></tr>
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Michael Balsom

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Synthesis of Practices for Work Zone Speed Management


| Auteur (s) | Affiliation (s) |
|---|---|
| Milton D. Harmelink<br>Rodney Edwards | Arges Training & Consulting |

| Nom et adresse de l'organisme parrain | Nom et adresse de l'organisme exécutant |
|---|---|
| Association des transports du Canada<br>2323, boul. St-Laurent<br>Ottawa K1G 4J8 | Arges Training & Consulting<br>106 Hollyroad Hts. Dr<br>Mississauga, ON L5G 2H4 |



Résumé

Aux dires des constructeurs de routes et des équipes d'entretien de ces dernières, les excès de vitesse dans les zones de travaux constituent l'une des infractions les plus courantes aux règlements de la circulation, en même temps qu'une menace pour la sécurité des équipes de travailleurs routiers et de tous les types d'usagers de la route.

Cette *Synthèse des pratiques de gestion de la vitesse de circulation dans les zones de travaux* propose un examen des efforts consentis dans ce domaine au Canada et aux États-Unis. Le rapport brosse un aperçu des technologies et des méthodes utilisées dans ce contexte, en explorant notamment différents sujets connexes dont les réductions des limites de vitesse affichées, la diminution de la largeur des voies, les panneaux mobiles à messages variables et les mesures coercitives (forces de l'ordre) de respect des limites de vitesse prescrites dans les zones de travaux. Outre la gestion desdites zones, le rapport traite par ailleurs de certaines autres méthodes de gestion des vitesses, y compris le contrôle de la circulation convergente, l'éducation des conducteurs et des travailleurs ainsi que les systèmes d'information en temps réel sur la circulation. Le rapport propose enfin un certain nombre de conclusions et de recommandations fondées sur la synthèse proprement dite, conclusions et recommandations qui cernent certains des principaux problèmes, solutions à l'appui.



Mots-clés

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de la circulation
Chantier
Limitation de vitesse
Information du conducteur
Aide electronique a la conduite
Brise vitesse


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## PROJECT STEERING COMMITTEE

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Bernie Clancey, Chair
Nova Scotia Transportation and Public Works

Rob Bradford
Canadian Construction Association

Gord Cebryk
City of Edmonton

Richard Chow
Alberta Infrastructure and Transportation

Nathalie Gosselin
Ministère des Transports du Québec

Paul Hunt
Saskatchewan Highways and Transportation

Michel Masse
Ministère des Transports du Québec

John Morrall
Consultant

Kevin Ramsay
City of Vancouver

Brad Sacher
Manitoba Transportation and Government Services

# EXECUTIVE SUMMARY

The Transportation Association of Canada (TAC) and a number of Canadian jurisdictions have recognized the need to provide national guidance on work zone safety practices, specifically on the speed management topic. The long-term objective of the Road Safety Standing Committee of TAC is to develop a Best Practice Guide for Work Zone Safety. The first chapter to be developed is intended to address work zone speed control measures. The material from this Synthesis of Practices document will act as a baseline for the development of this chapter.

The scope of this project, advanced through the Road Safety Standing Committee of the Transportation Association of Canada, is to review the current practices, research studies and publications on work zone safety and speed control. The Geometric Design and Traffic Operations and Management Standing Committees also support this project.

The report provides an overview of work zone collisions and fatalities in Canada and the U.S., to the extent that data permit. The most frequent traffic crashes in work zones are rear-end collisions, followed by sideswipe collisions.

Roadway work zones should be designed around the basic principles of worker safety, motorist safety, and motorist mobility.

Work zone speed management is one of many aspects of work zone safety. There are many issues involved in work zone speed management. These include:

1. philosophy of work zone speed management (to what extent is it desirable and feasible to try to reduce work zone speeds?), and method for determining where work zone speed limit reductions should be applied
2. division of responsibilities regarding work zone safety
3. roadway type (urban or rural, high speed or low speed, freeway or non-freeway)
4. driver attitudes to work zone speed reductions
5. design of the work zone
6. provision of work zone information to the public, including locations, duration, effects, etc.
7. credibility of work zone signing and posted work zone speeds
8. techniques/methodologies for reducing work zone speeds
9. work zone speed enforcement

The first seven issues listed above are discussed in section 1.0. The last two, point 8 (techniques/ methodologies for reducing work zone speeds) and point 9 (work zone speed enforcement), are the main focus of this report and are discussed in sections 3.0 and 4.0.

The methodology used was to conduct a survey of practices of Canadian provinces and municipalities (section 5.0), along with an extensive literature review (section 6.0), from which the synthesis of practice, including recommendations on the most effective speed management practices, was developed.

Work zone speed management strategies reviewed and discussed include the following: posted speed limit reductions in work zones; enforcement of reduced speed limits in work zones; actual speed display, with regulatory posted speeds; portable variable message signs; narrower lanes; pilot vehicles and pace vehicles; optical speed bars; and portable rumble strips.

Other speed-related safety measures briefly reviewed included: advance warning of work zone; innovative devices for worker and motorist safety (ITS); merge control; queue warning and real-time traffic information; work zone intrusion alarms; work zone safety training; and driver education. Non-speed-related safety measures reviewed briefly included road closures and better information to the traveling public.

Of the work zone speed management techniques reviewed in the literature, and listed in the questionnaire survey, the most effective techniques were found to be:

- reduced regulatory speed limits together with police enforcement;
- portable variable message signs on the approach to the work zone;
- pace vehicles and pilot vehicles;
- radar speed measurement and speed display.

It was found that the effectiveness of any measure is enhanced by police enforcement or presence.

Techniques which were found to be less commonly used, but reasonably effective, were:

- photo radar
- narrow lanes (to a minimum of 3 m)
- portable rumble strips
- ITS applications

Techniques that were found to be less effective were:

- advisory speed limits
- optical speed bars
- variable speed limits (comprehensive test results not yet available)
- increased fines for work zone speeding (effectiveness depends on enforcement)

Section 4.0 contains 42 conclusions and recommendations derived from the synthesis of practices.

# SOMMAIRE

L'Association des transports du Canada (ATC) et un certain nombre d'administrations routières canadiennes ont reconnu le besoin de formuler des conseils de portée nationale sur les pratiques de sécurité dans les zones de travaux, et plus spécifiquement sur la gestion de la vitesse de circulation dans lesdites zones. L'objectif à long terme que poursuit le Comité permanent de la sécurité routière de l'ATC est d'élaborer un guide des meilleures pratiques de sécurité dans les zones de travaux. Le premier chapitre du futur guide doit traiter des mesures de contrôle de la vitesse de circulation dans les zones de travaux. L'information contenue dans la présente synthèse des pratiques servira de fondement à l'élaboration de ce chapitre.

Mis de l'avant par l'entremise du Comité permanent de la sécurité routière de l'Association des transports du Canada, ce projet a pour but de passer en revue les pratiques actuelles ainsi que les rapports de recherche et les publications portant sur la sécurité et le contrôle de la vitesse de circulation dans les zones de travaux. Le Comité permanent de la conception géométrique et le Comité permanent des techniques et de la gestion de la circulation appuient également le projet.

À la lumière des données disponibles sur le sujet, le rapport brosse un aperçu des collisions et décès qui surviennent dans les zones de travaux au Canada et aux États-Unis. Les accidents de la circulation les plus fréquents dans ces zones sont d'abord les collisions par l'arrière, puis les collisions latérales.

Les zones de travaux routiers devraient être aménagées selon trois principes de base : la sécurité des travailleurs, la sécurité des automobilistes et la mobilité des automobilistes.

La sécurité des zones de travaux regroupe de nombreux aspects, notamment la gestion de la vitesse de circulation dans ces zones, un domaine qui lui-même comporte plusieurs volets dont ceux ci-après.

1. La philosophie de gestion de la vitesse de circulation dans les zones de travaux (dans quelle mesure est-il souhaitable et faisable d'essayer de réduire la vitesse dans ces zones?) et la méthode de détermination des endroits où les diminutions des limites de vitesse devraient être appliquées dans ces zones.
2. Le partage des responsabilités concernant la sécurité dans les zones de travaux.
3. Le type de route (route urbaine ou rurale, route à grande ou à faible vitesse, autoroute ou route ordinaire).
4. Les attitudes des conducteurs vis-à-vis les diminutions des limites de vitesse dans les zones de travaux.
5. La conception des zones de travaux.
6. La diffusion auprès du public d'informations sur les zones de travaux, y compris l'emplacement de ces dernières, la durée des travaux, leurs incidences sur la circulation, etc.
7. La crédibilité de la signalisation dans les zones de travaux et des vitesses qui y sont affichées.
8. Les techniques/les méthodes de diminution de la vitesse dans les zones de travaux.
9. Mesures coercitives (forces de l'ordre) de respect des limites de vitesse prescrites dans les zones de travaux.

Les sept premiers points susmentionnés sont examinés à la section 1.0. Les deux derniers points, soit le point 8 (Les techniques/les méthodes de diminution de la vitesse dans les zones de travaux) et le point 9 (Mesures coercitives (forces de l'ordre) de respect des limites de vitesse prescrites dans les zones de travaux) forment l'objet principal de ce rapport et sont analysés aux sections 3.0 et 4.0.

La méthodologie utilisée à l'appui de la présente synthèse a pris la forme d'une enquête sur les pratiques employées par les provinces et les municipalités canadiennes (section 5.0) ainsi que d'une analyse documentaire exhaustive (section 6.0). De là, la présente synthèse des pratiques a été élaborée, recommandations à l'appui sur les pratiques les plus efficaces de gestion de la vitesse de circulation dans les zones de travaux.

Les stratégies de gestion de la vitesse de circulation dans les zones de travaux qui ont été examinées et débattues s'entendaient notamment des suivantes : diminution des limites de vitesse affichées dans les zones de travaux; mesures coercitives (forces de l'ordre) de respect des limites de vitesse réduites dans les zones de travaux; affichage de la vitesse réelle et de la vitesse prescrite; panneaux mobiles à messages variables; voies de moindre largeur; véhicules d'escorte et véhicules pilotes; détecteurs optiques de vitesse; bandes d'alerte portables.

Parmi les autres mesures de sécurité associées aux vitesses de circulation dont il est brièvement question dans le document, mentionnons : la signalisation avancée des zones de travaux; les dispositifs innovateurs de sécurité pour les travailleurs et les automobilistes (SIT); le contrôle de la circulation convergente; la diffusion d'avis de file d'attente et d'informations en temps réel sur la circulation; les dispositifs d'alarme contre les intrusions dans les zones de travaux; la formation sur la sécurité dans les zones de travaux et l'éducation des conducteurs. Certaines mesures de sécurité non liées aux vitesses de circulation ont également été explorées brièvement, dont les fermetures de route et la diffusion de meilleurs renseignements aux voyageurs.

De toutes les techniques de gestion de la vitesse de circulation dans les zones de travaux qui ont été analysées dans la documentation et mentionnées dans le questionnaire d'enquête, les plus efficaces sont à l'évidence les suivantes :

- diminution des limites de vitesse prescrites et participation/présence des forces de l'ordre pour en garantir le respect (mesures coercitives);
- utilisation de panneaux mobiles à messages variables à l'approche d'une zone de travaux;
- utilisation de véhicules pilotes et de véhicules d'escorte;
- mesure de la vitesse de circulation au moyen d'un radar et affichage de la vitesse.

Il appert que l'intervention concrète ou même la simple présence sur les lieux d'agents de police contribue à l'efficacité de toute mesure.

Au nombre des techniques d'utilisation moins courante mais qui sont néanmoins raisonnablement efficaces, mentionnons :

- le photoradar;
- le rétrécissement des voies de circulation dans le sens de la largeur (jusqu'à une largeur minimale de 3 m);
- l'utilisation de bandes d'alerte portables;
- différentes applications de SIT.

Les techniques jugées les moins efficaces sont :

- les limites de vitesse recommandées;
- les détecteurs optiques de vitesse;
- les limites de vitesse variables (résultats d'essais approfondis non disponibles pour l'instant);
- augmentation des amendes pour excès de vitesse dans les zones de travaux (l'efficacité de cette mesure est fonction de la diligence des forces de l'ordre).

La section 4.0 contient 42 conclusions et recommandations dérivées de la synthèse des pratiques.

# 1.0 INTRODUCTION & BACKGROUND

## 1.1 Background

The Transportation Association of Canada (TAC) and a number of Canadian jurisdictions have recognized the need to provide national guidance on work zone safety practices, specifically on the speed management topic. The long-term objective of the Road Safety Standing Committee of TAC is to develop a Best Practice Guide for Work Zone Safety. The first chapter to be developed is intended to address work zone speed control measures. The material from this Synthesis of Practices document will act as a baseline for the development of this chapter.

It is generally acknowledged that work zones are more hazardous than other sections of road, although statistics on work zone collisions and collision rates are difficult to obtain, due to definition, recording, and reporting problems. Reasons for increased work zone hazard, relative to other road sections, include the unexpected and unfamiliar nature of specific work zones, violations of driver expectations, and the presence of workers.

A perspective on traffic safety and traffic hazard in work zones is presented in Table 1, based on Canadian and U.S. statistics, where available.

**TABLE 1 Characterization of Work Zone Fatalities and Injuries**

| Measure | Canada | U.S. |
|---|---|---|
| Total number of traffic fatalities | Avg 2000-3: 2,854<br>2003: 2,778 | 2000: 41,945<br>2001: 42,116 |
| Total number of traffic fatalities in work zones | Not available | 1999: 872<br>2000: 1,026<br>2001: 989<br>2002: 1,186<br>2003: 1,028 |
| Total number of road users injured in work zones | | 2003: 41,000 |
| Breakdown of road users killed in work zones | | 85% drivers & occupants; 15% pedestrians & cyclists |
| Average proportions of road users killed in work zones (Construction, maintenance, and utility work zones) | | Construction: 90%<br>Maintenance: 9%<br>Utilities: 1% |
| Percentage of work zone traffic fatalities on roads with speed limit greater than 88 km/h (55 mph) | | Approximately 60% |
| Number of road workers killed in work zones (traffic and non-traffic causes) | | Approximately 100 per year |
| Number of road workers killed in work zones (traffic-caused) | | Approximately 50 per year |

*Sources:*
*1. Transport Canada web site: www.tc.gc.ca/roadsafety* (95)
*2. U.S. FHWA Safety web site: safety.fhwa.dot.gov/fourthlevel/pro_res_wzs_facts.htm* (98)
*3. U.S. Bureau of Transportation Statistics web site: www.transtats.bts.gov* (96)
*4.U.S. National Institute of Occupational Safety and Health (NIOSH) web site: www.cdc.gov/niosh/homepage.html* (99)

In brief, the total number of traffic fatalities in the U.S. has hovered around 40,000 per year for many years. Because of increasing numbers of drivers, vehicles, and vehicle-kilometres of travel over the last 30 years, this number, despite its magnitude, has remained relatively constant, and actually represents an improvement in safety over the years. The total number of traffic fatalities in Canada has gradually decreased over the past 20 years, and now totals just under 2,800. The number of traffic fatalities in work zones in the U.S. is now about 1,000 per year, or about 2.5% of the total number of U.S. traffic fatalities. The fact that this number increased significantly from 1999 to 2002 (although it has decreased in 2003) has caused considerable concern in the U.S. The vast majority of these fatalities (90%) occur in construction work zones. The number of road workers killed in U.S. work zones (all causes) is about 100 per year, or about 10% of the number of motorists killed in work zones. Of those 100 fatalities, approximately half are caused by road traffic, while the rest are caused by other hazards in the work site. Unfortunately, comparable statistics on work zone fatalities in Canada are not available, possibly due in part to lack of standard reporting, which may have led to anomalies in the data.

The most frequent traffic crashes in work zones are rear-end collisions, followed by sideswipe collisions. This suggests that, for whatever reason, drivers are often unprepared for the need to slow down, stop, or change lanes, even if well signed in advance. The two types of collision are probably often related, such as at a lane closure, where a driver leaving his/her lane change to the last moment either has a rear-end collision with the vehicle ahead or sideswipes a vehicle in the lane he/she is moving into, thereby often causing more rear-end collisions.

## 1.2 Work Zone Speed Management Issues

Work zone speed management is one of many aspects of work zone safety. Speed management in roadway work zones has been a challenging and sometimes controversial issue in many road jurisdictions. The challenge arises because of the difficulty of persuading drivers that they should slow down in work zones. Controversy arises due to differences of opinion on what constitutes a safe speed in work zones.

There are many issues involved in work zone speed management. These include:

- philosophy of work zone speed management (to what extent is it desirable and feasible to try to reduce work zone speeds?), and method for determining where work zone speed limit reductions should be applied
- division of responsibilities regarding work zone safety
- roadway type (urban or rural, high speed or low speed, freeway or non-freeway)
- driver attitudes to work zone speed reductions
- design of the work zone
- provision of work zone information to the public, including locations, duration, effects, etc.
- credibility of work zone signing and posted work zone speeds
- techniques/methodologies for reducing work zone speeds
- work zone speed enforcement

These issues are briefly discussed here, except for the last two, point 8 (techniques/ methodologies for reducing work zone speeds) and point 9 (work zone speed enforcement), which are the main focus of this report and are discussed in sections 3.0 and 4.0.

Roadway work zones should be designed around the basic principles of (58, 76, 77, 78, 79, 80, 91):

- worker safety
- road user safety
- road user mobility

In terms of safety, speed management contributes to increased safety by providing drivers with a realistic speed limit at which to proceed in order to negotiate the work zone in a safe and orderly manner. Safety is measured in terms of the number and severity of vehicle crashes in the work zone that are attributable to the presence of construction or maintenance activities, as opposed to a crash attributed to a driver falling asleep at the wheel. Another factor used to measure the safety of work zones is the number of citations issued. Decreasing numbers of citations may indicate improved safety conditions in the work zone, provided the posted work zone speed limit is realistic for the conditions.

In terms of mobility, speed management in work zones contributes to improved mobility by providing drivers with traffic condition information so that drivers can adjust their speeds accordingly. Mobility is measured in terms of the absence or decrease of observed or reported traffic backups or delays in the work zones.

The **philosophy of work zone speed management** and the **division of responsibilities regarding work zone safety** are intertwined. Responsibilities for worker safety, road user safety, and road user mobility may be distributed over more than one government agency, and these agencies may have different philosophies of work zone speed management. For example, in some jurisdictions, the Ministry of Labour has primary regulatory authority over worker safety. This may be its primary, even only, responsibility, and there may be little interest in motorist safety or mobility. Road authorities, including provincial ministries of transportation, municipal transportation departments, and private road owners, on the other hand, have an interest and responsibility to achieve all three objectives.

One perspective is that work zone speeds should be reduced to a very low level, e.g., 20-30 km/h, and should be posted at that level, in the interest of worker safety. Ministries of labour, road workers, labour unions representing them, and contractors often hold this view. Workers often feel safer if traffic speeds are low, and believe that posting and enforcing very low speed limits will enhance their safety. This viewpoint is supported, to some extent, by studies that have shown that pedestrians incur a risk of about 80% of being killed at a collision speed of 50 km/h, as opposed to a risk of about 10% at speeds of 30 km/h (61). Road workers also understandably feel frustrated because motorists frequently approach work zones at speeds above the normal posted regulatory speed, and continue to speed through the work zones, seemingly oblivious to the existence of a work zone or a reduced speed zone. Workers sometimes feel that motorists involved in a crash in a work zone have only themselves to blame and that the motorists benefit by being surrounded by a shield of metal, which the workers do not have available to them.

The flaw in this perspective is the belief that worker safety is independent of motorist safety, leading to the view that motorist fatalities and injuries are irrelevant provided that workers perceive themselves to be safer because motorist speeds are low. The problem is that if motorist safety is reduced in work zones, worker safety is also reduced, because the traffic crashes that occur often spill over into the work areas and put workers at risk. Data cited by Dewar (12), from Ha and Nemeth (24), showed that of four studies of lane closure situations, the predominant collision location in 3 of the 4 studies was within the work zone (lane closure, buffer area, or work area, that is close to workers), while the median crossover was more prominent at the fourth location. Figure 1 shows the distribution of crashes by location in the work zone from a study of crash characteristics in work zones by Garber and Zhao (21). This demonstrates that a high percentage of motorist crashes occur in the activity area, potentially also putting workers at risk. (See Figure 5 for locations of the component areas of a work zone.)

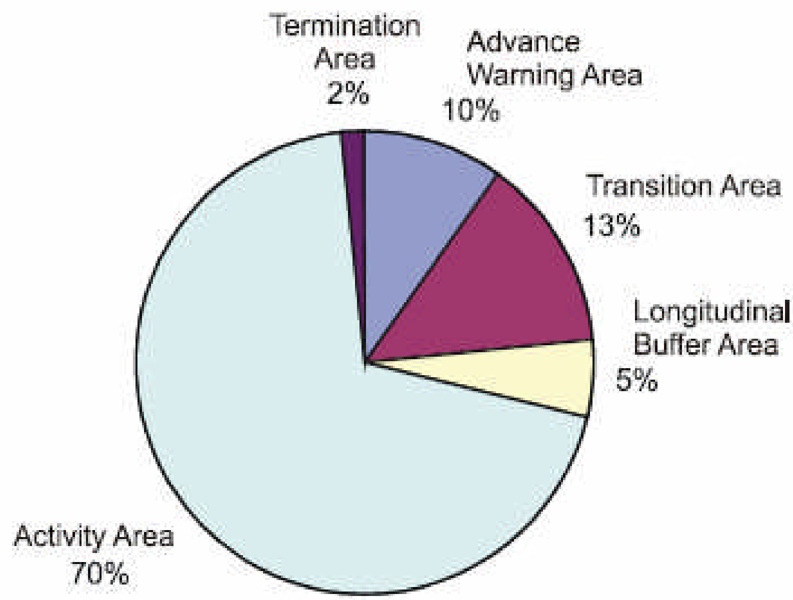


*Figure 1. Location Distribution of Work Zone Crashes (21)*

While this is true, the question might still remain as to why drastically reduced speed limits in work zones would increase hazard to motorists (and in turn to workers). Many studies have shown that the safest traffic flow occurs when all vehicles are traveling at approximately the same speed, that is 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. It follows then that the safest work zones are those with the smallest increase in the upstream-to-work-zone speed variance. Figure 2 presents data on the percentage increases in speed variance from upstream of the work zone to within the work zone (50).

As noted by the authors (50), "The percentage increases in speed variance appear to go through a minimum at a speed limit reduction of 16 km/h. In summary, it appears that, for work zones with speed limits that were not reduced, the speed variance in the work zone was 61 percent higher than the upstream speed variance. For work zones with a speed limit reduction of 16 km/h, the increase in speed variance in the work zone was only 34 percent. Finally, for work zones with speed limit reductions of 24 km/h or more, the increases in the work zone speed variance above the speed variance upstream of work zones were in the range from 81 to 93 percent." The greater variance at the higher speed reductions is due in part to the fact that some drivers will heed the lower posted speed while others will not, leading to a greater dispersion of speeds and a greater speed range and speed variance.

The authors also examined the collision experience in the work zones studied, using the subset of freeway work zones, because it accounted for the largest portion of the collision data set. Figure 3 summarizes the mean percentage increases in fatal-plus-injury collision rates during the construction period as a function of speed limit reduction.

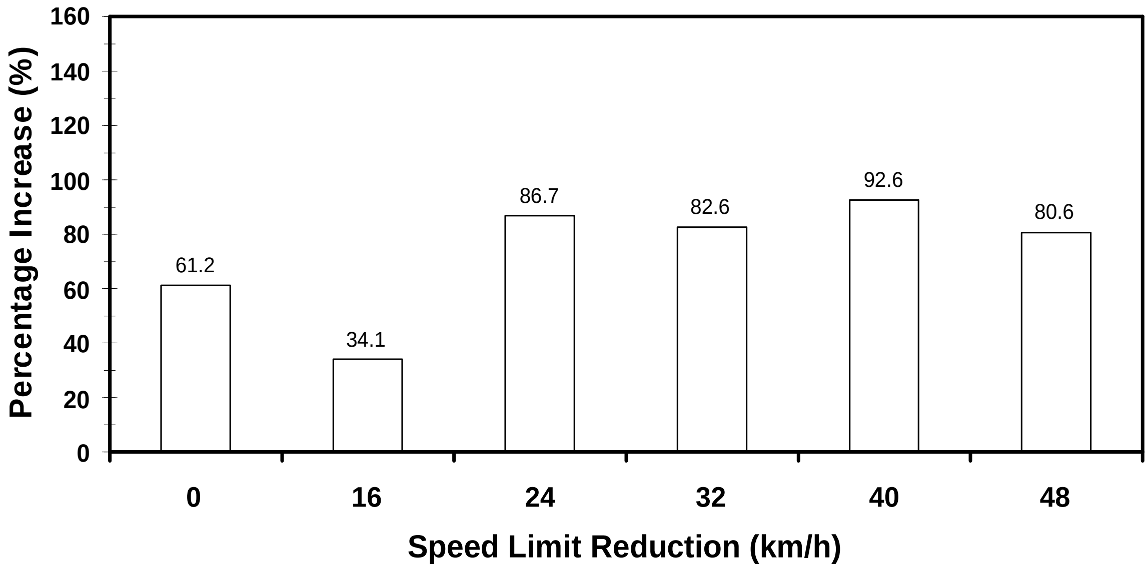


*Figure 2.* Percentage increase in speed variance from upstream to work zone locations for various work zone posted speed reductions (*Source: Migletz, Graham et al (50)*

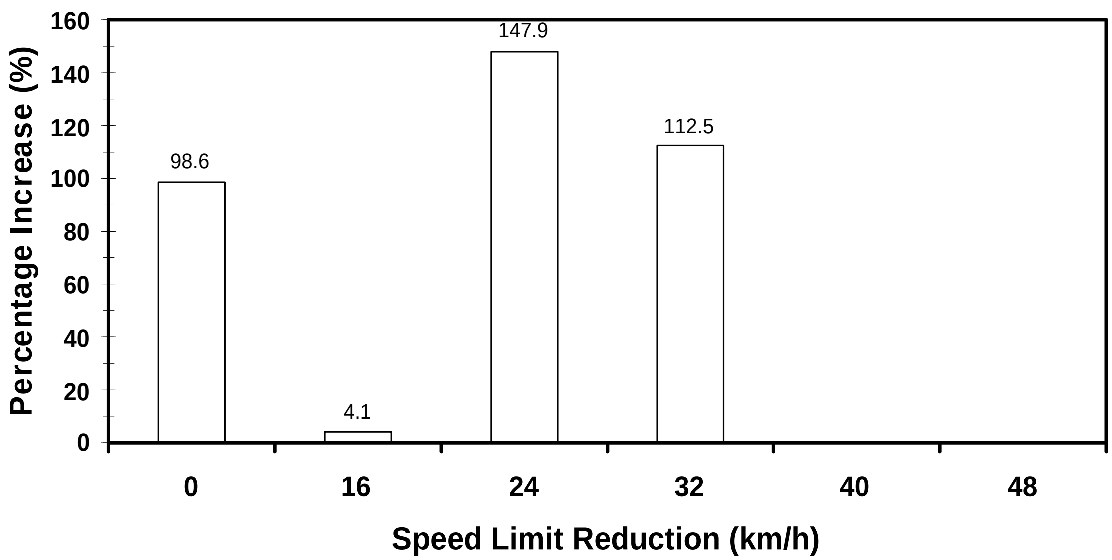


*Figure 3.* Percentage increase in fatal plus injury accident rate from the before to during construction periods (*Source: Migletz, Graham et al (50))*

Again, as noted by the authors: "Figure 3 shows that the minimum percentage increases in the fatal-plus-injury accident rates during the construction period occur for a speed limit reduction of 16 km/h. Work zones without speed limit reductions had the next smallest percentage increase in the fatal-plus-injury accident rate." This suggests that the greatest safety for motorists, and hence for workers, is achieved when work zone speed limit reductions of about 15-20 km/h are imposed. It further suggests that work zone speed limit reductions of greater than that are actually counter-productive in terms of safety. These data are for rural freeways; though not documented, it is expected that work zones on other types of roads, similar principles and behaviour would apply.

As a result, road authorities, with the multiple objectives of worker safety, motorist (road user) safety, and motorist (road user) mobility, generally have a policy of moderate rather than extreme reductions in posted work zone speed limits. Some think this means that road authorities jeopardize safety for the sake of mobility, but this criticism is not valid. As can be seen, the highest degree of safety is achieved with moderate speed reductions, not extreme ones. Most road authorities regard worker safety and motorist safety as being of paramount importance. Without in any way minimizing the importance of worker safety, the fact remains (based on U.S. data), that for every worker killed by traffic in work zones, approximately 20 motorists and other road users are killed.

The practical implications of these findings are discussed in sections 3.0 and 4.0.

Migletz and Graham in another paper (51) recommend a **method for determining work zone speed limits**, as described in section 3.2.1. The recommended speed limits for seven specific conditions are either 0 mph (0 km/h) or 10 mph (16 km/h, say 15-20 km/h).

**Roadway type** (urban or rural, high speed or low speed, freeway or non-freeway) also has a bearing on work zone speed management. Safety in all work zones is important. Generally, work zones and work zone speeds on low-speed urban non-freeways are easier to manage, and tend to be safer. As normal posted speed limits increase, work zone safety and work zone speed management become more of a challenge. As indicated in Table 1, in the U.S., 60% of work zone fatalities occur on roads with posted speeds greater than 55 mph (88 km/h). Freeways, despite their generally lower collision and fatality rates than other types of roads, pose even greater challenges than non-freeways for work zone safety and work zone speed management. There are several reasons for this. First, work zones are a violation of driver expectations of smooth flow on freeways, despite the frequency of congestion, especially on urban freeways, and the general frequency of work zones. Also, both posted speeds and driving speeds on freeways are higher than on other roads, and driving speeds frequently exceed normal posted speed to some degree. **Driver attitudes to work zone speed reductions** are a factor on all roads, but tend to be more pronounced on freeways. Drivers are unwilling to slow down and seem to resent construction and maintenance delays. As a result, drivers seem to be more aggressive than previously, and are even reported to drive directly at workers, including traffic control persons on two-lane roads. A further hazard on freeways is that drivers tend to slip into what has been called “rocking-chair mode”; they become inattentive, their level of awareness drops, or they become preoccupied (e.g., cell phones) or bored. While this is more prevalent on rural freeways, with fewer congestion delays, it also occurs on urban freeways, and indeed, on all types of roads to some degree.

**Design of the work zone** is very important in contributing to both safety and mobility. The Manual of Uniform Traffic Control Devices for Canada (MUTCDC) (41) stresses this as follows:

“Traffic safety should be designed as an integral part of construction and maintenance projects, rather than applied on a makeshift basis. Traffic should be routed through these areas in a manner that most closely resembles normal road conditions, but, just as importantly, ensures the safety of workers and road users…. Traffic movement should be interfered with as little as possible. Frequent or unnecessary changes, such as sudden lane narrowing and lane closures that result in sudden reductions in speeds and risky manoeuvring, should be avoided. Special precautions should be taken to ensure that work zone equipment can be operated safely without making it hazardous to passing traffic…. Where interference is unavoidable, the movements of all road users, including drivers, cyclists and pedestrians, should be guided in a clear and positive manner by adequate signs, devices, markers, pavement markings and traffic control persons, whichever control measure or combination of control measures is most appropriate."

The British Columbia (80), Alberta (76, 77), Saskatchewan (78), Manitoba (93), Ontario (58), New Brunswick (91) and Newfoundland and Labrador (79) work zone traffic control manuals use similar, and in some cases identical, language as follows:

"Risk to both drivers and workers can be reduced by the provision of a predictable, familiar roadway environment, to the extent practicable. The consistent and appropriate application of traffic control devices increases the probability of roadway users exhibiting the desired behaviour, and helps ensure the safety of workers. Work zones must be designed with explicit consideration of worker and traffic safety. Traffic Safety must be designed into construction and maintenance projects, rather than applied on a makeshift basis. Positive guidance, and the avoidance of violating driver expectation, should be used…. Traffic movement should be interfered with or inhibited as little as possible…. The travelled way through the work zone should be designed for normal highway speeds as much as possible. Frequent or unnecessary changes such as sudden lane narrowing, lane closings, reductions in speeds and risky manoeuvring should be avoided. Special precautions must be taken to ensure that construction equipment can be operated safely without making it hazardous to passing traffic. Roadway occupancy and work completion time should be minimized to reduce exposure to potential hazards. Where interference is unavoidable, drivers and pedestrians must be guided in a clear and positive manner by adequate signs, channelizing devices, pavement markings, traffic signals, or by traffic control persons, whichever control device/measure or combination of control devices/measures are most appropriate" (58).

Ontario's Policy Guidelines for Reducing Speeds in Construction Work Zones (23) state that explicit consideration of the need for speed reduction during design enhances the effectiveness of speed control during construction. For example:

- Detour design speed should be 20 km/h over the anticipated posted legal speed where practical
- Detour geometry should be chosen to avoid the need for a large speed reduction
- Work zone design should be chosen to permit construction vehicles to exit/enter near normal speeds
- Police car lay-bys should be built into the detour where possible/practicable

**Provision of work zone information to the traveling public** is also very important, including information on work zone location, duration, and expected delays. Most provincial work zone manuals state that maintaining good public relations is necessary, and that road users should be kept informed of the existence of and reasons for work sites. Good advance information reduces the element of surprise and helps manage expectations. Many other jurisdictions have also adopted the practice of providing work zone information to the public (see section 6.0, Literature Review). As noted in section 4.2.3.2, the literature indicates the following general or aggregated means of providing better information to the travelling public.

- Many U.S. states have developed public relations and information outreach programs for motorists and the public, to improve customer satisfaction and to improve safety, by a variety of means (92). Some states (e.g., Arizona) make public relations and information a bid item in construction contracts (92). Canadian provinces and municipalities have also developed public information programs on road construction projects. For example, Saskatchewan has an “Orange Zone Campaign” annually during the construction season, which includes an aggressive public awareness campaign of “Slow to 60 km/h in the Orange Zone” and fines and penalties. The campaign is included province wide within weekly and daily newspapers, radio and television advertisements (30).

- Indiana DOT has used media extensively over 20 years to notify motorists by radio, TV, and newspapers, of upcoming projects, possible delays and suggested alternate routes (92).

- In addition, there are some specific means of providing better information to the traveling public, which will alert them to work zones and help avoid hazardous violations of expectations and excessive speed. These include the use of Portable Variable Message Signs (PVMSs, described in more detail in sections 3.0 and 4.0), Highway Advisory Radio (HAR), commercial radio, internet web sites, displays of real-time work zone traffic conditions on large screens at rest areas, welcome centres, weigh stations, truck stops, major tourist attractions, large parking garages, large office buildings, employment centres, and/or other large traffic generators (46), and dissemination of information on current work zones through trucking associations.

**Credibility of work zone signing and of posted speed limits** is also critical to safety. There is an onus on everyone involved in work zone safety – road authorities, contractors, and workers – to ensure that work zone signing is credible, that is, that it describes conditions in effect at the time. All too often, such parties can be their own “worst enemies.” A typical example is the posting of construction zone and construction zone speed limit signs as soon as a contract is awarded. But for weeks, there may be no visible on-site activity, and drivers understandably do not slow down, because they see no need to slow down. When work does begin and workers appear on site, drivers are surprised, and may either not slow down at all or may slow down belatedly, in both cases putting workers at risk. The initial signing was not credible. One key to work zone speed management is to ensure that all signing is credible. The Ontario Traffic Manual (OTM) Book 7 (58) states: “Work sites should be carefully checked to make sure that traffic controls are continually updated to suit changing construction conditions due to work staging and progress, or if an immediate improvement to the traffic control is needed. Work zone traffic controls must reflect actual conditions, so that signing is credible, increasing the likelihood of driver compliance. All temporary conditions traffic control devices should be removed when no longer needed. When work is suspended for short periods, advance warning signs that are no longer appropriate must be removed, covered, or turned, and other inappropriate devices removed from the work area so they are not visible to drivers.” Similar provisions are included in the B.C., Alberta, Saskatchewan, Manitoba, Quebec, New Brunswick, and Newfoundland and Labrador manuals (80, 76, 77, 78, 93, 91, 79). Various jurisdictions have used different approaches to advise motorists that workers are present, and either explicitly or implicitly state that reduced speed limits are in effect when workers are present:

- Ontario recommends posting ROAD WORK AHEAD (Men at work) signs whenever workers are present, for both long duration and short duration work. (58) There is no signing to indicate that reduced speed limits are in effect whenever these signs are posted; rather, the intent is to build credibility for the work zone speed limits, so that drivers will reduce speed when they see workers present, and this sign indicating the presence of workers. These signs are to be removed when workers are no longer present. However, credibility of this type of signing depends on consistency, that is, all road authorities, contractors and workers need to accept and implement this practice.

- Several provinces and territories, and U.S. states, post signs stating “Speed Limitxx km/h (or mph) when workers are present.” Alberta’s and Manitoba’s signs state “Speed Limit xx km/h passing workers.” This explicitly ties the reduced speed limit to the presence of workers, and does not rely on consistency of practice by road authorities, contractors and workers.

- Several U.S. states post signs stating “Speed Limit xx mph when lights flashing” or “Workers Present When Flashing / Reduce Speed Max $yyy Fine,” as shown in Figure 4 (81). The amber flashers are activated by road crews when present, and turned off again when they leave. This directly ties the reduced speed limit to the presence of workers, but to the driver the message is implicit. The sign may also indicate that increased fines are in effect (when lights are flashing), or may indicate the dollar value of the fine. This approach has the advantage of the flashing lights drawing attention to the speed limit, but has the disadvantage of relying on the actions of workers in activating and turning off the amber flashers. Self-interest suggests that workers will activate the amber flashers, but carelessness in turning them off will damage credibility.


*Figure 4.* Warning Sign to Reduce Speed when Workers Present (Tennessee)
(*Source: Ullman et al (81)*

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# 2.0 SCOPE AND OBJECTIVES OF REPORT

## 2.1 Scope

The scope of this project, advanced through the Road Safety Standing Committee of the Transportation Association of Canada, is to review the current practices, research studies and publications on work zone safety and speed control. The Geometric Design and Traffic Operations and Management Standing Committees also support this project.

The Synthesis of Practices includes recommendations on a number of Work Zone Speed related issues, including:

- implementation of a work zone speed control area
- installation of required speed control devices
- maintenance of speed control zone (e.g. ensuring speed control devices are maintained through the course of the construction)
- progression of speed control zone (e.g. how the speed control zone moves along the construction site as work progresses and how to ensure it is properly in place)
- procedures for work zone safety speed management.

In addition, any identified related highway environment, safety and operational impacts are discussed.

## 2.2 Objectives

The primary goal of this project was to develop a synthesis of practices on work zone safety speed management for Canadian roads. Objectives in support of this goal were to:

- Identify relevant information sources and review the current practices, operational guidelines, existing warrants and research studies on speed management in work zones from Canadian, U.S. and international transportation jurisdictions. A survey of Canadian provinces and larger municipalities was undertaken under the auspices of the Transportation Association of Canada to obtain as much Canadian data as possible.

- Prepare a comprehensive Synthesis of Practices describing various types of speed management practices and their application in different roadway situations, including rural and urban conditions, and authority and use of regulatory or advisory (warning) signs.

- Provide recommendations on the most effective speed management practices in terms of the devices and methods to be used, their installation, maintenance and cost. The expected effects on other traffic modes (such as vulnerable road users), any site-related operational, environmental, and social conditions (such as the economic impact on business) were also addressed, where possible. The synthesis addressed such items as:

  - legislation
  - training
  - signing, including sign colour and authority
  - pavement markings
  - variable message systems

- enforcement
- rumble strips

## 2.3 Methodology

Two principal components were used to gather information on work zone speed management:

2.3.1 Survey Questionnaire (See section 5.0)

2.3.2 Literature Review (See section 6.0)

## 2.4 Report Content

This report consists of the following:

- An introduction to work zone speed management and related issues (section 1.0).
- Synthesis of Practices for Work Zone Safety Speed Management for Canadian roads (section 3.0).
- Conclusions and Recommendations on implementation, installation, and maintenance techniques and procedures for work zone speed management (section 4.0).
- A review, evaluation and summary of survey responses to a survey of Canadian provincial and municipal road authorities as to their current work zone speed management practices (section 5.0).
- A review of existing literature on work zone speed management practices (section 6.0).

# 3.0 SYNTHESIS OF PRACTICES: WORK ZONE SPEED MANAGEMENT

## 3.1 Overview of Section 3.0

Section 3.0 describes, reviews, and synthesizes a wide variety of work zone speed management practices. Section 4.0 draws conclusions and makes recommendations regarding appropriate work zone speed management practices, based on information obtained from Canadian sources through the survey questionnaire, from international sources through the literature review, and from the experience of the Project Steering Committee and the consultants. Inevitably, there is some overlap between sections 3.0 and 4.0 on the one hand, and sections 5.0 (Questionnaire Survey Results) and 6.0 (Literature Review) on the other.

## 3.2 Work Zone Speed Management

The solution to work zone speed management is not as straightforward as simply posting extremely low speed limits. It has generally been found that control of traffic speeds by imposing unwarranted regulatory speed limits has not been very effective. As discussed in section 1.2, posting unrealistically low speed limits tends to diminish safety rather than enhance it. The majority of drivers disregard posted speed limits if the construction/ maintenance activities or hazards encountered are not severe enough to warrant such lower speeds, or if there is no visible sign of work activity. If there are sudden posted speed reductions, motorists who do slow down may cause collisions. If motorist safety is reduced, worker safety is also likely to be reduced. Normal speeds should be maintained through the work zone as much as possible. The travelled way through the work zone should be designed at a design speed that is equal to or as close as possible to that of the approaches to the work zone. (Ref. most provincial manuals)

There are many types of maintenance and construction projects where a reduction of the normal speed limit is not required. Work zone speed limit reductions should be avoided, where possible, where all work activities are located on shoulder or roadside areas and in work zones where no work activities are under way. A basic guideline to follow is to attempt to reduce speeds only if there is a good reason for it (58).

Experience has shown that it is difficult to achieve an average speed reduction of more than 15 km/h. For this reason, and the reasons discussed in section 1.2, posted speed limits in construction zones should not be more than 20 km/h below the normal posted speed limit for that road section, except where required by restricted geometrics or other work zone features that cannot be modified (50, 51).

It is useful to consider the work zone in terms of its component areas. Depending on the jurisdiction and traffic control manual, a typical work zone may consist of four to six component areas. The Canadian MUTCD describes the typical work zone (on a four-lane road) in terms of five component areas, as shown in Figure 5. If drivers are to be given timely notice of the need to reduce speed, and if vehicle speed is to be reduced before reaching the work area, these must be done in the advance warning area and in the approach area. Many provincial manuals show similar figures.

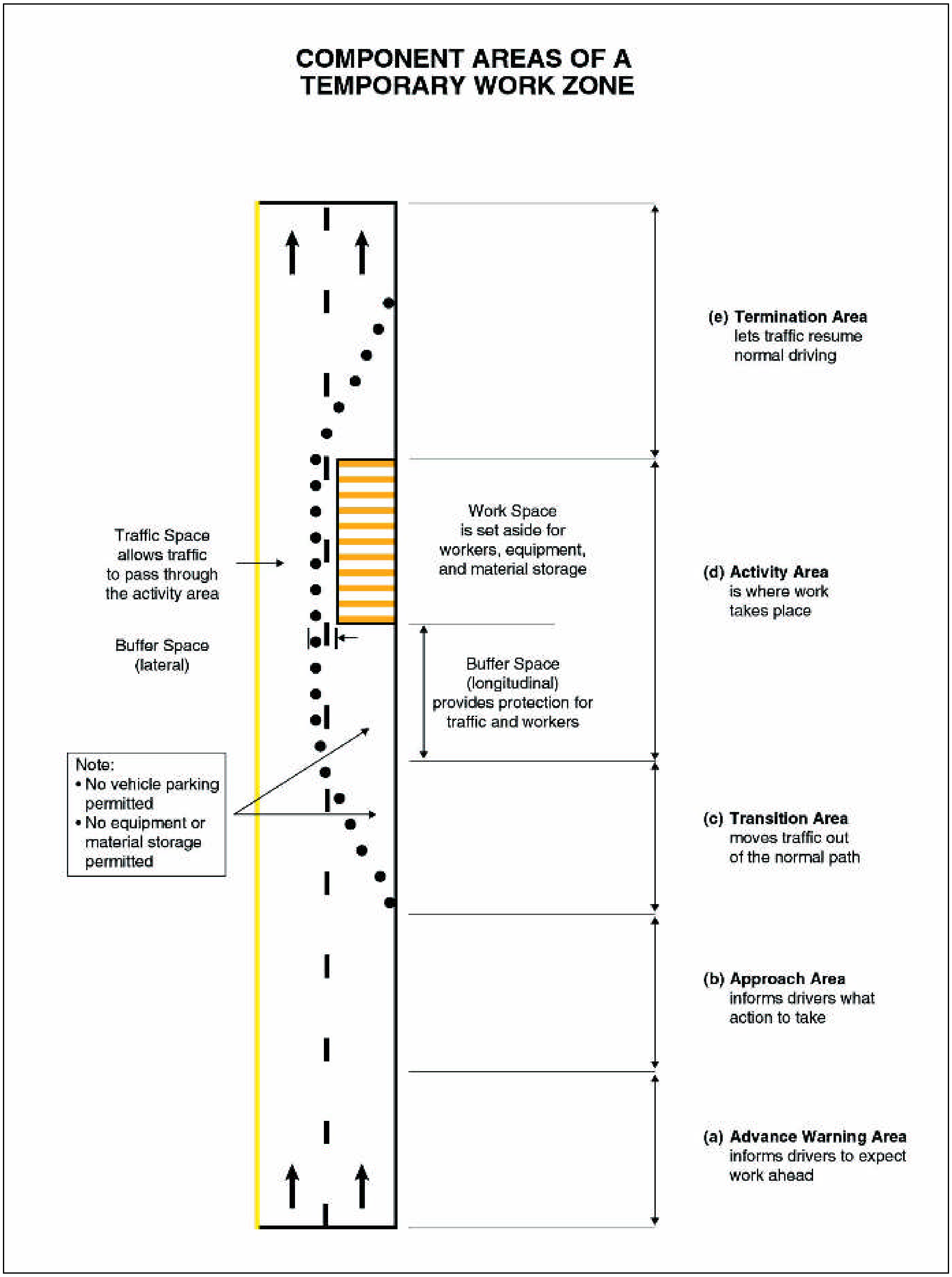



*Figure 5.* Component Areas of a Temporary Work Zone
*(Source: Manual of Uniform Traffic Control Devices for Canada (Fig. D1-1)(41))*

Work zone speed management approaches and techniques are described in the following sections.

### 3.2.1 Posted Speed Limit Reductions in Work Zones

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, supported by a Highway Traffic Act and/or municipal by-law.

Reduced speed limit signs should only be used when:

- work activity is actually occurring, and should be covered or removed when work is suspended or completed

- reduced or restricted design situations, such as narrow lanes, detours, diversions, or crossovers, remain, even though work is suspended (58, 76, 77, 78, 80). (Note: although such situations cannot always be avoided, a better approach, where possible, is to design the work zone for normal speeds)

- workers work within 3 m (or 1.5 m for low speed facilities) from a live lane for extended periods of time and temporary concrete barriers are not practical (23)

Reduced speed limit signs may be either regulatory (black/white) signs or advisory (black/orange) signs. Regulatory speed signs, properly authorized, are enforceable. Advisory speed signs are generally not directly enforceable, although some Canadian road authorities (e.g., Alberta) have indicated that their advisory speed signs are enforceable. Quebec uses black/orange speed signs in work zones, but they are regulatory, not advisory, and hence are enforceable.

Where regulatory work zone speed limits are used, they are typically used only for construction projects, which are longer in duration than most maintenance or utility projects. If reduced speed limits are used at all in maintenance or utility projects, they are generally advisory speeds, although some provinces can also use regulatory speeds for maintenance projects.

Migletz and Graham (51) recommend the following **method for determining work zone speed limits**, taking as a starting point the normal regulatory-posted speed (preconstruction speed limit). The recommended speed limits for seven specific conditions are either 0 mph (0 km/h) or 10 mph (16 km/h, say 15-20 km/h). The recommendations for the seven specific conditions are as follows:

*Condition 1:* Activities more than 3 m from the edge of the roadway: No speed reduction.

*Condition 2:* Activities less than 3 m but not less than 0.6 m from the edge of the roadway: speed reduction may be used where workers are present for extended periods within 3 m of roadway unprotected by barriers, or where there is horizontal curvature that might increase vehicle encroachment: maximum speed reduction of 15-20 km/h (10 mph).

*Condition 3:* Activities less than 0.6 m from the edge of roadway: speed reduction may be used where workers are present for extended periods within 0.6 m of roadway unprotected by barriers, where there is horizontal curvature that might increase vehicle encroachment, where there is barrier or pavement edge drop-off within 0.6 m of roadway, where there is reduced design speed for stopping sight distance, or where there are unexpected conditions: maximum speed reduction of 15-20 km/h (10 mph).

*Condition 4:* Intermittent or moving operation on the shoulder: No speed reduction.

*Condition 5:* Activities that occupy a lane (lane closure): speed reduction may be used where workers are present for extended periods in the closed lane unprotected by barriers, where there is a lane width reduction of 0.3 m or more with a resulting lane width less than 3.4 m, where traffic control devices encroach on a live traffic lane or within a closed lane but within 0.6 m of the edge of the open lane, where there is a reduced design speed for taper length or speed change lane length, where there is a barrier or pavement edge drop-off within 0.6 m of the roadway, where there is reduced design speed for horizontal curve or for stopping sight distance, where there is traffic congestion created by a lane closure, or where there are unexpected conditions: maximum speed reduction of 15-20 km/h (10 mph).

*Condition 6:* Activities that require a temporary detour (design speed of detour and transition should be equal to or greater than the normal regulatory speed limit): speed reduction may be used where there is a lane width reduction of 0.3 m or more with a resulting lane width less than 3.4 m, where there is a reduced design speed for detour roadway or transitions, or where there are unexpected conditions: maximum speed reduction of 15-20 km/h (10 mph).

*Condition 7:* Activities that encroach on the area on both sides of the centreline of a roadway or lane line of a multilane highway (centreline or lane line encroachment): speed reduction may be used where workers are present on foot in the travelled way or in the closed lane unprotected by barrier for extended periods, where the remaining lane plus shoulder width is less than 3.4 m, where there is a reduced design speed for taper length or speed change lane length, where there is a barrier or pavement edge drop-off within 0.6 m of the roadway, where there is reduced design speed for horizontal curve or for stopping sight distance, where there is traffic congestion created by a lane closure, or where there are unexpected conditions: maximum speed reduction of 15-20 km/h (10 mph).

Various jurisdictions will have their own methodology for determining where regulatory speed limits should be used.

The authors state that blanket policies mandating the reduction of work zone speed limit to a fixed value regardless of the normal regulatory speed limit or conditions in the work zone, are not recommended.

When it has been determined where regulatory work zone speed limits should be used, various jurisdictions have their own procedures for implementing regulatory work zone speed limit signs. In many provinces, for provincial highways construction projects requiring traffic control, construction speed zones may be established by the provincial ministry of transportation, through an administrative process delegated by the Highway Traffic Act (HTA). The MUTCD for Canada (41) does not include typical layouts for construction speed zones and signing, but the manuals for several Canadian provinces do. Figures 6 and 7 illustrate the signing for reduced speed limits on B.C. Highways (80). Figure 6 applies to two-lane roadways while Figure 7 applies to freeways. In both cases, a 20 km/h speed reduction from the normal regulatory posted speed is applied. Other typical layouts in the B.C. manual (e.g., for freeway median crossovers or for closures of two lanes on a three-lane roadway) show a 30 km/h speed reduction from the normal regulatory posted speed.

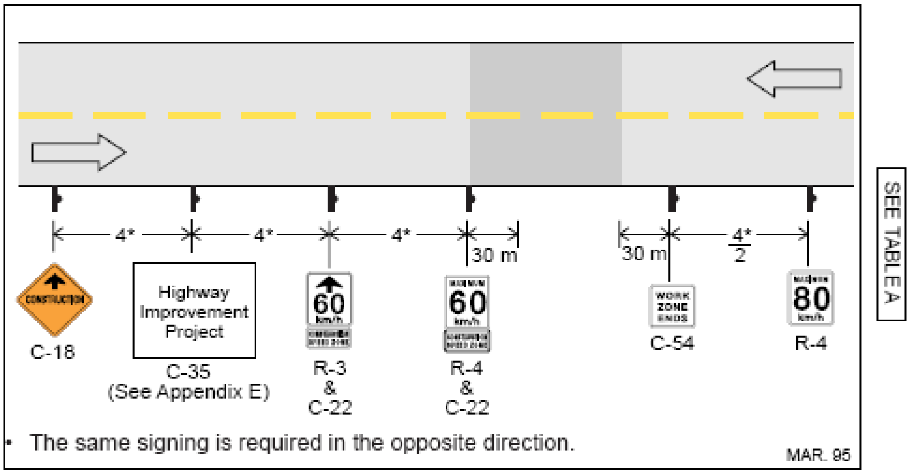



*Figure 6*. British Columbia Construction Speed Zone Signing (Two-lane Roads)
*(Source: B.C. Traffic Control Manual for Work on Roadways, Second Field Edition, 1995)(80)*

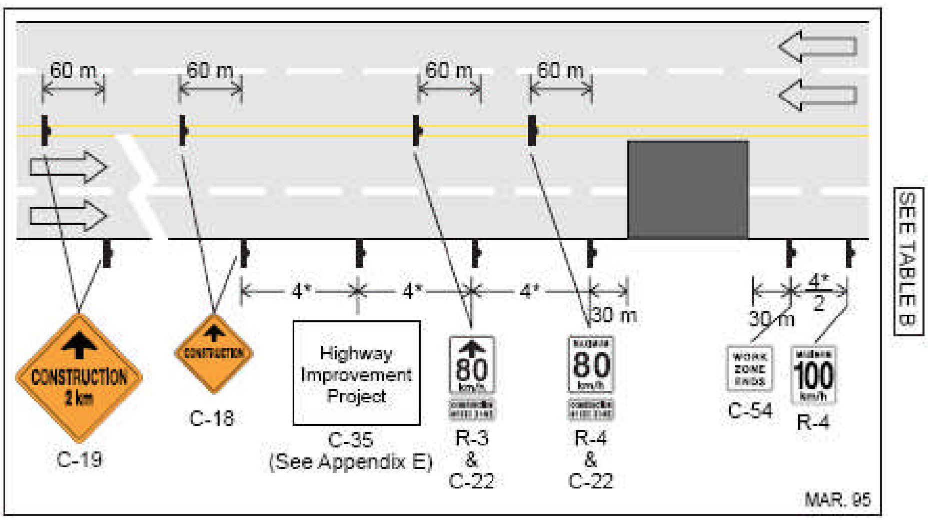



*Figure 7.* British Columbia Construction Speed Zone Signing
(Freeways-Longer Term Work)
*(Source: B.C. Traffic Control Manual for Work on Roadways, Second Field Edition, 1995)(80)*

With reference to Figures 6 and 7 for British Columbia (See summary Table 2 below):

- Table A applies to Two-lane Long Duration work and is a table of various dimensional elements of the work zone (e.g., 4* the minimum distance between signs) for each normal regulatory posted speed limit.
- Table B applies to Freeways, Long Duration work, and is a table of various dimensional elements of the work zone (e.g., 4* the minimum distance between signs) for each normal regulatory posted speed limit.

**TABLE 2 Distance between Construction Signs (B.C. Manual)(80)**

| Distances between construction signs (m) (Dimension 4) | Normal Regulatory Posted Speed (km/h) | | | | |
|---|---|---|---|---|---|
| | 50 | 60 | 70 | 80 | 90-100 |
| **Table A (Two-lane roads)** | 40 m | 60 m | 80 m | 100 m | 150 m |
| **Table B (Freeways)** | N/A | N/A | N/A | 200 m | 200 m |

In Alberta, when work is performed within the highway right-of-way on Department of Infrastructure and Transportation contracts or agreements, the Department has the authority, under the Highway Traffic Act, to authorize temporary speed reductions inwork zones on provincial highways. On Long Duration construction projects, the Department ensures local authorities are aware of the temporary speed reduction by requiring the Consultant to complete the "Order Fixing Maximum Speed" form. On Short Duration utility work or highway maintenance projects, where the work zone is often mobile and/or in place for less than a day, speed reductions are not applied (76).

Alberta uses both regulatory and advisory speed limit signs, and both can be enforced under the Highway Traffic Act which allows police agencies to enforce these signs through section 2(1) of the "Use of Highway and Rules of the Road Regulation" - Driving at Appropriate Speed. This section indicates "A person shall not… notwithstanding that a speed limit is prescribed by or pursuant to the Act or any other Act in respect of a highway, drive a vehicle on that highway at any rate of speed that is unreasonable having regard to all the circumstances….” However, most police agencies are unlikely to enforce the advisory speed limit sign, and regulatory speed limit signs are more commonly used. The Department's intention is to use the standard regulatory "Maximum Speed Limit" signs where a reduction in speed limit is deemed appropriate for the optimum traffic accommodation strategy for the work zone. Advisory speed tabs are used only in conjunction with another warning sign, as a caution warning on projects, as shown in Figure 8. The Department does not use black/orange speed limit signs.

Alberta Infrastructure and Transportation's speed management practice is based on the work situations as outlined in the Manuals, through the process of provision of a traffic accommodation strategy to the project sponsor for review. Normally, the Department's consultants and the Department's safety officers are involved in the review of the traffic accommodation strategy. The Department does not approve the traffic accommodation strategy but only recommends on changes. Traffic accommodation is the contractor's responsibility. There is no established fixed relationship between the normal (gazetted) posted speed and the temporary work zone posted speed. Each site is reviewed on its own with the use of the Manuals as guidance. Alberta Infrastructure and Transportation has a sign that says “Maximum 50 km/h Passing Workers.” The speed on the sign may vary in accordance with the traffic accommodation strategy (and is used only where it is called for in the traffic accommodation strategy); it is a regulatory sign and can be enforced. The Manual states that the “Maximum 50 km/h Passing Workers” sign is used when workers are on the roadway surface for short duration work on two-lane undivided highways only (8). The Alberta Manuals do not show a single typical layout for laying out a construction zone speed zone, but they include reduced speed limit signs on many of the typical layouts for a wide variety of work zone situations (76).


*Figure 8.* Use of Advisory Speed Tabs (Alberta, Saskatchewan) (76)

In Saskatchewan, the speed limit in a work zone when/where workers are present is established by law. The Saskatchewan Highway Traffic Act, section 37(1), states that: "No person shall drive a vehicle on a highway at a speed greater than 60 kilometres per hour when passing a highway worker or flag person, or any highway equipment occupied by a highway worker, whose presence on the highway is marked in accordance with the regulations made by the Highway Traffic Board" (27). The three signs that can be used to mark the work zone are "WD-A41 Men Working", "WD-A45 Flag person" and "WD-A46 Survey Crew". The 60 km/h reduced speed zone is established in the presence of highway workers or equipment when one of these signs is present.

The question of whether a black on orange speed sign is advisory or regulatory has not been completely clarified in Saskatchewan. The 60 km/h construction zone speed is enforceable when one of the above three signs is present in conjunction with highway workers or occupied equipment, whether any speed signs are present or not. In such situations, when black/orange speed signs are present they can be considered regulatory. At other times when they are not covered and there are no men or equipment present, they can be considered advisory. Advisory black/orange speed signs may also be posted for speeds other than 60 km/h. A black/white sign with the legend "Maximum 60 Passing Workers and Equipment" is also used as an optional advisory or general information sign within the work zone to inform motorists of the law.

*The (Saskatchewan) Highways and Transportation Act, 1997* section 20(1), states that the minister may establish a speed zone on any provincial highway and on any authorized detour from a provincial highway for any class of vehicle by erecting official signs indicating the maximum speed applying to each class of vehicle in the speed zone. Black/white regulatory speed signs are used to establish reduced speed zones after hours when physical constraints do restrict vehicle speeds.

Each project is assessed to determine if a speed restriction other than the maximums stipulated in current statutory provisions is required. Some of the factors considered in determining appropriate maximum speeds include traffic volumes, the normal highway speeds in the vicinity of the work zone, the distance affected by the work zone, the time required to complete the work, the nature and complexity of the work and the highway alignment in the work zone.

Saskatchewan also uses advisory black/orange Maximum Speed signs in place of the black/white regulatory speed signs where it is not practical to implement a regulatory speed limit, as well as advisory black/orange speed tabs in conjunction with other warning signs, as shown in Figure 8.

In Manitoba, the “Maximum 60 When Passing Workers” sign may be installed in any active work zones where there is a need to have traffic speeds reduced below the existing regulatory speed limit. It is a regulatory and enforceable speed as defined under the Highway Traffic Act. The sign is to be installed as close to the beginning of the active work zone as possible (and not more than 500 m from the beginning of the work zone), and should be removed when workers are not present. The sign should not be used when the existing speed limit is 70 km/h or lower, or where there is a flag person controlling traffic. On provincial highways, use of the sign must be recommended by the Director, Traffic Engineering, and approved by the Executive Director, Highway Engineering (42). In Manitoba, where black/orange speed limit signs are used, they are enforceable.

Where other reduced work zone speed limits are considered necessary, they may be approved by the Director, Traffic Engineering, an authority delegated by the Minister of Transportation and Government Services under the Manitoba Highway Traffic Act, provided the following criteria are met:

- It is unsafe or impossible to drive at the existing posted speed limit due to construction roadway conditions which exist over the full 24 hour day, and
- Standard construction signing is inadequate to convey to motorists that ongoing speed reduction is required over a long section of highway.

Other conditions that may warrant regulatory speed limits include:

- Severe geometric constraints throughout the construction or maintenance area will exist over a long period of time and over a long section of highway, e.g. two-lane two-way (2L2W) traffic on a normal four-lane divided highway.
- Unusual hazards will exist over extended periods of time and over a long section of highway, which can best be handled by speed limits, e.g. flying stones, unexpected dust conditions, large aggregate.
- Speed control by the use of MAXIMUM 60 WHEN PASSING WORKERS signs (MR-96) is inapplicable or ineffectual (70).

In Ontario, if construction speed zones with enforceable speed limits are to be established on provincial highways, it is an HTA requirement first to establish a designated construction zone and to install Construction Zone Begins and Ends signs in advance of and beyond the construction speed zone. See Figures 9 and 10 (Typical Layouts TL-3 and TL-4) (58). Regulatory speed limit signs should be installed only when the appropriate police authority has been informed, and intends to provide enforcement. Otherwise, only advisory signs should be used and all existing regulatory signs within the construction speed zone must be covered or removed for the duration of the construction project, or until agreement on enforcement can be reached with the police authority. The most common speed limit reduction used on Ontario highways is 20 km/h below the normal regulatory-posted speed.

The procedure for implementing regulatory work zone speed limits in construction projects on municipal roads in Ontario is more cumbersome. At present, the establishment of municipal construction speed zones, with enforceable regulatory reduced speed limit signs, must be done by municipal by-law. Advisory speed limit signs may be posted without requiring a by-law. Some Ontario municipalities have indicated that they do not reduce speed limits in work zones.

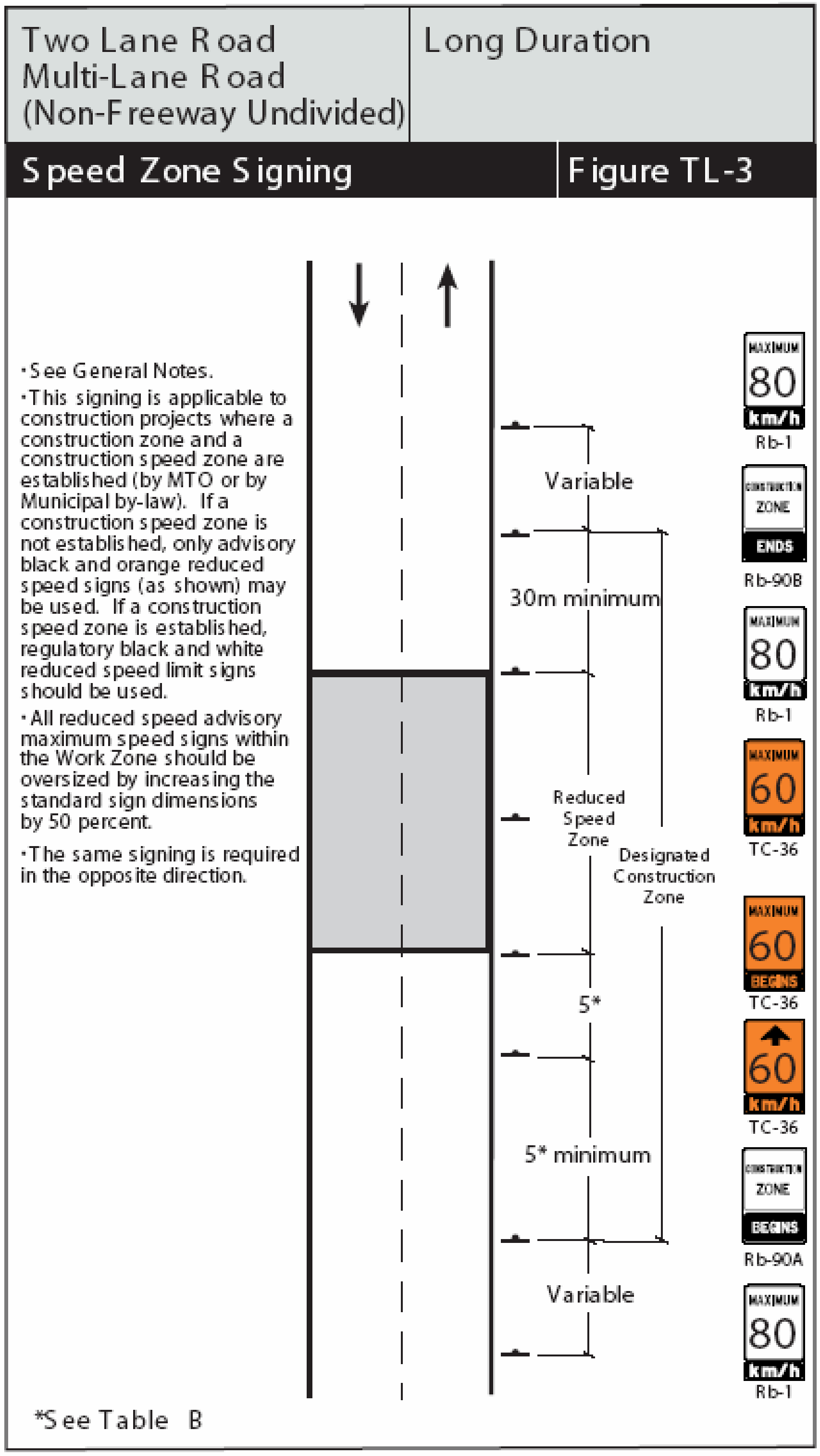



*Figure 9.* Ontario Construction Zone Speed Zone Signing Two-lane Roads and Undivided Multi-lane Roads *(Source: Ontario Traffic Manual Book 7 (Temporary Conditions)(58))*

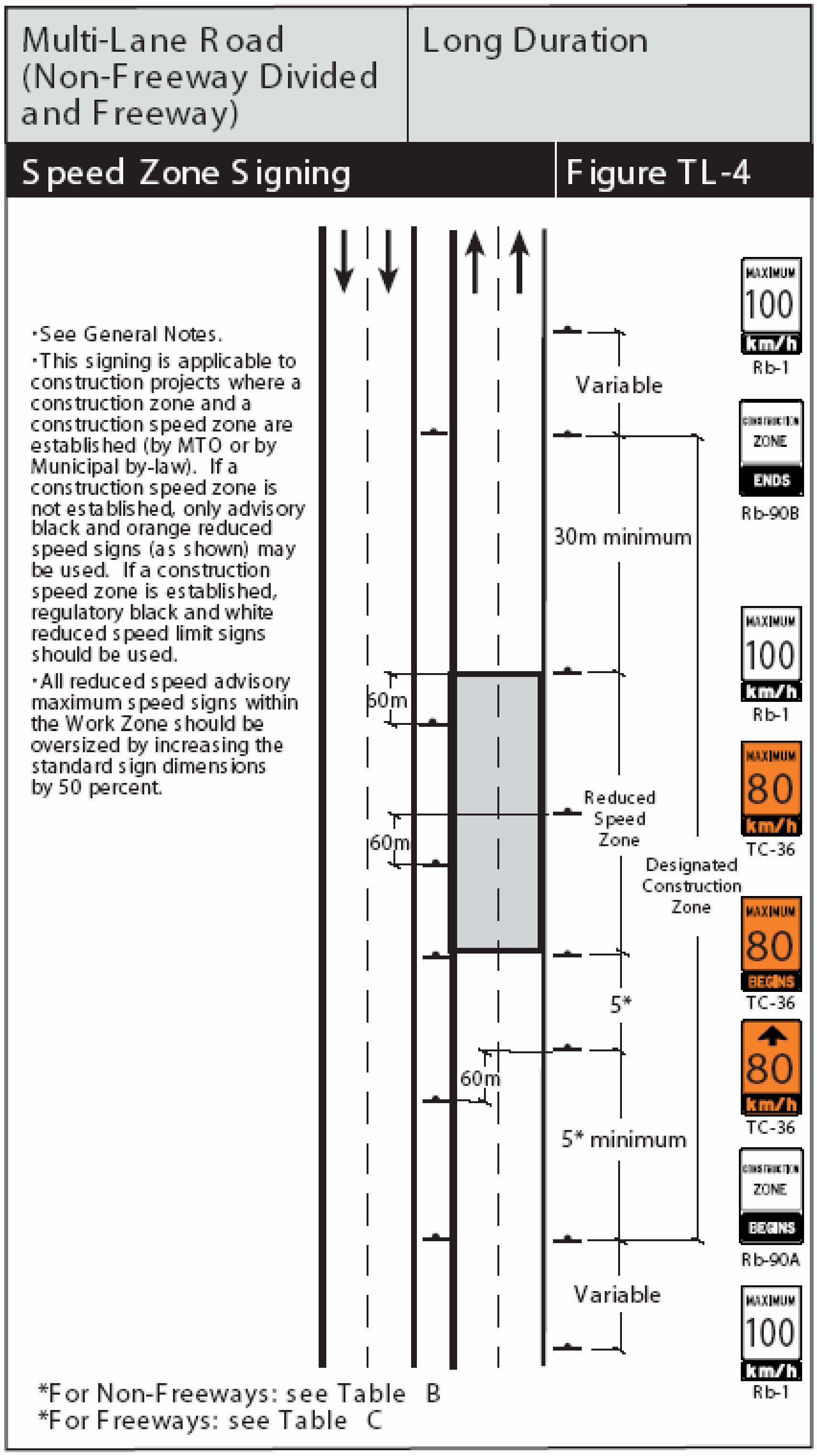



*Figure 10.* Ontario Construction Zone Speed Zone Signing Multi-lane Roads (Divided Non-freeways and Freeways) (*Source: Ontario Traffic Manual Book 7 (Temporary Conditions)(58)*)

With reference to Figures 9 and 10 for Ontario (See summary Table 3):

- Table B applies to Non-freeway Long Duration work and is a table of various dimensional elements of the work zone (e.g., 5* the minimum distance between signs) for each normal regulatory posted speed limit.
- Table C applies to Freeways, both Long Duration and Short Duration work, and is a table of various dimensional elements of the work zone (e.g., 5* the minimum distance between signs) for each normal regulatory posted speed limit.
- Tables B and C in the OTM Book 7 are essentially similar to the speed-dimension tables shown on many of the typical layouts in the MUTCDC.
- The primary difference between Figures 9 and 10 is whether the highway is divided or not; on divided roads, the signing should be provided on both sides of the roadway.
- The work zone (shown as the Reduced Speed Zone) includes all component areas shown in Figure 5 except the Advance Warning Area.

**TABLE 3 Distance between Construction Signs (Ontario OTM Book 7) (58)**

| Distances between construction signs (m) (Dimension 5) | Normal Regulatory Posted Speed (km/h) | | | | |
|---|---|---|---|---|---|
| | 50 or lower | 60 | 70 | 80 | 90-100 |
| **Table B (Non-freeways, Long Duration)** | 40-50 m | 90-100 m | 110-120 m | 130-140 m | 150 m |
| **Table C (Freeways, Short or Long Duration)** | N/A | N/A | N/A | 160 m | 90: 180 m<br>100: 200 m |

The signs shown in Figures 9 and 10 are Ontario standard signs. Canadian standard signs (regulatory and advisory) are those shown in Figures 11 and 12.


*Figure 11.*
Regulatory Speed Limit
Sign (Black/White)


*Figure 12.*
Advisory Speed Limit
Sign (Black/Orange)

Ontario's Guidelines (23) state that legal (regulatory) speed reductions should be used when there is a need to reduce the speed limit for an extended period of time (e.g., 5 days or more) and advisory speed limits should be used when the need is for a shorter period of time.

However, the time period is not as important as the nature of the work itself, and the type of work may dictate the use of a legal speed reduction for short duration work. Additional provisions of these Guidelines state that:

- Experience has demonstrated that compliance with speed limits increases when:
  - speed reductions are used consistently from one site to another
  - drivers perceive a real need for the speed reduction (e.g., workers present adjacent to live traffic lanes, unusually sharp curve)
  - drivers are warned about the speed reduction in advance
  - speed reduction is not more than 20 km/h below the normally posted speed
  - speed reductions are enforced
  - speed reduction extends for 300 m or more
  - police enforcement vehicles are located inside the work zone

- If regulatory speeds are reduced in the work zone, all existing regulatory signs within the construction speed zone must be covered or removed for the duration of the construction project. Also, reduced speed limits should be installed in accordance with the Highway Traffic Act and displayed only when work is actually taking place, and covered (and normal posted speed signs uncovered) when work activity is no longer taking place (58, 64, 79, 80, 91). Speed zones of 300 m or more should be established to increase the success of speed reductions using regulatory signs.

In Quebec, the speed limit signs used in work zones are black/orange. However, these are regulatory signs, not advisory signs, and they are enforceable. The fines for speeding for the black/orange speed limit signs are the same as those for the regular black/white regulatory signs. Black/orange signs are used to distinguish them and the work zone from the normal non-work-zone situation. This is considered to emphasize the fact that this is a temporary work zone speed limit and to enhance safety in the work zone. The advisory speed limit tab sign is used only in conjunction with construction warning signs such as road diversion, lane diversion, road and lane realignment or road features. The work zone speed limit is determined as follows, based on testing and analysis: Reduce the speed limit by 10 km/h for each closed lane, and an additional 10 km/h if the work zone is not protected by barriers, to a maximum speed reduction of 30 km/h from normal regulatory posted speeds. Reduced work zone speed limits are set by an administrative procedure, and posted in an official register (Ref. Survey response from Quebec).

In Nova Scotia, reduced speed limits are not automatically provided in all work zones, but the need is determined on a case-by-case basis. They are also not used on two-lane roads where traffic is controlled by Traffic Control Persons (exception: bridge rehabilitation projects) or where a pilot vehicle is used. Normal practice is to reduce the posted speed limit by a maximum of 20 km/h (100 km/h to 80 km/h), except that where the normal posted speed limit is 110 km/h, it may be reduced by up to 30 km/h (110 km/h to 80 km/h). This also applies for bridge rehabilitation projects and bridge replacement projects where a detour is required (10). Application for a work zone speed limit reduction on provincial highways must be made to either the District Traffic Authority (for two-lane highways) or the Provincial Traffic Authority (for freeways). A typical layout of a Nova Scotia reduced speed limit work zone is shown in Figure 13. Posted speeds are regulatory speeds; advisory work zone speed limit signs are not used.

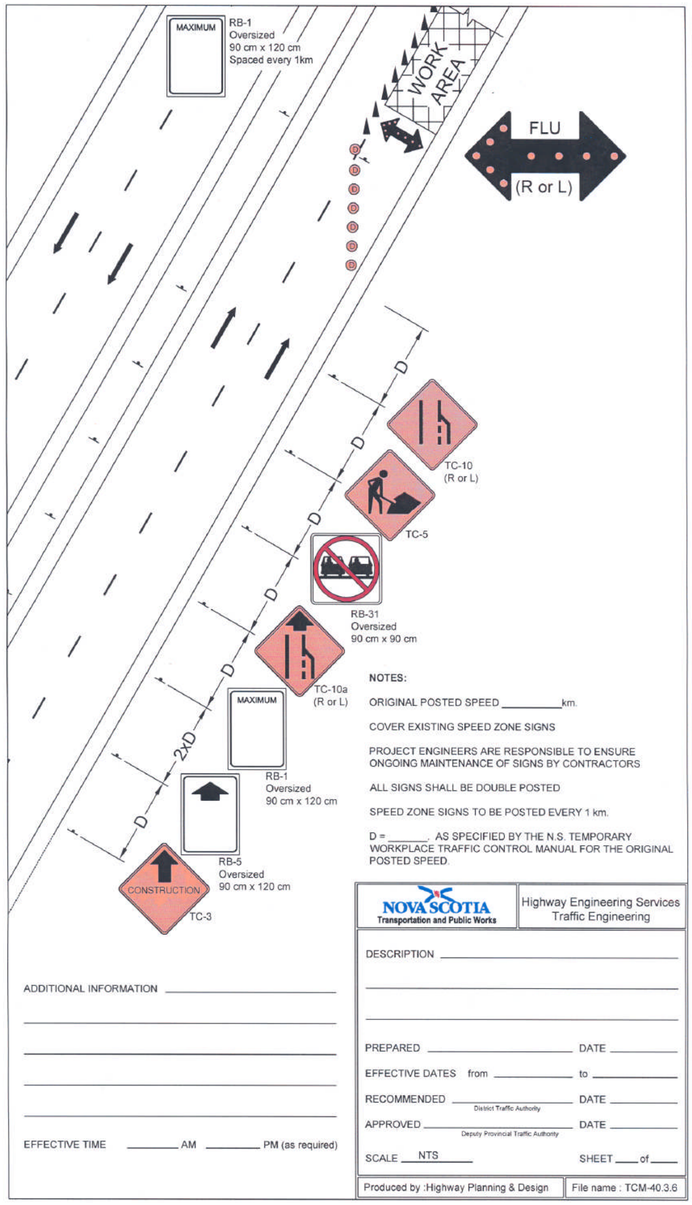



*Figure 13.* Nova Scotia Construction Zone Speed Limit Signing (Divided Highways)
(*Source: Nova Scotia Request for Temporary Construction Speed Zone – 100 Series Highways (65)*)

In other jurisdictions across Canada, the road authority must approve a reduced work zone speed limit, but processes vary. Most provinces and the Yukon can establish construction zone speed limits administratively, by authority delegated by the Highway Traffic Act, but the installation of the signs needs to meet the standards laid out in that jurisdiction's Highway Traffic Act. If the signs don't meet the relevant standards, judges may throw the charges out of court, leading to police services not wanting to spend time on enforcement. A number of municipalities can also set them administratively, by general application of their traffic by-law, such as Regina, Calgary, Edmonton, Victoria. Some others require provincial approval. Still others have no process for setting such speed limits. The City of Edmonton uses two types of work zones with two types of speed zones: Temporary Speed Zones (which appear to be short duration), where speed limits are posted only when workers are present, and Construction

Speed Zones (long duration) where temporary speed limits in a construction zone are intended for 24-hour continuous posting, where there are hazards over the length of a project necessitating slower speeds (75). More details are provided in section 5.0 (Survey of Road Authorities).

Some people have questioned the usefulness of advisory speed signs in those jurisdictions where they cannot be enforced (that is, where drivers cannot be charged with speeding). Advisory speed signs can still be useful, however. First, they do provide advice to drivers as to the recommended driving speed. Second, in many jurisdictions, if drivers ignore or violate the advisory speed signs and then have a crash, they can be charged with careless driving, a more serious charge than speeding.

Generally, if reduced work zone speed limits are used, regulatory speed limits are preferred for longer duration construction work zones, with the reduced speed limits displayed in the vicinity of work actually being carried out, and covered elsewhere, and where enforcement will be carried out. Advisory speed limits, where used, are generally preferred for shorter duration construction work zones, for maintenance work, or where enforcement is unlikely.

Work zone speed limits are a necessary, but not a sufficient, condition for achieving lower work zone speeds. They provide the legal basis for enforcement. Some jurisdictions do not reduce speed limits in work zones, however (See section 5.0). Graham and Migletz report that work zone speed limits alone have not proved very effective in reducing vehicle speeds in work zones (51). They also report that research suggests that advisory speeds have modest to little effect on driver speeds, particularly for drivers who are familiar with the road. This indicates that for work zone speed limits to be effective, they need to be supported by other measures, primarily enforcement.

This is supported by the responses to the survey questionnaire. Regarding the effectiveness of regulatory speed limit signs, 15% of respondents rated their effectiveness as high, 35% as moderate, 42% as low, and 8% as not effective. Regarding the effectiveness of advisory speed limit signs, 9% of respondents rated their effectiveness as high, 36% as moderate, and 55% as low. Interestingly, these results suggest that respondents, on average, found regulatory and advisory speed limit signs to be approximately equally effective (or ineffective).

The paragraphs above describe the **implementation of a work zone speed control area**, that is, how the work zone speed control area is to be laid out, and the devices are to be installed. Several manuals (58, 80) include general principles and/or detailed procedures for installing and removing traffic control devices at a work zone. **Maintenance of the speed control zone** and all traffic control devices within it is also important. As stated in the B.C. manual (80), "Maintenance of devices should be to a high standard to ensure that legibility is retained, that the devices are visible and that they are only in place when needed. Clean, legible and properly mounted devices, in good condition, command the respect of vehicle operators, cyclists and pedestrians. In addition to physical maintenance, functional maintenance is required to adjust needed traffic control devices to current conditions and to remove any that are unnecessary. The fact that a device is in good physical condition should not be a basis for retaining it if the message is inappropriate. Furthermore, carelessly executed functional maintenance can destroy the value of a group of devices by throwing them out of balance. For example, replacement of a sign in a group or series by one that is disproportionately larger or smaller." Other provinces (58, 76, 77, 78, 79, 91, 93) have similar statements regarding the need for good maintenance of traffic control devices in the work zone. In addition, regular inspection is required to ensure that all devices are in place as intended, and to replace or reposition those that may have been damaged or displaced by vehicles, wind, or other causes. Regarding good condition of devices, some road authorities, such as MTO (58), have quality replacement guidelines in their work zone traffic manuals, which provide guidance and performance measures on when damaged or degraded traffic control devices should be replaced. Several manuals outline details of good maintenance and inspection programs for work zone traffic control. On a related matter, if the construction site is one in which the work progresses within it, then the **progression of the speed control zone** as it moves along with the work also needs to be addressed. Several approaches are available to ensure that this happens. One method is to post signs advising that the lower speed limits are in effect either when workers are present, or when amber lights are flashing (indicating the presence of workers) at sufficiently close spacing to distinguish the various areas where work will progressively take place. Such signs might state “Speed Limit xx km/h when workers present” or “Speed Limit xx km/h when lights flashing.” Another method is to install signs throughout the work zone; some showing the normal regulatory posted speed limit and others the reduced speed limit. When work is occurring in a given location within the construction zone, the reduced speed limit signs approaching that location are uncovered, and the normal speed limit signs are covered. Elsewhere in the construction zone, where no work is occurring, the normal speed limit signs are uncovered, and the reduced speed limit signs are covered.

**Variable Speed Limits (VSLs)** have been, and are being, introduced as a means of providing more credible speed limit information to drivers, by displaying a speed limit that is based on real-time traffic flow, roadway and speed conditions. VSLs may be either regulatory or advisory. Eight Canadian survey respondents have indicated that they use variable speed limits; of these, one rated their effectiveness as high, three as moderate, and four as low.

In the U.S., variable message signs, which provide information to motorists about speeds for specific conditions (fog, high crosswinds, work zones), have been in use for some time. Some applications of VSLs are relatively simple and straightforward, such as the posting of a sign stating “Speed Limit xx mph when lights flashing.” (See section 1.2) The amber flashers are activated by road crews when present, and turned off again when they leave. This directly ties the reduced speed limit to the presence of workers. A similar approach has been used by the Minnesota DOT, but with electronic variable message signs. The system incorporates two BRICK modular message blocks on each speed limit sign placed in a work zone. When workers are not present, the speed limit continues to be 65 mph. When workers arrive, a designated worker changes the speed limit to 45 mph. The displayed speeds are enforceable (33).

Development of a new generation of technologies as part of the U.S. Intelligent Transportation Systems program 21 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. Traffic volume and speed data collected at various points within the work zone are used to calculate a recommended posted speed limit, which is varied frequently, as often as once per minute, but not until the difference between recommended speed and currently posted speed exceeds a given threshold, say 4 mph. By changing the speed limits in accordance with prevailing volume and speed conditions, they can be set to be relevant to conditions in the work zone, and can enhance credibility of signing to drivers, resulting in better speed compliance, improved safety and smoother traffic flow (33, 88)

International Road Dynamics Inc. (IRD) has developed an ITS system called Speed Ranger, which automatically displays required speed limits on a series of signs based on current traffic, weather, and construction conditions, providing safe speed reduction in work zone approaches (32)

Variable speed limits are now being used more widely (though not in work zones), particularly on motorway systems in some European countries and Australia. For example, Germany has an extensive system of variable speed limits, primarily to manage traffic flow under adverse environmental conditions on the autobahns. The systems have reportedly been successful in reducing crash rates (See section 6.0). The Netherlands and, more recently, Great Britain have introduced variable speed limits on a pilot basis on major motorways. Their primary purpose is to improve traffic flow in congested conditions by equalizing speeds in all lanes. Variable speed limits are most effective, however, before traffic becomes heavily congested. Under heavily congested conditions, the limits are unable to affect stop-and-start driving. Preliminary results indicate that, when the variable speed limits are in effect, traffic speeds are more uniform and—in the British pilot—automobile crashes are reduced. The results are promising, but more time is needed to determine whether these improvements can be sustained. Some of the VSLs were enforceable, and some were advisory.

### 3.2.2 Enforcement of Reduced Speed Limits in Work Zones

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, which has been shown in some locations to reduce not only the 85th percentile speeds, but also the speed variance. In some locations, police presence has been shown to increase speed limit compliance by 15 percent in work zones where speed limits were not reduced. Several studies have shown that police presence has resulted in significant collision reductions (58).

Of course, for enforcement to be effective, the speed reduction must be warranted, as discussed above. The motorist must understand the reason for the reduction, the reduction must appear reasonable, and the reduced speed limit must be posted only when it is necessary.

For more details on the information presented in this section, see sections 5.0 and 6.0.

Regarding the effectiveness of police enforcement, 55% of survey respondents rated their effectiveness as high, 30% as moderate, 10% as low, and 5% as not effective.

Many jurisdictions have recognized the importance of enforcement in reducing work zone speeds. The U.S. Federal Highways Administration (FHWA) has noted that there is universal agreement that the most effective way of controlling speed in the work zone is to have a staffed police car with flashing lights at the beginning of the work zone. (46). Several Canadian provincial survey respondents have also indicated that they consider this the most effective use of police enforcement. The U.S. National Institute for Occupational Safety and Health (NIOSH) recommends that in highly vulnerable situations that threaten worker safety, consideration should be given to reducing speed through use of police (64).

Interestingly, German highway agencies do not request traffic enforcement in work zones, as they believe it increases the risk of collisions. Contractors on the project are responsible for ensuring the safety of the work zone, and are held accountable for any collisions that occur.

Enforcement issues include: driver behaviour, frequency of enforcement, location of enforcement vehicles, live versus dummy police vehicles, penalties for speeding, methods of enforcement (including photo-radar), work zone training for police officers, and the traffic court system.

**Driver behaviour** is a significant issue in achieving lower speeds through work zones. As noted in section 1.2, drivers show increasing frustration at being delayed by work zones, and are reluctant to slow down. A critical difficulty in deterring speeding using traditional methods is maintaining the effect over time and space. The longevity of effects can be expressed in terms of a “halo,” that is, the spatial or temporal extent of the deterrence effect from the enforcement officer. Studies have shown a marked reduction in average traffic speeds in the vicinity of marked police vehicles to speeds close to posted speed limits. Reduction in speed dispersion, however, was less pronounced. The distance-halo effect decayed quickly downstream of the enforcement site. With regard to the time-halo effect, average traffic speeds remained depressed for 3 days following a single episode of enforcement activity and for considerably longer (up to 6 days) with repeated enforcement.

There is some evidence that those who drive well in excess of the speed limit are the most impervious to the deterrence effects of traditional enforcement methods. Studies of intensive police intervention to reduce speeding have found a greater reduction in the number of drivers breaking the speed limit by a small amount than in the number exceeding the limit by 20 mph (32 km/h) or more. Various studies have shown that driving well in excess of average speeds is associated with both higher crash probability and greater crash severity. This finding is confirmed by recent evidence from British Columbia that drivers with four or more excessive speed convictions had almost twice the overall crash rate of drivers whose most serious multiple offences were simply exceeding the posted speed limit.

To ensure a high level of compliance, speed limits have to be set at levels that are largely self-enforcing, or at the lowest speed the police are able to enforce.

**Frequency of enforcement** is an important factor in reducing work zone speeds. Increasing enforcement intensity would be expected to boost the deterrence effect by increasing the perceived risk of apprehension. Some studies have shown, however, that enforcement intensity must be increased significantly—to more than three times the initial level—before there is an appreciable effect on the perceived risk of detection or reduction in the number of speeding offences. Other enforcement campaigns that have significantly increased the certainty of apprehension, such as anti-drunk-driving programs, have experienced the same effect. Positive behavioural and safety effects are evident immediately after the adoption of the program. With a major initiative, the effect can last from a few months to a few years. However, deterrence effects of even a major program can diminish with time.

The deterrence effect of enforcement depends on creating the impression that road users who violate the law have a high probability of being apprehended. One way to achieve a credible level of enforcement without overstraining enforcement resources is to enforce speed regulations where and when risk-taking behaviours are most evident and traffic volumes are sufficient to justify the effort. Planned patrols on commuter routes at varying time intervals and locations, for example, have been effective in extending the time- and, to a lesser extent, the distance-halo effects of enforcement. Patrol vehicle presence can be reduced without disturbing the speed suppression effect, but only after an initial minimum period (6 weeks in one study) of continuous speed control activity. Varying the location of police patrols on commuter routes also appeared to extend the distance-halo effect, but the evidence was inconclusive.

In some provinces and U.S. states, the work zone contractor hires the police. Many U.S. states have also used or contracted with their state highway patrols to provide extra-enforcement or enhanced enforcement, through special funding provided for that purpose (e.g., California, Florida, New Jersey, Iowa, and New York). Criteria for selection of a work zone for extra enforcement include traffic volume, enforcement personnel availability, potential work zone congestion, remaining highway capacity, and work zone type.

New York State occasionally employs extra enforcement in work zones, but believes that overuse of police in work zones will lessen the positive impact of police presence in work zones. New York's policy in engaging enforcement is to first request State Police to patrol work zones. Local agencies may be approached to patrol the work zone if the State Police are unavailable. The decision to use dedicated police services in New York work zones is normally made during the design process of a project. High-speed, high volume traffic flow in combination with any of the following factors are applied to determine if dedicated police services need to be part of the project Traffic Control Plan: construction activities (paving, etc.), closely adjacent to traffic without positive protection; restrictions to traffic flow based on geometry; no shoulder, reduced shoulder width, reduced lane width, and reduced number of travel lanes; locations where incidents will produce substantial congestion and delays on the facility; special operations that require temporary or frequent shifts in traffic patterns; locations where traffic conditions and accident history indicate substantial problems may be encountered during construction; night time construction which may create special concerns involving the Traffic Control Plan; projects with heightened public concern regarding the impacts of the Traffic Control Plan. The decision to engage dedicated police in a work zone may also come after the project is underway if there is a recurrence of traffic collisions, objectionable delays and congestion, and/or widespread driver disregard for speed limits and other regulations.

The New York State Thruway uses the following practices: State police intermittently park in work zones for brief periods (15-30 minutes) with their lights flashing; signs are posted that traffic fines are double in work zones; ghost cars (recycled State Police cars) are placed in work zones (13).

Additional criteria applied in California for extra enforcement include daytime construction activity that is not obvious when inactive; work zones protected by flaggers with or without pilot cars; end of queue management; poor highway alignment approaching the work zone, high truck counts, or other unique situations; workers exposed to traffic and escape route blocked; night construction activity that is not obvious when inactive; activities with a large number of truck movements at the work area; night work in an identified work zone that requires a lane closure; work on freeways with 6 or more lanes.

The **location of police vehicles in relation to the work zone** also needs to be considered. Locations to be considered include: in advance of (upstream from) the work zone; within the work zone; and beyond (downstream from) the work zone. Generally, it is beneficial to position police vehicles upstream from 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 for police enforcement of work zone speeds. The U.S. NIOSH (64) has recommended that there should be increased presence of law enforcement at the beginning of the work zone. However, if a speeding vehicle is to be pursued, in order to charge the driver, that pursuit will take place, at least in part, within the work zone, which is undesirable. Sometimes, it is desirable to locate the police vehicle within the work zone, but this may pose difficulties in providing a space for the police vehicle to park, and space to pull vehicles over. One way around this is to plan and construct a parking/pull-over bay within the work zone. If the police vehicle is located downstream of the work zone, pursuit of speeders becomes easier and safer, but much of the deterrent effect is lost, since by the time the driver sees the police vehicle, he/she may already have traversed the work zone at high speed. The solution is labour-intensive: one police vehicle is positioned at the beginning of the work zone and a second police vehicle downstream of it. The first vehicle provides a deterrent effect, and the police officer can identify speeders' licence plates and radio them to the officer in the second vehicle, for flagging down or pursuit. In some U.S. jurisdictions, attention has been given to creating enforcement-friendly work zones through coordination between transportation and enforcement agencies, use of technologies to aid enforcement, and shoulders and enforcement pull-out areas.

The question of **live (manned) police vehicles versus dummy (unmanned) police vehicles** sometimes arises. Dummy vehicles can sometimes be used effectively, saving police resources, but drivers soon catch on, unless manned police vehicles are also used from time to time, keeping drivers off balance. In some northern communities, two-dimensional full-size full-colour cut outs of RCMP police cars have been used to slow traffic down (though not necessarily in work zones); the effectiveness of these is not known.

**Speeding penalties** are also an issue. It has been relatively common in recent years for road authorities to increase fines for speeding in work zones. About 40% of the survey respondents indicated that they imposed increased fines for work zone speeding. Saskatchewan has indicated that although they do not now have increased fines for speeding in work zones, they plan to introduce them shortly. Ontario has just announced a bill to double fines for speeding in construction work zones. Of the survey responses, 16% of respondents rated their effectiveness as high, 42% as moderate, and 42% as not effective. Almost all U.S. states have doubled the fines for speeding in work zones, and have posted signs to that effect. The U.S. NIOSH (64) has recommended that fines for motorists exceeding work zone speed limits should be increased. Evidence for the effectiveness of increased fines in reducing collisions and fatalities is not conclusive. Though not the complete picture, it is interesting to note that some U.S. states with the most draconian penalties for speeding still incur relatively high motorist fatalities in work zones. In any case, the effectiveness of this measure clearly depends on effective enforcement. Without enforcement, speeders will not be apprehended. While it may help initially to post a sign that increased fines are imposed for speeding, the effect will wear off over time if there is no enforcement. A Texas study (82, 83) analyzed the effectiveness in U.S. states of doubled speeding fines in work zones. The study indicated that implementation of the double-fine law had no measurable effect at the work zone study sites examined. Discussions with law enforcement officers in Texas suggested that the provision that workers must be present in order for the fine to be doubled would be difficult to enforce state wide (difficulty in establishing whether workers were actually present at the time of citation). Based on such discussions, the researchers recommended that efforts be taken to eliminate the worker presence requirement from the current law.

**Methods of speed enforcement** also need to be considered. Common methods of speed enforcement include: stop watch, radar, laser, aircraft, unmarked cars, special patrols, covert vehicles, and motorcycles. Speed enforcement using mobile patrol vehicles measuring driving speeds with radar is the most popular means of conducting speed enforcement in the United

States. The mobile patrol method involves a police vehicle circulating through traffic and citing speeding drivers. Stationary patrol enforcement, where a marked or unmarked police car parked along the side of the roadway uses radar or LIDAR (Light Distance and Ranging by laser speed gun) to measure speeds, is another common technique. Apprehension of speeding drivers occurs downstream of the monitoring vehicle, sometimes with another patrol officer. The merits of mobile and stationary patrols have been a topic of study. The former is effective in detecting specific violators and slowing traffic in the immediate vicinity of the patrol car. The latter is effective in deterring speeding at a particular location. The advantages and disadvantages of visible and concealed enforcement have also been studied. One purpose of concealed enforcement is to increase the uncertainty of where and when enforcement will occur. As a result of its limited visibility, however, its general deterrence effect appears to be limited.

Photo radar has been used in at least three Canadian provinces, Alberta (City of Edmonton), British Columbia and Ontario, although as of the date of this report its use in British Columbia and Ontario has been suspended. Photo radar is also being used and advocated by FHWA for U.S. work zones. In automated enforcement of speed limits, cameras are set to photograph any vehicle that exceeds the posted speed limit by a certain pre-determined threshold. The vehicle caught speeding is cited and a ticket is automatically issued. Signs can be set up prior to work zones to warn approaching drivers that photo radar is in use. As part of the Ontario program, a one-year pilot project was designed to evaluate the effectiveness of photo radar. Photo radar was deployed at three experimental sites: six-lane 100-km/h divided freeway, four-lane 100 km/h divided highway, two-lane 80-km/h undivided urban highway, and three control sites. The ministry's report covers the effects on speeds after 4 months of operation. Significant decreases in average vehicle speeds, and even more profound declines in the percentages of vehicles speeding by various amounts, especially the highest speeds, were found. Decreases were also noted at the control sites, but they were of lesser magnitude. The control site decreases were attributed to extensive media attention to the use of photo radar and to campaigns against speeding in general (52).

Photo radar is controversial. Its successful introduction requires adoption of legal changes (e.g., resolution of constitutional privacy issues, vehicle owner versus driver liability), funding, and public education. It should be deployed selectively at first, at locations that are hazardous and difficult to patrol with traditional methods and where speeding is a problem (such as work zones), to ensure essential public support. Unfortunately, photo radar is often criticized in the media as being a “money grab” rather than a safety strategy. As noted below, the safety effects of using photo radar are increasingly well documented.

Photo radar has the potential to increase safety through greater compliance with speed limits, improve both mobility and safety by decreasing the need for enforcement personnel to stop vehicles in and around work zones, and provide cost savings for enforcement personnel. It helps maintain an enforcement level that provides a meaningful deterrent to drivers by increasing the probability of detection for speeding violations. Because it can be deployed without police presence (where traditional enforcement can not be deployed), photo-radar can increase the perceived level of risk to drivers and hence compliance levels. It can be used in locations where patrol vehicles cannot be safely and effectively deployed. Moreover, when photo-radar is operated without police presence, it frees police for other traffic and law enforcement activities. The TRB Special Report 254 (52) reports on locales where photo-radar has been used and has been successful in reducing collision rates: Germany; Victoria, Australia; Norway; Arizona; California; Colorado.

Regardless of its other applications, work zones appear to be a good application for photo radar. Photo radar, coupled with increased fines for speeding in work zones, and signs advising drivers of both of these, can be quite effective in reducing work zone speeding.

**Training for police officers in work zone traffic control procedures** and the relevant traffic manuals is also important, and has been specifically recommended by the U.S. NIOSH (64). Many police officers are well trained in these matters, and do an excellent job of controlling traffic in and around work zones. Others, however, are less well trained and motivated, and seem to feel that their legal authority to control traffic provides them with an invisible shield, as they make unsafe vehicle manoeuvres and decline to wear adequate and visible protective garments.

**The traffic court system** is also an important component in effective speed enforcement. Courts may overturn speeding violations if judges think the speed limits are unreasonable or reduce fines if they believe the sanctions are too harsh. If the court system is lenient in its treatment of speeding offences and speeding citations are routinely dismissed, the incentive for the police to enforce the speed limits may be reduced. Thus it is important that the traffic court system—as well as the police and motorists—perceive that speed limits are reasonable and enforceable. Where an abnormally high number of speeding fines are given for a particular location, the court may feel that this is a “fishing area” for the police, and may then reduce or eliminate the fines. There should also be a means of linking the speeding offence to the driver’s insurance, so that a fine does not become just an irritant, the cost of doing business.

Variable speed limits pose a particular challenge to enforcement. One of the reasons for not implementing regulatory VSLs has been the difficulty of enforcement. Recently, however, a report (29) addresses the enforcement of variable speed limits, and includes a brief overview of use of variable speed limits in other countries as well as U.S. states, 40 of which responded that they used variable speed limits. In order to enforce variable speed limits successfully, the following elements are necessary:

- Government creation of a speed limit
- Proof of speed limit where the violation occurred
- Proof that the speed limit was posted
- Proof that posted speed limit signs were visible to the driver
- Proof of special circumstances justifying a reduced speed limit
- Proof of speed in excess of limit.

Suggested language for a law enabling the enforcement of variable speed limits is included in the referenced report.

### 3.2.3 Actual Speed Display, with Regulatory Posted Speeds

Measures that have proven to be effective in helping to manage speeds in work zones include measurement of drivers’ speed by means of radar, and display of the measured speeds on variable message signs (VMSs). The use of radar-controlled speed signs has been shown to reduce 85th percentile speeds an additional 4 to 8 km/h over the reduction caused by static signs, probably because the display is more dynamic than a static sign, the motorist sees his/her actual speed, and may infer that if his/her speed is being measured, there is probably a police officer nearby. The effect of a single VMS may be reduced with distance from the sign (halo effect), but the reductions can often be sustained with two or more VMSs. This measure will have lasting effectiveness only if supported by periodic police enforcement. However, there is one benefit even without police enforcement; people are sometimes unaware of their travel speed and will slow down when reminded of their speed by means of the display. An example of such a sign is shown in Figure 14.


*Figure 14.* Speed Display Sign *(Source: FHWA Research & Technology web site)*

Fifteen Canadian survey respondents have indicated that they use radar speed measurement and speed display signs; of these, six rated their effectiveness as high, eight as moderate, and one as low. They have been extensively tested in Saskatchewan urban work zones with significant reductions in average speed and improvements in speed limit compliance (from 7% before to 61% after).

In the U.S., these signs have been used in various ways, with varying degrees of effectiveness. Work zones on interstate highways and the Pennsylvania Turnpike for projects exceeding $300,000 must have speed-monitoring devices posted so motorists can see their speed. The devices must be posted as least 500 feet before the start of the work zone. Texas DOT found the speed display device to be the most effective way to decrease driver speeds approaching a short duration maintenance work zone. If an approaching driver's speed exceeds a preset level, a siren can be sounded, warning maintenance workers.

Nebraska DOT found that multiple speed radar displays reduced mean speeds by 5-7 km/h, 85th percentile speeds by 3-11 km/h, and increased compliance by 20-40%, over a period of five weeks in a long duration construction project. There was no increased police presence or enforcement during this test. In other studies, Nebraska and Kansas have used the SPEEDGUARD system, a portable trailer unit that measures speed by radar and displays actual speed on a 24-inch LED sign. The work zone speed limit was reduced from 75 mph to 55 mph. The speed display resulted in a significant reduction in mean speeds, 85th percentile speeds, percentage of drivers exceeding the posted limit, and speed variation.

Tests of radar speed displays in Georgia (84) provided significant speed reductions (11-13 km/h) at locations immediately adjacent to the display, but the influence on speed reductions did not appear to extend into the active work area, possibly because of the extended physical length of the work zone (19 km). Speed variances were reduced at both the display location and in the region adjacent to the active work area. Values of speed reduction and variance were sustained over the three-week test period, leading to the conclusion that the reductions were not due to a novelty effect.

In other studies, an evaluation of the effectiveness of roadside speedometers under several controlled deployment strategies (e.g., varied, intermittent, and continuous deployment, each with and without enforcement) found that the speedometer's presence reduced average traffic speed, especially the speeds of those drivers exceeding the speed limit by at least 10 mph (16 km/h), in the vicinity of the device and short distances downstream. However, the effectiveness was clearly linked with enforcement or implied enforcement, a finding of many other studies. Unless coupled with periodic enforcement, roadside speedometers appear to be ignored by motorists whether the deployment is continuous or intermittent (52). A study at Iowa State University (19) found 45 cm (18 inches) numerals to be relatively ineffective, and that numerals had to be 60 cm (24 inches) to be effective.

### 3.2.4 Portable Variable Message Signs (PVMSs)

Portable Variable Message Signs (PVMSs) have also been used to advise motorists of lower speeds (PVMSs also have other applications in addition to advising of lower speeds). An example of the use of PVMSs to advise of reduced speed limits is shown in Figure 15 (a single sign with a two-phase message).

Tests of the effects of PVMSs on speeds were carried out at ten rural highway work zones in New Brunswick (28). Mean and $85^{th}$ percentile speeds were reduced on average by 4.6 km/h and 5.7 km/h respectively. However, the standard deviation increased by 0.29 km/h and the percent of vehicles in the pace range decreased by 1.3%. The mean speed reduction was statistically significant; the increase in operating speed variability was not statistically significant. It was concluded that the PVMS installation would likely reduce a motorist's risk of collision.

Twenty-two Canadian survey respondents have indicated that they use PVMSs for work zones, to advise motorists approaching work zones and for speed limits; of these, seven rated their effectiveness as high, twelve as moderate, and three as low.



*Figure 15.* Use of PVMSs for Work Zone Speed Limits (*Source: Arges Training & Consulting)*

In the U.S., a number of states have used PVMSs in work zones. An FHWA report gives a useful overview of the types and applications of portable changeable message signs (PCMS in U.S. terminology, PVMS in international terminology), including sign technology and size, message selection and display (normal maximum 2 phases, up to 3 phases if necessary), acceptable and unacceptable abbreviations, placement, safety, need for credibility, and checklist for installation (74). Michigan DOT has used PVMSs to electronically change the speed limit on I-96, based on traffic volume, traffic speed and weather conditions, and workers being present. (It is not known whether these are regulatory or advisory speeds) (45, 32). Illinois DOT, on a bridge construction project on I-55, used 17 PVMSs, as well as 8 portable traffic sensors electronically linked to a central base station server, and 4 portable CCTV cameras electronically linked to a central base station using wireless communications, to provide real-time traveller information and to enhance motorist safety. The system acquires and processes data and automatically selects motorist information messages for display on PVMS without human intervention, and operates 24/7 for the duration of the work project. It displays independent advisory messages on each PVMS based on conditions near specific PVMSs, and allows adjustment of thresholds for advisory message selection or staff notification (33). In New Mexico, the deployment of PVMSs, automated traffic sensors and other ITS technologies at a freeway construction project in Albuquerque reduced the average clearance time for traffic incidents by 44 percent (59).

A study of PVMSs used along with radar speed measurement (20) on two Virginia Interstate highways, found that the best messages, in order of effectiveness, were:

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

The authors recommend the following guidelines:

- Set threshold speed at 5 km/h over the posted speed limit;
- Place the PVMS just before the start of the transition area; where a taper leads vehicles into a single lane, place the radar to detect one vehicle at a time, but if more than one lane is open, place the sign to be seen by drivers in both lanes.
- Use the message: YOU ARE SPEEDING SLOW DOWN.

Some European highway agencies use large truck- or trailer-mounted signs and portable signs to warn motorists of, and guide them through, work zones. On German and Dutch motorways, overhead sign gantries are used to post VMS signs over traffic lanes, which convey information about speed limits and work zones and detours. The Netherlands uses portable sign gantries to advise motorists of road conditions in advance of a work zone (overhead signs cantilevered over the lanes from a truck stationed on the shoulder). The signs cost $150,000 each; installation takes about 15 minutes; it is not necessary to stop traffic during installation; the signs are visible from 800-1000 m (71).

### 3.2.5 Narrower Lanes

Narrower lanes are sometimes used to reduce speeds through work zones, although this practice does not seem to be widespread in Canada. None of the survey respondents indicated that they use narrower lanes to reduce work zone speeds.

A comprehensive review of U.S. states' practices in setting design speed, operating speed, and posted speeds indicated a consensus view that narrow lanes and narrow shoulders lead to reductions in vehicle speeds (15). The U.S. NIOSH has recommended that in highly vulnerable situations that threaten worker safety, consideration should be given to reducing speed through funnelling and lane reduction (64). Richards and Dudek (from Dewar) outline the following considerations in the application of narrow lanes as a speed control measure:

- slight reductions in lane width (e.g., 30 cm) will reduce speeds modestly
- speed variance and erratic manoeuvres may increase
- cones can be quickly and easily installed, but are often hit by large vehicles
- narrow lanes must be continued throughout the entire work area to be effective
- this method is more practical for long-term projects than for short term ones

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.

European highway agencies commonly use narrower lanes, both to maintain capacity and traffic flow, and to reduce motorist speeds. The use of narrow lanes in work zones often goes beyond what would normally be considered in North America. The Europeans strive to maintain the number of lanes through work zones by use of shoulders and narrower lanes. In Scotland, 3.65 m wide lanes are reduced to 2.5 - 3.0 m in work zones. Typically one of the lanes is wider than the other; trucks must travel in the wider lane. In Belgian, German and Dutch work zones, typically a 3 m wide lane is open to all vehicles, and a 2.5 m wide lane is restricted to autos. This is done, even on a freeway median crossover, where one lane of traffic crosses the median and then operates as a contra flow lane in the other travel direction (71).

Narrow lanes need to be demarcated through the use of pavement markings or embedded pavement markers. This is common practice in Europe. This normally restricts their use to long duration construction zones. One of the difficulties associated with narrow lanes, indeed with any use of temporary pavement markings, is that of completely removing the old permanent markings. Even when covered with paint or when ground off, the old markings often still show through, especially at night and/or in wet conditions, potentially causing confusion between the old and new markings. Such confusion is undesirable in any situation, but may be especially problematic where lanes are narrower than usual. Some European countries use orange or yellow pavement markings to indicate temporary conditions; the permanent white markings are left in place, and drivers understand that in a temporary work zone, the coloured markings apply.

In North America, cones or barrels are typically used to delineate narrower lanes. While they are easily set up in a short time, they are more susceptible to being displaced from their intended position by being struck by vehicles or blown/sucked out of position by a truck in the narrowed lane.

Advance notice of narrow lanes should be provided through signing. For example, Ontario has a NARROW LANES sign, with an optional tab to indicate which lane(s) are to be used by trucks.

Virtual narrow lanes have also been tested, using pavement markings to create a visually narrower lane. Virginia tests (48) used 8-inch edge and lane lines rather than the usual 4-inch lines. Although vehicles were centred better within the lanes, and lane encroachment was reduced, the virtual narrow lanes had a minimal effect on motorist speeds through the work zone.

### 3.2.6 Pilot Vehicles and Pace Vehicles

Some jurisdictions regard pilot vehicles and pace vehicles to be synonymous, while other jurisdictions distinguish between them. For example, Ontario defines them as follows (58):

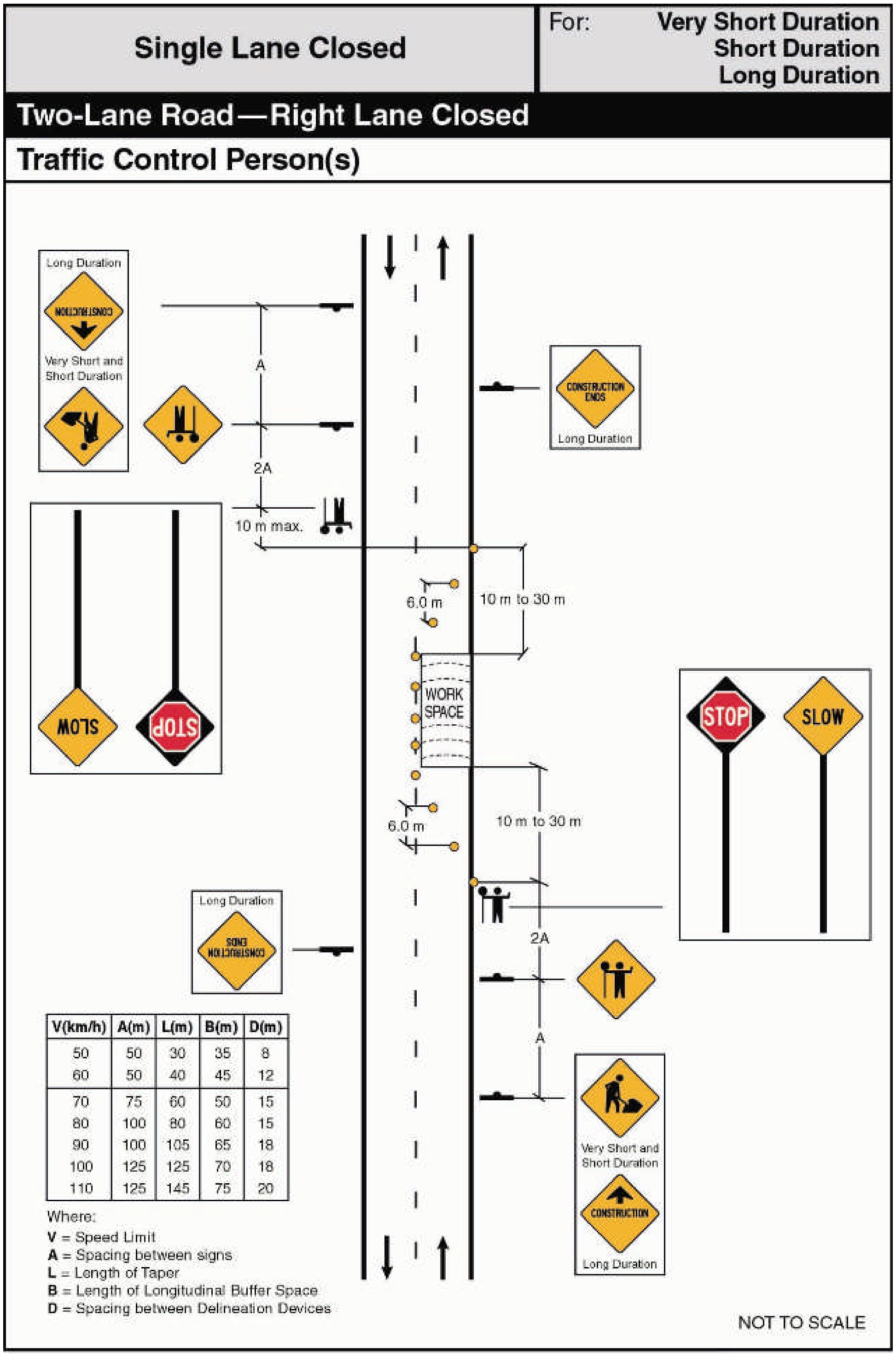
- A **pilot vehicle** is a vehicle used on a two-lane road to guide a queue of vehicles through a one-lane section of a temporary traffic control zone or detour or to control the speed of vehicles through the construction site, especially immediately adjacent to areas where workers are present.

- A **pace vehicle** is a vehicle that may be used on freeways, alone or along with others, one pace vehicle per open lane of traffic, to constrain and control the speed of vehicles traveling through the work zone, where reduced speed is necessary but it is difficult to achieve speed reductions by other means.

For purposes of this discussion, this distinction will be used.

**Pilot vehicles** are used along with Traffic Control Persons (TCPs), one TCP at each end of the work area. The primary purpose of TCPs is not speed control, but rather allocation of right-of-way to alternating flows of traffic that need to use the same traffic lane. The TCP's paddle shows SLOW on one side, and so may be partially effective in slowing traffic; however, it has not been notably effective in doing so. When speed control through the work zone is required, the addition of a pilot vehicle (or two) is far more effective.

The typical use of TCPs is shown in Figure 16, taken from the Manual of Uniform Traffic Control Devices for Canada (41). All provinces have similar typical layouts for TCP application, although the signing details may vary. For example, many provinces use a STOP/SLOW paddle, which is octagonal in shape, with the SLOW diamond, inscribed within the octagon shape.




| V(km/h) | A(m) | L(m) | B(m) | D(m) |
|---|---|---|---|---|
| 50 | 50 | 30 | 35 | 8 |
| 60 | 50 | 40 | 45 | 12 |
| 70 | 75 | 60 | 50 | 15 |
| 80 | 100 | 80 | 60 | 15 |
| 90 | 100 | 105 | 65 | 18 |
| 100 | 125 | 125 | 70 | 18 |
| 110 | 125 | 145 | 75 | 20 |

*Figure 16.* Application of Traffic Control Persons
(*Source: Manual of Uniform Traffic Control Devices for Canada, Figure D4-18 (41)*)

The use of pilot vehicles together with TCPs is illustrated in Figure 17.

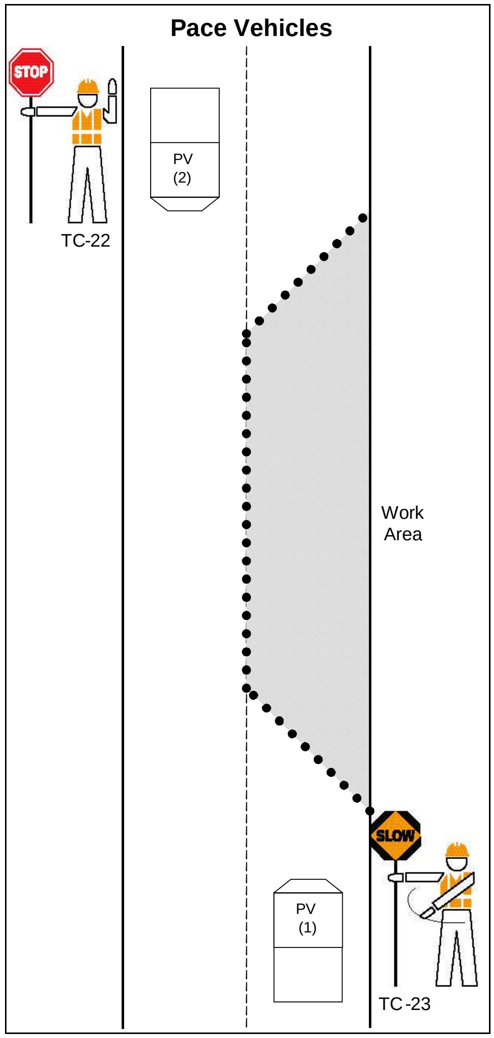



*Figure 17.* Use of Pilot Vehicles with TCPs (*Source: Arges Training & Consulting)*

As noted in both the Saskatchewan (78) and Ontario manuals (58), the operation of pilot vehicles must be coordinated, and communication links established, with other traffic controls at each end of the one-lane section, such as TCPs. As shown in Figure 17, the pilot vehicle should move into position at the head of the queue of vehicles about to be released by the TCP, and when directed by the TCP, guide the vehicles through the work zone (Direction 1, e.g., northbound in Figure 17). At the far end of the one-lane section, beyond the work zone, the pilot vehicle should pull over at the earliest safe opportunity, signaling the following queue to pass.

When the last vehicle of that queue clears the one-lane work zone section, the pilot vehicle in the other direction (Direction 2) should follow the same procedure as outlined above. This description assumes two pilot vehicles. Often, unless traffic volumes are high, a single pilot vehicle may be used for the two directions. When it reaches the far end of the one-lane section, the pilot vehicle turns around and takes its position at the head of the queue in the opposite direction (58, 78).

Twenty-one Canadian survey respondents have indicated that they use pilot vehicles and/or pace vehicles for work zones, to control motorist speeds through work zones; of these, fourteen rated their effectiveness as high, five as moderate, and two as low. This indicates those pilot vehicles and/or pace vehicles are among the most effective work zone speed management techniques available.

A sign is generally used on the vehicle to identify the pilot vehicle for drivers and to provide instructions as to what they should do. Ontario uses a DO NOT PASS WHEN FLASHING sign, as illustrated in Figure 18, together with rotating beacon on the roof of the vehicle or flashing amber lights.

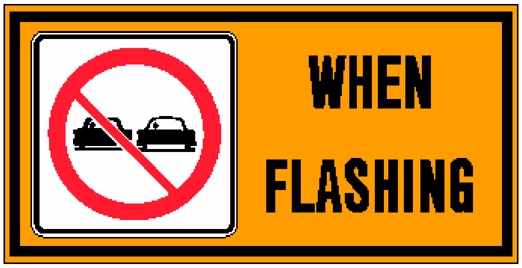



*Figure 18.* DO NOT PASS WHEN FLASHING Sign (Ontario, Pilot Vehicles and Pace Vehicles) (*Source: Ontario Traffic Manual Book 7 (Temporary Conditions)(58))*

Other provinces and territories use signs such as: PILOT CAR PLEASE FOLLOW (B.C., Figure 19), PILOT CAR FOLLOW ME with rotating or flashing amber light mounted on the roof (Saskatchewan), or simply PILOT CAR.


*Figure 19.* Pilot Car (British Columbia) (*Source: Arges Training and Consulting)*

**Pace vehicles** are often used in situations, such as freeway paving operations, where, on a long duration construction site, temporary concrete barriers cannot be provided, and yet workers must work within 1.5 m to 3 m of a live lane of traffic.

Depending on provincial legislation, regulations, and police practice, pace vehicles may be operated by police, road authorities, contractors, or a combination of these. Driver compliance is likely to be higher when paced by a police vehicle than when paced by a contractor vehicle.

The deployment of pace vehicles on freeways is not simple or straightforward, and care must be taken to ensure that it is done safely. Where significant queuing and congestion are expected, or where pace vehicles must be deployed in low volume situations with vehicles approaching at high speed, advance signing should be provided to warn of possible stops or of the use of pace vehicles. There is a significant concern about vehicles approaching at high speed, striking another vehicle at the end of the queue, and spilling into the work zone. Caution and experience are necessary to apply pace vehicles effectively and safely in low volume, high speed traffic situations. It may be useful to provide advance signing, such as BE PREPARED TO STOP, or STOPPED TRAFFIC AHEAD. Some provinces (e.g., Nova Scotia) do not permit use of pace vehicles for fear of a queue building behind the pace vehicles and high speed vehicles, not being aware of the queue, rear ending the last vehicle in the queue. Nova Scotia also cites the difficulty in getting contractors to sign well in advance of the point of potential queue.

Recommended guidelines of practice are provided in section 4.0. See also Figure 20 in section 4.0.

**Rolling closures** are a special application of pace vehicles. The purpose of rolling closures is to control the speed of vehicles upstream of a construction site, so as to create a time window when the road downstream of the lead vehicles is effectively clear of vehicles, creating an unhindered opportunity for workers to do work and/or make traffic control changes at the work site. Example situations of where rolling closures may be a good method of traffic control include the following:

- Changing a lane closure on a freeway from a right lane closure to a left lane closure, or vice versa;
- Installing or removing an overhead sign structure.

In such cases, these very short duration operations can be carried out safely and efficiently if traffic is temporarily prevented from entering the work zone.

Recommended guidelines of practice are provided in section 4.0. See also Figure 21 in section 4.0. It should be noted that some provinces do not permit or encourage the use of rolling closures.

### 3.2.7 Optical Speed Bars

Optical speed bars are transverse paint bars set out at gradually decreasing spacing in order to provide drivers a heightened perception of speed to slow traffic entering a work zone. Optical speed bars have been documented to work well with large desired speed reductions (e.g., from highway speed to a stop or near stop). They have also proven to be effective on approaches to roundabouts in Britain, or at freeway exit ramps where the ramps end at a STOP sign or traffic signal. They have also been used in advance of rural bus stops on winding mountain roads in Italy. They are less well documented concerning effectiveness in work zones where desired speed reductions are smaller. A number of studies of the effectiveness of optical speed bars are referenced in Ref. 10.

Some of the earliest tests of optical speed bars in Canada (though not in work zones) took place in Calgary in 1982 (39). In the experiment, transverse bars were applied to an exit ramp of a major freeway with the intent of reducing accidents at the ramp terminus. The lines extended from edge line to edge line. The markings occupied 404 m of the 900 m exit ramp. The spacing between the lines was graduated from 7.7 m to 2.75 m. Each individual line was 0.6 m wide and 3.5 to 4 m long. The evaluation showed that the average speed decreased from 63.5 km/h before the installation to 61.4 km/h after the installation. The percentage of vehicles exceeding 80 km/h decreased from 5.4% to 4.0%.

Optical speed bars were also tested in New Brunswick (28) as a supplementary traffic control device at four rural highway work zone test sites, over a five-week period. Mean and 85$^{th}$ percentile operating speeds were reduced by an average of 3.4 km/h and 3.8 km/h respectively (statistically significant). The only test site that demonstrated a statistically significant reduction was at night, probably due to the retro-reflective temporary marking tape. All four test-sites demonstrated a statistically significant reduction of standard deviation.

Some of the most extensive recent tests of optical speed bars were conducted in freeway work zones in Kansas (48), and their effectiveness in reducing speeds was evaluated. A design consisting of three separate patterns was developed. The optical speed bars comprised the pattern designated the *primary pattern.* To separate warning effects from perceptual effects, a pattern element was added upstream of the primary pattern, called the *leading pattern.* Based on the suspicion that motorist will resume their previous speeds after leaving the primary pattern, a third pattern element was added downstream of the primary pattern, called the *work zone pattern.*

The leading pattern was comprised of 20 evenly spaced transverse bars ('headway' of 15.85 m) placed immediately upstream of the primary pattern. All bars were 2.75 m long and 1.05 m wide. The length of the leading pattern was 332 m and the spacing of the bars in the leading pattern was equal to the largest spacing in the primary pattern. The length of the primary pattern was 279 m, and it consisted of 29 bars. The widths of the bars varied from 1.05 m to 0.60 m; the bar spacing varied from 15.7 m to 9.0 m. The work zone pattern spanned 747 m and consisted of four sets of six bars with 152 m between sets. Each bar was 0.60 m wide with spacing of 6 m.

The pattern of the optical speed bars was found to cause reductions in mean and 85$^{th}$ percentile speeds, as well as in standard deviations. Changes in speeds were small, and resulted from both warning effects and perceptual effects. The warning effects persisted downstream of the pattern while the perceptual effects did not, as drivers increased their speed once out of the area with graduating spacing. Reductions in speed variations also persisted downstream of the pattern. The work zone pattern did not appear to have any effect on speed or speed variations. The reductions in mean and 85$^{th}$ percentile speeds were considered to be probably too small to be of practical significance.

None of the Canadian survey respondents indicated that they use optical speed bars in work zones, to control motorist speeds through work zones.

### 3.2.8 Portable Rumble Strips

Portable rumble strips are sets of raised strips of a hard material placed transversely across the roadway on approaches to work zones. They have both a “startle” effect and a “discomfort” effect, which alerts drivers and causes them to slow down.

Seven of the Canadian survey respondents have indicated that they use portable rumble strips in work zones, to control motorist speeds through work zones; of these, three rated their effectiveness as high, three as moderate, and one as not effective.

Various U.S. jurisdictions are reported as using temporary rumble strips in work zones, both construction and maintenance: Michigan, California, Delaware, Illinois, Pennsylvania, Ohio, Maryland, Indiana, Kentucky, New Mexico, and South Dakota. The advantage of rumble strips is considered to be not so much a reduction in speed, but in raising the level of alertness of drivers. A portable rumble strip was developed through the Strategic Highway Research Program (SHRP) for use in low speed work zones, but there is considerable variability in the actual designs used:

- California uses raised (0.75 in.) or indented (up to 1.0 in.) rumble strips across the full width of the lane. Their standard spacing pattern is intermittent spacing of 50-100 feet between sets of 3 strips 3 inches wide, over a distance of 25 feet. California only allows their use when it is determined that they are a reasonable solution to an identified problem.

- Illinois uses raised high-strength polycarbonate strips that are 0.5 inches high and 3.5 inches wide with a tapered edge towards the approaching traffic. They use 6 strips evenly placed over 25 feet, placed 200 feet before each construction sign, extending the entire width of the travel lane.

- Pennsylvania uses raised 4-inch wide asphalt strips that are formed by nailing 0.5 inch x 4-inch plywood strips to the pavement and filling with asphalt overlay material. The plywood is then removed and the strips are rolled. These are in sets of 15 or 20 strips spaced 12 inches apart extending onto the shoulder. The sets are spaced at intermittent distances from 200 feet between sets 1 and 2, 100 feet between sets 2, 3, and 4, and 50 feet between sets 4 and 5 with the 6th set (also at 50 feet) used in advance of a detour. A "RUMBLE STRIPS AHEAD" sign is also required.

- Kentucky uses raised 8-inch wide asphalt strips, placed in sets of 10; the spacing, height, and spacing within sets, is varied according to the speed limit. For speeds greater than 45 mph, the strips are 0.38 inches to 0.5 inches, at 24-inch spacing.

- Ohio uses either raised or grooved strips both at a maximum of 0.5 inches high or deep. The number of strips in a set and the spacing of the groups are both dependent on the speed limit. They use 10 sets with 8 to 16 strips per set. They are placed in groups of 3 sets, 4 sets, and 3 more sets with the distance between groups of sets varying from 100 feet to 250 feet, and the distance between sets varying from 35 feet to 100 feet dependent on the speed.

- Indiana uses buzz strips (thermal plastic rumble strips) prior to traffic changes and in high collision areas. They are considered to be successful in getting drivers' attention.

- New York State DOT (NYSDOT) requires a final compacted thickness of 10 mm ± 3 mm, using 6 strips evenly spaced 3.0 m apart, across the entire width of the lane(s). In maintenance NYSDOT used raised asphalt strips, multiple layers of adhesive tape, used traffic counter tubes, and reinforced rubber belting (recycled tire tread strips) screwed to the pavement. NYSDOT recommends use of any of these, if properly applied, but only where audible and tactile warnings are necessary for the safety of exposed workers or drivers. Examples include a detour, lane splits, exit only lanes, one lane traffic with a traffic signal ahead, major reduction in the speed limit, and varying traffic patterns.

In Europe, the Netherlands uses portable rumble strips, called "Andreas strips", in closed traffic lanes, 150 m in advance of a parked work truck, to provide a final warning to motorists that they have intruded into a work area. The strips are 2 m long, 20 cm wide, and 4 cm thick, three strips at 5 m spacing (71).

Despite the number of jurisdictions applying portable rumble strips in work zones, there is little information available concerning their effectiveness in reducing speeds through work zones, and the test results available are not consistent. A study done in New Brunswick (28) found that portable rubber rumble strips reduced mean and 85$^{th}$ percentile operating speeds by 6.9 km/h and 9.5 km/h (statistically significant). Another study (47) reported that portable rumble strips are not very effective. Portable rumble strips have the disadvantages of relatively long installation and removal times, and the safety risk of worker exposure during installation and removal.

## 3.3 Other Speed-related Safety Measures

Other speed-related measures may also contribute to work zone speed management, or more basically, may contribute to work zone safety by helping avoid or reduce some of the speed-related hazards. These may involve more/better advance warning of the work zone, merge control, work zone intrusion alarms, and various ITS technologies. The most frequent types of collisions in work zones are sideswipe (related to both merges and excessive speed) and rear-end collisions (related to excessive speed). These measures generally go beyond the scope of this project, but several are described here, based on the review of the literature and web.

### 3.3.1 Advance Warning of Work Zone

Advance warning of the work zone is fundamental to good work zone management, and the advance warning area is one of the components of a good work zone, as shown in Figure 5. The advance warning area helps avoid violation of driver expectation, and prepares them for the work zone ahead. Work zone traffic manuals often show minimum typical guidelines or standards for the signing and other traffic control devices to be used for work zones; it may be necessary or desirable to provide more signs, such as more advance warning, where circumstances so indicate.

Advanced warning of the work zone may range from the simple to the comprehensive. The U.S. NIOSH recommends that motorists be given plenty of advance warning of upcoming work zones (64). Many U.S. states, for example, Pennsylvania DOT, station a uniformed police officer in a patrol car with emergency lights flashing 1/4 to 1/2 mile upstream of any queue.

### 3.3.2 Innovative Devices for Improved Worker and Motorist Safety

With the advent, development, and increasing use of Intelligent Transportation Systems (ITS), they have also found applications in work zone operations and safety. The Canadian ITS Architecture, modeled to a large extent on the U.S. ITS Architecture, added a number of ITS user services not originally in the U.S. Architecture, but which the U.S. FHWA subsequently adopted. One of these is the Maintenance and Construction Operations User Service (MCOUS) in the ITS Architecture, which identifies ITS systems that help ensure safe roadway operations during construction and other work zone activities and communicate with the traveller (40).

MCOUS identifies the following ITS technologies that may be applicable, under the title of **Smart Work Zones:**

- Roadway information/surveillance systems (Examples include inductive loops, CCTV, video imaging detection systems (VIDs), acoustic, radar). An example of this is the ADAPTIR system, a mobile traffic monitoring and management system, which was used in Iowa to advise drivers of slowing traffic speeds downstream, providing information via PVMSs. PVMS info was: Phase 1: Location & word ADVISORY; Phase 2: REDUCED SPEED AHD xx km/h., when speed differentials exceeded a threshold amount. In Iowa, these were found to be more effective when traffic approached congested levels, rather than in uncongested flow (33).
- Lane-drop smoothing or merge control systems (i.e., series of portable flashing beacon signs and electronic occupancy sensors) (See section 3.3.3)
- Traveler warning system (Examples include Dynamic Message Signs (DMS), highway advisory radio (HAR), radio broadcasts (AM and/or FM subcarriers), in-vehicle displays (e.g., graphical, text, audible, etc.), flashing beacons coupled with a static sign message, stand-alone static signs for warnings and/or diversion routes)
- Personal warning devices/systems (Examples include a device (i.e., beeper) that a worker wears that provides an indication when a vehicle enters (i.e., machine vision video cameras) or worker leaves a "safe zone" and/or provides a message to motorists via roadside DMS and/or HAR. Other examples include intrusion devices/alarms used for improving worker safety at work zones. See section 3.3.5)
- Moveable barrier systems (40)

Only one of the Canadian survey respondents indicated that they use ITS in work zones, to control motorist speeds through work zones; the respondent rated the effectiveness as moderate. However, this may reflect the assumptions respondents made about what is classed as ITS. For example, 22 respondents indicated that they use PVMSs.

Illinois, Michigan, New Mexico, and Nebraska are cited as U.S. states that have successfully applied ITS technologies in work zones to help manage traffic better. Applications included detectors and CCTV to collect data, which are analyzed, and the provision of real-time traffic information to drivers using PVMSs, HAR, and a web site (59).

Benefits of ITS in work zones (33) included reduced traffic queues, fewer traffic citations, increased safety (fewer collisions, including fewer secondary collisions), reduced construction time (one season rather than two), more effective communications with local agencies, quicker incident response and clearance time, better maintenance of traffic flow, and good public reaction. Key strategies for success were identified as:

- address communications process early
- allow start-up time when deploying a system
- use a proactive approach for building public awareness
- deliver accurate information to the public
- involve a wide range of stakeholder agencies
- carefully consider how to set up automated information delivery and sharing with other agencies

### 3.3.3 Merge Control

Since such a high percentage of work zone crashes are rear-end and sideswipe crashes, often occurring as a result of failure to notice a lane closure or to shift lanes at a lane closure, merge control offers a means of facilitating such manoeuvres and improving safety.

International Road Dynamics Inc. (IRD) has developed an ITS system called Lane Merger, which promotes smooth traffic flow leading into a work zone by creating a dynamic no-passing zone upstream of the construction site which results in reduced conflicts, fewer collisions, and reduced road rage. Michigan DOT has used this real-time information system and dynamic lane-merge system on I-94 to help improve traffic flow through work zones. The system uses a series of five trailers with flashing lights and signs that say "Left Lane Do Not Pass When Flashing." The purpose of the system is to have motorists merge early enough to prevent the backups that often occur with last minute merging. Prior experience with the system has proven very effective, often reducing travel times through a work zone significantly (38, 45).

Similarly, the Dynamic Work Zone Safety System, used in Indiana and Michigan, is designed to prevent dangerous merging in the tapered approach to work zones by creating a dynamic no-passing zone, the length of which depends on the length of the traffic backup. The coverage area of the no-passing zone is depicted by a series of signs. The trailer-mounted, portable signs consist of flashing lights, a "DO NOT PASS" sign, and a "WHEN FLASHING" sign. As sensors detect that traffic is backing up, the next upstream sign begins to flash. The signs are regulatory, and thus the DO NOT PASS message is enforceable. System components include non-intrusive traffic sensors, interface controllers, communication devices, regulatory signboard with flashers and trailer, and solar power equipment and batteries (33, 92).

### 3.3.4 Queue Warning and Real-time Traffic Information

FHWA studies have demonstrated the effectiveness of using PVMSs, together with traffic data on traffic flow, speed, and end of queue, to provide information to drivers and improve safety in work zones (56). No Canadian survey respondents indicated that they use such systems. Several U.S. states have used them, however, as indicated in section 6.0. These states include Illinois, Michigan, Missouri, and New Mexico. Also described in section 6.0 is an application in Belgium.

### 3.3.5 Work Zone Intrusion Alarms

Work zone intrusion alarms are still in the development and test phase, but appear to offer promise for improved worker safety, both real and perceived. The U.S. Strategic Highway Research Program (SHRP) and Pennsylvania DOT have tested several work zone intrusion technologies, the latter on a project with high traffic volumes and blind corners which made it difficult to see slowed or stopped traffic. Intrusion alarms detect vehicles entering the buffer area between work crews in the work area and vehicles driving past the work zone, and provide a warning to alert workers. Warning time may be short (4-7 seconds), but can be vital. Such alarms employ various technologies such as infrared, ultrasonic, microwaves, or pneumatic tubes, to detect the intruding vehicle. When the system detects an intrusion, it sounds a loud siren to warn the workers in the area. Transmission mechanisms include radio and hard-wired systems (33).

### 3.3.6 Work Zone Safety Training

The importance of work zone safety training cannot be over-emphasized. Most provincial legislation and regulations on construction safety require supervisor and worker training. Such training should include not only the provisions of the relevant labour ministry legislation and regulations, but also the provisions, guidelines, standards, and practices outlined in the province's work zone traffic control manual. Training programs need to provide workers with an understanding of safety hazards and methods of hazard reduction in highway and street construction. All workers should be trained in hazards and adaptations for work at night and in other low-visibility conditions.

Some provinces, often through the Occupational Health and Safety Act and regulations, require a Traffic Protection Plan or Traffic Control Plan for any work zone activities, describing the hazards to be protected against, the traffic control measures to protect workers, type of work, work zone characteristics, a layout of the work zone, and the crew. This helps ensure that all crewmembers understand the requirements of the work zone in question, including traffic control set-up and takedown procedures, and the need for monitoring and maintenance of the traffic control to ensure the integrity of the closures.

### 3.3.7 Driver Education

The third pillar of good traffic engineering, besides engineering and enforcement, is education. Drivers need to be educated as to what they should expect in work zones and what is expected of them. Driver instruction manuals, with which new drivers need to be familiar in order to obtain a driver's licence, should include information on work zone traffic control and expected driver behaviour, for safety. Experienced drivers should be provided periodic summaries or updates of such information, e.g., as inclusions in their notices of driver licence renewal.

The following information should be considered for inclusion in driver instruction manuals:

- The importance of safety for both motorists and workers.
- Explanation of orange warning signs for work activities on the road.
- The depiction and description of the most important work zone signs and traffic control devices, such as cones, barrels, barriers, and barricades.
- The need to slow down for work zones where indicated (by ROAD WORK signs, by signs indicating the speed limit when workers are present, by signs indicating reduced speed when lights are flashing, and/or by PVMSs).
- The need to stop (or proceed slowly) as indicated by Traffic Control Persons.
- Recommended driver action when encountering mobile work operations.

## 3.4 Non-speed-related Safety Measures

Work zone safety is a complex issue, and there are many safety measures that have been tested, evaluated, and applied, both speed-related and non-speed-related. The latter category goes beyond the scope of this report, but some examples are included here, which may be useful both in pointing the way to measures that remove the speed problem or help reduce the inclination to speed, and also in developing future chapters of a Work Zone Safety Manual.

### 3.4.1 Road Closures

The application of work zone speed management measures is usually predicated on the concept of keeping the road open to traffic. However, some road authorities in both the U.S. and Europe are moving toward a strategy of complete road closures, where possible, to make the construction project both faster and safer.

Full road closure is often not feasible, and certainly is not feasible in every situation. Some locales may simply lack suitable alternate routes, while others may reject the approach due to jurisdictional complications or the impacts full-closure would have on local businesses, among other reasons. But transportation agencies that have used the full closure method say it can greatly reduce the time needed to complete a construction project. It can also be safer than the traditional partial-closure approach, advocates say, because it doesn’t cause congestion that can lead to collisions. There are other potential benefits as well. Because construction crews can operate more efficiently in a traffic-free environment, full-closure projects can be both less expensive and of a higher quality than those undertaken with a partial-closure approach. Indiana and Oregon DOTs are cited as having had successful applications, as well as Kentucky, Michigan, Ohio, Delaware and Washington (59).

The Netherlands has also determined that it can often be cost-effective to close down a road for construction or maintenance (71). The approach is "Get in, stay in, get out, stay out." Michigan DOT has also adopted a "get in, stay in, get out, stay out" policy with regard to much of the Interstate construction in the Detroit area (92).

### 3.4.2 Better Information to the Travelling Public

It is beneficial, especially in long duration and long-length work zones, to tell motorists what they should expect in terms of delay. At the most basic level, drivers should be informed of the length of the work zone, and when/where delays may be expected. As reported by FHWA, the biggest motorist complaint in work zones is that the lane is closed and there’s no work going on. “To the public, the worst thing about work zones is being delayed. The second worst thing is not knowing why they’re being delayed.” U.S. NIOSH recommends installing warning signs that provide estimated time of delay and other road closure information so that drivers have sufficient opportunity to exit and take a different route (64). Many U.S. states, e.g., Michigan, Illinois, New Mexico, and Iowa, use sensors, communications and PVMSs to tell motorists how many minutes it will take them to reach the end of the work zone. International Road Dynamics Inc. (IRD) has developed an ITS system called Travel Messenger, which measures traffic conditions at strategic locations and determines and displays expected delays through a work zone. Advance messages advise drivers, reducing impatience and allowing alternate routes to be chosen.

In Germany, PVMSs are widely used to reroute traffic as necessary; the signs are part of an area wide signage and information system, including permanent orange trailblazers that indicate alternate routes that travellers can take to avoid work zone delays (71).

Many Canadian provinces and cities, and many U.S. states have developed public relations and information outreach programs for motorists and the public, to improve customer satisfaction and to improve safety, by a variety of means. Saskatchewan has an “Orange Zone Campaign” annually during the construction season, which includes fines and penalties. The campaign is included province wide within weekly and daily newspapers, radio and television advertisements. Some states (e.g., Arizona) make public relations and information a bid item in construction contracts (30, 92). Indiana DOT has used media extensively over 20 years to notify motorists by radio, TV, and newspapers, of upcoming projects, possible delays and suggested alternate routes (92).

In addition, there are some specific means of providing better information to the traveling public, which will alert them to work zones and help avoid hazardous violations of expectations and excessive speed. These include the use of PVMSs (described in more detail above), Highway Advisory Radio (HAR), commercial radio, internet web sites, displays of real-time work zone traffic conditions on large screens at rest areas, welcome centres, weigh stations, truck stops, major tourist attractions, large parking garages, large office buildings, employment centres, and/or other large traffic generators, and dissemination of information on current work zones through trucking associations.

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# 4.0 CONCLUSIONS AND RECOMMENDATIONS

## 4.1 Overview of Section 4.0, and General Conclusions and Recommendations

Section 3.0 describes, reviews, and synthesizes a wide variety of work zone speed management practices. Section 4.0 draws conclusions and makes recommendations regarding appropriate work zone speed management practices, based on information obtained from Canadian sources through the survey questionnaire, from international sources through the literature review, and from the experience of the Project Steering Committee and the consultants. Inevitably, there is some overlap between sections 3.0 and 4.0 on the one hand, and sections 5.0 (Questionnaire Survey Results) and 6.0 (Literature Review) on the other. Most of the key findings from the Literature Review are included in sections 3.0 and 4.0; section 6.0 need be read only if readers are looking for more detailed information references.

Included in this section 4.1 are general conclusions and recommendations related to the issues and approaches to work zone speed management. Sections 4.2 through 4.4 address conclusions and recommendations related to the material in sections 3.2 through 3.4. In general, work zone speed management is not considered to have significant impact on the highway environment.

1. **Conclusion and Recommendation**: Roadway work zones should be designed around the basic principles of:

   - Worker safety
   - Road user safety
   - Road user mobility.

2. **Conclusion:** If motorist safety is improved in work zones, worker safety is also improved because the traffic crashes that occur often spill over into the work areas and put workers at risk.

3. **Conclusion:** Roadway type (urban or rural, high speed or low speed, freeway or non-freeway) has a bearing on work zone speed management. Safety in all work zones is important. Generally, work zones and work zone speeds on low-speed urban non-freeways are easier to manage, and tend to be safer. As normal posted speed limits increase, work zone safety and work zone speed management become more of a challenge. Freeways, despite their generally lower collision and fatality rates than other types of roads, pose even greater challenges than non-freeways for work zone safety and work zone speed management.

4. **Conclusion:** Driver attitudes to work zone speed reductions are a factor on all roads, but tend to be more pronounced on freeways. Drivers are unwilling to slow down and seem to resent construction and maintenance delays. As a result, drivers become aggressive. A further hazard on freeways is that drivers become inattentive, their level of awareness drops, or they become preoccupied (e.g., cell phones) or bored. While this is more prevalent on rural freeways, with fewer congestion delays, it also occurs on urban freeways, and indeed, on all types of roads to some degree.

5. **Conclusion:** Design of the work zone is very important in contributing to both safety and mobility. Various traffic manuals, including the Manual of Uniform Traffic Control Devices for Canada (MUTCDC) (41), stress this as follows:

   **Recommendation:** Design traffic safety as an integral part of construction and maintenance projects, rather than apply it on a makeshift basis. Route traffic through work zones in a manner that most closely resembles normal road conditions, but also ensures the safety of workers and road users. Interfere with traffic movement as little as possible. Design the travelled way through the work zone for normal highway speeds as much as possible. Avoid frequent or unnecessary changes, such as sudden lane narrowing and lane closures that result in sudden reductions in speeds and risky manoeuvring. Where interference is unavoidable, guide the movements of all road users, including drivers, cyclists and pedestrians, in a clear and positive manner by adequate signs, devices, markers, pavement markings and traffic control persons, whichever control measure or combination of control measures is most appropriate.

6. **Recommendation:** Explicitly consider the need for speed reduction during design, to enhance the effectiveness of speed control during construction. For example:
   - Choose a detour design speed 20 km/h over the anticipated posted legal speed where practical;
   - Design detour geometry to avoid the need for a large speed reduction;
   - Design the work zone to permit construction vehicles to exit/enter near normal speeds;
   - Build police car lay-bys into the detour where possible/practicable.

7. **Conclusion:** Provision of work zone information to the traveling public is important, including information on work zone location, duration, and expected delays.

   **Recommendation:** Maintain good public relations. Keep road users informed of the existence of and reasons for work sites. Provide good advance information to reduce the element of surprise and help manage expectations.

8. **Conclusion:** Credibility of work zone signing and of posted speed limits is critical to safety.

   **Recommendation:** Everyone involved in work zone safety – road authorities, contractors, and workers – needs to ensure that work zone signing is credible, that is, that it describes conditions in effect at the time. Check work sites carefully to make sure that traffic controls are continually updated to suit changing construction conditions due to work staging and progress, or if an immediate improvement to the traffic control is needed. Ensure that work zone traffic controls reflect actual conditions, so that signing is credible, increasing the likelihood of driver compliance. Remove all temporary conditions traffic control devices when no longer needed. When work is suspended for short periods, remove, cover, or turn advance warning signs that are no longer appropriate, and remove other inappropriate devices from the work area so they are not visible to drivers.

   **Recommendation:** To enhance work zone safety and compliance with work zone traffic control, inform motorists that workers are present, and advise them that reduced speed limits are in effect when workers are present, by one or more of:

- Posting ROAD WORK AHEAD (Men at work) signs whenever workers are present, for both long duration and short duration work, and removing them when workers are no longer present;
- Posting signs stating “Speed Limit xx km/h when workers are present” or “Speed Limit xx km/h passing workers”; or
- Posting signs stating “Speed Limit xx km/h when lights flashing.” The amber flashers are activated by road crews when present, and turned off again when they leave. The sign may also indicate that increased fines are in effect (when lights are flashing).

9. **Conclusion:** The solution to work zone speed management is not as straightforward as simply posting extremely low speed limits. Control of traffic speeds by imposing unwarranted regulatory speed limits is not very effective. Posting unrealistically low speed limits tends to diminish safety rather than enhance it. The majority of drivers disregard posted speed limits if the construction/ maintenance activities or hazards encountered are not severe enough to warrant such lower speeds, or if there is no visible sign of work activity. If there are sudden posted speed reductions, motorists who do slow down may cause collisions. If motorist safety is compromised, worker safety is also likely to be compromised.

10. **Conclusion:** There are some types of maintenance and construction projects where a reduction of the normal speed limit is not required, for example, depending on the details of the work and worker exposure, work done on the shoulder or beyond it, very short duration or short duration work not involving lane closures, and some intermittent and mobile operations.

11. **Conclusion:** Experience has shown that it is difficult to achieve an average speed reduction of more than 15 km/h.

    **Recommendations:** Maintain normal speeds through the work zone as much as possible. Design the travelled way through the work zone at a design speed that is equal to or as close as possible to that of the approaches to the work zone. Avoid work zone speed limit reductions, where possible, where all work activities are located on shoulder or roadside areas and in work zones where no work activities are under way. Attempt to reduce speeds only if there is a good reason for it. Posted speed limits in construction zones should not be more than 20 km/h below the normal posted speed limit for that road section, except where required by restricted geometrics or other work zone features that cannot be modified.

12. **Recommendation:** Consider the work zone in terms of its component areas, as shown in Figure 5. Give drivers timely notice of the need to reduce speed in the advance warning area and in the approach area, but restrict the length of the reduced speed zone to the minimum length.

## 4.2 Work Zone Speed Management Techniques (See Section 3.2)

13. **Conclusion:** Of the work zone speed management techniques reviewed in the literature, and listed in the questionnaire survey, the most effective techniques were found to be:

    - reduced regulatory speed limits together with police enforcement

- portable variable message signs on the approach to the work zone
- pace vehicles and pilot vehicles
- radar speed measurement and speed display

Police enforcement or presence enhanced the effectiveness of these measures.

Techniques which were found to be less commonly used, but reasonably effective, were:

- photo radar
- portable rumble strips
- ITS applications

Techniques that were found to be less effective were:

- advisory speed limits
- variable speed limits
- increased fines for work zone speeding (effectiveness depends on enforcement)

### 4.2.1 Posted Speed Limit Reductions in Work Zones

14. **Conclusion:** 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, supported by a Highway Traffic Act or municipal by-law. Reduced speed limit signs may be either regulatory (black/white) signs or advisory (black/orange) signs or tabs. (In some jurisdictions (e.g., Quebec) black/orange speed limit signs are actually regulatory signs.) Regulatory speed signs, properly authorized, are enforceable. Advisory speed signs are generally not directly enforceable, although some Canadian road authorities have indicated that their advisory speed signs are enforced. Where regulatory work zone speed limits are used, they are typically used only for construction projects, which are longer in duration than most maintenance or utility projects. If reduced speed limits are used at all in maintenance or utility projects, they are generally advisory speeds. It is beneficial to have a methodology for determining where regulatory speed limits should be applied, and the amount of the speed reduction.

    **Recommendation:** Post reduced speed limit signs only when:

    - work activity is actually occurring, and cover or remove them when work is suspended or completed (generally, the maximum reduction in posted speed should be about 20 km/h)

    - reduced or restricted design situations, such as narrow lanes, detours, diversions, or cross-overs, remain, even though work is suspended. Although such situations cannot always be avoided, a better approach, where possible, is to design the work zone for normal speeds

    - workers work within 3 m (or 1.5 m for low speed facilities) from a live lane for extended periods of time and temporary concrete barriers are not practical

15. **Conclusion:** Most jurisdictions have their own procedures for implementing regulatory work zone speed limit signs, either legislative or administrative.

**Recommendation:** Where regulatory speed limits are to be used in work zones, implement construction speed zones and establish construction zone speed limits according to the process appropriate to the jurisdiction and road authority. Lay these out in general accordance with the examples given in Figures 6 and 7 (British Columbia), the Alberta Manual (various figures), Figures 9 and 10 (Ontario), or Figure 13 (Nova Scotia). Install regulatory speed limit signs only when the appropriate police authority has been informed, and intends to provide enforcement. Otherwise, use advisory signs.

To implement construction speed zones and speed limits, install the work zone signing, including the required speed control signing. First set out the CONSTRUCTION AHEAD signs in the advance warning area, as shown in Figures 6 and 7 or Figure 13. Then set out the signing for the construction speed zones and speed limits in advance (upstream) of the work zone (excluding the Advance Warning area, which comes before the speed signing) as shown in Figures 6, 7, 9, 10 and 13. Set out any signs informing drivers that the reduced speeds are in effect when workers are present, or when amber flashers are flashing. In Figures 6 and 7, the main part of the work zone is called the 'Highway Improvement Project'. In Figures 9 and 10, the main part of the work zone is called the 'Reduced Speed Zone'. The signing for the work zone itself is shown on a variety of typical layouts in the various road authorities' work zone traffic control manuals. Finally, set out the signing beyond the work zone for the construction speed limits, the construction ends location, and the resumed normal regulatory-posted speed. Examples of regulatory and advisory speed signs are shown in Figures 11 and 12 respectively.

Maintain the speed control zone in a credible manner, by displaying the reduced speed limits (whether regulatory or advisory) only when workers are present, and covering the reduced speed limits when no workers are present, and at the same time uncovering the normal regulatory speed limit signs. The exception to this is when work zone geometrics require a lower speed regardless of activity in the work zone; however, this is an undesirable situation, and consideration should be given to improving the work zone geometrics, to allow for normal speeds when no workers are present.

Use the principle outlined in the above paragraph also when the speed control zone progresses along the construction project as the work progresses. By uncovering only the reduced speed limit signs on the approach to, and in the vicinity of, the actual work sites on the project, and leaving other signs at their normal posted speed, one can ensure that the appropriate signs are in place and displayed where they are actually needed, at all times.

16. **Conclusion:** Compliance with speed limits increases when:
- Speed reductions are used consistently from one site to another;
- Drivers perceive a real need for the speed reduction (e.g., workers present adjacent to live traffic lanes, unusually sharp curve);
- Drivers are warned about the speed reduction in advance;
- Speed reduction is not more than 20 km/h below the normally posted speed;
- Speed reductions are enforced;
- Speed reduction extends for 300 m or more;
- Police enforcement vehicles are located inside the work zone.

17. **Conclusion:** Work zone speed limits are a necessary, but not a sufficient, condition for achieving lower work zone speeds. They provide the legal basis for enforcement. For

work zone speed limits to be effective, they need to be supported by other measures, primarily enforcement.

18. **Conclusion:** Variable Speed Limits (VSLs) can provide more credible speed limit information to drivers, by displaying a speed limit that is based on real-time traffic flow, roadway and speed conditions. The primary uses of VSLs have been to help manage congestion or to advise of adverse weather and/or roadway conditions. Both of these applications are potentially useful in long duration work zones. VSLs may be either regulatory or advisory. The relevant traffic legislation and regulations vary by jurisdiction. If VSLs are to be regulatory, most jurisdictions will need to amend their Highway Traffic Act and/or other related legislation. If VSLs are to be advisory, such legislative changes are not required. These systems 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. When used in work zones, traffic volume and speed data are collected at various points within the work zone and used to calculate a recommended posted speed limit, which is varied frequently, as often as once per minute, but not until the difference between recommended speed and currently posted speed exceeds a given threshold, say 7 km/h. By changing the speed limits in accordance with prevailing volume and speed conditions, they can be set to be relevant to conditions in the work zone, and can enhance credibility of signing to drivers, resulting in better speed compliance, improved safety and smoother traffic flow. These systems are still being tested, and it is not yet possible to provide specific recommendations for their use.

### 4.2.2 Enforcement of Reduced Speed Limits in Work Zones

19. **Conclusion:** 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 and reduce collisions in work zones include police presence and enforcement in the work zone. Enforcement issues include: driver behaviour, frequency of enforcement, location of enforcement vehicles, live versus dummy police vehicles, penalties for speeding, methods of enforcement (including photo-radar), work zone training for police officers, and traffic court judges.

20. **Conclusion:** Driver behaviour is a significant issue in achieving lower speeds through work zones. A critical difficulty in deterring speeding using traditional methods is maintaining the effect over time and space.

    **Recommendation:** To ensure a high level of compliance, set speed limits at levels that are largely self-enforcing, or at the lowest speed the police are able to enforce.

21. **Conclusion:** Frequency of enforcement is an important factor in reducing work zone speeds. Increasing enforcement intensity boosts the deterrence effect by increasing the perceived risk of apprehension. However, deterrence effects of even a major program can diminish with time. The deterrence effect of enforcement depends on creating the impression that road users who violate the law have a high probability of being apprehended.

**Recommendation:** Enforce speed regulations where and when risk-taking behaviours are most evident and traffic volumes are sufficient to justify the effort. Implement initial intense enforcement to make an immediate effect and create a greater time-halo effect. Vary enforcement patterns by time and location. Ensure that there is some periodic enforcement where regulatory work zone speed limits are implemented. Use extra enforcement where warranted. Criteria for selection of a work zone for extra enforcement include traffic volume, enforcement personnel availability, potential work zone congestion, remaining highway capacity, high speeds, work zone and activity type (e.g., closely adjacent to traffic without positive protection, and geometric limitations).

22. **Conclusion:** The location of police vehicles in relation to the work zone also needs to be considered. Locations to be considered include: in advance of (upstream from) the work zone; within the work zone; and beyond (downstream from) the work zone. Generally, it is beneficial to position police vehicles upstream from or at the beginning of the work zone, because of its powerful effect in getting vehicle speeds down before they enter the work zone.

    **Recommendation:** Position a manned police vehicle(s) in one of the following ways:

    - One police vehicle upstream from or at the beginning of the work zone, to obtain a strong deterrent effect in advance of the work zone (generally found to be most effective);
    - One police vehicle within the work zone, in a parking/pull-over bay constructed within the work zone.
    - Two police vehicles, one upstream of the work zone, and one downstream from the work zone. The first vehicle provides a deterrent effect, and the police officer can identify speeders' licence plates and radio them to the officer in the second vehicle, for flagging down or pursuit.
    - A mobile police patrol vehicle circulating through traffic, measuring driving speeds with radar and citing speeding drivers.

23. **Conclusion:** Dummy (unoccupied) police vehicles can sometimes be used effectively, saving police resources, but drivers soon catch on, unless manned police vehicles are also used from time to time, keeping drivers off balance.

    **Recommendation:** If dummy police vehicles are used, use them only on a short-term temporary basis. Supplement or replace them with manned police vehicles from time to time, to achieve continued effectiveness.

24. **Conclusion:** Speeding penalties are an issue in achieving work zone speed management, and increased penalties for speeding in work zones can be effective in reducing speeds. However, evidence for the effectiveness of increased fines in reducing collisions and fatalities is not conclusive. In any case, the effectiveness of increased fines in work zones clearly depends on effective enforcement. Without enforcement, speeders will not be apprehended. While it may help initially to post a sign that increased fines are imposed for speeding, the effect will wear off over time if there is no enforcement. A concern raised by a Texas study was doubled fines in conjunction with a worker-presence requirement (difficulty for police in establishing worker presence).

**Recommendation:** Use increased fines for speeding in work zones, on a selective basis, where work zone speeds cause significant hazard or in strategic areas, but only if supported by adequate enforcement.

25. **Conclusion:** Photo radar is the automated enforcement of speed limits through use of cameras set up to photograph any vehicle that exceeds the posted speed limit by a certain pre-determined threshold. The vehicle caught speeding is cited and a ticket is automatically issued. Signs can be set up prior to work zones to warn approaching drivers that photo radar is in use. (If the advance signs show drivers their actual speed, giving them a chance to slow down before reaching the work zone and the photo radar installation, this has an immediate positive benefit for the work zone. If photo radar is concealed, drivers may not notice it and may speed through the work zone. The ensuing fine may lead them to take greater care on another occasion, but the benefit for the first instance is lost.) Photo radar has the potential to increase safety, and has achieved improved safety in work zones, through greater compliance with speed limits, improving both mobility and safety by decreasing the need for enforcement personnel to stop vehicles in and around work zones, and providing cost savings for enforcement personnel. It helps maintain an enforcement level that provides a meaningful deterrent to drivers by increasing the probability of detection for speeding violations. Because it can be deployed without police presence, photo-radar can increase the perceived level of risk to drivers and hence compliance levels without producing a reduction in police surveillance levels. It can be used in locations where patrol vehicles cannot be safely and effectively deployed. Moreover, when photo-radar is operated without police presence, it frees police for other traffic and law enforcement activities. The safety effects of using photo radar are well documented.

    **Recommendation:** If permitted within the jurisdiction and road authority, use photo radar, coupled with increased fines for speeding in work zones, and signs advising drivers of both of these, to reduce work zone speeding. Work zones are a good application for photo radar.

26. **Conclusion:** Training for police officers in work zone traffic control procedures and the relevant traffic manuals is important, and has been specifically recommended by the U.S. NIOSH. Many police officers are well trained in these matters, and do an excellent job of controlling traffic in and around work zones. Others, however, are less well trained and motivated.

    **Recommendation:** Road authorities should work cooperatively with police in developing work zone safety training programs.

27. **Conclusion:** Traffic court judges are important participants in effective speed enforcement. They may overturn speeding violations if they think the speed limits are unreasonable or reduce fines if they believe the sanctions are too harsh. If judges are lenient in their treatment of speeding offences and routinely dismiss speeding citations, the incentive for the police to enforce the speed limits may be reduced. Thus it is important that traffic court judges—as well as the police and motorists—perceive that speed limits are reasonable and enforceable.

### 4.2.3 Actual Speed Display, with Regulatory Posted Speeds

28. **Conclusion:** Measurement of drivers' speed by means of radar, and display of the measured speeds on variable message signs (VMSs) have proven to be effective in helping to manage speeds in work zones. The use of radar-controlled speed signs has been shown to reduce 85th percentile speeds an additional 4 to 8 km/h over the reduction caused by static signs, probably because the display is more dynamic than a static sign, the motorist sees his/her actual speed, and may infer that if his/her speed is being measured, there is probably a police officer nearby. The effect of a single VMS may be reduced with distance from the sign (halo effect), but the reductions can often be sustained with two or more VMSs. This measure will have lasting effectiveness only if supported by periodic police enforcement. An example of such a sign is shown in Figure 14.

    **Recommendation:** Where work zone speeds cause significant hazard, use radar-controlled speed display signs, together with the speed limit in effect, supported by enforcement, to reduce work zone speeds.

### 4.2.4 Portable Variable Message Signs (PVMSs)

29. **Conclusion:** Portable Variable Message Signs (PVMSs) can be useful to advise motorists of lower speeds in work zones, and to achieve better speed compliance. An example of the use of PVMSs to advise of reduced speed limits is shown in Figure 15 (a single sign with a two-phase message).

    **Recommendation:** Use PVMSs to advise motorists of reduced speed limits in work zones, where other reduced speed signs have been ineffective, especially on high-speed freeways.

### 4.2.5 Narrower Lanes

30. **Conclusion:** Narrower lanes can be used to reduce speeds through work zones, although this practice does not seem to be widespread in Canada. However, virtual narrow lanes (using wider pavement markings to create a visually narrower lane) have a minimal effect on motorist speeds through the work zone.

    **Recommendation:** Use narrow lanes to reduce speeds in long duration construction work zones where other speed control measures have been ineffective, and where work zone speeds cause significant hazard. Do not reduce the lane width to less than 3.0 m. Demarcate narrow lanes through the use of pavement markings or embedded pavement markers, and ensure that old pavement markings are effectively covered or removed, to avoid driver confusion. If cones or barrels are used to create narrow lanes, frequent inspection is necessary to ensure that displaced devices are repositioned.

### 4.2.6 Pilot Vehicles and Pace Vehicles

31. **Conclusion:** In some situations, pilot vehicles and pace vehicles are very effective methods of controlling motorist speeds in work zones, without requiring police enforcement. These situations are:

(1) where a pilot vehicle is used (in conjunction with traffic control persons) on a two-lane road to guide a queue of vehicles through a one-lane section of a temporary traffic control zone or detour, and to control the speed of vehicles through the construction site, especially immediately adjacent to areas where workers are present; and

(2) where one or more pace vehicles are used on freeways, one pace vehicle per open lane of traffic, to constrain and control the speed of vehicles traveling through the work zone, where reduced speed is necessary but it is difficult to achieve speed reductions by other means. Pace vehicles are also effective in implementing rolling closures.

**Recommendation (Pilot Vehicles):** Use one or two pilot vehicles to control speed through one-lane sections of a temporary traffic control zone on a two-lane road, as shown in Figure 17, and as described here. Coordinate the operation of the pilot vehicle(s), and establish communication links between the pilot vehicles and other traffic controls at each end of the one-lane section (traffic control persons), as well as with work vehicles that need to enter and exit the work area. As shown in Figure 17, the pilot vehicle should move into position at the head of the queue of vehicles about to be released by the TCP, and when directed by the TCP, guide/lead the vehicles through the work zone (Direction 1, e.g., northbound in Figure 17). At the far end of the one-lane section, beyond the work zone, the pilot vehicle should pull over at the earliest safe opportunity, signalling the following queue to pass. When the last vehicle of that queue clears the one-lane work zone section, the pilot vehicle in the other direction (Direction 2) should follow the same procedure as outlined above. This description assumes two pilot vehicles. Often, unless traffic volumes are high, a single pilot vehicle may be used for the two directions. When it reaches the far end of the one-lane section, the pilot vehicle turns around and takes its position at the head of the queue in the opposite direction.

Use a sign on the pilot vehicle to identify the pilot vehicle for drivers and to provide instructions as to what they should do, such as those shown in Figures 18 or 19 or similar wording.

**Recommendation (Pace Vehicles):** Use pace vehicles, subject to approval by the road authority, to control speeds in long duration freeway construction work zones in situations, such as freeway paving operations, where temporary concrete barriers cannot be provided, and yet workers must work within 1.5 m to 3 m of a live lane of traffic. Depending on provincial legislation, regulations, and police practice, pace vehicles may be operated by police, road authorities, contractors, or a combination of these. Driver compliance is likely to be higher when paced by a police vehicle than when paced by a contractor vehicle.

Use care to ensure that the deployment of pace vehicles on freeways is done safely, as it is not simple or straightforward. Where significant queuing and congestion are expected, or where pace vehicles must be deployed in low volume situations with vehicles approaching at high speed, provide advance signing to warn of possible stops or of the use of pace vehicles. Caution and experience are necessary to apply pace vehicles effectively and safely in low volume, high speed traffic situations.

Recommended guidelines of practice for pace vehicles are as follows (58), as shown in Figure 20:

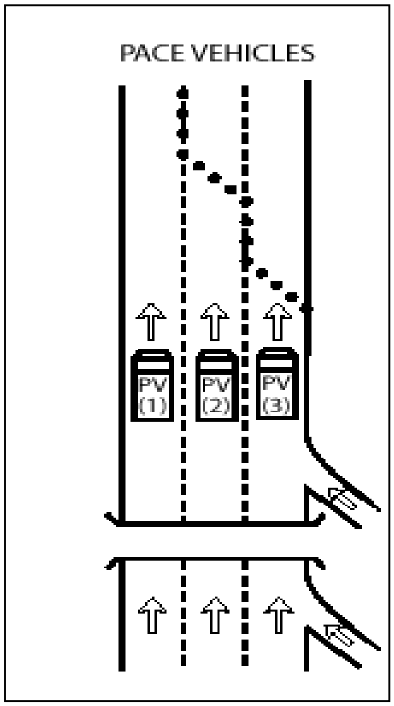


*Figure 20.* Pace Vehicles (*Source: Arges Training & Consulting)*

- The pace vehicle(s) (one per lane) must lead at a reasonable speed, not one that is so low that drivers approaching the work zone from upstream have such a large speed differential relative to the last vehicles in the queue, that they collide with those vehicles. A realistically achievable speed reduction from the normal regulatory-posted speed is about 15-20 km/h. An appropriate pace vehicle identification/warning sign must be mounted at a conspicuous location on the rear of any non-police pace vehicles.

- Pace vehicles should be used only in a single lane through the work zone. One or more vehicles may be necessary to pace traffic through one or more lane closures to reach the single lane section, with the pace vehicle in the closed lane merging into the traffic behind the pace vehicle in the remaining open lane.

- Sufficient pace vehicles are required to provide speed reductions on a continuous basis. When the last vehicle in one queue has entered the work zone, a pace vehicle(s) must be in place to lead and pace the next vehicles through the work zone. Otherwise, a high speed vehicle might reach the end of the slower queue, with a resulting collision right in the work zone itself, posing a hazard to workers. This means that the time to traverse the work zone, plus the time required to circle back and take position back in the traffic stream, must be considered.

  $PV = N_L \times$ (Cycle Time/Work Zone Traversal Time)

  PV is the number of pace vehicles needed, and $N_L$ is the number of lanes in the direction of interest (assuming only one lane is left open to traffic in the work zone).

Work zone traversal time is the time required to drive through the work zone at the pace vehicle speed, and the cycle time is the time required for a given pace vehicle to drive through the work zone, plus the time required to circle back to start another run through the work zone. The cycle time will be affected by traffic volume, and by the characteristics of the road network, that is, how directly and quickly a pace vehicle can drive around and get back to the beginning of the work zone.

For example, consider an operation with three lanes being progressively closed down to one, with a work zone traversal time of 10 minutes, and a return time of 20 minutes from the end of the work zone back to the beginning. To avoid the risk of fast vehicles closing in on slow vehicles adjacent to workers in the work zone, a new set of three pace vehicles will be required every 10 minutes. With a return time of 20 minutes, this means a total cycle time of 30 minutes for one set of 3 vehicles. The number of pace vehicles required is then 3 vehicles/set x 30/10 work zone passages per cycle = 9 pace vehicles. If the total cycle time is 40 minutes, this will require 3 x 40/10 = 12 pace vehicles.

- Since the purpose of pace vehicles is to control traffic speed, pace vehicles are not required during periods when traffic congestion alone results in traffic speeds at or below the desired speed. When congestion eases, however, and speeds increase, a careful eye on traffic conditions must be maintained, so that pace vehicles can be re-introduced into the traffic stream to control speeds when required.

In order to estimate the number of pace vehicles (and pace vehicle hours) required over the duration of a contract, it is necessary to relate these to the hours of the day or night during which work will be done, and to estimate:

- the number of hours during which lane closures will result in congestion and speeds below 80 km/h (pace vehicles not required)
- the number of traffic condition cases (volumes, work zone traversal times, and cycle times) and number of hours during which pace vehicles are required
- the number of pace vehicles required for each of the traffic condition cases and the number of hours they are required for each case

Good communication among pace vehicles is essential for good traffic control.

**Recommendation (Rolling Closures):** Use rolling closures on freeways where necessary, subject to approval by the road authority, to control the speed of vehicles upstream of a construction site, so as to create a time window when the road downstream of the lead vehicles is effectively clear of vehicles, creating an unhindered opportunity for workers to make traffic control changes at the work site. Example situations of where rolling closures may be a good method of traffic control include the following:

- changing a lane closure on a freeway from a right lane closure to a left lane closure, or vice versa
- installing or removing an overhead sign structure
- removing or placing beams for structural work

The concept embodied in a rolling closure is to let unrestrained traffic (downstream from the selected point at which traffic will be restrained) pass through the work area, and to hold back (restrain) all upstream traffic at a lower speed, by means of pace vehicles, to create a free, clear time window of 5-15 minutes in which the work operation can be carried out. On a freeway with a regulatory speed of 100 km/h, the maximum planned speed reduction should normally be about 20 km/h, which is a rolling closure speed of 70-80 km/h, led by the pace vehicles. An appropriate pace vehicle identification/warning sign must be mounted at a conspicuous location on the rear of any non-police pace vehicles.

Recommended guidelines of practice for rolling closures are as follows (58), as shown in Figure 21:

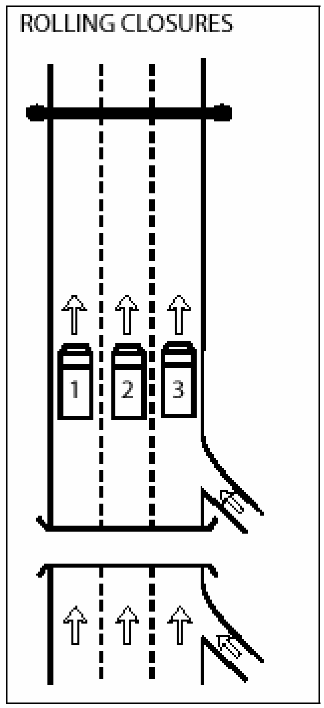


*Figure 21.* Rolling Closures (*Source: Arges Training & Consulting*)

(1) Urban, high volume freeways, with frequent interchanges.

On such freeways, drivers are generally accustomed to congestion, which may occur frequently. Also on such freeways, it is neither desirable nor practicable to prevent vehicles from entering the highway at all upstream entrance ramps. The rolling closure operation is initiated by sufficient lead pace vehicles traveling abreast – one vehicle per lane, several kilometres upstream of the closure site – to control the flow and speed of traffic approaching the closure site. As they approach the site, they gradually reduce their speed, allowing traffic ahead of them to clear out at normal speed. After they pass the entrance ramps of the last upstream interchange, the pace vehicles continue to reduce their speed, coming to a complete halt if necessary, just upstream of the closure site, to create the necessary time window. If the pace vehicle slowing and stopping is done progressively and gradually, drivers will have time to adjust to the situation, as in a similar congestion situation. When the work at the closure site is complete, the pace vehicles turn off their flashing lights and allow traffic to resume normal flow.

(2) Rural, low volume freeways, with infrequent interchanges.

On such freeways, drivers expect free flow conditions, and do not expect sudden congestion that may require them to come to a halt. Such a requirement would violate driver expectation, leading to potential hazard. For this reason, the approach for rolling closures on such freeways needs to be different. The use of advance warning signs, such as a BE PREPARED TO STOP sign, should be considered.

The rolling closure operation will have to be initiated a specific calculated distance upstream of the work zone, in order to create a time window of the desired duration, and for a given travel speed. This distance may be as great as 15-25 km. This means that a rolling closure is unlikely to be suitable in all situations, but must be carefully tailored to the road configuration and network involved. As the rolling closure is approaching the work zone, all entrance ramps at intermediate interchanges must be closed until the rolling closure has passed, to prevent vehicles (which, being unrestricted, might be travelling at high speed) from entering the clear zone ahead of the rolling closure lead vehicles.

It is often difficult to restrain entrance ramp traffic from entering the freeway if drivers are determined to go through. If these drivers see a rolling closure approaching, they are likely to want to enter the highway ahead of the queue rather than behind it. If the rolling closure starts a considerable distance upstream of the work zone, more than one interchange back, it may be desirable to have the lead vehicles in the rolling closure drive at a speed closer to the normal posted speed until they have passed the last interchange, and then decelerate to a lower speed when it is no longer possible for entrance ramp traffic to pass them or enter ahead of them. It is essential that all work vehicles involved in the rolling closure, at intermediate interchange entrance ramps, and at the work area itself, be in good communication with each other. It is important, if a determined driver at an entrance ramp forces his/her way onto the freeway, that others, particularly workers at the work area, can be given timely notice of such an approaching, unexpected vehicle.

The rolling closure requires one lead vehicle per lane, travelling side by side to prevent other vehicles from overtaking any of the lead vehicles and entering the clear zone. If the work operation results in a longer-term single-lane closure, as the lead vehicles approach the taper, the lead vehicle in the closed lane should merge behind the lead vehicle in the open lane. If the work operation, when completed, leaves both lanes clear, the lead vehicles may speed up at or beyond the work zone, and merge into one lane, permitting other traffic to pass them. As described above, the operation is more like a rolling slowdown. However, in some circumstances, it may be necessary or desirable to bring following vehicles to a very low speed or even to a stopped position. In this case the operation is truly a rolling closure. This need may arise if operations at the work area run into unexpected difficulties and require more time. Where such rolling closure operations are planned, or anticipated to be necessary, advance signing should be used to advise drivers that they may have to stop. Otherwise, their sudden arrival at the end of an unexpected queue may pose a traffic hazard.

It may often be best practice to arrange for police (if available) to deploy the lead vehicles in a rolling closure, although the road authority may authorize contractors to fulfill this function. An advantage of using police for lead vehicles is that driver compliance is likely to be higher when controlled by a police vehicle than when controlled by a contractor vehicle. This is particularly the case on urban, high volume freeways.

### 4.2.7 Optical Speed Bars

32. **Conclusion:** Optical speed bars (transverse paint bars set out at gradually decreasing spacing in order to provide drivers a heightened perception of speed, to slow traffic entering a work zone) appear to work well with large desired speed reductions (e.g., from highway speed to a stop or near stop). Their effectiveness in work zones, where desired speed reductions are smaller, is less well documented. Study results are mixed. Where used in work zones, they appear to be more effective in alerting drivers than in achieving actual speed reductions.

### 4.2.8 Portable Rumble Strips

33. **Conclusion:** Portable rumble strips (sets of raised strips of a hard material placed transversely across the roadway on approaches to work zones) have both a “startle” effect and a “discomfort” effect which, it has been thought, will alert drivers and cause them to slow down. Despite relatively frequent use of portable rumble strips in various countries, the benefit of rumble strips is considered to be not so much a reduction in speed, but in raising the level of alertness of drivers. Canadian assessments of their effectiveness have been mixed. A few studies have reported that portable rumble strips are not very effective, and that they have the additional disadvantages of relatively long installation and removal times, and the safety risk of worker exposure during installation and removal.

## 4.3 Other Speed-related Safety Measures (See Section 3.3)

As noted above, other speed-related measures may also contribute to work zone speed management, or more basically, may contribute to work zone safety by helping avoid or reduce some of the speed-related hazards. These may involve more/better advance warning of the work zone, merge control, work zone intrusion alarms, and various ITS technologies. These measures generally go beyond the scope of this project, but several are briefly described here.

### 4.3.1 Advance Warning of Work Zone

34. **Conclusion:** Advance warning of the work zone is fundamental to good work zone management. The advance warning area helps avoid violation of driver expectation, and prepares drivers for the work zone ahead.

    **Recommendation:** Provide sufficient advance warning of the work zone, to alert drivers of the work ahead and of the need to slow down. Where circumstances so indicate (e.g., collision record, poor horizontal or vertical visibility), provide more advance warning than indicated by the minimum guidelines included in traffic manuals, including bringing advance warning signs further upstream and/or doubling up (repeating) advance warning signs.

### 4.3.2 Innovative Devices for Improved Worker and Motorist Safety

35. **Conclusion:** Intelligent Transportation Systems (ITS) have proven to be beneficial in improving work zone operations and safety in some applications, and have the potential

to provide additional benefits. Benefits of ITS in work zones included reduced traffic queues, fewer traffic citations, increased safety (fewer collisions, including fewer secondary collisions), reduced construction time (one season rather than two), more effective communications with local agencies, quicker incident response and clearance time, better maintenance of traffic flow, and good public reaction. These applications include roadway information/surveillance systems, lane-drop smoothing or merge control systems (See section 4.3.3), traveler warning systems, personal warning devices/systems (See section 4.3.5), and moveable barrier systems. See also section 3.3.2.

**Recommendation:** Use ITS systems in work zones where they have demonstrated operational and safety benefits, or where analysis and/or tests show that they are likely to provide net benefits.

### 4.3.3 Merge Control

36. **Conclusion:** A high percentage of work zone crashes are rear-end and sideswipe crashes, often occurring as a result of failure to notice a lane closure or to shift lanes at a lane closure. Merge control systems promote smooth traffic flow leading into a work zone by encouraging early merges to avoid hazardous last minute merging. Such systems have resulted in reduced conflicts, fewer collisions, and reduced road rage.

**Recommendation:** Where merging hazard and collisions are a problem, or suspected to be a problem, consider application of merge control systems, such as the Lane Merger system developed by IRD.

### 4.3.4 Queue Warning and Real-time Traffic Information

37. **Conclusion:** FHWA studies have demonstrated the effectiveness of using PVMSs, together with traffic data on traffic flow, speed, and end of queue, to provide information to drivers and improve safety in work zones. No Canadian survey respondents indicated that they use such systems.

### 4.3.5 Work Zone Intrusion Alarms

38. **Conclusion:** Work zone intrusion alarms are still in the development and test phase, but appear to offer promise for improved worker safety, both real and perceived. Intrusion alarms detect vehicles entering the buffer area between work crews in the work area and vehicles driving past the work zone, and provide a warning to alert workers. Warning time may be short (4-7 seconds), but can be vital. Such alarms employ various technologies such as infrared, ultrasonic, microwaves, or pneumatic tubes, to detect the intruding vehicle. When the system detects an intrusion, it sounds a loud siren to warn the workers in the area.

### 4.3.6 Work Zone Safety Training

39. **Conclusion:** Work zone safety training is essential. Most provincial legislation and regulations on construction safety require supervisor and worker training.

**Recommendation:** Train all work zone supervisors and workers on both the provisions of the relevant labour ministry legislation and regulations, and the provisions, guidelines, standards, and practices outlined in the province's work zone traffic control manual. Through the training programs, provide workers with an understanding of safety hazards and methods of hazard reduction in highway and street construction. Train all workers in hazards and adaptations for work at night and in other low-visibility conditions.

### 4.3.7 Driver Education

40. **Conclusion:** Drivers need to be educated as to what to expect in work zones and what is expected of them, in terms of safe driving behaviour, to complement engineering and enforcement measures.

    **Recommendation:** Develop province-wide systems of driver education, for both new and experienced drivers, including material in driver instruction manuals on good work zone driving practice, and summary/update material on good work zone driving practice included with periodic notices of driver's licence or vehicle registration renewals.

## 4.4 Non-speed-related Safety Measures

As noted in section 3.4, work zone safety is a complex issue, and there are many safety measures that have been tested, evaluated, and applied, both speed-related and non-speed-related. The latter category goes beyond the scope of this report, but some examples are briefly included here, which may be useful both in pointing the way to measures that remove the speed problem or help reduce the inclination to speed, and also in developing future chapters of a Work Zone Safety Manual.

### 4.4.1 Road Closures

41. **Conclusion:** Although the application of work zone speed management measures is usually predicated on the concept of keeping the road open to traffic, some road authorities in both the U.S. and Europe have found a strategy of complete road closures (where possible) effective in making the construction project both faster and safer. The motto of this approach is "Get in, stay in, get out, stay out." Note that full road closure is often not feasible, and certainly is not feasible in every situation.

### 4.4.2 Better Information to the Travelling Public

42. **Conclusion:** Many road authorities, including Canadian provinces and cities, have found it beneficial, especially in long duration and long-length work zones, to advise motorists as to where work zones are located and to tell them what they should expect in terms of delay. Advance messages advise drivers, reducing impatience and allowing alternate routes to be chosen.

    **Recommendation:** Ensure that good information on the location of long duration work zones, expected traffic conditions and delays, and alternate routes is disseminated to the public using a variety of communication media, including some or all of the following: advertisements in newspapers, radio, and television, signs, PVMSs, Highway Advisory Radio, internet web sites, displays of real-time work zone traffic conditions on large screens at rest areas, welcome centres, weigh stations, truck stops, major tourist attractions, large parking garages, large office buildings, employment centres, and/or other large traffic generators, and dissemination of information on current work zones through trucking associations.

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# 5.0 SURVEY OF CANADIAN STAKEHOLDERS: CURRENT PRACTICES

## 5.1 Objectives and Methodology

The objective of the questionnaire survey was to obtain information on work zone speed management practices across Canada.

To do this, a questionnaire was designed to cover key aspects of such practices, and was sent out by e-mail to 55 provinces, territories, municipalities, road builders/ contractors, and other stakeholders. After the first and second rounds of responses, follow-up messages were sent to the remaining contacts to invite them to respond. The survey questionnaire is shown in section 5.4.

## 5.2 Results of Questionnaire Survey

From the original 55 stakeholders contacted, 32 responses have been received to date:

| | | |
|---|---|---|
| - | provinces | 8 |
| - | territories | 2 |
| - | municipalities | 12 |
| - | road builders and contractors | 10 (including 2 not originally surveyed) |

Overall, the importance of work zone safety was rated at 9 out of ten, with responses showing an almost perfect bell curve centred at 9.

A major finding of the surveys was that some techniques work well in some places, but not in others.

Enforcement is one measure that works well in most responding jurisdictions. The survey also showed a high percentage of jurisdictions using Portable Variable Message Signs (PVMSs), Pace vehicles/ Pilot vehicles, and Regulatory and Advisory Speed Limit signs, with varying degrees of success. In addition, some jurisdictions indicated that narrow lanes through construction work zones are effective in achieving speed reductions, although this item was not explicitly asked for in the survey. Several respondents also mentioned the use of Traffic Control Persons as an effective way to reduce speed. In several jurisdictions, including both provincial and municipal settings, black and orange advisory speed limit signs are used, and enforced as if they were regulatory speed limit signs. In Quebec, the black and orange signs are actually regulatory speed limit signs for work zones. This is not consistent from jurisdiction to jurisdiction but to most motorists this would probably not create issues. Usually, advisory speed limits are not enforceable. It is unclear whether enforcement of advisory speed limit signs has been challenged in court, and if so, what the outcome was.

In broad terms, the responses to the questions are shown below in Table 5.1. The Appendix 1 spreadsheet shows the question-by-question response by each respondent.

### TABLE 4 Usages of Speed Management Techniques (Survey)

| Speed Management Technique | No. of Respon-dents Using | Effectiveness | | | | Type of Facility where used | | |
|---|---|---|---|---|---|---|---|---|
| | | High | Medium | Low | Not Effective | Freeway | Non-freeway | Both F & NF |
| Regulatory Speed Limit Signs (black/white) | 26 | 4 | 9 | 11 | 2 | 4 | 2 | 20 |
| Advisory Speed Limit Signs (black/orange) (Reg. in Quebec) | 22 | 2 | 6 | 12 | 0 | 3 | 3 | 14 |
| Police Enforcement | 20 | 11 | 5 | 2 | 1 | 4 | 2 | 14 |
| Portable Variable Message Signs (PVMS) | 22 | 7 | 12 | 3 | 0 | 4 | 1 | 14 |
| Radar Speed Measurement & Speed Display | 15 | 6 | 8 | 1 | 0 | 2 | 3 | 10 |
| Variable Speed Limits | 8 | 1 | 3 | 4 | 0 | 1 | 0 | 7 |
| Photo radar | 3 | 3 | 0 | 0 | 0 | 1 | 0 | 2 |
| Pace vehicles / Pilot vehicles | 21 | 14 | 5 | 2 | 0 | 4 | 5 | 12 |
| Increased fines for work zone speeding | 12 | 2 | 5 | 5 | 0 | 4 | 2 | 6 |
| Portable rumble strips | 6 | 3 | 3 | 0 | 0 | 2 | 2 | 2 |
| ITS Applications (please describe) | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |

A number of jurisdictions sign a reduced speed of 60km/h as the maximum speed in the work zone when workers are present on the roadway. Signs are posted on the roadway in advance of the work zone to inform motorists of this law. In some instances where the Highway Traffic Act makes provisions for such signs, other speeds may be posted if considered desirable.

Generally, it is felt that police presence increases the effectiveness of any devices in place. A limitation of police enforcement, often leading to road authority frustration, is the fact that motorists return to whatever speed they feel is appropriate for the conditions once the police, for whatever reason, leave the site. Some jurisdictions do not use regulatory signs unless there is some assurance that police will be available and others only call on police efforts when all else fails.

To the question of enforceable advisory speed signs, 30% of the respondents indicated that the signs are enforceable, and 60% indicated that they do not use advisory speed signs. As noted above, in Quebec, the black/orange signs are actually regulatory signs, not advisory. Some provinces use black/orange advisory speed tabs, in conjunction with other warning signs.

Work zone speed limits are established in several different ways, including a maximum reduction of 20km/h (where a speed reduction is considered necessary), which is an approach recommended by several research studies on the subject. There are situations where the speed is dictated by the provincial or territorial Highway Traffic Act, which states that the maximum permitted speed on a roadway when workers are present is 60km/h, where so posted. Other responses included a standard 20 or 30 km/h reduction, depending on the road classification, engineering judgement, and discussions between the road authority and the contractor related to the complexity of work and the duration of the work. Some road authorities only post regulatory speed limits if there is a commitment on behalf of the policing community to provide some level of enforcement.

On the question regarding the duration and timing of the reduced posted speed in the work zone, about half the respondents indicated that the reduced speed limit is posted only when workers are present, while the other half indicated that the reduced speed limit is posted for the duration of the project. In the latter case, the speed is definitely posted when there are workers present, however there are times when due to a reduction in the geometric design speed, or local policies, that the reduced speed limit signs would appear for the duration of the project, even when no workers are present. Many of the responding jurisdictions use PVMSs to support work zone signing. Some use them in advance of the work zone and others use them within the work zone. Where PVMSs are used in advance of the work zone, typical messages used indicate alternate routes, type of work, length of the work zone, speed limit, and safety messages like “proceed with caution”. Where PVMSs are used within the work zone, the messages may typically indicate speed limits, lane configuration/reduction, police enforcement, time of closures etc. Many of the respondents indicated that they review all PVMS messages to be used by the contractor during the project and approve the messages.

There does not appear to be a consistent approach on where police conduct enforcement (upstream of the project, in the approach area, or downstream from the construction work). In many jurisdictions, policing occurs only rarely. When it does occur, it is for the most part with a cruiser and officer although there are jurisdictions that use the vehicle with a dummy, or even dummy vehicles. The approach area seems to be the most favoured location for police positioning, although they may also be positioned in the work zone or beyond it, where space permits. Many respondents indicated that much of the police enforcement is done by random trips through the work zone. Approximately a third of the respondents indicated that some enforcement takes place prior to the work being started. For the most part these were British Columbia (province and municipal), Red Deer, Alberta, and the North West Territories.

Regarding the process used to establish a construction zone speed limit different from the usual posted speed, the Highway Traffic Act is cited most often as the authority, for example, the “60 km/h when workers are present on the roadway” requirement, and the Highway Traffic Act permits designation of an administrative position to determine the posted speeds on each individual project. However this is used with input from the contractor, the road authority, police services and Traffic Engineer. In municipal settings it is usually done by municipal by-law, with engineering input and judgement provided by the traffic department, although some municipalities can establish reduced work zone speed limits administratively.

Question 11 asked what, if anything, was particularly challenging in managing traffic speeds through work zones, and Question 12 asked what respondents had done to address these concerns, both successes and failures.

The ignoring of speed signs by drivers is the main concern that has different responses depending on the number of lanes, the speed of the facility and the work being contemplated. The paving operation is one operation that leaves workers most exposed to hazard and needs to be dealt with in an aggressive manner. Traffic Control Persons are one way that several respondents deal with this problem on non-freeway roads; pilot vehicles may also be used. Pace vehicles and PVMSs are another way of getting information to the motorist on the higher speed freeways where the paving is taking place during times of low traffic volumes and higher speeds (hours of darkness). One respondent indicated that motorists in that area often ignored the TCPs.

An accepted view in the engineering field by the engineering personnel seems to be that the over-use of reduced speed limits and reducing the speed lower than required is a problem. It is difficult to convince a worker that reducing the speed does not necessarily improve safety and can create a much less safe operation than a more realistically posted speed. To quote one of the respondents, "construction and maintenance work zone speed limits which are too low, too long and make no sense to the motorist, will not work". This can be a difficult message to sell to the contractors, enforcement agencies and their own non-engineering staff.

There seems to be a recognition, however reluctant, that police services do not have the resources to spend the required time in work zones to effectively educate the motorist to the fact that speeding in the work zone will result in a fine.

Where there is a genuine need for motorists to reduce speed, but they cannot see any reason to do so, a problem arises, both in setting realistic speed limits that reflect the need to reduce speed, and in convincing the motorists that they really do need to slow down. It helps to give the motorist real time information in the form of static signs. Credibility with drivers is an issue. We may be quick to blame the motorist for all of our difficulties in getting the motorist to obey the signs, when in fact we may not be giving them a true and consistent reflection of what they can expect driving through our work zones. If work is not taking place, signs indicating that work is occurring or workers are present should be covered or removed. If motorists see signs advising of construction and reduced speed limits, but see no workers present and no work activity, they may conclude over time that the signs are meaningless, and need not be heeded. Then when workers are present, motorists are surprised to see them, and may slow down too late.

There were comments that indicated that certain devices did not work, including any static speed sign without police enforcement, rumble strips, Traffic Control Persons and frustrated comments regarding the qualifications of older and younger drivers.

## 5.3 Discussion with Project Steering Committee (PSC) at Quebec City, September 2004

In the discussion at the PSC meeting in Quebec City, September 2004, members of the PSC provided the following comments on their experiences with work zone speed management:

Signing

- Some respondents said that regulatory signs were only effective with enforcement.
- Some signed speeds are enforceable, while some are not.
- Signs raise awareness.
- There has been some success with radar signs (showing motorists' actual speed), but again, they are only effective when accompanied by enforcement.
- Radar ticketing along with variable speed signs has been somewhat effective, since it slows down motorists. However, a key component of the photo radar is news coverage (which is an unintentional, yet positive result of the signs). (Gord Cebryk – Edmonton)
- Signs are passive and easy to implement and forget. However, signage is not implemented consistently.
- Signs are resulting in some speed reductions in Manitoba. (Brad Sacher – Manitoba)

- Some drivers don't realize how fast they are going; informing them with speed display signs may cause them to slow down.
- The U.S. is conducting a pilot project on using enforceable variable speed signs. Gord Cebryk indicated that these systems are being used in Edmonton.

Speed

- If the normal posted speed is 80 or 90 km/h, what is the reasonable reduction in speed that can be expected?
- Speed should not be reduced by more than 20 km/h
- In Saskatchewan, 60 km/h through work zones was selected because it is possible to enforce at that level. I do not know how much analysis was done before selecting 60 km/h, but it has proven to be an effective limit for enforcement purposes. (Paul Hunt – Saskatchewan)
- An MTO forum on work zone speed indicated that the ministry responsible for workers' safety would like to reduce speeds to 10-15 km/h. However, police said those speeds would cause collisions.

Legislation

- In Alberta, the responsibility to set work zone speeds can be delegated to municipalities or provincial project managers. (Richard Chow – Alberta)
- Manitoba has one authority that sets speed limits. (Brad Sacher – Manitoba)
- In Edmonton, a by-law permits the city manager to set speeds administratively. (Gord Cebryk – Edmonton)

## 5.4 Survey Questionnaire

The Project Manager, Michael Balsom, sent out the survey questionnaire from Transportation Association of Canada offices with the following covering letter. The survey questionnaire follows the letter.

**TAC Letterhead** **August 19, 2004**

**Project:**
**Synthesis of Practices for Work Zone Speed Management**

**Addressee:**

The Road Safety Standing Committee of the Transportation Association of Canada has just commissioned a study to develop a Synthesis of Practices for Work Zone Speed Management, to be undertaken by the firm Arges Training and Consulting.

Part of the project involves surveying representative provinces and major municipalities as to their practices, successes, and concerns regarding speed management/control in work zones. To this end, we invite your participation in the project, by filling out the brief questionnaire attached to this letter.

In order to maintain the project schedule, we request that you return your completed questionnaire to me, electronically if possible, by September 8, 2004.

Thank you for your cooperation.

Best regards,

Michael Balsom
Project Manager
Transportation Association of Canada
2323 St. Laurent Boulevard
Ottawa, ON K1G 4J8
Tel. (613) 736-1350 ext. 232
Fax (613) 736-1395
mbalsom@tac-atc.ca

# Synthesis of Practices for Work Zone Speed Management

## Questionnaire

1. The management/control of motorist speeds through work zones is often a safety concern for road authorities, contractors and workers. In your view, on a scale of 1 to 10, how would you rate high speed hazard in work zones, relative to other work zone safety hazards (1 = very low hazard relative to other risks, 10 = very high hazard relative to other risks)? Circle your rating in the row of numbers:

   1 2 3 4 5 6 7 8 9 10

2. What measures do you use to manage/control motorist speeds through work zones? Are they effective in managing speeds? Please respond as indicated below: in the first column, check those measures that you use; in the second column, indicate effectiveness (high, medium, low, or not effective) by using H, M, L, or NE. In the last column, please indicate if such measures are used on freeways (F), non-freeways (NF) or both freeways and non-freeways (B):

| | Use? | Effectiveness? | F,NF,B? |
|---|---|---|---|
| Regulatory speed limit signs (black/white) | ____ | _________ | ________ |
| Advisory speed limit signs (black/orange) | ____ | _________ | ________ |
| Police enforcement | ____ | _________ | ________ |
| Portable Variable Message Signs (PVMS) | ____ | _________ | ________ |
| Radar speed measurement & speed display | ____ | _________ | ________ |
| Variable speed limits | ____ | _________ | ________ |
| Photo radar | ____ | _________ | ________ |
| Pace vehicles/pilot vehicles | ____ | _________ | ________ |
| Increased fines for work zone speeding | ____ | _________ | ________ |
| Portable rumble strips | ____ | _________ | ________ |
| ITS applications (Please describe) | ____ | _________ | ________ |

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Other (Please describe)

______________________________________________________________
______________________________________________________________
______________________________________________________________
______________________________________________________________
______________________________________________________________
______________________________________________________________
______________________________________________________________
______________________________________________________________

3. Which of the measures listed above are effective only if supported by police enforcement?

____________________________________________
____________________________________________
____________________________________________

4. Do you use posted speed limits with both construction and maintenance projects, or with construction projects only? Please check those that are applicable:

| | Regulatory Speed Limits | Advisory Speed Limits | No Posted Speed Limits |
|---|---|---|---|
| Both construction and maintenance | _____ | _____ | _____ |
| Construction projects only | _____ | _____ | _____ |

5. Are your advisory speed limits enforceable? (Yes/No) _______

6. If you use posted work zone speed limits (regulatory or advisory), how do you determine the applicable speed limit in the work zone, relative to the normal posted speed?

____________________________________________
____________________________________________
____________________________________________
____________________________________________
____________________________________________

7. Are reduced posted speed limits in the work zone displayed (a) only when workers are present and covered when there are no workers present, or (b) posted for the duration of the project, but with flashers activated when workers are present, so that the speed limits are effective only when flashing, or (c) posted for the duration of the project, whether or not there are workers present. Please check (a) ________, (b) _______ (c)_________ or (d) other(describe)

____________________________________________
____________________________________________

8. If you use PVMSs, which messages are posted on the approach to the work zone, and which messages are used in the work zone?

Approach:

____________________________________________
____________________________________________
____________________________________________
____________________________________________

In the work zone:

____________________________________________
____________________________________________
____________________________________________
____________________________________________
____________________________________________

9. Where police enforcement of work zone speeds is used, please explain how it is used (e.g., staffed vehicles or dummy vehicles), where it is used (e.g., approach to work zone, within it (with or without pullover bays), or beyond it), and how often (frequency of police presence):

Do you do any enforcement before work starts (e.g., to indicate that things are about to change, and/or to reinforce the need to slow down)? Yes___ No___

10. What process do you need to follow to establish regulatory speed limits in work zones? (e.g., legislation (including by-law), regulation, or administrative)

11. Are there particular challenges or problems that you have experienced in general, or with any specific measures, in achieving speed reductions in work zones? Please describe:

12. Are there speed control measures you have tried, that did not work well? Please describe.

Thank you for your response. If you have any questions, please contact

Milt Harmelink (905-274-6257 or mdharmel@pathcom.com) or
Rod Edwards (905-775-0590 or redwards@hmconline.ca)
Arges Training & Consulting

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# 6.0 LITERATURE REVIEW

## 6.1 Objectives and Methodology of Literature Review

The primary objectives of the literature review were:

- To identify information sources for speed management in work zones;
- To identify speed management applications in work zones which had been tested and evaluated elsewhere, including the degree of success and effectiveness that had been achieved, where possible;
- To prepare a bibliography of information sources reviewed.

The primary methodology used for the literature review was to scan information sources as provided in various technical publications, and on the world wide web, as well as information gleaned from personal contacts and from equipment suppliers.

There is a substantial amount of information on the World Wide Web regarding speed management in work zones. Efforts have been made to capture the most significant information sources, but it is virtually impossible to claim that the search has been complete and exhaustive, and no such claim is made here. For example, some information sources may cite other sources that are difficult to access or are out of print.

Results of speed management tests in work zones have been cited essentially as presented in the source material, with supplementary commentary where considered appropriate. Results may not be entirely consistent. For example, some speed management techniques may have been found to be effective in some situations tested, while in other situations, other researchers may not have found them to be effective, depending on the desired effect of the application.

## 6.2 Results of Literature Review

In terms of mobility, speed management in work zones contributes to improved mobility by providing drivers with traffic condition information so that drivers can adjust their speeds accordingly. Mobility is measured in terms of the absence or decrease of observed or reported traffic backups or delays in the work zones.

In terms of safety, speed management contributes to increased safety by providing drivers with a realistic speed limit at which to proceed in order to negotiate the work zone in a safe and orderly manner. Safety is measured in terms of the number and severity of vehicle crashes in the work zone that are attributable to the presence of construction or maintenance activities, as opposed to a crash attributed to a driver falling asleep at the wheel. Another factor used to measure the safety of work zones is the number of citations issued. Decreasing numbers of citations indicates improved safety conditions in the work zone.

References in the published literature have been categorized as shown below. The primary subsection, 6.2.1, addresses work zone speed management. Subsection 6.2.2 addresses other speed-related safety measures, and subsection 6.2.3 addresses non-speed-related safety measures.

### 6.2.1 Work Zone Speed Management

Excessive speed is among the major contributing factors most often reported for work zone collisions. Workers, contractors, and Ministry of Labour inspectors often feel that speed control is the most effective measure available, to improve worker safety in work zones. At times, extreme speed reductions (e.g., down to 20 km/h) are advocated.

The solution is not as straightforward as simply posting extremely low speed limits. Motorists often ignore unrealistic speed limits, or if they see no work activity present. Normal speeds should be maintained through the work zone as much as possible. If there are sudden posted speed reductions, motorists who do slow down may cause collisions. If motorist safety is reduced, worker safety is also likely to be reduced.

#### 6.2.1.1 Regulatory Posted Speeds

The literature indicates the following regarding setting work zone speed limits in general, and posted regulatory speeds, in particular:

- Imposing unwarranted regulatory speed limits is not effective. Most drivers disregard posted speed limits if the need is not evident, or if there is no visible sign of work activity. Speed reductions are more likely to be obeyed if they are perceived to be necessary (41, 80, 76, 77, 78, 93, 79, 91, 58).

- The travelled way through the work zone should be designed for normal highway speeds as much as possible (58).

- In many maintenance and construction projects, a reduction of the normal speed limit is not required. Work zone speed limit reductions should be avoided, where possible, where all work activities are located on shoulder or roadside areas and in work zones where no work activities are under way. A basic guideline to follow is to attempt to reduce speeds only if there is a good reason for it (58, 64).

- Explicit consideration of the need for speed reduction during design enhances the effectiveness of speed control during construction. For example:
  - Detour design speed is 20 km/h over the anticipated posted legal speed where practical;
  - Detour geometry is chosen to avoid the need for a large speed reduction;
  - Work zone design is chosen to permit construction vehicles to exit/enter near normal speeds;
  - Police car lay-bys are built into the detour where possible/practicable (23).

- Experience has demonstrated that compliance with speed limits increases when:
  - Speed reductions are used consistently from one site to another;
  - Drivers perceive a real need for the speed reduction (e.g., workers present adjacent to live traffic lanes, unusually sharp curve);
  - Drivers are warned about the speed reduction in advance;
  - Speed reduction is not more than 20 km/h below the normally posted speed;
  - Speed reductions are enforced;
  - Speed reduction extends for 300 m or more;
  - Police enforcement vehicles are located inside the work zone (Ref. 23).

- Drivers should be provided with advance warning of speed reductions by using one or more of the following:
  - Advance signing;
  - Variable message signs (VMSs) (e.g., 80 km/h Ahead) in special circumstances where drivers would not expect a reduced speed or where workers are working directly beside a live lane of traffic for extended periods of time;
  - Notification of local media and commercial vehicle companies (Ref. 23).

- It is difficult to achieve an average speed reduction of more than 15 km/h. Hence, 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 geometrics or other work zone features that cannot be modified (58).

- Legal (regulatory) speed reductions should be used when there is a need to reduce the speed limit for an extended period of time (e.g., 5 days or more) and advisory speed limits should be used when the need is for a shorter period of time. However, the time period is not as important as the nature of the work itself, and the type of work may dictate the use of a legal speed reduction for short duration work (23).

- For MTO construction projects requiring traffic control, construction speed zones may be established, as directed by MTO. Only MTO can establish construction speed zones on Ontario provincial highways. If construction speed zones with enforceable speed limits are to be established on provincial highways, it is a Highway Traffic Act (HTA) requirement first to establish a designated construction zone and to install Construction Zone Begins and Ends signs in advance of and beyond the construction speed zone. Regulatory speed limit signs should be installed only when the appropriate police authority has been informed, and intends to provide enforcement as outlined in the traffic enforcement plan. Otherwise, only advisory signs should be used. Regulatory speeds are usually reduced only in construction zones, but not maintenance work zones (58).

- If regulatory speeds are reduced in the work zone, all existing regulatory signs within the construction speed zone must be covered or removed for the duration of the construction project. Also, reduced speed limits should be installed in accordance with the Highway Traffic Act and displayed only when work is actually taking place, and covered (and normal posted speed signs uncovered) when work activity is no longer taking place (58). Speed zones of 300 m or more should be established to increase the success of speed reductions using regulatory signs (23).

- Reduced speed limit signs should only be used:
  - when work activity is actually occurring, and should be covered or removed when work is suspended or completed
  - when reduced or restricted design situations, such as narrow lanes, detours, diversions, or cross-overs, remain, even though work is suspended (58)
  - when workers work within 3 m (or 1.5 m for low speed facilities) from a live lane for extended periods of time and temporary concrete barriers are not practical (23)

- The City of Edmonton uses two types of work zones, with two types of speed zones:
  - Temporary Speed Zones, where for worker safety, temporary speed zones are established, and are in effect only when workers are present and activity is adjacent to moving traffic

  - Construction Speed Zones, where temporary speed limits in a construction zone are intended for 24-hour continuous posting, where it is imperative for motorists to reduce speed to safely navigate through hazards over the length of a project (75)

- For Ontario municipal construction projects requiring traffic control, construction speed zones may also be established. At present, the establishment of municipal construction speed zones, with enforceable regulatory reduced speed limit signs, must be done by municipal by-law in Ontario. Advisory speed limit signs may be posted without requiring a by-law, with the approval of the road authority (58).

- Normal speed limits should be restored when work is no longer in progress, when workers are no longer at the job site, or when hazards have been removed or protected (64).

- Various jurisdictions have used different approaches to advise motorists that workers are present, and either explicitly or implicitly state that reduced speed limits are in effect when workers are present:
  - MTO recommends posting ROAD WORK AHEAD (Men at work) signs whenever workers are present, for both long duration and short duration work (58). There is no signing to indicate that reduced speed limits are in effect whenever these signs are posted; rather, the intent is to build credibility for the work zone speed limits, so that drivers will reduce speed when they see workers present.
  - Several provinces and territories (42, 78), and US states, post signs stating “Speed Limit is xx km/h (or mph) when workers are present.” This explicitly ties the reduced speed limit to the presence of workers.
  - Several US states post signs stating “Speed Limit xx mph when lights flashing.” The amber flashers are activated by road crews when present, and turned off again when they leave. This directly ties the reduced speed limit to the presence of workers, but to the driver the message is implicit.

- Indiana DOT uses "45 mph WHEN FLASHING" Signs, activated in the vicinity of actual work occurring on the highway, and allows for higher speeds when and where roadwork is not in progress (92).

- Michigan DOT has used portable variable message signs (PVMSs) to electronically change the speed limit on I-96, based on traffic volume, traffic speed and weather conditions, and workers being present. (It is not known whether these are regulatory or advisory speeds) (32, 45).

- Minnesota DOT is using Variable Speed Limit systems in work zones. The system incorporates two BRICK modular message blocks on each speed limit sign placed in a work zone. When workers are not present, the speed limit continues to be 65 mph. When workers arrive, a designated worker changes the speed limit to 45 mph. The displayed speeds are enforceable (33). Minnesota DOT has also developed "A Guide to Establishing Speed Limits in Highway Work Zones" with the objectives of achieving good practice and uniformity (92). 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 will not use a fixed posted speed, but will measure real-time traffic, then compute and post a speed limit reflecting the safe speed at which drivers should be travelling (33).

- Variable speed limits offer drivers guidance on appropriate maximum and minimum speed limits on the basis of real-time monitoring of prevailing traffic and roadway conditions, using dynamic information displays to inform motorists of the appropriate limits (52). Variable message signs, which provide information to motorists about speeds for specific conditions (fog, high crosswinds, work zones), have been in use for some time. Development of a new generation of technologies as part of the US Intelligent Transportation Systems Program 21 has given new impetus to implementation of variable speed limit systems.

- Variable speed limits are now being used more widely, particularly on motorway systems in some European countries. For example, Germany has an extensive system of variable speed limits, primarily to manage traffic flow under adverse environmental conditions on the autobahns. The systems have reportedly been successful in reducing crash rates. The Netherlands and, more recently, Great Britain have introduced variable speed limits on a pilot basis on major motorways. Their primary purpose is to improve traffic flow in congested conditions by equalizing speeds in all lanes. Variable speed limits are most effective, however, before traffic becomes heavily congested. Under heavily congested conditions, the limits are unable to affect stop-and-start driving. Preliminary results indicate that, when the variable speed limits are in effect, traffic speeds are more uniform and—in the British pilot—automobile crashes are reduced. The results are promising, but more time is needed to determine whether these improvements can be sustained. Variable speed limit systems are not yet widely in use in the United States, but limited applications are being developed as part of the Intelligent Transportation Systems program (52).

- In recent years transportation departments have begun to use regulatory speed limits, rather than advisory speed warnings, in work zones. Work zone speed limits alone have not proved very effective in reducing vehicle speeds in work zones, and only limited evaluations of their effects on safety have been conducted (51). Several studies found that the presence of law enforcement officers in work zones was effective in reducing motorist speeds (51, 52).

- Operational tests of variable speed limits have been implemented in Maryland, Michigan and Virginia. Traffic volume and speed data collected at various points within the work zone are used to calculate a recommended posted speed limit, which is varied frequently, as often as once per minute, but not until the difference between recommended speed and currently posted speed exceeds a given threshold, say 4 mph. By changing the speed limits in accordance with prevailing volume and speed conditions, they can be set to be relevant to conditions in the work zone, and can enhance credibility of signing to drivers, resulting in better speed compliance, improved safety and smoother traffic flow (88).

- A report by Robinson outlines a range of applications of variable speed limits in the US, Australia and Europe. None of those cited was used for speed management in work zones. Some of the systems' speed limits were enforceable, but most were advisory (69).

#### 6.2.1.2 Advisory Posted Speeds

The literature indicates the following regarding advisory-posted speeds:

- In some cases, advisory speed limit signs (orange and black) together with narrower roadways or lanes through the work site may be more effective in reducing traffic speeds than the posting of legal speed limit controls. All reduced speed zones should be used in a flexible and up-to-date manner to reflect the changing conditions within the construction or maintenance zone (58).

- Michigan DOT has used portable variable message signs to electronically change the speed limit on I-96, based on traffic volume, traffic speed and weather conditions, and workers being present. (As noted above, it is not known whether these are regulatory or advisory speeds) (32, 45).

- Research suggests that advisory speeds have modest to little effect on driver speeds, particularly for drivers who are familiar with the road (51). One reason for poor compliance is that posted advisory speeds are often set unrealistically low; the current criteria for setting advisory speeds on curves, for example, are based on vehicles and tests from the 1930s (52).

### 6.2.1.3 Actual Speed Display, with regulatory or advisory-posted speed

The literature indicates the following regarding actual speed displays, along with the regulatory or advisory-posted speed:

- Measures that have proven to be effective in helping to manage speeds in work zones include measurement of drivers' speed by means of radar, and display of the measured speeds on variable message signs (VMSs). The use of radar-controlled speed signs has been shown to reduce 85th percentile speeds an additional 4 to 8 km/h over the reduction caused by static signs. The effect of a single VMS may be reduced with distance from the sign, but the reductions can often be sustained with two or more VMSs. This measure will have lasting effectiveness only if supported by periodic police enforcement (58).

- Radar-gun technology should be used to advise motorists when they are exceeding work zone speed limits. The extension of this technology to automatic issuance of speeding tickets (photo radar) should be explored (64).

- Work zones on interstate highways and the Pennsylvania Turnpike for projects exceeding $300,000 must have speed-monitoring devices posted so motorists can see their speed. The devices must be posted as least 500 feet before the start of the work zone.

- Michigan DOT has used advanced portable variable message signs, with radar, microwave sensors and wireless communication, on I-75, to alert drivers if their vehicle speed is too high (45).

- Texas DOT found the speed display device to be the most effective way to decrease driver speeds approaching a short duration maintenance work zone. If an approaching driver's speed exceeds a preset level, a siren can be sounded, warning maintenance workers (73).

- International Road Dynamics Inc. (IRD) has developed an ITS system called Speed Ranger, which automatically displays required speed limits on a series of signs based on current traffic, weather, and construction conditions, providing safe speed reduction in work zone approaches (32).

- Nebraska DOT found that multiple speed radar displays reduced mean speeds by 5-7 km/h, 85th percentile speeds by 3-11 km/h, and increased compliance by 20-40%, over a period of five weeks in a long duration construction project. There was no increased police presence or enforcement during the test (55).

- Nebraska and Kansas have used the SPEEDGUARD system, a portable trailer unit that measures speed by radar and displays actual speed on a 24-inch LED sign. Work zone speed was reduced from 75 mph to 55 mph. The speed display resulted in a significant reduction in mean speeds, 85th percentile speeds, percentage of drivers exceeding the posted limit, and speed variation (33).

- Various jurisdictions have provided drivers direct feedback about their driving speeds through the use of mobile roadside speedometers. The devices usually include a speed limit sign, a Doppler radar emitter and receiver to measure speeds, and a variable message sign that displays the speed of the approaching vehicle to the driver. Local jurisdictions are experimenting with these devices to supplement traditional enforcement measures in problem speed locations on city streets, in neighbourhoods, and in school and work zones. An evaluation of the effectiveness of roadside speedometers under several controlled deployment strategies (e.g., varied, intermittent, and continuous deployment, each with and without enforcement) found that the speedometer's presence reduced average traffic speed, especially the speeds of those drivers exceeding the speed limit by at least 10 mph (16 km/h), in the vicinity of the device and short distances downstream. However, the effectiveness was clearly linked with enforcement or implied enforcement, a finding of many other studies. Unless coupled with periodic enforcement, roadside speedometers appear to be ignored by motorists whether the deployment is continuous or intermittent (52).

- A Texas report describes tests of effectiveness of five traffic control devices: speed display trailers, radar drones, portable rumble strips, alternative (strong yellow green) worker vests, and fluorescent orange roll-up signs. Speed display trailers and SYG worker vests were found to be very effective in reducing speed in improving work zone visibility. The speed display trailers took only about 10 minutes to set up. Workers liked both the speed display trailers and the SYG worker vests. The other devices were not considered effective. Portable rumble strips had little effect on vehicle speeds and took a long time to install, a problem even on low-volume rural roads (17).

#### 6.2.1.4 Portable Variable Message Signs (PVMSs)

The literature indicates the following regarding the use of portable variable message signs to advise of lower speeds (PVMSs also have other applications in addition to advising of lower speeds):

- PVMSs were tested in a study at rural work zones in New Brunswick, and were found to produce mean speed and 85$^{th}$ percentile speed reductions of 4.6 km/h and 5.7 km/h respectively (28).

- Michigan DOT has used PVMSs to electronically change the speed limit on I-96, based on traffic volume, traffic speed and weather conditions, and workers being present. (It is not known whether these are regulatory or advisory speeds) (32, 45).

- Various studies have recommended variable message signs, traffic advisory radio, and early warning systems to warn motorists approaching congested work zones. Use of ITS hardware to safely guide motorists through the work zone is also recommended (46).

- In New Mexico, the deployment of VMSs, automated traffic sensors and other ITS technologies at a freeway construction project in Albuquerque reduced the average clearance time for traffic incidents by 44 percent (59).

- European highway agencies use large truck- or trailer-mounted signs and portable signs to warn motorists of, and guide them through, work zones (71).

- On German and Dutch motorways, overhead sign gantries are used to post VMS signs over traffic lanes, which convey information about speed limits and work zones and detours (71).

- The Netherlands uses portable sign gantries to advise motorists of road conditions in advance of a work zone (overhead signs cantilevered over the lanes from a truck stationed on the shoulder). The signs cost $150,000 each; installation takes about 15 minutes; it is not necessary to stop traffic during installation; the signs are visible from 800-1000 m (71).

- In Europe, trailer-mounted signs, with multi-coloured fibreoptic lights, are also used in WZs (71).

- Illinois DOT, on a bridge construction project on I-55, used 17 PVMSs, as well as 8 portable traffic sensors electronically linked to a central base station server, and 4 portable CCTV cameras electronically linked to a central base station using wireless communications, to provide real-time traveller information and to enhance motorist safety. The system acquires and processes data and automatically selects motorist information messages for display on PVMS without human intervention, and operates 24/7 for the duration of the work project. It displays independent advisory messages on each PVMS based on conditions near specific PVMSs, and allows adjustment of thresholds for advisory message selection or staff notification (33).

- An FHWA report gives a useful overview of the types and applications of portable changeable message signs (PCMS in US terminology, PVMS in international terminology), including sign technology and size, message selection and display (normal maximum 2 phases, up to 3 phases if necessary), acceptable and unacceptable abbreviations, placement, safety, need for credibility, and checklist for installation (74).

#### 6.2.1.5 Narrower Lanes

The literature indicates the following regarding the use of narrower lanes to prevent speeding:

- In highly vulnerable situations that threaten worker safety, consideration should be given to reducing speed through funnelling and lane reduction (64).

- European highway agencies commonly use narrower lanes, both to maintain capacity and traffic flow, and to reduce motorist speeds. They strive to maintain the number of lanes through work zones by use of shoulders and narrower lanes. In Scotland, 3.65 m wide lanes are reduced to 2.5 - 3.0 m in work zones. Typically one of the lanes is wider than the other; trucks must travel in the wider lane. In Belgian work zones, typically a 3 m wide lane is open to all vehicles, and a 2.5 m wide lane is restricted to autos. This is done, even on a freeway median crossover, where one lane of traffic crosses the median and then operates as a contra flow lane in the other travel direction (71).

- A comprehensive review of US states' practices in setting design speed, operating speed, and posted speeds indicated a consensus view that narrow lanes and narrow shoulders lead to reductions in vehicle speeds (15).

#### 6.2.1.6 Enforcement, without and with speed display signs

The literature indicates the following regarding enforcement in work zones, including enforcement of speed limits:

- Measures that have proven to be effective in helping to manage speeds in work zones include police presence and enforcement in the work zone, which has been shown in some locations to reduce not only the 85th percentile speeds, but also the speed variance. In some locations, police presence has been shown to increase speed limit compliance by 15 percent in work zones where speed limits were not reduced. Several studies have shown that police presence has resulted in significant collision reductions. In general, most speed reduction measures are unlikely to be effective unless supported by some police enforcement (58).

- In highly vulnerable situations that threaten worker safety, consideration should be given to reducing speed through use of police (64).

- Fines for motorists exceeding work zone speed limits should be increased (64).

- Penalties for motorists convicted of driving through the work zone under the influence of drugs or alcohol should be increased (64).

- There should be increased presence of law enforcement at the beginning of the work zone (64).

- A variety of speed control methods should be used throughout the course of a project so that motorists do not learn how to anticipate and avoid speed controls (64).

- Police officers need to be trained in work zone traffic control procedures and must know the MUTCD (64).

- Police officers working temporary traffic control need to be adequately protected from work zone hazards (64).

- There is universal agreement that the most effective way of controlling speed in the work zone is to have a staffed police car with flashing lights at the beginning of the work zone (46).

- Automated speed enforcement is recommended in confined and high-speed work zones (46).

- Scotland uses cameras to detect speeders in work zones, and thus slow traffic. Tickets are automatically issued to speeders caught on camera. Only about 10% of the cameras are operational at one time, but all cameras are set to periodically flash, so motorists don't know which ones are operational (71).

- German highway agencies do not request traffic enforcement in work zones, as they believe it increases the risk of collisions. Contractors on the project are responsible for ensuring the safety of the WZ, and are held accountable for any collisions that occur.

- The use of photo-radar is being used and advocated for US work zones. In automated enforcement of speed limits, cameras are set to photograph any vehicle that exceeds the posted speed limit by a certain pre-determined threshold. The vehicle caught speeding is cited and a ticket is automatically issued. Signs can be set up prior to work zones to warn approaching drivers that photo radar is in use. Such systems have the potential to increase safety through greater compliance with speed limits, improve both mobility and safety by decreasing the need for enforcement personnel to stop vehicles in and around work zones, and provide cost savings for enforcement personnel (33).

- California DOT has contracted with the California Highway Patrol (CHP) to provide enhanced enforcement in work zones, to provide awareness of work zones and enforcement of speed limits. Speed reduction could not be obtained solely through use of signs and channelizing devices. Florida DOT and New Jersey DOT have made similar arrangements in those states (92).

- The police are hired by the work zone contractors in other states (e.g., Oklahoma and Utah) and in many locations in Ontario (92).

- Iowa uses extra-enforcement in construction work zones to patrol and enforce existing motor vehicle laws. Officers that work in construction zones are on voluntary and overtime status. The Extra Enforcement project fund, set up after a successful pilot project, reimburses the officer and the vehicle mileage. The extra-enforcement is being assigned to work zones by taking the following factors into consideration: traffic volume, enforcement personnel availability, potential work zone congestion, remaining highway capacity, and work zone type (13).

- New York occasionally employs extra enforcement in work zones. They believe overuse of police in work zones will lessen the positive impact of police presence in work zones and draw large amount of Regional Capital Program funds. New York's policy in engaging enforcement is to first request State Police to patrol work zones. Local agencies may be approached to patrol the work zone if the State Police are unavailable. The decision to use dedicated police services in New York work zones is normally made during the design process of a project. High-speed, high volume traffic flow in combination with any of the following factors are applied to determine if dedicated police services need to be part of the project Traffic Control Plan: construction activities (paving, etc.), closely adjacent to traffic without positive protection; restrictions to traffic flow based on geometry; no shoulder, reduced shoulder width, reduced lane width, and reduced number of travel lanes; locations where incidents will produce substantial congestion and delays on the facility; special operations that require temporary or frequent shifts in traffic patterns; locations where traffic conditions and accident history indicate substantial problems may be encountered during construction; night time construction which may create special concerns involving the Traffic Control Plan; projects with heightened public concern regarding the impacts of the Traffic Control Plan. The decision to engage dedicated police in a work zone may also come after the project is underway if there is a recurrence of traffic accidents, objectionable delays and congestion, and/or widespread driver disregard for speed limits and other regulations. Dedicated police enforcement costs are paid through the Region's Capital program. The Engineer in Charge has control of the hours the State Police are present at the work zone (13).

- Caltrans has a program known as the Construction Zone Enhanced Enforcement Program or Maintenance Zone Enhanced Enforcement Program (COZEEP/MAZEEP) in which the

California Highway Patrol will be contracted to enforce speed compliance in work zones. Conditions warranting COZEEP/MAZEEP activity are the following: facility closures at night; daytime construction activity that is not obvious when inactive; work zones protected by flaggers with or without pilot cars; end of queue management; poor highway alignment approaching the work zone, high truck counts, or other unique situations; workers exposed to traffic and escape route blocked; night construction activity that is not obvious when inactive; activities with a large number of truck movements at the work area; night work in an identified work zone that requires a lane closure; work on freeways with 6 or more lanes (13).

- New Jersey has a dedicated New Jersey State Police (NJSP) Construction Unit assigned to the New Jersey Department of Transportation (NJDOT) construction projects. This unit assists the NJDOT in monitoring and enforcement of the approved traffic control plans. All members of this unit must receive specific work zone safety training. The NJSP construction unit is used on an as-needed basis at the request of the Resident Engineer for a variety of project types and classifications (13).

- Several other states also use enforcement in work zones. The New York State Thruway uses the following practices: State police intermittently park in work zones for brief periods (15-30 minutes) with their lights flashing; signs are posted that traffic fines are double in work zones; ghost cars (recycled State Police cars) are placed in work zones (13).

- Targeted enforcement combined with focused publicity campaigns can boost the effectiveness of traditional enforcement methods. Automated enforcement, particularly photo radar, has been shown to be efficient and effective where it has been used for speed control, particularly on high-volume arterials. Photo radar could also be coupled with variable speed limit systems on urban Interstate highways where high traffic volumes can make traditional enforcement methods hazardous. Redesigning roads to achieve greater congruity between driver perceptions of appropriate travel speeds and the cues provided by the road itself (e.g., narrowing lanes) may also influence motorists' speeds. A proper mix of these approaches can enable police to leverage their resources and deploy them efficiently (52).

- The traffic court system is also an important participant in effective speed enforcement. Judges may overturn speeding violations if they think the speed limits are unreasonable or reduce fines if they believe the sanctions are too harsh. If judges are lenient in their treatment of speeding offences and routinely dismiss speeding citations, the incentive for the police to enforce the speed limits may be reduced. Thus it is important that the traffic court system—as well as the police and motorists—perceives that speed limits are reasonable and enforceable (52).

- Automated enforcement, particularly photo radar, can be used to complement traditional enforcement methods, particularly where roadway geometrics or traffic volume makes traditional methods difficult or hazardous. Photo radar is controversial. Its successful introduction requires adoption of legal changes (e.g., resolution of constitutional privacy issues, vehicle owner versus driver liability), funding, and public education. It should be deployed selectively at first—at locations that are hazardous and difficult to patrol with traditional methods and where speeding is a problem—to ensure essential public support. In the near term, speed limits should be set at levels that are largely self-enforcing or at the lowest speed the police are able to enforce (52).

- Methods of speed enforcement used in the US include: radar, aircraft, lasers, VASCAR (Visual Average Speed Computer and Recorder), unmarked cars, special patrols, covert vehicles, stopwatch, motorcycle, and pace vehicles. Speed enforcement using mobile patrol vehicles measuring driving speeds with radar is the most popular means of conducting speed enforcement in the United States, according to a special survey conducted for this study. State police use aircraft as well as laser and VASCAR for speed detection. The mobile patrol method involves a police vehicle circulating through traffic and citing speeding drivers. Stationary patrol enforcement, where a marked or unmarked police car parked along the side of the roadway uses radar or LIDAR (Light Distance and Ranging by laser speed gun) to measure speeds, is another common technique. Apprehension of speeding drivers occurs downstream of the monitoring vehicle, sometimes with another patrol officer. The merits of mobile and stationary patrols have been a topic of study. The former is effective in detecting specific violators and slowing traffic in the immediate vicinity of the patrol car. The latter is effective in deterring speeding at a particular location. The advantages and disadvantages of visible and concealed enforcement have also been studied. One purpose of concealed enforcement is to increase the uncertainty of where and when enforcement will occur. As a result of its limited visibility, however, its general deterrence effect appears to be limited. Moreover, in jurisdictions where radar detectors are permitted, concealed police vehicles may be "seen" and their location communicated to others by CB radios, thereby compromising their concealment (52).

- A critical difficulty in deterring speeding using traditional methods is maintaining the effect over time and space. The longevity of effects can be expressed in terms of a "halo," that is, the spatial or temporal extent of the deterrence effect from the enforcement officer. Hauer and Ahlin (52) investigated both effects by measuring vehicle speeds before, during, and after enforcement using stationary, marked police vehicles on semi-rural, two-lane roads. Similar to earlier studies, the researchers found a marked reduction in average traffic speeds in the vicinity of the enforcement site to speeds close to posted speed limits. Reduction in speed dispersion, however, was less pronounced. Moreover, the distance-halo effect decayed quickly downstream of the enforcement site, following the general decay pattern of earlier studies. With regard to the time-halo effect, average traffic speeds remained depressed for 3 days following a single episode of enforcement activity and for considerably longer (up to 6 days) with repeated enforcement. Similar results were found for the effect of police presence on urban driving speeds (52).

- Increasing enforcement intensity should, according to deterrence theory, boost the deterrence effect by increasing the perceived risk of apprehension. In a review of European studies, Østvik and Elvik concluded that enforcement intensity must be increased significantly—to more than three times the initial level—before there is an appreciable effect on the perceived risk of detection or reduction in the number of speeding offenses (52). Studies of experience from other enforcement campaigns that have significantly increased the certainty of apprehension, such as anti-drunk-driving programs, have found the same effect. Positive behavioral and safety effects are evident immediately after the adoption of the program. With a major initiative, the effect can last from a few months to a few years. However, deterrence effects of even a major program can diminish with time (52). One explanation for this effect is the previously discussed behavioral adaptation of the police to the success of the program. Another reason is that enforcement may deter the unwanted behavior but does not necessarily change the underlying attitudes that ultimately determine the behavior (52).

- There is some evidence that those who drive well in excess of the speed limit are the most impervious to the deterrence effects of traditional enforcement methods. A recent study of an intensive police intervention to reduce speeding on a 40-mph (64-km/h) urban road in northern England found a greater reduction in the number of drivers breaking the speed limit by a small amount than in the number exceeding the limit by 20 mph (32 km/h) or more (52). This finding corroborates a related drivers' survey (part of the same study), which indicated that those who admitted to breaking the speed limit by a large amount in the past showed more intention to speed in the future than did those who admitted to speeding by smaller amounts. As discussed in section 2.0, driving well in excess of average speeds is associated with both higher crash probability and greater crash severity. This finding is confirmed by recent evidence from British Columbia that drivers with four or more excessive speed convictions had almost twice the overall crash rate of drivers whose most serious multiple offenses were simply exceeding the posted speed limit (52).

- To ensure a high level of compliance, speed limits have to be set at levels that are largely self-enforcing, or at the lowest speed the police are able to enforce (52).

- There is some evidence that enforcement does not deter those high-speed drivers who travel well in excess of the speed limit and pose a hazard to both themselves and other road users. These drivers obviously pose a special challenge for law enforcement (52).

- The deterrence effect of enforcement clearly depends on creating the impression that road users who violate the law have a high probability of being apprehended. One way to achieve a credible level of enforcement without overstraining enforcement resources is to enforce speed regulations where and when risk-taking behaviours are most evident and traffic volumes are sufficient to justify the effort. Planned patrols on commuter routes at varying time intervals and locations, for example, were effective in extending the time- and, to a lesser extent, the distance-halo effects of enforcement. Patrol vehicle presence was reduced without disturbing the speed suppression effect, but only after an initial minimum 6 weeks of continuous speed control activity. Varying the location of police patrols on commuter routes appeared to extend the distance-halo effect, but the evidence was inconclusive (52).

- Photo-radar serves as a useful complement to traditional enforcement methods. It helps maintain an enforcement level that provides a meaningful deterrent to drivers by increasing the probability of detection for speeding violations. Because it can be deployed without police presence, photo-radar can increase the perceived level of risk to drivers and hence compliance levels without producing a reduction in police surveillance levels. It can be used in locations where patrol vehicles cannot be safely and effectively deployed. Moreover, when photo-radar is operated without police presence, it frees police for other traffic and law enforcement activities. The TRB Special Report 254 reports on locales where photo-radar has been used and has been successful in reducing collision rates: Germany; Victoria, Australia; Norway; Arizona; California; Colorado (52).

- Attention has been given to creating enforcement-friendly work zones through coordination between transportation and enforcement agencies, use of technologies to aid enforcement, and shoulders and enforcement pull-out areas (81).

- A report **Judicial Enforcement of Variable Speed Limits** by Margaret Hines, published in the Legal Research Digest, National Cooperative Highway Research Program, March 2002 (29), addresses the enforcement of variable speed limits, and includes a brief overview of use of variable speed limits in other countries as well as US states, 40 of which responded that they used variable speed limits. In order to enforce variable speed limits successfully, the following elements are necessary:

- government creation of a speed limit
- proof of speed limit where the violation occurred
- proof that the speed limit was posted
- proof that posted speed limit signs were visible to the driver
- proof of special circumstances justifying a reduced speed limit
- proof of speed in excess of limit

Suggested language for a law enabling the enforcement of variable speed limits is included in the report.

- M25 Motorway traffic management systems around London, England, incorporate a speed measurement and enforcement system for variable speed limits, using radar speed measurement and camera recording of offences (63).

#### 6.2.1.7 Pilot Vehicles and Pace Vehicles

The literature indicates the following regarding use of pilot vehicles and pace vehicles in work zones:

- Measures that have proven to be effective in helping to manage speeds in work zones include the use of pilot vehicles, pace vehicles or rolling closures for speed reductions in specific periods of time or for specific work operations. A pilot vehicle is used on a two-lane road to guide a queue of vehicles through a one-lane section of a work zone or detour, or to control the speed of vehicles through the construction site, especially immediately adjacent to areas where workers are present. Pace vehicles are used to constrain and control the speed of vehicles travelling through the work zone, where reduced speed is necessary but it is difficult to achieve speed reductions by other means, e.g., freeway paving operations (58).

- Pace vehicles should be used to pull into lanes and slow traffic (64).

- Ontario and Florida use rolling closures and pace vehicles to slow traffic down for certain freeway work activities and to provide a very short-duration traffic-free work area while work must be done across or above the road (58, 92).

#### 6.2.1.8 Optical Speed Bars

Optical speed bars are transverse paint bars set out at gradually decreasing spacing in order to provide drivers a heightened perception of speed to slow traffic entering a work zone. Optical speed bars have been documented to work well with large desired speed reductions (e.g., from highway speed to a stop or near stop), but are less well documented concerning effectiveness in work zones where desired speed reductions are smaller. The literature indicates the following regarding use of optical speed bars in work zones:

- Optical speed bars were tested in work zones in Kansas, and evaluated as to their effectiveness in reducing speeds. The pattern of the optical speed bars was found to cause reductions in mean and 85$^{th}$ percentile speeds, as well as in standard deviations. Changes in speeds were small, and resulted from both warning effects and perceptual effects. The warning effects persisted downstream of the pattern while the perceptual effects did not, as drivers increased their speed once out of the area with graduating spacing. Reductions in speed variations also persisted downstream of the pattern. The work zone pattern did not appear to have any effect on speed or speed variations (48).

- Transverse pavement markings were also tested in rural work zones in New Brunswick (28), and were found to be moderately effective, with mean speed and 85$^{th}$ percentile speed reductions of 3.4 km/h and 3.8 km/h respectively.

#### 6.2.1.9 Portable Rumble Strips

- Portable rumble strips were tested in rural work zones in New Brunswick, and were found to be quite effective, with mean speed and 85$^{th}$ percentile speed reductions of 6.9 km/h and 9.5 km/h respectively (28).

- Michigan DOT has used transverse orange and white temporary rumble strips on I-94, to warn drivers to slow down (45).

- The Netherlands uses "Andreas strips" (portable rumble strips) in closed traffic lanes, 150 m in advance of a parked work truck, to provide a final warning to motorists that they have intruded into a work area. The strips are 2 m long, 20 cm wide, and 4 cm thick, three of them at 5 m spacing (71).

- Various US jurisdictions are reported as using temporary rumble strips in work zones, both construction and maintenance: Michigan, California, Delaware, Illinois, Pennsylvania, Ohio, Maryland, Indiana, Kentucky, New Mexico, and South Dakota. The advantage of rumble strips is considered to be not so much a reduction in speed, but in raising the level of alertness of drivers. A portable rumble strip was developed through the Strategic Highway Research Program (SHRP) for use in low speed work zones:
    - California uses raised (0.75 in.) or indented (up to 1.0 in.) rumble strips across the full width of the lane. Their standard spacing pattern is intermittent spacing of 50-100 feet between sets of 3 strips 3 inches wide, over a distance of 25 feet. California only allows their use when it is determined that they are a reasonable solution to an identified problem.
    - Illinois uses raised high-strength polycarbonate strips that are 0.5 inches high and 3.5 inches wide with a tapered edge towards the approaching traffic. They use 6 strips evenly placed over 25 feet, placed 200 feet before each construction sign, extending the entire width of the travel lane.
    - Pennsylvania uses raised 4-inch wide asphalt strips that are formed by nailing 0.5 inch x 4-inch plywood strips to the pavement and filling with asphalt overlay material. The plywood is then removed and the strips are rolled. These are in sets of 15 or 20 strips spaced 12 inches apart extending onto the shoulder. The sets are spaced at intermittent distances from 200 feet between sets 1 and 2, 100 feet between sets 2, 3, and 4, and 50 feet between sets 4 and 5 with the 6th set (also at 50 feet) used in advance of a detour. A "RUMBLE STRIPS AHEAD" sign is also required.
    - Kentucky uses raised 8-inch wide asphalt strips, placed in sets of 10; the spacing, height, and spacing within sets, is varied according to the speed limit. For speeds greater than 45 mph, the strips are 0.38 inches to 0.5 inches, at 24-inch spacing.
    - Ohio uses either raised or grooved strips both at a maximum of 0.5 inches high or deep. The number of strips in a set and the spacing of the groups are both dependent on the speed limit. They use 10 sets with 8 to 16 strips per set. They are placed in groups of 3 sets, 4 sets, and 3 more sets with the distance between groups

of sets varying from 100 feet to 250 feet, and the distance between sets varying from 35 feet to 100 feet dependent on the speed.

- Indiana uses buzz strips (thermal plastic rumble strips) prior to traffic changes and in high collision areas. They are considered to be successful in getting drivers' attention.
- NYSDOT requires a final compacted thickness of 10 mm ± 3 mm, using 6 strips evenly spaced 3.0 m apart, across the entire width of the lane(s). In maintenance NYSDOT used raised asphalt strips, multiple layers of adhesive tape, used traffic counter tubes, and reinforced rubber belting (recycled tire tread strips) screwed to the pavement. NYSDOT recommends use of any of these, if properly applied, but only where audible and tactile warnings are necessary for the safety of exposed workers or drivers. Examples include a detour, lane splits, exit only lanes, one lane traffic with a traffic signal ahead, major reduction in the speed limit, and varying traffic patterns.

#### 6.2.1.10 Other Speed Control Measures

The literature indicates the following regarding other speed control measures:

- Road authorities, law enforcement and others should work together to implement and evaluate alternative speed control measures in the work zone (64).

- Doubling the fines for speeding in work zones has been considered effective in the US, provided signs are only posted or visible when work is actually taking place, and sufficient enforcement is in place (46). Saskatchewan has indicated that although they do not now have increased fines for speeding in work zones, they plan to introduce them shortly (30).

- Iowa DOT used the Wizard Work Zone Alert and Information Radio (CB radio) to give drivers of heavy trucks enough advance warning of upcoming delays at maintenance sites or incidents to enable them to stop safely before encountering lines of halted vehicles. The Wizard unit automatically broadcasts an alert message over any CB channel (usually channel 19). Messages are typically seven to 10 seconds, and can be pre-recorded or recorded on site. The user has the option of transmitting a message every 30, 60, or 90 seconds. In order to avoid breaking in over another CB user, the equipment monitors the selected station and will only broadcast a message when no other activity is detected. The Wizard uses a standard CB antenna and a 12-volt power source, and can broadcast over approximately four miles. Sixty-three percent of the truck drivers that had their CB tuned to channel 19 as they passed the paint crew heard the Wizard CB Alert message and 41 percent stated that the CB message was their first indication that they were approaching the paint crew. The system reached a large portion of the target audience and passed on information that was important to its listeners. Many drivers voiced their approval of the system, showed their support for its continued use in the future, and even suggested additional situations where the system’s use would be helpful (90).

### 6.2.2 Other Speed-related Safety Measures

Other speed-related measures may also contribute to work zone speed management, or more basically, may contribute to work zone safety by helping avoid or reduce some of the speed-related hazards. These may involve more/better advance warning of the work zone, merge control, work zone intrusion alarms, and various ITS technologies. The most frequent types of collisions in work zones are side-swipe (related to both merges and excessive speed) and rear-end collisions (related to excessive speed). These measures generally go beyond the scope of this project, but several are mentioned here, based on the review of the literature and web.

#### 6.2.2.1 Advance warning of work zone

The literature indicates the following regarding advance warning of work zones ahead:

- Motorists should be given plenty of advance warning of upcoming work zones (64).
- It is helpful to install warning signs that provide estimated time of delay and other road closure information so that drivers have sufficient opportunity to exit and take a different route (64).
- Michigan DOT has used microwave sensors, wireless communications, and portable changeable message signs, to tell motorists on I-75 how many minutes it will take them to reach the end of the work zone (45).
- International Road Dynamics Inc. (IRD) has developed an ITS system called Travel Messenger, which measures traffic conditions at strategic locations and determines and displays expected delays through a work zone. Advance messages advise drivers, reducing impatience and allowing alternate routes to be chosen (IRD information, 2003).
- European highway agencies emphasize developing and implementing a communications plan to inform the public about work zones and alternative routes, before the project start date and also on real-time traffic situations, often through the use of ITS and other technologies. France distributes leaflets to motorists in neighbouring countries each year, and calendars within France, showing when and where WZ projects are scheduled. This is also available on the Internet. Information is considered credible, regardless of medium (71).
- In Germany, PVMSs are widely used to reroute traffic as necessary; the signs are part of an area wide signage and information system, including permanent orange trailblazers that indicate alternate routes that travellers can take to avoid work zone delays (71).
- Illinois DOT used a Real-Time Traffic Control System on I-55 to acquire and process data and provide real-time traveller information on PVMSs and also on the Internet (33).
- Michigan DOT collected and processed traffic data and automatically selected an appropriate motorist information message for display on PVMSs (independent advisory messages on each PVMS based on conditions at pre-defined locations), leaving the option for human intervention if needed. The system detected queued traffic and determined traffic volume in all kinds of weather and visibility conditions. Information was also provided on the Internet (33).
- New Mexico State Highway & Transportation Department (NMSHTD) used 8 fixed CCTV cameras, 8 modular PVMSs, 4 arrow dynamic signs, 4 LED PVMS trailers, 4 ADDCO SmartZone portable traffic management systems (which integrate CCTV and PVMSs on one portable system), and 4 HAR units, as well as Internet, radio, newspapers, TV, and pagers, to acquire and provide real-time traveller information on traffic conditions, on detour routes and major incidents (33).

- The Wizard CB Alert System was used in Iowa to automatically broadcast advisory messages to warn (mainly truck) drivers of traffic or road conditions/ hazards ahead. Most truckers surveyed had heard the message and thought it worthwhile and effective (33).

- Pennsylvania DOT stations a uniformed police officer in a patrol car with emergency lights flashing 1/4 to 1/2 mile upstream of any queue.

#### 6.2.2.2 Innovative Devices for Improved Worker and Motorist Safety

The literature indicates the following regarding use of innovative devices to improve worker and motorist safety:

- The Maintenance and Construction Operations User Service (MCOUS) in the ITS Architecture identifies ITS systems that help ensure safe roadway operations during construction and other work zone activities and communicate with the traveller (40).

- MCOUS identifies the following ITS technologies that may be applicable, under the title of **Smart Work Zones:**
- Roadway information/surveillance systems (Examples include inductive loops, CCTV, video imaging detection systems (VIDs), acoustic, radar)
- Lane-drop smoothing systems (i.e., series of portable flashing beacon signs and electronic occupancy sensors)
- Traveler warning system (Examples include DMS, highway advisory radio (HAR), radio broadcasts (AM and/or FM subcarriers), in-vehicle displays (e.g., graphical, text, audible, etc.), flashing beacons coupled with a static sign message, stand-alone static signs for warnings and/or diversion routes)
- Personal warning devices/systems (Examples include a device (i.e., beeper) that a worker wears that provides an indication when a vehicle enters (i.e., machine vision video cameras) or worker leaves a "safe zone" and/or provides a message to motorists via roadside DMS and/or HAR. Other examples include intrusion devices/alarms used for improving worker safety at work zones.)
- Moveable barrier systems (40).

- The ADAPTIR system, a mobile traffic monitoring and management system, can be used to advise drivers of slowing traffic speeds downstream, providing information via PVMSs. PVMS info was: Phase 1: Location & word ADVISORY; Phase 2: REDUCED SPEED AHD xx km/h., when speed differentials exceeded a threshold amount. In Iowa, these were found to be more effective when traffic approached congested levels, rather than in uncongested flow (33).

- Illinois, Michigan, New Mexico, and Nebraska are cited as US states that have successfully applied ITS technologies in work zones to help manage traffic better. Applications have used detectors and CCTV to collect data, which are analyzed, and real-time traffic information is provided to drivers using PVMSs, HAR, and a web site (59).

#### 6.2.2.3 Merge control

The literature indicates the following regarding merge control:

- Michigan DOT has used a real-time information system and a dynamic lane-merge system on I-94 to help improve traffic flow through work zones. The system uses a series of five trailers with flashing lights and signs that say "Left Lane Do Not Pass When Flashing." The purpose of the system is to have motorists merge early enough to prevent the backups that often occur with last minute merging. Prior experience with the system has proven very effective, often reducing travel times through a work zone significantly (38, 45).

- International Road Dynamics Inc. (IRD) has developed an ITS system called Lane Merger, which promotes smooth traffic flow leading into a work zone by creating a dynamic no-passing zone upstream of the construction site which results in reduced conflicts, fewer collisions, and reduced road rage (IRD information, 2003).

- The Dynamic Work Zone Safety System has been used in Indiana and Michigan, and is designed to prevent dangerous merging in the tapered approach to work zones by creating a dynamic no-passing zone, the length of which depends on the length of the traffic backup. The coverage area of the no-passing zone is depicted by a series of signs. The trailer-mounted, portable signs consist of flashing lights, a "DO NOT PASS" sign, and a "WHEN FLASHING" sign. As sensors detect that traffic is backing up, the next upstream sign begins to flash. The signs are regulatory, and thus the DO NOT PASS message is enforceable. System components include non-intrusive traffic sensors, interface controllers, communication devices, regulatory signboard with flashers and trailer, and solar power equipment and batteries (33, 92).

#### 6.2.2.4 Queue warning and real-time traffic information

The literature indicates the following regarding queue warning on approaches to work zones, and real-time traffic information:

- A combination of traffic queue detection equipment and dynamic message signs should be used to vary messages as traffic conditions change (64).

- FHWA studies have demonstrated the effectiveness of using PVMSs, together with traffic data on traffic flow, speed, and end of queue, to provide information to drivers and improve safety in work zones (56).

- Belgium installs pole-mounted video cameras on trailers at designated points in advance of the work zone. The cameras monitor traffic speed and lane occupancy and detect queues from traffic slowdowns. VMSs are mounted on the rear of the trailers, which automatically display "File XXX m", File being the word for Queue. If the backup continues to grow, additional signs are posted at 1500, 2000…. 3000 metres in advance of the WZ. Rear-end crashes at one location were reduced by 60% (71).

- Illinois DOT used a Real-Time Traffic Control System on I-55 to acquire and process data and provide real-time queue information and other traveller information on PVMSs and also on the Internet (33).

- Michigan DOT collected and processed traffic data and automatically selected an appropriate motorist information message for display on PVMSs (independent advisory messages on each PVMS based on conditions at pre-defined locations), leaving the option for human intervention if needed. The system detected queued traffic and determined traffic volume in all kinds of weather and visibility conditions. Information was also provided on the Internet (33).

- New Mexico State Highway & Transportation Department (NMSHTD) used 8 fixed CCTV cameras, 8 modular PVMSs, 4 arrow dynamic signs, 4 LED PVMS trailers, 4 ADDCO SmartZone portable traffic management systems (which integrate CCTV and PVMSs on one portable system), and 4 HAR units, as well as Internet, radio, newspapers, TV, and pagers, to acquire and provide real-time traveller information on traffic conditions, on detour routes and major incidents. The Arkansas State Highway and Transportation Department (AHTD) uses a similar system (33).

- Missouri DOT has used queue length detection and PVMSs to warn drivers of traffic conditions approaching and in work zones (92).

#### 6.2.2.5 Work Zone Intrusion Alarms

The literature indicates the following regarding work zone intrusion alarms:

- The US Strategic Highway Research Program (SHRP) and Pennsylvania DOT have tested several work zone intrusion technologies, the latter on a project with high traffic volumes and blind corners which made it difficult to see slowed or stopped traffic. Intrusion alarms detect vehicles entering the buffer area between work crews in the work area and vehicles driving past the work zone, and provide a warning to alert workers. Warning time may be short (4-7 seconds), but can be vital. Such alarms employ various technologies such as infrared, ultrasonic, microwaves, or pneumatic tubes, to detect the intruding vehicle. When the system detects an intrusion, it sounds a loud siren to warn the workers in the area. Transmission mechanisms include radio and hard-wired systems (33).

#### 6.2.2.6 Work Zone Safety Training

The literature indicates the following regarding work zone safety training:

- All supervisors and workers in highway work zones must be adequately trained (57).

- Training programs need to be developed that provide workers with an understanding of safety hazards and methods of hazard reduction in highway and street construction (64).

- All workers should be trained in hazards and adaptations for work at night and in other low-visibility conditions (64).

- All persons involved with the selection, placement, or maintenance of work zones should be trained in safe traffic control practices. This includes designers as well as field personnel (6).

### 6.2.3 Non-speed-related Safety Measures

Work zone safety is a complex issue, and there are many safety measures that have been tested, evaluated, and applied, both speed-related and non-speed-related. The latter category goes beyond the scope of this report, but some examples are included here, which may be useful both in pointing the way to measures that remove the speed problem or help reduce the inclination to speed, and also in developing future chapters of a Work Zone Safety Manual.

#### 6.2.3.1 Road Closures

The application of work zone speed management measures is predicated on the concept of keeping the road open to traffic. However, some road authorities are moving toward a strategy of road closures, where possible, to make the construction project both faster and safer.

- The Netherlands has determined that it can often be cost-effective to close down a road for construction or maintenance (71). The approach is "Get in, stay in, get out, stay out."

- The city of Columbus, Ohio, has also closed a section of road for a period of time, to accelerate completion of construction projects, reduce delay and reduce cost (92).

- Michigan DOT has adopted a "get in, stay in, get out, stay out" policy with regard to much of their Interstate construction in the Detroit area (82).

- Full road closure is not feasible in every situation. Some locales may simply lack suitable alternate routes, while others may reject the approach due to jurisdictional complications or the impacts full-closure would have on local businesses, among other reasons. But transportation agencies that have used the full closure method say it can greatly reduce the time needed to complete a construction project. It can also be safer than the traditional partial-closure approach, advocates say, because it doesn't cause congestion that can lead to accidents. There are other potential benefits as well. Because construction crews can operate more efficiently in a traffic-free environment, full-closure projects can be both less expensive and of a higher quality than those undertaken with a partial-closure approach. Indiana and Oregon DOTs are cited as having had successful applications, as well as Kentucky, Michigan, Ohio, Delaware and Washington (59).

#### 6.2.3.2 Better Information to Travelling Public

The literature indicates the following general or aggregated means of providing better information to the travelling public.

- Many US states have developed public relations and information outreach programs for motorists and the public, to improve customer satisfaction and to improve safety, by a variety of means (92). Some states (e.g., Arizona) make public relations and information a bid item in construction contracts (92). Saskatchewan has an “Orange Zone Campaign” annually during the construction season, which includes fines and penalties. The campaign is included province wide within weekly and daily newspapers, radio and television advertisements (30).

- Indiana DOT has used media extensively over 20 years to notify motorists by radio, TV, and newspapers, of upcoming projects, possible delays and suggested alternate routes (92).

- In addition, there are some specific means of providing better information to the traveling public, which will alert them to work zones and help avoid hazardous violations of expectations and excessive speed. These include the use of PVMSs (described in more detail above), Highway Advisory Radio (HAR), commercial radio, internet web sites, displays of real-time work zone traffic conditions on large screens at rest areas, welcome centres, weigh stations, truck stops, major tourist attractions, large parking garages, large office buildings, employment centres, and/or other large traffic generators (46), and dissemination of information on current work zones through trucking associations.

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# Appendix 1: Survey Questionnaire Responses

The survey questionnaire distributed to Canadian provinces, territories and municipalities is included in section 5.0. Section 5.0 also provides a summary of the survey responses.

The tabulation of the responses is provided in an attached Excel spreadsheet.

# Appendix 2: Abbreviations/Acronyms and References

## A2.1 Abbreviations/Acronyms

| | |
|---|---|
| 2L2W | Two-lane, two-way |
| AASHTO | American Association of State Highway & Transportation Officials |
| AB | Alberta |
| AM | amplitude modulation (radio) |
| BC | British Columbia |
| CCTV | Closed Circuit Television |
| CSHRP | Canadian Strategic Highway Research Program |
| DMS | Dynamic Message Sign |
| DOT | Department of Transportation |
| EIS | Electronic Integrated Systems Inc. |
| FM | frequency modulation (radio) |
| FHWA | U.S. Federal Highway Administration |
| HAR | Highway Advisory Radio |
| HTA | Highway Traffic Act |
| IRD | International Road Dynamics Inc. |
| ITS | Intelligent Transportation Systems |
| km/h | Kilometres per hour |
| LIDAR | Light Distance and Ranging (laser speed gun) |
| m | metre |
| MB | Manitoba |
| MCOUS | Maintenance and Construction Operations User Service |
| mph | Miles per hour (also shown as mi/h in some references) |
| MTO | Ministry of Transportation Ontario |
| MUTCDC | Manual of Uniform Traffic Control Devices for Canada |
| NB | New Brunswick |
| NCHRP | National Cooperative Highway Research Program, U.S. |
| NF | Newfoundland |
| NIOSH | U.S. National Institute for Occupational Safety and Health |
| $N_L$ | Number of Lanes |
| NS | Nova Scotia |
| NWT | North West Territories |
| OHSA | Occupational Health and Safety Act |
| ON | Ontario |
| OTM | Ontario Traffic Manual |
| PEI | Prince Edward Island |
| PV | Number of Pace Vehicles |
| PVMS | Portable Variable Message Sign |
| QC | Quebec |
| RCMP | Royal Canadian Mounted Police |
| SHRP | U.S. Strategic Highway Research Program |
| SK | Saskatchewan |
| TAC | Transportation Association of Canada |
| TCP | Traffic Control Person |
| TRB | Transportation Research Board, U.S. |
| U.S. | United States of America |
| U.S. MUTCD | U.S. Manual on Uniform Traffic Control Devices |
| VID | Video Imaging Detection System |

| | |
|---|---|
| VMS | Variable Message Sign |
| VSL | Variable Speed Limit |
| WZ | Work Zone |
| YK | Yukon Territory |

## A2.2 References

This list of references is made up of "primary" and "secondary" information sources. Primary references, those sources accessed directly, are listed with an annotated description attached. Secondary references, those sources referenced by the primary sources, are listed without an attached description. At the end, a list of useful web sites is included.

1. Armour, M. and Jenkins, S.E., Proceedings of a seminar on "street lighting and safety" held at Chisholm Institute of Technology, November 23, 1982, ARRB Internal Report AIR 000-196, South Vermont, Australia, Australian Road Research Board, 1982.

2. Baerwald, J.E., "The Influence of Speed and Speed Regulations on Traffic Flow and Accidents", International Road Safety and Traffic Review, Vol. 9, No. 1, Spring, 1961.

3. Belobraydich, Todd, Mudd, Glen, Griffith, Carl, "Reducing Exposure of Short-term Utility Work Zones through Effective Safety Planning", Presentation at FHWA Work Zone Workshop "Making Work Zones Work Better", Washington D.C., 2003.

   This paper describes the practices of the Louisville, KY Water Company, its contractor TRENCH-IT Inc, in ensuring safety at short-term utility work zones, including education and training at three levels, use of a traffic control contractor, and outlines a proposed utility model program, involving training, standards, and responsibility.

4. Benekohal, R.F., Resend, P.T.V., and Zhao, W., "Temporal Speed Reduction Effects of Drone Radar in Work Zones", Transportation Research Record #1409, pp. 32-41, Transportation Research Board, 1993.

5. Benekohal, R.F. et al, "Speed Reduction Patterns of Vehicles in a Highway Construction Zone", Transportation Research Record #1352, pp 35-45, Transportation Research Board, 1992.

6. Bryden, J.E., Mace, D.J., "A Procedure for Assessing and Planning Nighttime Highway Construction and Maintenance," NCHRP Report 475, Transportation Research Board, 2002.

   This report notes the necessity for nighttime work, in order to keep traffic facilities open, and describes a procedure for assessing and planning nighttime highway construction and maintenance. It presents a decision process to assist highway agencies in evaluating night work alternatives against other work schedules. It provides a comprehensive, quantitative basis for selecting the most cost-effective plan for ensuring the safety of the public and workers, maintaining capacity, minimizing the impact on the community, and getting the work completed on schedule. The two basic conditions that must normally be met in order for night work to offer any advantage in terms of meeting the basic objectives are reduced traffic volumes and easy set up and removal of the traffic control pattern on a nightly basis. Nighttime work raises additional safety problems. The objectives of the project were to (1) develop guidelines for nighttime roadwork to improve safety and operations and (2) formulate procedures to facilitate making decisions about undertaking nighttime work. This report presents procedures to assist highway agencies in determining whether to perform nighttime construction or maintenance. This report will be of particular interest to engineers responsible for scheduling construction and maintenance work.

7. Casey, S.M. and Lund, A.K., “The Effects of Mobile Roadside Speedometers on Traffic Speeds”, Accident Analysis and Prevention, 25 (5), pp. 627-634, 1993.

8. Chow, R., Alberta Infrastructure and Transportation, note dated February 9, 2005)

9. Clancey, B., “Work Zone Speed Limit Reduction Practices”, Nova Scotia Transportation & Public Works, note dated February 3, 2005.

10. Clancey, B., Nova Scotia Transportation & Public Works, note dated February 4, 2005.

11. Coleman, J. (Team Leader) and Study Tour Group, “FHWA Study Tour for Speed Management and Enforcement Technology”, Report of speed management practices in the Netherlands, Germany, Sweden and Australia, Federal Highway Administration, Washington D.C., December, 1995.

12. Dewar, Robert, “Work Zone Accidents”, December, 1998

This paper summarizes much information about work zone collisions, as they are affected by human factors. Subjects covered include: driver expectancy, work zone credibility, need for consistency, work zone collision characteristics, collision data problems, the most common types of work zone collisions (rear-end and sideswipes), location of collisions within the work zone, collision increases at nighttime and for trucks, driver perception and information processing, work zone speed issues and strategies, nighttime conditions, illumination, driver behaviour, older drivers, traffic control devices, trucks, shoulder width, and lane width.

13. **Effectiveness of Extra Enforcement in Construction and Maintenance Zones**, Evaluation Plan, FHWA, 2002.

This document outlines a plan for evaluating the effectiveness of extra enforcement in work zones. The frequency of maintenance activities and the potential severity of work zone crashes have intensified the importance of safe and efficient handling of traffic in work zones. Many agencies consider police enforcement as one of the most effective speed reduction strategies at work zones. However, there are some concerns that enforcement presence may cause additional traffic congestion at work zones. For example, in a few cases in Iowa, congestion increased as motorists noticed the enforcement vehicles near the work area.

The purpose of the study is to determine the appropriate use of enforcement agency personnel to patrol active construction or maintenance work zones. Many highway work zones are not designed to allow for safe ticketing of offending motorists, thus research into proper pull-off locations and design of these locations also needs to be undertaken.

The study will be conducted in two phases. Phase I of the study examines existing extra enforcement policies and procedures for highway work zones. The project will exhaustively review the existing and proposed enforcement practices being applied in long-term, short-term, and moving work zones throughout the country. The research outcomes will be used as a basis to recommend a limited number of field trials and evaluations to be conducted in Phase II of the project. Appendix I includes brief descriptions of extra enforcement practices currently conducted at some of the state agencies.

14. Fisher, A.J., "Road Lighting as an Accident Counter-measure", Australian Road Research, 7 (4), pp 3-16, 1977.

15. Fitzpatrick, Kay, Carlson, Paul, Brewer, Marcus A., Wooldridge, Mark D., Miaou, Shaw-Pin, **Design Speed, Operating Speed, and Posted Speed Practices**, NCHRP Report 504, Transportation Research Board, Washington D.C., 2003.

    This report describes the relationships between design speed, operating speed, and posted speed practices, and an analysis of geometric, speed, and traffic conditions. It includes the results of a survey of US states as to their practices. It does not address work zones specifically, or guidelines/practices for managing speeds in work zones. However, the report is of potential interest in providing guidance as to how to choose design elements to achieve normal operating speeds, to the extent feasible, or reduced speeds, through work zones. The strongest relationship found in the study was between 85th percentile operating speed and posted speed limit.

16. Fontaine, M.D., and Carlson, P.J., "Evaluation of Speed Displays and Rumble Strips at Rural Maintenance Work Zones", Paper presented at the Transportation Research Board 80th Annual Meeting, Washington D.C., 2001.

17. Fontaine, M.D., "Innovative Traffic Control Devices for Improving Safety at Rural Short-term Maintenance Work Zones", Presentation at FHWA Workshop "Making Work Zones Better," 2003.

    This report describes tests of effectiveness of five traffic control devices: speed display trailers, radar drones, portable rumble strips, alternative (strong yellow green) worker vests, and fluorescent orange roll-up signs. Speed display trailers and SYG worker vests were found to be very effective in reducing speed in improving work zone visibility. The other devices were not considered effective.

18. Fors, C., Speed Measurement Laboratories, Inc., "Field Evaluation of SpeedGuard Radar Display Trailer", report to Saskatchewan Highways and Transportation, July 11, 2000.

19. Fors, C., Speed Measurement Laboratories, Inc., note to K. Mandzuk and P. Hunt, Saskatchewan Highways and Transportation, dated February 22, 2005.

20. Garber, N.J. and Patel, S.T., "Control of Vehicle Speeds in Temporary Traffic Control Zones (Work Zones) using Changeable Message Signs with Radar", Transportation Research Record #1509, pp 73-81, Transportation Research Board, 1995.

21. Garber, N.J. and Zhao, M., "Crash Characteristics at Work Zones", Virginia Transportation Research Council, Charlottesville, Virginia, May, 2002.

22. Graham, J.L., Paulsen, R.J., and Glennon, J.C., "Accident and Speed Studies in Construction Zones", Report No. FHWA-RD-77-80, Federal Highway Administration, Washington D.C., June, 1977.

23. **Guidelines for Reducing Speeds in Construction Work Zones**, Ministry of Transportation Ontario, August, 2001.

This document sets out guidelines and principles for reducing speeds in construction work zones on MTO projects. It draws heavily from the Ontario Traffic Manual Book 7 (Temporary Conditions), with some additional specific items for MTO use.

24. Ha, T. and Nemeth, Z.A., "Detailed Study of Accident Experience in Construction and Maintenance Zones", Transportation Research Record #1509, pp 38-45, Transportation Research Board, 1995.

25. "Hall Signs Introduces Construction Zone Advisory Sign", Traffic Management & Engineering, July 30, 2002.

The SpeedView CZ advisory sign available from Hall Signs, improves safety in temporary construction work zones by informing drivers of their speed, according to the manufacturer. The super-bright LED sign employs the approach only sensor traffic radar, which eliminates false speeds generated by opposing direction traffic. The sign is portable and easily set up by one person. It has no moving parts, giving maintenance-free service and long life. It can be used on a variety of vehicles, and comes with a pickup side rail adapter kit. The weatherproof radar unit mounted with a Workers Present caution sign are integrated into one, easily portable, 38 lb. package.

26. Hanscom, F.R., "Effectiveness of Changeable Message Signing at Freeway Construction Site Lane Closures", Transportation Research Record #844, pp 35-41, Transportation Research Board, 1982.

27. **Highway Traffic Act** (HTA), (using this name or a similar name), for each province and territory in Canada.

28. Hildebrand, E.D., Wilson, F.R., Copeland, J.J., "Speed Management Strategies for Rural Temporary Work Zones", Proceedings of the Canadian Multidisciplinary Road Safety Conference XIII, June, 2003.

This study reports on the evaluation of several safety device enhancements established at several work zone test sites: PVMSs, portable rubber rumble strips, transverse pavement markings, and fluorescent orange construction sign sheeting. Traffic speed measurements were used to determine device effectiveness. Findings were that in terms of speed reductions, the portable rubber rumble strips were most effective (mean speed reduction 6.9 km/h, 85$^{th}$ percentile speed reduction 9.5 km/h), followed by PVMSs (4.6 km/h and 5.7 km/h reductions), and transverse pavement markings (3.4 km/h and 3.8 km/h reductions. The fluorescent orange sign sheeting was not effective in reducing speeds. The report also summarizes some other speed management studies.

29. Hines, Margaret, "Judicial Enforcement of Variable Speed Limits", Legal Research Digest, National Cooperative Highway Research Program, March, 2002.

This report addresses the enforcement of variable speed limits, and includes a brief overview of use of variable speed limits in other countries as well as US states, 40 of which responded that they used variable speed limits. In order to enforce variable speed limits successfully, the following elements are necessary:

- Government creation of a speed limit
- Proof of speed limit where the violation occurred
- Proof that the speed limit was posted
- Proof that posted speed limit signs were visible to the driver
- Proof of special circumstances justifying a reduced speed limit
- Proof of speed in excess of limit.

Suggested language for a law enabling the enforcement of variable speed limits is included in the report.

30. Hunt, P., "Construction Fines, Questions and Answers", Saskatchewan Highways and Transportation, September, 2004.

31. Hunt, P., Saskatchewan Highways and Transportation, note dated February 22, 2005.

32. "IRD Speed Ranger Launched in Michigan", Traffic Management & Engineering, June 7, 2002.

This article reports on the IRD Speed Ranger System, used to advise motorists driving through a work zone on I-96 in Michigan of their actual and required speeds. The Speed Ranger Variable Speed Limit System is used in the approach area leading into construction zones, and has the capability to automatically change displayed speeds on a series of portable electronic message signs, based on current traffic, weather, and construction conditions, thereby providing safe and practical speed reduction through work zones. When traffic is light and road conditions are good, the speed limit will be higher, and when traffic is congested and/or road conditions are poor, the speed limit would be set lower. Speed Ranger consists of a series of portable trailers each with a self-contained power supply, traffic monitoring sensor, system controller and speed limit signing. Speed limits are determined based on traffic conditions measured by traffic sensors.

33. **Intelligent Transportation Systems in Work Zones: A Cross-cutting Study**, ITS Joint Program Office, FHWA, November, 2002

This report summarizes the results of using ITS in four construction work zones, one each in Springfield, Illinois; Lansing, Michigan; Albuquerque, New Mexico; and West Memphis, Arkansas. Benefits included reduced traffic queues, fewer traffic citations, increased safety (fewer collisions, including fewer secondary collisions), reduced construction time (one season rather than two), more effective communications with local agencies, quicker incident response and clearance time, better maintenance of traffic flow, and good public reaction. Key strategies for success were identified as:

- address communications early;
- allow start-up time when deploying a system;
- use a proactive approach for building public awareness;
- deliver accurate information to the public;
- involve a wide range of stakeholder agencies;
- carefully consider how to set up automated information delivery and sharing with other agencies.

34. Jackels, J. and Brannon, D., “Work Zone Speed Limit Study on Rural I-35 in Minnesota”, Minnesota Department of Transportation, Office of Traffic Engineering, St. Paul, Minnesota, November, 1988.

35. Kemper, W.J., Lum, H.S., and Tignor, S.C., “The Safety of Narrow Lanes for Traffic Control at Construction Sites”, Institute of Transportation Engineers Journal, 10(1), pp 33-38, January, 1985.

36. Klatt, Michael P., “ITS and Traffic Control”, Presentation at FHWA Workshop “Making Work Zones Better”, 2003.

This presentation outlines the Automated Information Management System for work zones, a system developed by United Rentals Highway Technologies, which appears to do an effective job of integrating information from various sources in work zones, and makes it readily available for management action. ITS integration into traffic control is intended to integrate technologies (VMS, HAR, cameras, sensors and software) to support operations by providing accurate, timely, and pertinent information for use by properly trained information decision makers. Integration challenges are outlined.

37. Kratofil, Joseph A. Jr., “A Benefit-Cost Analysis for the Use of Intelligent Transportation Systems Technology for Temporary Construction Zone Traffic Management on the I-496 Reconstruction in Lansing, Michigan”, M.Sc. Paper, Central Michigan University, March, 2001.

This report describes the benefit-cost analysis of temporary use of ITS technologies on a long-duration (one season) construction zone on Interstate Highway I-496 in Michigan. The most work-intensive section of the freeway was closed for the construction. Benefits evaluated include anticipated reductions in accidents, travel time, environmental impacts and energy consumption. Additional benefits in terms of customer satisfaction, productivity and other factors may exist, but could not be quantified using available data. The evaluation framework used was that developed by Gillen, Li, Dahlgren, and Chang (1999), which sums the benefits and costs of all perspectives into a single, total value. Benefits are: safety, mobility, efficiency, productivity, energy & environment, and customer satisfaction. Unfortunately, the ITS technologies used are not described, but seem to have been directed to traveller information on route detours and incidents. The report also contains a useful literature review on benefit-cost evaluation techniques.

38. “Lane Merger System Proved Effective in Work Zones”, Traffic Management & Engineering, May 29, 2003.

This article reports on International Road Dynamics Inc.'s Dynamic Lane Merge system, which has proven to be a beneficial tool to improve safety and efficiency in highway work zones, according to a two year evaluation of the system, recently completed by Wayne State University in Michigan. The Dynamic Lane Merge encourages drivers to merge early as they approach a lane closure, while traffic is still flowing smoothly and there are sufficient openings for a safe lane change. A "no-passing" zone is created by a series of trailer mounted signs with flashers. Traffic sensors determine vehicle congestion, and the size of the zone is adjusted according to current traffic conditions to make it relevant to drivers. The evaluation concluded that the Dynamic Lane Merge system is effective in reducing peak period travel time (by over 30%), reducing number and duration of stops, and reducing aggressive driver manoeuvres (late merges) during peak hours (by 50-75%).

39. Leibel, D.J., and Bowron, D.J., "Use of Optical Speed Bars to Reduce Accidents – The Calgary Experience", Proceedings of the International Transport Congress, pp A27-A38, Ottawa, Canada, 1984.

40. **Maintenance & Construction Operations User Service (An Addendum to the ITS Program Plan),** U.S. DOT, prepared by SAIC & Transcore, January 26, 2001

    This document addresses Maintenance & Construction Operations (MCO) User Service which involve ITS technologies, and improve efficiency and safety. It describes the services it should provide, based on stakeholder needs, the operational concepts it should follow, the technologies that could be used, potential costs and benefits, and the organizational roles/responsibilities to make it happen. The focus is on four functional areas: (1) Maintenance Vehicle Fleet Management; (2) Roadway Management; (3) Work Zone Management and Safety; and (4) Roadway Maintenance Conditions and Work Plan Dissemination. There is much useful information on ITS for MCO, and a good description of stakeholder needs. All four functional areas are worth pursuing. In the third one (WZ Management & Safety), emphasis is on WZ information (to reduce the duration and frequency of work zones, and for better planning) and smart work zones (information on volume, occupancy, speed, headway, recommended speed; work zone intrusion detectors; traveller information messages; advanced warning to motorists of WZs; better set-up procedures; speed enforcement; personal worker warning devices/systems).

41. **Manual of Uniform Traffic Control Devices for Canada**, Transportation Association of Canada, Ottawa, Ontario, 1998 and subsequent revisions.

42. **Maximum 60 km/h When Passing Workers Sign**, Policy/Standard No. 900-C-7, Manitoba Transportation and Government Services, March 1, 2002.

43. Maze, T., Kamyab, A., and Schrock, S., "Evaluation of Work Zone Speed Reduction Measures", Project Report 99-44, Centre for Transportation Research and Education, Iowa State University, Ames, Iowa, April, 2000.

    This report includes a literature review which examined the current speed reduction practices at work zones ranging from posting regulatory and advisory speed limit signs to using the latest radar technologies to reduce speeds at work zones. The literature review chapter concluded that flagging and police enforcement speed reduction strategies have had very positive impacts in reducing work zone speeds. They are, however, labor intensive and can become costly with long-term use. Due to limited resources, the use of police officers at work zones is infrequent by many agencies. The impracticality of the extensive use of law enforcement at work zones may result in a short-term impact on motorists. Replacing these strategies with innovative technologies, such as robotic flaggers and photo-radar enforcement machines, may be practical, more cost-effective solutions. Other practices included: reduced lane width, drone radar (a device used to trigger radar detectors), speed monitoring display, rumble strips, optical speed bars, and various safety alert systems. A survey of U.S. states indicated that the most effective practices were regulatory speed limit signs together with police enforcement, followed by speed monitoring displays.

44. McCoy, P.T., Bonneson, J.A., and Kollbaum, J.A., “Speed Reduction Effects of Speed Monitoring Displays with Radar in Work Zones on Interstate Highways”, Transportation Research Record #1509, pp 65-72, Transportation Research Board, 1995.

45. “MDOT Aim to Improve Ride in Work Zones”, Traffic Management & Engineering, July 12, 2002.

This article reports on various ITS and other innovative applications being tested and used in Michigan DOT construction zones. These applications include:

- transverse orange and white temporary rumble strips on I-94, to warn drivers to slow down;
- moveable barrier walls on I-75;
- advanced portable changeable message signs, with radar, microwave sensors and wireless communication, on I-75, to alert drivers if their vehicle speed is too high;
- portable changeable message signs to electronically change the speed limit on I-96, based on traffic volume, traffic speed and weather conditions, and workers being present.
- a real-time information system and a dynamic lane-merge system to help improve traffic flow through work zones;
- use of microwave sensors, wireless communications, and portable changeable message signs, to tell motorists on I-75 how many minutes it will take them to reach the end of the work zone;
- a dynamic lane-merge system on I-94 to improve traffic flow. The system uses a series of five trailers with flashing lights and signs that say "Left Lane Do Not Pass When Flashing." The purpose of the system is to have motorists merge early enough as they approach the work zone to prevent the backups that often occur when drivers wait until the last minute to merge. MDOT has used the system for two years at locations where two lanes have been reduced to one. This year's test will determine the system's effectiveness when taking three lanes down to two. Prior experience with the system has proven very effective, often reducing travel times through a work zone significantly.

46. **Meeting the Customer's Needs for Mobility and Safety During Construction and Maintenance Operations**, Office of Program Quality Coordination, FHWA, September 1998.

This is a substantial report outlining the state of the practice and the state of the art in reducing delays and enhancing safety in work zones. It lists the best practices identified by transportation agencies to minimize delay and improve safety in construction and maintenance operations, and contains many conclusions and recommendations.

47. Meyer, E., “A Literature Review of Perceptual Countermeasures to Speeding”, Report to Kansas Department of Transportation, July, 2000.

48. Meyer, Eric, “Evaluation of Data from Test Application of Optical Speed Bars to Highway Work Zones”, Final Report, Project K-TRAN-KU-00-4, University of Kansas, July, 2000.

Optical speed bars were tested in work zones in Kansas, and evaluated as to their effectiveness in reducing speeds. The pattern of the optical speed bars was found to cause reductions in mean and 85$^{th}$ percentile speeds, as well as in standard deviations.

Changes in speeds were small, and resulted from both warning effects and perceptual effects. The warning effects persisted downstream of the pattern while the perceptual effects did not, as drivers increased their speed once out of the area with graduating spacing. Reductions in speed variations also persisted downstream of the pattern. The work zone pattern did not appear to have any effect on speed or speed variations.

49. Meyer, E., “Evaluation of Orange Removable Rumble Strips for Highway Work Zones”, Transportation Research Record #1715, pp 36-42, 2000.

50. Migletz, J., Graham, J. L., Anderson, I. B., Harwood, D. W., and Bauer, K. M., “Work Zone Speed Limit Procedure”, Transportation Research Record 1657, Transportation Research Board, 1999

This report provides the data and analysis demonstrating that both speed variance and fatal and injury collision rates in work zones are lowest for posted speed reductions of 10 mph (16 km/h), and increase with larger posted speed reductions. The report also validates the results of NCHRP project 3-41, and recommends use of the procedure outlined there (Reference 51).

51. Migletz, J., Graham, J.L., and Harwood, D.W., “Procedure for Determining Work Zone Speed Limits”, NCHRP Research Results Digest, No. 192, (NCHRP Project 3-41), September, 1996.

This comprehensive paper summarizes the results of a literature review on this subject, provides information on the relation of speed and speed variance to traffic collisions, discusses regulatory and advisory speed limits, and their effects on vehicle speeds, and on safety. It also surveys U.S. state work zone speed limit policies and guidelines and summarizes them in three categories ((1) states that avoid reducing work zone speed limits whenever possible; (2) states with “blanket” reduced work zone speed limits; and (3) states that reduce work zone speed limits based on an identified procedure or set of factors). The authors recommend a procedure for determining work zone speed limits, which they be recommend be included in the U.S. Manual on Uniform Traffic Control Devices.

52. Milliken, J.G., Chairman, and Committee for Guidance on Setting and Enforcing Speed Limits, **Managing Speed: Review of Current Practice for Setting and Enforcing Speed Limits**, Special Report 254, Transportation Research Board, Washington D.C., 1998

While not directed specifically at speed management in work zones, many principles for setting and enforcing speed limits included in this report also apply to a greater or lesser degree to work zones. This is a comprehensive report, addressing: effects of speed; managing speeds: speed limits; speed enforcement and adjudication; other speed management strategies; and guidance on setting and enforcing speed limits. An appendix also covers automated technologies for setting and enforcing speed limits.

The report notes that targeted enforcement combined with focused publicity campaigns can boost the effectiveness of traditional enforcement methods. Automated enforcement, particularly photo radar, has been shown to be efficient and effective where it has been used for speed control, particularly on high-volume arterials. Photo radar can also be coupled with variable speed limit systems on urban Interstate highways where high traffic volumes can make traditional enforcement methods hazardous. Redesigning roads to achieve greater congruity between driver perceptions of appropriate travel speeds and the cues provided by the road itself (e.g., narrowing lanes) may also influence motorists' speeds. A proper mix of these approaches can enable police to leverage their resources and deploy them efficiently. Traffic court judges are also important participants in effective speed enforcement. They may overturn speeding violations if they think the speed limits are unreasonable or reduce fines if they believe the sanctions are too harsh. If judges are lenient in their treatment of speeding offenses and routinely dismiss speeding citations, the incentive for the police to enforce the speed limits may be reduced. Thus it is important that traffic court judges—as well as the police and motorists—perceive that speed limits are reasonable and enforceable.

53. "Mobile Highway Advisory Radio", Midwest States Smart Work Zone Deployment Initiative, 1999

This report describes the use of mobile HAR in maintenance work zones (zone painting operations), in Kansas. The mobile HAR is a radio transmitter that is mounted on a trailer, allowing it to be easily moved and set up for short time periods, with an accompanying sign instructing drivers to tune their radios to the appropriate station for important information. Possible uses include, work zone, moving maintenance operations, and traffic control during special events.

54. Morgan, Rickey, "Temporary Rumble Strips", FHWA/NY/SP-03/140, Special Report 140, Transportation Research & Development Bureau, New York State Department of Transportation, July, 2003.

This report describes a literature review of the use of temporary rumble strips in work zones (both construction and maintenance), as well as tests of various kinds of temporary rumble strips in New York work zones. Benefits and challenges of installing temporary rumble strips in work zones are described; however, the report does not indicate how effective the strips were in reducing motorists' speeds. Also, most of the applications, both in New York and in the literature, were on relatively low speed roads (speed limit up to about 50-55 mph), not on freeways. Appendices review the reaction of contractors and NYSDOT maintenance staff, the majority of whom felt that the rumble strips were effective and beneficial.

55. "Multiple Radar Speed Displays", Nebraska Department of Transportation.

The long-term effects of multiple (3) speed monitoring displays (SMD) on speed reduction were tested over a period of five weeks on a long-duration construction project on Interstate I-80 in Nebraska. Vehicle speeds were displayed on a panel with 24-inch LED numerals. The message YOUR SPEED was mounted on the trailer beneath the variable speed display, and a speed limit sign was mounted above the display. The road section was a four-lane divided interstate highway, located between two relatively long sections operated as a two-lane two-way roadway. Because of the opportunity for overtaking on the test section, speed-limit compliance was low. Normal regulatory posted speed was 75 mph, but the speed limit in the study area was 55 mph. The signs were not supplemented with police presence or enforcement during the test. The radar speed displays reduced mean speed by 3 to 4 mph (5-7 km/h), with a 2 to 7 mph (3-11 km/h) reduction in 85th percentile speed, over the test period. There was a 20 to 40 point increase in the percentage of vehicles complying with the speed limit. About 22% of the traffic were commuters; the truck percentage was 21%. Several other references are cited, which indicate similar results. The report has a good list of other references.

56. "News versus Queues", ITS International, March/April, 2001.

This article reports on the use of an EIS-developed RTMS (remote traffic microwave sensor) multi-zone radar sensor, together with RF modems and portable variable message signs (PVMSs) to warn of queues ahead. The RTMS station sends the resulting information back up the road to a tiny controller. This activates flashing lights on a strategically-located warning sign which alerts drivers to 'PREPARE TO STOP', when the end of a queue reaches the location of the RTMS sensor station. This is designed as a local real-time traffic-monitoring solution for permanent or temporary installations. Up to 16 warning-triggering events can be defined by the user. These are based on measurement of traffic volume, occupancy and speed from up to eight RTMS stations, each of which is capable of measuring traffic in up to eight separate lanes. The combination of remote radar detectors with RF modems makes installation possible without the need for lane closures. The intelligence of the system allows fail-safe operation. Work zone safety systems are another important application of the system. Recent studies by the US Department of Transportation (USDOT)'s Federal Highway Administration (FHWA) have shown that installing them can save lives. The PVMS messages typically warn drivers to lower their speed when it is too high, or to merge into a single lane. Other systems can reduce drivers' frustration by providing a reliable prediction of the travel time through the remaining stretch of the work zone area still lying ahead. One of the most important criteria for a successful work zone system is the ease and speed of redeployment of the measurement stations as the zone moves on to cover the next road segment. Experience indicated a ten-minute set-up and calibration period for a three-lane road. www.rtms-by-eis.com

57. **Occupational Health & Safety Act (OHSA) and Regulations for Construction Projects**, Revised Statutes of Ontario, November, 2001.

58. **Ontario Traffic Manual, Book 7 (Temporary Conditions)**, Traffic Office, Ministry of Transportation Ontario, March 2001 (published by University of Toronto Press, Toronto, Ontario).

This manual is a comprehensive guide to all aspects of work zone safety and traffic control. It includes the following material on speed management in work zones (section 1.11).

"It has generally been found that control of traffic speeds by imposing unwarranted regulatory speed limits has not been very effective. The majority of drivers disregard posted speed limits if the construction/ maintenance activities or hazards encountered are not severe enough to warrant such lower speeds, or if there is no visible sign of work activity. The travelled way through the work zone should be designed at a design speed that is equal to or as close as possible to that of the approaches to the work zone.

There are many types of maintenance and construction projects where a reduction of the normal speed limit is not required. Work zone speed limit reductions should be avoided, where possible, where all work activities are located on shoulder or roadside areas and

in work zones where no work activities are under way. A basic guideline to follow is to attempt to reduce speeds only if there is a good reason for it.

Experience has shown that it is difficult to achieve an average speed reduction of more than 15 km/h. For this reason, posted speed limits in construction zones should not be more than 20 km/h below the normal posted speed limit for that road section, except where required by restricted geometrics or other work zone features that cannot be modified.

Experience has also shown that speed reductions are more likely to be obeyed by the motorist if they are perceived as being necessary. If there is a good reason for reducing speed which may not be readily apparent to the motorist, then he/she should be informed of the reason for speed reduction through advance notice, including advance signing, possibly repeated, and other means, such as highway advisory radio. In some cases, advisory speed limit signs (orange and black) together with narrower roadways or lanes through the work site may be more effective in reducing traffic speeds than the posting of legal speed limit controls. All reduced speed zones should be used in a flexible and up-to-date manner to reflect the changing conditions within the construction or maintenance zone.

Measures which have proven to be effective in helping to manage speeds in work zones include:

- Police presence and enforcement in the work zone has been shown in some locations to reduce not only the 85th percentile speeds, but also the speed variance. In some locations, police presence has been shown to increase speed limit compliance by 15 percent in work zones where speed limits were not reduced. Several studies have shown that police presence has resulted in significant collision reductions. In general, most speed reduction measures are unlikely to be effective unless supported by some police enforcement.

- Measurement of drivers' speed by means of radar, and display of the measured speeds on variable message signs (VMSs). The use of radar-controlled speed signs has been shown to reduce 85th percentile speeds an additional 4 to 8 km/h over the reduction caused by static signs. The effect of a single VMS may be reduced with distance from the sign, but the reductions can often be sustained with two or more VMSs. This measure will have lasting effectiveness only if supported by periodic police enforcement.

- Use of pilot vehicles, pace vehicles or rolling closures (See section 2.5) for speed reductions in specific periods of time or for specific work operations.

Traffic enforcement plans (formal or informal) in work zones should be developed jointly by cooperation between the road authority and the police.

For M.T.O. construction projects requiring traffic control, construction speed zones may be established, as directed by MTO. The contractor does not have the authority to establish such zones… If construction speed zones with enforceable speed limits are to be established on provincial highways, it is an HTA requirement first to establish a designated construction zone and to install Construction Zone Begins and Ends signs (Rb-90A and Rb-90B, formerly TC-41A and TC-41B) in advance of and beyond the

construction speed zone. See Typical Layouts TL-3 and TL-4 in OTM Book 7. Both regulatory and advisory speed limit signs can be used on different portions of the same contract; however, regulatory speed limit signs shall be installed only when the appropriate police authority has been informed, and intends to provide enforcement as outlined in the traffic enforcement plan. Otherwise, only advisory signs should be used and all existing regulatory signs within the construction speed zone must be covered or removed for the duration of the construction project, or until agreement on enforcement can be reached with the police authority. Reduced speed limit signs should only be used either:

- when work activity is actually occurring, and should be covered or removed when work is suspended or completed; or

- when reduced or restricted design situations, such as narrow lanes, detours, diversions, or cross-overs, remain, even though work is suspended.

For municipal construction projects requiring traffic control, construction speed zones may also be established. At present, the establishment of municipal construction speed zones, with enforceable regulatory reduced speed limit signs, must be done by municipal by-law. Advisory speed limit signs may be posted without requiring a by-law."

59. “Optimizing the System, Saving Lives, Saving Time”, American Association of State Highway & Transportation Officials (AASHTO), 2004.

60. Parker, M.R., Jr., “Synthesis of Speed Zoning Practices”, Report No. FHWA/RD-85/096, Federal Highway Administration, Washington D.C., July, 1985.

61. Peden, M., Scurfield, R., Sleet, D., Mohan, D., Hyder, A., Jarawan, E., Mathers, C., **World Report on Road Traffic Injury Prevention**, World Health Organization, Geneva, 2004

62. Pigman, J.G., and Agent, K.R., “An Analysis of Accidents in Construction and Maintenance Work Zones”, Kentucky Transportation Research Program, Report #UKTRP-88-13, Lexington, Kentucky, June, 1988.

63. Poynton, John, **Controlled Highways**, Presentation, Highway Agency, UK

This report describes on a system of traffic control, including mandatory variable speed limits, on the M25 motorway near London, England. Features of a controlled motorway include mandatory motorway signals, automatic speed limit enforcement (radar speed measurement, recorded by cameras), and the automatic control system MIDAS (Motorway Incident Detection and Automatic Signaling System). The police have a Camera Detected Offences Unit.

64. Pratt, Stephanie G., Fosbroke, David F., Marsh, Suzanne M., **Building Safer Highway Work Zones: Measures to Prevent Worker Injuries from Vehicles and Equipment, DHHS/NIOSH Pub. No. 2001-128,** National Institute for Occupational Safety and Health, 2001.

This extensive report describes recommended Injury Prevention Measures for work zones. Recommendations are made in a number of areas, including: work zone layout, use of temporary traffic control devices, motorist education and speed enforcement, flaggers, high visibility apparel, illumination of the work zone, developing internal traffic control plans, implementing internal traffic control plans, accountability and coordination at the work site, equipment operation and maintenance, safe equipment operation around workers on foot, training and certification, changes in the contracting process, laboratory and field research needs, and data and record keeping. There are several recommendations that address ITS in work zones. The report includes many detailed recommendations, an extensive bibliography, a list of useful web sites, and detailed descriptions of 29 collision/injury case studies from around the US.

65. **Request for Temporary Construction Speed Zone – 100 Series Highways**, Nova Scotia Transportation and Public Works.

66. Richards, S.H., and Dudek, C.L., "Implementation of Work Zone Speed Control Measures", Transportation Research Record #1086, pp 36-42, Transportation Research Board, 1986.

67. Richards, S.H., Falkner, M.J.S., and Dudek, C.L., "Traffic Management During Freeway Reconstruction and in Rural Work Zones", Report No. 263-7F, Texas Transportation Institute, College Station, Texas, October, 1982.

68. Richards, S.H. et al, "Improvements and New Concepts for Traffic Control in Work Zones, Volume Speed Control in Work Zones", Report No. FHWA/RD-85/037, Federal Highway Administration, Washington D.C., September, 1985.

69. Robinson, Mark, "Examples of Variable Speed Limit Applications", Presentation at Speed Management Issues Workshop, Transportation Research Board Annual Meeting, 2000.

This PowerPoint presentation briefly summarizes variable speed applications in the US (Arizona, Colorado, Michigan, Minnesota, Nevada, New Jersey, New Mexico, Oregon, Washington) and abroad (Australia, Finland, France, Germany, Netherlands, UK). Most of these were permanent installations, intended for use in advising motorists of appropriate speeds in the event of congestion, poor weather or visibility, or steep downgrades. None of those listed was used for managing speeds in work zones.

70. **Speed Limits in Construction and Maintenance Areas**, Policy/Standard No. 900-C-6, Manitoba Transportation and Government Services, March 15, 2002.

71. Steinke, Donald P., et al, "Methods and Procedures to Reduce Motorist Delays in European Work Zones", Federal Highway Administration, International Technology Exchange Program, October, 2003.

This report summarizes the findings of a U.S. scanning tour through Germany, the Netherlands, Belgium, Scotland and France, to look at how these countries manage traffic through temporary work zones, both construction and maintenance. Highway agencies in those countries view the work zone as a marketplace, with drivers as "customers" who should be inconvenienced as little as possible. Emphasis is placed on developing a good communications plan and using ITS technologies to keep drivers informed about roadwork projects. Scanning team recommendations include: shortening contract times; improving communications with motorists; adopting a coordinated policy, planning, and programming approach to work zone planning and operations; possibly reducing lane widths; designing for future maintenance; and evaluating the use of yellow markings in work zones. (www.international.fhwa.dot.gov)

72. Stidger, R.W., "How MnDOT Sets Speed Limits for Safety", Better Roads, November, 2003.

73. "Study Tests Devices to Improve Work Zone Safety", Texas Transportation Institute, January 11, 2002.

This article reports on tests of various traffic control devices in short-term work zones in Texas, to improve work zone conspicuity and to reduce driver speeds. Short-term rural work zones present special challenges in providing safe conditions for work crews. Maintenance crews in short-term rural work zones have a frightening job. They must perform their repair work while on constant alert for drivers who do not regard or notice the warning signs to slow down. In 1999, 372 deaths occurred in work zones in Texas, compared to 342 in 1998, and 209 in 1997. This study attempted to identify devices that would better alert drivers to work zone conditions and motivate them to change the way they drive within the work zone. An effective traffic control device in a short-term work zone must be easy to set up and remove without compromising the safety of the workers. Because protective concrete barriers are not used, the key to successful traffic control is to gain the driver's attention by using devices with high visibility. This study examined a total of nine devices by setting them up in short-term work zones and monitoring their effectiveness at slowing traffic. Two of these devices showed promise for improving work zone safety conditions: (a) The speed display trailer was the most effective traffic control device tested to control speed in a work zone. Drivers slowed an average of 5 mph in the work zone after passing a speed display trailer. The key advantage of these trailers is that they are easy to set up and dependable. They also have a 130 dB siren that can be activated by vehicles traveling over a preset speed. The siren warns the maintenance crew if a vehicle is approaching at a very high rate of speed; and (b) Fluorescent yellow-green vests and hard hat covers greatly improved worker visibility. These devices are more visible against typical work zone backgrounds and have a greater luminance than the traditional orange garments. The yellow-green safety vests were shown to greatly increase the visibility of the flaggers and maintenance crews.

74. Swanlund, Mark, **Portable Changeable Message Sign (PCMS) Handbook**, Report FHWA-RD-03-066, FHWA, Washington D.C., 2003.

This report gives us a useful overview of the types and applications of portable changeable message signs (PCMS in US terminology, PVMS in ours), including sign technology and size, message selection and display (normal maximum 2 phases, up to 3 phases if necessary), acceptable and unacceptable abbreviations, placement, safety, need for credibility, and checklist for installation.

75. "Temporary Traffic Control Guideline: Work Zone Speed Reductions", City of Edmonton Traffic Operations Branch, September, 2004.

This documents sets out guidelines for work zone speed reductions in the City of Edmonton, including contractor responsibilities, need for City approvals, and stipulation that unless otherwise approved, all work zones speed reductions will be Temporary Speed Zones (only in effect when workers are present) rather than continuous Construction Speed Zones. Signing to be used is also included.

76. **Traffic Accommodation in Work Zones**, 2nd Edition, Alberta Infrastructure and Transportation, May, 2001.

77. **Traffic Accommodation in Work Zones, Urban Areas**, 1st Edition, Alberta Infrastructure and Transportation, May, 2003.

78. **Traffic Control Device Manual for Work Zones**, (Office Edition), Saskatchewan Highways and Transportation, 2001, and Field Edition, 2003.

79. **Traffic Control Manual for Roadway Work Operations**, (Field Edition) Newfoundland and Labrador Department of Works, Services and Transportation, 1999.

80. **Traffic Control Manual for Work on Roadways**, British Columbia Ministry of Transportation, Consolidated Office Edition, 1999.

81. Ullman, Gerald L., Fontaine, Michael D, Schrock, Stephen D., "Creating Enforcement-friendly Work Zones", FHWA Workshop "Making Work Zones Better", 2003.

This paper summarizes some of the difficulties of speed enforcement in work zones and outlines how to make work zones more enforcement-friendly. These approaches include:

- Improved coordination between transportation and enforcement agencies throughout the planning, design, and work phases;
  - Special enforcement staff to enforce work zone safety and OHSA requirements (NJ)
- Technologies to improve work zone enforceability;
  - Flashing lights and "Workers Present" sign when workers present (Tennessee)
  - Automated speed enforcement (e.g., photo radar) for real-time enforcement
- Designs to improve work zone enforceability.
  - Shoulders and enforcement pull-out areas.

82. Ullman, G.L., Carlson, P.J., Trout, N.D., and Parham, J.A., "Work Zone-related Traffic Legislation: A Review of National Practices and Effectiveness", Texas Transportation Institute Report 1720-1, September, 1997.

83. Ullman, G.L. Carlson, P.J., Trout, N.D., "Work Zone Traffic Legislation in Texas", Texas Transportation Institute Report FHWA/TX-99/1720-3, March, 1999.

84. Wang, J., Dixon, K.K., and Jared, D., "Evaluation of Speed Reduction Strategies for Highway Work Zones", Proceedings of the 82nd Annual Meeting of the Transportation Research Board, No. 2003-2099, Washington D.C., 2002.

This paper reports on tests done in Georgia of three trial measures to reduce work zone speeds: (a) fluorescent microprismatic sheeting on standard work zone static signs; (b) innovative message signs (e.g., "Slow Down, My Dad Worker Here"), and (c) a variable message sign with radar. Test results indicated that:

(a) fluorescent sheeting on work zone static signs had a minor effect (1-3 mph) on work zone speeds, but the novelty effect wore off after several weeks;
(b) innovative message signs had a minor effect (0.2 to 1.8 mph) on daytime work zone speeds at one site and no effect at another; no effect at nighttime; and possibly a retained effect after several weeks.
(c) variable message signs with radar provided significant reductions in speed (7-8 mph) and in speed variance; there appeared to be no novelty effect and the speed reductions were sustained through the period of the test.

85. Wang, J., Hughes, W.E., Council, F.M., Paniati, J.F., "Investigation of Highway Work Zone Crashes: What We Know and What We Don't Know", Transportation Research Record #1529, pp 54-62, Transportation Research Board, 1996.

86. Warren, Davey, "Restoring Credibility to Speed Setting: Engineering, Enforcement & Educational Issues", FHWA, available at FHWA web site (http://safety.fhwa.dot.gov/programs/speedmont.htm).

The report summarizes the findings of workshops that brought together critical engineering, enforcement, and judiciary personnel to discuss the multi-disciplinary aspects of managing speed. A "planning guide" for others who want to sponsor speed management workshops is under development.

87. Warren, Davey, "Variable Speed Limits (VSL) in Work Zones Demonstration Project Underway", FHWA Safety Activities, FHWA web site, Jan/Feb 2003.

VSL demonstrations in work zones are getting underway in Maryland, Michigan, and Virginia. VSL systems use input regarding traffic speed and other variables to determine and post an appropriate speed limit that changes in real time. The Maryland demonstration project includes extensive before and after evaluations, including speed profiles and driver performance analyses. Contact: Davey Warren, FHWA, 202-493-3318. (http://safety.fhwa.dot.gov)

88. Warren, Davey, and Alicandri, Elizabeth, "Managing Speed in Work Zones: Variable Speed Limit Systems", Presentation at FHWA Workshop "Making Work Zones Better", Washington D.C., 2003.

This paper outlines the difficulty of controlling speeds in work zones and outlines the constrained scope for managing speeds. It describes the use of variable speed limits in work zones, which are posted on changeable message signs and are varied frequently in accordance with prevailing volume and speed conditions. Varying the speed limits in work zones as conditions change holds substantial promise in restoring the credibility of work zone speed limits, resulting in greater speed compliance, improved safety and smoother traffic flow. Operational tests in Maryland, Michigan, and Virginia are described. These tests are mostly but not exclusively in longer duration construction projects.

89. Wiley, C.C., et al, "Effect of Speed Limit Signs on Vehicular Speeds", Department of Civil Engineering, University of Illinois, September, 1949.

90. "Wizard CB Alert System", Midwest States Smart Work Zone Deployment Initiative, 1999.

This report describes the results of a CB announcement initiative in Iowa to provide truck drivers advance notice of a zone striping operation ahead. After some fine-tuning, the application was considered very effective.

91. **Work Area Traffic Control Manual**, Maintenance and Traffic Branch, New Brunswick Department of Transportation, Fredericton, New Brunswick, 1994.

92. **Work Zone Operations: Best Practices Guidebook**, Publication No. FHWA-OP-00-010, FHWA, available at FHWA web site, April 2000.

This is a comprehensive guide to best practices in work zone operations implemented by various US states. The best practices included are descriptive, not prescriptive. That is, they describe approaches used by transportation agencies, along with contact information. The best practices were organized into 11 major groupings:

- Policy/procedures
- Public Relations/Education/Outreach
- Prediction Modelling and Analysis
- Planning & Programming
- Project Development/Design
- Contracting and Bidding
- Specs, Materials, Methods and Practices
- Traveller and Traffic Information
- Enforcement
- ITS and Innovative Technology
- Evaluation & Feedback

The report also contains a number of links to other related web sites.

93. **Work Zone Traffic Control Manual**, Manitoba Transportation and Government Services, March, 2002.

**Useful Web Sites**

94. Information on European practices: www.information.fhwa.dot.gov

95. Transport Canada web site: www.tc.gc.ca/roadsafety

96. U.S. Bureau of Transportation Statistics web site: www.transtats.bts.gov

97. U.S. FHWA Best Practices web site: www.fhwa.dot.gov/reports/bestprac.pdf
**(= Meeting the Customer's Needs for Mobility & Safety in Maintenance & Construction Work Zones)**

98. U.S. FHWA Safety web site:
www.safety.fhwa.dot.gov/fourthlevel/pro_res_wzs_facts.htm

99. U.S. National Institute of Occupational Safety and Health (NIOSH) web site:
www.cdc.gov/niosh/homepage.html

100. U.S. National Clearinghouse for Work Zone Safety at Texas A&M University:
http://wzsafety.tamu.edu

101. http://www.safety.dot.gov

102. http://wzsafety.tamu.edu/searches/practices.stm

103. http://wzsafety.tamu.edu/searches/contacts.stm

104. http://www.fhwa.dot.gov/workzones