Transport Research Laboratory

Development of the Measurement of Injury Risk (MIRi) Index

by C Fowler, S Clark, I Rillie, R Cuerden and L Smith

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Task 400(1308)HALC

CLIENT PROJECT REPORT

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	Development of the Measurement of Injury Risk (MIRi) Index
Client:	**Highways Agency, NetServ**
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This Draft Report has been prepared for Highways Agency for the sole purpose of Project Report Review. It may only be disseminated once it has been completed and issued with a final TRL Report Number.

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Executive summary

Every year a number of road workers suffer fatal or life changing injuries as a consequence of their work. Other road workers suffer less serious injuries but the Highways Agency is committed to ensuring the safety of all road workers involved in maintaining the strategic road network. This requires prioritisation of investment and activity to ensure that safety of road workers is improved and that the benefits from these improvements can be measured and realised.

The highest risk process undertaken by road workers is traditionally viewed to be the deployment and removal of temporary traffic management (TTM). The MIRi Index has been developed from an in-depth understanding of the work processes involved with deploying TTM. The index applies to the deployment and retrieval of TTM associated with relaxation closures (excluding the longitudinal coning), which accident and incident data suggests is the highest risk activity undertaken by road workers.

The MIRi Index has been supplemented with a carriageway crossing value. This is based on an aggregated value of carriageway crossings and is not a precise value against which the Supply Chain should be assessed, but instead is designed to allow quantification of the substantial reductions in carriageway crossings that can be achieved by changes in working practices.

Examining the data from the MIRi Index demonstrates that the selection of the base method for deployment and retrieval of TTM is critical to achieving the lowest possible MIRi Index score. Elimination of carriageway crossings is an important part of reducing risk but without a sound base MIRi Index score it is likely that eliminating carriageway crossings will not drive down risk to road workers to a level that can be shown to be as low as reasonably practicable.

The analysis of the MIRi Index and carriageway crossing data was extended to two potential techniques that have been identified as approaches to reduce carriageway crossings. The TTM Sign Simplification (TTMSS) approach seeks to eliminate the 600 yard and 200 yard advance signing together with the Detail 'A' elements on the hard shoulder adjacent to the entry taper. This approach has the potential to reduce the MIRi Index by up to 22% and to decrease carriageway crossings by up to 52%.

If an aggregated value is calculated for likely decrease (based on best-estimate for the number of TM installations carried out using each method), TTMSS can achieve a national reduction in MIRi Index of 19% and a reduction in carriageway crossings of 46%. This is a substantial reduction which can be achieved with no additional equipment or requirements for road workers.

The second approach considered is that of offside signs relaxation (OSSR), where for nearside lane closures the offside signs are omitted. This achieves a similar reduction in MIRi Index (up to 28%) but reduces carriageway crossings by 100%. However, as this technique is only applicable to nearside lane closures its contribution towards achieving a substantial reduction in carriageway crossings is limited; if the two techniques are combined the indications are that the MIRi Index will decrease by an additional 2% to 21%, with carriageway crossings decreasing by an additional 9% to 55%.

These figures are based on a number of assumptions; it is recommended that these are validated from the Schedule of Road Works before these values are cited as evidence of likely benefit.

1 Introduction

Every year a small number of road workers are seriously injured or killed whilst maintaining the Highways Agency (HA) strategic road network and a significant number of other road workers suffer less serious harm. A number of these operatives are involved in setting out the cones, signs and lamps associated with road works. These road workers undertake some of the most hazardous activities during their work, as they work in close proximity to live traffic travelling at or above the national speed limit with little or no physical protection and often during the hours of darkness.

The HA's '*Aiming for Zero(AfZ): Safety for Our Road Workers*' strategy sets out a bold vision to achieve a "substantial" reduction in crossings of the live carriageway by the end of 2011 and eliminate completely the requirement for road workers to be on foot on live carriageways during routine maintenance operations carried out after 2016 ("*Exposure:Zero*"). Quantifying the risk associated with on-road operations gives a measurement of injury risk (MIRi) that can be used to prioritise activity and demonstrate progress and improvements toward AfZ targets.

The work required for development of the MIRi Index has required investigation of current practices for road works and analysis of the current level of exposure to injury risk associated with these operations. A three dimensional risk matrix has been designed which, unlike other risk matrices, incorporates a measure of the road workers' duration of exposure to risk, thus allowing a benchmark Measurement of Injury Risk (MIRi) Index to be calculated. The MIRi Index has been developed in such a way that it will remain a useful measure for road worker safety improvements once the vision of "*Exposure:Zero*" is achieved.

This report presents the results from the development of the MIRi Index as described above. It begins by looking at the relationship between vehicle impact speed and injury outcome, and investigates accident data via analyses of Stats 19 and AIRSWeb data for accidents to road workers. The report then outlines the methodology for the development of the MIRi Index and presents the results from applying this methodology to deriving the MIRi Index values for currently reported industry practice (benchmark MIRI Index for 2010), and for two proposed temporary traffic management initiatives (reduction in advanced signing; and offside signs relaxation). The effect of combining initiatives is discussed along with potential future developments in the MIRi Index that would enable quantification of risk to all road workers.

2 Relationship between vehicle impact speed and pedestrian injury outcome

When the front of a moving vehicle strikes a pedestrian there are a number of factors which directly contribute to the risk and the type of injuries that he or she may sustain, these include:

- the biomechanical tolerance of the pedestrian, often related to their age and state of health;
- the height of the pedestrian, which has a bearing on where and how the different parts of the body are loaded by the vehicle;
- the shape and stiffness properties of the vehicle's front structure, from flat fronted vans or lorries to low profile sports cars; and
- the speed of the vehicle on impact.

This section summarises the larger body of work presented in Appendix A

2.1 Background

The overall risk of injury for an individual accident is complex, as a number of different parameters need to be understood. Figure 2-1 gives a breakdown of Great Britain's reported pedestrian road casualties (STATS19, 2009),with injury severities classified by the police according to the British government's definitions of Fatal, Serious or Slight.

Proportionally more males suffered fatal injuries when involved in pedestrian accidents than females, whilst younger pedestrians received a higher proportion of serious injuries, with older pedestrians suffering fatal outcomes more frequently.

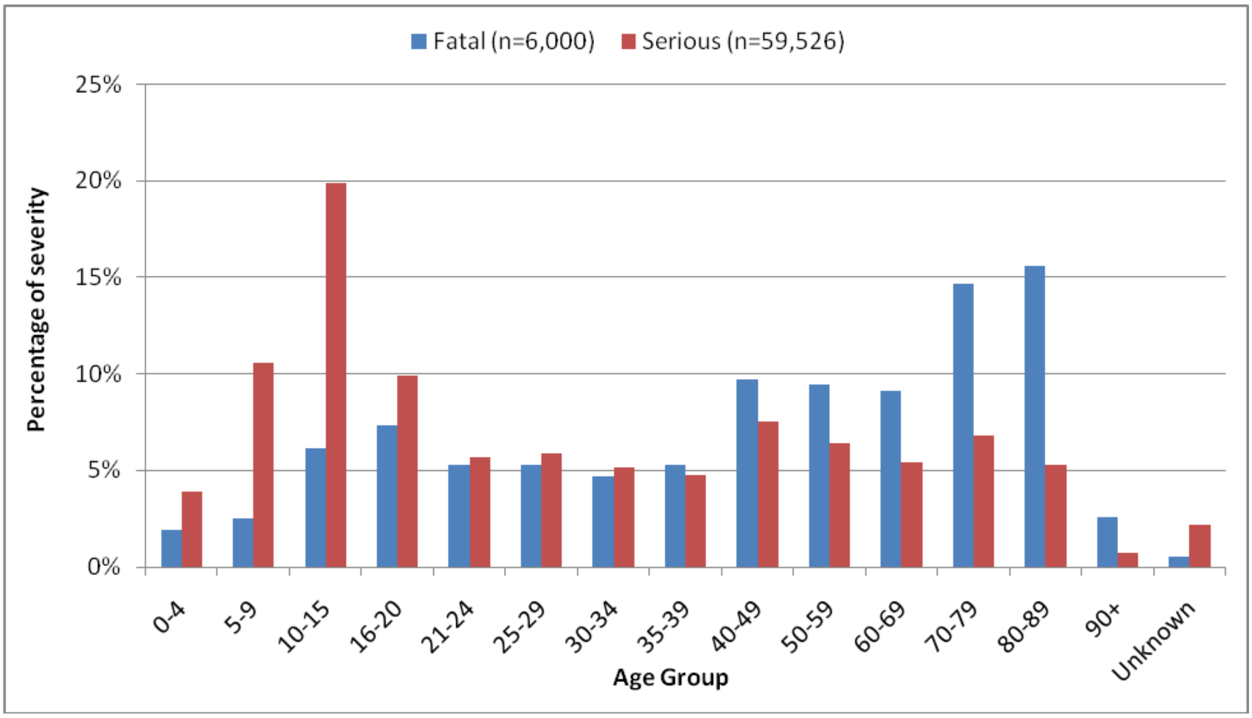


Figure 2-1: Injury severity by age (STATS19)

Figure 2-2 shows the distribution of pedestrian injury severity by the type of vehicle involved in the accident. Nearly 70% of the fatalities and over 80% of the serious casualties are due to impacts with cars. As would be expected, heavy transport vehicles are over-represented when the pedestrian is fatally injured whereas cars/taxis were under-represented.

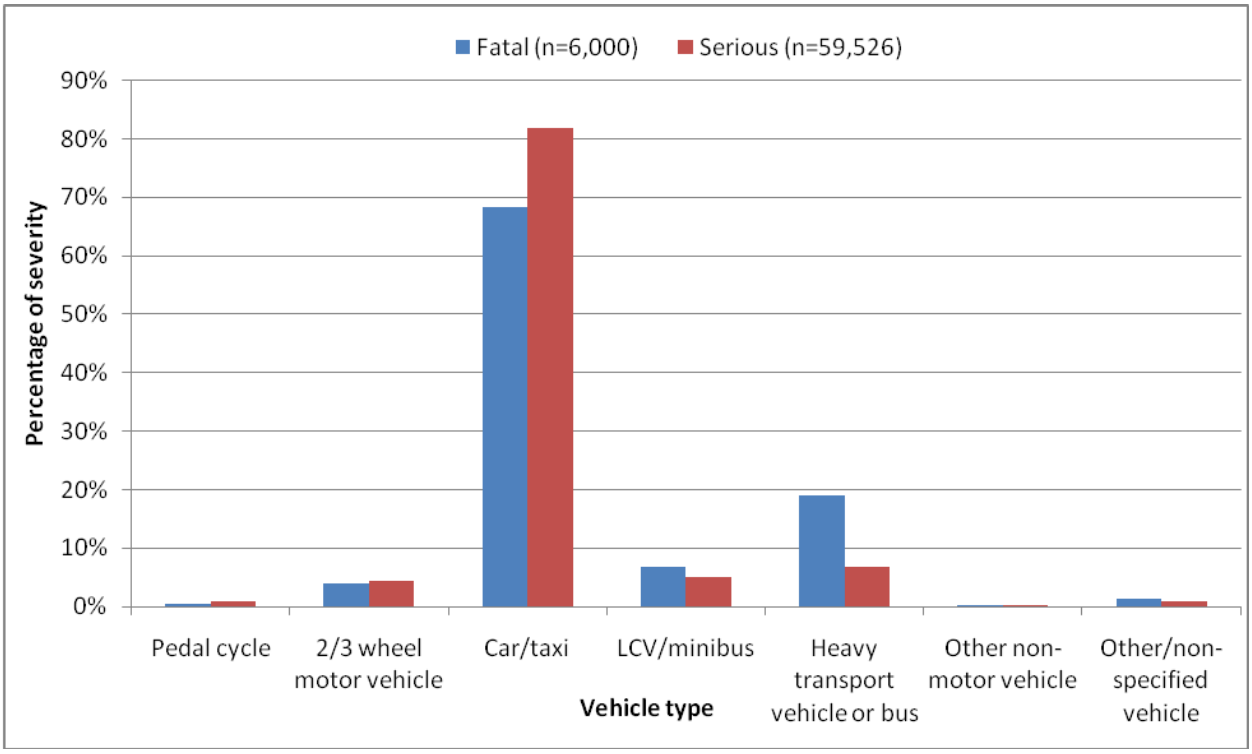


Figure 2-2: Injury severity and vehicle type (STATS19)

2.2 Car and pedestrian collisions

Recent research by TRL (Richards, 2010, Cuerden *et al*. 2008) has quantified the risk of pedestrian injury when struck by the front of a car (Figure 2-3).

Figure 2-3 highlights the risk of suffering injury of a given severity depending on the impact speed, where for low speeds, for example less than 10mph, over 90% sustain slight injuries; whereas for high speeds, for example above 60mph, over 90% are killed. For pedestrians struck by the front of cars at 20mph, approximately 1% are killed, 26% are seriously injured and 73% are slightly injured. When the impact speed increases to 50mph, approximately 72% are killed, 21% are seriously injured and 7% are slightly injured.

Due to the wide range of impact types and people considered there are outliers in the data, with some individuals surviving very high speed impacts and others being killed at relatively low speeds. However, the overall pattern is very clear, with a significant rise in the gradient of the fatal risk curve above impact speeds of 30mph.

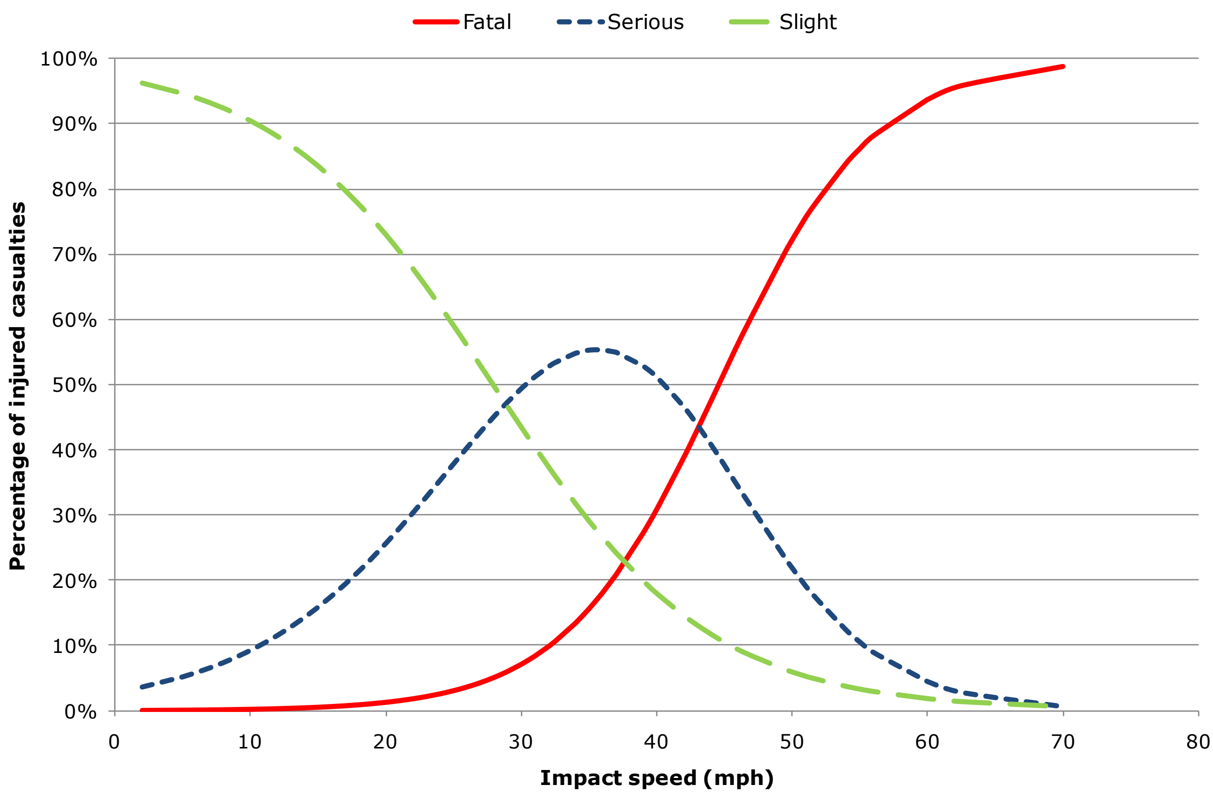


Figure 2-3: Risk of pedestrian injury by impact speed (front of cars, all ages of pedestrian)

For low speeds, for example less than 10mph, over 90% sustain slight injuries; whereas for high speeds, for example above 60mph, over 90% are killed. For pedestrians struck by the front of cars at 20mph, approximately 1% are killed, 26% are seriously injured and 73% are slightly injured. When the impact speed increases to 50mph, approximately 72% are killed, 21% are seriously injured and 7% are slightly injured.

Due to the wide range of impact types and people considered there are outliers in the data, with some individuals surviving very high speed impacts and others being killed at relatively low speeds. However, the overall pattern is very clear, with a significant rise in the gradient of the fatal risk curve above impact speeds of 30mph.

2.3 Larger vehicle and pedestrian collisions

Compared with car impacts, the pedestrian kinematics during an impact are generally different when larger goods vehicles or buses or coaches are involved, with associated different injury mechanisms. For accidents involving larger vehicles, there are a significant minority of casualties, perhaps up to 30% in the UK, who are struck at relatively low speeds (less than 15mph) and are literally run-over by the tyres. The remaining casualties experience higher impact-energy crashes, but much less is known about the relationship of the impact speed and the risk of injury compared with car impacts.

For the purpose of this project it is reasonable to assume that larger vehicles present at least the same risk as passenger cars for travelling speeds above 15 mph, which would represent a lower estimate.

2.4 Summary – risk of pedestrian injury by impact speed

This work has not attempted to account for travelling speed and any possible braking or pre-impact avoidance manoeuvres that may occur in road traffic accidents, it has simply considered the speed of the vehicle at the point of impact. This equates to a road worker being struck by a vehicle when the driver has not seen the road worker or has had insufficient time to react to their presence.

The risk of injury is presented for pedestrians who were struck by the fronts of cars with respect to their impact speed. This is likely to be a conservative estimate for larger vehicles, especially where the pedestrian is struck by the corner of the HGV and experiences head contact with the metal windscreen surround; for this group of accidents it is anticipated that the risk of serious and fatal injury will be considerably more than the average values derived for cars (Figure 2-3). It is not possible to quantify this increase, but it is reasonable to assume that a factor of 1.5 could be applied (i.e. divide the impact speed axis by 1.5). This would mean that over 90% of pedestrians struck at 50mph by the front corner of a lorry would be expected to be killed.

It is unfortunately the case that road workers are at potentially higher risk of being struck by the front corner of a lorry than by the front itself. Most heavy vehicle incursions onto hard shoulders involve only partial encroachment of the vehicle into the closed lane. This increases the likelihood of impact between the road worker and the front corner of the vehicle and so increases the likelihood of fatal injury.

Where the vehicle fleet is largely made-up of cars (approximately 70% of the reported deaths) the data presented represent a realistic parameter for assessing risk with the current impact speed values. This situation would apply to road workers working adjacent to the central reservation barrier where (except on two-lane dual carriageways) heavy goods vehicles are prohibited from using the offside lane

Thus, in summary, at 50 mph, 72% of people struck by a car will be killed. Based on a synthesis of these data and expert opinion it is likely that over 90% of pedestrians struck at 50 mph by the front corner of a lorry would be expected to be killed. From this, it can also be deduced that impact between a road worker and any vehicle moving at 50mph is likely to have a fatal outcome. This influences the risk to road workers exposed to live traffic especially where workers are at risk from collision with HGVs.

3 Examination of Accident Data for Road Workers

3.1 Stats19 HA data for road workers

Stats19 is the national database of injury accidents reported to and by the police and includes details on the accident circumstances, the vehicles involved and the casualties involved. Since 2005, the casualty details have included whether a pedestrian casualty was 'in the course of on the road work' which relates to a work activity carried out on the public highway and not trips made between different work locations.

The circumstances given in Stats19 of the pedestrians injured in the course of on the road work on the HA network have been analysed in order to assess the number of road worker accidents on the network.

Accidents which did not involve a member of the public, that is, those accidents which occurred within a road works site may not be included, and those accidents included are likely to include some pedestrians that were not road workers, for example, emergency service or vehicle recovery personnel.

3.2 Accident circumstances

Between 2005 and 2009, 94 pedestrians were recorded as being killed or injured in the course of on the road work. These 94 pedestrians were injured in 79 accidents; 7 fatalities were in 6 accidents. Table 3-1 shows the severity of the pedestrian's injury by road class and type

Table 3-1: Number of pedestrians injured in the course of on the road work by road type and severity (2005-09)

Road type	Killed	Seriously injured	Slightly injured	Total	Percentage
Motorway	4	9	37	50	53%
A-single	1	1	11	13	14%
A-dual	2	10	19	31	33%
Total	7	20	67	94	100%

About 43% of the length of the HA network is motorway, and 53% of the 94 pedestrians injured in the course of on the road work on the road network between 2005 and 2009 were on motorways (although the amount of road works on each road type and the traffic on each road type will affect the number of road workers injured).

Table 3-2 shows the times of day when the pedestrians were injured in the course of on the road work.

Table 3-2: Number of pedestrians injured in the course of on the road work by time and severity (2005-09)

Time	Killed	Seriously injured	Slightly injured	Total	Percentage
00.00-03.59	2	2	9	13	14%
04.00-07.59	0	3	4	7	7%
08.00-11.59	1	4	13	18	19%
12.00-15.59	0	5	12	17	18%
16.00-19.59	0	2	9	11	12%
20.00-23.59	4	4	20	28	30%
Total	7	20	67	94	100%

Four of the seven pedestrians that were killed, were between 8pm and midnight. This is the period where there is both darkness and a reasonable amount of traffic (compared to after midnight). Short term road works often occur overnight to reduce disruption to traffic, although not all of the pedestrians injured in the course of on the road work were injured where road works were present, as shown in Table 3-3.

Table 3-3: Number of pedestrians injured in the course of on the road work by special conditions at site and severity (2005-09)

Special Conditions at site	Killed	Seriously injured	Slightly injured	Total	percentage
Auto traffic signal out	0	0	1	1	1%
Road works	4	4	23	31	33%
None	3	16	43	62	66%
Total	7	20	67	94	100%

The results show that of the 94 pedestrians injured on the road network, 31 were working in the presence of road works. The largest proportion of the 94 had no special conditions linked to where they were injured. This suggests that two-thirds of the pedestrians injured in the course of on the road work were probably not road workers. These pedestrians may have been other pedestrians that were on the road as part of their work, for example, traffic officers, emergency services and vehicle recovery operators.

3.3 Striking vehicle details

In the Stats19 data, each pedestrian is linked to the vehicle which hit them. Table 3-4 shows the types of vehicles which hit the pedestrians.

Table 3-4: Number of pedestrians injured in the course of on the road work by Vehicle type and severity (2005-09)

Vehicle hit by	Killed	Seriously injured	Slightly injured	Total	Percentage
Car	5	13	35	53	56%
Bus or coach	0	1	0	1	1%
LGV	0	2	9	11	12%
HGV	2	3	20	25	27%
Other motor vehicle	0	1	2	3	3%
Unknown	0	0	1	1	1%
Total	7	20	67	94	(100%

Over 50% of the 94 pedestrians injured on the road network were struck by a car and 38% were struck by a goods vehicle.

Table 3-5 shows the manoeuvres of the vehicles which hit the pedestrians.

Table 3-5: Number of pedestrians injured in the course of on the road work by Vehicle manoeuvre and severity (2005-09)

Vehicle manoeuvre	Killed	Seriously injured	Slightly injured	Total	Percentage
Reversing	1	2	6	9	10%
Parked	2	5	8	15	16%
Waiting to go ahead but held up	0	0	1	1	1%
Slowing or stopping	0	0	1	1	1%
Moving off	0	0	7	7	7%
Turning left	0	0	1	1	1%
Changing lane	0	1	8	9	10%
Overtaking	0	0	4	4	4%
Going ahead left hand bend	0	1	1	2	2%
Going ahead right hand bend	0	0	2	2	2%
Going ahead other	4	11	28	43	46%
Total	7	20	67	94	100%

47 of the 94 pedestrians were injured by vehicles going ahead. Of these, 4 were at bends and the other 43 were going along straight. Interestingly, 15 of the 94

pedestrians (16%) were injured due to being struck by a parked vehicle. These accidents are likely to be those where another vehicle in the accident struck a parked vehicle which was then pushed towards the pedestrian. 9 pedestrians were struck by a reversing vehicle.

Table 3-6: Number of pedestrians injured in the course of on the road work by Vehicle location and severity (2005-09)

Vehicle location	Killed	Seriously injured	Slightly injured	Total	Percentage
On main carriageway not in restricted lane	5	17	55	77	82%
On lay-by/hard-shoulder	2	3	11	16	17%
Footway (pavement)	0	0	1	1	1%
Total	7	20	67	94	100%

77 of the 94 pedestrians (82%) were struck by vehicles on the main carriageway. In addition, 16 were injured by vehicles on the lay-by/hard shoulder, underlining this to be a vulnerable place for pedestrians.

3.4 Casualty

Table 3-7 shows the ages of the pedestrian casualties.

Table 3-7: Number of pedestrians injured in the course of on the road work by Age and Severity (2005-09)

Age	Killed	Seriously injured	Slightly injured	Total	percentage
<20	0	0	1	1	1%
20-29	2	4	13	19	20%
30-39	0	6	20	26	28%
40-49	3	3	20	26	28%
50-59	1	4	9	14	15%
60-69	1	2	1	4	4%
70-79	0	1	3	4	4%
Total	7	20	67	94	100%

It is not surprising to see that the largest majority of the 94 pedestrians injured were between the ages of 20 and 50 since they make up the largest proportion of the people who are likely to be working on the road network.

Table 3-8 shows the location of the pedestrians.

Table 3-8: Number of pedestrians injured in the course of on the road work by Location and Severity (2005-09)

Location	Killed	Seriously injured	Slightly injured	Total	Percentage
In carriageway, crossing	0	2	3	5	5%
On footway or verge	0	3	3	6	6%
On refuge, central island or central reservation	1	0	4	5	5%
In carriageway, not crossing	4	13	47	64	68%
Unknown or other	2	2	10	14	15%
Total	7	20	67	94	100%

61% of pedestrians injured on the road network were in the carriageway but not for the purpose of crossing to the other side. There were 14 pedestrians whose location was unknown.

3.5 Contributory Factors

There were 49 pedestrians injured in the course of on the road work in the study period in accidents that were attended by the police and had contributory factors reported.

Table 3-9: Number of pedestrians injured in the course of on the road work with pedestrian and vehicle factors (2005-09)

Factors	Killed	Seriously injured	Slightly injured	Total
Vehicle factor(s) only	1	4	22	27
Pedestrian factor(s) only	0	10	10	20
Vehicle and pedestrian factor(s)	4	2	6	12
Other	2	2	1	5
Total	5	11	33	49

More than half (27/49) of the pedestrians were in accidents where there were vehicle factors only, that is, the actions of the pedestrian did not contribute to the accident.

20 of the pedestrians were in accidents where the pedestrian was reported with contributory factors and none were attributed to any vehicles, suggesting that the actions of the vehicle did not contribute to the accident.

12 pedestrians were in accidents where actions of the vehicle and the pedestrian were reported as contributing towards the accident.

The most common pedestrian factor was ‘failed to look properly’, recorded for 10 pedestrians.

Table 3-10: Number of pedestrians injured in the course of on the road work with pedestrian and vehicle factors (2005-09)

Pedestrian Factor	Killed	Seriously injured	Slightly injured	Total
Failed to look properly	2	3	5	10
Dangerous action in carriageway	1	3	1	5
Other	0	1	2	3
Pedestrian wearing dark clothing at night	0	2	1	3
Failed to judge other person’s path or speed	0	1	2	3
Careless, reckless or in a hurry	1	1	1	3
Impaired by alcohol	0	1		1
Wrong use of pedestrian crossing facility	0	0	1	1
Crossing road masked by stationary or parked vehicles	0	0	1	1
Temporary road layout	0	0	1	1
Disability or illness, mental or physical	0	0	1	1
No pedestrian factor	3	6	23	32
Total	5	11	33	49

The most common factors for vehicles were:

- Failed to look properly
- Careless, reckless or in a hurry
- ‘Other’
- Loss of control
- Aggressive driving

3.6 Fatal files

TRL hold an archive of fatal files from selected police forces, consisting of the files relating to fatal accidents when a police force has completed their investigation.

Details of the six fatal accidents involving a pedestrian injured in the course of on the road work were matched with the fatal files archive held at TRL.

Only one file was available in the fatal file archive and the summary of this file is presented below:

Triple fatality when car enters road works site

Two road workers were killed when a car driven by a member of the public ploughed into a coned area. The driver of the car was also killed.

The accident was on the motorway in the evening. There were road works in progress, which were barrier repairs due to a previous accident. The road works were laid out according to guidelines and Lane 3 was coned off.

The taper started about 400m from collision scene, VMS were displayed with advance warning of works with ‘workforce in carriageway – slow’ and 50mph advisory limit displayed.

Both road workers were within the coned area when they were struck by the car travelling at about 80mph. At the time of the incident the longitudinal line of cones had been completed and lamped, with a safety zone installed adjacent to the proposed works area and the END sign erected in the central reserve south of the traffic management vehicle (TMV). The TMV was parked at the south end of the closure and the two roadworkers were outside the vehicle. This collision occurred as a result of the actions of the car driver. Despite ample warning of the presence of workers in the carriageway and advisory 50mph being set, the vehicle was driven at high speed and in a very dangerous manner. Approaching the road works, the vehicle entered the coned off area and collided with two roadworkers causing fatal injuries to both roadworkers and the driver of the vehicle. The car driver showed a complete disregard for their own safety and that of other road users. It is likely that their judgement and ability to drive were severely impaired by the effects of drugs.

Although this case illustrates some of the hazards associated with working on high speed roads, a single case cannot be considered as robust evidence. Although police investigations (on which fatal accident files are based) are thorough it is not possible for the investigation to answer all questions, as shown by the suggestion of impairment of the driver.

As such, the case study is included for sake of completeness but it was not appropriate to use the information contained within it to reach any conclusions.

3.7 Summary

Analysis of the Stats19 database of reported injury accidents showed that there were 94 pedestrians killed or injured in road accidents over a 5-year period reported as being 'in the course of on the road work'.

- About half of these casualties occurred on motorways and about half occurred between 8pm and 8am.
- Seven out of the 94 pedestrians were killed, of which 4 were on motorways and 4 were between 8pm and midnight.
- About one-third of the pedestrians were at locations where road works were present, strongly indicating that these pedestrians were road workers. Where no special conditions were recorded the pedestrians may be road workers not at roadwork sites or may be other workers on the road, for example, emergency services, breakdown patrols.
- The majority (53) of the pedestrians were hit by a car; 36 were hit by a goods vehicle.
- The majority (47) of the pedestrians were hit by a vehicle which was described as 'going ahead'. 15 were struck by a parked vehicle and 9 by a reversing vehicle
- 16 of the pedestrians were on the hard shoulder or layby at the time of the accident
- More than half (27/49) of the pedestrians were in accidents where there were vehicle factors only, that is, the actions of the pedestrian did not contribute to the accident.
- 20 of the pedestrians were in accidents where the pedestrian was reported with contributory factors and none were attributed to any vehicles, suggesting that the actions of the vehicle did not contribute to the accident.
- 12 pedestrians were in accidents where actions of the vehicle and the pedestrian were reported as contributing towards the accident.

- The most common pedestrian factor was 'failed to look properly', recorded for 10 pedestrians.
- The most common factors for vehicles were: 'Failed to look properly', 'Careless, reckless or in a hurry', 'Other', 'Loss of control' and 'Aggressive driving'.

The Stats19 data link to the TRL fatal file archive was used to find more detailed information regarding the circumstances of these accidents. Only one file was available, involving a high-speed collision between a vehicle and two road workers in which the workers and driver were all killed. This single case could not be used to reach any robust conclusion.

4 Examination of AIRSWeb Data

AIRSWeb is the database of reported hazards, near misses and accidents involving road workers who are working for the HA. The HA's supply chain partners complete this database as a contractual commitment.

The extracted AIRSWeb data covered the period from 1997 up to 15th December 2010 and included details such as:

- Incident date
- Incident description (free text)
- Incident type (for example fatality, near miss, fire)
- Types of work present
- Activities/tasks undertaken
- TTM (temporary traffic management) scheme type
- Which part of TTM
- When in TTM process (for example, setting out or removal)
- Speed limit
- Vehicle involvement
- Investigation causes

131 records, including 119 in 2008, had the description 'dummy record' (relating to the testing of the database) and were removed from the analysis. Removing these 131 records left 8,748 incident occasions in the dataset.

Table 4-1 shows the incidents and involved contractors and members of the public by incident type and year. Incidents are categorised as

- Abuse
- Damage/loss
- Hazard
- Illness
- Injury
- Near miss
- Service strike

Each incident can be recorded as one or more of the types listed above and each incident may involve more than one person, therefore the total in Table 4-1 sums to more than 8,748. Near misses could be categorised as a near miss which would have resulted in an accident or a near miss which could have resulted in a different incident type, e.g. fire, service strike.

Excluding the 'dummy records', there were 4,863 recorded incident occurrences in 2010 which included 4,881 incident types/people.

Table 4-1: Number of incident types/people reported in AIRSWeb by incident type and year

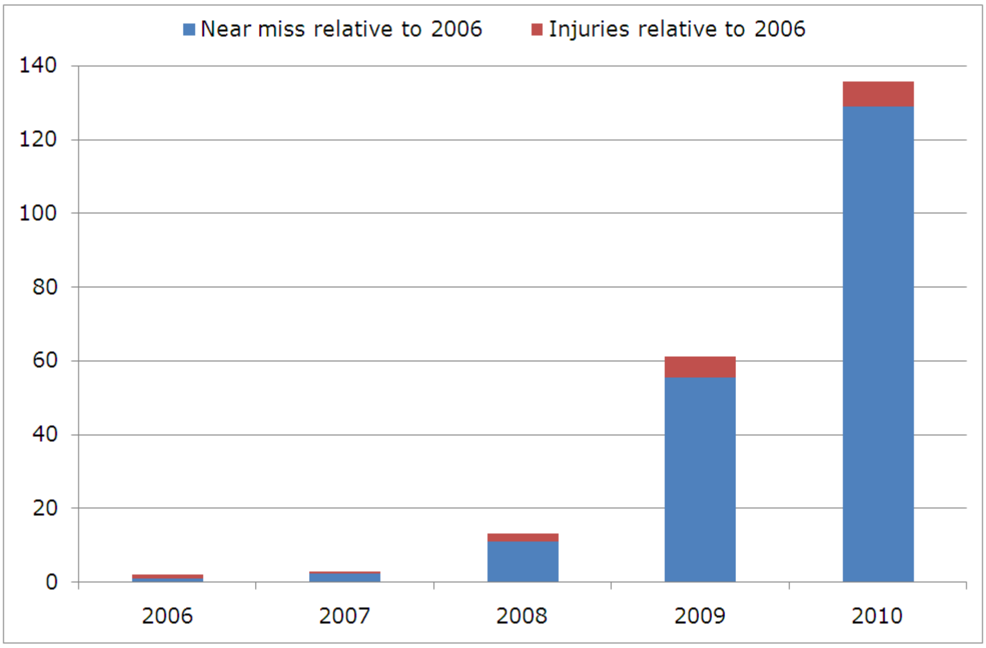
Year	Abuse	Damage / Loss	Hazard	Illness	Injury	Near Miss	Service Strike	Total
1997	0	0	0	0	16	0	0	16
1998	0	0	0	0	19	0	0	19
1999	0	0	0	0	49	1	0	50
2000	0	4	0	0	63	2	2	71
2001	0	8	0	0	89	6	0	103
2002	0	6	0	0	108	1	0	115
2003	0	5	0	0	68	3	0	76
2004	0	12	0	0	73	5	0	90
2005	0	6	0	0	68	3	0	77
2006	2	24	0	0	110	26	11	173
2007	2	23	2	0	71	59	17	174
2008	9	51	10	0	216	290	9	585
2009	23	174	121	2	629	1,441	61	2,451
2010	39	295	388	4	724	3,356	75	4,881
Total	75	608	521	6	2,303	5,193	175	8,881

Over the last few years there has been a large increase in the total number of incident types/involved people reported. This increase is likely to be due to changes in reporting rather than more incidents occurring in the later years.

In particular the number of reported near misses has been increasing by a large proportion every year since 2006. In 2010 there were 3,356 entries in AIRSWeb relating to near misses compared with fewer than 10 in each year prior to 2006. Near misses made up 3% of database entries in 2000, 15% in 2006 and 69% in 2010.

Figure 4-1 shows the near miss and incident numbers from 2006 relative to their 2006 values. The chart shows that although the numbers of both injuries and near misses have increased, the number of near misses has increased by significantly more.

Figure 4-1: AIRSWeb reported near miss and injury data relative to 2006



The incident types/involved people are further split in incident type subcategories, the subcategories for incident type 'injury' being:

- Fatality-Riddor
- Fatality-Other
- Major Injury
- Lost Time > 3 days
- Lost Time ≤ 3 days
- Injuries - First Aid
- Injuries - Medical Treatment
- Injuries - Self/Non treatment
- MOP (member of public) taken from the scene to hospital

No indication is given (apart from in the text description) whether the fatalities are members of the public or road workers.

4.1 Quality of data

Through analysis of the dataset it became apparent that a large proportion of the fields are left blank / unknown. It is sometimes unclear from the data whether a blank record means no, not present, not applicable or is just an unknown/unrecorded value.

For example, the fatal incident described in Section 3.6 was matched with the AIRSWeb data. Whilst the incident description included references to traffic management and the incident type was recorded as fatal, much of the other data relating to the TTM was left blank.

4.2 Analysis

Between 2006 and 2010 there were 6,920 injuries and near misses recorded in the AIRS database. 5,170 (66%) of these were near misses. Two of the near misses were recorded for incidents where there was also a reported injury; these two near misses were therefore removed from the dataset.

5,537 (80%) of the 6,918 entries in the analysed dataset had no data recorded for the field 'was there scheduled works'. 80% of the entries with valid data were recorded as having scheduled works present.

Table 4-2 shows that 6,280 (91%) of the entries in the dataset had no value recorded for 'road works which part'. 21% of the remaining entries took place on the live carriageway. 56% were within the works area / safety zone, adjacent to a live carriageway.

Table 4-2: Number of injuries and near misses by 'road works which part' and year

Road Works Which Part	2006	2007	2008	2009	2010	Total	% of all parts
On a live carriageway (i.e. open to traffic)	35	22	27	27	22	133	1.9%
On a hard shoulder	7	8	13	6	12	46	0.7%
On a not normally trafficked carriageway (e.g. chevroned area)	0	0	1	3	2	6	0.1%
In a central reservation	2	2	5	5	10	24	0.3%
Off carriageway (e.g. green field site)	16	30	8	6	10	70	1.0%
Within works area / safety zone (adjacent to a live carriageway)	20	32	133	96	78	359	5.2%
Unknown	56	36	319	1925	3,944	6,280	90.8%
Total	136	130	506	2,068	4,078	6,918	100.0%

Table 4-2 shows the injuries that were received for each of the known categories above.

Table 4-3: Number of injuries and near misses by 'road works which part' (where known) and injury type

Road Works Which Part	Fatality-Other	Fatality-Riddor	MOP taken from the scene to hospital	Major Injury	Lost Time > 3 days	Lost Time =< 3 days	Injuries - First Aid	Injuries - Medical Treatment	Injuries - Self/Non treatment	Near Miss	Total
On a live carriageway (i.e. open to traffic)	1	4	31	3	11	1	3	3	4	72	133
On a hard shoulder	0	0	2	2	14	0	3	2	1	22	46
on a not normally trafficked carriageway (e.g. chevroned area)	0	0	0	0	0	0	0	0	0	6	6
In a central reservation	0	0	0	3	5	1	0	1	2	12	24
off carriageway (e.g. green field site	0	0	2	14	22	2	5	2	3	20	70
Within works area / safety zone (adjacent to a Live carriageway)	1	6	10	18	38	7	5	13	9	252	359
Total	2	10	45	40	90	11	16	21	19	384	638

The text descriptions recorded for the five fatalities which occurred on a live carriageway in the table above were as shown below. Three of the fatalities were members of the public and two were road workers.

Table 4-4: Incident descriptions for five fatalities which occurred on live carriageway

Incident Description	Description Of Contracted Works
A 3 man TM crew were pre-laying equipment when they were struck from behind by a LGV.	The TM crew were pre-laying TTM equipment in preparation for a closure and diversion that was programmed to take place at a later date.
Gully cleaning works were being carried out in Lane 3 under the protection of a standard mobile lane closure. The operation had commenced but the operation halted while the RCC were contacted and requested to set the matrix signs between the next junctions. While waiting for the matrix signs to be set the IPV was hit from the rear by two or three vans. The collision pushed the IPV into the central reservation safety fence with the driver incurring minor injuries to the arms, neck, and back. The drivers of two of the vans were killed, with the driver of the third van suffering a broken leg (2 fatalities)	Highway Maintenance
N/B vehicle within TM for works, collided with central barrier and veered to left. Went through TM which was closing off lane 1, over hard shoulder and travelled behind temporary varidguard barrier which was protecting bridge parapet. Vehicle then over turned and went over edge of bridge parapet dropping upside down onto verge road below. Metal Fence post penetrated vehicle and killed rear seat passenger.	Replacement of Bridge Parapets following significant accident damage to Northbound parapet. New parapets to current standards
The collision was within the road works for [location] improvements. 2 vehicles collided the driver of one of the vehicles died at the scene, A passenger in the other vehicle was taken to hospital with serious injuries	On line widening / construction of structures

6,442 (93%) of the 6,918 entries had no value recorded for 'which part of TTM'. 76% of those entries with valid values were recorded as 'in, or alongside, main works area. 11% were recorded as within entrance taper.

Table 4-5 shows the number of injuries and near misses by the field 'when in TTM process'. 6,505 (94%) entries had no process recorded and 74% of the remaining incident type injuries occurred when the TTM scheme was fully in place and not being changed. 62 entries are recorded as having occurred as the TTM was being set out, and 26 during removal of TTM, however, these numbers are very likely to be underestimates given the amount of unknown data.

Table 4-5: Number of injuries and near misses by 'when in TTM process' and year

When In TTM Process	2006	2007	2008	2009	2010	Total	% of all processes
TTM scheme fully in place and not being changed.	25	16	96	99	69	305	4.4%
Setting Out	3	5	16	21	17	62	0.9%
Removal	2	0	5	10	9	26	0.4%
Maintenance		2	1	5	3	11	0.2%
Modification	4	0	0	2	3	9	0.1%
Unknown	102	107	388	1,931	3,977	6,505	94.0%
Total	136	130	506	2,068	4,078	6,918	100.0%

Table 4-6 shows the number of injuries and near misses which occurred during setting out, removal, maintenance or modification of the TTM by incident sub-type. There were three fatalities (RIDDOR) and 5 major injuries, two of the fatalities and four of the major injuries took place whilst the TTM was being set out.

About half of the incidents that occurred during setting out were near misses.

Table 4-6: Incident sub type injuries by 'when in TTM process'

Incident Sub Type	Setting Out	Removal	Maintenance	Modification	Total
Fatality-Riddor	2	0	1	0	3
MOP (member of the public) taken from the scene to hospital	5	1	0	4	10
Major Injury	4	1	0	0	5
Lost Time > 3 days	12	4	4	1	21
Lost Time =< 3 days	1	2		0	3
Injuries - First Aid	1	0	2	0	3
Injuries - Medical Treatment	2	0	0	0	2
Injuries - Self/Non treatment	2	3	0	0	5
Near Miss	33	15	4	4	56
Total	62 (57.4%)	26 (24.1%)	11 (10.2%)	9 (8.3%)	108

Text descriptions of the fatalities in the table above were as follows:

- Setting Out: A 3 man TM crew were pre-laying equipment when they were struck from behind by a LGV.
- Setting Out: Transit van hit the taper and went straight into the back of the crash cushion.
- Maintenance: IP was fatally injured after being run over by a wheeled excavator. Further details to follow.

4.3 Summary

AIRSWeb data were used to assess the number of road worker casualties associated with various parts of their work. The number of incidents recorded in AIRSWeb has increased significantly over the last few years, especially the number of near misses reported.

AIRSWeb contains many data fields relating to what TTM were present, where the incident occurred in relation to the TTM and when in the process the incident occurred. However, these fields are not completed for the majority of incidents. This means that analyses of these fields in the AIRSWeb data are limited to those incidents where these data are available, which may not be a representative sample of all incidents that occurred.

The AIRSWeb data showed that there were 6,920 injuries and near misses reported between 2006 and 2010, of which about two-thirds were near misses.

Where data were available:

- 133 (21%) injuries and near misses occurred on a live carriageway
- 359 (56%) occurred within the works area or safety zone (adjacent to the live carriageway)
- There were 12 fatalities where 'road works which part' was known, 7 within the works area and 5 on a live carriageway. The text description of the 5 fatalities on a live carriageway showed that 3 were members of the public.

- 62 injuries and near misses (15%) occurred during the setting out of TTM and 26 occurred during removal
- There were 2 fatalities where 'when in TTM process' was reported as 'during setting out and 1 which occurred during TTM maintenance. All three were road workers.

This analysis supports the assertion that setting out and taking down of TTM represent the most significant risks to road workers. This provides some context for the development of the risk index, although the data from both AIRSWeb and STATS 19 did not provide as much risk data as originally hoped.

5 The Development of the MIRi Index

5.1 Current Practices for Temporary Traffic Management Procedures

The Traffic Signs Manual Chapter 8 (DfT, 2009) sets out clear guidance for temporary traffic management (TTM) layouts for all roads, including high-speed roads such as those on the Highways Agency network. Chapter 8 does not, however, specify the method used to install the TTM schemes; this varies between Service Providers and traffic management contractors as well as being influenced by the location in which the works are installed.

Developing a suitable and effective MIRi Index required a full understanding of the different methods used to install TTM. An understanding of operational procedures was gained during meetings which were set up with key service providers such as Carillion WSP, A-one+, Colas, HW Martin and Balfour Beatty Mott Macdonald to discuss techniques used to install TTM and the methods employed by their subcontractors. 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 Areas on the HA network and observed the TTM installation and removal. Observations were undertaken on different road types (with and without hard shoulder) and for different lane closures (nearside and offside).

Through discussions with service providers, reviewing associated methods statements and observation of operational procedures on the network, a clear understanding of TTM installation methods was gained. The key methods used in TTM installation have been outlined in Appendix B (Current On-road Practices).

5.2 Phases of Temporary Traffic Management (TTM)

The basic MIRi Index applies to relaxation layouts for the setting out and removal of advance signing and the entry taper on unlit dual carriageways with and without hard shoulder. The full scope is in Appendix E

For the purposes of the development of the MIRi Index, TTM has been considered in five key phases:

1. Installation of advanced signing
2. Installation of Detail A
3. Taper Installation
4. Taper Removal (including the removal of Detail A)
5. Removal of advanced signing

5.2.1 Installation of Advanced Signing

Currently, advanced signing for a relaxation layout consists of the workforce in road sign (nearside only), road works 1 mile ahead and the 800yd, 600yd, 400yd and 200yd wicket signs – all of which are installed on the off side and near side. All central reserve sign installations require carriageway crossings, with the exception of remotely operated signs (ROS) which are operated remotely from the nearside. ROS however, do need carriageway crossings for initial installation, routine maintenance and repair. It must be noted that Chapter 8 Plan DZA2 does not require a 'road works one mile ahead' sign to be installed on all-purpose dual carriageways where relaxations apply. However, through discussions with contractors, it became apparent that the '1 mile ahead' sign is installed regardless of the road type.

Fixed plate temporary signs are either secured with sand bags, ratchet straps (or similar) or are barrier mounted. Where a relaxed closure is going to be repeated on consecutive nights, signs may be laid flat and secured with sandbags, to reduce subsequent carriageway crossings. Some organisations use folding signs so the sign can be folded shut when not in use.

Remotely operated signs can be installed if TTM is required for several consecutive nights (generally more than 5 nights). Some areas of the motorway network have preplaced remotely operated signs at strategic locations to be used during the installation of TTM.

For a lane 2 or lane 3 closure with a hard shoulder, advanced signing is installed from the hard shoulder. For a lane 1 closure, with no hard shoulder, the advanced signing is installed from lane 1. For a lane 2 or a lane 3 closure with no hard shoulder, advanced signing is installed from lane 1 for the workforce in road sign, road works 1 mile ahead, 800yd and 600yd wicket and typically from lane 2/3 for the 400yd and 200yd wicket. The movement from the nearside to offside lane after the installation of the 600yd wicket is to minimise the time a traffic management vehicle is conflicting with the wicket message.

There are some key factors that influence the way in which advanced signing is installed and therefore influence the risks associated with advanced sign installation. These factors are:

- Vehicle type. The risk level associated with advanced sign installation varies with vehicle type due to different levels of impact protection, number of vehicles required and the number of operatives involved. The vehicle types to be included are as follows:
    - Traffic Management Vehicle (TMV)
    - Traffic Management Impact Protection Vehicle fitted with a lorry mounted crash cushion (LMCC) device (TMIPV)
    - Traffic management vehicle with a separate impact protection vehicle (TM + IPV)
- Road Type. The method used to install advanced signing varies depending on the road type, that is, whether or not there is a hard shoulder and the number of lanes. Where a hard shoulder is present, advanced signing is installed from the hard shoulder. Where there is no hard shoulder, the position of the vehicle will depend on the closure type. The number of lanes will also affect the amount of time that a road worker is exposed to the hazard of crossing a carriageway as it takes more time to cross 3 lanes than 2 lanes.
- Closure type. The position of the vehicle whilst installing advanced signing will depend on whether lane 1 or lane 2/3 is being closed. This is only relevant where there is no hard shoulder. For a lane 1 closure, with no hard shoulder, the advanced signing is installed from lane 1. For a lane 2/3 closure with no hard shoulder, advanced signing is installed from lane 1 for the workforce in road sign, road works 1 mile ahead, 800yd and 600yd wicket and from lane 2/3 for the 400yd and 200yd wicket. Whilst the initial signs are being installed and the vehicle is in lane 1, the position of the vehicle conflicts with the lane closure information displayed on the wicket.
- Sign type. There are numerous sign types, and the methods of installing and fixing the signs depend on the contractor and the barrier present. The signs/ fixing methods being considered for the basic MIRi index are as follows:
    - Fixing using sandbags/ sand bag bars on the sign A-frame
    - Ratchet straps/ similar straps attaching the A-frame to a barrier or similar
    - Laying signs flat for TTM on consecutive nights
    - Remotely operated signs

- Barrier mounted signs deployed in previously installed sockets

The reliability of remotely operated signs and the subsequent maintenance requirements have been discussed with various contractors. The installation and maintenance has not been considered for the basic MIRi index.

5.2.2 Installation of Detail A

Detail A (shown below) requires a 610 arrow above and behind 3 traffic cones on the hard shoulder in line with the start and end of the taper on a lane 2 or 3 closure.

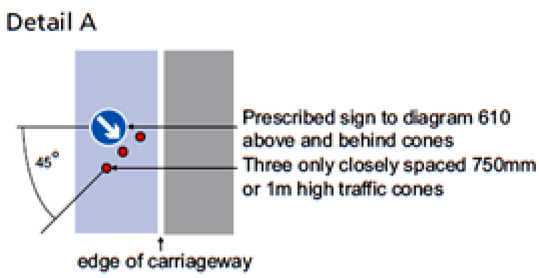


Figure 5-1: Components and location of Detail A

There are 2 core methods for installing Detail A:

Method DA1	Put up advanced signing Put up detail A at start and end of taper. Drive round link to start of temporary traffic management (TTM) and position in lane 2/3 for taper installation
Method DA2	Put up advanced signing Move into lane 2/3 for taper installation Walk detail A (x2) across carriageway onto hard shoulder

When considering the risk levels associated with the installation of Detail A, the following factors must be considered:

- Vehicle type. The type of vehicle used when installing Detail A is important as the consequences of the passengers in the vehicle if it is struck by a road user will vary depending on the vehicle type. The following vehicle types are considered:
    - TMV (Method DA1 only as a TMV would not be in lane 3 without an IPV)
    - TMIPV (Methods DA1 and DA2)
    - TM + IPV (Methods DA1 and DA2)
- The method of installation as detailed above. From discussions with contractors, it is clear that there are numerous variations on the core methods used to install Detail A. In some instances, Detail A is preplaced on the hard shoulder; in this way Method DA2 does not require operatives to cross the carriageway carrying the signs, cones and sandbags. Where an additional TM crew is available to assist, the additional crew installs Detail A from the hard shoulder whilst the initial crew installs the taper. For the basic MIRi index methods DA1 and DA2 have been considered as they are the most commonly used methods

- Road type. Detail A is only installed on carriageways where there is a hard shoulder; therefore carriageways without hard shoulders have not been considered. However, the number of lanes a road worker is required to cross will affect the exposure duration to the hazard, therefore 2 and 3 lane carriageways have been considered

5.2.3 *Taper Installation*

It is generally accepted that there are four main methods of taper installation.

Method TI1	Separate IPV and TMV, IPV follows the TMV into the closure
Method TI2	Separate IPV and TMV, IPV remains at start of taper
Method TI3	TMIPV
Method TI4	No vehicle in the lane to be closed, operative walk closure out.

The methods detailed above are currently used to install temporary traffic management TTM. Typically, contractors have their preferred option but may use a variety of techniques. For example, it may be a contractor's preferred option to use Method TI4 and walk the taper out from the hard shoulder but the same contractor may use one of the other methods when a hard shoulder is not present.

When considering the risk levels associated with the installation of the taper, the following factors were considered:

- Method used; TI1, TI2, TI3 and TI4
- Road type. It is important to know whether the carriageway has a hard shoulder for several reasons, primarily because a TMV without an IPV cannot operate in the live lane. In addition, lane 1 closures will be installed from the hard shoulder where possible, which will therefore reduce the probability of being struck by a vehicle
- Closure type. The position of the vehicle will vary depending on whether a lane 1 or a lane 2/3 closure is being installed. A lane 1 closure with a hard shoulder will be installed from the hard shoulder, whereas a lane 2/3 closure will be installed from the live lane being closed where a crash cushion is present

5.2.4 *Taper Removal*

The three main methods for taper removal are as follows:

Method TR1	Separate IPV and TM vehicles
Method TR2	Combined TM vehicle and crash cushion
Method TR3	No vehicle in lane, operatives walk in closure

It can be seen that there are three methods for taper removal compared with four for taper installation. This is because whereas an IPV may follow a TMV into the closure for taper installation, it will not reverse with the TMV to collect cones. The IPV will instead remain at the start of the taper. When considering the risk levels associated with taper removal the following factors were considered:

- Method used; TR1, TR2 or TR3.
- Road type. A lane 1 closure taper will often be removed from the hard shoulder where present, thus reducing the probability of being struck by a vehicle. Method TR3 cannot be conducted on carriageway without a hard shoulder as it would require a TMV without IPV to be in the live lane. Therefore it is necessary to distinguish between carriageways with and without hard shoulders.
- Closure type. The type of closure will change the position of the vehicle and therefore the probability of being struck and the severity of the consequences.

5.2.5 *Advanced Sign Removal*

Advanced signs are removed using the same method as advanced sign installation. It is likely that traffic flows may be different from advanced sign installation depending on the time of removal. Traffic flows and operation times have not been considered in the basic MIRi index, where it has been assumed that flows are less than 1200 vehicles per hour per lane and remain constant. Therefore it is assumed that the risks associated with advanced sign removal are the same as those associated with advanced sign installation.

The different variables for each of the phases of temporary traffic management (TTM) installation (that is road type, method used, vehicle type, equipment used etc) can be seen in Appendix C (Variables).

5.3 Task Analysis

One of the aims of the MIRi Index is to create a tool that can demonstrate the influence of safety initiatives on the MIRi Index value. It may be that future initiatives concern *part* of a task or the operations of *one* of the crew members. Therefore it was essential to separate the tasks involved in temporary traffic management (TTM) installation and removal into subtasks for the TM crew and then by individual TM operative member. This subtask analysis was supported by information received from contractors during discussions, method statements and observations of TTM installation on the HA network.

The exact methods used do vary between contractors. For example one contractor may cross the carriageway carrying the sign and stand together whilst another may carry them separately. The roles of crew members also vary between contractors, with the key difference being the role of the TMIPV driver. Some contractors require the driver to remain in the vehicle throughout the TTM installation, whilst others require the driver to get out of the vehicle and assist in the installation. Using the varying practices outlined for each of the phases of TTM, there are 181 variations. It was necessary, for practicality) to limit the permutations and ensure that common practices were indexed, thus the following assumptions were made:

- Two crew members are required to install a barrier mounted sign. One to install and one to act as 'look out'. Signs and stands are crossed over the carriageway separately.
- Two crew members are required to carry sufficient sandbags to fix the sign. The driver of the IPV remains in the vehicle at all times.
- The driver of a TMV or TMIPV assists with the TTM installation.
- The vehicle driver installs signs on the verge/ hard shoulder whilst the other two crew members install signs on the off side.
- The installation, repair and maintenance of remotely operated signs have not been considered.
- Signs and cones can be unloaded from either side of the vehicle, meaning that equipment is always loaded and unloaded away from live traffic.

An example of the breakdown of tasks into subtasks and roles of crew members can be seen in Appendix D (Substasks).

5.4 Development of the MIRi Index

Risk is defined as 'the probability or exposure to a hazard, combined with the consequences of such exposure'. Traditional risk matrices combine the likelihood of an event occurring with the severity of the consequences to calculate a risk level. This risk level can then be used to determine whether the level of risk is tolerable. For example, the following risk matrix is outlined in BS8800: Guide to Occupational Health and Safety Management Systems:

	Slightly Harmful	**Harmful**	**Extremely Harmful**
Highly Unlikely	Trivial Risk	Tolerable Risk	Moderate Risk
Likely	Tolerable Risk	Moderate Risk	Substantial Risk
Unlikely	Moderate Risk	Substantial Risk	Intolerable Risk

In this case, there are five different levels of risk for different likelihood and severity consequences. The HA currently use a five by five matrix but only four risk levels (Figure 5.2). Other matrices may have three levels in line with the HSE Tolerability of Risk Criteria (2001); that is an unacceptable region, tolerable region and broadly acceptable region.

5 X 5 Matrix	IMPACT				
	Negligible Minor injury involving no absence from work. (e.g minor cut requiring no treatment other than a plaster	**Minor** Lost time incident with absence under 3 days. (e.g slip trip or fall or something requiring visit to Doctor and/or a medical treatment	**Major** RIDDOR defined major injury/disease or defined major incident	**Very Serious** Permanent disability such as loss of limb., or indefinite inability to return to work	**Fatality (ies)** Fatality or multiple injury
	Minimal injury requiring no/minimal intervention or treatment Incident resulting in a bruise/graze No time off work	Minor injury or illness, requiring minor intervention but does not require a hospital visit Requiring time off work for <3 days Laceration, sprain, anxiety requiring occupational health counselling (but no time off work required)	Requiring time off work for over 3 days Physical attack causing injury RIDDOR/agency reportable incident	Long-term incapacity or disability such as loss of limbs, perm loss of sight. Indefinite inability to return to work	Incident leading to multiple injuries, permanent incapacity or severe disability, death or irreversible health effects
LIKLIHOOD – **Frequent** An event that is expected to occur and be experienced by most staff (100s) each year.					
LIKLIHOOD – **Probable** An event that is expected to occur and be experienced by many staff (10s) each year					
LIKLIHOOD – **Occasional** An event that could occur at some time and may effect several people at least once a year					
LIKLIHOOD – **Remote** Unlikely although may affect 1 or 2 staff from the whole staff population once per year					
LIKLIHOOD – **Improbable** So unlikely that it may never happen					

Residual Risk Rating	**Management / Employee Action**
Green	Ensure that all safe working practices in the risk assessment are adhered to.
Amber	Ensure that all safe working practices in the risk assessment are adhered to and that there are no additional Safety control measures that are reasonably practicable.
Red	This activity must not be undertaken without discussing it with your line manager and Director and getting express permission to do so.
Red Hatched	This activity must not be undertaken under any circumstances.

Figure 5-2 Highways Agency Risk Matrix

There are numerous matrices like this that require the risk level to be read from a table; others assign numbers to likelihood and severity and multiply the values together that can then be banded into risk levels. The number of risk levels varies between techniques but generally ranges from 3 to 6. A two-dimensional risk matrix as described may consider the frequency of an undesired event, whilst estimating the probability of occurrence but does not consider the exposure duration. Using a risk matrix, a worker exposed to a hazard for 1 hour has the same nominal risk level as a person exposed to a hazard for a more prolonged time period. This is clearly inappropriate for road workers who are exposed to risk for varying lengths of time. Thus, in line with the HA strategy 'Aiming for Zero', TRL recognised the need to develop a matrix which would consider a road workers' exposure duration to the identified hazard.

There are various nomograms and risk graphs detailed in safety literature and British Standards which attempt to include worker exposure into the risk calculation. BS 5304:1988, the British Standard Code of Practice for Safety of Machinery" (BS 5304:

1988) included a nomogram with three scales: potential severity of injury, probability of injury and exposure time ranging from minutes to days. Similarly the BSEN 954-1 Risk Graph considers probability, severity and exposure. When probability of occurrence is multiplied by the highest foreseeable severity, the outcome is an overestimation of risk. Interestingly, this risk graph requires 'usual' consequences to be selected as opposed to the more standard 'worst' consequences. In 1989 a risk calculator was developed (Raafat, 1995) that provided a tool for the ranking of risks resulting from work machinery and equipment. This calculator considers the probability of an event occurring ranging from 1 in 10 to 1 in 1 million; the frequency and duration of exposure to the hazard ranging from very rare (1%) to continuous exposure (100%) and the potential severity of injury/ damage measured on a scale ranging from minor loss to multiple fatalities.

These graphs and calculators have primarily been developed for the rapid screening of risks associated with machinery and allow risks to be ranked in terms of high, medium and low.

The MIRi Index, on the other hand, needed to consider factors such as probability, exposure duration and consequence severity to allow meaningful comparisons of risk levels to be made. When developing the MIRi index, the following factors were considered:

1. Probability levels. Typically probability scales used within risk management tools range from 1 in 10 (frequent) to 1 in 1,000 000 (extremely remote). The accident data analysis in sections 3 and 4 showed that road worker injury is an infrequent event. Using a typical scale, the risks being calculated for a road worker would largely fall within the lower categories of the scale, resulting in risks being ranked using only a small amount of the scale. It was considered to be more appropriate to create a scale that would allow probabilities to be ranked using the full length of the scale to allow for greater variation and improve the resolution of the index.

   Accident data exists for incidents that have occurred during the installation of temporary traffic management (TTM) but there is insufficient data to create quantitative probability for each of the subtasks. Therefore, it was considered to be appropriate to create a scale where the probability of being struck by a vehicle for each of the subtasks could be ranked relative to other probabilities, rather than on a predetermined scale of absolute probability.

2. Exposure to the hazard. The exposure scale on the BS 5304:1988 nomogram range from 1 minute to 5 days on a logarithmic scale. One of the key elements of the MIRi index is to be able to demonstrate the risk reduction a future safety initiative creates. An initiative may reduce road worker carriageway crossings by 2, which over a 3 lane motorway may account to 18 seconds exposure reduction. It was therefore important to create a scale where a few seconds difference in exposure would create a noticeable risk level change. A logarithmic scale was developed that would allow for a time range from a few seconds to several hours to be included on the same scale.

3. Consequences. The Abbreviated Injury Scale (AIS) 2005 was considered as the basis for the consequence severity scale. However the AIS is more appropriately used to categorise injuries of people who have already been involved in an accident. The MIRi index needed to be developed as a proactive tool to allow future risk decisions to be evaluated. Therefore it was considered to be most appropriate to use existing HA severity descriptions that are used within the current HA risk matrix. As detailed in Section Two, TRL has expert knowledge of the likely consequences for vehicle occupants and pedestrians from vehicle impact testing, accident studies and research. This knowledge was used to determine *likely* consequences of vehicle impact as opposed to highest foreseeable severity. Of key consideration was the effect of vehicle type on road worker risk and the mechanism by which an impact could occur between a worker

and a vehicle. This suggested that the risk for road workers on the hard shoulder would be greater than that for road workers in offside lanes of the live carriageway, as the likelihood of an HGV encroaching into the hard shoulder and the front corner of the vehicle striking a road worker would be greater due to the significant proportion of HGVs in the nearside lane.

4. Risk level. For the MIRi index, it was considered to be important to be able to categorise risks into more than 3 levels, so that movement between levels after the implementation of safety initiatives could be easily demonstrated. In addition to this, risks levels needed to be calculated for individual subtasks and traffic management operative members and then combined to create overall risk levels for each task and method. A scale was created with numbered levels to allow the effectiveness of risk reduction measures to be easily demonstrated and to allow combination of individual risk scores into overall risk level values.

Example use of the MIRi calculator

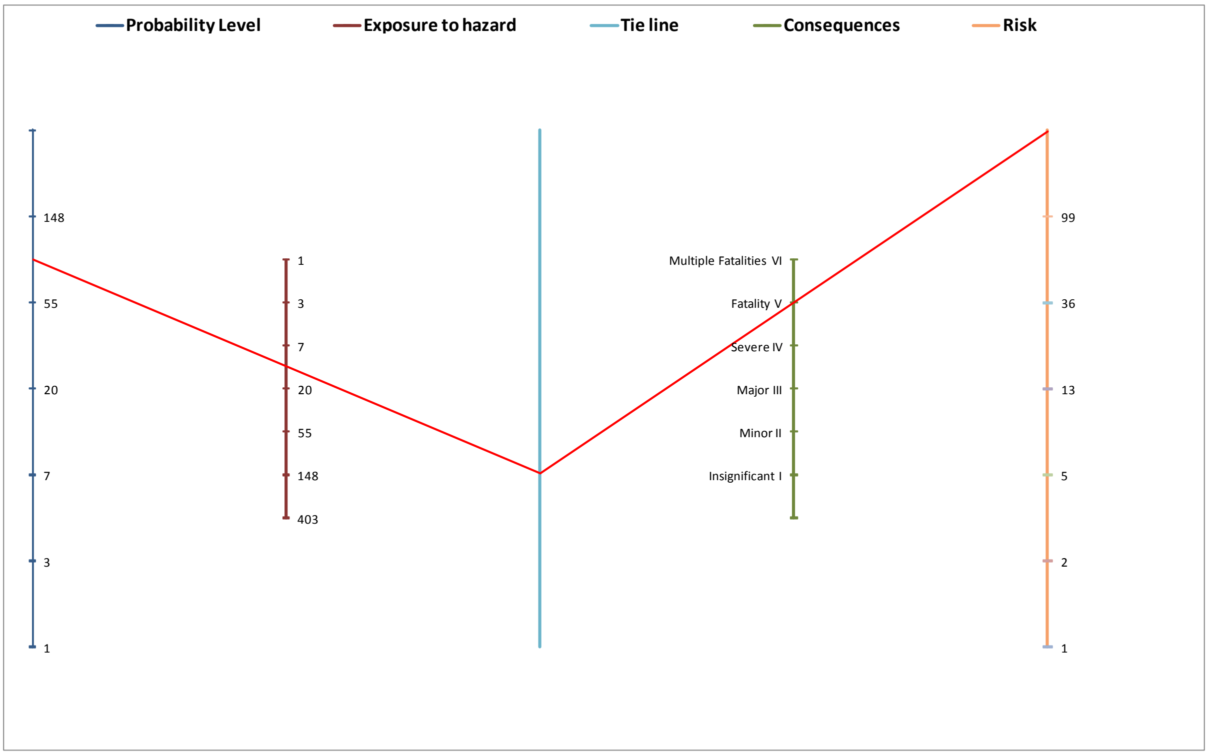


Figure 5-3: Example use of the MIRi calculator

Figure 5.3 shows the MIRi calculator with input parameters of probability level 90, time of exposure to hazard of 12 seconds, with a consequence of a fatality. The MIRi risk level for these conditions is 267.

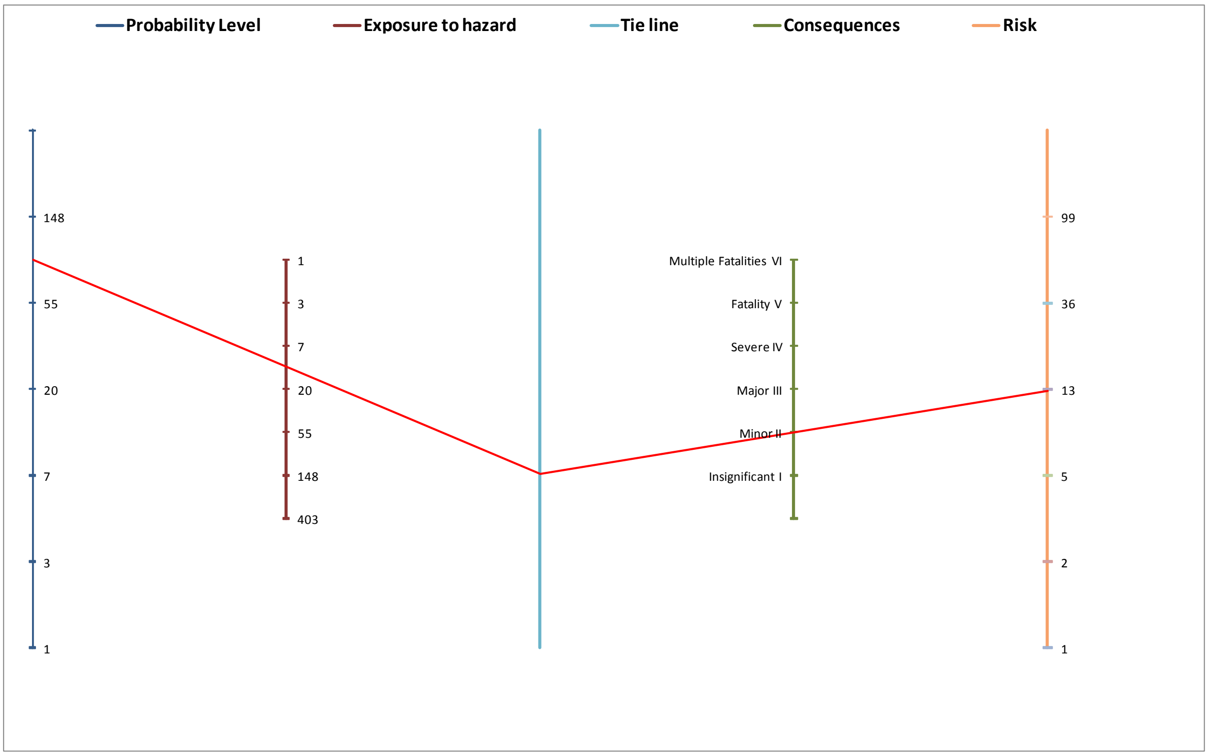


Figure 5-4 Example use of the MIRi calculator

Figure 5-4 shows what happens if the consequence of the hazard occurring is reduced from a fatality to a minor injury. In this set of circumstances, for a probability level of 90, with an exposure time to hazard of 12 seconds, the MIRi value is 13.

5.5 Populating the MIRI Index

Detailed research into the installation of temporary traffic management (TTM) revealed that it is a vast subject area with an almost infinite number of operating practices, equipment types and personal preferences. It was important for the basic MIRI index to set a suitable scope that allowed baselines and index scores to be calculated for 'typical' TTM installations but still allowed for future indices to be calculated for more 'less typical' and more in depth methods of TTM installation. The population of each of the 3 dimensions of the MIRi index is outlined below. Scope and assumptions for each dimension can be seen in Appendix E (Scope and Assumptions).

5.5.1 Probability levels

The probability of being struck by a vehicle varies depending on the task the road worker is conducting. For example, during advanced sign installation the probability of being struck by a vehicle may be different when installing a sign than when the sign is being unloaded from the vehicle. Similarly the probability of being struck by a vehicle is different for the operative member waiting in the IPV than the operative member waiting to cross the carriageway with sandbags.

Appendix D shows a detailed example of the subtasks. For example, the subtasks for taper installation, when using a separate traffic management vehicle (TMV), with the impact protection vehicle (IPV) are:

- TMV and IPV stop on hard shoulder at start of taper.
- Unload 610 arrow, stand and sandbags
- Install sign at start of taper
- TMV and IPV travel along hard shoulder dropping cones from non-trafficked side of the vehicle at appropriate spacings
- TMV and IPV stop on hard shoulder at end of the lane closure
- Operatives walk back along hard shoulder to start of taper
- Walk cones and lights out from hard shoulder to form the taper
- Install 610 arrow sign at end of taper

Probability data was obtained using a combination of professional judgement and expert knowledge. The experience of traffic management specialists was used to guide and advise the ranking of tasks via a focus group. The focus group ranked all of the subtasks for each of the phases of TTM installation based on the probability of being struck by a vehicle whilst conducting that subtask. The subtasks were considered separately for different carriageway types including:

- 3 lane carriageway with hard shoulder off side closure
- 3 lane carriageway with hard shoulder, near side closure
- 2 lane carriageway, no hard shoulder, off side closure
- 2 lane carriageway, no hard shoulder, near side closure.

The effect of vehicle type, equipment, and TM operative role on probability levels was also considered.

All subtasks were assigned a probability level. These probability figures were verified using information gained through discussions with contractors during site visits and observations on the network.

5.5.2 Exposure to the hazard

The exposure times for the MIRI scale were calculated primarily through timing the subtasks during observations whilst on the network. Subtasks which were not observed were discussed with TM experts and exposure times estimated based on expert and operational knowledge.

5.5.3 Consequences

The HA definitions of consequence severity were used to categorise the consequence severity of being struck by a vehicle. The HA categories are as follows:

I. Negligible: Minor injury involving no absence from work (e.g. minor cut requiring no treatment other than a plaster)

II. Minor: Lost time accident with absence under 3 days (e.g. slip, trip, fall or something requiring visit to doctor and or medical treatment)

III. Major: RIDDOR defined major injury/ disease or defined major incident

IV. Very Serious: Permanent disability such as loss of limb, or indefinite inability to return to work

V. Fatality: fatality or multiple injuries

An additional level VI, 'multiple fatalities', was added to these categories to ensure the MIRi Index can calculate catastrophic consequences, should this be required in the future. This "future proofing" of the MIRi Index was included, as it was identified early on in the index development that an advanced index may be required in the future to assess additional risks not included in the basic index. This would include, for example, the risk to road workers laying the longitudinal, working in the coned off area or working at the side of the hard shoulder. Section 6 explores the advanced MIRi Index requirement in more detail.

Although accident data does exist for TTM installation accidents, there have not been enough accidents to provide detailed consequence severity data for each of the identified subtasks. Therefore, subtasks were assigned a consequence severity rating based on experience and knowledge of vehicle crash testing, high speed road networks and accident investigation

5.5.4 Risk Levels

The risk levels calculated allowed comparison of methods of installation by road type. Calculating the risk levels allowed the highest risk activities to be identified and targeted, to allow risks to be eliminated or reduced at source. The MIRI Index also allows safety improvements to be demonstrated clearly through the reduction of the risk levels.

5.6 Calculation of the Benchmark MIRI Index

For each of the TTM variables listed in Appendix 5, the sub task list was populated with the appropriate probability value, exposure to hazard time (in seconds) and consequence category. The risk value was calculated for each of the subtasks and risk values for each variable were then combined to give a total MIRi value for each method of TTM installation.

The MIRi value for each of the four current methods TTM installation was averaged to give the benchmark MIRi value. Table F-1

6 Discussion

The accident data examination exercise carried out for this task indicated there was a scarcity of data suitable for quantification of risk. Near-miss reports are unfortunately subjective (as there is no centrally agreed and defined reporting criterion for near-misses) and as such should only be considered indicative. The injury accident data available comprised higher severity injuries. It is unlikely that this is due to under-reporting of RIDDOR reportable accidents, which suggests that when a road worker is involved in an injury accident the severity of that accident is likely to be high.

The investigation into injury outcome confirms this suggestion from the accident data study, namely when road workers are struck by vehicles the injury consequences are severe or fatal. The injury outcome work also provides a speed/injury relationship that can be used to understand the consequence of impact; this allows the relative risk of being struck by a large vehicle (such as a HGV) or a lighter vehicle (such as a car) to be taken into account when determining risk. Understanding this speed/injury relationship leads to the (perhaps) slightly counter-intuitive position whereby the risk from impacting vehicles is greater for workers on the hard shoulder than in the central reservation. This would not be apparent without considering the injury risk associated with the proportion of large vehicles in Lane 1 compared to Lane 3.

The risk to road workers on the hard shoulder would appear at first instance to be lower than for workers in the offside lane of a carriageway. However, if the injury criteria are taken into consideration the risk to road workers on the hard shoulder from heavy vehicle encroachments into the hard shoulder would cause a greater risk of serious or fatal injury compared to an impact with a lighter vehicle such as a car. Thus the risk for road workers on foot on the hard shoulder was considered to be greater than for those in the offside lane. This also suggests that risk to road workers operating on foot on the hard shoulder should be considered more fully once the key risks to road workers such as carriageway crossings and operating in live lanes are fully understood. This could be approached via a more advanced version of the MIRi Index applied to all road workers that would ensure the risks associated with on-road operations by any road worker (including recovery operatives) could be fully quantified and understood.

Similarly, the data from the accident study indicate that the risk to road workers is greatest from setting out and taking in road works. When near-misses are taken into account from AIRSWeb data, the data indicate that over 75% of all reported accidents, incidents or near-misses involved a road worker either setting out or removing traffic management. When examining the two activities in further depth, it appears that setting out is the higher risk activity, with over 50% of all reported accidents, incidents or near-misses associated with setting out operations. This is reasonably intuitive, as the situation of taking a live carriageway containing high-speed traffic and closing part of it would be expected to carry a higher risk than reopening a closed portion of that carriageway.

These indications provide a sound foundation for the development of the MIRi Index. The speed/injury relationship is not directly applicable to the basic index but as described above will provide a significant input parameter to any enhancements necessary to develop an advanced MIRi Index. Any advanced index would need to consider the risk to all road workers (as opposed to just traffic management operatives) from passing traffic, taking into consideration the type of vehicle and potentially the traffic flow and composition. The consideration of speed/injury risk will form a key part of the index, together with risk exposure duration and proximity to the live traffic. More detailed considerations of the advanced MIRi Index are presented in Appendix A

The complexity of traffic management operations presented a particular challenge when constructing the MIRi Index. It is true to say that there is no such thing as a "standard" technique for deployment of traffic management nor any "approved" method that is required by the HA. While guidance on traffic management layouts is provided in the Traffic Signs Manual Chapter 8 Part 1: Design, this is a performance specification and does not prescribe how the traffic management should be installed. Similarly, the Manual of Contract Documents for Highway Works Volume Volume 1 Section 117 (MCHW, 2006) sets out compliance with the requirements of Chapter 8 as a contract condition but only specifies that "*The Contractor shall … provide, erect, maintain, reposition, cover and uncover and finally remove traffic signs as required by the Works. In so doing, such other measures shall be taken by the Contractor as may be necessitated by the Works in accordance with … recommendations in Chapter 8 of the Traffic Signs Manual published by The Stationery Office*".

This defines the outcome required from the contractor in terms of traffic management that complies with the layouts specified in the Traffic Signs Manual Chapter 8. It does not, however, specify the operational technique required to install and remove these layouts, which presented a particular technical challenge for this task.

Previous work had been undertaken for the HA in an attempt to determine the basic methods used by the Supply Chain to install and remove traffic management. This work significantly predated the 'Aiming for Zero' road worker safety initiatives and thus a number of changes had been introduced over the intervening years that made the previous work not representative of current practice. As a consequence, the range and variation in traffic management techniques encountered in this task necessitated development of a number of generic technique definitions (as described in Section 5) based on a series of base assumptions (documented in Appendix E).

These generic techniques provided a framework to calculate MIRi Index values but in themselves provide valuable information into techniques used for traffic management. Examination of these techniques indicates that the risk associated with deploying even one type of traffic management layout varies considerably. For example, considering the baseline MIRi Index value, Table 6-1 shows the baseline value for an offside lane closure is obtained from a significant range of individual values and involves a varying number of carriageway crossings:

Traffic management method	MIRi Index
Offside lane closure benchmark value	256259
TM+IPV, IPV following	240321
TM + IPV	231337
TMIPV	264043
TM	289336

Table 6-1 MIRi Index for a Chapter 8 (diagram DZB3) relaxation layout for an offside closure

The significantly greater MIRi Index value for the last technique in the list comes from the increased carriageway crossings associated with installation of the entry taper from the hard shoulder. However, the three other techniques share the same number of carriageway crossings but there is still a variation of 32,706 between the highest and lowest MIRi Index values that share a common number of carriageway crossings. This is primarily due to the different levels and durations of exposure to risk within the different methods rather than the number of crossings of the carriageway.

This indicates that while reduction in carriageway crossings is a potential indicator of a lower MIRi Index value, it is not the sole indicator nor can it be assumed that a zero carriageway crossing value will result in the lowest possible MIRi Index value. This point is further illustrated by the comparison between the TTM Sign Simplification and the Offside Sign Relaxation examples for a nearside lane closure.

The TTM Sign Simplification approach of removing the 600 yard and 200 yard wicket signs decreases the MIRi Index value by 34,800. This gives a range of MIRi values for the various techniques from 178274 (TMIPV) to 217351 (TM+IPV).

For the offside signs relaxation there are no carriageway crossings and the MIRi value drops by 59390. This, on first inspection, would suggest that the offside signs relaxation technique will always be superior to the TTM sign simplification technique as it eliminates all carriageway crossings. However, there is a significant overlap in the range of MIRi Index values for the offside signs relaxation significant versus the TTM Sign Simplification values, as the chart below shows:

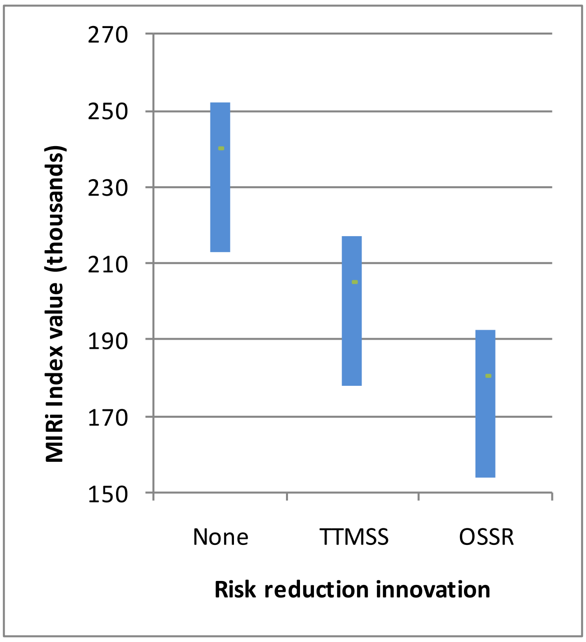


Figure 6-1 Overlap of MIRi Index values with various interventions

Thus, while it is possible to state that for the same method (e.g. installation from a TMIPV) elimination of carriageway crossings should achieve a relative reduction in MIRi Index value, cross-technique comparison indicates this generalisation cannot and should not be applied to absolute MIRi Index values.

This also demonstrates that the base method of TM deployment and retrieval is critical to driving down risk and thus achieving the lowest overall MIRi Index value. The base method has a significant effect on the absolute score and can result in techniques involving carriageway crossings having a lower MIRi Index than those which do not.

A proper understanding of the base MIRi Index value for any particular technique is critical to achieving the greatest safety improvement. Significant decreases in MIRi Index can be achieved simply by changing the generic method. While it is recognised this has practical limitations due to vehicle fleet and operational procedure issues, this approach could realise a significant risk reduction depending on the nature of the change in technique applied.

Figure 6-2 shows the effect of changing between the four generic methods for installation of an offside lane closure:

		New method for installing an offside lane closure			
Original method for installing an offside lane closure		TM + IPV	TM + IPV (f)	TMIPV	TM
	TM + IPV	no change	+8984 (+4%)	+32706 (+14%)	+57999 (+25%)
	TM + IPV following	-8984 (-4%)	no change	+23722 (+10%)	+49015 (+20%)
	TMIPV	-32706 (-12%)	-23722 (-9%)	no change	+25293 (+10%)
	TM	-57999 (-20%)	-49015 (-17%)	-25293 (-9%)	no change

Figure 6-2 Effect of changing generic method of installation of TTM on MIRi Index

Although the magnitudes of the numerical changes between the methods are identical, varying only in sign (e.g. -57,999 versus +57,999), comparison of these with the base methods result in different percentage values. For example:

TM+IPV changing to TM vehicle only (numerical change +57999):

Base MIRi Index for TM+IPV = 231337 (from Table 6.1 above)

Percentage change = 57999 ÷ 231337 x 100 = 25.0%

TM vehicle only changing to TM + IPV (numerical change -57999):

Base MIRi Index for TM vehicle only = 289336 (from Table 6.1 above)

Percentage change = 57999 ÷ 289336 x 100 = 20.0%

Thus, if the current method is a TM vehicle, shifting to a TM vehicle with separate IPV will reduce risk by 20% but moving to using a TMIPV would only realise a 9% risk reduction. Similarly, if a company using a TMIPV chose to move to a TM + IPV arrangement this would decrease the MIRi Index score by 12% compared to their current situation; moving to a TM vehicle alone would also increase the score, but only by 10%.

It should be noted that this change in method matrix shown in Figure 6-2 applies only to an offside lane closure. Different matrices could be developed using the base data for other conditions and specific methods or sub-methods.

Change in method thus has the potential to achieve MIRi Index reductions of up to 20%. In addition, changing methods also has the potential to reduce carriageway crossings significantly. For example, considering the MIRi Index values for installation of an offside taper (from Table 6-2):

Technique	Carriageway Crossings
TM + IPV	99
TM + IPV, IPV following	99
TMIPV	99
TM	162

Table 6-2 Carriageway crossings for an offside relaxation closure for the different generic methods

Hypothetically, if the view is taken that the only unavoidable carriageway crossings are those associated with installation of advanced signing (notwithstanding the benefits to be gained from TTM sign simplification or offside signs relaxations), then the number of carriageway crossings in all techniques will decrease to 99. Estimating the effect of this change is difficult as there is a scarcity of data on exactly which technique is used for installation of specific road works TTM, which presents an issue in calculating any benchmark index for all TTM operations across the HA network.

It is possible to obtain details of which specific TTM contractor has installed each set of road works on the network from the Schedule of Road Works maintained by the HA. However, this information is only part of the data required to calculate the total risk exposure and likely number of carriageway crossings. Without the knowledge of which technique is used by which contractor (and, where more than one technique could be used by a specific contractor which is most likely to have been used) it is impossible to calculate or estimate a benchmark value with any accuracy. Such data would be required for the calculation of an advanced MIRi Index value, but falls outside of the scope and requirements of the basic index.

If, however, it is assumed for the sake of this hypothetical example each technique accounts for 25% of the total relaxed TTM operations on the network, then only permitting carriageway crossings associated with the installation of advanced signing would drop the average number of carriageway crossings for installation of an offside lane closure by 17%. This is, perhaps, a generous figure insofar as it assumes that 25% of offside lane closures are installed using a TM vehicle alone.

However, even if the technique where the taper is installed from the hard shoulder is only used 15% of the time, restricting carriageway crossings to advance signing only would still yield a reduction in carriageway crossings of 11%.

Although this approach is only given as an example, it indicates how the MIRi Index can be used to calculate where initiatives can contribute to achieving a substantial reduction in carriageway crossings in support of HA targets. It should be pointed out that the TM vehicle technique carries the greatest risk for installation of a taper in an offside lane because the vehicle cannot be used to provide protection for the workers, necessitating their crossing the carriageway to install the taper. However, where a nearside lane taper is installed from the hard shoulder and carriageway crossings are not required the risk from the TM vehicle technique has a comparable (and in some cases lower) risk than the other techniques examined.

In terms of the benefits achievable at present from changing methods of installation of road works, the TTM sign simplification and offside signs relaxation approaches offer perhaps the best opportunity to reduce carriageway crossings and reduce risk to road workers. The TTM sign simplification (omission of Detail ‘A’ plus 600 yard and 200 yard advance signing) can achieve a 52% reduction in carriageway crossings for installation of an offside lane taper. This applies for all techniques except the TM vehicle method, where the reduction in carriageway crossings is only 28% due to the influence of the carriageway crossings required to install the taper.

Using the same proportions as before (i.e. 15% of closures installed using the TM vehicle method), national adoption of the TTM sign simplification technique would reduce carriageway crossings by around 45%.

Looking at offside sign relaxations is slightly more difficult as this technique can only be applied for nearside lane closures, unlike the sign simplification technique which could be applied at all relaxed road works. Additionally, when claiming benefits it is not possible simply to add the reductions in carriageway crossing percentages as the percentage reduction is a relative and not an absolute measure. It is also necessary to consider whether benefits are genuinely cumulative (i.e. initiatives are complementary) or whether one initiative will effectively replace part or all of another, thus reducing the benefit realised from it.

However, with some modelling it is possible to calculate the overall cumulative effect. For the sake of this worked example, the following assumptions have had to be made:

- Relaxed works only will benefit from changes in technique
- 80% (estimated) of relaxed works are offside lane closures
- Remaining 20% of relaxed works are nearside lane closures

- 15% of closures are installed using a TM vehicle
- 25% of closures are installed using a TM vehicle + IPV following
- 25% of closures are installed using a TM vehicle + IPV
- 35% of closures are installed using a TMIPV

Thus, in Scenario 1, the benefit of TTM sign simplification (TTMSS) is realised nationally on 100% of relaxed works

This achieves a reduction in MIRi Index for both nearside lane closures and offside lane closures from the application of the TTMSS technique. As offside lane closures represent the majority of closures in this worked example, the change in MIRi Index and carriageway crossing value are dominated by the benefits to the offside lane closure situation.

Scenario 1: TTMSS only - MIRi Index reduction: 19%

Scenario 1: TTMSS only - carriageway crossing reduction: 46%

In Scenario 2, the benefit of TTMSS is again realised nationally on 100% of relaxed works but the additional benefit of offside signs relaxation (OSSR) is realised on any nearside lane closures. This results in the benefit realised from TTMSS on nearside lane closures being removed and replaced instead with the benefit from OSSR. For offside lane closures, the benefit from TTMSS remains.

As offside lane closures represent the majority of closures in this worked example, the additional benefit from introducing OSSR in terms of MIRi Index reduction is only 2%. The carriageway crossings benefit is limited as crossings can only be eliminated in 20% of closures, which provides an additional 9% of carriageway crossing reductions compared to the original baseline.

Scenario 2: TTMSS + OSSR - MIRi Index reduction: 21%

Scenario 2: TTMSS + OSSR - carriageway crossing reduction: 55%

Comparing this approach with the 100% reduction in carriageway crossings achievable from the offside signs relaxation and the 45% reduction in carriageway crossings from TTM sign simplification shows that new initiatives may not always deliver the huge reductions in carriageway crossings that they may at first sight promise to deliver. The key element is uptake i.e. how often will the new approach be used and thus realise its benefits? This is critically dependent on opportunities to apply the new technique, which is in turn dictated by the Schedule of Road Works. As shown in the example, the relatively small number of nearside lane closures leads to a relatively small additional benefit being realised from the offside signs relaxation technique.

Better estimates for the effectiveness of cumulative interventions could be made with greater knowledge of the types of road works carried out. Sensitivity analysis of the model used to prepare the worked example shows for each 10% increase in the number of nearside closures reduces the carriageway crossings by around 5%. The model also assumes 100% uptake by the Supply Chain; experience from the roll-out of the innovative entry taper technique (via AMM125/10) indicates that there is often reluctance to change established methods in favour of something considered unproven or even “unsafe”.

Calculating the benefit from adding three or four initiatives together is possible, but it is clearly important that initiatives must be genuinely cumulative. Similarly, logic dictates that any initiative added must have a MIRi Index and carriageway crossing reduction at least as great as the initiative or practice that it replaces. Failure to ensure that both these criteria are satisfied is critical as failing to do so will result in either marginal gains or potentially in an increase in MIRi Index and/or carriageway crossing value.

7 Conclusions and Future Developments

The workers who maintain the Highways Agency road network operate in close proximity to fast-moving traffic that is not under their direct control. This presents an injury risk that can result in fatal or life-changing injury to road workers.

Understanding this risk is a key step towards improving its management by prioritising initiatives to ensure the safety of road workers. This is a complicated task as there is no single common approach taken to deploy temporary traffic management (TTM) at road works, necessitating an in-depth understanding of the work processes used.

The MIRi Index has been developed from an in-depth understanding of the work processes involved with deploying TTM. This knowledge has been used to identify four generic methods for deployment of TTM; from these methods and a detailed study of the individual processes involved in their execution the benchmark MIRi Index has been calculated. This applies to the deployment and retrieval of TTM associated with relaxation closures (excluding the longitudinal coning), which accident and incident data suggests is the highest risk activity undertaken by road workers.

The MIRi Index has been supplemented with a carriageway crossing value. This is based on an aggregated value of carriageway crossings and is not a precise value (thus should not be used as a benchmark) but allows quantification of the benefits from changing TTM installation methods in terms of risk and carriageway crossings.

Examining the data from the MIRi Index demonstrates that the selection of the base method for deployment and retrieval of TTM is critical to achieving the lowest possible MIRi Index score. Elimination of carriageway crossings is an important part of reducing risk but without a sound base MIRi Index score it is likely that eliminating carriageway crossings will not drive down risk to road workers to a level that can be shown to be as low as reasonably practicable.

Comparison of methods also shows that there is a significant range from the lowest risk to highest risk and that the MIRi Index value for a technique varies depending on whether it is used to deploy a nearside or offside lane closure. This information is important as it can be used to direct interventions and guidance issued to the Supply Chain to reduce carriageway crossings to a minimum level (typically those associated with installation of advance signing), which has the potential to reduce carriageway crossings by 10%. It also indicates that there is not a "one size fits all" approach to reducing risk and that selection of TTM vehicle and technique will usually be a compromise between the two types of lane closure commonly deployed at relaxed works.

The analysis of the MIRi Index and carriageway crossing data was extended to two potential techniques that have been identified as approaches to reduce carriageway crossings. The TTM Sign Simplification (TTMSS) approach seeks to eliminate the 600 yard and 200 yard advance signing together with the Detail 'A' elements on the hard shoulder adjacent to the entry taper. This approach has the potential to reduce the MIRi Index by up to 22% and to decrease carriageway crossings by up to 52%. If an aggregated value is calculated for likely decrease (based on best-estimate for the number of TM installations carried out using each method), TTMSS can achieve a national reduction in MIRi Index of 19% and a reduction in carriageway crossings of 46%. This is a substantial reduction which can be achieved with no additional equipment or requirements for road workers.

The second approach considered is that of offside signs relaxation (OSSR), where for nearside lane closures the offside signs are omitted. This achieves a similar reduction in

MIRi Index (up to 28%) but reduces carriageway crossings by 100%. However, as this technique is only applicable to nearside lane closures its contribution towards achieving a substantial reduction in carriageway crossings is limited; if the two techniques are combined the indications are that the MIRi Index will decrease by an additional 2% to 21%, with carriageway crossings decreasing by an additional 9% to 55%. These figures are based on a number of assumptions; it is recommended that these are validated from the Schedule of Road Works before these values are cited as evidence of likely benefit.

7.1 Benefits realisation

The primary benefit of the MIRi Index and linked carriageway crossing index is the ability to quantify reduction in risk associated with changes to operating methods within the Supply Chain. This will enable the HA to demonstrate that the target of a "substantial" reduction in carriageway crossings (which was launched at the Aiming for Zero: Safety for our Road Workers event in November 2009) has been realised. This will require on-road implementation of initiatives identified by the MIRi Index as contributing to the target (and subsequent monitoring using the Schedule of Road Works to ensure that the benefits realised are valid and auditable) but this will drive and deliver a significant improvement to road worker safety.

A key secondary benefit from the MIRi Index is the ability to pre-screen potential interventions for effectiveness. This enables the index to predict the likely benefit and contribution to the Aiming for Zero targets that could be realised from introduction of any specific intervention. The overall assessment of any particular intervention requires understanding of the whether its effect is cumulative with existing safety improvements or replaces an existing intervention. In either case, the MIRi Index can be used to calculate its overall impact on risk and carriageway crossings, which can then be put in the context of its impact on cost and operational considerations.

The basic MIRi Index approach could also be applied to new techniques for deployment or retrieval that fall outside of current practices. While this would not be a direct calculation, the principles and knowledge used to develop the index can be applied to techniques such as using high-level signs to replace offside signing at offside lane closures, the innovative cone taper technique or use of mobile lane closures to deploy advanced signing. This enables the effectiveness of these techniques to be compared with the current practices and generic techniques identified in this report and for investment decisions to be taken based on sound data and prediction of likely benefit.

Although the basic MIRi Index only applied to traffic management operatives, the need to develop an advanced MIRi Index has been examined and a number of key enablers included in the basic index. Development of an advanced MIRi Index will be important once the early benefits from the Aiming for Zero programme are realised and carriageway crossings have been significantly reduced. An advanced index would be an evolution of the basic index, but would increase the scope of activities for which risk was quantified to include the longitudinal coning and in-site activity. This would also incorporate the speed/injury relationship defined in Section 2 to quantify relative risk levels for road workers by proximity to live traffic, traffic flow and traffic composition.

The approach devised and adopted for the MIRi Index could be applied to any area where operational safety concerns require prioritisation of activity or quantification of risk. The MIRi Index could be applied to other HA 'Aiming for Zero' workstreams such as the construction safety workstream or the Traffic Officer Service, subject to collection of appropriate data to enable modelling and quantification of risk exposure and duration.

References

HSE Books 2001 Reducing risks, protecting people, HSE's decision-making process
http://www.hse.gov.uk/risk/theory/r2p2.pdf

DfT (2009) The Traffic Signs Manual Chapter 8: Traffic Safety Measures and Signs for Road Works and Temporary Situations, London:TSO

BS 8800:1996 Guide to occupational health and safety management systems (since withdrawn and revised 2004)

H. Raafat (1995) Machinery safety: the risk based approach, practical guidelines on risk assessment, standards and legislation. Technical Communications (Publishing) Ltd

BS 5304:1988, obsolete British Standard Code of practice for safety of machinery.

ISO 13849-1 (EN 954) Safety of machinery – safety related parts of control systems Part 1. General principles for design

The Reporting of Injuries, Diseases and Dangerous Occurrences Regulations 1995

Pasanen, E. (1992). Driving speeds and pedestrian safety; a mathematical model. Helsinki University of Technology, Transport Engineering, Publication 77.

Pasanen, E., Salmivaara, H. (1993). Driving speeds and pedestrian safety in the city of Helsinki. Traffic Engineering & Control 34(6): 308-310.

Rosén, E., and Sander, U. (2009). Pedestrian fatality risk as a function of car impact speed. Accident Analysis and Prevention 41:536-542.

Rosén, E., Stigson, H., and Sander, U. (2010). Literature review of pedestrian fatality risk as a function of car impact speed. To be submitted for publication.

Glossary of terms and abbreviations

MIRi	Measurement of Injury Risk Index
TTM	Temporary Traffic Management
TMV	Traffic Management Vehicle
TMIPV	Traffic management vehicle combined with a cushion
TM +IPV	Traffic management vehicle with a separate impact protection vehicle
AIS	Abbreviated Injury Scale
TTMSS	Temporary Traffic Management Sign Simplification
OSSR	Offside Signs Relaxation

Appendix A Impact speed and pedestrian injury outcome

Relationship between vehicle impact speed and pedestrian injury outcome

Significant numbers of pedestrians are injured or killed as a result of being struck by motor vehicles every year. The relative importance of pedestrians with respect to all traffic casualties varies between different countries, but typically the most common pedestrian crash scenario involves them being struck by the front of a passenger car. Pedestrians account for approximately 14% of the road fatalities in the EU 15 (2004). In Great Britain the proportion of pedestrians with respect to the number of people killed each year in traffic collisions is higher at roughly 21%.

One major factor that influences pedestrian injury outcome during a collision is the vehicle speed at the point of impact. This study provides a comparative review of real world casualty injury severity for pedestrians who were struck by the front of a car with respect to the speed at impact. The report only considers the risk of injury for the data available and **does not** present precise probability measures of injury related to a given impact speed; rather it outlines the general trends. Further the report **does not** present any data or comment on the contributory or causal factors associated with the accidents.

A.1 Background

Vehicle speed affects both the risk of an accident and the associated injury severity. It has been observed that a reduction of the speed limit on a road from 60 kph to 50 kph produced a 20 % drop in pedestrian accidents, and a 50 % drop in pedestrian fatalities [6]. Section A.6 considers the travelling speed of vehicles and their potential to brake to avoid or lessen the severity of a potential collision.

Pedestrian accidents are known to occur at a wide variety of impact speeds [7], although the majority (about 85 %) are believed to be below 50 kph [8]. Pedestrians are usually hit from the side, and are 3 to 4 times more likely to be crossing the path of the vehicle than travelling in a parallel direction to it [8]. Cases where the vehicle runs over the pedestrian (where the wheels travel over the pedestrian as they lie in the road) are rare, with estimates varying between 2 % and 10 % [5] of pedestrian casualties.

It has been found that children and the elderly are overrepresented in pedestrian casualties (where "children" refers to under 16s and the elderly to over 60s) [6]. The impact kinematics of a child and adult pedestrian are known to be different when struck by the front of a car. One reason for this is that pedestrian height is directly related to the structure on the car they strike, with taller casualties more frequently striking the upper bonnet and/or windscreen.

The body parts with the highest risk of injury (frequency x severity) for a pedestrian struck by a vehicle are the head, followed by the lower extremities, the thorax, and the pelvis [5]. For non-fatal injuries, the lower extremities have been seen as the most frequently injured. These injuries tended to be to the knee ligaments for impacts speeds around 20-30 kph, and to be fractures for accidents around 40 kph [2].

The head is often subject to two impacts, the first with the car itself, and the second with the ground as the pedestrian is thrown from the car. In relation to the relative severity of these two impacts, the literature is divided. Some observe that the primary impact (with the car) is the most severe impact [5]. This is in line with papers suggesting that the injuries caused by secondary impact are fewer and less serious than those caused by primary impact [9]. However, others claim that the secondary impact is often a source of injury comparable to the primary impact [8].

Euro NCAP undertakes pedestrian sub-system impactor tests that are designed to rate new car models on the protection they offer to pedestrians in a frontal impact. In order to produce repeatable and scientific measurements leg forms and head forms are used to represent the pedestrian's associated body regions. The leg and head forms are projected towards the vehicle at 40 kph. The leg forms impact with the bumper and the bonnet leading edge and the head forms strike the bonnet at a variety of locations. The impactors are instrumented and the resulting measurements are used to predict the risk of injury.

While speed is certainly a factor directly linked to the severity of injury during pedestrian-vehicle collisions, other factors also come into play, making a pure assessment of the effects of speed very difficult. For example one study has shown that a long bonnet on a car reduces the injury risk of pedestrians in collision with that car [5]. This difficulty is exacerbated by the varied nature of pedestrians, who will be of all ages, heights and weights and have very different biomechanical tolerances [7]. As people age their biomechanical strength decreases leaving them more vulnerable to injury for a given loading condition.

For several reasons, including those noted above, it is impossible to predict solely from the speed of an accident what the injury outcome of a given pedestrian will be. Fatal accidents have occurred at very low speeds, under 20 kph and as low as 12 kph; and slight injuries have been seen at much higher speeds (above 40 kph) [5] [7]. However, it is possible to identify boundary speeds, where the proportion of accidents changes from being mainly slight accidents to mainly severe accidents, and where the proportion changes from mainly survivable accidents to mainly fatal accidents.

A.2 Data sources

This study has used real world accident data from the On The Spot (OTS), Heavy Vehicle Crash Injury Study (HVCIS), the UK Police fatal file archive and an International Harmonized Research Activity (IHRA) dataset.

A.2.1 On The Spot (OTS)

As part of this study, pedestrian casualties recorded in the On The Spot (OTS) study and Police fatal files have been used to estimate the relationship between impact speed and pedestrian injury severity.

In 1999, the UK's Department for Transport and Highways Agency (HA) commissioned the 'On the Spot' (OTS) accident research project to collect information at the scene of all types of road accidents. In-depth accident investigations were carried out to study their causes, injury mechanisms, human involvement, highway design and vehicle design. This allows research to be conducted to investigate the causes of crashes, their subsequent injuries and the associated societal costs.

The project started to collect data in June 2000, which is incorporated into a database detailing 500 in-depth investigations per year. Two investigation teams, the Vehicle Safety Research Centre (VSRC) at Loughborough University and the Transport Research Laboratory (TRL), work in close co-operation to produce the joint dataset. The teams work in the Nottinghamshire and Thames Valley Police Force areas respectively, and each investigate 250 accidents per year.

A comprehensive description of the methodology and investigations achieved was published in February 2008 (Cuerden et al). A brief outline of the number and type of accidents investigated by each research centre can be found in this report, and further details may be viewed on the project website (www.ukots.org).

A.2.2 Heavy Vehicle Crash Injury Study (HVCIS)

The HVCIS fatal accident database contains over 2000 fatal accident cases involving larger vehicles. Fatalities are comprised of large vehicle occupants and their opponents.

This study features a sample of the pedestrian impacts and provides information on the nature of pedestrian injury associated with collisions with larger commercial vehicles.

A.2.3 Police Fatal file archive

Police fatal file collision reports contain information arising from Police investigations into fatal traffic collisions, and provide detailed information on the events leading up to a collision, as well as giving details of driver errors and/or vehicle defects which may have contributed to the collision and to the injuries that resulted in the fatality. They provide a unique insight into how and why fatal collisions occur.

Since 1992 TRL, on behalf of DfT, has received fatal files from Police forces in England and Wales. The current archive contains over 34,000 Police fatal collision reports.

From the pedestrian accidents in OTS and the Police fatal files, a sample of 197 pedestrian casualties was obtained, including 66 fatalities. These pedestrians were hit by the front of cars, in accidents occurring from 2000-2009. Accidents where the pedestrian was lying down or where the vehicle “sideswiped” the pedestrian were excluded. All ages of pedestrian casualty were included in the sample, including those of unknown age.

A.2.4 International Harmonized Research Activities (IHRA)

The International Harmonized Research Activities (IHRA) Pedestrian Accident Dataset was initially compiled by NHTSA, from data supplied by the German In-Depth Accident Study (GIDAS), by JARI of Japan, and by the Pedestrian Crash Data Study (PCDS) of the USA. From each of these studies, seven fields of information were identified which were common to all three studies. For each injury, these were input into the IHRA accident dataset. The seven fields were country, case number, pedestrian age, impact speed, AIS injury level, body region injured, and vehicle source causing the injury. The data were made available to the IHRA Working Group members, contained within an Excel spreadsheet.

The data provides a comparison group for the UK in-depth accident data and allows results to be checked, which is very important as some of the sample sizes are quite small.

The IHRA dataset presented in this study is:

- Cars only: For Germany it was accidents involving passenger cars. For the US it was accidents involving cars, light trucks & vans, which is probably a good match to their vehicles that are functionally cars. For Japan it was accidents involving ‘bonnet type cars’.
- Frontal only: Germany frontal only, no run-over’s, were supplied to IHRA (other cases available but not supplied to IHRA). US vehicle moving forward and first contact forward of the top of the A-pillar (this restriction is on their study, so other directions / first contacts not available). Japan ‘pedestrians against front portions’.

Inevitably with combined data of this type, there will have been differences in methods, interpretation, coding, etc. that limit the comparability of data from the different sources. Further details on the individual studies can be found in the Working Group’s 17th ESV (2001) paper (paper number 280) and in their 2001 Report. Both are available from http://www-nrd.nhtsa.dot.gov/ihra/. The paper and report also contain analyses of the dataset that were carried out by NHTSA.

The German In-Depth Accident Study (GIDAS) was a joint study by the Automotive Industry Research Association and the Federal Road Research Institute. The accidents were from Dresden and Hanover, and surrounding rural areas. Accidents where a passenger car collided with more than one pedestrian or a pedestrian was hit by more than one passenger car were excluded, as were accidents where the car ran over the pedestrian or where the impact speed could not be established.

Japan supplied two datasets to NHTSA for the IHRA dataset. The first was collected from 1987 to 1988 and the second from 1993 to 1998. See "The present situation of pedestrian accidents in Japan" by H Ohashi, K Ono (both JARI), A Sasaki (JAMA), N Ohashi, & S Misawa, presented at IRCOBI, 1990. Although this reference describes data collection, selection of accident locations, etc. for the first dataset, the second dataset was collected in the same way.

A.3 Terminology and definitions of key variables

A.3.1 Collision Severity Measures (Impact Speed)

The collision or impact severity is determined by the OTS investigation team. Wherever possible, physical scene evidence is used to derive estimates of the speed of the vehicle at the point of impact. These techniques include mathematical reconstructions based on the trace marks vehicle tyres leave on the road surface due to heavy braking and evaluation of the pedestrians' throw distance correlated to the probable impact speed.

Often there is very little physical evidence either on the road surface or vehicle that can be used to calculate an impact speed. Sometimes the only evidence of pedestrian impact with the vehicle are faint cleaning marks on the bumper or bonnet surface. In such cases it is still possible to estimate impact speeds, but the level of accuracy is clearly lower. The OTS team collates information from witnesses, crash participants and the characteristics of traffic flow along with other scene related information to validate and help inform any vehicle to pedestrian impact speed measures.

A.3.2 Classification of Casualty Injury Severity

Casualties' injuries are classified by their severity by the police according to the British government's definitions of Fatal, Serious or Slight. Further, the OTS and other in-depth crash research studies use a more refined and detailed methodology to classify injuries with respect to the risk of death (Abbreviated Injury Scale).

A.3.3 Police Injury Classification of Injury Severity

The casualties' injury severity is classified by RRCGB and by OTS according to the UK government's definitions of Fatal (Killed), Serious or Slight.

'Fatal' injury includes only those where death occurs in less than 30 days as a result of the accident. Fatal does not include death from natural causes or suicide.

Examples of 'Serious' injury are:

- Fracture of bone
- Internal injury
- Severe cuts
- Crushing
- Burns (excluding friction burns)
- Concussion
- Severe general shock requiring hospital treatment
- Detention in hospital as an in-patient, either immediately or later
- Injuries to casualties who die 30 or more days after the accident from injuries sustained in that accident

Examples of 'Slight' injuries are:

- Sprains, not necessarily requiring medical treatment
- Neck whiplash injury
- Bruises
- Slight cuts
- Slight shock requiring roadside attention

A.3.4 Abbreviated Injury Scale Classification of Injury Severity

The OTS casualties' injuries and characteristics (gender, age, height, weight etc.) are obtained from police reports, questionnaires, hospital records or HM coroner reports depending on the casualties' injury severity. The injuries sustained are coded using 'The Abbreviated Injury Scale (AIS) 1990 Revision' *(Association for the Advancement of Automotive Medicine, AAAM).* Each injury description is assigned a unique six digit numerical code in addition to the AIS severity score. The first digit summarises the body region; the second digit identifies the type of anatomical structure; the third and fourth digits identify the specific anatomical structure or, in the case of injuries to the external region, the specific nature of the injury; the fifth and sixth digits identify the level of injury within a specific body region or anatomical structure. Finally, the digit to the right of the decimal point is the AIS severity score. This study specifically uses the AIS code for the body region injured and the AIS severity score. The body regions injured are classified by:

- Head
- Face
- Neck
- Thorax
- Abdomen
- Spine (cervical, thoracic and lumbar)
- Upper Extremity
- Lower Extremity
- Unspecified

The AIS severity score is a consensus-derived anatomically-based system that classifies individual injuries by body region on a six point ordinal severity scale ranging from AIS 1 (minor) to AIS 6 (currently untreatable), shown in Table A 1

Table A 1: AIS Values

AIS Score	Description
1	Minor
2	Moderate
3	Serious
4	Severe
5	Critical
6	Maximum
9	Unknown

MAIS denotes the maximum AIS score of all injuries sustained by a particular occupant. It is a single number that attempts to describe the seriousness of the injuries suffered by that occupant.

The AIS system therefore allows injuries to be coded by their type and severity in terms of threat to life. In OTS, the injuries are then correlated with the associated vehicle damage to try to determine the ultimate cause of each individual injury.

A.4 Relationship between speed and injury outcome

This section considers passenger cars and larger commercial vehicles separately as their geometry and stiffness properties are very different and this has a direct affect on the mechanism of pedestrian injury observed and the influence of impact speed.

A.4.1 Relationship between speed and injury outcome for passenger cars

Figure A 1 and Figure A 2 compare OTS and IHRA data and provide a cumulative percentage distribution for seriously injured pedestrians (non-minor) and fatally injured pedestrians who were struck by the front of passenger cars. They confirm that the OTS data and the IHRA data are very similar. There appears to be a small shift towards higher speeds in the OTS data, but the curves are very similar shapes.

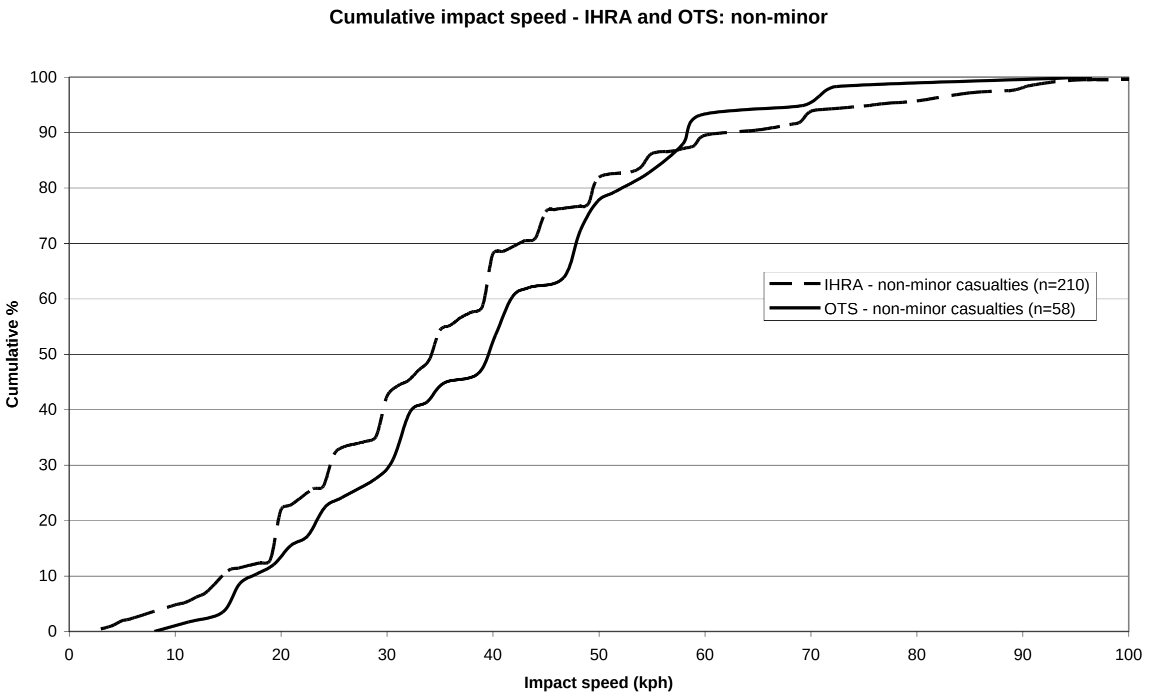


Figure A 1 Cumulative impact speed for pedestrians with non-minor injuries in OTS and IHRA

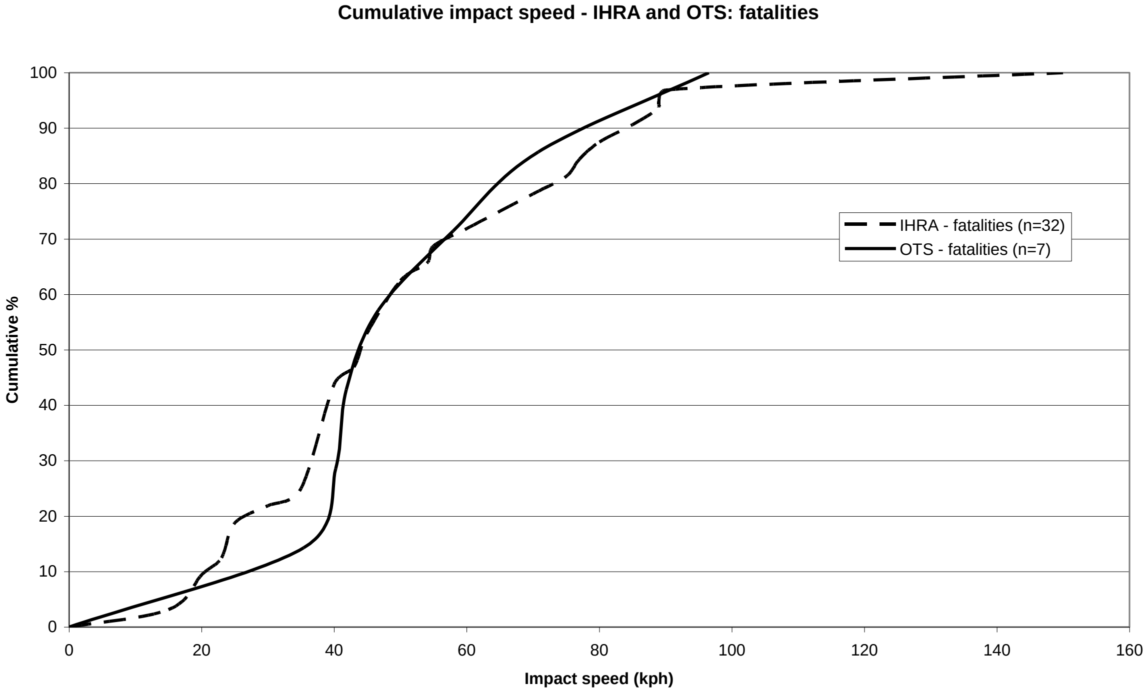


Figure A 2 – Cumulative impact speed for fatalities in IHRA and OTS

Figure A 3 is an approximate risk curve for the pedestrians in the OTS and IHRA datasets, produced from the data. It shows the probability given by the two datasets of suffering injury of a given severity depending on the impact speed. There were very few casualties in the OTS and IHRA datasets with impact speeds above 60 kph, therefore the probabilities given above this speed are a best estimate, to give the reader an impression of what the probabilities may be above these speeds. The probability of a fatal injury has been set to 100 % at 95 kph, and the probability of a MAIS>1 injury has been set to zero at 95 kph.

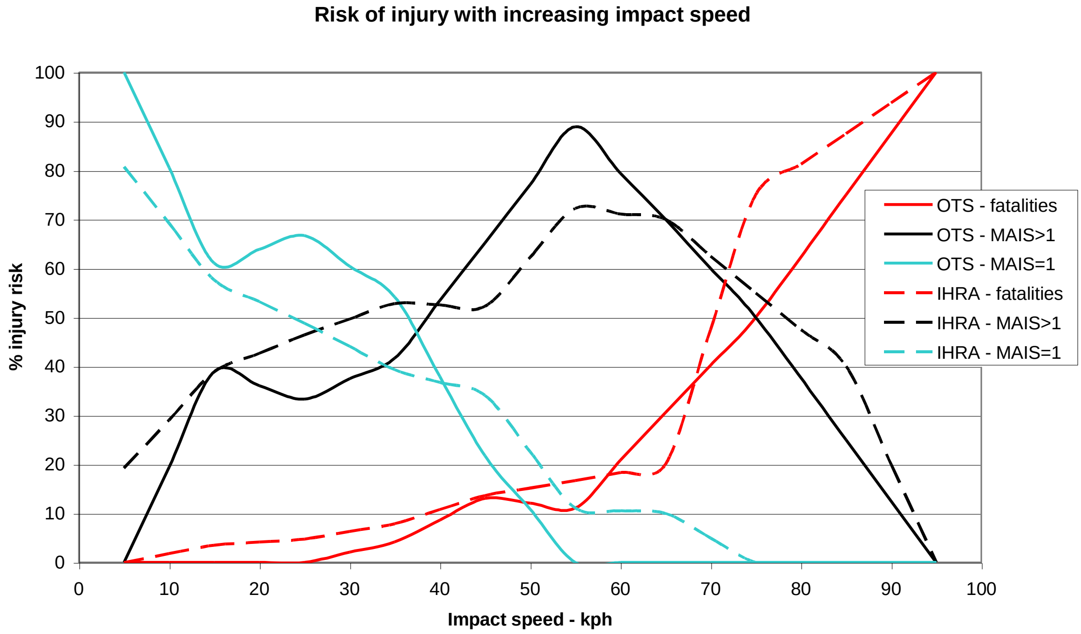


Figure A 3 – Approximate risk of injury given by OTS and IHRA data

Figure A 3 highlights some boundary condition between serious and fatal injury outcome, where the respective injury severity distribution lines cross.

A.4.2 Pedestrian fatal injury risk for passenger cars

A review of the literature on the relationship between impact speed and pedestrian injury found that two main sources of accident data have been used to calculate this relationship. These are data collected by Ashton and Mackay in Birmingham in the 1970s, and data collected by the German In-Depth Accident Study (GIDAS). In addition to these, recent data from the UK has been used for the pedestrian injury risk curves in this study (Police fatal files and the On The Spot project).

There are two main stages to calculating pedestrian injury risk curves. The first involves weighting the data to match national statistics, and the second is the calculation of the injury risk curves themselves and their associated confidence using logistic regression. These curves have been calculated for three sources: Ashton and Mackay data from the 1970s; GIDAS data from 1999-2007; and OTS and Police fatal file data from 2000-2009.

Richards (2010) used logistic regression on the weighted pedestrian dataset in Ashton (1980). The result of using this method on the total Ashton and Mackay pedestrian sample is shown in Figure A-1. This figure shows that the estimated risk of a pedestrian being killed if they are hit at a speed of 30 mph is approximately 9%. The risk at an impact speed of 40 mph is much higher, approximately 50%. This figure also shows that the confidence intervals (the dashed lines in the figure) get much wider as the impact speed increases. This is because there are fewer pedestrians in the sample at higher speeds, which reduces the precision of the estimated risk at these speeds.

Richards (2010) applied a nonlinear regression model based on the least squared method, and calculated the following relationship between impact speed in metres per second (v) and probability of fatality (P):

$$P = \frac{1.027}{1 + 37e^{-0.017v^2}} - 0.027$$

Equation 7-1

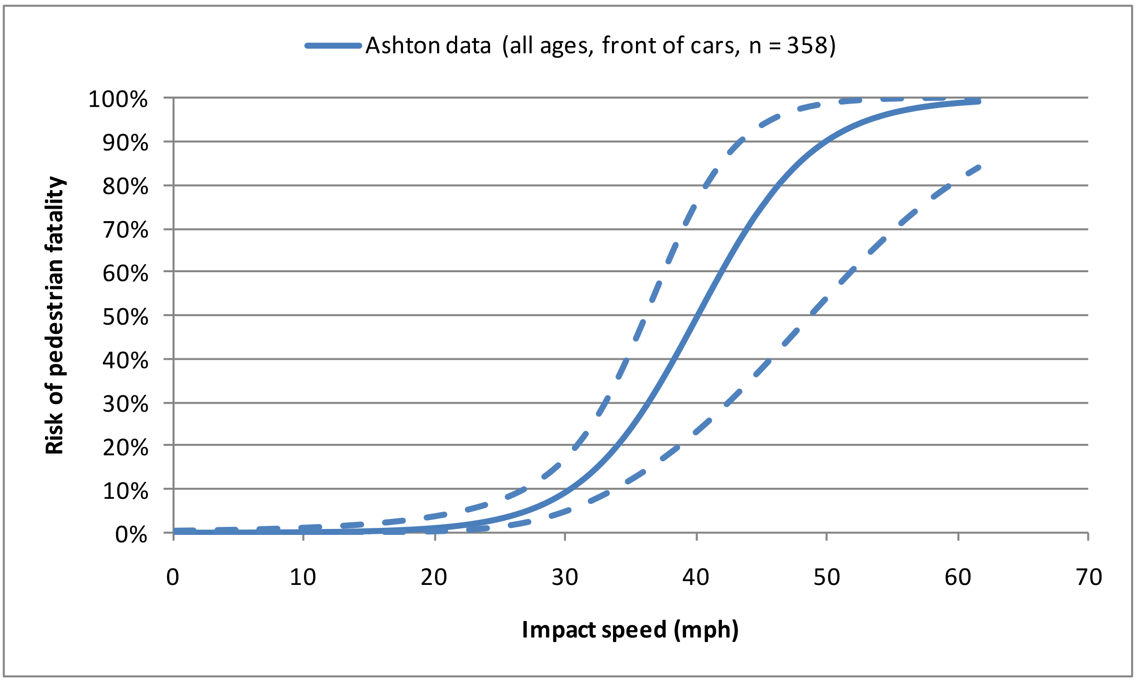


Figure A-1. Risk of pedestrian fatality calculated using logistic regression from Ashton and Mackay data

A study by Rosén and Sander (2009) used GIDAS data to calculate the relationship between impact speed and risk of pedestrian fatality. This sample included pedestrian impacts occurring between 1999 and 2007, where the pedestrian was hit by the front of the car and the impact speed was known. Pedestrians hit by sport utility vehicles, pedestrians who were lying down, and pedestrians who were "sideswiped" were removed from the sample. The final sample used contained 490 pedestrians aged 15-96, including 36 fatalities. There were no children under the age of 15 in the GIDAS pedestrian dataset. The number of fatal, serious, and slight casualties in this sample was weighted to the number of pedestrian casualties in Germany from 2003-2007. Rosén and Sander used logistic regression to calculate the relationship between impact speed v (in kph) and risk of pedestrian fatality P. The relationship found was:

$$P = \frac{1}{1 + e^{6.9 - 0.090v}} \qquad \textbf{Equation 7-2.}$$

Rosén and Sander did not publish full details of their sample. However, through a collaborative work with Autoliv it was possible to analyse the relevant dataset for use in this project.

Figure A-2 shows the results of using the logistic regression on the GIDAS data supplied by Rosén and Sander, and also shows the function calculated by Rosén and Sander themselves. This data contains pedestrians aged 15-96 years. Only one of these curves is visible, because the results are identical: the logistic regression method matches that used by Rosen and Sander themselves. This figure shows that the risk of pedestrian fatality at an impact speed of 30mph is approximately 7%, and the risk of fatality at 40mph is approximately 25%.

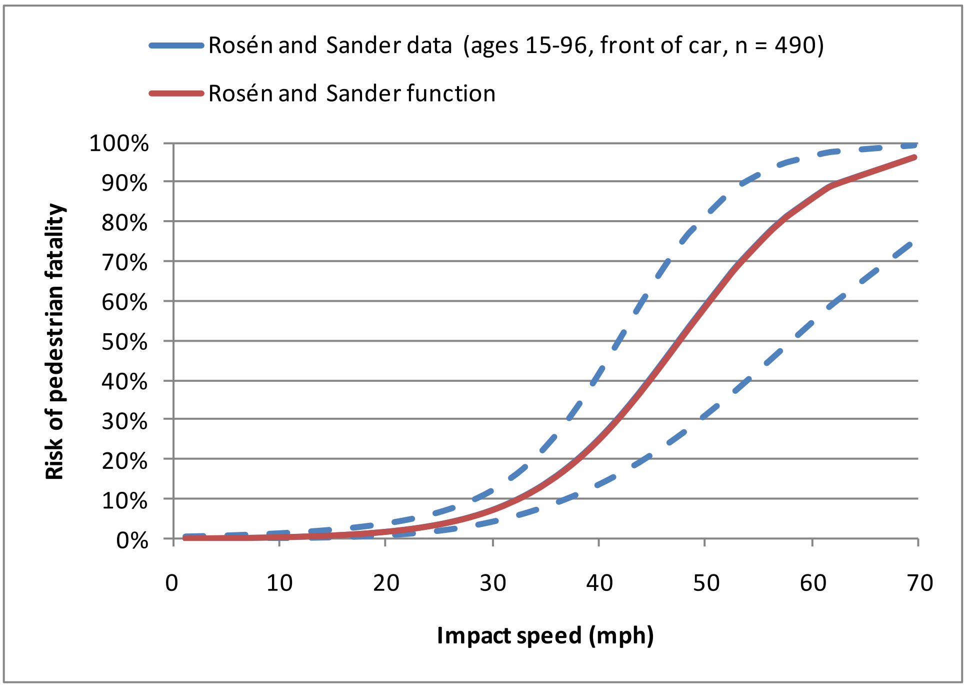


Figure A-2. Risk of pedestrian fatality calculated using logistic regression from Rosén and Sander GIDAS dataset

Richards (2010) collated pedestrian accidents in OTS and the Police fatal files, a sample of 197 pedestrian casualties was obtained, including 66 fatalities. These pedestrians were hit by the front of cars, in accidents occurring from 2000-2009. Accidents where the pedestrian was lying down or where the vehicle "sideswiped" the pedestrian were excluded. All ages of pedestrian casualty were included in the sample, including those of unknown age.

Figure A-3 shows the cumulative impact speed of the pedestrians in the OTS and Police fatal file dataset. This shows that approximately half of fatally injured pedestrians in the dataset were hit at an impact speed of 30 mph or less. In order to perform the logistic regression, the number of slight, serious, and fatal casualties in this dataset was weighted to match the number of pedestrian casualties in the national statistics.

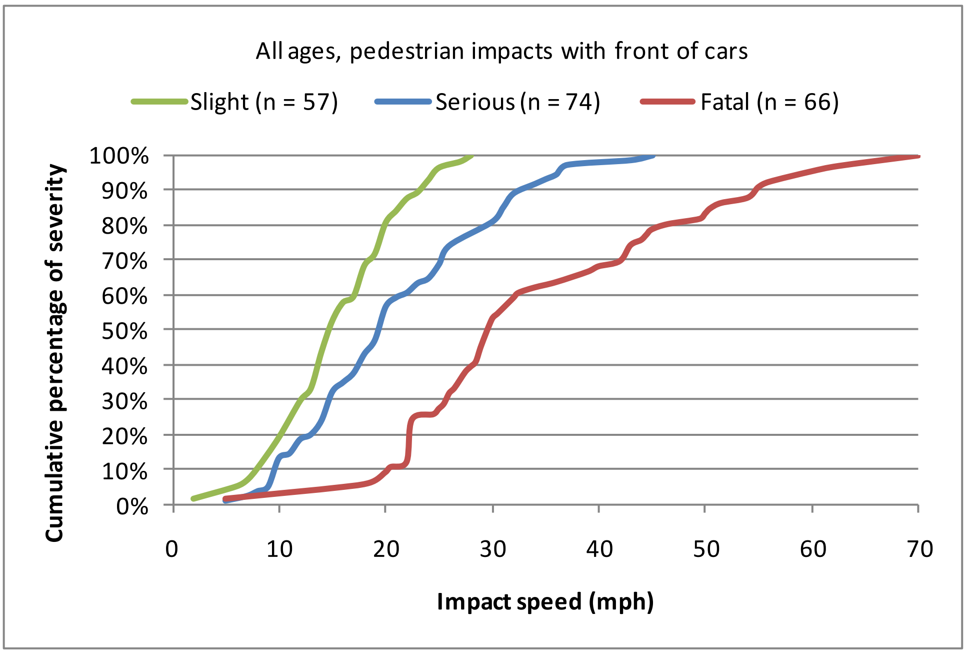


Figure A-3. Cumulative impact speed for pedestrian casualties in the OTS and Police fatal file dataset

Figure A 4 shows the relationship between impact speed and the risk of pedestrian fatality, calculated using the logistic regression method. This figure gives the risk of pedestrian fatality at an impact speed of 30 mph as approximately 7%, and the risk at an impact speed of 40 mph as approximately 31%. The number of cases in the sample is too small to allow the results to be broken down by age group.

Data from three pedestrian datasets (for Great Britain in the 1970s, Germany from 1999-2007, and Great Britain from 2000-2009) has been treated in the same way for comparison. The conclusions of this study are as follows:

- The three pedestrian datasets show a similar pattern in fatality risk. The risk increases slowly until impact speeds of around 30 mph. Above this speed, risk increases rapidly – the increase is between 3.5 and 5.5 times from 30 mph to 40 mph.
- The risk of fatality is generally higher for the dataset from the 1970s, indicating that the risk of pedestrian fatality has reduced over the last 30 years.
- Even though the risk of pedestrians being killed at 30 mph is relatively low, approximately half of pedestrian fatalities occur at this impact speed or below.

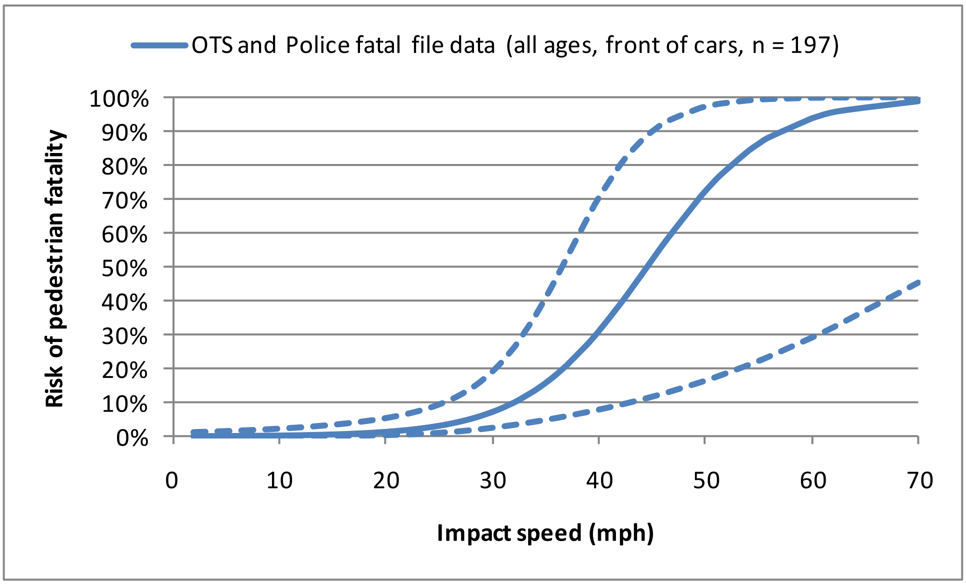


Figure A 4. Risk of pedestrian fatality calculated using logistic regression from the OTS and Police fatal file dataset

A.5 Relationship between speed and injury outcome for larger vehicles

The data contained 173 pedestrians where the most severe impact was with an HGV, 116 that were impacted by an LPV and 59 pedestrians in impacts with LCVs. Figure A 5 shows a comparison of the distribution of differences between impact locations. It is important to note that STATS19 records the first point of impact and the HVCIS data contains multiple impacts and is analysed using the most severe impact. This may explain some of the differences but pedestrian accidents are more likely to involve single impacts than multiple vehicle collisions.

Figure A 5 shows that the representativeness of the data for accidents involving HGVs extends to the distribution of impact location. For LPVs and LCVs the data is less representative and when considering the following analysis, which considers impacts to the front of the vehicle, the data will be under-representing the national picture.

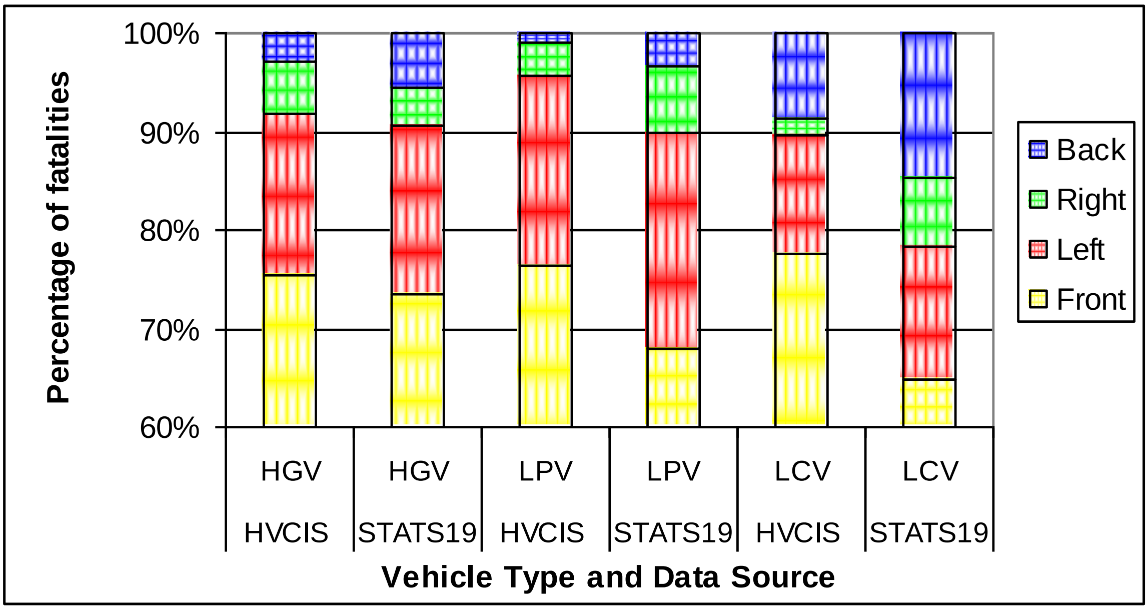


Figure A 5. Comparison of impact locations between HVCIS and STATS19 by vehicle type[1].

The HVCIS database contains data in addition to what is available from STATS19 such as:

- Driver behaviour factors
- Impact speed
- Cause of death
- More detail on impact location/sequence
- Fatality (pedestrian) behaviour factors

The following analysis compares some of this additional data for the three vehicle types LPV, HGV and LCV, focusing on impacts to the front of the HGV.

The impacts are coded using the direction of force, side and part components of the collision damage classification (CDC) (Nelson, 1980). Figure A 6 summarises the impact locations on the front of the vehicles where this was known.

[1] The HVCIS data has an additional impact location of the underside of the vehicle. For the purpose of the comparison, the small number of impacts to the underside has been excluded as unknown. For LPVs and LCVs they account for 1.7% of fatalities and for HGVs 1.2%.

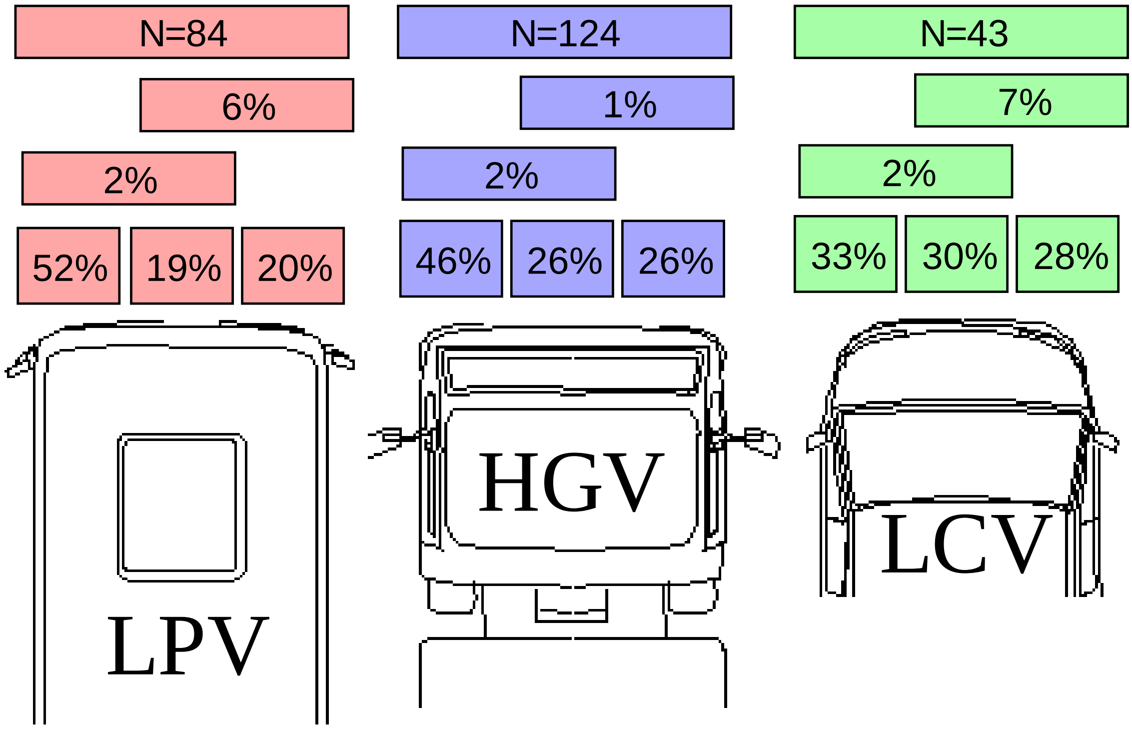


Figure A 6. Pedestrian impact location on front of LPV (left), HGV (centre) and LCV (right).

The left side of the front of the vehicle is the most frequent impact location, which is to be expected for right hand drive vehicles because this is the side nearest to the footpath. The proportion of pedestrians in impacts with the front left of the vehicle varies by vehicle type. For LPVs and HGVs approximately 50% of the pedestrians impact the front left, whereas for LCVs the distribution of impact locations is more even. There are some cases where the impact is described as being distributed across two-thirds of the vehicle. In these cases, the exact impact location may not have been clear.

Data on impact speed is taken from witness statements, police calculations or from tachograph charts where they were analysed by the police. The data for impacts between the front of the vehicle and pedestrians is shown in Figure A 7.

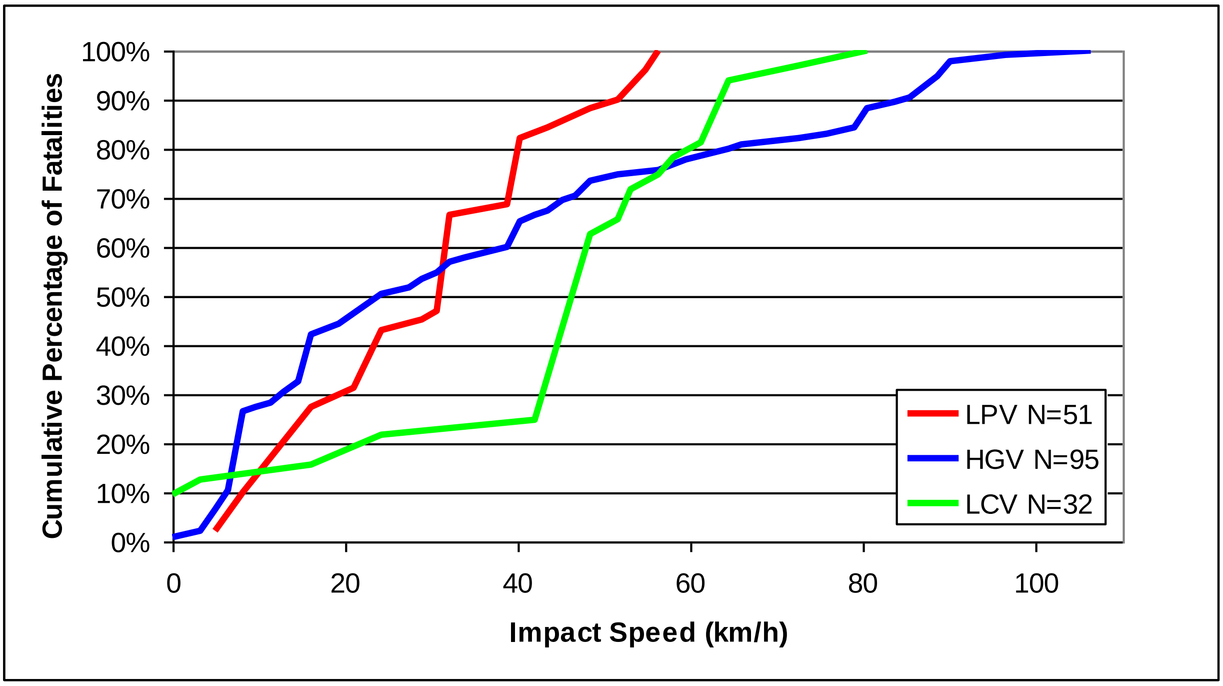


Figure A 7. Cumulative percentage of impact speed by vehicle type.

The median impact speed is approximately 25km/h for HGVs, 30 km/h for LPVs and 45km/h for LCVs. Offering protection to pedestrian in impacts up to 40 km/h could protect up to 25% of those in impacts with LCVs, up to 65% of those in impacts with HGVs and up to 80% of those in impacts with LPVs. However, when considering potential countermeasures, the primary impact with the vehicle may not always be the cause of the fatal injuries. For example the pedestrian could be run over or the secondary impact with the ground may be more severe than the impact with the vehicle.

For impacts with LCVs, 10% of the LCVs have a collision speed of zero which is consistent with frequency of parked LCVs involvement in accidents

The cause of death is also an important factor when considering potential countermeasures. Figure A 8 summarises the cause of death where the information was available.

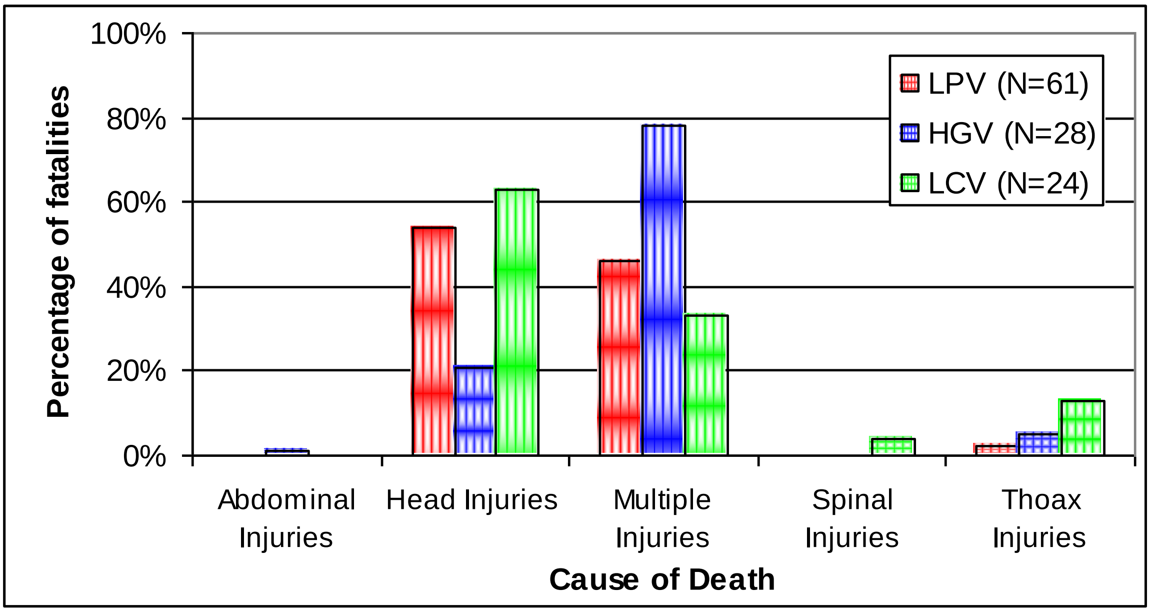


Figure A 8. Cause of death for pedestrians in impacts with the front of LPVs, HGVs and LCVs.

For pedestrians in impacts with LPVs or LCVs, the most frequent cause of death in head injuries, however it is not possible to identify whether the injuries were caused by the impact with the vehicle or the impact with the ground. For pedestrians in collision with an HGV, multiple injuries is the most frequent cause of death, which suggests that collisions with HGVs are more severe than impacts with other vehicle types.

Data relating to body regions that sustain serious injury is also collected. The head was the most frequently injured body region. Where the seriously injured body regions were known, 90% of pedestrians in collision with an LPV, 71% of those in collision with an HGV and 83% of those in collision with an LCV sustained a serious injury to the head, either alone or in conjunction with other serious injuries. The head was the sole serious injury for 40%, 34% and 62% of those in collision with LPVs, HGVs and LCVs respectively.

A.6 Travelling speed of vehicles and driver reaction

Collision avoidance and impact speed

Understanding the avoidance manoeuvres, if any, that the drivers or riders undertook just prior to the collisions with the pedestrians, provides valuable insight into how future accidents could be prevented or the injuries mitigated. Smith et al (2010) undertook an in-depth review of approximately 100 police fatal forensic reports. This included an investigation of the travelling speed of the vehicles involved and avoidance manoeuvres undertaken by the drivers and riders with the impact speed of the vehicle (Table A 2). The impact speed is defined as the speed of the vehicle at the moment it strikes the pedestrian; this is equal to the travelling speed for those who took no avoiding actions.

Table A 2: Vehicle avoidance manoeuvre by impact speed

Avoidance manoeuvre	Vehicle impact speed (mph)									
	0-9	10-19	20-29	30-39	40-49	50-59	60-69	70-79	Not known	Total
None	7	3	5	7	7	6	3	3	2	43
Braking only:										
Skid marks	1	1	2	9	0	2	2	0	0	17
No marks - driver stated	2	1	5	2	1	1	0	0	1	13
Other evidence	0	0	1	1	0	0	0	0	1	3
Steering only	0	0	0	1	1	0	0	0	0	2
Steering & braking	0	1	4	4	3	0	0	0	2	14
Other manoeuvre	0	0	0	1	0	0	0	0		1
Not known	0	0	0	0	0	0	0	0	2	2
Total	10	6	17	25	12	9	5	3	8	95

Table A 3 details 43 drivers and riders (avoidance manoeuvre was known for 93 collisions), who did not actively alter the speed or directions of their vehicles (brake and/ or steer) prior to the impact.

Nearly half the drivers in the sample did not take avoiding action. Failure to take any avoiding action does not appear to be associated with any particular travel speed. It should be noted that this section of the project did not differentiate between drivers and riders who failed to take avoiding action because, perhaps, they were not paying sufficient attention and those who were unable to take any avoiding action because the pedestrian 'stepped out' in front of them without sufficient warning. However, the accident descriptions provide a variety of reasons for the lack of reaction. These included the immediate nature of the incident from the perspective of the driver or rider and the lack of warning time and distance; in some instances the driver simply didn't see the pedestrian, because they were obscured by part of the vehicles structure or other obstacle; or he/she did not perceive or judge correctly the impending impact.

Forty seven of the drivers and riders applied their brakes prior to the collision, with 14 of this group steering to avoid the collision too. This is an important gauge for the potential effectiveness of brake assist (BAS) technologies in the real world. However, it was beyond the scope of this study to evaluate whether the fitment of such technologies could have prevented any of the fatalities.

In total, 16 of the drivers or riders reacted by steering in an attempt to avoid the collision with the pedestrian.

Braking confirmed by skid mark evidence tended to be associated with slightly higher travel and therefore impact speeds (76% were higher than 30mph), as would be expected, compared to braking claimed by the driver. For these cases where the braking was not supported by evidential trace marks on the road surface, 33% (of those with known travel speed) were higher than 30mph. Overall, braking is the most common avoiding action in this sample. Steering and braking also appears to be associated with slightly higher speed accidents (58% of those with known travel speed higher than 30mph).

The effect of the avoidance manoeuvres with respect to the impact speed the pedestrians experienced is shown in Table A 4 . Approximately 43% of vehicles have unknown impact speeds, compared to only about 8% with unknown travel speeds. In the majority of cases, the impact speed is in the same range as the travel speed. One vehicle has an impact speed in a higher range than the travel speed. On investigation, this vehicle was pulling off from rest, and is recorded as having a travel speed of between 8 and 9mph and an impact speed of 11mph. The 30-39mph travel speed category is the only one where a significant number of vehicles (7) change to a lower impact speed category. Most of these were travelling at or just above a 30mph limit, and they braked to just under the limit.

The total distance travelled by a vehicle from the time an event occurs and prompts the driver to brake, to it stopping, is the sum of the reaction (thinking) distance and the braking distance, both of these are subject to variability. The reaction distance is related to the human performance with respect to perceiving the danger and then physically applying the brakes. The stopping distance is directly related to the amount of force applied to the brake pedal by the driver and the associated vehicle braking performance and environmental factors (such as the coefficient of friction of the road surface and the gradient of the road). The vehicle related factors include the roadworthiness of the brake system and tyres and the characteristics of any advanced brake assist or similar technologies.

Table A 4 Vehicle travel speed by impact speed

Vehicle travel speed (mph)	Vehicle impact speed (mph)									
	0-9	10-19	20-29	30-39	40-49	50-59	60-69	70-79	Not known	Total
0-9	4	1							5	10
10-19		1							5	6
20-29		1	11						5	17
30-39		1	7	10					7	25
40-49				1	4				7	12
50-59					1	4			4	9
60-69					1	1	2		1	5
70-79						1		2		3
Not known			1						7	8
Total	4	4	19	11	6	6	2	2	41	95

Considering those collisions with known travel and impact speeds only, it is worth noting that 18 vehicles were known to have been travelling at less than 30mph, but 26 experienced impact speeds below 30mph (8 vehicles which were travelling at 30mph or above braked prior to the impact).

Unlike the distance a vehicle travels during the reaction phase of an emergency event, the distance required to stop from the point when full braking is applied is not linear. For example, a modern car travelling at 20mph (8.9m/s) could stop in a braking distance of 6m, compared to 24m if it was travelling at 40mph (17.8m/s). The non-linear relationship between travelling speed and stopping distance means that reducing the original travel speed by a relatively small margin can affect a proportionally much greater reduction with respect to the actual impact speed experienced in a collision where prior braking is applied. It could be argued that if the vehicles which had time to brake in this sample had been travelling at slower speeds prior to their avoidance manoeuvre or they had been braked more efficiently, the tragic consequences **could** have been avoided or at least mitigated as the impact speed would have been reduced further.

[1] Speed and Pedestrians (Cullen, P -1998 Aston University Civil Engineering Conference)

[2] Effects of Vehicle Bumper Height and impact Velocity on type of lower extremity injury in vehicle-pedestrian accidents (Accident Analysis and Prevention, 2005-06 v37 n4 p633-40)

[3] San Francisco pedestrian injury surveillance: Mapping, under-reporting and injury severity in police and hospital records (Sciortino, S; Vassar, M; Radetsky, M; Knudson, MM – Accident Analysis and Prevention, 2005-11 v37 n6 p1114-20)

[4] Pedestrian Subsystem Head Impact results reflect the severity of pedestrian head injuries (Anderson, R; Street, L; Ponte G; Van de Griende, M; Lindsay, T; Mclean, J – International Journal of Vehicle Design, 2003 v32 n1/2 p1-15)

[5] Influence of Impact speed and vehicle parameter on injuries of children and adults in pedestrian accidents. (Appel, H; Sturtz, G; Gotzen, L)

[6] General Problems concerning Car-Pedestrian collision (Costano, A – Tenth International ESV conference, 1985 vol 2, p943-8)

[7] Some characteristics of the population who suffer trauma as pedestrians when hit by cars and some resulting implications (Ashton, S J; MacKay, G M – Proceedings of the 4th IRCOBI conference 1979)

[8] Vulnerable Road User Scenario Analysis (Gavrila, DM; Marchal, P; Meinecke, MM – SAVE-U Project Deliverable 1-A, 2003)

[9] Analysis and Load Assessment of Secondary Impact to Adult Pedestrians after Car Collisions on Roads (Dietmar,O; Pohlemann, T – IRCOBI 2001)

[10] "Think" campaign website - www.thinkroadsafety.com

[11] Road Accident Data in the Enlarged European Union (ETSC - 2006)

[12] The Physics of Throw Distance in Accident Reconstruction (Searle, J.A., SAE paper No. 930659, 1993)

[13] Car Design for Pedestrian Injury Minimization (Ashton, S.J., Mackay, G.M. 7th International Technical Conference on Experimental Safety of Vehicles, Paris, June 1979)

[14] Safety of Pedestrians and Cyclists in Urban Areas (European Transport Safety Council, Brussels, 1999)

[15] Summary of IHRA Pedestrian Safety WG Activities – Proposed Test Methods to Evaluate Pedestrian Protection Afforded by Passenger Cars (Y Mizuno, 2005)

[16] Development and implementation of the UK On The Spot accident data collection study. Phase I. (Hill, J.R. and Cuerden, R., AR2501 , November 2005, Department for Transport http://www.dft.gov.uk/stellent/groups/dft_rdsafety/documents/page/dft_rdsafety_610416.pdf)

[17] Injury Patterns In Pedestrian Accidents And The Associated Methodology Of A Real World In-Depth Study. (Cuerden, R., Automotive Environmental Impact and Safety IMechE Autotech 1997 Congress, Birmingham, UK. November 1997. ISBN 1860581161, Paper reference C524/155/97, pages 215-229)

[18] 'On The Spot' Crash Investigations in the UK: New Insights for Vehicle Safety Research, (Cuerden, R., Lunt, H., Fails, A. and Hill, J.R. , Proceedings of the 18th International Technical Conference on the Enhanced Safety of Vehicles , US Department of Transportation, National Highway Traffic Safety Administration, Nagoya, Japan, 12 pp , [CD-ROM]. 19-22 May, 2003)

[19] The methodology of on the spot accident investigations in the UK. Hill, J.R., Thomas, P. D., Smith, M. and Byard, N., ESV Conference, National Highway Traffic Safety Administration, 17th International Technical Conference on the Enhanced Safety of Vehicles, pp 1-10. Amsterdam, June 2001)

[20] A Preliminary Assessment of the Potential for Pedestrian Injury Reduction Trough Vehicle Design. (Ashton, S. Proceedings of the 24th Stapp Car Crash Conference, 1980, p607-35)

[21] The UK On The Spot Accident Data Collection Study – Phase II Report. Cuerden R, Pittman M, Dobson E and Hill J. Department for Transport Road Safety Research Report No. 73, 2007.)

[22] A correlation of car impact speed and pedestrian injury. Cuerden R, Richards D, Brightman T, Danton D, Dobson E and Hill J. TRL Unpublished Project Report (UPR/T/062/07). 2008.

[23] Relationship between speed and risk of fatal injury – Pedestrians and car occupants. Richards D. Department for Transport Road Safety Web Publication No.16. http://www.dft.gov.uk/pgr/roadsafety/research/rsrr/theme5/researchreport16/pdf/rswp116.pdf

[24] Review of pedestrian fatal road traffic accidents. Smith L and Cuerden R. TRL Unpublished Project Report (CPR103). 2010.

Appendix B Current Practices

Stage	Method Reference	Description
Detail A	Method DA1	Once advanced signing (workforce in road sign, one mile road works, 800yd, 600yd, 400yd, 200yd wickets) has been installed from the hard shoulder, the vehicle remains on the hard shoulder until parallel to the start of the taper. Detail A is assembled on the hard shoulder parallel with the start and end of the taper. The vehicle drives round to start of advanced signing and manoeuvres into offside lane in preparation for taper installation.
Detail A	Method DA2	Once advanced signing (workforce in road sign, one mile road works, 800yd, 600yd, 400yd, 200yd wickets) has been installed from the hard shoulder, the vehicle manoeuvres from the hard shoulder into the off side lane in preparation for taper installation. Equipment required for 2 Detail A is walked across the carriageway onto the hard shoulder where Detail A's are assembled. Operatives cross carriageway for start of taper installation.
Taper Installation	Method TI1	This method requires the use of a separate IPV and TMV. The TMV stops at the start of the taper with the IPV approximately 50 metres behind, to ensure a safe clearance zone. The TMV, followed by the IPV drops cones along the non-trafficked lane line of the lane being closed. Operatives install taper once initial cones have been dropped, behind the IPV.
Taper Installation	Method TI2	This method requires the use of a separate IPV and TMV. The TMV stops at the start of the taper with the IPV approximately 50 metres behind, to ensure a safe clearance zone. The TMV, drops cones along the non-trafficked lane line of the lane being closed. The IPV remains at the start of the taper. Operatives install the taper once initial cones have been dropped and are positioned in between the TMV and the IPV.
Taper Installation	Method TI3	TMIPV stops at start of the taper. TMIPV drops cones along the non-trafficked lane line of the lane being closed. Operative walk back to start of cone line and install taper.
Taper Installation	Method TI4	TMV drops cones along hard shoulder. Operatives walk cones across carriageway and position along central reserve. Operatives walk the cones out to form the taper.
Taper Removal	Method TR1	IPV is positioned at the start of the taper. Operatives walk cones along lane line. TMV reverses along cone line and collects from the well of the vehicle.
Taper Removal	Method TR2	TMIPV is positioned at the end of the taper. Operatives walk the cones along the lane line. The TMIPV reverses along the lane line collecting cones from the vehicle well.
Taper Removal	Method TR3	Operatives walk the cones along the non-trafficked lane line. Cones are then walked across the carriageway to the hard shoulder.

Figure B 1 Method TI 1: Separate IPV and TM vehicle. IPV follows TM vehicle into the closure

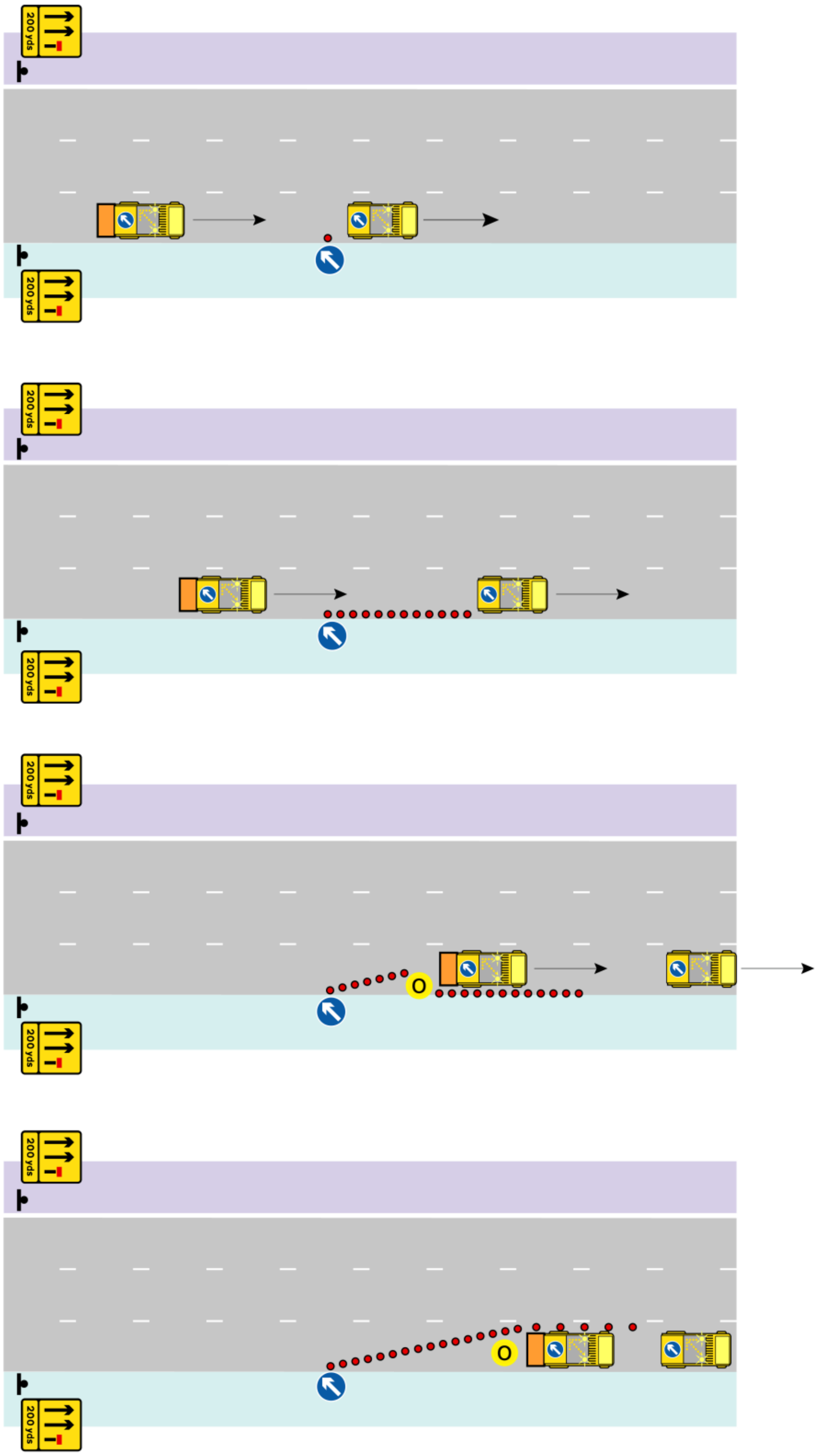


Figure B 2 Separate IPV and TM vehicle. IPV remains at start of taper

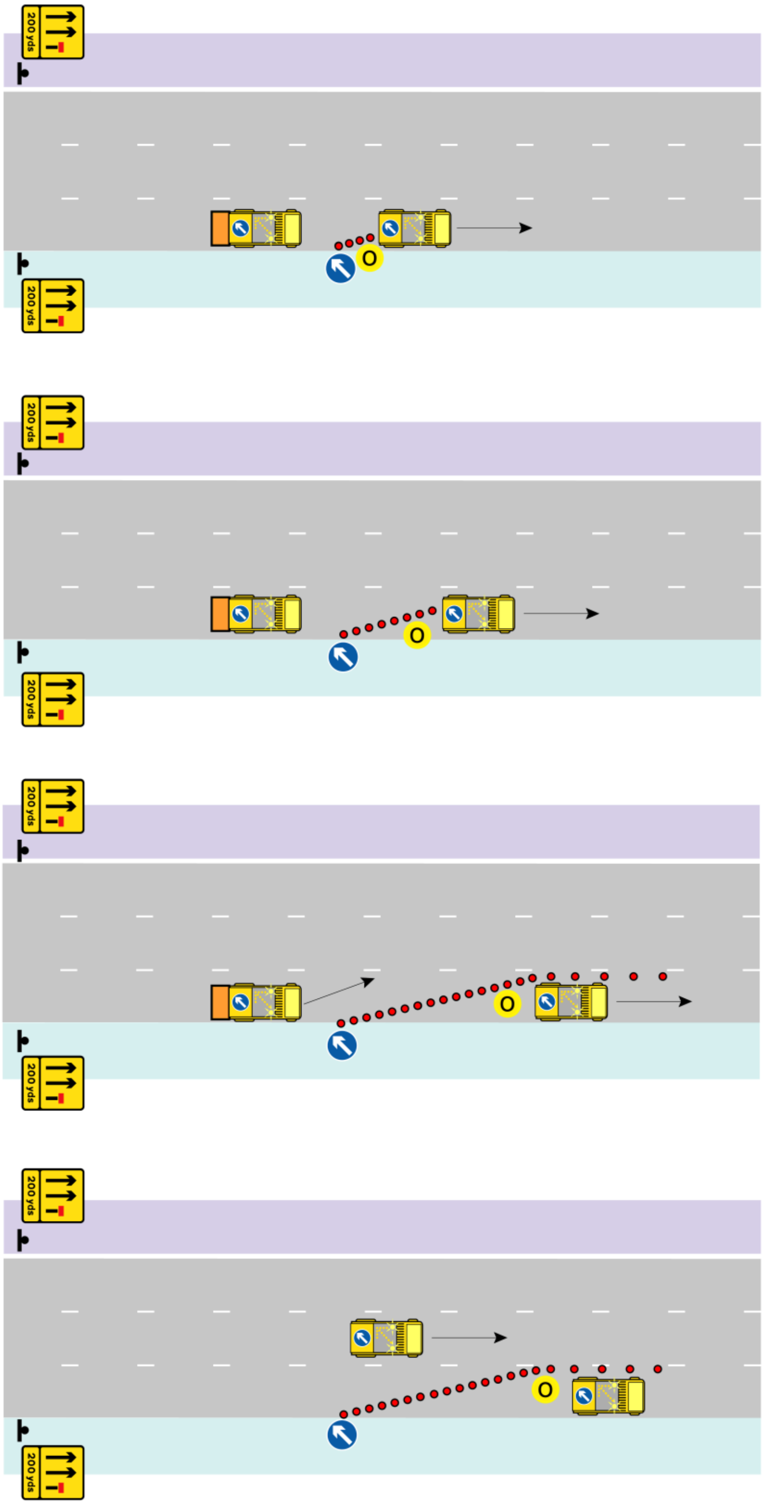


Fig B-3: Traffic management vehicle with LMCC device

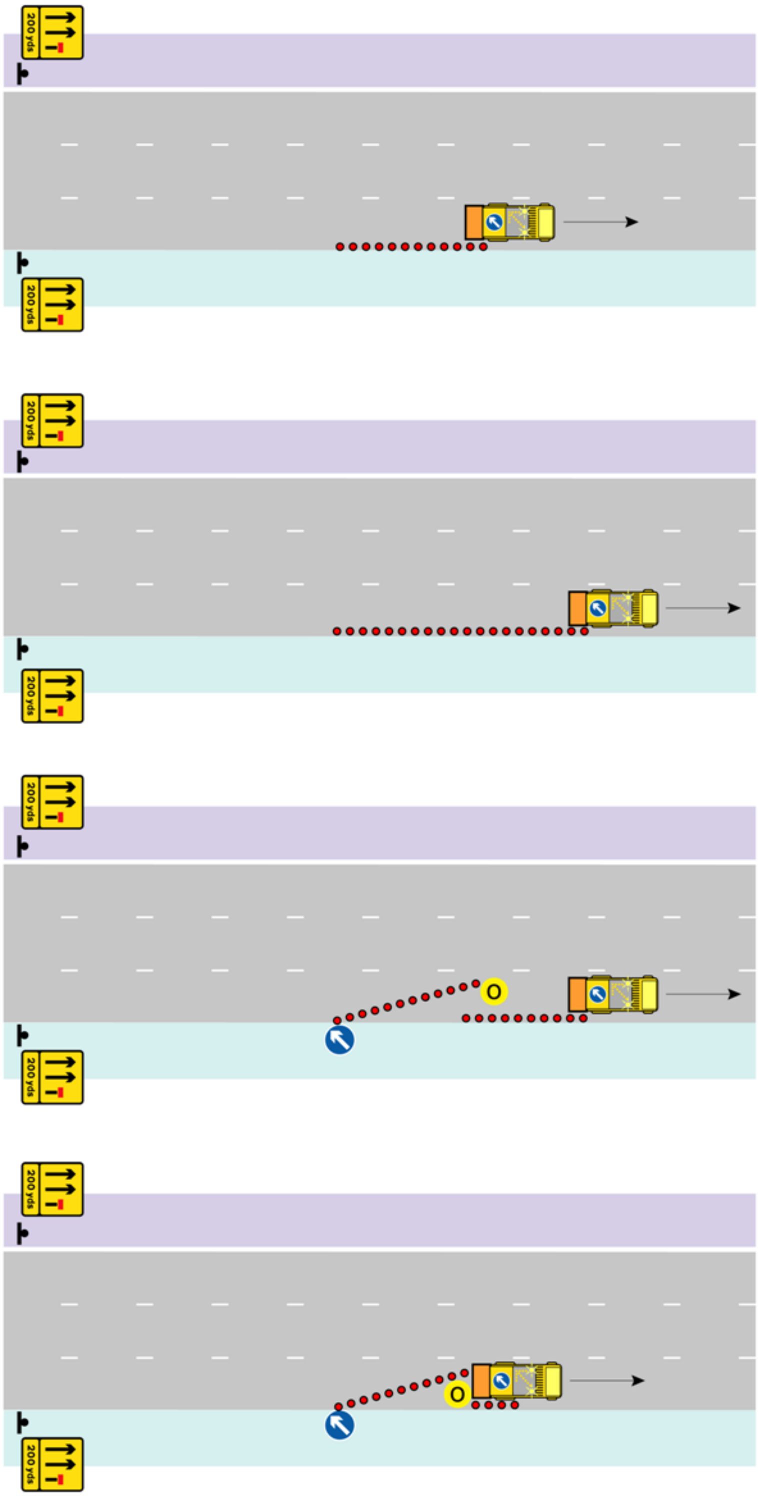
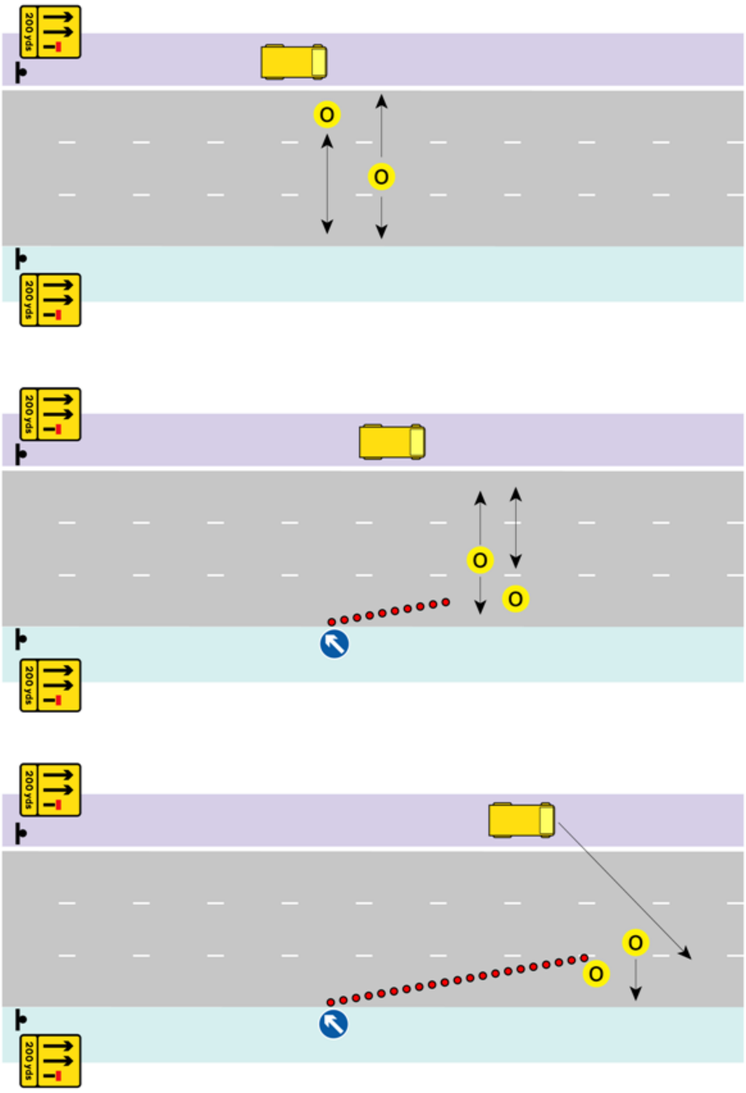


Fig B-4: No vehicle in lane to be closed. Operatives walk the closure out



Appendix C Variables

C.1 Advanced Signing

Option	TM Vehicle	TM vehicle with crash cushion	TMV and separate IPV	No hard shoulder	Hard shoulder	2 lanes	3 lanes	Nearside closure	Offside closure	Sandbags	Ratchet straps	Laying signs flat	Smart Signs	Barrier Mounted Signs
1.	•				•	•		n/a	n/a	•				
2.	•				•	•		n/a	n/a		•			
3.	•				•	•		n/a	n/a			•		
4.	•				•	•		n/a	n/a				•	
5.	•				•	•		n/a	n/a					•
6.	•				•		•	n/a	n/a	•				
7.	•				•		•	n/a	n/a		•			
8.	•				•		•	n/a	n/a			•		
9.	•				•		•	n/a	n/a				•	
10.	•				•		•	n/a	n/a					•
11.		•			•	•		n/a	n/a	•				
12.		•			•	•		n/a	n/a		•			
13.		•			•	•		n/a	n/a			•		
14.		•			•	•		n/a	n/a				•	
15.		•			•	•		n/a	n/a					•
16.		•			•		•	n/a	n/a	•				
17.		•			•		•	n/a	n/a		•			
18.		•			•		•	n/a	n/a			•		
19.		•			•		•	n/a	n/a				•	
20.		•			•		•	n/a	n/a					•
21.		•		•		•		•		•				
22.		•		•		•		•			•			
23.		•		•		•		•				•		
24.		•		•		•		•					•	
25.		•		•		•		•						•
26.		•		•			•	•		•				
27.		•		•			•	•			•			
28.		•		•			•	•				•		
29.		•		•			•	•					•	

Option	TM Vehicle	TM vehicle with crash cushion	TMV and separate IPV	No hard shoulder	Hard shoulder	2 lanes	3 lanes	Nearside closure	Offside closure	Sandbags	Ratchet straps	Laying signs flat	Smart Signs	Barrier Mounted Signs
30.		•		•			•	•						•
31.		•		•		•			•	•				
32.		•		•		•			•		•			
33.		•		•		•			•			•		
34.		•		•		•			•				•	
35.		•		•		•			•					•
36.		•		•			•		•	•				
37.		•		•			•		•		•			
38.		•		•			•		•			•		
39.		•		•			•		•				•	
40.		•		•			•		•					•
41.			•		•	•		n/a	n/a	•				
42.			•		•	•		n/a	n/a		•			
43.			•		•	•		n/a	n/a			•		
44.			•		•	•		n/a	n/a				•	
45.			•		•	•		n/a	n/a					•
46.			•		•		•	n/a	n/a	•				
47.			•		•		•	n/a	n/a		•			
48.			•		•		•	n/a	n/a			•		
49.			•		•		•	n/a	n/a				•	
50.			•		•		•	n/a	n/a					•
51.			•	•		•		•		•				
52.			•	•		•		•			•			
53.			•	•		•		•				•		
54.			•	•		•		•					•	
55.			•	•		•		•						•
56.			•	•			•	•		•				
57.			•	•			•	•			•			
58.			•	•			•	•				•		
59.			•	•			•	•					•	
60.			•	•			•	•						•
61.			•	•		•			•	•				
62.			•	•		•			•		•			
63.			•	•		•			•			•		
64.			•	•		•			•				•	

Option	TM Vehicle	TM vehicle with crash cushion	TMV and separate IPV	No hard shoulder	Hard shoulder	2 lanes	3 lanes	Nearside closure	Offside closure	Sandbags	Ratchet straps	Laying signs flat	Smart Signs	Barrier Mounted Signs
65.			•	•		•			•					•
66.			•	•			•		•	•				
67.			•	•			•		•		•			
68.			•	•			•		•			•		
69.			•	•			•		•				•	
70.			•	•			•		•					•

C.2 Detail A

Method 1	Put up advanced signing Put up detail A at start and end of taper. Drive round to start of TTM and position in lane 2/3 for taper installation
Method 2	Put up advanced signing Move into lane 2/3 for taper installation Walk detail A (x2) across carriageway onto hard shoulder

Option	TM Vehicle	TM with crash cushion	IPV	2 lane	3 lane	Method 1	Method 2
1	•			•		•	
2		•		•		•	
3		•		•			•
4		•			•		•
5			•	•		•	
6			•	•			•
7			•		•		•

C.3 Taper Installation

Method 1	Separate IPV and TM vehicles, IPV follows the TM vehicle into the closure
Method 2	Separate IPV and TM vehicle, IPV remains at start of taper
Method 3	TM vehicle with crash cushion attached
Method 4	No vehicle in the lane to be closed, operative walk closure out.

Option	Hard shoulder	No hard shoulder	Nearside closure	Offside closure	Method 1	Method 2	Method 3	Method 4
1	•		•		•			
2	•		•			•		
3	•		•				•	
4	•		•					•
5		•	•		•			
6		•	•			•		
7		•	•				•	
8	•			•	•			
9	•			•		•		
10	•			•			•	
11	•			•				•
12		•		•	•			
13		•		•		•		
14		•		•			•	

C.4 Taper Removal

Method 1	Separate IPV and TM vehicles
Method 2	Combined TM vehicle and crash cushion
Method 3	No vehicle in lane, operatives walk in closure

Option	Hard shoulder	No hard shoulder	Nearside closure	Offside closure	Method 1	Method 2	Method 3
1	•		•		•		
2	•		•			•	
3	•		•				•
4		•	•		•		
5		•	•			•	
6	•			•	•		
7	•			•		•	
8	•			•			•
9		•		•	•		
10		•		•		•	

C.5 Advanced Sign Removal

Option	TM Vehicle	TM vehicle with crash cushion	TMV and separate IPV	No hard shoulder	Hard shoulder	2 lanes	3 lanes	Nearside closure	Offside closure	Sandbags	Ratchet straps	Laying signs flat	Smart Signs	Barrier Mounted Signs
1.	•				•	•		n/a	n/a	•				
2.	•				•	•		n/a	n/a		•			
3.	•				•	•		n/a	n/a			•		
4.	•				•	•		n/a	n/a				•	
5.	•				•	•		n/a	n/a					•
6.	•				•		•	n/a	n/a	•				
7.	•				•		•	n/a	n/a		•			
8.	•				•		•	n/a	n/a			•		
9.	•				•		•	n/a	n/a				•	
10.	•				•		•	n/a	n/a					•
11.		•			•	•		n/a	n/a	•				
12.		•			•	•		n/a	n/a		•			
13.		•			•	•		n/a	n/a			•		
14.		•			•	•		n/a	n/a				•	
15.		•			•	•		n/a	n/a					•
16.		•			•		•	n/a	n/a	•				
17.		•			•		•	n/a	n/a		•			
18.		•			•		•	n/a	n/a			•		
19.		•			•		•	n/a	n/a				•	
20.		•			•		•	n/a	n/a					•
21.		•		•		•		•		•				
22.		•		•		•		•			•			
23.		•		•		•		•				•		
24.		•		•		•		•					•	
25.		•		•		•		•						•
26.		•		•			•	•		•				
27.		•		•			•	•			•			
28.		•		•			•	•				•		
29.		•		•			•	•					•	
30.		•		•			•	•						•
31.		•		•		•			•	•				
32.		•		•		•			•		•			

Option	TM Vehicle	TM vehicle with crash cushion	TMV and separate IPV	No hard shoulder	Hard shoulder	2 lanes	3 lanes	Nearside closure	Offside closure	Sandbags	Ratchet straps	Laying signs flat	Smart Signs	Barrier Mounted Signs
33.		•		•		•			•			•		
34.		•		•		•			•				•	
35.		•		•		•			•					•
36.		•		•			•		•	•				
37.		•		•			•		•		•			
38.		•		•			•		•			•		
39.		•		•			•		•				•	
40.		•		•			•		•					•
41.			•		•	•		n/a	n/a	•				
42.			•		•	•		n/a	n/a		•			
43.			•		•	•		n/a	n/a			•		
44.			•		•	•		n/a	n/a				•	
45.			•		•	•		n/a	n/a					•
46.			•		•		•	n/a	n/a	•				
47.			•		•		•	n/a	n/a		•			
48.			•		•		•	n/a	n/a			•		
49.			•		•		•	n/a	n/a				•	
50.			•		•		•	n/a	n/a					•
51.			•	•		•		•		•				
52.			•	•		•		•			•			
53.			•	•		•		•				•		
54.			•	•		•		•					•	
55.			•	•		•		•						•
56.			•	•			•	•		•				
57.			•	•			•	•			•			
58.			•	•			•	•				•		
59.			•	•			•	•					•	
60.			•	•			•	•						•
61.			•	•		•			•	•				
62.			•	•		•			•		•			
63.			•	•		•			•			•		
64.			•	•		•			•				•	
65.			•	•		•			•					•
66.			•	•			•		•	•				
67.			•	•			•		•		•			

Option	TM Vehicle	TM vehicle with crash cushion	TMV and separate IPV	No hard shoulder	Hard shoulder	2 lanes	3 lanes	Nearside closure	Offside closure	Sandbags	Ratchet straps	Laying signs flat	Smart Signs	Barrier Mounted Signs
68.			•	•			•		•			•		
69.			•	•			•		•				•	
70.			•	•			•		•					•

Appendix D Subtasks

				Probability of being struck				Exposure (seconds)				Consequence			
Stage	Option	Task Number	Task Description	Driver of TMV	Driver of IPV	Operative 1	Operative 2	Driver of TMV	Driver of IPV	Operative 1	Operative 2	Driver of TMV	Driver of IPV	Operative 1	**Operative 2**
3	1	1	TMV and IPV stop on hard shoulder at start of taper.	35	35	35	35	220	220	10	10	V	IV	V	V
		2	Unload 610 arrow, stand and sandbags.	n/a	n/a	35	35	n/a	n/a	60	60	V	n/a	V	V
		3	Install sign at start of taper.	n/a	n/a	100	100	n/a	n/a	150	150	V	n/a	V	V
		4	TMV and IPV travel along hard shoulder dropping cones from non-trafficked side of the vehicle at appropriate spacings.	35	35	35	35	360	360	360	360	V	IV	V	V
		5	TMV and IPV stop on hard shoulder at end of the lane closure.	35	35	n/a	n/a	150	810	n/a	n/a	V	IV	V	V
		6	Operatives walk back along hard shoulder to start of taper.	35	n/a	35	35	360	n/a	360	360	V	n/a	V	V
		7	Walk cones and lights out from hard shoulder to form the taper.	90	n/a	90	90	300	n/a	300	300	V	n/a	V	V
		8	Install 610 arrow sign at end of taper.	n/a	n/a	60	60	n/a	n/a	150	150	V	n/a	V	V
3	2	1	TMV stops on hard shoulder at start of taper.	35	n/a	35	35	220	n/a	10	10	V	n/a	V	V
		2	IPV stops on hard shoulder 50m before the start of the taper.	n/a	35	n/a	n/a	n/a	1390	n/a	n/a	n/a	IV	n/a	n/a

				Probability of being struck				Exposure (seconds)				Consequence			
Stage	Option	Task Number	Task Description	Driver of TMV	Driver of IPV	Operative 1	Operative 2	Driver of TMV	Driver of IPV	Operative 1	Operative 2	Driver of TMV	Driver of IPV	Operative 1	**Operative 2**
		3	Unload 610 arrow, stand and sandbags.	n/a	n/a	35	35	n/a	n/a	60	60	n/a	n/a	V	V
		4	Install sign at start of taper.	n/a	n/a	100	100	n/a	n/a	150	150	n/a	n/a	V	V
		5	TMV travel along hard shoulder dropping cones from non-trafficked side of the vehicle at appropriate spacings.	35	n/a	35	35	360	n/a	360	360	V	n/a	V	V
		6	TMV stop on hard shoulder at end of the lane closure.	35	n/a	n/a	n/a	150	n/a	n/a	n/a	V	n/a	n/a	n/a
		7	Operatives walk back along hard shoulder to start of taper.	35	n/a	35	35	360	n/a	360	360	V	n/a	V	V
		8	Walk cones and lights out from hard shoulder to form the taper.	90	n/a	90	90	300	n/a	300	300	V	n/a	V	V
		9	Install 610 arrow sign at end of taper.	n/a	n/a	60	60	n/a	n/a	150	150	V	n/a	V	V
3	3	1	TMIPV stop on hard shoulder at start of taper.	35	35	35	35	220	n/a	10	10	IV	n/a	IV	IV
		2	Unload 610 arrow, stand and sandbags.	n/a	n/a	35	35	n/a	n/a	60	60	V	n/a	V	V
		3	Install sign at start of taper.	n/a	n/a	100	100	n/a	n/a	150	150	V	n/a	V	V
		4	TMIPV travel along hard shoulder dropping cones from non-trafficked side of the vehicle at appropriate spacings.	35	35	35	35	360	n/a	360	360	IV	n/a	IV	IV

				Probability of being struck				Exposure (seconds)				Consequence			
Stage	Option	Task Number	Task Description	Driver of TMV	Driver of IPV	Operative 1	Operative 2	Driver of TMV	Driver of IPV	Operative 1	Operative 2	Driver of TMV	Driver of IPV	Operative 1	**Operative 2**
		5	TMVIPV stop on hard shoulder at end of the lane closure.	35	35	n/a	n/a	150	n/a	n/a	n/a	IV	n/a	n/a	n/a
		6	Operatives walk back along hard shoulder to start of taper.	35	n/a	35	35	360	n/a	360	360	V	n/a	V	V
		7	Walk cones and lights out from hard shoulder to form the taper.	90	n/a	90	90	300	n/a	300	300	V	n/a	V	V
		8	Install 610 arrow sign at end of taper.	n/a	n/a	60	60	n/a	n/a	150	150	V	n/a	V	V
3	4	1	TMV stop on hard shoulder at start of taper.	35	35	35	35	220	n/a	10	10	V	n/a	V	V
		2	Unload 610 arrow, stand and sandbags.	n/a	n/a	35	35	n/a	n/a	60	60	V	n/a	V	V
		3	Install sign at start of taper.	n/a	n/a	100	100	n/a	n/a	150	150	V	n/a	V	V
		4	TMV travel along hard shoulder dropping cones from non-trafficked side of the vehicle at appropriate spacings.	35	35	35	35	360	n/a	360	360	V	n/a	V	V
		5	TMV stop on hard shoulder at end of the lane closure.	35	35	n/a	n/a	150	n/a	n/a	n/a	V	n/a	n/a	n/a
		6	Operatives walk back along hard shoulder to start of taper.	35	n/a	35	35	360	n/a	360	360	V	n/a	V	V
		7	Walk cones and lights out from hard shoulder to form the taper.	90	n/a	90	90	300	n/a	300	300	V	n/a	V	V

				Probability of being struck				Exposure (seconds)				Consequence			
Stage	Option	Task Number	Task Description	Driver of TMV	Driver of IPV	Operative 1	Operative 2	Driver of TMV	Driver of IPV	Operative 1	Operative 2	Driver of TMV	Driver of IPV	Operative 1	**Operative 2**
		8	Install 610 arrow sign at end of taper.	n/a	n/a	60	60	n/a	n/a	150	150	V	n/a	V	V
3	5	1	TMV and IPV stop on lane 1 at start of taper.	35	100	35	35	220	220	10	10	V	IV	V	V
		2	Unload 610 arrow, stand and sandbags.	n/a	n/a	35	35	n/a	n/a	60	60	V	n/a	V	V
		3	Install sign at start of taper.	n/a	n/a	35	35	n/a	n/a	150	150	V	n/a	V	V
		4	TMV and IPV travel along lane 1 dropping cones from non-trafficked side of the vehicle at appropriate spacings.	35	100	35	35	360	360	360	360	V	IV	V	V

Appendix E Scope and Assumptions

- Only 'relaxation' traffic management schemes, as defined in Chapter 8, have been considered. (Relaxation TM schemes are installed where there is good visibility; low traffic flows and are in situ for less than 24 hours.)
- Only *planned* traffic management will be considered as opposed to operations conducted in response to an accident/ incident.
- Only temporary traffic management on the carriageway will be considered (not hard shoulder, exit or entry slip roads as these have different methodologies and considerations).
- The carriageway is considered to be unlit, so that none of the temporary signs require lighting
- The installation and removal of advanced signs, Detail A and the taper has been included in the scope but the longitudinal run has not.
- There are numerous hazards that road workers are exposed to including noise, slips and trips, and manual handling. All of these can cause injury and present risks to road workers. However, for the basic MIRi index the only hazard that is considered is the primary hazard of being struck by a road user vehicle. Therefore, the risks calculated will be the risk of a worker or vehicle being struck by a vehicle as opposed to being injured by other means.
- Barrier type, varying restraint systems within vehicles, remotely operated sign reliability, traffic flows, carriageway topography and equipment reliability have not been considered at this stage.

Exposure Assumptions:

- It takes an average of 3 seconds for one operative to cross one lane
- It takes an average of150 seconds for an operative to put up a sign and stand.
- It takes an operative 160 seconds to put up sign with ratchet strap
- It takes an operative 150 seconds to reassemble a sign when it has been laid flat with sandbags.
- It takes 100 seconds for an operative to mount a sign on a barrier. 2 people for barrier mounted sign – one as look out.
- 2 operatives are required to cross the carriageway for 1 sign and 1 stand
- 2 operatives are required to cross carriageway with sufficient sand bags
- It takes an average of 60 seconds to drive between sign locations (this time includes getting in and out of vehicle.)
- It takes an average of 60 seconds to unload the signs from the traffic management vehicle.
- The drivers of traffic management vehicles (with or without combined crash cushion) exit the vehicle and assist with sign installation.
- The driver of an IPV remains in the vehicle for the entire temporary traffic management installation.
- The traffic management vehicle driver puts up signs on the verge/ hard shoulder whilst the remaining 2 operatives assemble signs on the central reserve.
- The total of all the waiting in vehicles, for example whilst moving signs, securing load, lowering truck sides etc is detailed under one subtask for each task entitled 'wait in vehicle'.
- 30 seconds stopping time is required for operatives to raise remotely operated sign from within the traffic management vehicle
- Waiting time in a live lane is the same as waiting time on the hard shoulder
- It takes an operative longer to off load Detail A as cones as well as signs
- The driver is out of the traffic management vehicle when installing Detail A but is not actually involved with the installation
- For the Detail A installation using method DA2 the sign, stand and sand bags are crossed over the carriageway separately. This equates to 8 crossings (4 for each

operative) = 24 seconds for each operative for 2 lane and 36 seconds for each operative for 3 lanes.
- Traffic management vehicles travel at 5 km/h when dropping cones which equates to 360 seconds for a 500 m taper
- It is assumed that for method DA2, operatives are required to cross a three lane carriageway
- 25 crossings are required for 51 cones to be walked out to the central reserve. This assumes that operatives carry 2 cones each for each crossing.

Consequence Assumptions

- If a vehicle is struck in lane 3, it is more likely to be struck by a car than any other vehicle due to the vehicle composition in lane 3.
- If a vehicle is struck on hard shoulder, it is most likely to be struck by an HGV
- If a vehicle is struck in lane 1, it is likely to be struck by an HGV. This assumes a worst case scenario but also considers that at off peak times when TTM is being deployed there are likely to be more HGVs than cars in lane 1.
- If an IPV is struck by a car travelling at 70mph, it is not likely to be shunted beyond the 50m clearance zone
- If an IPV is struck by an HGV travelling at 56mph it is likely to be shunted beyond the 50m clearance zone
- Passengers of a TMIPV have same protection as the driver when sitting in vehicle cab using the appropriate vehicle restraints.
- If a crash cushion is struck by an HGV, the driver and passengers are likely to have very serious injuries (IV)
- If a crash cushion is struck by a car, the driver and passengers are likely to have minor injuries (II)
- If an operative is on the back of a TMIPV and it is struck by an HGV the consequences are likely to be very serious (IV)
- If an operative is on the back of a TMIPV and it is struck by a car the consequences are likely to be major (III)
- If an operative is struck by any vehicle the consequence is likely to be fatal (V).
- If a TM vehicle is struck by a vehicle on the hard shoulder the consequences are likely to be fatal (V)
- If a TM vehicle is struck in lane 3 (cars) then the consequences are likely to be very serious (IV)
- If any vehicle is struck whilst operatives are on the back of the vehicle, the consequences are likely to be fatal. (V).

Appendix E Tables of Comparative MIRi Index values and Carriageway Crossings

Table F-1

Current Chapter 8 relaxed signing as in DZB3, for a 3 lane motorway, with a hard shoulder using sandbags

Closure	Method/ vehicle		Advanced signs	Detail A	Taper installation	Taper removal	Advanced Signs	Total	Benchmark value (average)
Offside lane	TM+IPV, IPV following	MIRi	66433	15849	55920	35686	66433	240321	256259
		c/way crossing	40	19	0	0	40	99	
	TM+IPV	MIRi	66433	15849	46936	35686	66433	231337	
		c/way crossing	40	19	0	0	40	99	
	TMIPV	MIRi	50695	15765	68251	78637	50695	264043	
		c/way crossing	40	19	0	0	40	99	
	TM	MIRi	60382	17674	74585	76313	60382	289336	
		c/way crossing	40	0	41	41	40	162	
Nearside lane	TM+IPV, IPV following	MIRi	66433	n/a	59451	59834	66433	252151	240062
		c/way crossing	40	0	0	0	40	80	
	TM+IPV	MIRi	66433	n/a	59451	59834	66433	252151	
		c/way crossing	40	0	0	0	40	80	
	TMIPV	MIRi	50695	n/a	46980	64704	50695	213074	
		c/way crossing	40	0	0	0	40	80	
	TM	MIRi	60382	n/a	55024	67083	60382	242871	
		c/way crossing	40	0	0	0	40	80	

Table F-2 Removal of 600yd and 200yd wicket and Detail A (3 lane motorway with hard shoulder, offside closure)

Closure	Method/ vehicle		Advanced signs	Detail A	Taper installation	Taper removal	Advanced Signs	Total	Benchmark value (average)
Offside	TM+IPV, IPV following Carriageway crossings	MIRi	49033	0	55920	35686	49033	189672	205175
		c/way crossing	24	0	0	0	24	48	
	TM+IPV	MIRi	49033	0	46936	35686	49033	180688	
		c/way crossing	24	0	0	0	24	48	
	TMIPV	MIRi	33295	0	68251	78637	33295	213478	
		c/way crossing	24	0	0	0	24	48	
	TM	MIRi	42982	0	74585	76313	42982	236862	
		c/way crossing	24	0	41	41	24	130	

Removal of 600yd and 200yd wicket (3 lane motorway with hard shoulder, nearside closure)

Closure	Method/ vehicle		Advanced signs	Detail A	Taper installation	Taper removal	Advanced Signs	Total	Benchmark value (average)
Nearside	TM+IPV, IPV following	MIRi	49033	n/a	59451	59834	49033	217351	205262
		c/way crossing	24	0	0	0	24	48	
	TM+IPV	MIRi	49033	n/a	59451	59834	49033	217351	
		c/way crossing	24	0	0	0	24	48	
	TMIPV	MIRi	33295	n/a	46980	64704	33295	178274	
		c/way crossing	24	00	0	0	24	48	
	TM	MIRi	42982	n/a	55024	67083	42982	208071	
		c/way crossing	24		0	0	24	48	

Table F-3 Comparison of MIRi Index values and carriageway crossings for Offside Signs Relaxation

Three lane motorway with hard shoulder			Nearside closure, with sandbags						
Closure	Method/ vehicle		Advanced signs	Detail A	Taper installation	Taper removal	Advanced Signs	Total	Benchmark value (average)
Nearside	TM+IPV, IPV following	MIRi	66433	n/a	59451	59834	66433	252151	240062
		c/way crossing	40	0	0	0	40	80	
	TM+IPV	MIRi	66433	n/a	59451	59834	66433	252151	
		c/way crossing	40	0	0	0	40	80	
	TMIPV	MIRi	50695	n/a	46980	64704	50695	213074	
		c/way crossing	40	0	0	0	40	80	
	TM	MIRi	60382	n/a	55024	67083	60382	242871	
		c/way crossing	40	0	0	0	40	80	

Offside signs relaxation, remove , 1 mile board,800, 600, 400, 200 yd wickets from centre reserve

Closure	Method/ vehicle		Advanced signs	Detail A	Taper installation	Taper removal	Advanced Signs	Total	Benchmark value (average)
Nearside	TM+IPV, IPV following	MIRi	36738	n/a	59451	59834	36738	192761	180672
		c/way crossing		0	0	0			
	TM+IPV	MIRi	36738	n/a	59451	59834	36738	192761	
		c/way crossing		0	0	0			
	TMIPV	MIRi	21000	n/a	46980	64704	21000	153684	
		c/way crossing		0	0	0			
	TM	MIRi	30687	n/a	55024	67083	30687	183481	
		c/way crossing		0	0	0		0	

Table F-4: Percentage reductions for Sign Simplification, offside closure

Method/vehicle	Carriageway crossing reduction	Percentage reduction	MIRI reduction	Percentage reduction
TM+IPV, IPV following	51	(99 to 48) = 52%	50649	21%
TM+IPV	51	(99 to 48) = 52%	50649	22%
TMIPV	51	(99 to 48) = 52%	50565	19%
TM	32	(162 to 130) = 20%	52474	18%

Table F-5: Percentage reductions for Sign Simplification, nearside closure

Method/vehicle	Carriageway crossing reduction	Percentage reduction	MIRI reduction	Percentage reduction
TM+IPV, IPV following	32	(80 to 48) = 40%	34800	13.8
TM+IPV	32	(80 to 48) = 40%	34800	13.8
TMIPV	32	(80 to 48) = 40%	34800	16.3
TM	32	(80 to 48) = 40%	34800	14.3

Table F7: Percentage reductions for offside sign removal, nearside closure

Method/vehicle	Carriageway crossing reduction	Percentage reduction	MIRI reduction	Percentage reduction
TM+IPV, IPV following	80	(80 to 0) = 100%	59390	24%
TM+IPV	80	(80 to 0) = 100%	59390	24%
TMIPV	80	(80 to 0) = 100%	59390	28%
TM	80	(80 to 0) = 100%	59390	24%