DRAFT PROJECT REPORT RPN2600

IPV Guidance Supporting Documentation

C Reeves and J Manning

Prepared for: Highways Agency,
Project Ref: 11112365

Quality approved:
B Lawton (Project Manager)
I Rillie (Technical Referee)

© Transport Research Laboratory 2013
Disclaimer

This report has been produced by the Transport Research Laboratory under a contract with Highways Agency. Any views expressed in this report are not necessarily those of Highways Agency.

The information contained herein is the property of TRL Limited and does not necessarily reflect the views or policies of the customer for whom this report was prepared. Whilst every effort has been made to ensure that the matter presented in this report is relevant, accurate and up-to-date, TRL Limited cannot accept any liability for any error or omission, or reliance on part or all of the content in another context.

When purchased in hard copy, this publication is printed on paper that is FSC (Forest Stewardship Council) and TCF (Totally Chlorine Free) registered.
## Contents

1 Introduction  

2 Dual or Single Vehicle Working  
   2.1 Dual vehicle working  
   2.2 Single vehicle working  

3 Overview of Existing IPV Usage Guidance for TTM Operations  
   3.1 Traffic Signs Manual Chapter 8  
      3.1.1 Static works  
      3.1.2 Mobile lane closures  
   3.2 Contractor policies  
      3.2.1 IPV assessment toolkit  
      3.2.2 Network Map  
   3.3 Summary  

4 International Evaluation of IPV Usage  
   4.1 United States of America  
   4.2 Ontario, Canada  
   4.3 Queensland, Australia  
   4.4 New Zealand  
   4.5 Dubai  
   4.6 Norway  
   4.7 Belgium  
   4.8 Summary  

5 Risk Evaluation  
   5.1 Core parameters  
      5.1.1 Likelihood of collision  
      5.1.2 Number of injured operatives  
      5.1.3 Severity of collision  
   5.2 Additional risk factors  
      5.2.1 Obscuration  
      5.2.2 Manoeuvrability  
   5.3 MIRi Index  
   5.4 Summary  

6 Collision Modelling  
   6.1 Modelling software and parameters  
   6.2 IPV collision involving HGV
6.3 IPV collision involving a passenger car 37
6.4 Conclusions 40
6.5 Recommendations 40

7 Operational Factors 42
7.1 Site characteristics 42
  7.1.1 Number of lanes 42
  7.1.2 Lane(s) closed 42
  7.1.3 Safe taper locations 43
  7.1.4 Hard shoulder presence 43
  7.1.5 Presence of VMS/infrastructure availability 44
  7.1.6 Street lighting 44
  7.1.7 Road geometry/topography 45
  7.1.8 Presence of junctions 47

7.2 Traffic characteristics 50
  7.2.1 Flow 50
  7.2.2 Number of HGVs 50
  7.2.3 Lane occupancy 51
  7.2.4 Speed of approaching vehicles 51
  7.2.5 Issues with compliance of signs or signals 51

7.3 Operational considerations 52
  7.3.1 Availability of escape route 52
  7.3.2 Weather/visibility 53
  7.3.3 Time of day 53
  7.3.4 Vehicle being used 54
  7.3.5 Advance signing method 54
  7.3.6 Carriageway crossings 56
  7.3.7 Taper deployment method 56
  7.3.8 Longitudinal method 62
  7.3.9 Confirmation of Setting of Variable Signs and Signals 63
  7.3.10 Communications with the Regional Control Centres 63

7.4 Specific considerations for Smart Motorways 63
7.5 Summary 64

8 Conclusions and Recommendations 65

Glossary 68

References 70

Appendix A Obscuration Photos 71
1 Introduction

The Highways Agency (HA) set out its overarching Aiming for Zero (AfZ) Strategy in April 2010. The AfZ Road Worker Safety Strategy has an overall aim of significantly reducing health and safety risks to road workers, by eliminating road worker fatalities and serious injuries. More recently, the Highways Agency has outlined the third target in this programme: to reduce risks to road workers associated with works on, or in close proximity to, IPVs. Meeting this target, whilst not increasing the risk to road users, is the focus of the guidance.

The Highways Agency’s service providers depend on the use of Impact Protection Vehicles (IPVs) for routine maintenance operations on the Strategic Road Network. Impact protection vehicles are equipped with a lorry mounted crash cushion (LMCC) that is designed to absorb impact energy during a collision. As a result, impact protection vehicles are primarily intended to reduce the injury severity to road users in the event of a collision, though they may also afford road workers some protection when conducting high risk activities such as installation and removal of temporary traffic management. IPVs are equipped with a light arrow sign which is used to direct road users to the left or right of the vehicle; hence reducing the likelihood of a collision between a road user's vehicle and a works vehicle.

The installation and removal of temporary traffic management in live lanes may be carried out using either two vehicles per lane (dual vehicle working) with an impact protection vehicle positioned 75m (+/-25m) upstream of the works vehicle, or with one vehicle (single vehicle working) which acts as both impact protection and a works vehicle. Depending on the activity undertaken, these situations can result in substantially different risk of injury to road workers. This difference in injury risk means the risk to road workers is not necessarily As Low As Reasonably Practicable (ALARP) when a single vehicle is used.

The Management of Health and Safety at Work Regulations require service providers to fully assess the risks prior to conducting any work on the Strategic Road Network. The Traffic Signs Manual Chapter 8, Section O2.2.1 states:

*The Management of Health and Safety at Work Regulations 1999 require that a suitable and sufficient risk assessment, specific to the task being performed, must be carried out to provide input to the method statement as it is being drafted. Consideration must be given to ways of firstly eliminating, or if this is not possible, then minimising the risk to operatives and the public. Information on formulating a risk assessment is given in the HSE free publication "Five steps to risk assessment".*

The purpose of the guidance is not to provide a checklist from which dual or single vehicle working may simply be selected, but to give service providers the framework needed to conduct a site-specific risk assessment which considers all of the relevant factors. This report details the findings of the research used to form the basis of the evidence for this guidance. It also outlines the principles used to assess the risk involved with an operation; these principles should be applied to each site-specific risk assessment.

The information within this report has been obtained from a number of sources including expert knowledge, assessment of the likely risk, and collision modelling. The expert
knowledge has been obtained from service providers to understand why they consider the use of two vehicles to be safer than the use of a single vehicle, and vice-versa.

This report explains the concepts of dual and single vehicle working (section 2), details current practice (section 3) and evaluates international practices (section 4). The aspects of risk involved when using each method are described in section 5. Collision modelling was used to explore the likely separation distance required between vehicles (section 6) and section 7 describes the operational factors that need to be considered when conducting a site specific risk assessment and selecting dual or single vehicle working.
2 Dual or Single Vehicle Working

This section defines the techniques of dual and single vehicle working that are referred to throughout this document.

2.1 Dual vehicle working

Dual vehicle working refers to the use of two vehicles operating with a separation distance of 50-100m as specified in Plan MLC1 of TSM Chapter 8 (Department for Transport, 2009). The upstream vehicle (an IPV) is equipped with an LMCC and shall only be occupied by a driver. The downstream works vehicle may or may not be equipped with an LMCC, as shown in Figure 1.

![Figure 1: Dual vehicle working – with one or two LMCC (Lane 3)](image)

The separation distance is intended to provide a balance between the risks associated with:

- a vehicle coming between the IPV and works vehicle,
- the IPV being shunted into the downstream vehicle, and
- the IPV blocking the view of approaching vehicles.

Dual vehicle working is commonly used for mobile works where the works vehicle is undertaking works or tasks that require frequent short stops upon the carriageway (e.g. a sweeper or gulley emptier). This technique is also used for static traffic management where the downstream vehicle is a traffic management vehicle setting out Temporary Traffic Management (TTM). Dual vehicle working can be used on the hard shoulder or in a live lane.

For dual vehicle working, involving the setting out of static TTM, four operatives are normally required: a driver for each vehicle and two operatives working from the downstream vehicle. (In some situations, dual vehicle working can be deployed with only three operatives, for example when the operator and driver of the works vehicle work together to pre-place signs while the vehicles are stationary.)

During installation and removal of TM, operatives work off the rear of the vehicle to pre-place cones and unload signs and sandbags. When the downstream vehicle is stationary...
within the closure, the driver of this vehicle will often exit the cab and assist the operatives with installation of the taper. The driver of the upstream vehicle will remain in the cab protecting the downstream vehicle for the entire duration the vehicle is required. Figure 2 shows dual vehicle working on-road.

![Figure 2: Dual vehicle working](image)

2.2 Single vehicle working

Single vehicle working refers to the use of a combined traffic management and impact protection vehicle (TMIPV) for installation and removal of static works (Figure 3). This vehicle works in isolation to set out advance warning signs and cones, and to warn road users of the presence of road workers in a live lane. The vehicle, equipped with a Lorry Mounted Crash Cushion (LMCC), can be used in live lanes or on the hard shoulder (Department for Transport, 2009).

![Figure 3: Single vehicle working with an LMCC (Lane 3)](image)

For single vehicle working, involving the setting out of static TTM, three operatives are required: two operatives and a driver. During installation and removal of TM, operatives work off the rear of the vehicle to pre-place cones and unload signs and sandbags. When the vehicle is stationary within the closure, the driver will often exit the cab and assist the operatives with installation of the taper. When working in a live lane one of the operatives will often act as a lookout, observing the approaching traffic and giving advance warning to the other operatives of any vehicles which may pose a danger to their safety.

Figure 4 displays some pictures of single vehicle working.
Figure 4: Single (combined) vehicle working

Single vehicle working may also refer to the use of a traffic management vehicle (TMV) without a crash cushion (Figure 5). This vehicle should not operate in the live lane of a dual carriageway without protection from an IPV (i.e. dual vehicle working).

Figure 5: Single vehicle working with no LMCC (hard shoulder)

When setting out static TTM from a TMV, three operatives are required (as with the TMIPV).
3 Overview of Existing IPV Usage Guidance for TTM Operations

This section details current IPV usage in the UK including relevant sections of guidance and information obtained from service providers relating to the current assessments involved in the choice of dual or single vehicle working.

3.1 Traffic Signs Manual Chapter 8


Section O5.4.1 details the requirement for vehicles to be fitted with an LMCC:

*Impact Protection Vehicles (IPV), Mobile Lane Closure (MLC) vehicles, and Mobile Carriageway Closure (MCC) vehicles shall be fitted with a lorry-mounted crash cushion (LMCC).*

The requirements for LMCCs are given in Departmental Standard TD 49/07 ‘Requirements for lorry-mounted crash cushions’ (Department for Transport, 2007).

3.1.1 Static works

Chapter 8 states the requirement for preparation of a site specific method statement which details the implementation, maintenance and removal of traffic management arrangements (section O2.4.1). One of the points to be addressed within the method statement is positioning of vehicles. Section O2.4.5 states:

*If parking the vehicle in a live traffic lane is unavoidable, a risk assessment shall be carried out and, for works on dual carriageway roads, consideration should be given to utilising an Impact Protection Vehicle (see paragraph O5.5.5), or a vehicle-mounted road works sign to diagram 610 or 7403.*

IPVs used for the installation, maintenance and removal of static traffic management on high-speed roads shall comply with the specifications given in section O5.5.5:

- conspicuous colour (e.g. yellow or white – a non-reflective yellow is recommended (see paragraph O5.5.2));
- 10 tonne minimum on the road weight;
- lorry-mounted crash cushion (LMCC) – see Section O5.4. For details of the latest specification for LMCCs see Departmental Standard TD 49 "Requirements for lorry-mounted crash cushions” (DMRB 8.4.7);
- automatic brake activation system in accordance with Appendix 4.2; see also paragraph O5.4.4;
- signing equipment in accordance with Section O10.7;
- light arrow sign in accordance with Section O10.8;
- reversing bleeper;
- 140 mm capital letter height “HIGHWAY MAINTENANCE” sign to diagram 7404 (externally mounted on rear of vehicle) (see also paragraph O5.2.8);
“Class RA2” to BS EN 12899-1 or microprismatic reflective markings on the rear of the vehicle in accordance with paragraph O5.2.3 (c) or (d) when LMCC is in the stowed position;

front-mounted amber light bar with two independent light sources and rear-mounted flashing amber beacons visible when the cushion and the light arrow are in the stowed position;

all seats shall be fitted with head restraints and seatbelts with a minimum of three points of anchorage to the vehicle; and

CCTV for rearward vision.

Section O8.1.5 details the requirement for crash cushions when conducting works which involve a vehicle either standing for a short-duration or operating at low speed in the carriageway, where a Mobile Lane Closure is inappropriate:

On roads where the speed limit is 40mph or more, if practical and appropriate, and subject to risk assessment, consideration should be given to fitting a lorry-mounted crash cushion (LMCC) to the working vehicle and/or any escort vehicle that may be employed.

Hence, static traffic management can be installed and removed using either dual or single vehicle working. A risk assessment should be carried out to decide on the method used.

### 3.1.2 Mobile lane closures

In contrast to static traffic management, dual vehicle working is a requirement for mobile lane closures in a live lane. TSM Chapter 8 section O10.6 details the vehicles required for a mobile lane closure. In summary:

- Dual vehicle working (where the block vehicle is fitted with a LMCC) is required when working within a live lane (O10.6.2).
- Dual vehicle working (where the block vehicle is fitted with a LMCC) or single vehicle working (where the works vehicle is equipped with a LMCC) is required when working on the hard shoulder (O10.6.9).

Section O10.1.4 provides advice on specific techniques which require particular care. For example, when working through junctions on roads of an urban nature or with a speed limit of 40mph or less, single vehicle working may be more appropriate due to restricted sight lines.

### 3.2 Contractor policies

Each contractor, currently has their own method for determining whether dual or single vehicle working should be employed. Some contractors always operate use the same method regardless of the situation, whilst others make the choice between dual and single vehicle working based on site specific risk assessments.

Engagement with a number of service providers has highlighted the different tools used to aid this decision; two of these are described below.
### 3.2.1 IPV assessment toolkit

One Service Provider has developed an IPV assessment toolkit to assist with the choice of dual or single vehicle working. This toolkit is comprised of a number of questions, each with a different weighting, giving a final score which indicates which method is most appropriate. The questions cover a range of issues including the legal and third party requirements, observed and predicted hazards, and business benefits.

Although this approach provides a simple method of providing advice on the requirement for dual or single vehicle working, there are a number of limitations with the tool itself. This tool is only intended to provide advice to the Technical Officer completing the form; however there is a risk with tools such as this that this comprises the entire decision process for dual or single vehicle working. The questions covered by the tool assess a wide range of considerations; however, additional factors (not included within the current version of the tool) may also influence the choice of dual or single vehicle working. Such factors may include flow, installation/removal method and traffic speed. Some factors may not have a ‘yes/no’ answer and there may be confounding factors which influence the choice of method.

Within the current tool, the most weight is given to the customer requirement for dual vehicle working. This may not be the most appropriate basis for a decision and careful consideration should be given to whether the current weightings applied to each factor are appropriate. Any local guidance needs to ensure that the approach taken minimises risk.

### 3.2.2 Network Map

Another Service Provider has developed a network map which codes the network based on three different protocols for installation of TM:

1. Installation vehicle only (dual carriageway with/without hard shoulder, including motorways)
2. Installation vehicle only + Variable Message Signs (single carriageway)
3. Impact protection vehicle + TM vehicle and the use of VMS (dual carriageway with no hard shoulder)

This map was developed based on the characteristics of each link including availability of a hard shoulder, topography of the carriageway and traffic flow.

Some of the characteristics upon which the decision for dual or single vehicle working have been based are variable e.g. traffic flow. Other factors which may influence the decision and vary within a given area include visibility due to weather, number of HGVs and vehicle speed. Specific consideration of these ‘on the day’ factors may change the decision for dual or single vehicle working from the suggested choice detailed on the map.

### 3.3 Summary

Current guidance requires the use of dual vehicle working only for mobile lane closures in a live lane. Dual or single vehicle working may be employed for all other works; the decision should be based on a site specific RAMS which details the implementation, maintenance and removal of traffic management arrangements. This site specific risk assessment is the focus of the guidance. Currently, each Managing Agent Contractor
(MAC) has a different method for determining whether dual or single vehicle working should be employed. Each of these methods has their advantages and disadvantages; however, many do not appear to consider all of the relevant environmental and operational factors which should be considered as part of a site specific risk assessment. Section 7 details these factors and how each of them should be considered.
4 International Evaluation of IPV Usage

This section considers the use of vehicles equipped with a LMCC in other countries. This evaluation was designed to give an indication of the approach taken in relation to dual or single vehicle working in a variety of countries around the world; it is not a comprehensive review into their use nor does the situation in other countries necessarily transfer directly to the UK road environment.

4.1 United States of America

The Manual on Uniform Traffic Control Devices (MUTCD) for streets and highways (Federal Highway Administration, 2009) contains information relating to the use of truck-mounted attenuators (i.e. crash cushions).

Within the MUTCD, there is some guidance which is mandatory, some which is recommended, and some which is supporting information.

Section 6F.86 details the use of crash cushions.

Paragraph 05 is mandatory:

*Truck-mounted attenuators shall be energy-absorbing devices attached to the rear of shadow trailers or trucks. If used, the shadow vehicle with the attenuator shall be located in advance of the work area, workers, or equipment to reduce the severity of rear-end crashes from errant vehicles.*

Paragraph 06 is supporting information:

*Trucks or trailers are often used as shadow vehicles to protect workers or work equipment from errant vehicles. These shadow vehicles are normally equipped with flashing arrows, changeable message signs, and/or high-intensity rotating, flashing, oscillating, or strobe lights located properly in advance of the workers and/or equipment that they are protecting. However, these shadow vehicles might themselves cause injuries to occupants of the errant vehicles if they are not equipped with truck-mounted attenuators.*

Paragraph 07 is recommended but not mandatory:

*The shadow truck should be positioned a sufficient distance in advance of the workers or equipment being protected so that there will be sufficient distance, but not so much so that errant vehicles will travel around the shadow truck and strike the protected workers and/or equipment.*

The American Traffic Safety Services Association (ATSSA) has developed a field guide which details guidelines on the use of shadow vehicles and Truck Mounted Attenuators (TMAs) in highway work zones (American Traffic Safety Services Association, n.d). The guidelines provide recommendations for the application of shadow vehicles based on the facility type (freeway or other), the type of activity (stationary or mobile), and whether the activity will involve a lane closure or a shoulder closure. The guidelines also detail the recommended spacing between a shadow vehicle and the works vehicle if a shadow vehicle is used; these are based on weight of the shadow vehicle and traffic operating speed (see Table 1). Finally, diagrams display typical applications of when and how shadow vehicles are used.
Table 1: Spacing guidelines for shadow vehicles (American Traffic Safety Services Association, n.d)

<table>
<thead>
<tr>
<th>Weight of shadow vehicle</th>
<th>Operating speed</th>
<th>Stationary operation</th>
<th>Moving operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recommended spacing for vehicles weighing &gt;22,000lbs (10,000kg)</td>
<td>Greater than 55mph</td>
<td>150 feet</td>
<td>172 feet</td>
</tr>
<tr>
<td></td>
<td>45mph to 55mph</td>
<td>100 feet</td>
<td>150 feet</td>
</tr>
<tr>
<td></td>
<td>Less than 45mph</td>
<td>74 feet</td>
<td>100 feet</td>
</tr>
<tr>
<td>Recommended spacing for vehicles weighing 9,900 (4,500kg) to 22,000lbs (10,000kg)</td>
<td>Greater than 55mph</td>
<td>172 feet</td>
<td>222 feet</td>
</tr>
<tr>
<td></td>
<td>45mph to 55mph</td>
<td>123 feet</td>
<td>172 feet</td>
</tr>
<tr>
<td></td>
<td>Less than 45mph</td>
<td>100 feet</td>
<td>100 feet</td>
</tr>
</tbody>
</table>

In summary, in the USA when vehicles fitted with crash cushions are used for protection of operatives and equipment, these vehicles are often used as part of a dual vehicle arrangement in advance of the work area. It is recommended that, if used, shadow trucks (vehicles equipped with truck-mounted attenuators and flashing arrows) are positioned a sufficient distance in advance of the works, but not so far that errant vehicles manoeuvre round the cushioned vehicle and collide with workers downstream.

4.2 Ontario, Canada

Canada is split into ten provinces and three territories. Ontario is a province located in East-Central Canada. Book 7, Ontario Traffic Manual (Ontario, 2001) provides an example of the requirements for crash cushions in Canada.

Section 5 describes the requirements for impact protection vehicles (or Buffer Vehicles) during temporary conditions across Ontario.

*For stationary operation on freeways, Buffer Vehicles (BVs) are used in combination with a Longitudinal Buffer Area (LBA). An LBA is an empty space upstream of the BV that out of control vehicles can use to brake to a full stop.*

*A BV without a Traffic Mounted Attenuator (TMA) is defined as a Blocker Truck (BT). A BV with a TMA is defined as a Crash Truck (CT). A BV also requires a mounted flashing arrow board and four-way flashers.*

The requirements for use of Buffer Vehicles can be summarised as follows:

- all Buffer Vehicles used on freeways must be Crash Trucks;
- for projects on freeways requiring five days or fewer to complete, Buffer Vehicles and an LBA are required for stationary operations;
- one or more Buffer Vehicles are required for mobile operations (e.g. longitudinal pavement marking, zone painting or street sweeping);
- Buffer Vehicles are not required on freeways where the lateral offset of 3m or more exists between the work area and traffic;
- Buffer Vehicles are not required for very short duration works on freeway shoulders (i.e. works at a fixed location for up to 30 minutes);
- Buffer Vehicles are not specifically required on non-freeways but an LBA is required for stationary operations on multi-lane roads for regulatory speeds of 70km/h or higher.

Figure 6 shows the positioning of buffer vehicles for stationary operations on non-freeways, freeways and during mobile works. LIDG is the Lateral Intrusion Deterrence Gap i.e. a suitable distance in front of the BV such that an errant vehicle will pass the work area before a decision can be made to turn into the gap. This distance is dependent upon speed (as described in Table D – not included here).

When mobile works are being carried out:
- The BV is positioned 2.5 seconds in relative traffic time upstream of the moving work vehicle (i.e. it should typically take 2.5 seconds for a vehicle to pass the works vehicle from when it passes the buffer vehicle);
- Additional BVs may be required because depending on the mass, speed, angle and braking of the two vehicles, the BV may be pushed ahead a distance which exceeds the LIDG and strike the back of the moving vehicle.

In summary, in Ontario, Canada an IPV (or Buffer Vehicle) is required for stationary operations (e.g. TTM) on freeways where the lateral offset between the works area and traffic is less than 3m; on non-freeways an IPV is not a specific requirement. Mobile operations require one or more Buffer Vehicles. The IPV should be positioned a suitable...
distance from the works area (stationary operations) or the works vehicle (mobile operations); this distance is dependent upon speed of approaching road user vehicles.

### 4.3 Queensland, Australia

Australia is split into six states and two main territories. Queensland is a state located in North-East Australia. The Manual of Uniform Traffic Control Devices (MUTCD), Part 3 Work on Roads (Queensland Government, 2003) provides an example of the requirements for crash cushions in Australia.

In Queensland, slow-moving or stationary work vehicles which are exposed to potential collisions by approaching traffic may be fitted with truck-mounted crash attenuators i.e. single vehicle working.

The MUTCD details that, when conducting short term low impact works in open road areas (section 4.3.8) and built-up areas (section 4.4.8), the work should be protected by a specialist vehicle:

This work involves the use of a vehicle fitted with a truck-mounted attenuator. The vehicle shall be fitted with an illuminated flashing arrow sign. The activities may include:

- a) placement and recovery of temporary signing and barriers;
- b) mobile lane closures; and
- c) slow moving or stationary vehicles operating on the roadway e.g. maintenance of traffic signals, street lighting and emergency phones.

A temporary speed zone may be created by the use of a vehicle-mounted speed restriction sign. If determined acceptable by a risk assessment, the specialist vehicle may be replaced by a shadow vehicle fitted with an illuminated flashing arrow.

For mobile works where workers are on foot (e.g. when laying a taper) a shadow vehicle must be used (section 4.6.2):

A shadow vehicle is required to provide close-up protection to the rear of workers on foot (e.g. laying pavement markers, operating a pedestrian type linemarking machine). The shadow vehicle shall travel a clear distance of 20m to 40m behind the work vehicle and shall be equipped with a truck-mounted crash attenuator whenever it is protecting workers.

In summary, in Queensland, Australia works vehicles installing/removing temporary signs, moving slowly or remaining stationary on the carriageway and those completing mobile lane closures are required to be fitted with a crash cushion. Where risk assessment allows, single vehicle working where the vehicle is equipped with a crash cushion (i.e. use of a TMIPV) may be replaced with dual vehicle working, where the upstream vehicle is fitted with a crash cushion and travels 20-40m upstream of the works vehicle, which may also have a crash cushion fitted.
4.4 New Zealand

In New Zealand, roads are defined using 3 levels (NZ Transport Agency, 2012):

- **Level 1 road** - a low to medium-volume road designated by a road controlling authority (RCA) with an annual average daily traffic (AADT) fewer than 10,000 vehicles per day (vpd).
- **Level 2 road** - a high-volume road designated by the road controlling authority (RCA) and with an annual average daily traffic (AADT) more than 10,000 vehicles per day (vpd).
- **Level 3 road** - a high-volume, high-speed, multi-lane road or motorway road designated by the road controlling authority (RCA) and with an annual average daily traffic (AADT) more than 10,000 vehicles per day (vpd).

Section B11.1.3 of the Traffic control devices manual states that "TMAs [Truck-Mounted Attenuators] are to be used on all levels of road where required."

Section C17.1.4 details the use of TMAs:

*While TMAs are primarily used for mobile and semi-static operations they can also be useful in some high-risk static operations.*

*For static operations TMAs:*

- *are generally only considered for sites occupied by personnel or objects that will present a hazard to road users, and*
- *are generally only justified on level 2 and level 3 roads for lane closures.*

When operating with a TMA in static operations (section C17.1.5):

*There must be a clear distance of at least 10m in front of a truck mounted with an attenuator to allow the truck to safely move forward if impacted by a light vehicle travelling at a speed of less than 100km/h.*

*This space must be kept clear of personnel and equipment.*

*The longitudinal and lateral safety zones must be provided in advance of the TMA and between the TMA and live traffic lane respectively.*

This layout is displayed in Figure 7.
Section D1.10.1 details the requirements for TMAs in mobile works:

The need for a vehicle in a mobile operation to be fitted with a rear-mounted attenuator, commonly known as a truck-mounted attenuator or TMA, varies with the level of TTM required, in the following manner:

Level 1:
- A TMA is not necessary on any vehicle used in a mobile operation on a level LV or level 1 road.

Level 2:
- A TMA is not necessary on a lead pilot vehicle.
- A TMA is not needed on the tail pilot vehicle of a mobile operation on a level 2 road when the work activity is not on the carriageway and both the tail pilot vehicle and work vehicle are located more than 2m from the edgeline.
- An AWVMS [advance warning variable message sign] may be used to give advance warning.
- Where other vehicles are used to either provide advance warning or shadow protection, a compliant TMA must be used when a mobile operation on a level 2 road is on the live lane or is on the road shoulder within 2m of the live lane.

Figure 7: Static operations using a Truck-Mounted Attenuator (NZ Transport Agency, 2012)
Level 3:
- A TMA must be used on all shadow vehicles in a mobile operation on a level 3 road.
- A TMA is not required on an AWVMS.

The distance required between vehicles during mobile works is defined in section D1.10.4:

*When a shadow vehicle is used to protect workers on foot in the lane then a minimum 10m roll-ahead distance must be provided in front of the shadow vehicle to allow the truck to safely move forward if impacted.*

This is displayed in Figure 8.

![Figure 8: Mobile operations using a Shadow vehicle (NZ Transport Agency, 2012)](image)

Section D2.1.2 defines the requirement for workers on the rear of a works vehicle: “Workers on the back of a working vehicle must be protected by a shadow vehicle at all times.”

In summary, in New Zealand crash cushions are generally only required on static and mobile works on level 2 & 3 roads (high volume roads with more than 10,000 vehicles per day). Mobile operations on level 3 roads require the use of a shadow vehicle fitted with a crash cushion; when protecting workers on foot these should be positioned with at least 10m roll-ahead distance to any personnel or equipment.
4.5 Dubai

Within the Work Zone Traffic Management Manual for Dubai (Roads and Transport Authority, 2007) the requirement for the use of crash cushions is detailed in section 4.4.5:

Typically a works vehicle used for linemarking or to effect a lane closure on a high speed, multilane road requires a vehicle mounted crash cushion, in addition to appropriate vehicle mounted warning lights and flashing arrow board.

When linemarking, the convoy should include a shadow vehicle when protection is required for workers on foot (e.g. laying pavement markers, operating a pedestrian type linemarking machine). The shadow vehicle should travel a distance of between 40m to 50m behind the nearest worker. As required, vehicles used for convoy operations shall be equipped with vehicle mounted crash cushions.

In summary, in Dubai both single and dual vehicle working is used – the requirement for crash cushions is ‘as required’.

4.6 Norway

The requirements and guidelines regarding warning and protection of road works (Norwegian Directorate of Public Roads, 2012) details that transverse protection is the first safety measure road users meet on approach to a worksite. Section 4.1 defines transverse protection:

Transverse protection is a physical obstacle that shall ensure that the road user that does not pay attention to the warning equipment that has been set up:

- does not enter the work area and inflict injury on him- or herself, the workers or the equipment.
- does not injure him- or herself by driving into equipment, machinery or structures or by driving into a work trench.

Transverse safety equipment may be:

- vehicles placed in front of the worksite.
- equipment specially developed to be transverse protection, placed on the carriageway, often energy absorbing.
- vehicles with energy absorbing equipment mounted on them, placed in front of the worksite.

Guidelines are also given describing when energy absorbing transverse protection should be used:

At speed levels of 60 km/h or higher, the transverse protection shall be energy absorbing.

For work on multi-lane roads with speed limits of 60 km/h and higher, impact attenuation vehicles shall be used as protection for short-term roadworks, including setting out or taking in warnings and protection for long-term roadworks.
For work in boom lifts (cherry pickers), where the work vehicle must stand on or by the carriageway, another vehicle shall be used as protection, and it shall be an impact attenuation vehicle if the speed limit is 60 km/h or higher.

In summary, in Norway, on roads where the speed limit is 60km/h dual vehicle working where the protection vehicle is fitted with a crash cushion is required for work requiring the use of works vehicle which must stand on or by the carriageway (e.g. cherry pickers).

4.7 Belgium

The PRAISE report (European Transport Safety Council, 2011) states:

Belgium has prepared specific instructions for signage and usage of TMAs on roads with a speed limit above 90 km/h. It states that no cones will be placed between the protection vehicle and the work zone and that protection vehicles will be used for protection only. For works on non-motorways on a lane with continuous traffic one protection vehicle (TMA) will be used and provided with proper signing and will be placed at 50 m in front of the work zone. On motorways two protection vehicles (TMA) will be used (MOV Instructions for use of TMA in MOW AWV 2009).

The specific requirements, including the distances required between vehicles, given in section 3.4.1 of the referenced document (MOV Instructions for use of TMA) have been translated as follows:

Section 3.4.1.A – road works on roadway with through-traffic:

- On non-motorways, use one crash cushion vehicle placed 50m before the work zone;
- On motorways, use two cushions placed 30 and 80m before the work zone. The first cushion should be placed closer to the passing traffic than the second;
- The crash cushions should have illuminated arrows indicating the side on which traffic should pass. If the cushions are placed on the hard shoulder, the light arrows should be replaced by a red cross;
- No cones are placed between the cushions and the work zone;
- The crash cushion vehicles may in no circumstances be used as working vehicles;
- The prior warning signal vehicle, also equipped with a crash cushion, is placed 500m before the protective crash cushions.

Section 3.4.1.B Work on slip roads:

- On motorways, use the same three crash cushions (two protection and one warning) as described in the through traffic case;
- On non-motorways, it may be acceptable to use only one protective cushion.

Section 3.4.1.C Road marking works:

- There are specific rules for the protection of workers applying road markings;
- The complete lane where the markings are being applied is protected by cones every 25m;
• The first crash cushion follows the line marking machine 75m back;
• The second crash cushion follows the first a further 75m back;
• The distance between the line marker and the cone recovery vehicle is dependent on the paint drying time.

In summary, in Belgium, dual vehicle working or, in some cases, triple vehicle working is mandatory: crash cushion vehicles cannot be used as working vehicles. On non-motorways with a speed limit above 90km/h one crash cushion vehicle is required; on motorways with a speed limit above 90km/h and for road marking works two crash cushions are required.

4.8 Summary

An assessment of the use of vehicles equipped with LMCCs in a number of countries around the world demonstrates a wide range of traffic management approaches, especially in relation to the requirements for dual or single vehicle working. For static operations, some countries mandate the use of dual (or triple) vehicle working in certain situations. For example, Belgium has specific requirements on high speed roads (90km/h or higher) that state that protection vehicles (crash cushion equipped vehicles or TMAs) are to be used for protection only. On non-motorways only one protection vehicle is required; however, on motorways two protection vehicles are used. In other countries, for example the USA, shadow vehicles equipped with crash cushions are often used to protect workers and equipment (e.g. as part of a dual vehicle arrangement) but are not a mandatory requirement.

The separation distances required between the vehicle equipped with the crash cushion and either operatives on foot or the front vehicle (in the case of dual vehicle working) range from a minimum of 10m (New Zealand) to approximately 68m (USA). Some countries provide guidance on the separation distance required based on a number of factors including the weight of the IPV, the operation being carried out and on the approaching vehicle speed.
5  Risk Evaluation

This section details the considerations required when determining the relative risks of dual and single vehicle working (section 5.1). During consultation with service providers a number of issues were raised, specifically in relation to the use of dual vehicle working; these are documented in section 5.2.

Section 5.3 explains how the MIRi Index was developed by TRL for the Highways Agency to assess the relative risks to road workers when using different TTM techniques. The tool has been used to evaluate the relative risks of dual and single vehicle working in generic circumstances.

5.1  Core parameters

In this section, dual and single vehicle working are considered in relation to three aspects of risk:

- Likelihood of collision (section 5.1.1);
- Number of operatives injured (section 5.1.2);
- Severity of injury in such collisions (section 5.1.3).

5.1.1  Likelihood of collision

When using dual vehicle working, high energy impacts (i.e. where the impacting vehicle is an HGV) to the rear of the IPV are likely to result in the upstream vehicle being ‘shunted’ downstream towards the works vehicle. If the impact energy is large enough and the separation distance between the two vehicles is not sufficient, then there is a risk of a secondary collision where the IPV subsequently collides with the rear of the downstream vehicle, resulting in injury to those on and within the working vehicle and to the driver of the IPV.

Where a sufficient distance between vehicles is maintained, a collision involving a low mass vehicle is unlikely to result in the IPV being shunted into the works area. Therefore the risk of injury to downstream operatives and any elevated risk of injury to the IPV driver from a secondary collision are reduced or eliminated, although the primary collision risk to the IPV driver remains.

Operating multiple vehicles (dual vehicle working) as opposed to a single vehicle increases the number and total size of stationary vehicles (“target size”) and therefore potentially affects the likelihood of a collision occurring, but reduces the probability of the works vehicle on which operatives are working being struck.

5.1.2  Number of injured operatives

If dual vehicle working is in operation and a suitable separation distance between vehicles is maintained, then the likelihood of a secondary collision should be minimal. Should a collision occur with the IPV, it is likely only the driver of this vehicle may be injured. With appropriate restraint and seating this can be minimised (see section 5.1.3).

If dual vehicle working is in operation but a suitable separation distance between vehicles is not maintained, the likelihood of a secondary collision will be increased. If a collision occurs with the IPV, a secondary collision may then occur with the works vehicle...
(which may or may not be equipped with an LMCC). If enough warning is given to operatives working from the rear of the works vehicle, and a safe exit route has been established, then it may be possible to reduce the number of operatives likely to be injured to one or two (the IPV driver and possibly the protected vehicle driver dependent upon his or her location at the time). However, a worst-case scenario involves likely injury to all four operatives.

Alternatively, if single vehicle working is in operation then the number of operatives injured depends on the use of a suitable lookout system which warns the operatives of an impending collision. A lookout system provides advanced warning of a vehicle approaching too close to the rear of the TMIPV. This system may be electronic (e.g. by means of a camera detection system) and/or may be through use of a designated operative whose only task is to act as a lookout. The designated operative should use a suitable means of communication to ensure operatives working on and around the IPV are sufficiently informed of a likely imminent collision.

If a warning can be given to operatives working from the rear of the vehicle far enough in advance of a collision, and a safe exit route has been established, the number of operatives likely to be injured could be reduced to one; it is unlikely that the driver would have sufficient time to unclip their seatbelt or harness, exit the cab and reach a place of safety. If this warning system were ineffective, or if no warning system were in place, both operatives and the driver are likely to be injured in such a collision.

### 5.1.3 Severity of collision

The severity of a collision refers to the maximum injury severity suffered by an operative or driver. Three severities may apply to a collision:

- **Fatal** – single or multiple fatalities where death occurs in less than 30 days as a result of injuries sustained in the collision.
- **Serious** – serious injuries include broken bones, head injuries, internal injuries, loss of limb and deep cuts/lacerations. Serious injuries often require detention in hospital as an in-patient.
- **Slight** – slight injuries include whiplash or neck pain, shallow cuts/lacerations, sprains and strains, bruising and slight shock.

Dual and single vehicle working have very different severity outcomes dependent upon:

- the characteristics of the approaching vehicle (such as speed and mass),
- the availability of both a pre-collision warning system and suitable escape route, and
- the separation distance between vehicles.

Impacting HGVs travelling at a maximum speed of 56mph represent the worst-case scenario in terms of energy distribution during a collision. For dual vehicle working, if the IPV is hit from the rear by a HGV travelling at 56mph, this is likely to result in the upstream vehicle being shunted towards the works vehicle. If the separation distance is large enough, a secondary collision is unlikely to occur and the collision severity is likely to be serious (with only the driver of the IPV being injured). This severity can possibly be
reduced to slight if impact mitigations, such as the appropriate use of restraints, are in place.

If the separation distance is too small and a secondary collision occurs, the collision severity is likely to be serious unless the operatives working from the rear of the works vehicle have sufficient warning and manage to get to a place of safety. However, if the secondary collision occurs and the operatives do not escape the rear of the vehicle, the severity is likely to be fatal (with either single or multiple fatalities to the operatives).

If a single TMIPV is struck by a HGV travelling at 56mph then the outcome is defined by the effectiveness of a look-out system. If operatives are given sufficient warning and can escape to a place of safety, the outcome is likely to be serious because the TMIPV driver should be suitably restrained within the cab. If operatives do not escape the rear of the vehicle then severity is likely to be fatal (with either single or multiple fatalities to the operatives). Similarly, if the driver is unrestrained within the cab this could result in a fatality.

Although impacting cars are likely to be travelling faster than 56mph, the energy dispersed in such a collision is likely to be much lower than in a collision involving a HGV, due to the difference in impacting mass. IPVs are designed to Departmental Standard TD 49/07 “Requirements for lorry-mounted crash cushions” (Department for Transport, 2007). This standard defines the maximum total test mass to be a 1500kg car and the maximum impact speed as 110km/h (68mph). Thus these vehicles are not tested to a standard where they would absorb all the impact energy in a HGV collision. This means that injuries resulting from such collisions are likely to be higher in injury severity than those involving a car.

During the crash tests defined in Departmental Standard TD 49/07, a number of severity indices are calculated for the occupant of the impacting car: the Acceleration Severity Index (ASI), Theoretical Head Impact Velocity (THIV), Occupant Ridedown Acceleration (ORA) and Occupant Impact Velocity (OIV). These are determined for all tests and compared with the maximum permitted values. No severity indices are required for occupants of the IPV itself: in order to determine the likely injuries sustained by the driver and operatives within the IPV cab, data would be required on impacts and accelerations of IPV occupants.

In the event of a collision, the injury severity sustained by operatives secured within the cab will depend, to some extent, on the ergonomics of the cab itself. Aftermarket seats often have head restraints which are too low to offer protection to the typical UK male. Improvements to the positioning and condition of seats and restraints could reduce the injury severity of operatives secured in the cab.

5.2 Additional risk factors

Dual vehicle working is considered by some – but not all – practitioners to be safer than single vehicle working in many circumstances. Two issues were identified by service providers as increasing the risk of collision when operating using dual vehicle working compared to single vehicle working:

- Obscuration (examined in section 5.2.1);
- Manoeuvrability (examined in section 5.2.2).
5.2.1 Obscuration

During communications with service providers, it was suggested that a vehicle in an upstream position may often reduce the ability of operatives to see oncoming traffic. Two issues were identified:

- Reduction in the time available for operatives to become aware of an imminent collision and hence the chance of a lookout providing an effective pre-collision warning;
- Limitation in the field of vision of an operative who is required to cross the carriageway.

In accordance with TSM Chapter 8 Part 1 2009 paragraphs D3.6.1 to D3.6.6, taper locations should be selected such that sight lines are “good”, as defined in Appendix A2 (Department for Transport, 2009). Consideration should also be given to safety issues involved in placing, erecting and removing advance warning signs and cones in the taper and the provision of safe pulling off points for traffic management vehicles. Evidence suggests that this guidance is not always followed and often tapers are located on significant bends; this reduces the visibility upstream for operatives but also increases the likelihood that a road user will collide with a vehicle or the taper, depending on the bend radius and whether the road curves to the left or right.

Dual vehicle working reduces, but does not eliminate, the reliance on a dedicated operative acting as a lookout for other operatives working in and around the works vehicle. If suitably located, the upstream IPV provides protection for the works vehicle and reduces exposure to high risk activities such as working from the rear of a traffic management vehicle directly exposed to live traffic. It is beneficial if the lookout has a clear view of any vehicles likely to strike the downstream vehicle. However, provided a suitable separation distance is maintained between vehicles, the risk of direct collision with the downstream works vehicle should be low.

New temporary traffic management techniques including sign simplification and offside signs removal, (Highways Agency, 2012) reduce or eliminate the requirement for carriageway crossings in order to install advance signs. When carriageway crossings are reduced or eliminated, obscuration of oncoming traffic by an upstream vehicle during carriageway crossings becomes less of an issue or is eliminated altogether.

Figure 9 provides photos of the upstream view for operatives operating using dual vehicle working at varying distances from an IPV and on different road curvatures. These pictures represent a typical upstream view for an operative crossing the carriageway from the hard shoulder to erect advance signing in the central reserve or acting as a lookout for road user vehicles likely to collide with the works vehicle, when the upstream vehicle is positioned at the minimum (50m) and maximum (100m) separation distances as given in Plan MLC1, Chapter 8 (Department for Transport, 2009).

Photos showing the degree of obscuration by the upstream vehicle at a wider range of distances (25m, 50m, 75m and 100m) and at varying locations within the hard shoulder are displayed in Appendix A.
Figure 9: Operatives view (from the rib line) upstream on a variety of road curvatures
When standing on the rib line, straight roads provide adequate sight lines (HSE, 2000) in which to determine a suitable gap in the traffic in order to cross safely. Right hand bends represent the best view of upstream traffic. Left hand bends represent the worst: even when the two vehicles are positioned at the maximum separation distance (100m), as defined in TSM Chapter 8 Plan MLC1 (Department for Transport, 2009), and the operative is stood on the rib line, the bend may be such that the operative does not have an adequate sight line in which to determine a suitable gap in the traffic.

In addition to the curvature of the road and the presence of the upstream vehicle, vegetation, banks and static VMS panels may add to the obscuration experienced by an operative when crossing the road.

The photos within Appendix A show that standing on the rib line often offers a much better view upstream than standing on the edge of the hard shoulder. When carrying a sign or frame, standing close to the rib line may be impossible given the overlap of the frame with the nearside lane. Where carriageway crossings are necessary, it may be possible to reduce the risk associated with determining a suitable crossing gap by utilising a lookout system. One operative (the lookout) can stand close to the rib line in order to assist with the identification of an adequate crossing gap. The second operative (carrying the sign) stands in a place of relative safety, choosing when to cross with the assistance of the lookout.

The photos do not show the obscuration from within the live lane which may occur when a taper is being built in the live lane between the two vehicles. The obscuration of oncoming vehicles associated with this technique will be different to that experienced when operating from the hard shoulder. This needs consideration when deciding which taper installation or removal technique should be used.

5.2.2 Manoeuvrability

Manoeuvrability when using dual vehicle working was also identified by service providers as an issue affecting the risk involved. Two specific instances where manoeuvrability is a particular issue were recognised:

- installation of the advance signs, it is often difficult for both vehicles to pull out into live traffic at the same time, in order to travel to the offside lane to install the taper;
- after installation of the taper (using the method where the IPV remains upstream of the taper – see Figure 28) the IPV can often have difficulty manoeuvring back into traffic.

Figure 10 displays the first of these issues.
When pulling out into live traffic sufficient space must be present such that the vehicles can pull out safely to prevent the situation displayed in Figure 10 from arising. It may be beneficial for the upstream IPV to pull into the lane first; this vehicle often has the better view of oncoming traffic and can create a ‘safety zone’ in front of the IPV in which the works vehicle can then pull into.

If dual vehicle working is being used it is more critical that both vehicles are equipped with an LMCC if a situation may arise where the downstream vehicle may be unprotected in a live lane.

Figure 11 displays the manoeuvrability issues when installing the taper.

If the IPV is positioned too close to the start of the taper, it may be difficult to reach an appropriate near-traffic speed by the time it joins traffic travelling in lane 2. An IPV travelling considerably slower than approaching vehicles presents a hazard to other road users. The likelihood of collision in this situation is increased.

When using this method, the IPV needs to be positioned a sufficient distance from the beginning of the taper to ensure it can manoeuvre easily around the cones and reach near-traffic speed by the time it merges into lane 2. However, this distance should not
be too large as this may encourage drivers to cut back in after the IPV prior to the taper cones.

5.3 MIRi Index

Risk is defined as “the probability or exposure to a hazard, combined with the consequences of such exposure". Traditional risk matrices are often used to calculate risk; these combine two factors: the likelihood of an event occurring and the severity of the consequences. The Highways Agency’s 5x5 risk matrix is shown in Table 2.

**Table 2: Highways Agency’s 5x5 risk matrix**

<table>
<thead>
<tr>
<th>LIKELIHOOD</th>
<th>IMPACT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Negligible</td>
</tr>
<tr>
<td>Frequent</td>
<td></td>
</tr>
<tr>
<td>Probable</td>
<td></td>
</tr>
<tr>
<td>Occasional</td>
<td></td>
</tr>
<tr>
<td>Remote</td>
<td></td>
</tr>
<tr>
<td>Improbable</td>
<td></td>
</tr>
</tbody>
</table>

The concepts of risk outlined in section 5.1 have been combined in into a tool which quantifies the risk associated with different techniques. The Measurement of Injury Risk (MIRi) Index was developed by TRL for the Highways Agency to measure the relative risk of different TTM operations. The index applies to the deployment and retrieval of TTM for relaxation closures, considering the risk to road workers only.

The tool was developed with assistance from operatives working across the TM industry. Key service providers including Carillion WSP, A-one+, Colas, HW Martin and Balfour Beatty Mott Macdonald were consulted to establish which TTM techniques were commonly used. Method statements were gathered where possible from these contractors; in addition to this, members from the TRL project team joined traffic management crews in several HA Areas on the network and observed the TTM installation and removal operations. Observations were undertaken on different road types (with and without hard shoulder) and for different lane closures (nearside and offside). The most common techniques were selected for inclusion in the tool.

The MIRi tool quantifies risk using three factors:

- Likelihood of collision
- Duration of exposure
- Severity of injury in such collisions

The likelihood data was obtained using a combination of professional judgement and expert knowledge. A focus group comprising experienced traffic management specialists was used to guide the ranking of different subtasks. The subtasks were considered separately for different carriageway types.
The duration of exposure was obtained by timing operations on the network to measure how long it took to complete each subtask.

The consequence data was based on a number of assumptions which take into account the impacting vehicle type, whether or not the operative concerned is in an unsecured position and whether or not the TM vehicle is equipped with a crash cushion.

The tool separates the risk for installation and removal of TTM. It further separates the task of installation into four main task stages:

- Install advance signs
- Install Detail A (if required)
- Install taper
- Install longitudinal run

Similar task stages are used for removal. These task stages are further disaggregated into each individual subtask e.g. “install 800 yards advance sign on verge” and “drop taper cones from vehicle”.

The risk associated with a specific subtask is calculated (using the probability, consequence and exposure figures) for each individual operative involved in the task. For example, if it takes two operatives to install one advance sign the risk associated with both operatives is calculated for each operative separately for this subtask.

These risks are then summed up over all operatives to get a value for the subtask, over all subtasks to get a value for the task stage, over all task stages to get the score for either installation or removal and finally summed to get the MIRi index value for the total operation of installing and removing TTM. This process is depicted in Figure 12.
The MIRi tool assesses the relative risk of a number of techniques including dual and single vehicle working. Within the tool, dual vehicle working requires a crew of four people: two drivers and two operatives. Single vehicle working requires three: one driver and two operatives.
The scores generated by the tool are based on generic 2 and 3 lane carriageways with and without a hard shoulder and thus provide an evidence base for the relative risks when using each vehicle combination. The MIRi Index is generic – while it is indicative, it does not eliminate the need to consider site specific characteristics which may change these relative risks.

Table 3 shows the relative MIRi scores for installation and removal of TTM using each of the four vehicle combinations. The MIRi scores are presented as percentages relative to the baseline of a TMIPV. Percentages are comparable within a column only. For example, for a single nearside closure on a two lane carriageway with no hard shoulder, the risk to road workers installing and removing TTM is estimated to be 23% lower with a TMIPV+IPV than with a TMIPV. However, the figures should not be compared between columns because the risk of installing and removing TTM using a TMIPV on a single lane closure is not the same on all road types or in all lanes.

The percentages in the table are based on:

- Utilising the hard shoulder to install the advance signs (where available).
- Using offside signs removal as the advance signing method for the single nearside closure on the three lane carriageway. Using sign simplification for the single offside closure on the three lane carriageway and the single nearside and offside closures on the two lane carriageway. This is in accordance with IAN 150/12 (Highways Agency, 2012).
- Installing the taper upstream of the vehicle(s) or, in the case of a nearside closure on a road with a hard shoulder, walking the taper out into lane 1 from the hard shoulder without the works vehicle(s) situated in a live lane. This taper installation method was selected for the calculations as it was identified as the most practicable for service providers based on the manoeuvrability and obscuration issues identified in section 5.2.
- Removing the taper by reversing the works vehicle in the live lane to pick up the cones. When operating using dual vehicle working, except for nearside closures on roads with hard shoulders, the IPV is positioned in the live lane a suitable distance upstream of the start of the taper. This provides protection to the works vehicle while it is reversing and an operative picks up the cones. In the case of a nearside closure on a road with a hard shoulder, the taper cones are walked in from lane 1 to the hard shoulder with no works vehicles situated in a live lane.
- Installing and removing the longitudinal run using a single vehicle.
Table 3: MIRi scores relative to the baseline of TMIPV

<table>
<thead>
<tr>
<th>Risk for installation and removal of TTM</th>
<th>Chapter 8 relaxation closure on three lane carriageway with hard shoulder</th>
<th>Chapter 8 relaxation closure on two lane carriageway with no hard shoulder</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technique</td>
<td>Single nearside lane</td>
<td>Single offside lane</td>
</tr>
<tr>
<td>TMIPV+IPV</td>
<td>98%</td>
<td>92%</td>
</tr>
<tr>
<td>TMV+IPV</td>
<td>111%</td>
<td>103%</td>
</tr>
<tr>
<td>TMIPV</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>TMV</td>
<td>114%</td>
<td>126%</td>
</tr>
</tbody>
</table>

The tool suggests that, on a typical three lane carriageway with hard shoulder, the risk to road workers is very similar when using two vehicles equipped with a crash cushion and when using one vehicle equipped with a crash cushion, for a nearside lane closure. For an offside lane closure, dual vehicle working (where both vehicles are equipped with a crash cushion) appears to be slightly safer than single vehicle working. The majority of the difference in risk between dual vehicle working and single vehicle working in this situation arises during the removal of the taper where the IPV waits a sufficient distance upstream of the taper and the works vehicle reverses to pick up the cones.

On a typical two lane carriageway with no hard shoulder, the technique with the lowest relative risk to road workers is dual vehicle working where both vehicles are equipped with a crash cushion, for both nearside and offside closures. Even in the case where the works vehicle has no cushion, the risk associated with dual vehicle working is still lower than the single vehicle option.

It is important to recognise that the figures above have been estimated using a model that is based on a typical road layout. They are therefore indicative only and hence do not eliminate the need to assess the risk associated with undertaking the specific operations at the specific location concerned. What this does show is the critical importance of a suitable and sufficient risk assessment which takes into account the site-specific factors that the generic model cannot.

The MIRi tool details the generic relative risk to road workers associated with installation and removal of TTM, but does not consider the risk to road users. It is important that the risk to road users is also considered as part of a site specific risk assessment. Other considerations with dual vehicle working include obscuration and manoeuvrability, as outlined in section 5.2. Assessment of these factors is covered in more detail in section 7.
5.4 Summary

Section 5.1 and 5.2 of this chapter consider the general concept of risk in relation to dual and single vehicle working. Section 5.3 combines these concepts into relative risk values. This tool was developed to assess the relative risks of TTM techniques and can be used to compare the relative risks of typical operations using dual and single vehicle working. It takes into account the concepts discussed in section 5.1 (likelihood of collision, number of operatives injured and likely severity of collision). The specific issues of obscuration and manoeuvrability around the taper associated with dual vehicle working identified in section 5.2 should be considered as part of a site-specific risk assessment.
6 Collision Modelling

When operating using dual vehicle working for Mobile Lane Closures (MLCs) TSM Chapter 8 (Department for Transport, 2009) recommends a separation distance of 50-100m between vehicles. This section summarises the results of some initial analysis which investigates whether this recommended distance is likely to be appropriate. The separation distance should be a compromise between:

- the need to keep the gap small to discourage road user vehicles from cutting back in between the two vehicles,
- allowing sufficient room to avoid the upstream vehicle being shunted forward into the works vehicle should a collision occur, and
- the IPV obscuring the view of approaching vehicles.

To investigate the effect of a collision between a road user vehicle travelling wholly or partially within the same lane as the IPV and a stationary and braked Impact Protection Vehicle, collision reconstruction software was used.

The software was used to determine the likely longitudinal distance a 10 tonne IPV would travel if hit by a 44 tonne HGV travelling at 56mph or a passenger car travelling at 80mph. However, no consideration was given to the path taken by the impacting vehicle post collision.

6.1 Modelling software and parameters

For this analysis the software used was HVE 3D (Human Vehicle Environment) and in particular a calculation model known as the Dynamic Mechanical Shell (DyMesh). Accurately modelling the crash cushion of the IPV would require specific information with regard to the performance and capabilities of the cushion itself. From this it would then be possible to validate the model of the cushion and vehicle. Due to the complexities of modelling the crash cushion, the initial modelling of the moving vehicle versus a stationary and braked IPV vehicle was performed without the addition of the crash cushion. The crash cushion is designed to absorb energy in a collision, reducing the forward travel of the vehicle. Thus the initial modelling represents a worst-case scenario.

Within HVE there are a number of vehicle models that are predefined. However, in addition to these there are a number of generic vehicle models that do not represent any specific vehicle, but provide a reasonable estimate for each parameter. There are generic vehicle models within each category of vehicle such as passenger cars, trucks, pickups, vans, trailers etc. Each of the parameters for the generic vehicle has been determined from either research test results or from direct measurements of vehicles. From these data the figures were then averaged to provide an approximation of the required value for each vehicle class and category. For certain parameters it was not possible for the data to be obtained and thus the developers of HVE have, over the years since the program was developed, estimated values and have iterated these to ensure the results are realistic, for example the roof stiffness.

For the simplified IPV model, the generic “Truck” model within HVE was used and the parameters stated are shown in Table 4 below. The vehicle mass used in this simulation was 10 tonnes i.e. the recommended minimum on-road weight for an impact protection vehicle (Department for Transport, 2009).
Two different impacting vehicles were modelled to consider the effect of these classes of vehicles colliding with the stationary simplified model of the IPV. The impacting vehicles were a 44 tonne lorry and trailer, and a passenger car.

For the initial analysis of the trajectory and thus travel distance of the simplified IPV following the collision with the 44t lorry and the passenger car, three impact configurations were considered. These were 100% overlap (full width), 50% overlap and 25% overlap, where the overlap percentage is the proportion of the width of the narrowest vehicle. The simplified IPV was stationary in all of the scenarios prior to the collision, with the brakes applied to the vehicle. The impacting vehicle speeds were 90km/h (~56mph) and 128km/h (~80mph) for the lorry and the car respectively. The brakes of the 44t lorry were applied once the collision had occurred to prevent any secondary impacts occurring and to ensure that the vehicles become separated in the collision. Whilst the secondary impacts may occur in the ‘real-world’ the purpose of this analysis is to provide an overview of the initial collision.

The tyre/road coefficient of friction was modelled to be approximately 0.6 for the lorry and the simplified IPV and approximately 0.7 for the passenger car. These values typically represent dry conditions.

Section 6.2 details the results of the collision involving the 44t lorry and section 6.3 covers those from the collision with the passenger car.

---

**Table 4: Summary of the parameters stated within the HVE model of the simplified IPV**

<table>
<thead>
<tr>
<th>Model Specification</th>
<th>Simplified IPV Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle Length</td>
<td>6800mm</td>
</tr>
<tr>
<td>Vehicle Width</td>
<td>2438mm</td>
</tr>
<tr>
<td>Wheelbase</td>
<td>3590mm</td>
</tr>
<tr>
<td>Front Overhang</td>
<td>1440mm</td>
</tr>
<tr>
<td>CofG to front axle</td>
<td>1795mm</td>
</tr>
<tr>
<td>Vehicle Mass</td>
<td>9995kg</td>
</tr>
</tbody>
</table>
6.2 IPV collision involving HGV

Table 5 gives an overview of the impacting 44t lorry used in the simulation.

**Table 5: Summary of the parameters stated within the HVE model for the impacting lorry**

<table>
<thead>
<tr>
<th>Model Specification</th>
<th>Impacting Lorry Model</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Vehicle Length</strong></td>
<td>7944mm (lorry)</td>
</tr>
<tr>
<td></td>
<td>13335mm (trailer)</td>
</tr>
<tr>
<td><strong>Vehicle Width</strong></td>
<td>2438mm</td>
</tr>
<tr>
<td><strong>Wheelbase</strong></td>
<td>5963mm (lorry)</td>
</tr>
<tr>
<td><strong>Front Overhang</strong></td>
<td>736mm (lorry)</td>
</tr>
<tr>
<td><strong>CofG to front axle</strong></td>
<td>1561mm (lorry)</td>
</tr>
<tr>
<td><strong>Vehicle Mass</strong></td>
<td>7996kg (lorry)</td>
</tr>
<tr>
<td></td>
<td>35983kg (trailer)</td>
</tr>
</tbody>
</table>

The full width (100% overlap) collision between the 44t lorry and the stationary braked simplified IPV was modelled and the simulation is shown below in Figure 13. The results show that the initial contact between the 44t lorry and the simplified IPV caused the rear of the IPV to lift from the ground slightly and thus reduce the effectiveness of the braking capability of the vehicle. Whilst it is possible that this may occur in the ‘real-world’, it may also be a function of the model and further analysis of the position of the centre of gravity of the IPV and actual mass of the vehicle may eradicate or validate this. The simplified IPV travelled a total distance of approximately 63 metres (in the longitudinal [X axis] direction i.e. along the road) following the collision with the 44t lorry.

**Figure 13: The simulation output for the 100% overlap collision between the 44t lorry travelling at 56mph and the stationary braked simplified IPV**
Realigning the 44t lorry such that it overlapped the rear of the simplified IPV by 50% changed the dynamics of the collision as would be expected. The reason for this is due to the position the force was applied with respect to the centre of gravity of the vehicle. In the 100% overlap configuration the collision force was directly along the longitudinal access of the vehicle and encompassed its centre of gravity entirely, thus the majority of the force was in the longitudinal direction and very little rotational moment was induced. The simulation results of the 50% overlap collision between the 44t lorry and simplified IPV are shown in Figure 14.

![Figure 14: The simulation output for the 50% overlap collision between the 44t lorry travelling at 56mph and the stationary braked simplified IPV](image)

The offset impact configuration causes the simplified IPV to rotate during its displacement which in turn reduces the distance the vehicle travels in the longitudinal direction but can (and as shown above does) increase the lateral distance the vehicle travels. In the 50% offset collision with the 44t lorry the simplified IPV model travels a total of approximately 55 metres in the longitudinal direction.

In the final impact configuration, the offset of the 44t lorry was reduced to 25% and the simulation was re-run (Figure 15). The reduced overlap between the two vehicles increased the rotational element of the collision and thus the forward travel of the IPV reduced when compared to that in the 100% overlap configuration. The forward travel distance of the IPV vehicle was approximately 21 metres when the 44t lorry overlapped it by 25%.
Figure 15: The simulation output for the 25% overlap collision between the 44t lorry travelling at 56mph and the stationary braked simplified IPV

6.3 IPV collision involving a passenger car

Table 5 gives an overview of the impacting passenger car used in the simulation.

Table 6: Summary of the parameters stated within the HVE model for the impacting passenger car

<table>
<thead>
<tr>
<th>Model Specification</th>
<th>Impacting Car Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle Length</td>
<td>4438mm</td>
</tr>
<tr>
<td>Vehicle Width</td>
<td>1699mm</td>
</tr>
<tr>
<td>Wheelbase</td>
<td>2616mm</td>
</tr>
<tr>
<td>Front Overhang</td>
<td>871mm</td>
</tr>
<tr>
<td>CofG to front axle</td>
<td>951mm</td>
</tr>
<tr>
<td>Vehicle Mass</td>
<td>1224kg</td>
</tr>
</tbody>
</table>

For the passenger car collision, the vehicle was travelling at approximately 128km/h (≈80mph) at the point of impact with the rear of the simplified IPV. The overall width of the passenger vehicle was less than that of the simplified IPV and thus the overlap percentage was determined from the width of the passenger car. The mass of the passenger car in the HVE model was approximately an eighth of that of the simplified IPV. Therefore, from simple conservation of linear momentum where the total
momentum before the collision equals the total momentum after the collision, due to the large mass of the stationary vehicle it is likely that the post collision velocity of the two vehicles will be much lower and thus the total post collision distance travelled by the simplified IPV would be less than the simulated collision with the 44t lorry.

The collision simulation for the 100% overlap is shown in Figure 16 below. Due to the height of the rear of the simplified IPV the passenger car is noted to underride the rear of the vehicle and thus in a real-world situation if this was to occur the energy absorbing structures of the passenger car (such as the lower rails) would not be utilised. In certain vehicles an underrun guard is fitted to the rear of the lorries or their trailers to prevent this and to enable the energy absorbing structures of the vehicle to engage upon structure of the opposing vehicle. The total distance the simplified (and braked) IPV travelled following the 100% overlap collision with the passenger car was approximately 2 metres.

![Simulation output](image)

**Figure 16: The simulation output for the 100% overlap collision between the passenger car travelling at 80mph and the stationary braked simplified IPV**

As mentioned above, the offset percentage was determined from the width of the passenger car. Therefore for the collision configuration where the passenger car was offset by 50% effectively less than 50% of the simplified IPV was impacted. The collision simulation is shown below in Figure 17.
Figure 17: The simulation output for the 50% overlap collision between the passenger car travelling at 80mph and the stationary braked simplified IPV

The total distance the simplified IPV travelled after it was impacted by the 50% offset passenger car was approximately 1.5 metres. The travel distance was less due to the fact that some of the collision energy from the passenger car was not directed to the simplified IPV. Rather, it was converted into a rotational element for the passenger car and hence the reason that the passenger car was found to travel further also post collision.

In the final collision configuration the overlap of the passenger car was reduced to 25%. As occurred with the lorry simulations the reduced overlap increased the rotational element of the lightest vehicle in the collision which in this case was the passenger car, in addition the post impact travel distance of the simplified IPV reduced further to approximately 1 metre. The 25% passenger car collision simulation is shown below in Figure 18.

Figure 18: The simulation output for the 25% overlap collision between the passenger car travelling at 80mph and the stationary braked simplified IPV
6.4 Conclusions

Table 7 summarises the approximate longitudinal distance travelled by the simplified IPV during the simulations.

Table 7: Summary of approximate simulated longitudinal distance travelled by the simplified IPV by impacting vehicle and percentage overlap

<table>
<thead>
<tr>
<th>Overlap</th>
<th>44t lorry</th>
<th>Passenger car</th>
</tr>
</thead>
<tbody>
<tr>
<td>100% overlap</td>
<td>63 metres</td>
<td>2 metres</td>
</tr>
<tr>
<td>50% overlap</td>
<td>55 metres</td>
<td>1.5 metres</td>
</tr>
<tr>
<td>25% overlap</td>
<td>21 metres</td>
<td>1 metre</td>
</tr>
</tbody>
</table>

As expected, the 44t lorry shunts the simplified IPV much further than a passenger car; this is due to the increased mass and impact energy involved in such a collision.

The simulation shows that when the simplified IPV was struck by a 44t lorry at 100% and 50% overlap the IPV was shunted beyond the minimum recommended separation distance between vehicles (50m).

However, the Impact Protection Vehicle used in the model did not accurately reflect the true performance and capabilities of the cushion; thus the modelling is likely to represent the worst-case scenario.

The modelling did not consider the path taken by the impacting vehicle following the collision. However, some of the energy will be absorbed by the vehicles themselves, including the crash cushion, substantially reducing the vehicle speed involved. In the situation in which the collision is with the upstream of two vehicles, this may provide operatives with several seconds warning (if they hear the collision with the IPV) before any impacting vehicle reaches them, assuming they are located suitably far downstream of the upstream IPV.

Whilst these simulations provide an insight into the modelling capabilities of such a collision, at this stage no sensitivity analysis has been performed to determine the effect of a change in mass, change in impact speed, approach angle or change in environmental conditions.

6.5 Recommendations

The simulations showed that, in collisions where the impacting vehicle is a passenger car (or similar lightweight vehicle), the IPV is not shunted very far; in these collisions the recommended separation distance of 75m (+/-25m) appears to be appropriate. In two of the scenarios, when the IPV was struck by a 44 tonne lorry, it was shunted beyond the minimum recommended separation distance (50m). Hence, if the IPV is likely to be struck by a HGV, longer separation distances may be more appropriate. However, it is worth noting that an IPV which has been shunted 50m down the carriageway is likely to be travelling substantially slower than immediately after the initial impact. Thus, if the works vehicle were positioned 50m downstream, it is likely that the injuries sustained by operatives working in and around this vehicle would be minor, even if the operatives had not managed to exit the vehicle having had several seconds’ warning. If the works vehicle were also equipped with a crash cushion then it is likely the majority of the energy in any secondary collision would be absorbed.
Improvements to the IPV used within the simulation, for example the addition of a crash cushion which accurately reflects the true performance and capabilities of the cushion, would improve the accuracy of the simulated collisions. Crash cushions are designed to absorb some of the impact energy in a collision; inclusion of a crash cushion within the modelling may reduce the longitudinal distance travelled by the IPV post-collision. In addition, the modelling was conducted with a 10t IPV; this is the minimum on road weight for such vehicles and, as such, any IPV heavier than this is likely to travel less post-collision. It also modelled the likely worst case in terms of the speed of the colliding vehicle.

When operating using dual vehicle working a site specific risk assessment should be used to determine a suitable separation distance, which should be maintained between vehicles at all times. This distance should be decided based on consideration of the following points:

- Shorter distances decrease the risk of road users re-entering the closed lane between the two vehicles but may increase the risk that if the upstream vehicle is hit it may be shunted into the rear of the works vehicle;
- Longer distances decrease the risk of the upstream vehicle being shunted into the rear of the traffic management vehicle but present a greater likelihood of road users cutting back in to the gap between the two vehicles and colliding with the rear of the works vehicle;
- Collisions involving HGVs are likely to shunt the IPV much further than collisions involving a passenger car (see sections 7.1.2 and 7.2.2);
- Obscuration by the upstream vehicle is worse when the distance between vehicles is shorter (see section 5.2.1);
- Errant vehicles are more likely to deviate to the outside of a curve on the road (see section 7.1.7).

In addition, it may be that the consistent use of dual vehicles would increase the public awareness that there may be a second vehicle downstream of any IPV.
7 Operational Factors

The Management of Health and Safety at Work Regulations require service providers to fully assess the risks prior to conducting any work on the Strategic Road Network. The Traffic Signs Manual Chapter 8, Section O2.2.1 states:

*The Management of Health and Safety at Work Regulations 1999 require that a suitable and sufficient risk assessment, specific to the task being performed, must be carried out to provide input to the method statement as it is being drafted. Consideration must be given to ways of firstly eliminating, or if this is not possible, then minimising the risk to operatives and the public. Information on formulating a risk assessment is given in the HSE free publication "Five steps to risk assessment".*

There are a number of operational factors to be considered when conducting this assessment. These factors include site characteristics e.g. road geometry; traffic characteristics e.g. flow; and operational considerations e.g. requirement for carriageway crossings.

The site specific risk assessment should also record the method used to install or remove temporary traffic management, specifically the use of dual or single vehicle working. The following sections explain the likely considerations required for each factor. Where available, evidence in the form of pictures or diagrams is included to support understanding of each consideration.

Each factor should be considered in relation to the three aspects of risk (likelihood of collision, number of injured operatives and severity of collision) outlined in section 5.1.

7.1 Site characteristics

7.1.1 Number of lanes

The number of lanes on a given carriageway may be an indicator of flow: more lanes indicating higher flows. Higher flow may increase the likelihood of collision (section 7.2.1); however, lane occupancy (section 7.2.3) is also likely to be a factor.

The number of lanes influences the type of vehicle travelling in each lane; for example, on three or more lane carriageways, HGVs and other heavy vehicles should not travel in the outside or right-most lane (Department for Transport, 2013). Hence, if an IPV is in operation in an offside lane of a carriageway with three lanes or more, the likelihood that a HGV will collide with an IPV located in this lane is low. The subsequent injury severity of any collision which does occur is likely to be lower than a collision which occurs in a nearside lane, due to the likely smaller impacting mass of any colliding vehicle.

7.1.2 Lane(s) closed

The lane(s) closed links to other factors such as the number of lanes (section 7.1.1), hard shoulder presence (section 7.1.4) and HGV number (section 7.2.2).

Due to restrictions on heavy vehicles travelling in the offside lane (of three or more lane carriageway), nearside operations are likely to represent a higher likelihood of a collision involving a HGV than offside operations.
7.1.3  **Safe taper locations**

Safe taper locations are defined within section D3.6 of TSM Chapter 8 (Department for Transport, 2009).

When deciding on safe taper locations things to be considered include:

- Selection of a site where visibility is good; avoiding bends and especially left hand bends where possible;
- Safety issues involving placing, erecting and removing advance warning signs and cones in the taper;
- Provision of safe pulling off points for TM vehicles;
- Provision of advance signing without the need for stationary or slow-moving works vehicles to encroach into live lanes when pre-placing, erecting or removing TM equipment;
- Provision of adequate advance signing, especially on a left-hand bend where visibility is reduced.

Selecting taper locations such that live lane exposure of IPVs is reduced and visibility for both road workers and road users is adequate will reduce the likelihood of a collision occurring.

7.1.4  **Hard shoulder presence**

The presence of a hard shoulder influences the way in which advance signs and the taper are installed. A hard shoulder can reduce live lane exposure for the IPV(s) as advance signs are installed from the hard shoulder rather than a live lane. Nearside tapers can also be installed from the hard shoulder. At some locations, the hard shoulder may be present alongside some of the carriageway at the site concerned but absent along other parts of the carriageway at the site concerned. Consideration of the location and method of installation and removal of TTM should take specific account of these hard shoulder discontinuities; in some situations it may be beneficial to move the taper further upstream to avoid them.

When operating from the hard shoulder the likelihood of a full overlap collision with the rear of a vehicle is lower than when operating from a live lane because approaching vehicles should not be driving in the lane in which the IPV is located. If a collision were to occur it is more likely to be a side swipe or a road user vehicle clipping the corner of the vehicle.

Previous research (Wood, Reeves, & Lawton, 2012) indicated that approximately one third of collisions between 2007 and 2011 occurred when the vehicle was parked on the hard shoulder. Encroachments by road user vehicles onto the hard shoulder present a considerable risk for IPVs and road workers operating within this lane.

HGVs predominantly travel in lane 1 and hence, if a collision were to occur with a vehicle parked on the hard shoulder, it is more likely to result in higher severity injuries compared to a collision in the offside lane (see sections 7.1.1 and 7.2.2).
7.1.5 **Presence of VMS/infrastructure availability**

There are two types of variable message sign:

- Temporary VMS e.g. a VMS mounted on a trailer parked at ground level off the carriageway;
- Permanent VMS e.g. gantries or MS4s over the carriageway.

Both types are used to provide additional warning of a closure (in a different manner to that given by the ground-level advance signs). Advisory or mandatory speed limits can also be displayed. Some examples of temporary and permanent VMS are given in Figure 19.

![Temporary and permanent VMS](image)

**Figure 19: Temporary and permanent VMS**

Use of VMS provides additional warning of the presence of the closure making drivers more aware of the situation ahead and potentially reducing the likelihood of collision. Speed limits may decrease speeds and reduce both collision likelihood and maximum injury severity. However, other mitigation measures may also need to be considered as part of the risk assessment as there is a chance the VMS may not remain available throughout the period required (see section 7.3.9).

Little research has been conducted into the effect Variable Message Signs (VMS) have on lane choice and thus the risk of collision with an IPV. Current on-road trials aim to examine this effect as the HA trials the use of MS4s and gantries as advance warning of lane closures.

The presence of VMS on a carriageway may influence the sight lines of both the road user and road workers crossing the carriageway: see sections 7.1.3 and 7.3.6.

7.1.6 **Street lighting**

The presence of street lighting is likely to have an impact on the appearance of the IPV within the works area, for example:

- signs and signals to the rear of the IPV may become less visible to the road user due to the reduced contrast;
- street lighting may help approaching drivers to observe the location of the vehicle on the carriageway;
- street lighting may assist operatives in identifying a suitable path of escape.
However, the advantages or disadvantages of each of these points cannot easily be quantified and, as such, the presence of street lighting should be considered but is unlikely to be a major factor within a site specific risk assessment.

In addition, consideration should also be given to whether or not the street lights will be switched off; in some areas street lights are turned off at midnight which may have an effect on how drivers approach the works.

### 7.1.7 Road geometry/topography

Road geometry refers to the curvature and topography refers to the gradient of any slopes within a given section of road. Road geometry and topography are closely linked to visibility with sharp bends and steep hills reducing the visibility of worksites for approaching vehicles. Within TSM Chapter 8 section D1.6.3 (Department for Transport, 2009) ‘good visibility’ is defined as visibility extending to the full length of the stopping sight distance where ‘stopping sight distance’ is the distance required for a vehicle to come to a stop, taking into account the time taken to perceive, react, brake and stop safely. Table 8 displays the desirable minimum stopping sight distances by speed.

**Table 8: Stopping sight distances by design speed (Highways Agency, 2002)**

<table>
<thead>
<tr>
<th>Design speed (km/h)</th>
<th>Stopping sight distance - desirable minimum (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>120</td>
<td>295</td>
</tr>
<tr>
<td>100</td>
<td>215</td>
</tr>
<tr>
<td>85</td>
<td>160</td>
</tr>
<tr>
<td>70</td>
<td>120</td>
</tr>
<tr>
<td>60</td>
<td>90</td>
</tr>
<tr>
<td>50</td>
<td>70</td>
</tr>
</tbody>
</table>

Where visibility is poor, the likelihood of collision with an IPV is higher as drivers have less time to observe, understand and react to the presence of an IPV on the carriageway.

When operating using dual vehicle working on a bend, consideration should be given to the separation distance between vehicles. Out of control road user vehicles are more likely to deviate from the carriageway to the outside of any curvature in the road. If a vehicle deviates whilst travelling on a curve, and the distance between the vehicles is too great, there is an increased chance it may miss the rear upstream vehicle and strike the rear of the works vehicle (see Figure 20).
The distance between vehicles should be shorter when operating on the outside of a curve in the road, whilst still remaining within the 75m (+/-25m) recommended range. When operating on the inside of a curve there is less chance a road user will enter the gap between the two vehicles and as such site specific risk assessment may indicate that a distance towards the upper end of the recommended range is more appropriate.

When operations are conducted on a straight road, provided the gap between the vehicles is not too large that road users come in between the two vehicles, a direct collision with the rear of the works vehicle is unlikely if the approaching vehicle is travelling in a nearside lane, for example an HGV in lane 1 encroaching across the rib line. These vehicles are more likely to side swipe the works vehicle or clip the offside front corner. A collision with the rear of the works vehicle may be more likely if a vehicle is changing multiple lanes from the offside lane to the nearside lane and loses control during the manoeuvre (see Figure 21).

---

2 Note that the curvature of the road is exaggerated to show the influence clearly
The geometry and topography of a site do not just affect the sight lines for road users; road workers acting as a lookout or attempting to cross the carriageway in order to install advance signs on the central reserve may have difficulty observing oncoming traffic. When sites are risk assessed, it is important that both sight lines for road users and road workers are considered; tapers should be positioned in safe locations (see section 7.1.3).

Road topography is also closely linked to the availability of an escape route: for example, elevated sections provide no escape route for operatives should a collision with the vehicle seem imminent (see section 7.3.1).

### 7.1.8 Presence of junctions

#### 7.1.8.1 Slip roads and junctions

Worksites located close to slip roads often present greater risk for those working on the rear of the works vehicle. When dual vehicle working is employed, there are often times where the downstream vehicle is unprotected from approaching traffic (Figure 22).
This can be especially dangerous for operations in the nearside lane where vehicles entering from an on-slip are at near-traffic speed. In these situations, it may be beneficial to close the slip road to prevent such incidents occurring, or to ensure the downstream vehicle is also equipped with an LMCC to absorb some of the impact energy in a collision (though this is unlikely to help protect the operatives working from the rear of the vehicle in a collision). When working in an offside lane, reducing the distance between the two vehicles may reduce the likelihood of a collision with the works vehicle, as drivers are less likely to cut between them.

When working close to other junctions, for example where local roads join trunk roads, a similar situation may arise where the works vehicle is unprotected from the upstream IPV. In these situations, the likely impact speed may be lower than on slip roads, but the sight lines are often worse. The mitigations described above may also be beneficial in these situations.

7.1.8.2 Roundabouts

Roundabouts often present issues of manoeuvrability when operating using dual vehicle working: if the distance between arms is short then dual vehicle working may not be a practicable way of reducing risk as the works vehicle may be left unprotected from approaching traffic (Figure 23).
Figure 23: Dual vehicle working on a roundabout where the upstream vehicle cannot sufficiently protect the works vehicle

On roundabouts with short distances between arms, speed is likely to be low. If a collision were to occur then the injury severity for operatives should be low. However, it is recommended that, where possible, the works vehicle used should be fitted with an LMCC to protect drivers.

On larger roundabouts, where the distance between arms is greater and speed is likely to be higher, dual vehicle working is likely to provide more protection for the operatives. The upstream vehicle should be situated such that it is unlikely an approaching vehicle will collide with the rear of the works vehicle; this method of working will normally reduce the overall injury severity and number of operatives injured (Figure 24).

Figure 24: Dual vehicle working on a roundabout where the upstream vehicle sufficiently protects the works vehicle
When using dual vehicle working, depending on the geometry of the roundabout, the distance between the two vehicles may decrease. However, the traffic speed is likely to be lower (due to the radius of the curve) so the likelihood of a secondary collision with the works vehicle, if the IPV were to be hit, may be reduced.

When conducting a site specific risk assessment involving a roundabout, consideration should be given to the protection offered by a second vehicle. Whilst the distance may not be sufficient between arms to provide full protection to the works vehicle whilst negotiating the roundabout itself, dual vehicle working may still represent a lower level of risk than single vehicle working, particularly when working on the entry roads to a roundabout or exit roads where sightlines are poor.

7.2 Traffic characteristics

7.2.1 Flow
Flow refers to the number of vehicles per hour that use a given carriageway. Increasing flow changes lane occupancy and may increase the number of vehicles in the lane in which, or adjacent to which, the IPV is located. Traffic volume is the single most important factor influencing the number of road accidents (Elvik, 2004). The higher the traffic flow past an IPV, the greater the likelihood that another vehicle will collide with the IPV. Unless traffic begins to become congested, which is unlikely when temporary road works are taking place, an increase in flow is therefore likely to increase road worker risk.

7.2.2 Number of HGVs
Accidents involving HGVs are likely to be more severe than those involving a car; as such, a higher number of HGVs in the lane in which the IPV is in operation increases the injury risk to operatives working in and around the vehicle. Dual vehicle working is likely to reduce this injury risk both in terms of severity and number of operatives injured. If the rear of the upstream vehicle is struck by a HGV, its driver is likely to be seriously injured. However, provided the works vehicle is a sufficient distance downstream of the IPV, the operatives working on the rear of the works vehicle should not be injured.

IPV collisions involving HGVs are less likely when operating on the offside of a carriageway with three or more lanes, as HGVs must only use lanes 1 and 2.

The number of HGVs is also likely to have a substantial effect on a number of other factors, such as:
- overtaking manoeuvres;
- overall speed;
- lane occupancy;
- obscuration of advance warning signs and/or the taper.

For example, a larger number of HGVs is likely to result in increased obscuration. This obscuration may result in other road users having reduced information on the presence and location of the works and thus manoeuvres (e.g. overtaking) may be undertaken later increasing the likelihood of a collision with an IPV.
7.2.3 Lane occupancy

On dual carriageway roads lane occupancy refers to the proportion of vehicles in each lane. The biggest influence on lane occupancy is flow: in low flow conditions, the majority of vehicles should be travelling in the nearside lane (Department for Transport, 2013). Increasing flow pushes more vehicles into lane 2 (and any other offside lanes).

The number of HGVs may also influence lane occupancy as vehicles choose to change lane to overtake slow moving HGVs travelling in the nearside lane(s) (see section 7.2.2).

If the flow is low in the lane in which the IPV is in operation, (and unlikely to change over the period in which the IPV is in operation) then the likelihood of collision may also be low. However, if flow is particularly low then this may increase the speed of approaching vehicles (see section 7.2.4).

7.2.4 Speed of approaching vehicles

Speed is linked to a number of other factors including flow (section 7.2.1), number of HGVs (section 7.2.2) but also to the speed limit of the road in question.

HGVs are limited to 60mph (or 56mph) on motorways and 50mph on dual carriageways. Cars often travel in excess of 70mph, creating a speed differential between the two vehicle types. Previous research (Taylor, Lynam, & Baruya, 2000) has shown that the greater the coefficient of variance of speed (a measure of the range or ‘spread’ of speed behaviour), the higher the accident rate, although this is often correlated with average speed.

Lower speeds allow drivers more time to observe the presence of an IPV within a live lane and react accordingly (provided other factors such as geometry do not interfere with the line of sight of an approaching driver). Lower speeds also result in less impact energy in a collision and thus the severity of injuries sustained within these accidents (by both the road user and road worker(s)) is likely to be lower than in a collision involving a much higher speed road user vehicle.

7.2.5 Issues with compliance of signs or signals

As discussed in section 7.4, where the hard shoulder is commonly used as a running lane, IPV(s) located within this lane may have a higher likelihood of collision than on roads where the hard shoulder is never opened as a running lane, due to driver expectancy that the lane will be open. Poor compliance with signs and signals might arise as a result of drivers:

- not paying attention to the signs and signals,
- paying attention to but not reading the signs and signals,
- reading the signs and signals but not understanding them

The following list contains examples of when the above might be more likely:

- Obscuration by other vehicles, bridges, vegetation etc.;
- Faulty signs or signals e.g. missing LED’s on VMS panels or inadequate cleaning of hard signing;
- Inadequate contrast for the ambient lighting conditions e.g. difficult to read in bright sunlight;
- Lack of enforcement e.g. areas where drivers perceive prosecution levels are low;
- Contradictory signs or signals;
- Driver impairment issues resulting from the information given e.g. information overload.

Each of these points needs to be considered when evaluating the likely level of compliance. At sites where compliance is likely to be low, collision likelihood will be higher.

### 7.3 Operational considerations

#### 7.3.1 Availability of escape route

When operating an IPV, the driver of the vehicle should be correctly restrained within the cab using seatbelts with a minimum of three points of anchorage and the head restraint (specified in TSM Chapter 8 O5.5.5 (Department for Transport, 2009)). Correctly fitting restraints help to reduce the injury severity should a collision with the vehicle occur.

Operatives working from the rear of the works vehicle have no such protection; if the vehicle is struck then the injuries sustained are likely to be fatal or severe. If there is the chance that the vehicle upon which the operatives are working may be struck by an approaching vehicle, then the availability of an escape route (and the availability of a pre-collision warning system) is likely to be beneficial.

In locations where an escape route is not available, for example in tunnels, on elevated sections or where noise barriers are present (see Figure 25), dual vehicle working is likely to be particularly beneficial. Dual vehicle working reduces the need for an escape route; if a collision occurs it is likely it will be with the upstream vehicle and, provided the separation distance between vehicles is appropriate, there is a much lower chance that operatives working from the rear of the works vehicle will be seriously injured.
7.3.2 Weather/visibility

The likelihood a road user will collide with an IPV is increased when visibility is reduced. Road users approaching a worksite can experience reduced visibility as a result of poor weather (e.g. fog, rain or snow) or as a result of factors affecting the sight lines (e.g. road signs, vegetation or the curvature of the road). Relaxation works should only be carried out where there is good visibility; taper locations should be chosen such that sight lines are sufficient for both road users and road workers (see section 7.1.3).

Poor visibility can be a particular issue when operatives are crossing the carriageway in order to install advance signs (see section 7.3.6).

7.3.3 Time of day

Live lane static traffic management is predominantly carried out at night when traffic flows are lower. In these situations, vehicle speeds are often higher than during the day and lane occupancy may also differ. See sections 7.2.1, 7.2.3 and 7.2.4 for information on flow, lane occupancy and speed.

IPV lighting may appear differently in daylight and in darkness. However, in a given condition, an approaching driver will see no difference in the appearance of the rear of the vehicle between single and dual vehicle working (unless the approach is on a bend). Hence, time of day is unlikely to be a major factor within a site specific risk assessment to determine whether to use dual or single vehicle working.
7.3.4 Vehicle being used

Traditional TM vehicles require one operative to work on the rear of the vehicle to pass signs faces and frames to an operative on the ground. This position on the rear of the vehicle is high risk; if a collision were to occur the operative would be thrown forwards towards the cab of the vehicle and equipment stored on the vehicle would likely be thrown on top of them. Collisions such as these are likely to result in very serious or even fatal injuries to the operative on the rear.

Engineering solutions can reduce the need for operatives to be in high risk positions. For example, if sign faces and frames are stored at low level on the rear of the vehicle this eliminates the need for operatives to be on the bed of the vehicle when in a live lane.

The risk calculations in section 5.3 assume that any IPV or TMIPV which is used meets the 10 tonne minimum weight requirements for these vehicles (Department for Transport, 2009). Works vehicles (TMVs) are also assumed to be of a similar size and weight. In some situations, where used as part of a dual vehicle arrangement, a smaller works vehicle such as a small truck might be used. This may reduce the likelihood of a collision because it is narrower than other TMVs. However, if this vehicle were to be struck by a road user vehicle, then injuries to operatives may be more severe than if a >10 tonne TMV was used. The absence of a crash cushion and the lower mass means the vehicle will experience higher acceleration when struck and less of the impact energy will be absorbed by the vehicle.

When dual vehicle working is used, consideration should be given as to whether the downstream works vehicle should also be equipped with an LMCC; the risk calculations in section 5.3 demonstrate that this may achieve a lower level of risk for road workers. If a collision with this vehicle were to occur, the LMCC would absorb some of the energy in the collision, potentially reducing the injury severity of both the road workers and road users.

However, it is not always practicable to fit the works vehicle with a cushion. For example, it may not be possible to fit a small truck or other works vehicles such as sweepers and drain cleaners with an LMCC.

In the small truck scenario, the risk assessment should consider whether the reduced collision likelihood from using a narrower vehicle offsets the likely increased severity should a collision occur. The risks to both road users and road workers should be considered and the vehicle selected on the basis of reducing the risk to ALARP.

In the case of sweepers and drain cleaners, it is vital that a suitable separation distance is maintained between the two vehicles; this distance should not be too long as road users may choose to cut back in between the two vehicles, but should not be so short that, if a collision were to occur, the IPV would be shunted downstream into the works vehicle.

7.3.5 Advance signing method

The Chapter 8 standard relaxation layout involves the use of advance signs on both the nearside and offside at 800, 600, 400 and 200 yards from the taper. Alternative layouts include sign simplification and offside signs removal (as described in IAN 150/12 (Highways Agency, 2012)). These layouts are shown in Figure 26.
The reduction in signs and carriageway crossings achieved through use of one of the alternative layouts (sign simplification or OSSR) reduces the exposure of operatives and vehicles to traffic and hence reduces the likelihood of a collision with an IPV compared to the standard Chapter 8 relaxation layout (see section 7.3.6).

Another way to reduce the risk associated with installation/removal of advance signs is use of alternative vehicles such as vehicles which store signs and frames at a low level reducing the need for operatives to be on the rear of the vehicle (see section 7.3.4).

On roads with a hard shoulder the vehicle(s) will park on the hard shoulder in order to unload and install signs. When installing the advance signing for a nearside closure on a road with no hard shoulder, the IPV is located in lane 1 when installing the advance signs (section 7.1.4). When installing from lane 1, there is a higher likelihood that the IPV will be struck.

There may be situations in which the presence of a works vehicle within a live lane contradicts the signs already installed. For example, when installing the advance signing for an offside closure on a road with no hard shoulder, the IPV may be temporarily located in lane 1 when installing the advance signs; the presence of the vehicle within this lane conflicts with the information displayed on the signs. Hence, in this situation there is an increased likelihood of collision.

For offside closures, after the advance signs have been installed, the vehicle(s) will manoeuvre from the hard shoulder to the offside lane, ready to begin installation of the taper. When operating using two vehicles, manoeuvrability may be an issue and there is a chance the works vehicle may be temporarily unprotected in a live lane (section 5.2.2).

Figure 26: Advance signing layouts
The HA is currently trialling the use of gantries and MS4s as advance warning of lane closures. If these methods prove to be acceptable then under certain conditions installation and removal of advance signing may no longer be required; all advance signs will be set from a regional control centre.

### 7.3.6 Carriageway crossings

The need for carriageway crossings can be reduced by application of IAN 150/12 (Highways Agency, 2012). This IAN outlines two techniques which reduce and eliminate the need for carriageway crossings. Sign simplification reduces the number of times operatives must cross to the central reserve (see Figure 26 (b)) and offside signs removal completely eliminates the need for operatives to cross the carriageway when installing advance signs (see Figure 26 (c)). Reducing carriageway crossings reduces the exposure of operatives and hence the exposure of the vehicle(s) involved. This therefore reduces the likelihood of collision with the rear of an IPV.

During communications with service providers, it was indicated that a vehicle in an upstream position may reduce the ability of operatives to see oncoming traffic. CIS53 (HSE, 2000) details the requirement for ‘adequate sight lines’ for workers crossing the carriageway on high-speed roads. The extent to which an IPV parked upstream obscures the view of workers crossing the carriageway has been investigated for varying separation distances and road geometries (section 5.2.1). A shorter separation distance between vehicles increases the obscuration of oncoming traffic by an upstream vehicle. Location within the hard shoulder is also seen to have an effect. Right hand bends obscure the view upstream the least and left hand bends the most whilst other factors such as trees and signs can compound the issue further.

### 7.3.7 Taper deployment method

The decision as to whether to use dual or single vehicle working affects the way in which the taper can be installed and removed. The implications for the installation and removal of the taper therefore need consideration when deciding whether to use dual vehicle working.

When using dual vehicle working there are three possible methods for installation of the taper:

- IPV follows works vehicle into the closure (Figure 27);
- IPV remains at start of taper (Figure 28);
- IPV remains at start of taper and taper cones moved to allow IPV into the closure (Figure 29).
Figure 27: Dual vehicle working - IPV follows works vehicle into the closure
Figure 28: Dual vehicle working - IPV remains at start of taper
When using the method in which the IPV follows the works vehicle into the closure (Figure 27), there is limited benefit to having the IPV present as it is very difficult to maintain a suitable separation distance; as the taper is installed the distance between the vehicles decreases from over 100m to less than 50m. If a vehicle were to hit the rear of the upstream IPV when it is close to the works vehicle, a secondary collision may occur and more operatives are likely to be injured than if single vehicle working had
been employed. More importantly, operatives will work upstream of both vehicles and as such have no vehicular protection from oncoming vehicles.

When using the method in which the IPV waits upstream of the taper (Figure 28), careful consideration should be given to the separation distance between the two vehicles. After the taper cones have been deposited from the vehicle, the distance between the two vehicles will exceed the recommendation of 75m (+/-25m) due to the length of the taper; this may increase the risk of a road user vehicle cutting back between the two vehicles and colliding with the taper or the rear of the works vehicle. When installing the taper itself, operatives will work between the IPV and the works vehicle; consideration should be given to the separation distance between the IPV and the operatives. The distance should be sufficient to mitigate the risk of operatives being hit by the IPV if it is struck and shunted downstream.

In addition to the separation distance considerations, there may also be manoeuvrability issues (as discussed in section 5.2.2) associated with this method. These issues may be resolved by using the method where a number of the taper cones are moved to allow the IPV into the closure (Figure 29).

When using dual vehicle working, the alternative taper (Figure 30) can be constructed using two methods: the IPV follows the works vehicle into the closure and the IPV remains at the start of the taper. It is more difficult to use the method in which the taper cones are moved to allow the IPV into the closure due to the positioning of the cones. as lateral "bars" across the carriageway.
Figure 30: Alternative taper
### 7.3.8 Longitudinal method

The longitudinal run consists of a number of components (Figure 31).

![Figure 31: Taper and longitudinal run components](image)

*Figure 31: Taper and longitudinal run components*
The longitudinal safety zone is an area within the closure into which vehicles and operatives should not enter. Errant drivers, entering the closure from the taper, may start to brake as taper cones are hit. If the vehicle does not come to a stop before the end of the taper, the safety zone should provide sufficient additional braking distance for the vehicle to come to a halt before it enters the area in which operatives and vehicles are present. Once the safety zone is complete, there is a reduced need for two vehicles due to the protection offered by the exclusion zone. However, there is still a risk that vehicles enter the closure laterally; therefore the use of an LMCC equipped vehicle should still be considered even after the requirement for two vehicles has been reduced.

During removal of the longitudinal run, consideration should be given to the practicalities of manoeuvring and positioning two vehicles. Reversing with two vehicles can be very difficult and, due to the reduced need for a block vehicle whilst the safety zone is in place, single vehicle working may be more suitable in this instance. The presence of an IPV may only become beneficial after the safety zone has been removed.

### 7.3.9 Confirmation of Setting of Variable Signs and Signals

As discussed in section 7.1.5, the presence of variable signs and signals can provide additional warning of a lane closure ahead. However, there are occasions where the VSS fail or display an incorrect message due to operator or technical errors. It is important that, if VSS are used, the information they display is consistent with the message displayed on the conventional ground-level signs. It may be prudent for a service provider staff member to drive past the closure to confirm the signs and signals are displaying as they should after the VSS have been set and at regular intervals thereafter. It’s possible that the VSS may be required for other purposes during the works (e.g. to sign an incident); as a result, VSS should only be used as additional safety measure and not as a primary mitigation mechanism.

### 7.3.10 Communications with the Regional Control Centres

Suitable communication channels should exist between the on-road team and the Regional Control Centre (RCC) staff. These channels should be used to notify the RCC when the VSS should be set, what they should be displaying and when they are to be switched off or changed.

Poor communication between the site and the RCC could lead to incorrect electronic signalling being used, which could increase the risk to operatives working on the carriageway.

If the VSS fail for any reason, the on-road team should be notified as soon as possible by the RCC so that this is taken account of in the on-going dynamic risk assessment by the service provider.

### 7.4 Specific considerations for Smart Motorways

The term ‘Smart Motorway’ covers three different types of motorway:

- Controlled motorway - three or more lane motorways with variable speed limits. The hard shoulder should only be used in emergencies.
- Dynamic use of the hard shoulder (DHS) - the hard shoulder is opened at busy times and the speed limit is reduced.
- All lane running (ALR) - there is no hard shoulder on these sections of motorway, variable speed limits apply.

The introduction of these motorways in recent years has presented a number of additional considerations to those outlined in sections 7.1 to 7.3. These considerations do not just apply to Smart Motorways themselves, but also to stretches of road downstream of a Smart Motorway.

When a hard shoulder is present, live lane exposure for the vehicle(s) and operatives is reduced. On sections of road where the hard shoulder is sometimes used as a running lane (i.e. DHS), IPV(s) located within this lane may have a higher likelihood of collision than on roads where the hard shoulder is never opened as a running lane. This increased collision likelihood is related to driver expectancy; on these motorways regular users of the motorway section may expect the hard shoulder to be open and thus use it as a running lane even when it is no longer in operation (this is referred to as hard shoulder abuse). Hard shoulder abuse may also be prevalent on roads downstream of DHS or ALR motorway sections if users do not realise the nature of the carriageway has changed. If the likelihood of hard shoulder abuse is high then this increases the likely benefit arising from having an upstream vehicle.

When operating on Smart Motorways, consideration should be given to using variable message signs to provide additional warning of the presence of the closure making drivers more aware of the situation ahead and potentially reducing the likelihood of collision. VMS can also be used to display variable speed limits; use of these should decrease speeds and thus may reduce both collision likelihood and maximum injury severity.

Consideration should also be given to the positioning of the works vehicle(s) relative to VMS. Vehicle(s) should be positioned such that road users have sufficient distance to see and understand the information given on the VMS and to take the desired action. On ALR sections all lanes are live lanes; hence there is no relative place of safety (i.e. a hard shoulder) on which to stop the vehicle(s). This increases the likely benefit of using dual vehicle working as the upstream IPV acts as a physical mitigation measure for the operatives working from the works vehicle. Where applicable, consideration should be given to using Emergency Refuge Areas (ERAs) whilst, for example, unloading signs and frames from the works vehicle.

### 7.5 Summary

Prior to works commencing on the Strategic Road Network a site specific risk assessment should be conducted and suitably recorded. This assessment should ensure that the risk to road workers is as low as reasonably practicable (ALARP), whilst not increasing the risk to road users. The likelihood of a collision occurring, the likely number of operatives that would be injured and the likely severity of injuries arising from a collision should all be considered as part of the risk assessment.

The choice of dual or single vehicle working should be part of the risk assessment and should be based on consideration of each of the factors described within this section.
8 Conclusions and Recommendations

The installation, maintenance and removal of temporary traffic management in live lanes may be carried out using either two vehicles per lane (dual vehicle working) with an impact protection vehicle positioned 75m (+/-25m) upstream of the works vehicle or with one vehicle (single vehicle working) which acts as both impact protection and a works vehicle. These situations can result in substantially different risk of injury to road workers.

Current guidance only requires the use of dual vehicle working for mobile lane closures in a live lane. Dual or single vehicle working may be employed for all other works; the decision should be based on a site specific RAMS which details the implementation, maintenance and removal of traffic management arrangements.

Currently, each Managing Agent Contractor (MAC) has a different method for determining whether dual or single vehicle working should be employed. Each of these methods has their advantages and disadvantages; however unification of the process to be followed, including information on the relative risks, would be beneficial in order to ensure best-practice is followed across the industry. Risks to road workers and road users should be reduced to levels that are truly ALARP.

An assessment of the use of vehicles equipped with LMCCs in a number of countries around the world demonstrates a wide range of traffic management approaches; especially in relation to the requirements for dual or single vehicle working. For static operations, some countries mandate the use of dual (or triple) vehicle working in certain situations. For example, Belgium have specific requirements on high speed roads (90km/h or higher) that state protection vehicles (crash cushion equipped vehicles or TMAs) are to be used for protection only. On non-motorways only one protection vehicle is required; however on motorways two protection vehicles are used. In other countries, for example the USA, shadow vehicles equipped with crash cushions are often used to protect workers and equipment (e.g. as part of a dual vehicle arrangement) but are not a mandatory requirement.

The separation distances required between the vehicle equipped with the crash cushion and either operatives on foot or the vehicle in front (if dual vehicle working is in operation) range from a minimum of 10m (New Zealand) to approximately 68m or 222ft (USA). Some countries provide guidance on the separation distance required based on a number of factors including the weight of the protection vehicle, the operation being carried out and on the approaching vehicle speed.

The MIRi index was developed to assess the relative risks of TTM techniques and can be used to compare the relative risks of typical operations using dual and single vehicle working. It takes into account the likelihood of collisions, the number of operatives who would be injured in a collision and the likely severities of the injuries. MIRi therefore provides an indication of the relative risk of different operations on different road types. However, this does not detract from the site-specific risk assessment that is required before installing or removing TTM. The specific issues of obscurcation and manoeuvrability around the taper associated with dual vehicle working, as discussed in section 5.2, should be considered as part of this site-specific risk assessment.
When operating using dual vehicle working for Mobile Lane Closures Chapter 8 (Department for Transport, 2009) recommends a separation distance of 50-100m between vehicles. Collision reconstruction software was utilised to investigate whether this separation distance is likely to be appropriate. The modelling investigated the effect of a collision between two different road user vehicles (44 tonne HGV and passenger car) travelling wholly or partially within the same lane as the IPV and a stationary and braked Impact Protection Vehicle.

The simplified Impact Protection Vehicle used in the model did not accurately reflect the true performance and capabilities of the cushion; thus the modelling is likely to represent the worst-case scenario.

The software was used to determine the likely longitudinal distance a simplified 10 tonne IPV would travel if hit by a 44 tonne HGV travelling at 56mph or a passenger car travelling at 80mph. (Although no consideration was given to the path taken by the impacting vehicle post collision, the speed is likely to be sufficiently lower that it would provide operatives with enough warning to avoid a secondary incident, providing they are located at a suitable separation distance.)

The simulations showed that in collisions where the impacting vehicle is a passenger car (or similar lightweight vehicle) the simplified IPV is not shunted very far; in these collisions the recommended separation distance of 75m (+/-25m) appears to be appropriate. In two of the scenarios, when the simplified IPV was struck by a 44 tonne lorry, it was shunted beyond the minimum recommended separation distance (50m). Hence, if the IPV is likely to be struck by a HGV, then longer separation distances may be more appropriate. However, it is worth noting that an IPV which has been shunted 50m down the carriageway is likely to be travelling substantially slower than immediately after the initial impact. Thus, if the works vehicle were positioned 50m downstream, it is likely that the injuries sustained by operatives working in and around this vehicle would be minor, even if the operatives had not managed to exit the vehicle having been given several seconds’ warning.

When operating using dual vehicle working a site specific risk assessment should be used to determine a suitable separation distance, which should be maintained between vehicles at all times. This distance should be decided based on consideration of the following points:

- Shorter distances decrease the risk of road users re-entering the closed lane between the two vehicles but may increase the risk that if the upstream vehicle is hit it may be shunted into the rear of the works vehicle;
- Longer distances decrease the risk of the upstream vehicle being shunted into the rear of the traffic management vehicle but present a greater likelihood of road users cutting back in to the gap between the two vehicles and colliding with the rear of the works vehicle;
- Collisions involving HGVs are likely to shunt the IPV much further than collisions involving a passenger car;
- Obscuration by the upstream vehicle is worse when the distance between vehicles is shorter;
- Errant vehicles are more likely to deviate to the outside of a curve on the road.
Dual vehicle working where both vehicles are equipped with LMCCs normally represents the lowest level of relative risk for both road workers and road users. Single vehicle working where the vehicle is not equipped with an LMCC has the highest relative risk.

When selecting the method of working, a site specific risk assessment should be conducted and suitably recorded. There are a number of operational factors to be considered when conducting this assessment, these factors include:

- Site characteristics e.g. road geometry
- Traffic characteristics e.g. flow; and
- Operational considerations e.g. requirement for carriageway crossings.

The assessment should consider each of the factors including how dual and single vehicle working relate the three aspects of risk: the likelihood of a collision occurring, the likely number of operatives injured and the likely severity of the collision.

This report has focussed on the risks associated with installing, maintaining and removing temporary traffic management in live lanes. The principles covered in this report may apply to other on-road activities conducted on behalf of the Highways Agency which use IPVs to provide protection to slow moving or stationary vehicles or personnel on the carriageway. It may therefore be beneficial for the HA to consider applying the principles reported here within other HA standards.
Glossary

**ALARP**
As low as reasonably practicable.

**Block vehicle**
An IPV acting as protection for vehicles and operatives working downstream. This vehicle should normally be positioned within the same lane as the downstream vehicle at a suitable separation distance.

**Dual vehicle working**
Use of two vehicles operating with a suitable separation distance. The upstream vehicle (an IPV) is equipped with an LMCC; the downstream works vehicle may or may not be equipped with an LMCC.

**Errant vehicle**
An out-of-control road user vehicle which poses a threat to vehicles or operatives working on the carriageway.

**Good visibility**
Visibility extending to the full length of the stopping sight distance. For site stopping distances see TD 9 “Highway Link Design” (DMRB 6.1.1), Table 3 (Highways Agency, 2002).

**Heavy vehicle**
Any of the following vehicles:
- Any vehicle drawing a trailer;
- A goods vehicle between 3.5 tonnes and 7.5 tonnes, which is required to be fitted with a speed limiter;
- A goods vehicle exceeding 7.5 tonnes (HGV);
- A passenger vehicle exceeding 7.5 tonnes adapted to carry more than eight seated passengers;
- A passenger vehicle not exceeding 7.5 tonnes which adapted to carry more than eight seated passengers which is required to be fitted with a speed limiter.

**HGV**
A goods vehicle with a maximum laden weight exceeding 7.5 tonnes.

**IPV**
Impact Protection Vehicle – a vehicle equipped with an LMCC conforming to the specification detailed in TSM Chapter 8 section O5.5.5 (Department for Transport, 2009).

**LMCC**
Lorry Mounted Crash Cushion.

**Protection vehicle**
See block vehicle.

**RAMS**
Risk assessment and method statement.

**Separation distance**
Distance required between the protection vehicle (IPV) and downstream works vehicle. This distance is specified as 50-100m within TSM Chapter 8 (Department for Transport, 2009).
<table>
<thead>
<tr>
<th><strong>Single vehicle working</strong></th>
<th>Use of a combined traffic management and impact protection vehicle (TMIPV) or traffic management vehicle not equipped with an LMCC (TMV).</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TMA</strong></td>
<td>Truck mounted attenuator</td>
</tr>
<tr>
<td><strong>TMIPV</strong></td>
<td>Traffic Management Impact Protection Vehicle – a combined traffic management and impact protection vehicle. This vehicle is equipped with an LMCC and can be used for installation and removal of the works. It can be used with or without an upstream protection vehicle.</td>
</tr>
<tr>
<td><strong>TMV</strong></td>
<td>Traffic Management Vehicle - this vehicle is not equipped with an LMCC. It can be used for installation and removal of the works when protected by an upstream IPV. It should not operate in a live lane of a dual carriageway unprotected by an IPV.</td>
</tr>
<tr>
<td><strong>VMS</strong></td>
<td>Variable Message Sign e.g. overhead gantries, MS4s etc.</td>
</tr>
<tr>
<td><strong>Works vehicle</strong></td>
<td>Any vehicle involved in installation, maintenance or removal of traffic management.</td>
</tr>
</tbody>
</table>
References


Appendix A Obscuration Photos

Figure 32: Operatives view (from the edge of the hard shoulder) upstream on a straight road
**Figure 33:** Operatives view (from the rib line) upstream on a straight road
Figure 34: Operatives view (from the edge of the hard shoulder) upstream on a right hand bend
Figure 35: Operatives view (from the rib line) upstream on a right hand bend
Figure 36: Operatives view (from the edge of the hard shoulder) upstream on a left hand bend
Figure 37: Operatives view (from the rib line) upstream on a left hand bend