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Package Order 001/4/45/12 - Traffic Officer Vehicle Conspicuity

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Executive Summary

The Highways Agency (HA) Traffic Officer Service (TOS) operates a continuous service that seeks to keep traffic moving on the Strategic Road Network. The HA has a duty to ensure that all practicable steps are taken to protect Traffic Officers (TOs); the correct use and application of conspicuity enhancements is a key part of managing their risk.

This project sought to identify the effect of a Traffic Officer Vehicle's (TOV's) lighting use and orientation on the behaviour of passing traffic when the TOV was parked on a hard shoulder,. In addition, the outcomes of simulated collisions between a vehicle parked on the hard shoulder and passing traffic were reviewed to determine whether appropriate guidance can be prepared regarding appropriate places for TOs to stand when outside the TOV.

The results of the TOV's parking orientation analysis indicated that:

- The range of angles at which TOs park when attending an incident is quite variable.
- Selection of the fend angle does not seem to be related to ETM deployment, time of day or incident vehicle type.
- When the TOV was parked in fend, vehicles in lane 1 were, on average, further from the rib line separating the TOV from the passing vehicle than when the TOV was parked in parallel.
- Vehicles in lane 1 were, on average, at very similar distances from the nearest point of the TOV when the TOV was in fend and when it was in parallel.

The data studied suggest there is little benefit of parking at fend on the hard shoulder compared to parallel in terms of the average distance from the nearest point of the TOV to a passing vehicle.

Analysis of the effect of different lighting configurations on driver behaviour was not possible, due to the use of amber and red beacons in all identifiable incidents.

The simulations conducted identified an area that would not be advisable for people to stand in when the vehicle is stationary, which suggested a zone of length 100m x 75m should be established wherever possible. In addition, the simulations suggested that the effect of steered wheels makes little difference to the overall travel distance of the vehicle, so guidance on wheel orientation is not required.

Based on the simulations, it is suggested that TOs should not stand forward of the rear of the vehicle, and it is recommended that advice on pedestrian safe areas should be extended to other road workers and the general public.

During the project, the TOV was involved in two incidents, which were informative for this work and are discussed in detail. The implications for TOS Incident Procedures from these incidents, the on road trials and the simulations are considered, together with the wider implications from the project's findings.

The results have identified that TOS procedures may not represent good practice for real-world attendance at incidents, and that TOs may have unrealistic expectations of the degree of protection which their vehicle and standard operating procedures may provide.

It is recommended that TOS procedures are re-evaluated and modified, in particular with regard to:

- Fend parking and front wheel alignment
- Incident safety zone
- Pedestrians on the carriageway
- Fend parking by location

It is recommended that TOs attending incidents on the hard shoulder should use parallel parking by default. Particularly in the case of shorter duration incidents, the additional time associated with placing a TOV into fend is unlikely to be worthwhile. Where TOs have reason to park in a live lane, a fend orientation is still recommended, and there may be a case for giving advice to 'fill the lane'. Advice on wheel orientation is unnecessary and can be removed.

The simulation results have significant implications for all personnel on the hard shoulder. The same simple advice, "Stand in a place where you are off the carriageway and can see the rear of your vehicle" is equally applicable to all people, whether professionals such as the TOS, road workers, etc. who are on the roadside as part of their work, or road users who find themselves on the hard shoulder with their broken-down vehicle. This is likely to be particularly important as the HA moves towards the introduction of All Lane Running on Managed Motorways.

For short duration incidents, it is recommended that the TOV should remain within close proximity to the incident vehicle, preferably with everyone located upstream of the TOV. For medium duration incidents, with ETM deployment, it is recommended that the TOV should be positioned 100m upstream of the incident vehicle.

It is important to acknowledge that no area adjacent to a road carrying high-speed traffic can be considered fully 'safe' and, as such, vigilance and good lookout principles must be maintained.

The project did not set out to champion the introduction of in-vehicle CCTV systems and, during the briefings introducing the on road trial to the TOS, concerns were expressed over the use of video recording during data gathering. However, the video recordings obtained from the incidents highlighted significant benefits could be obtained by using video from an on-screen vehicle attending an incident. It is recommended that the opportunity should be taken to further evaluate such systems and determine likely benefits, particularly of live-streaming capabilities.

Delivery Matrix

Previous research (Diels et al., 2009) recommended that Traffic Officer Vehicles (TOVs) parked on the hard shoulder should not display rear facing red flashing lights, and that these should be reserved for use in live lanes. Instead, the research recommended that TOVs on the hard shoulder should display amber beacons only and park 'fend off', whereby the nose of the vehicle is directed towards the live lane, when on the hard shoulder. The project described in this report sought to provide verification of the findings from the previous work on TOV conspicuity, and also to understand vehicle dynamics in the event of a collision with a vehicle parked in a 'fend' position.

The two initial workstreams for the project were:

1. Real-world confirmation of the hard shoulder lighting colour and parking orientation data obtained from the previous research, presented in the form of a report. This considered on-road scenarios split by lighting colour, parking orientation and night/day in order to provide clear data-led instructions for TOV parking and lighting arrangements.
2. Desktop review of how TOVs behave when struck in different parking orientations, including a consideration of the effect of front wheel orientation. This was to provide clear data on the consequences of such collisions. The results of this review, where data were available and suitable, were to provide a framework for guidance to indicate where road workers should and should not stand when in the vicinity of a parked TOV.

The review and the on-road data gathering guided impact simulation work.

A further task was added, to identify existing in-vehicle CCTV systems and discuss the potential benefits for the HA and TOS of the installation of such systems.

The following sections within this report detail the work conducted:

Requirement in proposal	Report section
WP1: Real-world confirmation of the hard shoulder lighting colour and parking orientation	2
• Monitoring method and experimental design	2.2
• Instrumented TOV	2.3
• Calibration	2.3.1
• Analysis	2.5, 2.6, 2.7, 2.8, 2.9, 2.10
WP2: Simulation of how a TOV will behave when struck, based on different parking orientations	3
• Re-examine existing research	3.2
• Define proposed scenarios for modelling	3.3, 3.4, 3.5, 3.6, 3.7
• Analysis and results	3.8, 3.9, 3.10, 3.11, 3.12, 3.13, 3.14
• Conclusions and recommendations	3.15
Implications for TOS Incident Procedures	5
Recommendations	7
Additional work	
• TOV Incident involvement	4
• In-vehicle CCTV systems	6

1 Introduction

1.1 Background and key drivers

The Highways Agency (HA) Traffic Officer Service (TOS) operates a continuous service that seeks to keep traffic moving on the Strategic Road Network. The HA has a duty to ensure that all practicable steps are taken to protect Traffic Officers (TOs) and any members of the public who may be affected by their activities. As TOs operate in a relatively high-risk environment on-road, the correct use and application of conspicuity enhancements (such as vehicle markings, lighting and parking orientation when stationary) is a key part of managing their risk.

Previous work (Diels et al., 2009) suggests that there may be a benefit for the TOS in retaining the right to use rear-facing flashing red lights on Traffic Officer Vehicles (TOVs). This right is linked to the TOs' 'special powers' under the Traffic Management Act 2004 (The Stationery Office, 2004). However, clearer guidance is needed for TOs to ensure that the best combination of vehicle lighting is used when their vehicle is stationary at an incident (which represents a considerable part of operational activity).

In addition, the previous research suggests potential benefits of 'fend' parking (parking the vehicle so that it is not parallel to approaching traffic). Parking at fend may have unanticipated negative consequences in the event of an impact. In order to ensure the safety of TOs, it is essential that the likely consequence of impact is understood. This will allow for clear guidance to be given to TOs (and potentially other road workers operating on the HA network) regarding appropriate places to stand when outside the TOV.

This project sought to address these issues, by conducting a real-world examination of previous research results, potentially enabling provision of data-led guidance for lighting use and parking orientation when a TOV is parked on the hard shoulder. Also, the outcome of a simulated collision between a vehicle parked on the hard shoulder and passing traffic was reviewed to determine whether appropriate guidance can be prepared regarding appropriate places for Traffic Officers to stand when outside the TOV.

This project set out to ensure that any change to TOS procedures is based on real-world data and that the risk implications of any change are fully understood. It also advises as to what steps should be taken to ensure and improve the safety of TOs.

1.2 Structure of this report

This report covers the following aspects of work undertaken:

- Workstream 1: Use of Lighting and Fend Parking
- Workstream 2: Consequences of Impacts
- TOV Incident Involvement
- Implications for TOS Incident Procedures
- Wider Implications from Findings of Impact Consequences
- In-Vehicle CCTV Systems
- Recommendations

1.3 Parking orientation

Within this report three different parking orientations are used to describe the way in which Traffic Officer's position their vehicles when parked on the hard shoulder: fend off, fend in and parallel.

The TO manual (Hewitt, 2006) says **"whatever position is adopted, in all cases the vehicle should be left with its front wheels steered straight ahead parallel to the vehicle."**

The TOV is parked in 'fend off' when the nose of the vehicle is directed towards the live lane (Figure 1).

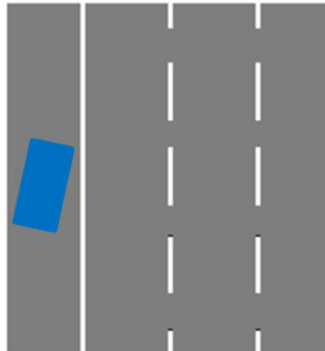


Figure 1: TOV parked 'fend off' within the hard shoulder

The TOV is parked in 'fend in' when the nose of the vehicle is directed away from the live lane (Figure 2).

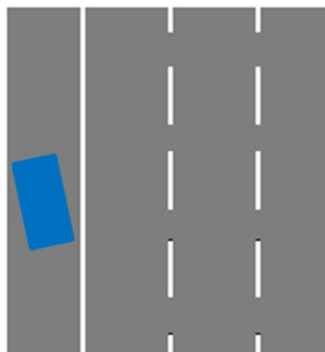


Figure 2: TOV parked 'fend in' within the hard shoulder

Figure 3 shows the TOV parked 'parallel' within the hard shoulder: the vehicle is positioned such that it is parallel to approaching traffic.

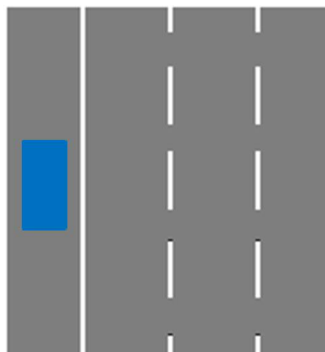


Figure 3: TOV parked 'parallel' within the hard shoulder

2 Workstream 1: Use of Lighting and Fend Parking

Workstream 1 investigated the effect of TOV's fend angle and lighting (when parked on the hard shoulder) on the lateral clearance given by other drivers passing the TOV. This workstream was supported by previous research on lighting (e.g. Diels, Palmer, Sterling & Rillie, 2009), as well as research on fend parking detailed in Section 3.

2.1 Previous simulator studies

Previous research (Diel et al., 2009) using the TRL car simulator allowed scenarios to be controlled and repeated and to be carried out in a safe, off-road, environment. Two simulation studies were conducted to identify how much space drivers left as they passed a TOV which was parked in the hard shoulder. The variations in this distance associated with different lighting configurations in both simulated daytime and night-time conditions were investigated.

The simulator study results were divided into two types: fend parking and lighting colour. The results from the lighting colour trial suggested that drivers tend to use peripheral vision to pick up visual cues when assessing hazards on the hard shoulder. There may have been a small effect in favour of the use of amber lights when on the hard shoulder during the day: the greatest distance between the TOV and passing traffic was observed when the amber lighting configuration was in use.



Figure 4: Screenshot from the simulator database, showing the TOV parked fend in (left), and parallel parked, displaying blue flashing lights (right)

2.1.1 Conclusions and recommendations from simulator studies

The simulator studies demonstrated that the presence of an unlit TOV on the hard shoulder (LBS1) or in Lane 1 (LBS2) will influence the approaching drivers' choice of speed and course and that lighting and parking orientation (parallel, fend in, fend off) will cause further changes. However none of the variations between the lighting conditions were found to be statistically significant.

Post-trial questionnaires identified drivers' understanding of the varying colours of lighting, as well as the actions they would take in response to the different roof bar configurations. It was found that:

- Amber is largely understood to indicate drivers to 'slow down'.
- Red, and red combined with amber, are understood to require drivers to either 'slow down' or 'stop'.

The proportion of 'don't know / no idea' responses was larger for the red plus amber lighting configuration, suggesting participants were less familiar with the meaning and required actions of this configuration compared to the red only and amber only configurations.

The effect of fend parking was also investigated. The findings regarding fend off parking on the hard shoulder and live lane seem to indicate that this parking orientation may carry a benefit for the TOV. This is assumed to be due to a subconscious message carried by the vehicle positioning suggesting drivers should pass to the right of the vehicle. If this theory is correct, parking fend in when in the outside lane would carry a similar benefit.

The simulator study led to the recommendations that the TOS guidance and that issued to the Supply Chain is updated to reflect the findings of this review. Specifically, this should include:

1. TOVs operating on the hard shoulder should display amber lights only, since there is no conspicuity benefit from the use of red plus amber lights.
2. Vehicles operating in live lanes that are presenting a rear aspect or fend aspect to traffic should display rear-facing red flashing lights only.
3. Rear-facing red flashing lights should be reserved for use in live lanes only, so that drivers will make an association between red flashing lights and TOVs in live lane situations.
4. There is a benefit in parking vehicles on the near-side of the road in a fend off position.
5. There is likely to be a similar benefit in parking vehicles on the off-side of the road in a fend in position; however, more research is required to support this supposition.

2.2 Trial approach

Although the simulator study resulted in a range of recommendations for TOS working practices, it was decided that an on-road trial should be undertaken in order to investigate whether the simulator study's tentative findings transferred to on-road conditions, and to confirm its recommendations.

Achieving this required acquisition of appropriate data from observations taken from actual TOS attendance at incidents on the Network. However, it was essential that the data gathering process did not impact on the TOs' on-scene activities as this might adversely affect their safety. Similarly, the data gathering method should not be obvious to passing drivers. The real-world data gathered could also be used to refine the impact simulations carried out during workstream 2.

In order to achieve the necessary data collection, the following elements for the trials were identified:

- Design, specify and produce an appropriate TOV-mounted monitoring system
- Identify a suitable vehicle and TOS Outstation
- Calibrate the data collection system to ensure the accuracy of comparisons made during analysis

These elements are detailed in the following sections.

2.3 Monitoring system

A measuring and logging system was required to measure the lateral position of vehicles passing the parked TOV. However, no suitable systems could be identified, so a specification was created which was presented to a number of suitable companies. The specification included:

- The system was to be used to calculate the number, type (if possible) and proximity of passing road user vehicles
- The system would operate when the TOV's warning beacons were in use (the system was to be operated automatically)
- The proximity sensor would identify the lateral clearance distances of passing vehicles
- The sensor would have a resolution suitable to collect proximity measurements for passing vehicles at speeds of up to 80mph
- The system would include two roof-mounted video cameras (forward- and rear-facing) with good resolution throughout a 24-hour period (day and darkness)
- The time and date were to be recorded with the distance measurements and video data
- The system was to be powered from the vehicle or (non-preferred) from a simply-charged battery system
- The data and video was to be recorded to removable media (e.g. memory cards)
- CSV (or similar) output of data would be provided for:
 - Vehicle lighting in use
 - Lateral clearance
 - Length of passing vehicle
 - Time and date
- The entire system needed to be robust and weather resistant

The requirement for two video cameras was made to allow each stop made by the TOV to be assessed for inclusion within the trials data set. Filtering would be carried out to exclude data from incidents which did not conform to the following criteria:

- TOV to be stationary on hard shoulder
- TOV to be in either parallel or fend off orientation
- No other emergency or recovery vehicles in attendance
- No Emergency Traffic Management (ETM) to be in use
- Incident attended will not affect behaviour of passing drivers

It was intended that data from TOV attendance at longer-duration incidents could be used during the initial pilot trial period, then subsequently (e.g. when ETM has been deployed) excluded.

Several suitable manufacturers were provided with the specification; subsequently CSS Group was awarded the task of design, manufacture and fitting of the measurement and logging system. Fitting was undertaken within TRL's vehicle workshops. Figure 5 shows the roof-mounted video cameras; Figure 6 shows the laser distance sensor, mounted on the TOV's spare wheel cover, directed horizontally to the right side of the vehicle at a level where it was expected to measure the widest selection of passing vehicles.



Figure 5: Roof-mounted video cameras



Figure 6: Laser distance measurement sensor, fitted to spare wheel cover on rear of TOV

The system was powered from the vehicle's 12V system, and operated via the main lighting control switching system already installed in the TOV. When the TOV was arriving at an incident scene one of the crew would select the 'Arrival' button (while the vehicle was still travelling in a live lane), which operated both amber and red beacons. Connections made within the roof-mounted light bar were used to identify which beacons were in use.



Figure 7: Lighting control panel

Although the logging system required a short time to power-up and become fully operational, this time coincided with the vehicle moving from the live lane onto the hard shoulder. The video system was recording continuously, with approximately 20-30 seconds of video being recorded prior to the logging system being fully operational. Similarly, the video continued to record for a short time after the beacons were switched off.

The mobile PC and video recorder were mounted in the TOV's passenger compartment, behind the rear seat back (see Figure 8). Video was recorded onto a CompactFlash card; distance measurements and beacon trigger information were recorded onto USB memory.

USB memory



CompactFlash Card



Figure 8: Mobile PC (left) and video logger (right) installed into TOV

2.3.1 Measurement system calibration

The measurement logging system was the only practicable method with which to take recordings of the distance from the TOV to passing vehicles. The drawback with this system was that on its own, it did not provide sufficiently accurate data from which to determine the position of passing vehicles within their lane. There are two ways in which the distance measurements might be inaccurate for the 'in lane' requirement:

1. The TOV could be parked at a range of angles relative to the carriageway, from parallel to the lanes to 'fend' parking; as the 'fend' angle increases the inaccuracy of the distance measurement (relative to a measurement perpendicular across the carriageway) increases. Thus parking orientation must be identified.
2. The TOV would not be positioned at a fixed position relative to the hard shoulder to Lane 1 divider line, so a range of lateral positions must be identified.

In order to allow for those two inaccuracies, it was necessary to first identify the fend angle at which the TOV was parked and its lateral offset, then adjust the data recorded and supplied for analysis. The variables of fend angle and lateral offset are shown in Figure 9.

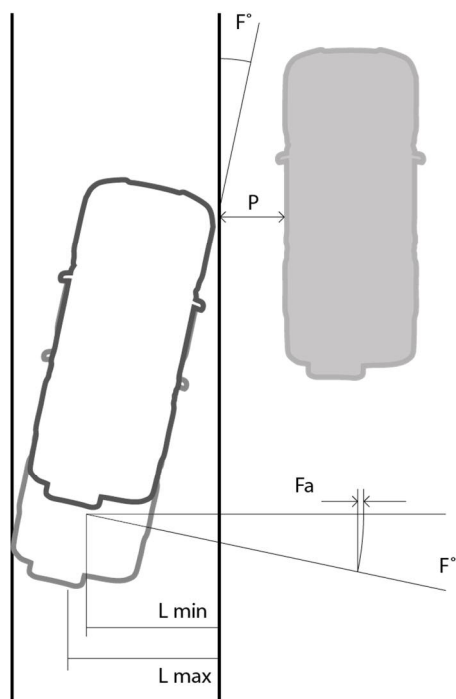


Figure 9: Adjustment variables for distances recorded

Lmin and Lmax show the range of lateral offsets possible when the vehicle is parked within the hard shoulder, measured from the laser lens to the edge of the lane marking. The two extreme conditions used during test track calibration when determining the likely ranges of lateral offsets were:

1. The front of the TOV would be parked as close to the live lane as possible, but with no part of the TOV projecting over the demarcation line between the hard shoulder and Lane 1.
2. The TOV would be parked as far from the live lane as possible, with its nearside rear tyre against the left edge of the hard shoulder (the width of the hard shoulder was set at 3m).

F° is the fend angle at which the vehicle was parked. When this angle was not zero degrees, the measurement from the laser system was greater than the perpendicular distance to the vehicle. Therefore an adjustment to calculate F_a was required to obtain the perpendicular measurement from the measured distance.

By adjusting the laser measurements to account for F_a (if applicable) and L , it was possible to determine the perpendicular distance from the nearside of the passing vehicles to both:

- the lane line, and
- the closest point of the TOV.

However, it is important to note that the measurements obtained from this process did not discriminate between vehicle types, for example between an HGV or relatively narrow car. Given their width, HGVs are likely to be the vehicles with their left side (nearside) closest to the left edge of the lane.

Figure 10 shows a screen image from video taken during calibration on the TRL test track. The horizontal (red) scale was used to identify the angle in degrees (from straight ahead) at which the vehicle was parked. The lines drawn along the carriageway identify, from the white line markings along the track, the 'vanishing point'; a vertical line from that vanishing point to the horizontal scale shows the fend angle (in this example, 0° , i.e. straight ahead).



Figure 10: On-track calibration for fend parking angle

Measurements and screen images were also taken with the TOV position at lateral extremes likely on the hard shoulder. In a similar manner to which the longitudinal line markings appear to 'move' relative to the vehicle as the fend angle alters, changes in the vehicle's lateral position also 'moved' those lines within the image. The appearance of these markings depends on a fixed point of measurement (i.e. camera position on the vehicle).

Figure 11 demonstrates how a screen grab from the TOV's forward-facing video can be used to identify the vehicle's fend angle while attending an incident.



Figure 11: Identifying fender angle from incident video

Figure 12 shows how the white line adjacent to the right side of the vehicle appears further away from the TOV in the left image, showing that the TOV is further left within the hard shoulder. It is likely that the TOV is further towards the right of the hard shoulder in the right hand image so that the driver performing the wheel change is afforded some protection from passing traffic.



Figure 12: Determination of fender angle and lateral offset

Figure 13 gives further examples of TOV attendance at incidents, showing a variety of fender angles and range of lateral positions within the hard shoulder.



Figure 13: Examples of incidents attended, showing the variety of fender angles and range of lateral positions used

2.4 Data received

TRL received data from the TOV between 18th October 2012 and 20th December 2012. These data totalled approximately 38 hours of camera footage, capturing a total of approximately 400 incidents along with various distance measurements recorded using the laser sensor during each incident.

Each incident was coded for suitability according to the criteria previously described. The number of incidents recorded with a full data set was restricted due to a number of problems with both the TOV and the logging system, culminating with a vehicle colliding with the TOV while it was attending an incident.

This collision wrote off the TOV and hence limited the number of incidents for which camera footage and other data were obtained. Data were used to give indication of the distances left by motorists when passing a parked TOV, and how these vary depending on lighting configuration and parking orientation.

It was found during analysis that, on two occasions between incidents during the on-road trial, the position of the camera had changed, invalidating the pre-calibrated scale. In Figure 14 the bodywork of the TOV, as visible in the camera view, is shown in colour. The green lines and vehicle outline show the original camera view as at system installation; the yellow and red lines and outline show the camera view after the first and second time on which the camera position had changed.

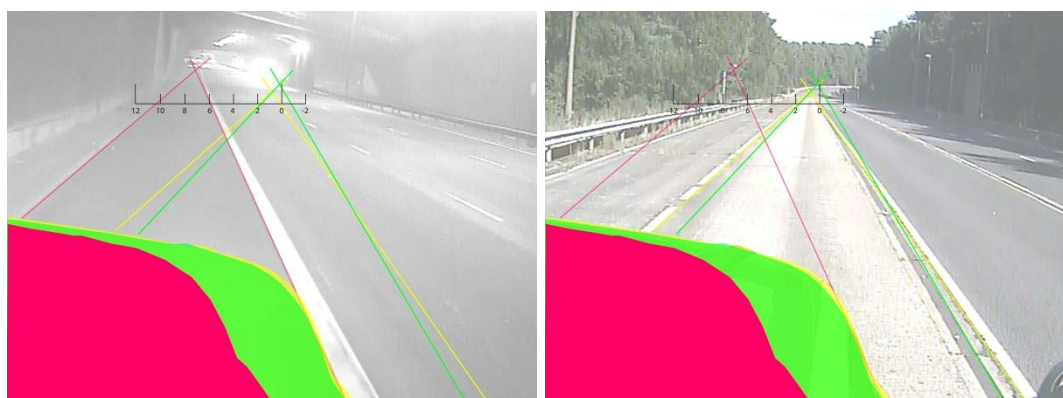


Figure 14: Camera movement. Green (right image) shows original calibration

It was possible to re-orientate the 'straight ahead' (i.e. 0° parking orientation) from the video obtained whilst the vehicle was being driven forwards (Figure 15), though this approach did mean that the pre-calibrated scale was not as accurate as it had been previously for angles other than 0° . It was intended that a visit would be undertaken to re-measure and re-calibrate the scale in full, but the collision involving the TOV led to it being written off and so this was not possible. Therefore, accurate measurements could not be obtained from the laser measurement system, and the distances and angles used are therefore approximations only.



Figure 15: Live lane with TOV travelling forward; image as used to reorient the fender angle scale after camera movement

2.5 Camera data analysis

Using the available camera footage, the location of the TOV during each incident was identified. Figure 16 shows the number of system activations recorded split by type.

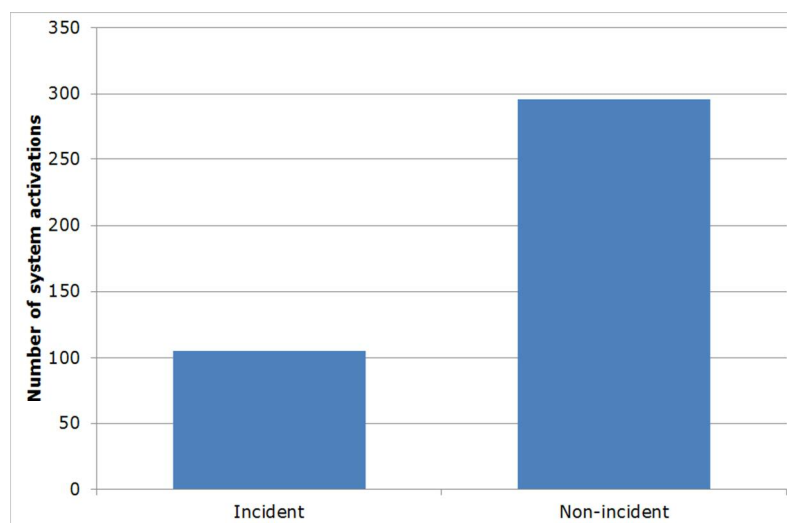


Figure 16: Number of system activations by type

The majority of the non-incidents occurred when the vehicle was undergoing daily checks (so the beacons were activated) or travelling on link roads accessed via the hard shoulder, hence these were not of interest. There were 105 incidents; of these, incidents were excluded where:

- Other vehicles, such as recovery vehicles and traffic management vehicles, were present
- The TOV was stopped in a live lane
- The TOV did not stop (e.g. the driver was conducting a rolling road block) or
- The view of the camera was obscured by dirt or frost.

The remaining 32 incidents comprised approximately 2¼ hours of camera footage during which the TOV was stationary on the hard shoulder.

2.6 Fend angle analysis

It was possible to analyse estimated fend angles used, although the data available represent only a small sample of the incidents attended by TOVs. Figure 17 provides an indication of the range of fend angles used by TOs when attending an incident. The methods used by TOs to place the vehicle into fend when attending incidents is considered in section 5.1.

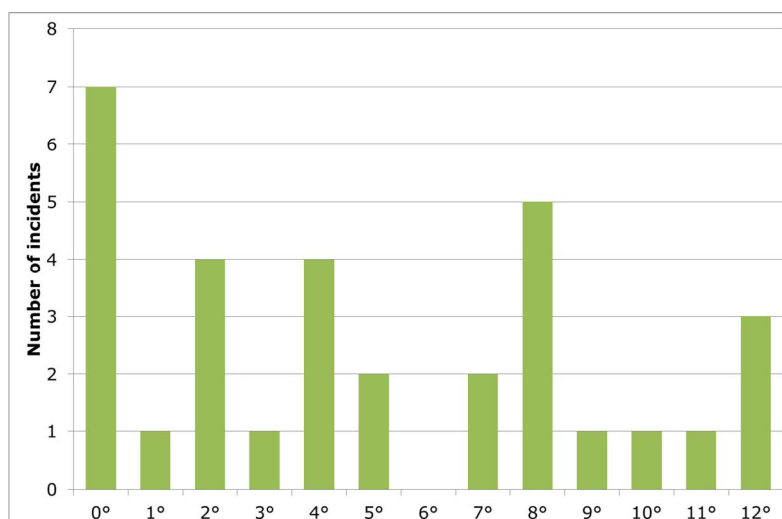


Figure 17: Variety of fend angles (degrees) identified (not to scale), and quantities of each orientation recorded

This range shows that 12° is the maximum angle at which the TOVs were parked. Certain road conditions such as an adjacent lane closure, however, may allow the TOV to be parked at greater angles and not encroach on the lane containing passing traffic.

Given the TOS procedures, it was expected that the data would tend to be focussed around 0° (parallel) and 10° (fend). The data show that the range of angles at which TOs park when attending an incident is much more variable than expected.

2.7 Incident types

The 32 incidents that could be used for analysis comprised 19 daytime incidents and 13 night-time incidents. Each incident was classified by the number of vehicles involved and whether or not ETM was used (see Table 1).

Table 1: Number of incidents by type and ETM

Type of incident	Type of vehicle(s)	ETM installed?	
		Yes	No
Single vehicle stopped on hard shoulder	Car	0	21
	HGV	1	5
Multiple vehicles stopped on hard shoulder	Cars	2	1
No vehicle – TOV stops on hard shoulder	n/a	0	2
Total		3	29

ETM was installed for only three of the 32 incidents considered in this analysis. The majority of incidents (27) occurred when a single vehicle had stopped on the hard shoulder.

Given the wide range of fend angles identified, comparisons were made to determine whether these choices were related to factors concerning the incident, such as the vehicles involved or time of day. These comparisons are shown below in Figure 18 to Figure 20.

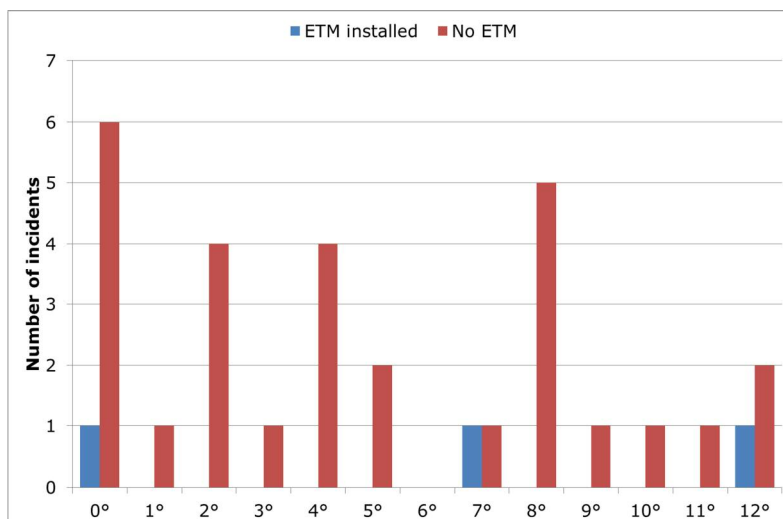


Figure 18: Fend angle selected according to ETM use: ETM deployed (left), no ETM (right)

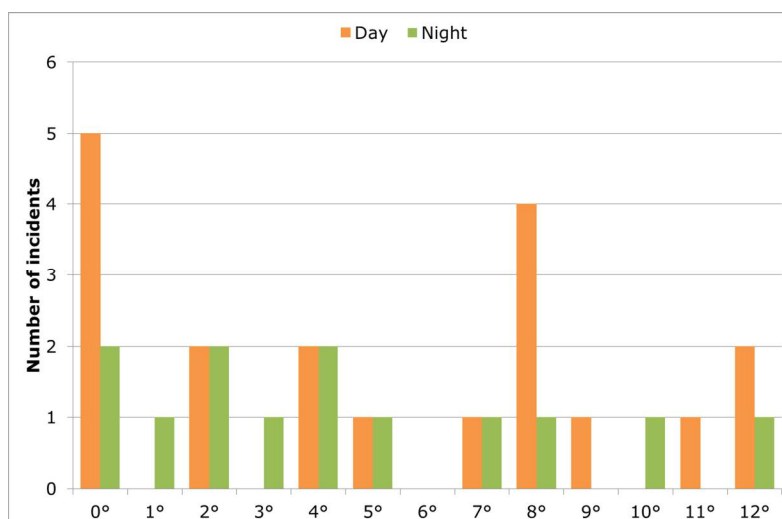


Figure 19: Fend angle selected according to time of day: daytime (left), night time (right)

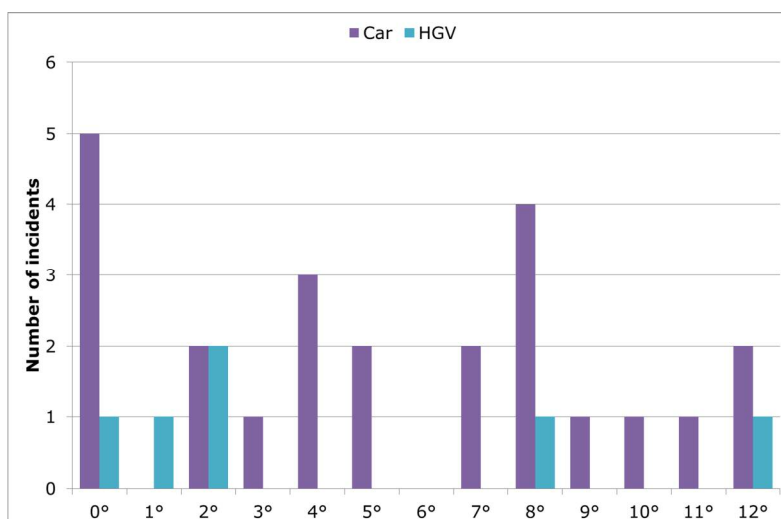


Figure 20: Fend angle selected according to incident vehicle: car (left), HGV (right)

Figure 18 to Figure 20 suggests that selection of fend angle does not seem to be related to any aspect of the incidents attended.

2.8 Laser data analysis

The system measured the distance from the TOV to passing vehicles during each incident. This section examines how close passing vehicles travelled to the stationary TOV when it was parked on the hard shoulder.

Laser data were valid for 16 of the 32 incidents. For those incidents at which ETM was installed, analysis of the data from the laser system was only completed during the time where no ETM was deployed.

Due to the frequent measurements taken by the laser, it was likely that two adjacent measurements would often be from the same vehicle. Adjacent measurements within 0.05m were therefore assumed to be the same vehicle, with only the initial measurement used for the analysis.

When the vehicle was parked fend off, the distances measured by the laser were as shown in Figure 21.

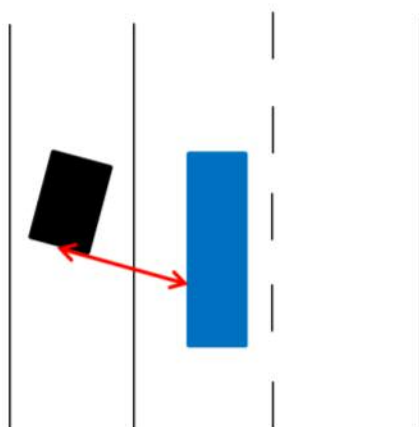


Figure 21: Laser measurement when parked at fend

Using trigonometry, the measurements recorded by the laser in each of these incidents were therefore converted into the two measurements shown in Figure 22.

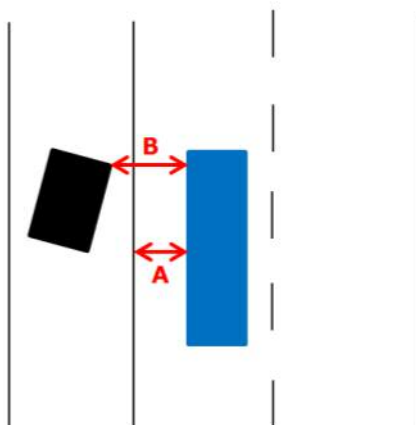


Figure 22: Converted measurements

Distance A is the distance from the rib line to the passing vehicle. Distance B is the distance from the nearest point of the TOV to passing traffic.

Any vehicles for which distance A is smaller than 0 i.e. those vehicles which appear to be driving on the hard shoulder were removed. It is likely that these values are due to measurement errors. In total, distances were measured for 1,231 vehicles, though these vehicles were not distributed evenly across the 16 incidents.

2.9 Effect of fend

For the purposes of this analysis the range of fend angles experienced during the trial were grouped as in Table 2. In the graphs below, each fend type has a different colour: incidents where the TOV was classified as being parked in 'parallel' are green and those where the vehicle is parked in 'fend' are red.

Table 2: Grouped fend angles

Fend type	Fend angles	Incident numbers	Number of vehicles for which distance measurements were obtained
Parallel	0° to 5°	3, 4, 5, 6, 7, 11, 13, 14, 15, 16, 17 & 18	1,131
Fend	6° to 12°	2, 8, 9 & 10	100

Figure 23 shows the range of distances from the 'rib' line (the line between the hard shoulder and lane 1) to passing vehicles recorded in each incident (distance A). Figure 24 shows the range of distances from the TOV to the passing vehicle (distance B). The legend shows the number of passing vehicles (n) for which measurements were obtained in each incident.

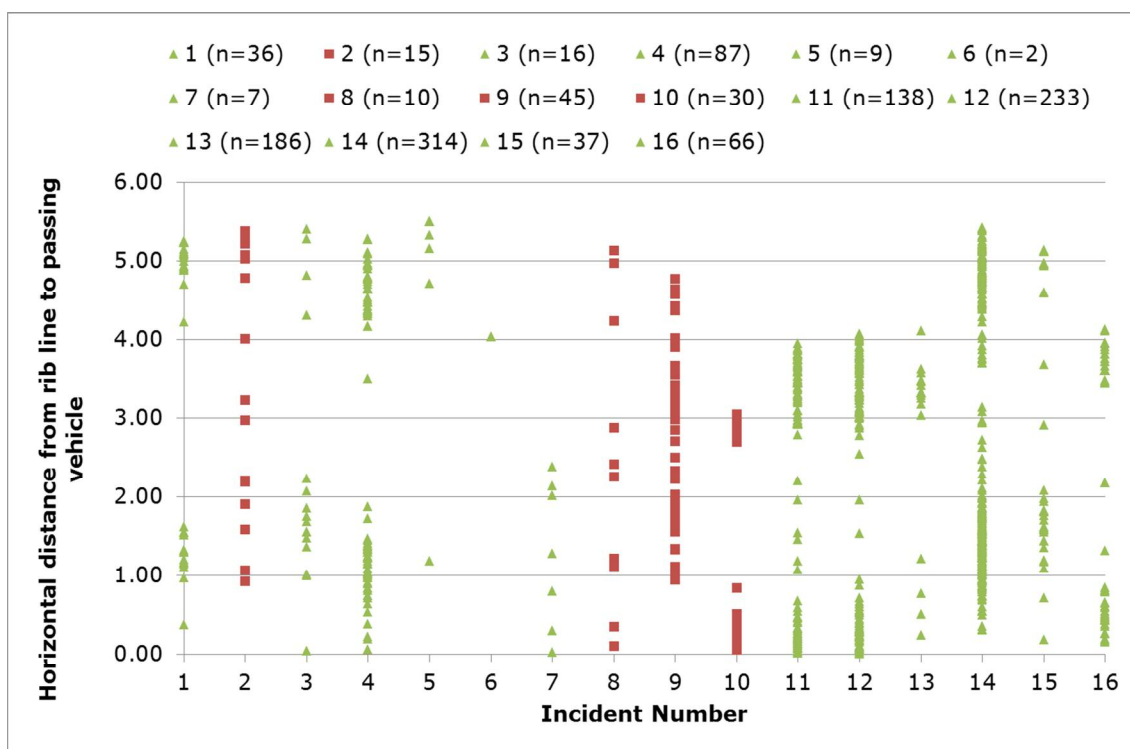


Figure 23: Distance A - horizontal distance from rib line to passing vehicle
[parallel = green, fender = red]

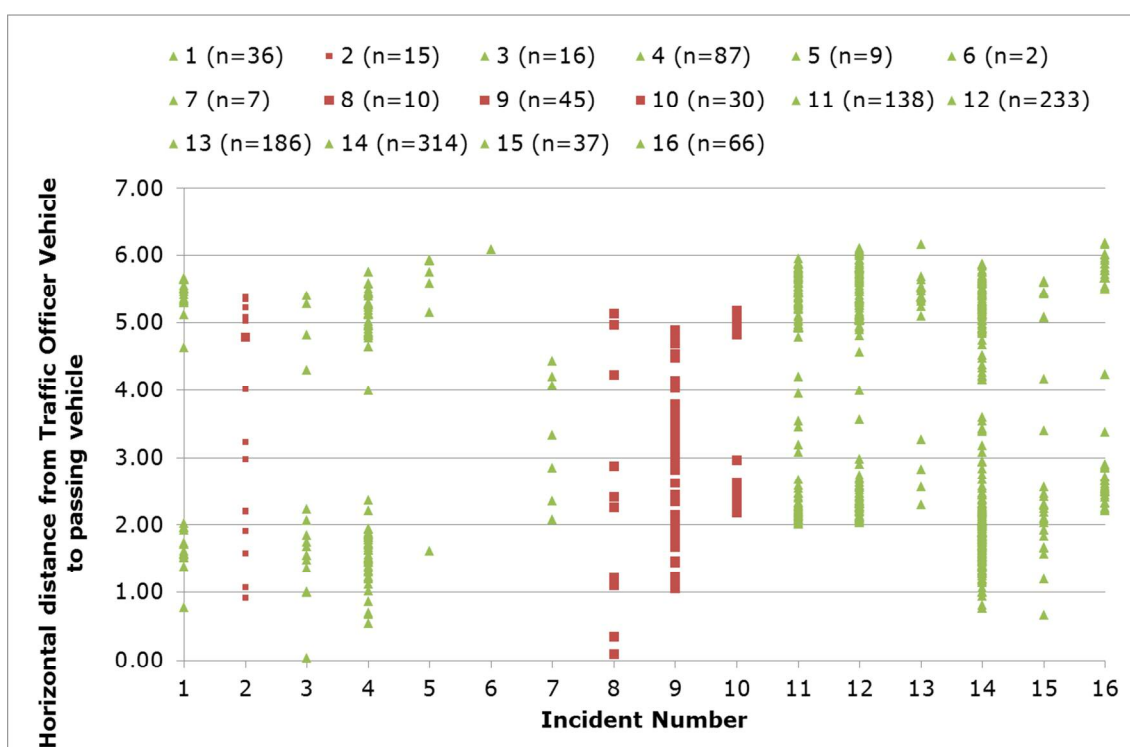


Figure 24: Distance B - horizontal distance from TOV to passing vehicle
[parallel = green, fender = red]

A number of the incidents show two distinct groups of distances; these represent the vehicles in the closest two lanes to the TOV.

Given that lane widths are typically 3.6m, it was possible to identify those vehicles which were travelling in the lane 1 to the TOV and examine their average distance from the TOV for each of the two fend types. Figure 25 displays the average distance from the rib line to the vehicle passing in lane 1 by fend type. Figure 26 displays the average distance from the TOV to the vehicle passing in the lane 1 by fend type.

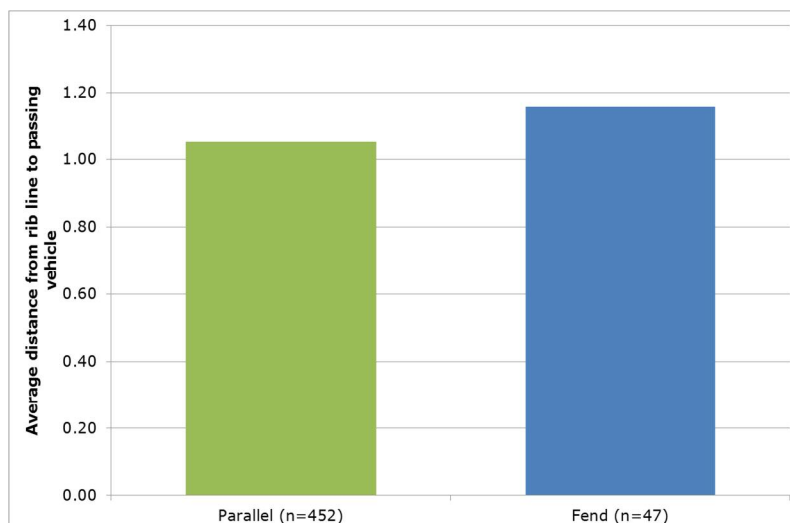


Figure 25: Average distance from the rib line to the vehicle passing in the lane 1 by fend type (average distance A)

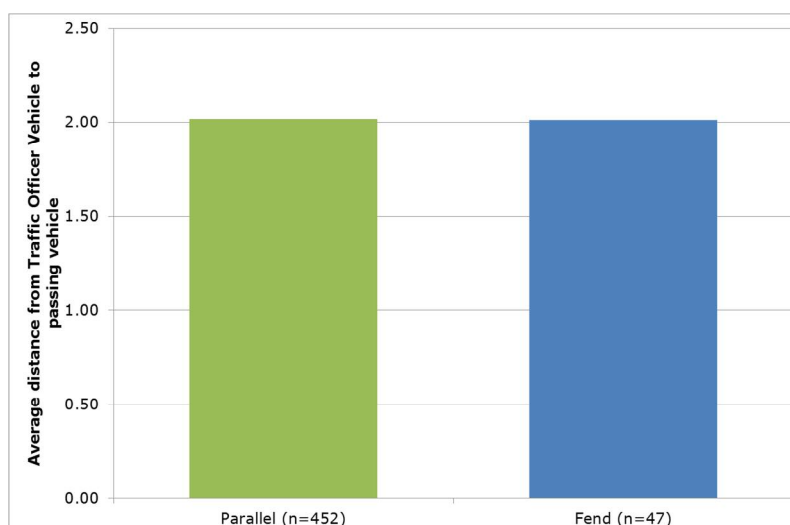


Figure 26: Average distance from the TOV to the vehicle passing in the lane 1 by fend type (average distance B)

Figure 25 shows that when the TOV is parked in fend, vehicles in lane 1 were on average further from the rib line separating the TOV from the passing vehicle. Figure 26 demonstrates that when the additional distance to the nearest point of the TOV was incorporated, the average distance was very similar when the TOV was in fend and when it was in parallel. However, given the small sample size, these data are not suitable for statistical analysis.

2.10 Effect of lighting

The system's on-board computer recorded whether the vehicle's beacons were on and, if they were, the colours of the lights being displayed. Initially, this was stored on the computer only, though for later incidents, the system was re-engineered to copy it to a removable memory stick.

The modified approach provided beacon information for later incidents. The intention had been to retrieve information on the operation of the beacons for earlier incidents from the on-board computer at the end of the trial period. Unfortunately, this was not possible due to the vehicle being taken out of service following a collision; this is discussed in Section 4. Careful analysis of night-time video did allow the beacons in use to be determined from the colour of reflections that were visible.

In all cases for which beacon information was obtained, red and amber lighting was used together. This meant that no analysis of the effect of different lighting configurations on driver behaviour was possible.

2.11 Summary

The aim of the trial was to conduct an on-road study similar to that previously conducted in the TRL simulator. The purpose of this was to confirm the recommendations made in the report (Diels et al., 2009). Data were collected using a TOV-mounted monitoring system which comprised of two roof-mounted video cameras, a laser measurement system and a data logger. The number of incidents recorded by the system was restricted due to a number of problems with both the TOV and the logging system, culminating with a vehicle colliding with the TOV while it was attending an incident.

Data limitations meant that the results were not suitable for statistical analysis. However, the results do show that:

- The range of angles at which TOs park when attending an incident is much more variable than expected.
- Selection of the fend angle does not seem to be related to ETM deployment, time of day or incident vehicle type.
- When the TOV was parked in fend, vehicles in lane 1 were, on average, further from the rib line separating the TOV from the passing vehicle than when the TOV was parked in parallel.
- Vehicles in lane 1 were, on average, at very similar distances from the nearest point of the TOV when the TOV was in fend and when it was in parallel.

Analysis of the effect of different lighting configurations on driver behaviour was not possible, due to the use of amber and red beacons at all suitable incidents.

The limited data studied suggest there is little benefit of parking at fend compared to parallel in terms of the average distance from the nearest point of the TOV to a passing vehicle when the TOV is parked on the hard shoulder.

3 Workstream 2: Consequences of Impacts

3.1 Introduction

This workstream has considered the effect of the orientation and impact configuration upon the deflection of the TOV. The aim of this analysis was to determine the zone within which TOs, members of the public and other incident personnel are at substantial risk of being struck by the TOV if it is hit by a passing vehicle. From determination of that zone it has been possible to produce guidance on the safer positions to stand, while still acknowledging that no area adjacent to a road carrying high-speed traffic can be considered fully 'safe' and, as such, vigilance and good lookout principles must be maintained.

3.2 Previous relevant work

3.2.1 Initial review

Marsh (2003), as part of the initial review prior to setting up the TOS, examined the vehicle dynamics when a collision with a parked vehicle occurs. This work was based solely on previous experience at the point that the TOS was being formed. This work was not revisited following the foundation of the TOS, resulting in some areas where the initial research does not align with the operational and practical experience of the TOS.

3.2.1.1 Review of operational practices

Marsh (2003) identified that the Central Motorway Police Group (CMPG) adopted an approach of:

- Turning the front wheels towards the nearside when there is no barrier
- Turning the wheels to the offside where there is a barrier.

The reasoning for this was that, if the parked vehicle was struck from behind with its wheels turned towards the nearside, it would be projected along the barrier and towards people, or other vehicles, positioned within the 'work zone'.

Marsh (2003) also identified that AmeyMouchel (a road works contractor) was concerned that, if the front wheels were turned towards the live traffic lanes and the vehicle was struck from behind, it could be projected into the path of passing vehicles. AmeyMouchel therefore adopted the approach of turning the front wheels away from the running lanes.

AmeyMouchel also had a policy that no person or vehicle should be within 25 metres of the front of the parked vehicle and that no work should be undertaken more than 150m beyond the vehicle. The area between these two distances was described as the 'work zone'.

In both cases, the body of the vehicle remained parallel to the carriageway, with just the wheels at an angle to the carriageway.

3.2.1.2 Simulation

Marsh (2003) used computer simulation software for preliminary modelling of relevant collision situations, assuming the vehicle parked on the hard shoulder was a Mercedes

Sprinter, with a wheelbase of 3.55 metres and a total mass of 4,500 kg. An alternative vehicle mass of 2,000 kg was also modelled to analyse the sensitivity. Three striking vehicle types were modelled, their masses being:

- 1,000 kg – a typical passenger car
- 7,500 kg – a rigid lorry
- 30,000 kg – an articulated lorry

The striking vehicle was assumed to have been travelling at speeds of up to 110mph (cars), 80mph (rigid lorries) or 70mph (articulated lorries). Initial simulations were carried out with an approach angle of 0 degrees and a 100% overlap between the two vehicles during impact.

Parallel parking was modelled, with fend parking considered later, and three braking 'scenarios' for the parked vehicle were modelled:

- Hand brake applied, i.e. locked rear wheels, with the vehicle in gear
- Hand brake applied, i.e. locked rear wheels, but out of gear
- Engine braking only, i.e. no brake application, but with the vehicle in gear

Additional simulations were carried out to examine the effect of a 50% overlap between the vehicles during impact and to examine how parking the vehicle at an angle on the hard shoulder affects its post-impact trajectory.

The nature of the analyses undertaken meant that the effects of suspension properties and vehicle structure and shape were not considered in detail. They therefore did not consider the possibility of rollover which could occur due to significant rotation experienced by the parked vehicle during its post-impact trajectory, nor the effects of underide / override collisions.

Additionally, the barrier used in the simulations represented a simplified rigid barrier of infinite mass. While a corrugated barrier would be expected to behave somewhat differently during a collision (particularly during HGV impacts), the simplified barrier was considered appropriate for the purpose of the preliminary analyses. To include a deformable barrier would have required further research into its deformation characteristics under impact conditions which would most likely have required physical testing.

In Scenario 1, an effective deceleration rate of 0.5g was assumed based on a friction coefficient of 0.8g for the rear locked wheels, and a deceleration rate of 0.2g at the front wheels due to engine braking.

In Scenario 2, it was assumed that the front wheels would experience rolling friction lowering the effective deceleration rate to approximately 0.4g.

In Scenario 3, it was assumed that the vehicle would experience braking only on the front wheels, resulting in an effective deceleration rate of approximately 0.1g.

3.2.1.3 Distance travelled

The values presented in Table 3 indicate the approximate distance that a vehicle parked on the hard shoulder might be projected based on these assumptions, and assuming the vehicle did not undergo significant rotation.

For example, if a passenger car travelling at 55mph struck the parked vehicle, the latter would be expected to come to a halt after approximately 2m if the hand brake was applied and the vehicle was parked in gear.

Table 3: Approximate projection distances

Pre-impact speed of striking vehicle			Change in speed of parked vehicle	Distance to stop		
Passenger car	Rigid lorry	Semi-trailer		Scenario 1	Scenario 2	Scenario 3
55mph	15mph	10mph	10mph	2m	3m	10m
110mph	30mph	20mph	20mph	10m	10m	40m
-	45mph	30mph	30mph	20m	20m	90m
-	60mph	40mph	40mph	35m	40m	>150m
-	80mph	50mph	50mph	50m	65m	>150m
-	-	60mph	60mph	75m	90m	>150m
-	-	70mph	70mph	100m	120m	>150m

In the case of a full rear impact, therefore, AmeyMouchel's work zone (25m – 150m) could be entered by a parked vehicle that has experienced a full rear impact by a lorry travelling at a legal speed.

The subsequent travel of the impacting vehicle does not appear to have been considered in this work: it appears to have been assumed that this is brought to a complete standstill by the collision.

3.2.1.4 Effect of steering

For some scenarios and at some speeds, a parked vehicle was also modelled with the steering wheel turned one revolution towards the offside, but parked parallel to adjacent lanes, in the centre of a 3.3m wide hard shoulder. When the striking vehicle is moving at a higher speed, the path followed by the parked vehicle post-collision tends to be flatter. The calculated forward distances travelled by this vehicle before it crosses into the live carriageway (i.e. travels a lateral distance of 0.6m), depending on the pre-collision speed of the striking vehicle, are presented in Table 4.

Table 4: Forward distance travelled before crossing into live carriageway

Pre-impact speed of striking vehicle			Change in speed of parked vehicle	Distance to cross edge of carriageway marking	
Passenger car	Rigid lorry	Semi-trailer		Scenario 1/2	Scenario 3
55mph	15mph	10mph	10mph	2.0m	
110mph	30mph	20mph	20mph	3.5m	
-	45mph	30mph	30mph	5.5m	6.5m
-	60mph	40mph	40mph	7.5m	
-	80mph	50mph	50mph	10.0m	
-	-	60mph	60mph	10.5m	
-	-	70mph	70mph	11.0m	12.0m

Scenario 3 was also modelled with the steering wheel turned through two revolutions for the same speeds as presented above for one revolution. Instead of the distances of 6.5m and 12.0m shown for one revolution in Table 4 above, the distances with two revolutions were 5.5m and 11.0m respectively.

In all of the above cases, it was assumed that the vehicle's ignition was switched off and that the steering wheel therefore remained locked, and that it remained locked throughout. In particular, it was explained that:

It is important to note that for all simulations the steering wheel was maintained at the adopted steering angle throughout the impact and post-impact trajectory. This would be consistent with the vehicle's ignition being turned off, causing the steering wheel to lock and to remain locked. Changes in steering angle caused by lateral forces experienced during vehicle rotation have not been considered as part of this preliminary analysis, e.g. through braking of the steering lock or with the ignition turned on. Such effects could be analysed during more detailed modelling.

3.2.1.5 Effect of overlap, approach angle and parking angle

A range of approach angle and offside overlap conditions were modelled. In both cases, the parked vehicle was projected towards the nearside regardless of steering orientation. After collision with a nearside barrier, a vehicle steered to the right would then veer out towards the live lane.

When parked at an angle on the hard shoulder, some configurations allowed for the vehicle to rotate 180 degrees as a result of the collision, pivoting around its contact point with a nearside barrier. The likelihood of this happening increases when parked at higher angles. If the vehicle does rotate, then wheels which are at an angle to the vehicle cause it to travel in the opposite direction: if steered to the right and travelling backwards, the vehicle will tend to travel towards the barrier, limiting encroachment into live lanes.

3.2.2 Further simulation analyses

3.2.2.1 Simulation – base scenarios

TRL (2004) carried out some simulation analyses similar to those in Marsh (2003) using:

- a vehicle of mass 2,600kg, parked at an angle of 15 degrees¹
- two types of errant vehicle: a standard 1,500kg passenger car and a 7,500kg tonne rigid lorry, with an impact angle of 10 degrees
- errant vehicle speeds of 40mph and 70mph, and
- collisions involving full overlap, 25% overlaps, and glancing type collisions (in which the errant vehicle hits the side of the parked vehicle).

¹ The usual hard shoulder width would prohibit a typical TOV from being parked at a fend angle greater than 12° without encroaching onto either the adjacent live lane or the verge etc. off the hard shoulder.

All four wheels on the parked vehicle were locked throughout the simulations, with no steering applied i.e. the wheels parallel to the body of the vehicle. In particular, it was explained that:

The Highways Agency has advised that the HATO [Highways Agency Traffic Officer] vehicle fleet comprises Mitsubishi and Land Rover four wheel drive vehicles. It is understood that these vehicles are automatic, and thus, with the vehicle in 'park' gear and with the handbrake engaged, all wheels will be locked (when in 4x4 mode). It is understood, however, that the Mitsubishi is not a permanent four wheel drive vehicle, and therefore when in two wheel drive mode, the front wheels will not be locked either by the hand brake or by the 'park' gear.

Table 5 summarises all of the simulated conditions described above.

Table 5: Base scenarios simulated

Errant vehicle	Errant vehicle impact speed	Overlap
Passenger car	40mph	Full
Passenger car	40mph	25% offside
Passenger car	40mph	25% nearside
Passenger car	40mph	Glancing
Passenger car	70mph	Full
Passenger car	70mph	25% offside
Passenger car	70mph	25% nearside
Passenger car	70mph	Glancing
7.5 tonne lorry	40mph	Full
7.5 tonne lorry	40mph	25% offside
7.5 tonne lorry	40mph	25% nearside
7.5 tonne lorry	40mph	Glancing
7.5 tonne lorry	70mph	Full
7.5 tonne lorry	70mph	25% offside
7.5 tonne lorry	70mph	25% nearside
7.5 tonne lorry	70mph	Glancing

In the 40mph errant vehicle scenarios, braking on all four wheels of the errant vehicle was assumed throughout; in the 70mph errant vehicle scenarios, both front vehicles were assumed to lock in the full overlap condition, and one front wheel to lock in the other conditions.

All the simulations were run until either both vehicles came to a rest or until the errant vehicle travelled more than 25 metres, and hence into the safety zone.

Neither vehicle was found to breach a 25 metre safety zone in any of the collisions involving a passenger car or a 7.5 tonne lorry travelling at 40mph. This was also the case for the 70mph car full impact collision. However, the errant vehicle was found to breach the 25 metre safety zone in the partial and glancing 70mph car impacts, and in all of the 70mph 7.5 tonne lorry impacts.

In the full impact 70mph 7.5 tonne lorry collision, both vehicles were found to still be travelling at around 45mph to 50mph when they breached the 25 metre safety zone. In the partial and glancing 70mph 7.5 tonne lorry impacts, the errant vehicle was found to breach the safety zone at around 50mph to 60mph.

In the full overlap conditions, the parked vehicle was projected along the hard shoulder and slightly towards the live lanes, though without significant encroachment. The errant vehicle tended to continue travelling towards the barrier.

For the 25% offside overlap conditions and the glancing conditions, the parked vehicle was projected towards the verge/barrier. For the 25% nearside overlap conditions, the parked vehicle was projected towards the live lanes, this type of collision resulting in the greatest extent of encroachment into the live lanes.

In the 25% offside overlap conditions, the impacting passenger car tended to rotate anti-clockwise, at least initially, towards the live lanes. In the glancing conditions, the passenger car tended to be redirected towards the live lanes whereas the impacting lorry tended to continue along the hard shoulder towards the roadside barrier. The barrier that was simulated was described as follows:

The barrier used in the simulations is representative of a rigid barrier of large mass, similar to a New Jersey type barrier. To include a deformable barrier as part of the simulation analyses would require further research into its deformation characteristics under impact conditions which would require physical testing.

3.2.2.2 Simulation – sensitivity analyses

Sensitivity analyses were also carried out, with only the rear wheels locked, for:

- the full overlap passenger car 70mph condition, and
- the full overlap 7.5 tonne lorry 40mph condition.

In both cases, the front wheels were assumed to be steered straight and to remain straight throughout in one simulation each. In others, the simulations modelled the effect of the wheels turned one steering wheel revolution, representing a wheel angle of approximately 20 degrees, and the assumption that they remain locked at this angle throughout.

An impact angle of zero degrees was also modelled for the scenario in which a 7.5 tonne truck was travelling at 40mph, colliding with a parked vehicle with all four wheels locked, once with the truck travelling along the middle of the hard shoulder, and one with it travelling immediately adjacent to the barrier.

Table 6 summarises all of the simulated conditions described above.

Table 6: Sensitivity analysis conditions simulated

Errant vehicle	Parked vehicle locked wheels	Parked vehicle wheel angle	Errant vehicle impact angle	Errant vehicle impact speed
Passenger car	Rear only	0 degrees	10 degrees	70mph
7.5 tonne lorry	Rear only	0 degrees	10 degrees	40mph
Passenger car	Rear only	20 degrees left	10 degrees	70mph
7.5 tonne lorry	Rear only	20 degrees left	10 degrees	40mph
Passenger car	Rear only	20 degrees right	10 degrees	70mph
7.5 tonne lorry	Rear only	20 degrees right	10 degrees	40mph
7.5 tonne lorry	All	0 degrees	Zero (along barrier)	40mph
7.5 tonne lorry	All	0 degrees	Zero (centre of hard shoulder)	40mph

When only the rear wheels were locked, and the steering wheel was straight, the parked vehicle was projected further and encroached further into the live lanes, than when all the wheels were locked. It also tended to rotate around 180 degrees.

If rotation did occur, the parked vehicle tended to travel towards the barrier once it started travelling backwards when the front wheels were steered to the offside, and further into the live lanes when the front wheels were steered to the nearside.

When the approach angle was zero degrees and along the barrier, the parked vehicle was projected further into the live lanes; when the approach angle was zero degrees and along the centre of the hard shoulder, the parked vehicle was projected along the hard shoulder, parallel to the carriageway.

The effect of a collision with a barrier was also simulated for the full impact 40mph 7.5 tonne lorry collisions, both in which the parked vehicle had all four wheels locked and in which it had only the rear wheels locked, all with the front wheels steered straight.

In both scenarios, the parked vehicle rotated clockwise and was projected along the hard shoulder, parallel to the carriageway. With all four wheels locked, the rear nearside of the parked vehicle collided with the barrier causing the front of the vehicle to rotate backwards. With only the rear wheels locked, the vehicle continued to rotate until it started travelling backwards into the live lanes.

In both cases, the errant vehicle collided with the barrier and continued along the hard shoulder, coming to a rest before entering the live lanes.

3.2.3 The Netherlands approach

The Netherlands approach (The Netherlands Traffic Management Centre, 2005) to live lane incidents is to park the first emergency assistance vehicle arriving at the scene of an incident in the fend off position, suggesting that it makes the vehicle more visible to traffic, with the direction of the vehicle dictating the direction of the traffic flow. However, when a breakdown mechanic is providing breakdown assistance to a car in the

right-hand emergency lane (i.e. the hard shoulder), the instruction is for the vehicle to be parked straight, with the front wheels steered away from the traffic.

A 100m safety zone is specified, as it "...provides sufficient protection for most incident situations" (p.7).

3.2.4 Current HA guidance

The TO manual (Hewitt, 2006) says **"whatever position is adopted, in all cases the vehicle should be left with its front wheels steered straight ahead parallel to the vehicle."**

Chapter 8 (Department for Transport / Highways Agency, 2009) section 07.2.77 says "the fend off position is generally considered the most advantageous vehicle orientation and should be used unless factors identified by a dynamic risk assessment indicate that is inappropriate."

It describes some of these factors and lists a number of perceived advantages and disadvantages of each parking position. Section 07.2.78 repeats the guidance in the TO manual, but with additional text:

"Whatever position is adopted, in all cases the vehicle should be left with its front wheels steered straight ahead parallel to the vehicle, and in the case of a vehicle fitted with an automatic gearbox, with the gear selector in 'park'. The handbrake shall be set and if available, the four-wheel drive mode engaged. If it is necessary to leave the engine running, 'run lock' should be used, if available."

However, during analysis of video from TOV attendance at incidents, two methods of parking in 'fend' were identified:

1. Driving forwards; typically the TOV enters the hard shoulder travelling forwards, and is immediately placed into the fend position.
2. Reversing; the TOV is driven up to the incident so that the passenger TO can disembark, then the TOV is reversed away to give a clearance distance then placed into fend.

In both of these methods it is likely that the TOV's front wheels are steered slightly towards the left when it is parked, more particularly with the second since the width of the hard shoulder would not be sufficient for the vehicle to travel further rearwards with the front wheels steered straight ahead. With both methods, especially when traffic volumes are higher, it is likely that the driver will build speed while travelling forwards on the hard shoulder before entering the live lane. This will require that the front wheels are steered left when starting off so that the vehicle remains within the hard shoulder width while moving forwards. Steering the front wheels while a vehicle is stationary, either to straighten them when the vehicle is in fend or turn them for driving off, may cause mechanical damage to the vehicle and/or damage to the carriageway surface.

3.2.5 Summary of previous impact research work

A wide range of impact research work has been examined. This work has covered a range of variables, including parallel and fend parking, different braking combinations of the impacted vehicle, and the parked vehicle's front wheels being both straight (in-line

with the vehicle) and steered. Impacts have been simulated with several types of impacting (errant) vehicles at a range of speeds.

However, according to both the TOS procedures, and the activities (which have possibly been in response to the particular incident circumstances) identified during analysis of video gathered during the on-road trials, these previous simulations do not fully cover the current on-road activity of TOs attending incidents. Therefore, it was considered that additional simulations of impacts involving parked TOVs were needed, using a specific set of parameters that represent both current and desired practices.

3.3 Modelling requirements

The impact angles and impact overlaps used previously seem appropriate but were not conducted for all scenarios / locations. Therefore, the following inputs were determined to guide the modelling element of workstream 2:

- Impacted (Traffic Officer) vehicle:
 - Type: 4x4 (Mitsubishi Shogun / Land Rover Discovery 4)
 - Maximum Vehicle Weight: 2.63t – 2.95t
 - Transmission: automatic gearbox, 4WD engaged, wheels locked as in 'Park'
 - Steering lock can be activated when vehicle is running on the key out system
- Two orientations for impacted vehicle:
 - Parallel
 - 10° fend
- Angle of wheels on impact
 - TO procedures state 'in-line with vehicle'
- Three locations:
 - Hard shoulder with barrier
 - Hard shoulder without barrier
 - Offside lane with barrier
- Impacting vehicle:
 - Large goods vehicle (44T) at 40mph, 50mph and 60mph
- Three angles of impact (errant vehicle path):
 - 0° 10° 20°
- Impact overlap:
 - 10% 20% 40% 80%

The outputs required from the modelling to be:

- Distance of travel for both impacting and impacted vehicle
- Path of travel of both vehicles (including encroachment on live carriageway and work zone)
- Rotation of both vehicles and risk of rollover or ride-over
- Influence of a barrier on collisions

Some previous modelling work which was analysed did not continue to track the path of the errant vehicle post-collision. This has been included in the new modelling as it is important for defining a safe area.

3.4 Workstream 2 simulations

It is known that an infinite number of configurations could be determined with regard to a vehicle colliding with a stationary vehicle upon the hard shoulder. This is due to the potential variations in driver input, vehicle speed, impact angle, vehicle type, overlap, environmental conditions and road furniture all contributing to how the vehicles would interact and then how they would travel post-collision. To consider each of these items separately and in a 'real-world' test environment would be prohibitively costly in both time and money.

Therefore, to provide analysis where as many variables as possible can be evaluated, three-dimensional collision investigation and reconstruction software is utilised. The collision reconstruction software used for this analysis is HVE 3D (Human Vehicle Environment), developed by Engineering Dynamics Corporation (EDC). HVE consists of a number of different two- and three-dimensional calculation modules for the simulation of vehicle and collision dynamics. The Simulation Model Non-Linear (SIMON) model is one such module. It is a mathematically constrained simulation program that uses the laws of physics to determine the results of vehicle to environment interactions. Within SIMON there is a calculation model known as the Dynamic Mechanical Shell (DyMesh) which enables the simulation of three dimensional collision forces. Therefore, DyMesh enables more detailed collision simulations (vehicle-to-vehicle and vehicle-to-environment interactions) to be made than has previously been possible within this software.

Within HVE it is possible to change many different parameters with the vehicles, environment and the driver inputs to determine the effect each would have upon the end result. With regard to the environment and the vehicles it is thus possible to replicate as closely as possible the conditions that are present in the 'real world'.

3.5 Environment

The environment model for this project was created to represent a typical three-lane motorway with a hard shoulder. The model was created within the Rhinoceros 3D modelling software. Lanes 1-3 of the motorway were created with widths of 3.65m and the hard shoulder was 3.00m wide. Dashed white lines were used to separate the 'live' traffic lanes. The line lengths were 1.0 metres and the separation was 8.0 metres. Between the hard shoulder and lane 1 a solid white line was used, with a similar solid white line used to highlight the extents of the hard shoulder (Figure 27).

The motorway environment was simulated to be flat and therefore did not include any provision for camber or cross fall as may occur on some sections of highway. The area to

the nearside of the hard shoulder was created as a flat 'run-off' area. Whilst this area may not necessarily be representative of the environment in the real-world due to the inclusion of concrete barriers, grass embankments etc., it provided an opportunity to investigate the interaction between a striking vehicle and the TOV parked on the highway, as well as the potential route the vehicles would follow post-collision.

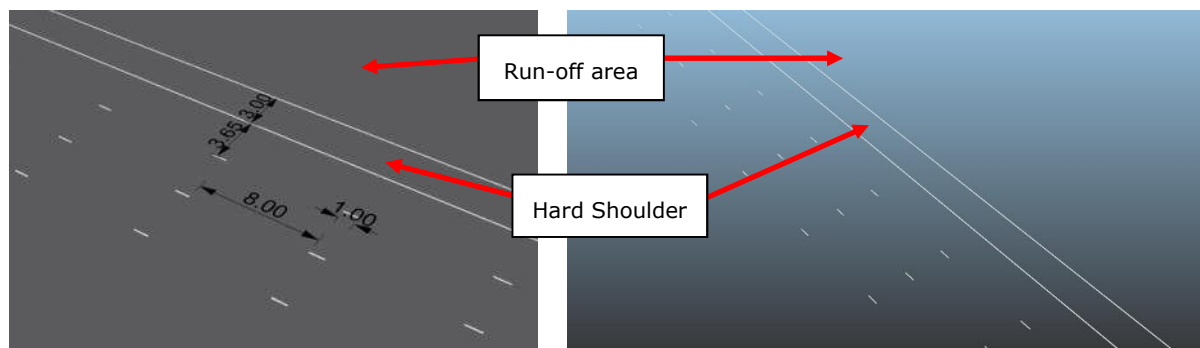


Figure 27: The three-lane motorway with hard shoulder and flat run-off area environment model

To help with the alignment of the vehicle models within the HVE environment, lines were added to the surface model to show the orientation and position of the impacting vehicle and the position and orientation of the TOV (see Figure 28). The angle of impact, overlap and angle of the TOV on the hard shoulder will be discussed later.

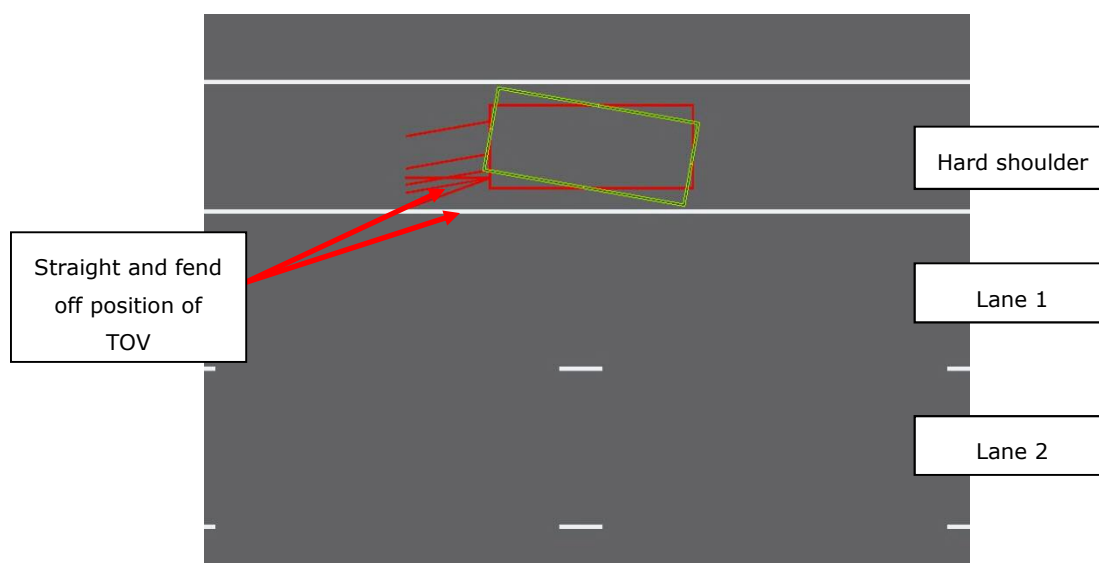


Figure 28: Lines laid onto the surface of the hard shoulder to show the position of the stationary TOV

Within the HVE Environment model it is possible to modify certain attributes, including the friction factor. This figure enables the user to modify the multiplying factor for the friction at the tyre/road interface (and in the case of a rollover the vehicle/road interface). The frictional properties of the vehicle's tyres are specified within the vehicle model but if, for example, the road surface was known to have very low frictional properties (e.g. if it was covered in a layer of ice), it would be possible to change the multiplier within the model from the default value of 1 to a much lower value. The software then applies the multiplier to each vehicle and reduces the need for the user to

modify each vehicle or tyre separately. For the baseline tests the friction factor multiplier was kept at the default value of 1. The effect of changing the multiplier and thus coefficient of friction between the tyre and road was investigated as part of the sensitivity analysis.

3.6 Vehicle models

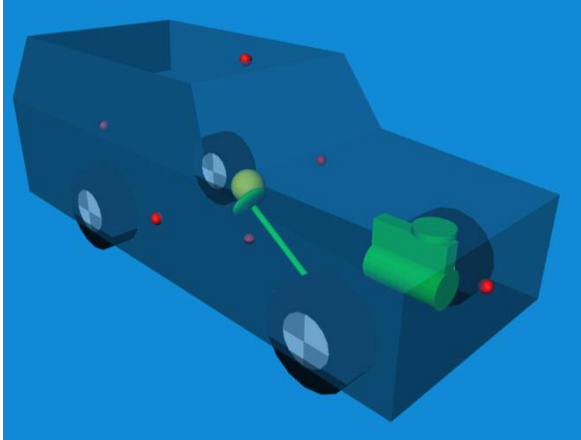
The model of TOV used in the simulations was based upon the Mitsubishi Shogun, a four-wheel-drive sports utility vehicle. The HA vehicle would be parked on the hard shoulder with the rear wheels locked and the brakes applied to lock the front wheels, as would be the case with four wheel drive, and the handbrake engaged. The front wheels were aligned along the line of the vehicle (i.e. the steering angle at the steering wheel was initially zero).

Within the HVE software it is possible to utilise pre-existing vehicle models. If a particular vehicle model is not available within the library database then it is possible to use a 'generic' vehicle model which have a simplified geometry and contain data that are representative of a similar sized vehicle. A 'generic' vehicle model with similar mass and dimensional properties to the Shogun was selected from the HVE vehicle database. Amendments were then made to the vehicle model with respect to the exterior dimensions (wheel position, mass and centre of gravity position) to ensure it replicated those of the Shogun as closely as possible. Previous research had been performed on TOV's to determine their centre of gravity position². For the Mitsubishi Shogun it was found that with an unladen vehicle (no TOs) plus the cargo (equipment in the boot) the centre of gravity was approximately 1.54 metres rearwards of the centre of the front axle, along the centre line of the vehicle and approximately 0.74 metres above the ground plane. The mass of the vehicle was initially modelled as an unladen vehicle plus the mass of the equipment in the rear of the vehicle, which was a total of approximately 2630kg.

HVE contains a large number of tyre models, the data for which have come from real-world testing of tyres. In certain cases there is not a tyre model available that matches exactly the size required for the test vehicle. In this instance the closest tyre model available was a tyre of size 265/70 R16 and this was selected for use with the Shogun. The coefficient of the slide friction was 0.75 for the tyre/road interface of the tyres for the TOV model. The wheels of the TOV are all locked due to the braking applied.

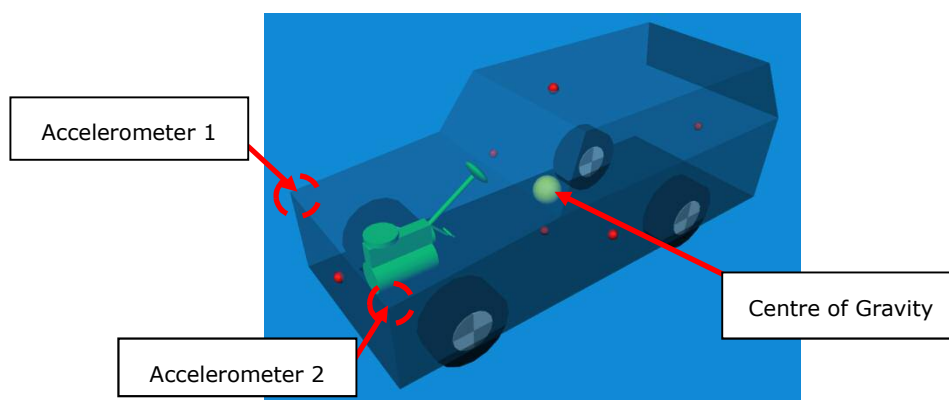
² TRL Report Number RPN055 Highways Agency Traffic Officer Vehicle Safety Assessment: Task 4 Stability and Handling of Vehicles (2008)

Table 7: Summary of the HA Traffic Officer Vehicle specification in HVE

Actual Vehicle Specification		HVE Vehicle
Ground Clearance	220mm	
Wheelbase	2780mm	
Front Overhang	750mm	
Rear Overhang	1175mm (bumper)	
	1305mm (wheel carrier)	
Wheels and Tyres	265/60 R18 (265/70 R16 used in HVE)	
Kerb Weight	2265kg	
Loaded Vehicle Weight	2630kg	

It is possible to alter and modify many components of the vehicle within the HVE software, for example engine power, gearbox ratios, steering settings, suspension settings to name just a few. However, due to a large proportion of this data being unknown, and in some part irrelevant for these simulations due to the vehicle being stationary in the hard shoulder when impacted, the predetermined 'generic' vehicle settings were accepted.

The deflection and the route of the TOV after the collision formed part of the analysis. To provide a 'map' of the deflection, it was necessary to identify the location of specific points of the vehicle and be able to track these. The X, Y and Z position of the centre of gravity and two further points are required to enable not only the location but the specific orientation of the vehicle to be known. Within HVE it is possible to 'place' virtual accelerometers at specific coordinate locations on the vehicle. Due to the vehicle being impacted at the rear and thus the rear of the vehicle sustaining deformation the accelerometers are placed on the front nearside and offside corners (Figure 29). From these accelerometers it is possible to obtain their location at a specific instant in time.

**Figure 29: Location of the accelerometers on the TOV model to determine the displacement and orientation of the vehicle post-collision**

Whilst the TOV was rather easy to determine due to their being a limited number of vehicle types and models (Land Rover Discovery, Mitsubishi Shogun and Toyota Land

Cruiser) determining an impact vehicle was much more complex. There is a wide range of vehicles that use the motorway and trunk road network and these can all differ in their speed potential, mass and the likelihood of them being involved in a collision. However, as this project was to consider the effective displacement of a TOV post-collision it was considered, from a conservation of linear momentum theory, that the largest transfer of impact energy to the stationary TOV would be from a heavy goods vehicle travelling at its maximum permitted speed. The heavy goods vehicle modelled in the HVE software was a fully loaded 44 tonne articulated lorry. Unlike the TOV there was not a specific model of lorry that was simulated and thus a 'generic' tractor unit was used and a box style trailer. The masses of the tractor and trailer unit were altered to achieve realistic masses assuming a total combined mass of approximately 44,000kg.

Table 8: Summary of the specification of the HGV tractor unit and trailer unit used in HVE to act as the impacting vehicle

Vehicle Specification		HVE Vehicle
Tractor Unit Weight	7996kg	
Tractor Unit Length	7944mm	
Tractor Unit Wheels and Tyres	295/75 R22.5	
Trailer Unit Weight	35983kg	
Trailer Length	13335mm	
Coupling	5 th Wheel	

3.7 Impact simulation configurations

It would not be possible to consider all impact configurations. However, to attempt to encompass as many variables as possible, two orientations of the TOV and seven different impact angles and overlap percentage for the impacting HGV were modelled.

The first orientation of the TOV was such that it was straight within the hard shoulder lane (i.e. parallel to the line of the road) and central (laterally) within its lane. The second orientation was such that the vehicle was angled at 10 degrees to the straight ahead direction in a fend off position (Figure 30). The wheels of the TOV were straight (in the line of the vehicle) with zero steering angle in both vehicle orientations.

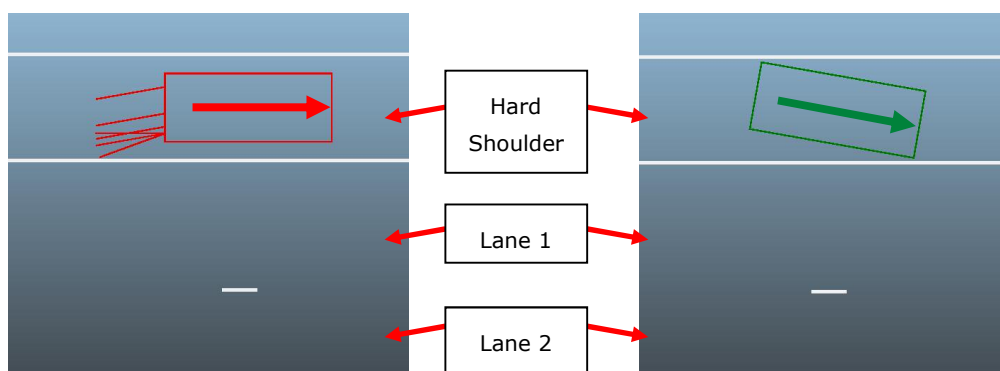
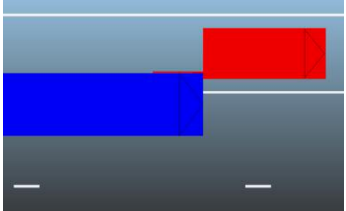
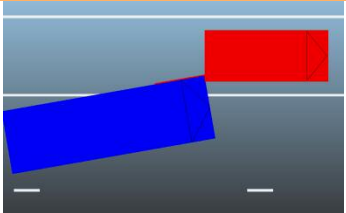
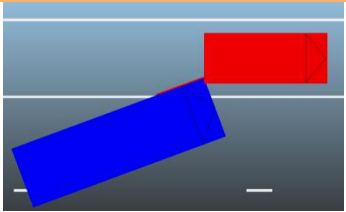
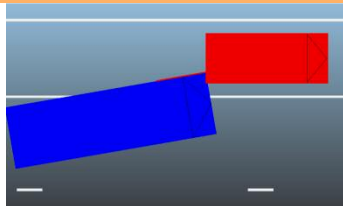
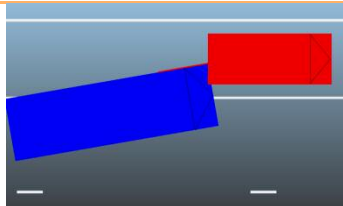
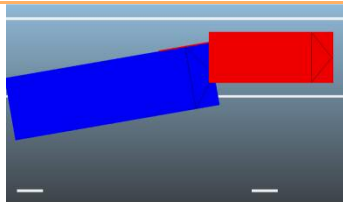
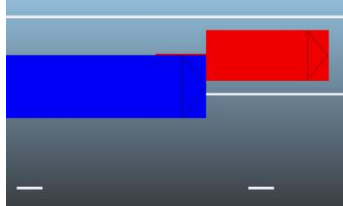


Figure 30: The orientation of the TOV in the straight and fend off position within the hard shoulder

The approach angle and overlap of the impacting vehicle are shown in Table 9 for when the TOV is straight and within the hard shoulder lane. The angles and overlap were chosen to represent a large proportion of collisions and would include simulating a vehicle that had encroached upon the hard shoulder, vehicles using a large proportion of the hard shoulder and those vehicles that had approached the hard shoulder at a larger angle such as a swerve manoeuvre. The overlap percentage is a measure of the percentage of the width of the TOV, and the approach angle is with respect to the direction of travel of the 'live' lanes.

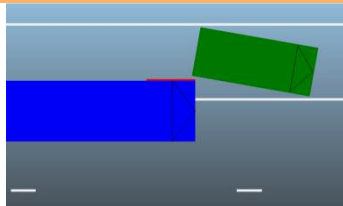
Table 9: Simulation Impact configuration for when the TOV is straight

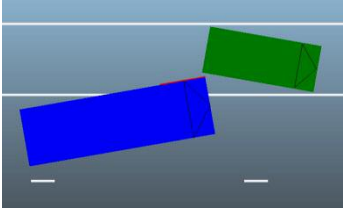
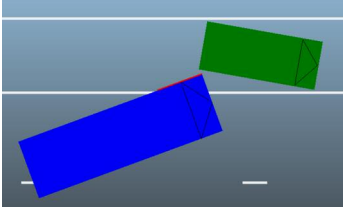
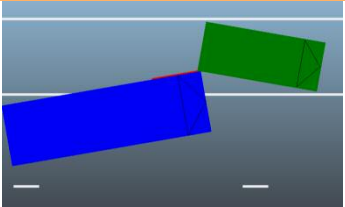
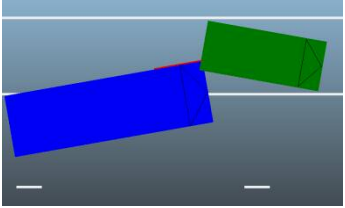
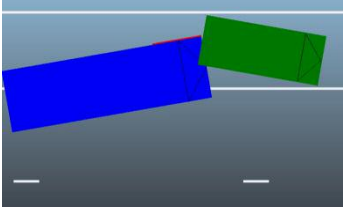
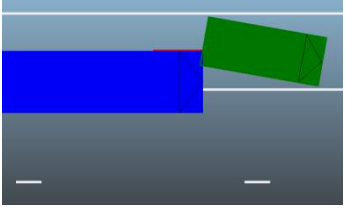
Run Number	TOV Orientation	Impacting Vehicle		Alignment Image
		Approach Angle	Overlap Percentage	
1	Straight	0 degrees	10%	
2	Straight	10 degrees	10%	
3	Straight	20 degrees	10%	

Run Number	TOV Orientation	Impacting Vehicle		Alignment Image
		Approach Angle	Overlap Percentage	
4	Straight	10 degrees	20%	
5	Straight	10 degrees	40%	
6	Straight	10 degrees	80%	
7	Straight	0 degrees	50%	

For the simulations where the TOV was angled at 10 degrees in the fend off position, the approach angle of the HGV was not changed between the two orientations. This was to enable the difference in the orientation of the TOV to be considered. Table 10 shows the impact alignment. To achieve the 10 degree fend off position the TOV was rotated about its centre of gravity, with the centre of gravity of the vehicle remaining central (laterally) within the hard shoulder lane.

Table 10: Simulation impact configuration for when the TOV is in a 10 degree fend off position

Run Number	TOV Orientation	Impacting Vehicle		Alignment Image
		Approach Angle	Overlap Percentage	
8	Fend off	0 degrees	10%	

Run Number	TOV Orientation	Impacting Vehicle		Alignment Image
		Approach Angle	Overlap Percentage	
9	Fend off	10 degrees	10%	
10	Fend off	20 degrees	10%	
11	Fend off	10 degrees	20%	
12	Fend off	10 degrees	40%	
13	Fend off	10 degrees	80%	
14	Fend off	0 degrees	50%	

For the baseline tests the HGV was modelled to be travelling at 60mph (96km/h) at the point of impact. This speed is 4mph above the maximum permitted speed for vehicles of this type, however, it was increased to this level to provide a worst case scenario and to take account of foreign vehicles that may not have the restrictor fitted and thus have the potential to travel above 56mph. No steering input or braking of the HGV was included. To achieve the approach angles for each run the HGV was aligned on a straight route to

collision, this removed the need for a steering input and therefore removed any variability which this could cause.

3.8 Sensitivity analysis

As mentioned earlier in the report there are many variables that can contribute to the outcome of the collision. The HVE software enables many of these variables to be modified and the sensitivity of their effect considered. In order to evaluate the sensitivity of the collision simulation to changes in certain variables, three of the baseline runs for each orientation of the TOV were used. The variables considered for the sensitivity analysis were:

- Friction coefficient + 10%
- Friction coefficient – 10%
- Rear offside TOV wheel and tyre and front nearside wheel and tyre of the tractor unit damaged at impact
- Rear offside TOV wheel and tyre damaged at impact
- TOV mass reduced to 2265kg (kerb weight of Shogun)
- Lorry mass reduced to a combined total of 15 tonnes
- Rear stiffness of the TOV + 20%
- Rear stiffness of the TOV – 20%
- Yaw inertia of the TOV + 20%
- Yaw inertia of the TOV – 20%

In the simulation where the wheels of the vehicles were damaged at impact, the software simulated the wheel to lock and the tyre to effectively deflate. This represents impact configurations where the deformation is such that it damages the wheel and tyre of the vehicle.

3.9 Simulation output

The main aim of this project was to investigate the displacement of the TOV following the collision with the lorry. Whilst HVE can provide data on a wide aspect of variables the output for these simulations consist of the X and Y position data for the centre of gravity and the two accelerometer positions (front nearside and offside corners) of the TOV. As the analysis only considers the distance forwards and laterally that the vehicle is displaced, the change in height (Z axis direction) of the vehicle was not required. The simulation was arranged such that when the TOV was stationary on the hard shoulder (i.e. pre impact position) the centre of gravity of the vehicle was at the origin, i.e. 0,0,0.

Once the simulations had been performed and the positions vs. time data downloaded, the data for each point was imported back into the Rhinoceros 3D software. This program enabled the path of each simulation run to be imported as a separate layer and then overlaid so they could be compared. The sign convention that exists within the HVE software and that of the Rhinoceros 3D differ, therefore the sign convention for the Y direction data from the HVE output needed to be reversed before being imported.

3.10 Simulation results

Each simulation was run until the TOV had come to rest following the impact with the lorry. It was found that during Run 13 when the TOV was in the fender off position that the TOV became positioned in front of the lorry and was therefore pushed along the road surface and did not come to rest. One reason for this occurring was that the brakes of the lorry were not applied during the simulation and therefore continued to 'drive' forwards following the initial collision.

An example of the output from the simulation is shown in Figure 31. This shows Run 3, where the TOV was positioned straight in the hard shoulder lane, the collision overlap was 10% and the lorry approach angle was 20 degrees. The centre of gravity point of the TOV in Run 3 was displaced approximately 58 metres in the X direction (longitudinal movement along the road) and 28 metres in the Y direction (lateral movement, perpendicular to the road). The total (vector) distance travelled by the centre of gravity of the TOV in Run 3 was approximately 64 metres.

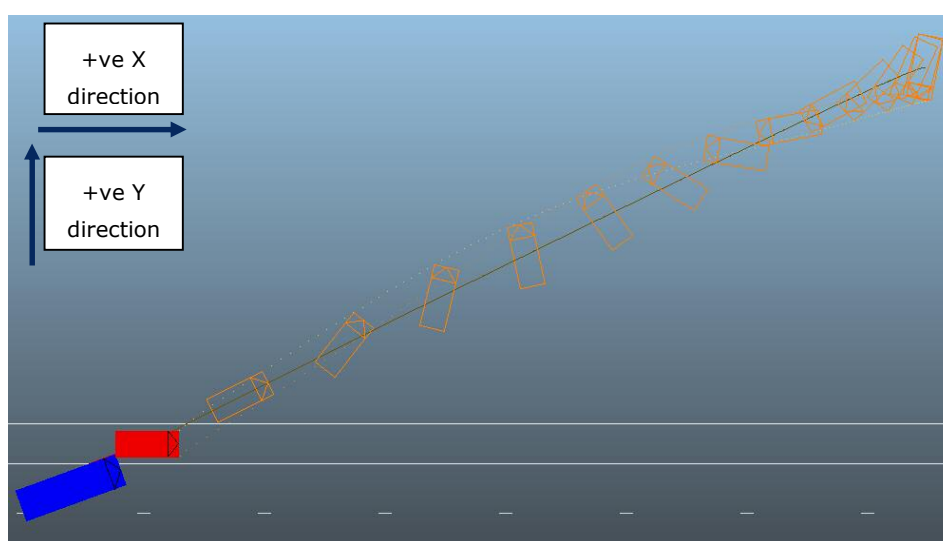


Figure 31: The displacement and track of the TOV following the impact from the lorry when the TOV was straight and the lorry was overlapping by 10% and approaching at an angle of 20 degrees (Run 3)

Figure 32 shows the position of the vehicle at various stages of the Run 3 simulation, taken from the HVE software. These can be compared with the vehicle position analysis shown above.

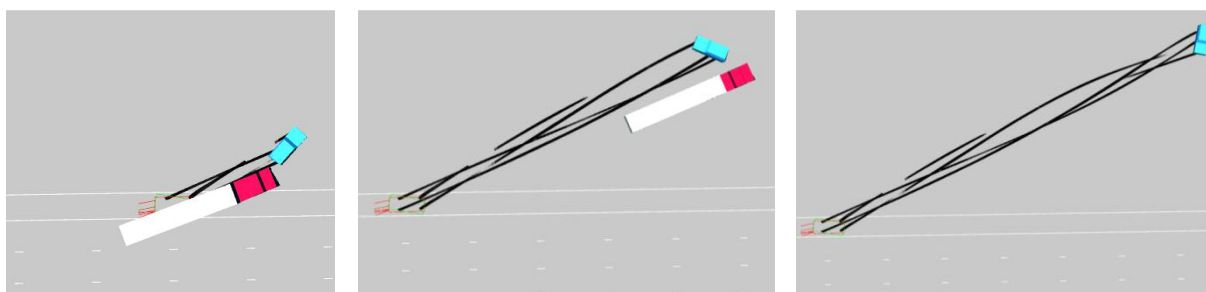


Figure 32: Images of Run 3 from the HVE software, the TOV was stationary and straight in the hard shoulder pre impact

The point of impact on the TOV with respect to its centre of gravity position determines how the vehicle will rotate or displace after the collision. For example if the point of collision is such that the extents of the front of the lorry (thus the direction of force) are not aligned with the centre of gravity of the TOV then it will cause the vehicle to rotate (Figure 33).

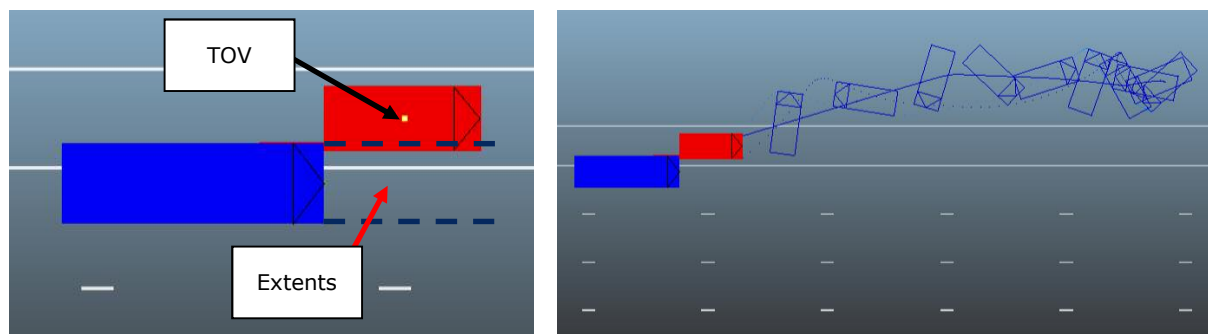


Figure 33: Run 1 simulation configuration showing the alignment of the extents of the lorry and the TOV centre of gravity position

If, however the centre of gravity of the TOV lies within the width of the lorry at impact then the TOV will effectively be 'pushed' in the direction of the lorry (Figure 34). The reason for this is due to how the principle direction of force acts about the centre of gravity of the TOV. When the percentage overlap is low (i.e. Run 1), the exchange of momentum is lower and a larger proportion of the energy from the collision that is transferred to the TOV is then dissipated in its rotation and thus the displacement of the vehicle is lower. Vice versa, when the interaction overlap is larger (i.e. Run 6) a lower proportion of the energy from the collision will be dissipated through rotation, thus the displacement of the TOV will be larger.

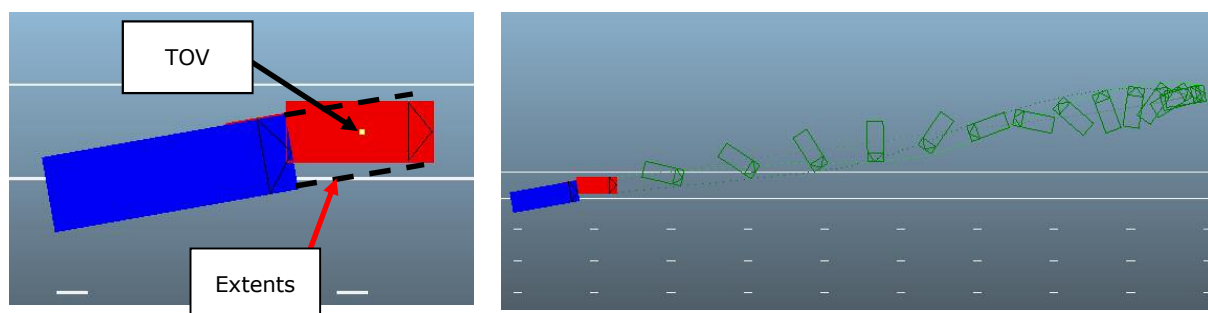


Figure 34: Run 6 simulation configuration showing the alignment of the extents of the lorry and the TOV centre of gravity position

The results of each of the runs are shown in Appendix A in two dimensional plan form, showing the track and rotation of the TOV and how it is affected by the changing approach angle and overlap. Table 11 shows a summary of the displacement of the centre of gravity of the TOV when it was positioned straight in the hard shoulder for each of the simulation runs.

Table 11: The displacement of the centre of gravity of the TOV when positioned straight in the hard shoulder

Run Number	Displacement		
	X direction	Y direction	Travelled distance (Vector)
1	34m	5m	35m
2	43m	12m	45m
3	58m	28m	64m
4	59m	20m	62m
5	64m	17m	66m
6	69m	10m	70m
7	63m	8m	64m

With regard to the simulations when the TOV was parked on the hard shoulder in a fend off position the displacement of the vehicle was found to alter. This was predominantly due to the effect of the point of impact changing. For example Run 1 (straight) and Run 8 (fend off) consisted of the same approach angle and overlap, however, due to the orientation of the TOV the point of impact on the vehicle changed and thus it changed how the TOV was displaced (Figure 35).

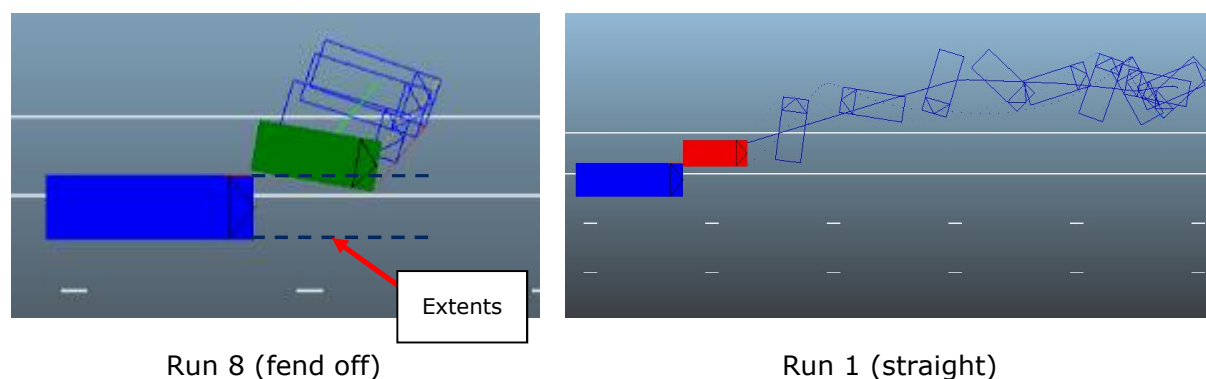


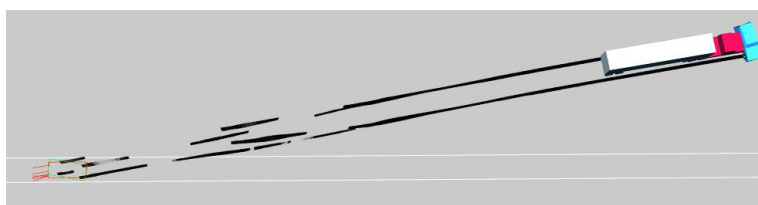
Figure 35: The displacement route of the TOV following the collision with the lorry in Run 8 (fend off) and Run 1 (straight) showing the difference due to the differing impact points

In Run 8, it is effectively a glancing contact between the lorry and the TOV, hence the reason for the vehicle appearing to travel sideways post impact. The two dimensional plan of the track and rotation of the fend off TOV post impact are shown in Appendix B. Table 12 shows a summary of the displacement of the centre of gravity of the TOV when it was parked in a fend off position in the hard shoulder for each of the simulation runs.

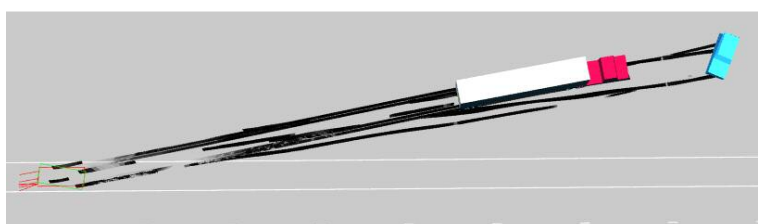
Table 12: The displacement of the centre of gravity of the TOV when positioned in a fend off position in the hard shoulder (* indicates the simulation where the TOV did not come to a rest due to the unbraked lorry continually pushing it)

Run Number	Displacement		
	X direction	Y direction	Travelled distance (Vector)
8	2m	3m	4m
9	16m	16m	23m
10	65m	46m	80m
11	28m	24m	37m
12	67m	19m	70m
13*	N/A	N/A	N/A
13A	69m	12m	70m
14	61m	9m	62m

Run 13 was the impact configuration where it was found that the unbraked impacting lorry continued to push the TOV after the collision. Whilst this is possible, it is more likely that the driver of the impacting vehicle would react to the collision and apply the brakes or at minimum remove any application to the throttle. Consequently, Run 13 was re-run with the brakes of the tractor unit being applied immediately after the collision to remove the secondary contact and the pushing of the TOV by the lorry. This simulation has been termed Run 13A (Figure 36).



Run 13 (Lorry unbraked)



Run 13A (Lorry braked)

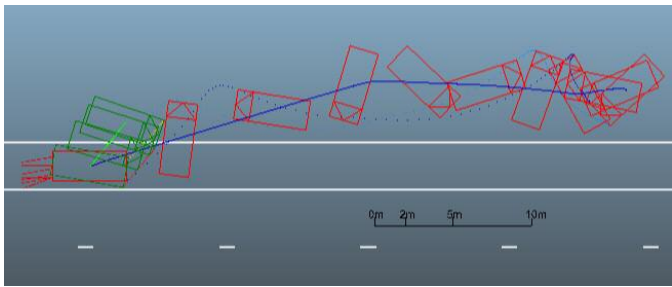
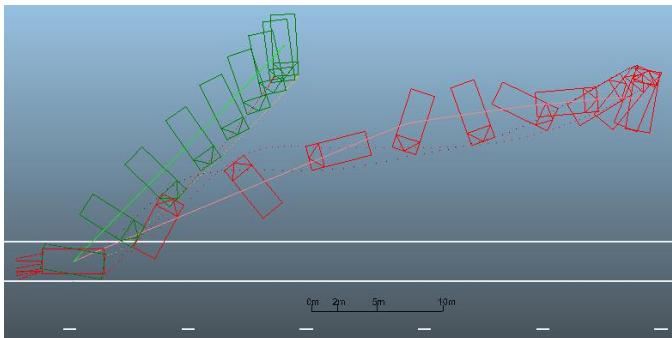
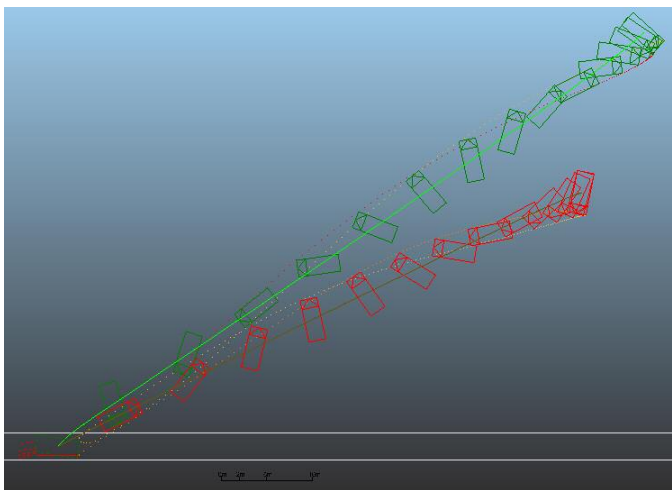
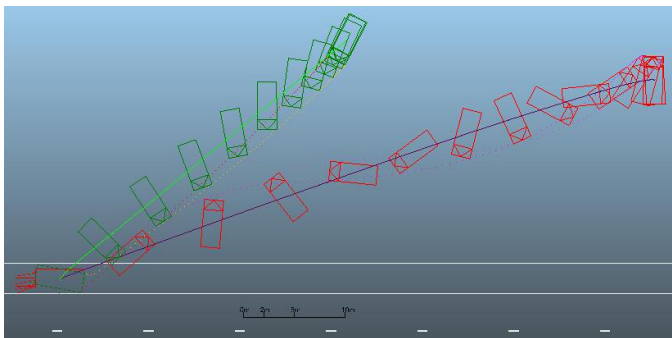
Figure 36: Comparison of Run 13 where the lorry is unbraked and braked

3.11 The effect of the orientation of the TOV

It is known that TOVs can be parked on the hard shoulder in either the straight or fend off position. Therefore, this project does not aim to consider which of the two orientations the Traffic Officers should use; rather it is an investigation into the possible

displacement of the TOV and how a different impact overlap or approach angle can affect this. However, for analysis purposes, Table 13 shows the comparison between a straight and fend off orientation for each of the approach angles and overlaps. In the table the red vehicle represents the TOV that was aligned straight in the hard shoulder and the green outline represents the vehicle parked in the fend off position.

Table 13: A comparison of the effect of the two orientations of the stationary TOV on its trajectory when impacted by the lorry in the HVE simulation.

Run Number	Comparison of Trajectories
Run 1 and Run 8	
Run 2 and Run 9	
Run 3 and Run 10	
Run 4 and Run 11	


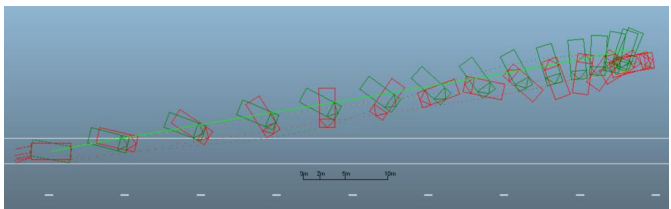

Run Number	Comparison of Trajectories
Run 5 and Run 12	
Run 6 and Run 13A	
Run 7 and Run 14	

Table 13 demonstrates the effect on the TOV trajectory due to the two different orientations of the vehicle when stationary. It is seen from the above that the collision configurations where the overlap is greater and thus the extent of the impacting vehicle encompasses more of the TOV and its centre of gravity, the more similar the post-collision trajectory of the vehicle. When the alignment causes a glancing style collision or where it causes the TOV to undertake significant rotation about its centre of gravity, the trajectories are noted to differ. In certain configurations the straight TOV orientation rotated in an opposite direction to that of the fend off orientation and this is mainly due to the point of impact on the vehicle and the influence that has upon how the energy of the collision acts around the centre of mass of the vehicle. However, due to the TOV currently being permitted to park in either of these configurations on the hard shoulder, all of the simulations and the consequent trajectories of the TOV should be considered.

3.12 Sensitivity analysis

As mentioned earlier in the report, there are many factors that can affect the outcome of a collision and thus can potentially affect the displacement and trajectory of the TOV. The HVE software enables the effect of these variables and the sensitivity of the collision configuration to be investigated. See section 3.8 for a discussion of which variables would be considered in the sensitivity analysis. However it was deemed unnecessary to perform the sensitivity analysis on each of the baseline configurations. Instead, three of the impact configurations from each TOV orientation were selected to be evaluated. Utilising three baseline tests from each orientation would enable any trends to be identified. The selected Runs were 1, 3 and 6 where the TOV was stationary in a straight orientation within the hard shoulder and Runs 8, 10 and 13A where it was stationary in a fend off position. Run 13A included braking of the impacting lorry immediately post-collision to ensure that a secondary collision between the vehicles did not occur.

The reason for selecting Runs 1 and 6 was that they had the lowest measured displacement post-collision. In addition, with Run 1 the point of impact, overlap alignment and angle of approach resulted in a large rotational moment, which caused the vehicle to rotate about its centre of gravity most significantly of all the impact configurations considered.

Runs 3 and 10 were selected due to having the largest approach angle. In Run 10 the approach angle and TOV being in the fend off position resulted in the largest displacement of the TOV. Run 6 and 13A were selected to investigate the impact configuration with the largest vehicle overlap and Run 6 was found to have the largest displacement when the TOV was stationary in the straight ahead orientation.

Table 14 below shows a summary of the sensitivity analysis and the effect upon the displacement of the centre of the gravity of the TOV following the collision when the TOV is initially stationary in a straight ahead orientation. From the analysis it was noted that the variables that had the greatest effect upon the displacement were the friction coefficient between the tyres of the vehicle, the road surface and the mass of the impacting vehicle.

Table 14: Summary of the displacement of the centre of gravity (CofG) of the TOV in the sensitivity analysis when the TOV was stationary and straight in the hard shoulder

Sensitivity Analysis (TOV Straight)		Run 1			Run 3			Run 6		
		X	Y	Vector	X	Y	Vector	X	Y	Vector
Baseline simulation	CofG displacement	34m	5m	35m	58m	28m	64m	69m	10m	70m
Friction Coefficient +10%	CofG displacement	27m	3m	27m	48m	23m	53m	62m	9m	63m
	Difference from Baseline	-7m	-2m	-8m	-10m	-5m	-11m	-7m	-1m	-7m
Friction Coefficient -10%	CofG displacement	40m	10m	41m	64m	31m	71m	79m	12m	80m
	Difference from Baseline	+6m	+5m	+6m	+6m	+3m	+7m	+10m	+2m	+10m
O/S/R TOV and F/N/S lorry wheel and tyre damaged at impact	CofG displacement	31m	9m	32m	51m	28m	58m	69m	10m	70m
	Difference from Baseline	-3m	+4	-3m	-7m	0m	-6m	0m	0m	0m
O/S/R TOV wheel and tyre damaged at impact	CofG displacement	31m	9m	32m	51m	28m	58m	69m	10m	70m
	Difference from Baseline	-3m	+4	-3m	-7m	0m	-6m	0m	0m	0m
TOV Mass 2265kg	CofG displacement	37m	9m	38m	58m	28m	64m	73m	14m	74m
	Difference from Baseline	+3m	+4m	+3m	0m	0m	0m	+4m	+4m	+4m
Lorry Mass 15t	CofG displacement	23m	3m	24m	45m	22m	50m	61m	10m	62m
	Difference from Baseline	-11m	-2m	-11m	-13m	-6m	-14m	-8m	0m	-8m
Rear Stiffness of TOV +20%	CofG displacement	33m	5m	34m	58m	28m	64m	69m	10m	70m
	Difference from Baseline	-1m	0m	-1m	0m	0m	0m	0m	0m	0m
Rear Stiffness of TOV -20%	CofG displacement	35m	5m	35m	58m	28m	65m	69m	10m	70m
	Difference from Baseline	+1m	0m	0m	0m	0m	+1m	0m	0m	0m
Yaw inertia of TOV +20%	CofG displacement	33m	3m	33m	59m	28m	65m	70m	10m	71m
	Difference from Baseline	-1m	-2m	-2m	+1m	0m	+1m	+1m	0m	+1m
Yaw inertia of TOV -20%	CofG displacement	29m	2m	29m	58m	28m	64m	69m	10m	70m
	Difference from Baseline	-5m	-3m	-6m	0m	0m	0m	0m	0m	0m

The effect of the friction was such that, if the coefficient of friction between the tyres and road surface was increased (i.e. higher level of 'grip') then the TOV would not be displaced as far due to the increased resistance to the locked tyres travelling over the surface. With the coefficient of friction between the tyres and road surface reduced (i.e. lower level of 'grip') then the resistance to the tyres sliding across the road surface is lower and the TOV travels further post-collision (Figure 37). As mentioned earlier in the report a road surface does not have a particular coefficient of friction, as it is a function of the interaction between the vehicle tyres and the road surface. In addition the environmental conditions at the time of the collision are also likely to affect the coefficient of friction between the vehicle tyres and the road surface. If the road surface is dry, wet or icy it will affect the coefficient and thus potentially affect the displacement of the vehicle.



Figure 37: The track and displacement of the TOV in the HVE Simulation in Run 1 showing the effect of a change in coefficient of friction between the tyres and the road surface

The HVE sensitivity analysis simulations showed that when the TOV was stationary on the hard shoulder, reducing the mass of the impacting vehicle resulted in the overall displacement being reduced. This is due to the energy involved in the collision. For example for the baseline tests, the kinetic energy of the lorry immediately prior to the point of collision (approximately 44,000kg and 96km/h) was approximately 15,644kJ. Comparing this with the kinetic energy of the lorry when its mass has been reduced by approximately two thirds to 15,000kg (at 96km/h) the energy of the collision reduces to approximately 5,333kJ. Therefore due to the law of conservation of energy (energy cannot be created nor destroyed, only transferred one form to another), the higher mass lorry has a greater impact energy to impart upon and transfer to the TOV during the collision and thus the TOV will travel further post-collision (Figure 38).

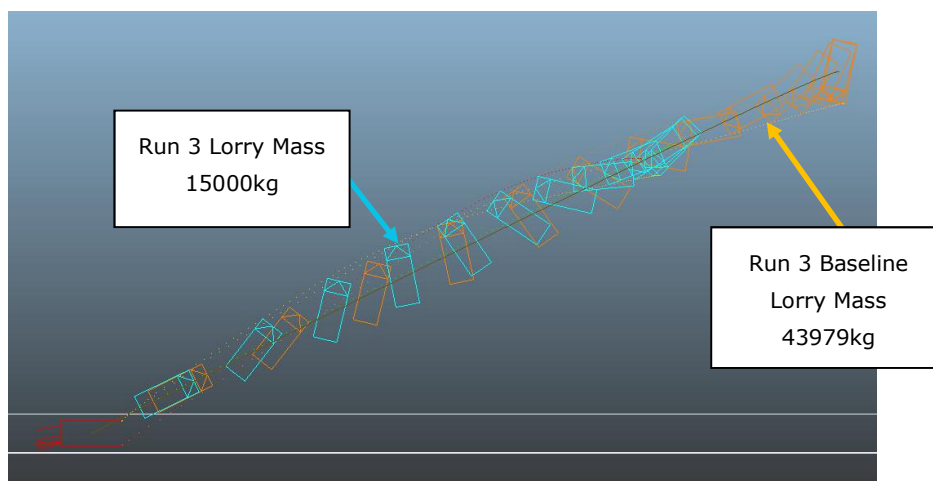


Figure 38: The track and displacement of the TOV in the HVE Simulation in Run 3 showing the effect of a change in mass of the impacting vehicle

Table 15 below shows a summary of the sensitivity analysis and the effect upon the displacement of the centre of the gravity of the TOV following the collision, when the HA vehicle is initially stationary in a fend off orientation. From the analysis it was noted that the variables had little effect on the displacement output of the TOV in the Run 8 impact configuration. This was predominantly due the impact being a glancing impact with little interaction between the two vehicles, and thus little opportunity for the variables to affect the output.

Table 15: Summary of the displacement of the centre of gravity (CofG) of the TOV in the sensitivity analysis when the TOV was stationary and in the fend off position in the hard shoulder

Sensitivity Analysis (TOV fend off)		Run 8			Run 10			Run 13A		
		X	Y	Vector	X	Y	Vector	X	Y	Vector
Baseline simulation	CofG displacement	2m	3m	4m	65m	46m	80m	69m	12m	70m
Friction Coefficient +10%	CofG displacement	2m	3m	4m	58m	41m	71m	60m	12m	61m
	Difference from Baseline	0m	0m	0m	-7m	-5m	-9m	-9m	0m	-9m
Friction Coefficient -10%	CofG displacement	3m	3m	4m	71m	50m	87m	71m	12m	72m
	Difference from Baseline	+1m	0m	0m	+6m	+4m	+7m	+3m	0m	+2m
O/S/R TOV and F/N/S lorry wheel and tyre damaged at impact	CofG displacement	2m	3m	4m	64m	44m	78m	68m	12m	69m
	Difference from Baseline	0m	0m	0m	-1m	-2m	-2m	-1m	0m	-1m
O/S/R TOV wheel and tyre damaged at impact	CofG displacement	2m	3m	4m	63m	43m	76m	62m	12m	63m
	Difference from Baseline	0m	0m	0m	-2m	-3m	-4m	-7m	0m	-7m
TOV Mass 2265kg	CofG displacement	3m	3m	4m	70m	45m	83m	65m	12m	66m
	Difference from Baseline	+1m	0m	0m	+5m	-1m	+3m	-4m	0m	-4m
Lorry Mass 15t	CofG displacement	2m	2m	3m	38m	31m	49m	54m	9m	55m
	Difference from Baseline	0m	-1m	-1m	-27m	-15m	-31m	-15m	-3m	-15m
Rear Stiffness of TOV +20%	CofG displacement	3m	3m	4m	70m	46m	84m	70m	13m	71m
	Difference from Baseline	+1m	0m	0m	+5m	0m	+4m	+1m	+1m	+1m
Rear Stiffness of TOV -20%	CofG displacement	2m	2m	3m	55m	41m	69m	68m	12m	69m
	Difference from Baseline	0m	-1m	-1m	-10m	-5m	-11m	-1m	0m	-1m
Yaw inertia of TOV +20%	CofG displacement	2m	3m	4m	59m	44m	74m	63m	13m	64m
	Difference from Baseline	0m	0m	0m	-6m	-2m	-6m	-6m	+1m	-6m
Yaw inertia of TOV -20%	CofG displacement	3m	3m	4m	Roll Over	Roll Over	Roll Over	64m	12m	65m
	Difference from Baseline	+1m	0m	0m				-5m	0m	-5m

The displacement of the TOV in the fend off position was affected in a similar manner to that when the TOV was aligned straight within its lane, in that as the friction coefficient between the tyres and road surface was increased, the displacement reduced, and vice versa. The greatest influence on the displacement was noted to be the mass of the impacting vehicle. This, as explained for the straight alignment of the TOV, was due to the reduction in the energy of the collision.

For the Run 10 impact configuration it was found during the simulation that if the yaw moment of inertia (which is a measure of the vehicle's resistance to rotation – in this instance, turning) about the vertical (Z) axis was lowered, the vehicle rolled. For a given amount of angular momentum (i.e. due to the alignment of and collision with the impacting lorry) a reduction in the moment of inertia (yaw inertia) will result in the increase of the angular velocity of the vehicle and thus the speed at which the vehicle spins. In this instance, the vehicle was noted to spin and the unsettling of the vehicle caused the offside wheels to trip and the vehicle to roll. Further work would be needed to consider if this effect is likely to occur with a TOV, as the inclusion of embankments and road side restraints in the 'real world' that would potentially limit this would cause the vehicle to travel along the hard shoulder or be deflected into the live lanes.

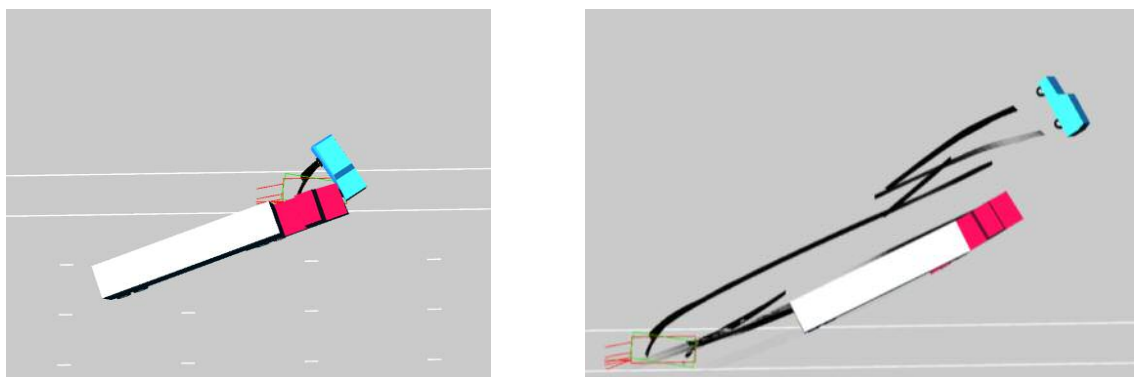


Figure 39: Run 10 with the yaw inertia reduced by 10% showing the vehicle rolling in the HVE simulations

3.13 Zone of displacement

The overall aim of this simulation assessment was to consider the possible deflection of the stationary TOV following a collision with a lorry travelling at 60mph. As has been shown through the sensitivity analysis, it is possible that variation in factors associated with the collision (the coefficient of friction, the mass of the impacting vehicle etc.) can all affect the actual outcome of the collision. It is therefore possible for the maximum displacement of the TOV to be greater than that shown in the baseline simulation results. It would not be possible to consider all impact configurations or variables and thus a safety margin should be considered when making any assessment of the displacement and potential area that the vehicle could travel into.

Figure 40 below shows the seven baseline simulation runs performed when the TOV was initially stationary and aligned straight in the hard shoulder. In the HVE simulations in the X direction (i.e. along the carriageway) the maximum displacement of the TOV is approximately 70 metres measured from the front offside corner of the HA vehicle in its pre-impact position to the furthest extent of the vehicle in Run 6. The largest displacement in the HVE simulation of the TOV in the Y direction is approximately 32

metres measured from the front offside corner of the HA vehicle in its pre-impact position to the furthest extent of the vehicle in Run 3.

Figure 41 shows the eight baseline simulation runs performed when the TOV was initially stationary and in the fend off position. The additional run (Run 13A) is included and shows the displacement of the TOV when the lorry is braked and does not have a secondary impact as is the case in Run 13. In the HVE simulation the maximum deflection in the X direction when the TOV is initially in the fend off position was approximately 70 metres (not including the Run 13 where the TOV was 'pushed' by the unbraked lorry) measured from the front offside corner of the HA vehicle in its pre-impact position to the furthest extent of the vehicle in Run 13A. The largest displacement based upon the results from the HVE simulation of the TOV in the Y direction was approximately 50 metres measured from the front offside corner of the TOV in its pre-impact position to the furthest extent of the vehicle in Run 10.

Due to the point of impact on the TOV when it is in the fend off position and the approach angle of the lorry, it is possible in some of the configurations that the lorry impacts the side of the TOV. This can cause the vehicle to be displaced sideways. It is noted that this does not occur when the TOV is straight within the hard shoulder. Consequently, if the TOV is to be positioned in a fend off orientation the TOs should be aware that standing by the side of the vehicle may cause them to be struck by the TOV if it is impacted.

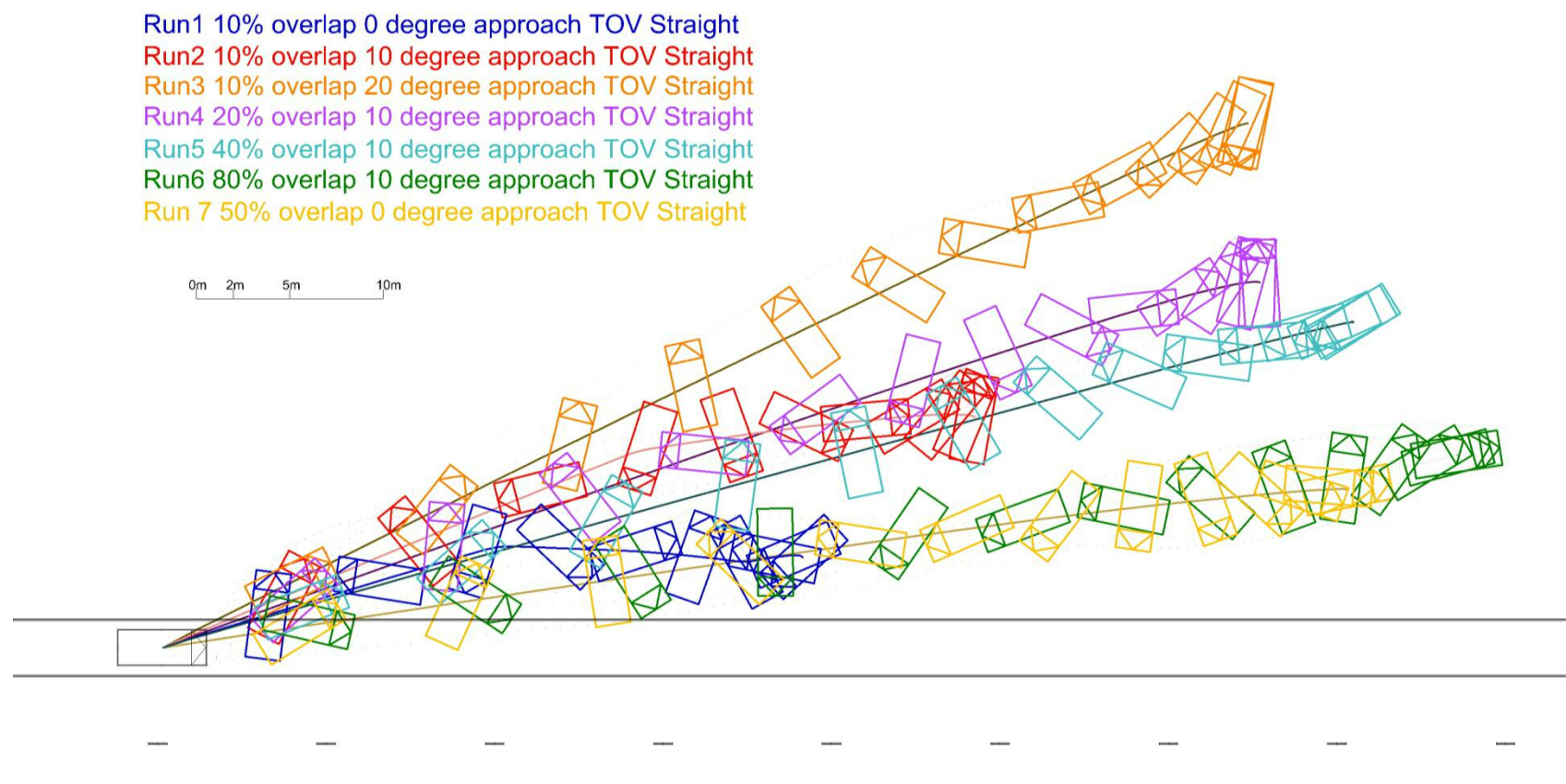


Figure 40: Overlay of the displacements of the TOV in the HVE simulations when the TOV is initially stationary and straight within the hard shoulder

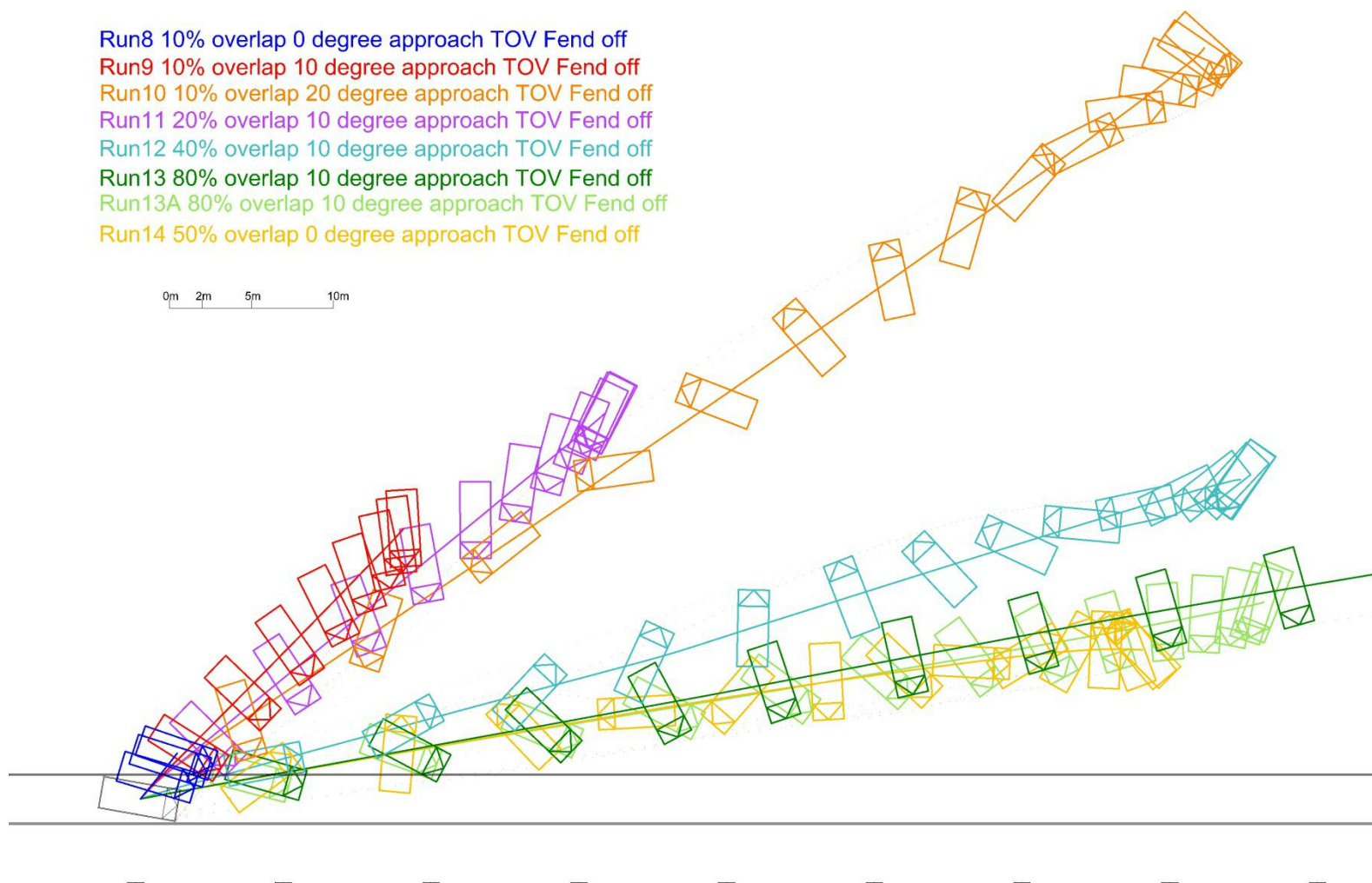


Figure 41: Overlay of the displacements of the TOV in the HVE simulations when the TOV is initially stationary and in a fend off position within the hard shoulder

Due to the sensitivity analysis finding that changes to variables such as the coefficient of friction can affect the overall displacement of the vehicle, it is important to add a margin onto the maximum displacement in the baseline results to account for this. Whilst the absolute maximum value that the TOV could be displaced is unknown (due to the possibility that the vehicle could be left without the four wheel drive engaged or the handbrake applied for example), assuming these precautions are taken it is prudent to consider a safety margin of the order of 50%. Therefore, this would increase the zone of possible displacement with regard to the straight TOV simulations to 105 metres in the X direction and 48 metres in the Y direction. For the vehicle being stationary in the fend off position the zone of displacement would increase to 105 metres in the X direction and 75 metres in the Y direction (both measured from the front nearside of the vehicle). The figure calculated for the X direction possible displacement zone is similar to that calculated by the Dutch Forensic Institute (The Netherlands Traffic Management Centre, 2005). The calculations do not take into consideration a vehicle being deflected from an embankment or road side restraint into the live lanes.

As mentioned previously, in the simulations with the TOV in the fend off position if the collision configuration is such that the impact is glancing (i.e. Run 8) then the TOV is displaced in a sideways direction. Consequently it is not recommended that any person stand forwards of the rear of the vehicle, irrespective of how the TOV is orientated. Therefore, any zones believed to be unsafe for a person to stand within should also include the length of the vehicle. This increases the X direction of the zone to approximately 110 metres (Figure 42 and Figure 43).

The environment model created for this initial phase of simulation was a simple flat area which demonstrated the displacement of the HA vehicle should it have an unobstructed post-collision path. The environment at the side of the motorway or trunk road can differ depending upon its location and can be a rigid concrete barrier or a grass angled embankment, for example. Further consideration would be needed to quantify the exact effects of the different environments. However, interaction with barriers and/or grass embankments can have the net result of helping to dissipate the energy of the collision and thus reduce the overall displacement of the vehicle. Consideration should also be given with regard to whether an embankment or road side restraint can cause the vehicle to be deflected towards the live lanes. Whilst this initial study has positioned the vehicle within the hard shoulder, due to there being no interaction with barriers, or the embankments being simulated, it is possible to place the TOV in any lane and apply the zones of displacement to show the areas that are not believed safe for a TO or member of the public to stand.

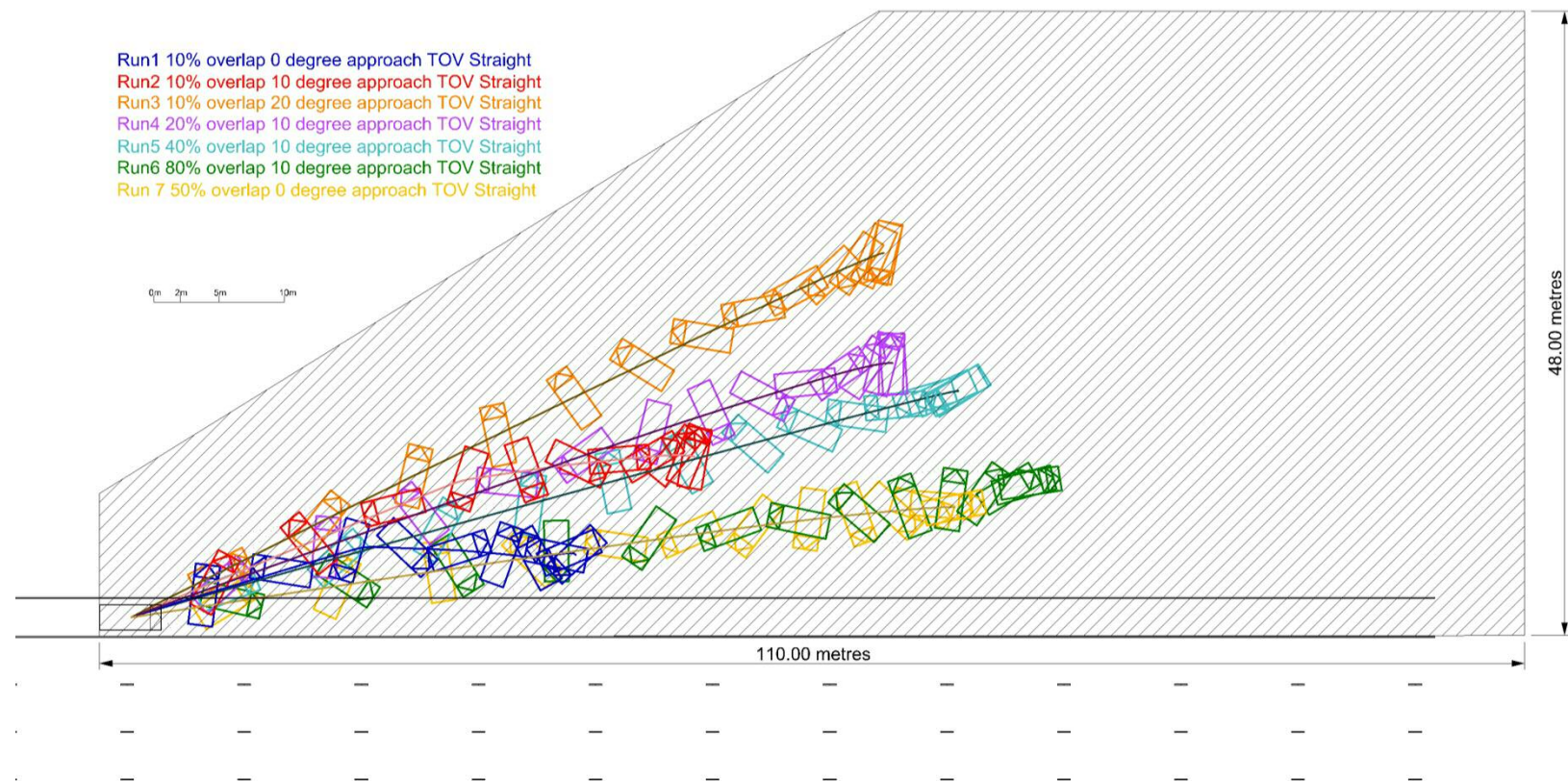


Figure 42: The area including a margin of safety believed from the simulation analysis to be unsafe for a person to stand within when the TOV is stationary in a straight orientation.

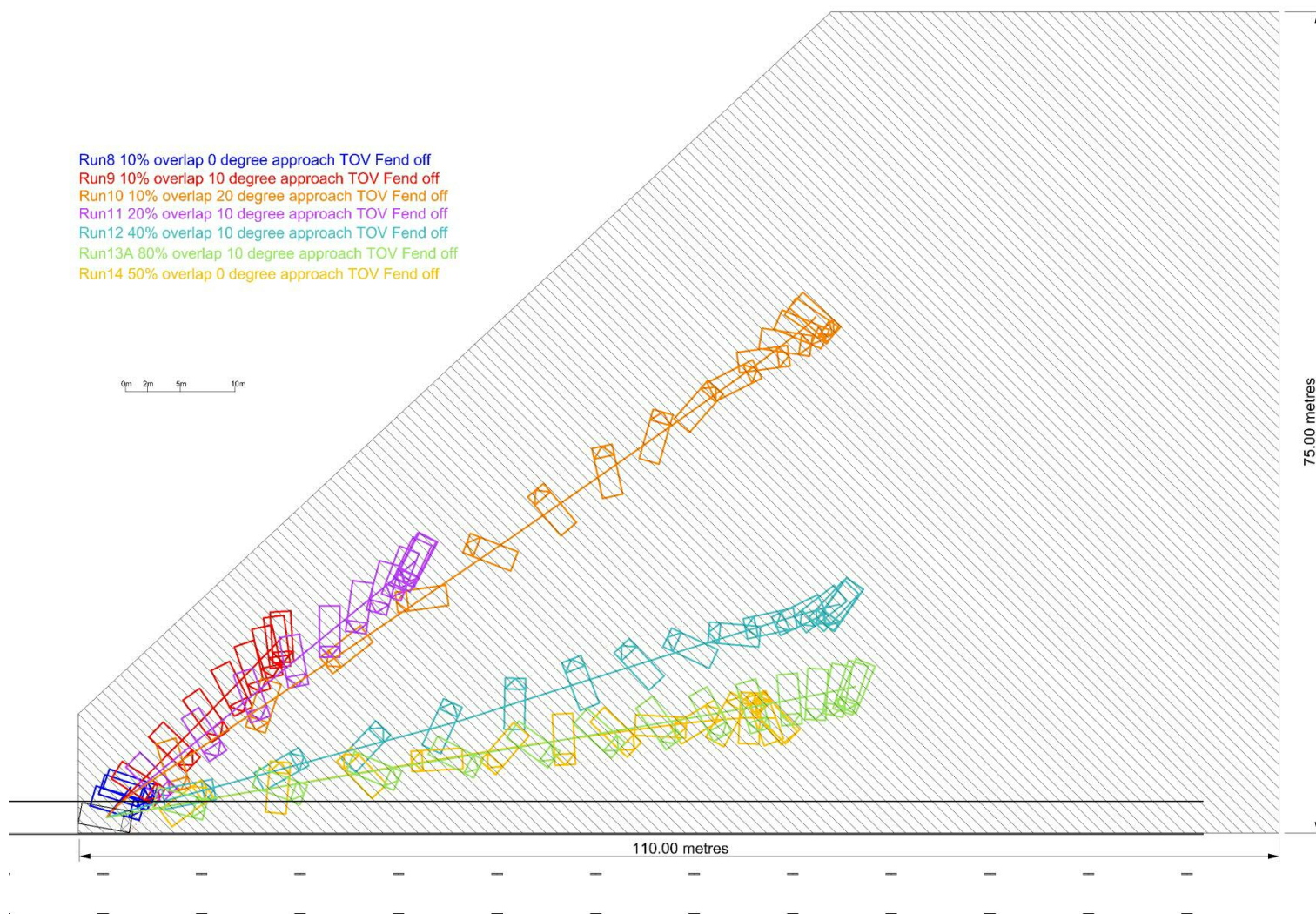


Figure 43: The area including a margin of safety believed from the simulation analysis to be unsafe for a person to stand within when the TOV is stationary in the fend off position.

3.14 The effect of steered wheels' orientation

It is known that when parked it is possible for the steered wheels of the TOV to be at angles other than straight ahead (i.e. steering wheel angle not zero). As part of the HVE modelling, Run 3 (where the TOV was straight in the hard shoulder) was re-run with both a positive and negative steering angle on the front axle of the TOV. The angle of the front wheels was changed so that it represented a wheel angle of approximately 16 degrees which, in the 3D model, represented approximately 280 degrees of steering wheel angle. The images below show the trajectory and travel path of the TOV with and without the steering angles applied.

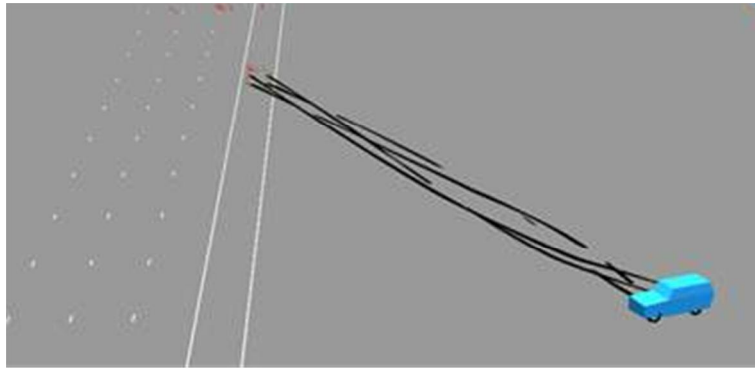


Figure 44: Steered wheels angled towards the live lanes (offside of the vehicle)

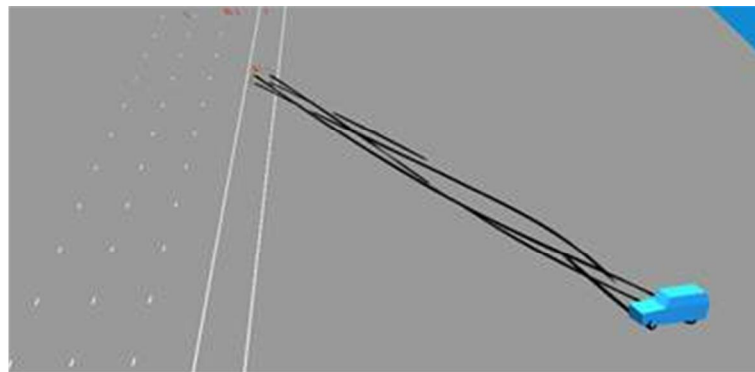


Figure 45: Steered wheels angled towards the nearside of the vehicle

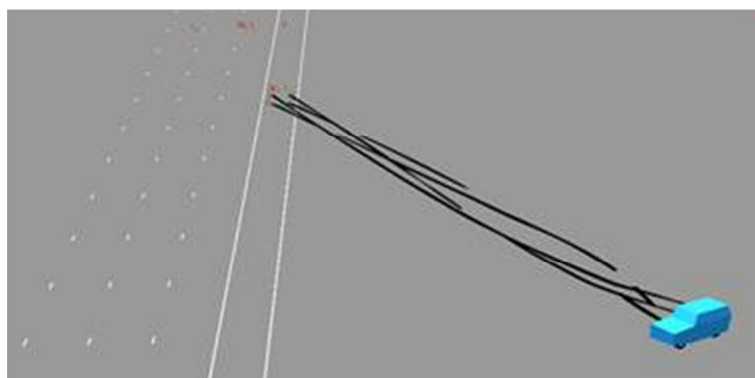


Figure 46: Zero steering applied (i.e. steered wheels in-line with the vehicle)

It was found that, at the simulated collision speed of approximately 60mph and where it was impacted with a model of a 44t lorry, the effect of the steered wheels made little difference to the overall travel distance of the vehicle and was within the range of the values previously shown in the sensitivity analysis.

3.15 Conclusions and recommendations

The aim of this workstream was to investigate, through computer simulation techniques, the possible displacement of a TOV stationary on the hard shoulder when impacted by a lorry travelling at 60mph. Two possible orientations of the TOV were considered: the first with the TOV straight and central within the hard shoulder and the second with the TOV was in a 10 degree fend off position. The environment model was created in 3D modelling software (Rhinoceros 3D) and the simulations were performed using the EDC HVE collision software.

This initial phase of simulation was performed with a flat run-off area to the left of the hard shoulder. This provided a baseline investigation into the displacement of the vehicle with no influence of the off-carriageway environment such as rigid barriers, grass verges or angled embankments.

The dimensions and vehicle details of the TOV were provided and represent the Mitsubishi Shogun with no driver or passenger in the vehicle.

The TOV was stationary within the hard shoulder, the front steered wheels were straight (i.e. the steering wheel was at 0 degrees) and the brakes were applied.

The impacting lorry was simulated with a tractor and trailer unit with a combined mass of approximately 44,000kg and a velocity at collision of approximately 60mph.

Seven different impact configurations, with regard to approach angle and overlap for each of the two TOV orientations were performed. An additional run was performed for one of the fend off configurations as it was found that when the impacting lorry was unbraked through the collision it resulted in a secondary collision with the TOV which resulted in it being 'pushed' along in front of the lorry. For the additional run the lorry was braked immediately after impact.

In addition to the baseline simulations, a sensitivity analysis was also performed to determine the effect of changing certain variables within the simulation model. Further runs were performed to examine the effect, if any, from altering the TOV's steered wheels' orientation.

From the simulations conducted, the following recommendations can be made:

- From the analysis and based upon the HVE simulations it was possible to create an area that would not be advisable for people to stand in when the TOV is stationary. Incorporating a margin of safety, this area extended from the rear of the vehicle forwards approximately 110 metres and to approximately 75 metres to the side of the vehicle. Therefore, it is recommended that a 100m zone should be established whenever possible.
- The effect of the steered wheels made little difference to the overall travel distance of the TOV and was within the range of the values shown in the sensitivity analysis, so guidance on wheel orientation should be removed from TOS procedures.

- It is suggested, based upon these simulations, that the TOs do not stand forward of the rear of the vehicle.
- It is recommended that advice on pedestrian safe areas should be extended to other road workers and to the general public.

4 TOV Incident Involvement

During the time the instrumented TOV was based at the Quinton TOS Outstation, it was involved in two incidents. The first, a near miss, occurred in the TOV's first week, and involved an HGV passing under 'red X' signals and approaching the TOV, with ETM deployed, in the closed lane. This incident was fully described in the interim report (Palmer, Lawton & Manning, 2012), but details are given again here as they show a clear example of the dangers faced by TOs attending incidents on the APTR network.

4.1 M6 near miss, October 2012

At approximately 6:30a.m. on Friday October 19th 2012, a two-person crew from the Quinton TOS Outstation was attending an incident on the M6. The incident, a broken down vehicle, was located at marker post location 180/7 on the southbound carriageway.

Because of the work necessary, the crew deployed ETM to close Lane 1 (LBS2), then moved the TOV into the lane, parked in fend off orientation. It is understood that at least one upstream gantry signal was displaying the red 'X' signal, indicating that the lane was closed. The incident was immediately prior to the gantry visible in Figure 47.



Figure 47: Approach to incident location



Figure 48: TOV in coned-off Lane 1 (LBS2), recovery vehicle ahead on hard shoulder (post-incident, note cone debris in Lane 2, LBS3)

The following sequence of images were taken by the TOV's rear-facing camera. The image changes from colour to monochrome when the HGV shields the camera and causes the camera to switch to infrared.





The following two images are from the front-facing camera, also operating on infrared.



4.2 Simulation of impacts

Due to the rarity of such incidents being captured on video, and the potential of the footage to be used for education and training purposes, additional simulations of how the near miss might have developed were included as special cases within the on-going impact simulation work (workstream 2). The scenarios modelled were:

- The impacting vehicle continues straight along its original course, the driver brakes for one second prior to impact.
- The driver maintains speed but attempts to swerve to the right of the TOV, but impacts the TOV. Due to extreme steering being applied, the HGV driver over-corrects to avoid hitting the central reserve steel barrier.

It is important to understand that these are 'what if?' demonstrations and dependent upon many variables, none of which are fully predictable. Also, the simulations show a straight approach rather than the actual incident scene's right-hand curve approach. However, they do show the potential effects of such impacts, with associated risk to TOs and others at the scene, including other passing motorists.

The images provided here are taken from real-time videos of the simulations as viewed from a single 'camera' viewpoint. Additional 'camera views' could be defined, as the videos are simply outputs from the completed simulation.

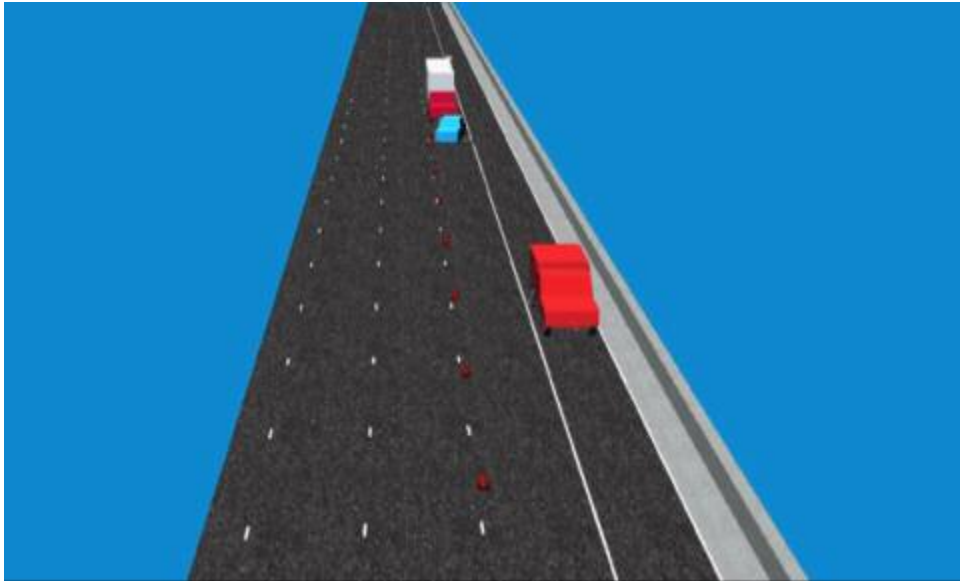


Figure 49: Simulation 1; HGV continues straight ahead, 1s braking prior to impact



Figure 50: Simulation 1; final positions of vehicles

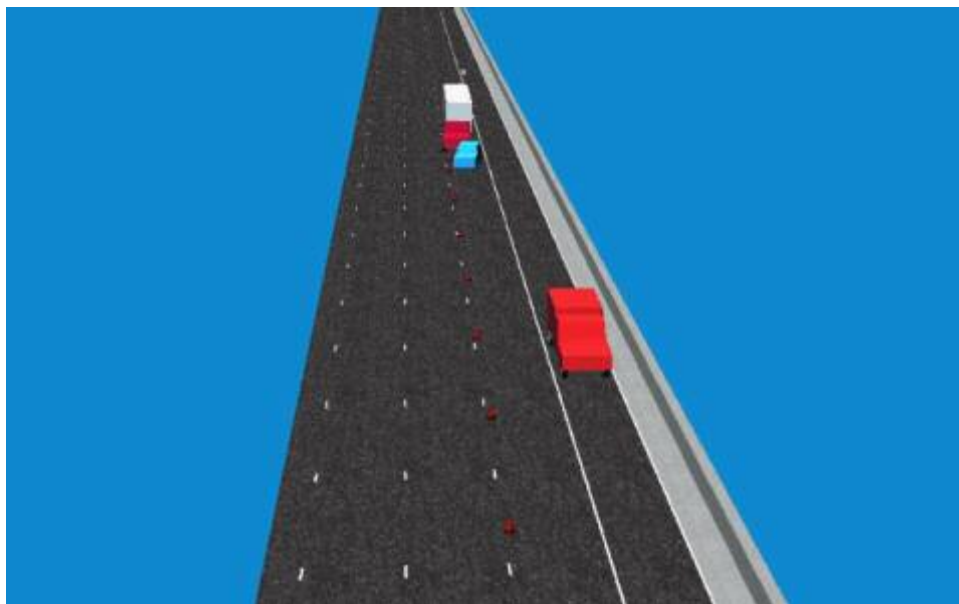


Figure 51: Simulation 2; no braking, HGV swerves



Figure 52: Simulation 2; final positions of vehicles

Both of these simulations graphically demonstrate how far both the errant (impacting) and impacted (TOV and recovery) vehicles might travel along the carriageway as a result of the collision, with implications for any pedestrians present at the scene.

It is known that the two TOs were in close proximity to the TOV: one was at the nearside rear door, the other returning to the vehicle and close to the front nearside. A recovery operative is seen on the video exiting from his vehicle shortly prior to the incident.

4.3 M6 collision, January 2013

In January 2013 the instrumented TOV was involved in a further event while in attendance at an incident, also on the M6, but on this occasion the vehicle was impacted and suffered extensive damage. The damage was deemed beyond economic repair, leading to the TOV being written off (meaning the system could not be recalibrated). The main contact point was the laser distance sensor mounted to the rear of the vehicle. This incident occurred after the project trials had ended data collection and so, unfortunately, no video was obtained.

The collision occurred at about 6:30 a.m. A lane 1 closure was required for a tyre fitter to work safely, so the closure was implemented to be finished before the traffic became too heavy.

When the incident occurred the TO implementing the closure was approaching the vehicle to collect the remaining lamps, stored in the rear of the TOV, to light the longitudinal line of coning.



Figure 53: Laser distance measurement equipment, post-impact

5 Implications for TOS Incident Procedures

Results from both workstreams have identified that TOS procedures may not represent best practice for real-world attendance at incidents and that TOs may have unrealistic expectations of the degree of protection which their vehicle and standard operating procedures may provide.

Therefore, it is essential to consider whether TOS procedures should be re-evaluated and modified, in particular with regard to:

- Fend parking and front wheel alignment
- Incident safety zone
- Pedestrians on the carriageway
- Fend parking by location
- Beacon use by location

Furthermore, these results have significant implications for all personnel on the hard shoulder, whether TOS, emergency services, road workers, other professionals (such as the recovery industry), or members of the public.

5.1 Fend parking and front wheel alignment

Although this project did not undertake a review of TOs' reasons for their use of various parking practices (such as variations in fend angle and methods for placing the vehicle into 'fend'), it is important that the preferred practices which TOs have developed should be considered. Similarly, there was no review of TOs' training other than viewing the TOS Manual. Some aspects were discussed with TOs when the opportunity allowed and others were identified from the video recordings obtained through the on-road trial.

It is important to note that, during written and verbal briefings prior to the trial commencing, TOs were assured that data collected during the project "will not be used to observe TO activity at incidents".

However, the data analysis suggests that TOS procedures relating to the use of the TOV may be impractical for attendances at some incidents, in particular:

- 10° fend angle; it was identified from the video recordings that the majority of 'fend' parking was at lower angles than the 10° specified in TOS procedures. This may be because the angle is difficult to determine when on-road, or because the TO is unwilling to place the TOV with a reduced clearance from the adjacent live lane. As the fend angle nears 12° so the opportunity to vary the vehicle's lateral position reduces.
- Wheels 'in-line'; During video analysis, two distinct methods for placing the TOV into 'fend' were identified:
 - Drive forwards, along the left of the hard shoulder, then steer 'right' to achieve the fend angle, resulting in the TOV's front wheels being steered to the right.
 - Reverse, then steer left, leaving the front wheels pointing to the left.

In both these cases, the limited space available within the hard shoulder restricts the driver's ability to return the TOV's front wheels to be in line with the vehicle unless this is done with the vehicle stationary, potentially damaging the vehicle or roadway. Also, if those wheels are placed in line with the vehicle, unless they are steered back toward the hard shoulder then the vehicle will have to leave the hard shoulder directly into the live lane.



Figure 54: TOV parked in fend off orientation; note proximity of front offside wing to live lane and front wheels steered to left (TOV was reversed into fend)

It appears that the TOS procedures require a parking method which is not practical for use at incidents, so should be reconsidered.

5.2 Incident safety zone

Workstream 2 has identified that a TOV positioned in conformance with TOS procedures 50m upstream of an incident may, if subjected to a high-energy impact, be propelled through the current 50m 'safe' zone and into the incident and working space.



Figure 55: Left: M6 near miss incident ETM, with 50m safety zone; right: simulation 1 post-impact vehicle locations

Furthermore, having identified that a parked TOV could be propelled over 70m, Workstream 2 suggests that, after applying a 50% safety factor, the 'at risk' zone extends up to 110m from the TOV's location (rounded to 100m).

It would be impractical to suggest that the TOV should remain at a distance of 100m during all incident attendances, since this would require the TOs to be on foot on the

hard shoulder between the TOV and incident, so extending both the duration of their attendance at the incident and increasing their risk from exposure to live traffic.

During analysis of incident video it was noted that the TOs often approach close to the incident (e.g. a broken down vehicle) so that the passenger can disembark, then the driver reverses upstream to create a safety zone. Therefore, a two-stage incident procedure may be more appropriate:

- Initial / short duration attendance; during the initial attendance at an incident the TOV remains in close proximity (approximately 20m clearance). Since workstream 2 identified that a TOV placed 50m upstream is likely to be propelled through the 50m safety zone, it may be that an effective mitigation to reduce risk is to shorten incident attendance by remaining closer.
- Extended duration, with ETM deployment; when the TOV is expected to remain on scene for extended time, particularly with ETM deployed, the TOV should be placed 100m upstream, reducing substantially the likelihood of an impacted TOV being propelled through the safety zone into the incident/work area.

Each of these methods would be subject to variation according to the type of incident and its individual circumstances, for example with regard to the presence of pedestrians (such as from a broken down vehicle or collision) and their ability to walk to a place of safety.

5.3 Pedestrians on the carriageway

The displacement diagrams generated from the impact simulations clearly show the areas in which pedestrians are at risk of being hit by a displaced TOV. Perhaps unexpectedly, these areas extend back alongside the parked TOV (it is known that the TOs attending the M6 incident were both stood adjacent to their TOV).

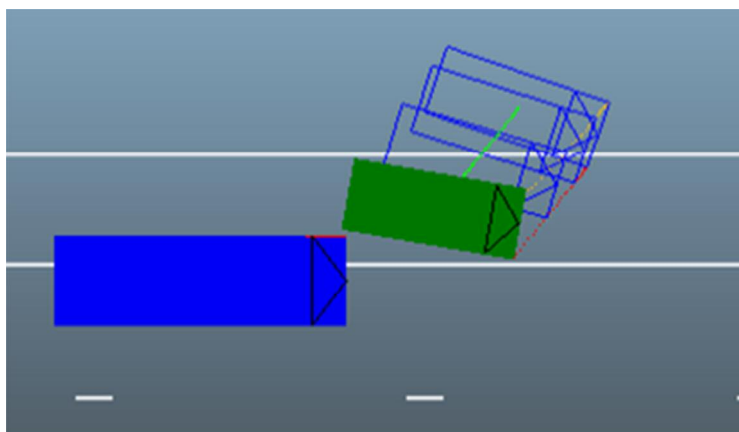


Figure 56: Simulation Run 8 (fend off), displacement route of the TOV following the collision

This indicates that revised advice should urgently be given to TOs regarding where they stand. It is suggested that this advice is simply:

“Stand in a place where you are off the carriageway and can see the rear of your vehicle.”

This general principle applies even when the TO is beyond a barrier, since the TOV could cause substantial damage to the barrier or be propelled over it.

Importantly, as well as TOs, this advice applies equally to other pedestrians on or alongside the carriageway. A later section will explore this further.

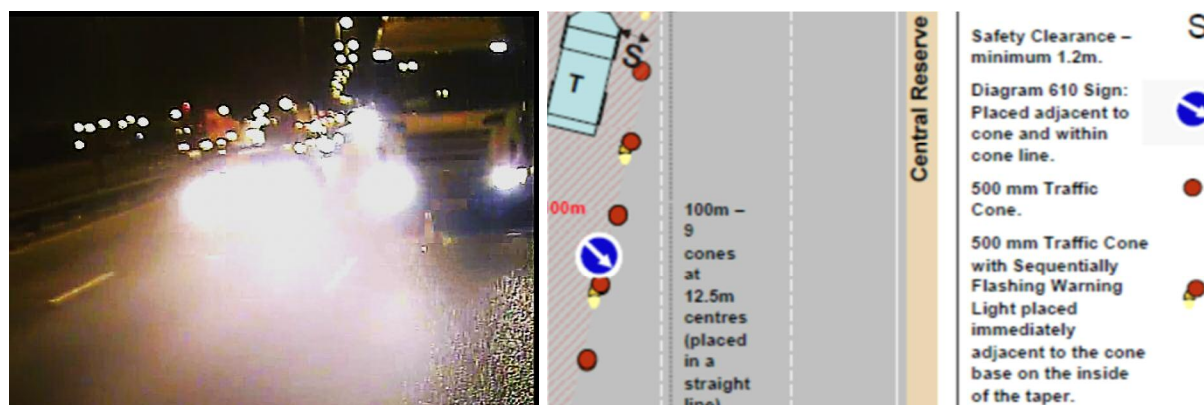
5.4 Fend parking by location

The issue of potential benefits from the use of fend parking, and previous research to support its use, was explored in detail in this project's interim report (Palmer et al., 2012). That report also showed that improvements in detection of the TOV in 'fend off' by approaching drivers might be negated by the decrease in clearance between the front of the TOV and the live lane. Therefore, it is possible that a safer option for TOs would be to reserve use of the fend off orientation for occasions when the TOV is positioned in a live lane. However, there may be incidents where use of the fend off orientation could be beneficial whilst on the hard shoulder. For example, the incident shown in the left image in Figure 57 gives an example of where fend parking might be beneficial to improve safety for the motorists performing an offside wheel change close to the live lane, whereas the vehicle in the right image is further away from passing traffic.



Figure 57: Incident attendances, showing (left) where fend off may be beneficial for road user safety

For live lane parking fend parking, there may be distinct advantages beyond those described in the previous interim report (Palmer et al., 2012). This is shown from careful examination of the near miss incident video, which shows how close the HGV approached the TOV. As can be seen in the image below, the ETM cone is impacted over half way across the HGV's width. These cones are placed in a straight line to pass 1.2m from the parked TOV (the full ETM layout diagram is given in Appendix B). In this incident, the use of the fend off orientation may have provided just enough additional clearance to allow the HGV to pass without impacting the parked TOV.



**Figure 58: Left: near miss video screenshot, - ETM cone impact
Right: extract from TOS procedures for ETM layouts, - 1.2m safety clearance**

5.5 Beacon use by location

Although this project was unable to add to the data obtained from the previous simulator trial (Diels et al., 2009), it is worth noting the findings of the participant questionnaires carried out after the simulator drives which identified the understanding drivers have of the varying colours of lighting displayed and the actions drivers they would take in response to the different roof bar configurations:

- Amber is largely understood to indicate drivers to 'slow down'
- Red and red combined with amber are understood to require drivers to either 'slow down' or 'stop'

The proportion of 'don't know / no idea' responses was larger in the red plus amber lighting configuration, suggesting participants were less familiar as to the meaning and required actions of this configuration compared to the red only and amber only configurations.

On this basis, it is recommended that the TOS should maintain a distinction between beacon use on the hard shoulder and live lanes, retaining the use of rear flashing red beacons solely for while the TOV is parked in live lanes. Maintenance of this distinction may become more important as the HA moves towards All Lane Running (ALR) on managed motorways. TOVs attending incidents will need to reinforce the message given on MS4s using their beacons. The comprehension of red lights should be improved by consistent use in live lanes only. At typical motorway closing speeds between traffic and a parked TOV it is essential to reduce or avoid driver confusion and aid understanding, helping drivers to make the correct response to the hazard and take appropriate avoiding action.

5.6 Wider implications of advice to pedestrians

As mentioned in Section 5, the implications for TOs on the carriageway are equally appropriate for other personnel and run contrary to much of the advice currently given. It should be considered whether the advice of "stand in a place where you are off the carriageway and can see the rear of your vehicle" can be promulgated widely.

Examples of advice currently given include in The Official Highway Code, by the SURVIVE Working Group 1 and the Highways Agency are given below.

5.6.1 The Official Highway Code

The Highway Code is potentially the only reference manual which learner drivers will encounter as part of their test preparation. Also, although not all rules contained within the Highway Code are enforced by law, it acts a reference during legal proceedings when good driving practise is being considered.

Its advice regarding breakdowns includes:

“Rule 274: Breakdowns – do not stand (or let anybody else stand) between your vehicle and oncoming traffic”

“Rule 275: If your vehicle develops a problem, leave the motorway at the next exit or pull into a service area. If you cannot do so, you should:

pull on to the hard shoulder and stop as far to the left as possible, with your wheels turned to the left

return and wait near your vehicle (well away from the carriageway and hard shoulder).”



Figure 59: Highway Code advice, Rule 275

However, the illustration given within the Highway Code shows that, should the broken down vehicle be struck, then the pedestrian is likely to be hit by their own vehicle whilst using the emergency telephone, and is also within the ‘at risk’ zone identified by the simulations when stood away from the carriageway.

5.6.2 SURVIVE Working Group 1

The SURVIVE group (Safe Use of Roadside verges in Vehicular Emergencies) are involved in the creation of working protocols and best practice guidance, in particular their Working Group 1. Their published information states:

“Safety - The working group have also discussed the safest positioning of drivers and passengers once the technician had arrived at the breakdown scene. The safest place to wait was agreed as being behind a barrier if one existed. If no barrier was present, then they should remain adjacent to the technician's vehicle.”

Remaining adjacent to the technician's vehicle (e.g. breakdown service or recovery vehicle) places those pedestrians within the ‘at risk’ zone. The advice “stand in a place where you are off the carriageway and can see the rear of your vehicle” is equally applicable.

5.6.3 The Highways Agency

The Highways Agency has published a wide range of guidance information for road users, including a set of videos under the banner name 'Stay Safe Keep Moving'. One of these, 'Using the Hard Shoulder' includes advice to supplement that given by the Highway Code. Similar to the Highway Code advice, this demonstrates stopping prior to the emergency telephone, placing the pedestrian at risk from their own vehicle if it is struck. Also, the vehicle is shown with its wheel steered 'left'.



Figure 60: Screenshots from the Highways Agency video 'Using the Hard Shoulder'

5.6.4 Interim Advice Note 115/08 Revision 01

For professional personnel, the HA's Interim Advice Note 115/08 Requirements and Guidance for Works on the Hard Shoulder and Road Side Verges on High Speed Carriageways, Revision 01, gives extensive guidance on good working practices, although this guidance may raise unrealistic expectations of the protection which can be afforded by the parked vehicle, perhaps confusing the safety which might be provided by the use of conspicuity markings and beacons with that of physical protection. Also suggested is a safety zone of 18-50m, potentially much smaller than that contained within TOS procedures. However, it does suggest a parking location for off-hard shoulder works which accords with the new proposed advice (in bold):

"V(3) The conspicuity of the parked vehicle may offer partial protection to the vehicle itself and also may offer some protection to the area where there are people and works are being undertaken during short and medium duration stops. Subject to suitable site specific risk assessment, when works are being undertaken on the hard shoulder vehicles should be parked at least 18m but no more than 50m upstream of the works area. **When works are being carried out off the hard shoulder but site conditions require vehicles to be parked on the hard shoulder, vehicles should be parked at least 3m downstream of a point adjacent to the location of personnel off the carriageway.**"

5.7 Summary

This project, particularly from the extensive impact simulations, has identified that substantial revisions of the TOS procedures may be required, and that the same simple advice ("stand in a place where you are off the carriageway and can see the rear of your vehicle") is equally applicable to all people, whether professionals such as the TOS, road workers, etc. who are on the roadside as part of their work, or road users who find themselves on the hard shoulder with their broken-down vehicle.

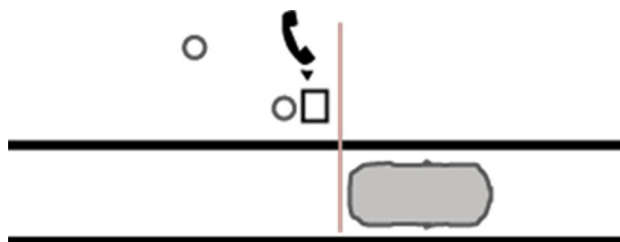


Figure 61: Parking relative to emergency telephones and safer pedestrian locations when stopped on the hard shoulder or in a live lane

The process of promulgating this advice should be begun as soon as possible, ensuring that the consistent advice is given through as many channels as possible.

As the HA moves towards the introduction of ALR on managed motorways, it is likely that a greater number of motorists will break down and have to leave their vehicles in live lanes. For those people, this advice could be essential to maximise their safety.

6 Workstream 3: In-Vehicle CCTV Systems

As a result of the video recordings obtained during this project, both of day-to-day activities, recording during incident attendances and of the M6 near miss, an additional task was added to the project brief, to:

- Identify the availability of existing vehicle-mounted CCTV systems, and
- Give examples of their potential uses and benefits.

However, it is essential re-state the caveat given earlier that, during written and verbal briefings prior to the trial commencing, TOs were assured that data collected during the project “will not be used to observe TO activity at incidents”. Therefore, specific instances will not be reported here, although it should be highlighted that examples of good practice and particularly skilful driving were noted during video analysis.

6.1 Existing CCTV systems

The instrumentation fitted to the TOV used during this project was a bespoke system within which the CCTV was included in order to allow filtering of the incidents attended by the TOV. This system is described fully in the interim report (Palmer et al., 2012). A number of screenshots from this system have been used throughout this report. Although not used to retrieve video, 3G connectivity included within the system allows live streaming video to be obtained from the vehicle’s cameras.

Other vehicle-mounted systems were identified, and they are described below.

6.1.1 Premier Hazard Commander

Premier Hazard supply a range of in-vehicle CCTV systems, including the option of a remotely-controlled camera integrated into the vehicle’s roof-mounted lighting bar (Figure 62). Their multi-camera systems are able to provide live streaming of video, whilst within the vehicle a hard disk recorder and mirror recording to SD cards provide data security.



Figure 62: CCTV camera 'dome' integrated into Premier Hazard light bar

6.1.2 Global Live

Global Live have implemented a number of in-vehicle multi-camera systems, including:

- on buses and coaches
- for the security industry, for the protection of loads such as cash in transit
- on HGVs with to detect illegal immigrants and protect the drivers from prosecution for ‘people smuggling’.

Figure 63 shows a montage from a multi-camera system with live streaming capability, one of several ConnectPlus/BalfourBeatty traffic management vehicles fitted with

systems. These systems also included front and rear G-sensors, allowing instant reporting of impacts.

They also provide lone-worker systems which include a belt-worn sensor which can be used to notify the control room if the wearer is incapacitated.



Figure 63: Montage of multi-camera system images

6.1.3 Vision Techniques

Vision Techniques provide an extensive range of systems to improve safety and security. Systems installed onto fleets have been shown to be cost-effective in eliminating false and fraudulent insurance claims against equipped vehicles and their drivers. Their VT Live system allows multi-camera live streaming. Vision Techniques have also installed systems onto traffic management vehicles, and have captured an impact (see Figure 64).



Figure 64: Screenshots immediately prior to (left) and after an impact into a Veolia vehicle (Vision Techniques installation)

6.1.4 Colas TMIPV

Colas is involved with the traffic management industry and wished to increase the safety of their crews while they are engaged in deployment and retrieval of traffic management signs etc. They have been involved with the development of a multi-camera system with live streaming ability, but with the recent enhancement of a two-stage warning system which utilises Bosch video analysis software to identify vehicles encroaching into predetermined 'at risk' zones behind the Traffic Management Impact Protection Vehicle (TMIPV). If the system identifies approaching vehicles within those zones, additional warning beacons are displayed to the rear and the TM crew are given warnings of imminent impact. An early version of this camera system, prior to the development of the driver and crew warning element, captured several video sequences documenting a high-speed impact from an HGV while the TMIPV was stationary in a live lane during the retrieval of road works advanced warning signs (see Figure 65 and Figure 66).



Figure 65: Camera view into vehicle load area, with crew moving away from the vehicle moments before impact



Figure 66: Rear view from a camera installed above the crash cushion, views immediately prior to and after impact

The live streaming video part of the system has also been used to deter and identify thefts of diesel fuel from the Colas fleet.



Figure 67: Bosch Archive Player screenshot, immediately prior to impact

6.1.5 HA Incident support vehicles

The HA has installed CCTV on a number of Incident Support Units (ISUs), but it is not known whether this equipment has been used at incidents.



Figure 68: Incident Support Unit, with CCTV camera mast installed behind the cab

6.2 Potential uses and benefits of CCTV

This project did not set out to champion the introduction of in-vehicle CCTV systems. During the briefings to introduce the project to the TOS, concerns were expressed over the use of video recording during data gathering. However, the video recordings obtained during the M6 near miss incident highlighted how critical video from an on-

scene vehicle attending an incident might be when provided over a live streaming link to the control room.

The existing in-vehicle CCTV systems that were identified have been targeted at particular markets, but they demonstrate the potential benefits such systems might have for the TOS. These benefits include:

- Live incident management; the ability of the control room to monitor the development of incidents could allow quicker deployment of appropriate resources. This may be especially effective when incidents are out of view of existing fixed CCTV or when such equipment is not in place. The TOS could develop their role as the HA's 'eyes and ears on the Network'.
- Data gathering; aspects such as traffic flow, queue development, etc. can be monitored, particularly when MIDAS or CCTV is not available. Live streaming would allow appropriate action to be taken immediately.
- Infrastructure monitoring; since the TOS conduct regular patrols of the HA's APTR network, vehicle-mounted CCTV would permit rapid monitoring of deficits in the quality of the infrastructure, particularly any which are safety-critical, such as poor surfacing due to adverse weather conditions or standing water.
- Enforcement; although the TOS do not have an enforcement role, the M6 near miss demonstrated how video evidence might be made available to support prosecutions.
- Training and supervision; regular monitoring of video recordings could be undertaken to help TOs to improve their professional skills and ensure compliance with procedures. To achieve acceptance it would be essential that such supervision should not lead to reprimands or other action. Instead, retraining should be provided where appropriate. However, acknowledgement, recognition and praise for the demonstration of high standard service should also be given in equal measure.
- Lone worker safety; TOs work in a high-risk area, often encountering members of the public and unusual situations. The ability to monitor their safety, especially if lone working should be introduced, would aid the HA in its duty of care to its staff, 'watching their back'. Additional body-worn sensors are available which may identify if the wearer is incapacitated and so give an alert message to a control room. There is also the possibility to integrate an alert system into the vehicle to ensure the TOV "watches the back" of the TO when the vehicle is stationary.

7 Recommendations

This project has the potential to deliver wide-ranging changes, far in excess of those originally anticipated at its inception.

It has become apparent that TOS procedures, in particular for the use of 'fend' parking and front wheel orientation, do not acknowledge the practicalities of incident attendance. Also, the current longer-duration procedures, including ETM deployments, should be modified to recognise the at-risk zone which has been identified.

7.1 Recommendations for TOS incident attendance

Recommendations for the TOS cover the following aspects of incident attendance:

- Use of beacons
- Use of parallel / fend parking
- Incident attendance methods
- Use of vehicle-mounted CCTV

7.1.1 *Use of beacons*

It is recommended that the TOS retain its current procedures for use of beacons in order to maintain differentiation by the use of amber beacons when parked on the hard shoulder and red beacons whilst in live lanes. The reasons for maintaining this distinction are:

- Consistent message to drivers; although it will be a relatively rare event for the general public to encounter the TOS, a clear, consistent, message to drivers should be maintained.
- Aid earlier decision-making by drivers; with that clear message should come earlier decision-making, allowing safer lane changes out of closed lanes.
- Managed Motorways; the differentiation of closed lanes is potentially becoming even more important with Managed Motorways Dynamic Hard Shoulder (MM-DHS) and the planned Managed Motorways All Lane Running (MM-ALR) schemes, both using red signals to close lanes. However, the MM-ALR will not have the option of providing a temporary hard shoulder, so approaching drivers must be made aware that a TOV attending an incident will be obstructing a live lane, therefore it is essential that drivers plan to move out of that lane.

Anecdotal evidence suggests that the use of amber and red beacons together is widespread while the TOS are attending hard shoulder incidents. Previous research identified that drivers do not understand a clear message from mixed beacon use, so cannot always be expected to make appropriate decisions. This information should be made widely available to TOs, particularly in view of future expansion of the APTR network with further Managed Motorway sections.

7.1.2 Parking orientation

The current TOS procedures provide guidance to TOs on the potential benefits of both parallel parking (i.e. in-line with the carriageway) and the two options of 'fend in' and 'fend off' (i.e. angled).

It is recommended that this guidance should be simplified, giving a clear distinction between attendance at hard shoulder and live lane incidents, as outline below.

7.1.2.1 Hard shoulder: parallel parking

TOs attending incidents on the hard shoulder should use parallel parking, unless a properly recorded DRA shows fend parking is necessary, for example where the incident is close to the lane separation line. This guidance to remain in parallel parking is particularly important for shorter-duration attendance, where placing the vehicle into 'fend' will take additional time. Whilst this might only extend attendance by a few seconds, it should be the TOs' aim to reduce as far as reasonably possible the time they are exposed to risk while attending incidents. Furthermore, the current trial results suggest that any benefit from approaching drivers moving laterally away from a TOV parked fend out are negated by the TOV being closer to the live lane; this is because the TOV uses more of the hard shoulder width when it is not parked in parallel.

7.1.2.2 Live lane: fend parking

TOVs at live lane incidents should be parked in the appropriate 'fend' orientation. The psychological benefits of this are understood to be:

- 'Prompt' of a vehicle parked at angle; when a vehicle is placed at an angle within a live lane, it suggests to the approaching drivers that the vehicle cannot be travelling forwards along the lane, thereby providing an early indication of an unusual situation ahead.
- 'Looming'; a vehicle parked in fend provides a larger visual object than one parked in parallel, so is likely to be identified earlier by approaching drivers.
- 'Go that way' implicit signal; placing of a vehicle into 'fend' may also give an implicit signal to approaching drivers of which direction they should pass the obstruction.

Current TOS procedures state that a 10° fend angle should be used. It has been identified that this angle is rarely used by TOs, possibly due to the practical difficulties in determining the actual angle. There may be a case for use of a greater angle, possibly giving advice to 'fill the lane'. Also, it is known that retro-reflective materials, as used to provide the TOV's high conspicuity livery, are often not effective at low observation angles. In addition, if the TOV is parked at an angle, a driver of a passing vehicle has extra space for correction as s/he pulls out of the TOV's lane. Therefore it may be beneficial, for night-time incidents in particular, to use a greater fend angle.

7.1.2.3 Steered wheels' orientation when parked

In the simulations undertaken, the effect of the steered wheels made little difference to the overall travel distance of the TOV when struck by an errant vehicle, and was within the range of the values shown in the sensitivity analysis. Therefore it is recommended that the requirement to park with wheels in line with the TOV is removed from TOS

procedures and that TOs should leave the wheels orientated as appropriate for the parking orientation used and the method used to gain that orientation.

7.1.3 Incident attendance procedures

It is recommended that two alternative incident attendance methods are given within TOS training and procedures, relative to the type of incident and the duration of attendance:

- Short-duration³: during short-term attendance at incidents, TOs should endeavour to reduce their attendance time and thus exposure to impacts. Therefore, it is recommended that the TOV should remain within close proximity to the incident vehicle (subject to operational constraints etc.). Twenty metres is suggested as the maximum separation distance. No-one should remain within the space between the two vehicles; preferably, everyone should be located upstream of the TOV.
- Medium-duration (with ETM): for long-duration incidents, it is recommended that the TOV should be positioned 100m upstream of the incident vehicle, with ETM deployed according to the current procedures and additional cones to extend the longitudinal cone line the extra 50m. It is acknowledged that there are operational restrictions on the number of cones which can be carried within the existing TOVs, so these should be examined to determine whether the additional ETM is feasible.

In both cases, the safe pedestrian location advice should be maintained:

“Stand in a place where you are off the carriageway and can see the rear of your vehicle.”

Also, it is important to acknowledge that no area adjacent to a road carrying high-speed traffic can be considered fully ‘safe’ and, as such, vigilance and good lookout principles must be maintained.

7.2 Use of CCTV

The near miss incident involving the instrumented TOV has highlighted the potential benefits of TOVs carrying CCTV. It is recommended that the opportunity should be taken to further evaluate such systems and determine likely benefits, particularly of live-streaming capabilities. This might also further extend the operational capabilities of the TOS.

7.3 Recommendations for other responders and the general public

The implications for change extend beyond the TOS and affect other responder organisations, the recovery industry and the general public. These implications are in two areas of incident attendance:

- Use of parking orientation and steered wheel alignment
- Safe pedestrian location advice

³ Definitions of short and medium duration should align with IAN115/08 Revision 1 guidance cited in TSM Chapter 8

It may be necessary for the HA to lead the process of change, ensuring that a consistent message is widely promulgated. This principle was proposed by SURVIVE in their report on Hard Shoulder and Roadside Safety (SURVIVE 2000):

"There should be standard advice given to the public regarding safety procedures on the hard shoulder. This should be disseminated in a variety of ways that should include driving test literature, Highway Code, DVLA/DSA/DETR literature, motoring organisation literature and police literature."

"In addition standard advice should be given verbally by organisations responding to breakdown or other emergency calls. The same advice should be displayed prominently on or in motorway emergency telephones."

"There should be a national strategy and campaign to educate the public on the appropriate use of the hard shoulder."

"This should relate to behaviour on the hard shoulder and the correct use of the emergency telephones. It should seek to educate the public on risks and the potential consequences of accidents rather than simply instruct."

"The messages should be common and should be effectively targeted to the motoring public."

The advice on safe pedestrian locations should be delivered as a simple message to:

"Stand in a place where you are off the carriageway and can see the rear of your vehicle."

As the HA moves towards the introduction of ALR on managed motorways, it is likely that a greater number of motorists will break down and have to leave their vehicles in live lanes. For those people, the advice on safer locations could be essential in safeguarding their safety.

However, this should be expanded where necessary to include advice on parking adjacent to motorway emergency telephones, where they are provided:

"Park beyond the telephone."

The process of promulgating this advice should be begun as soon as possible, ensuring that the consistent advice is given through as many channels as possible.

8 Acknowledgements

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Premier Hazard www.premierhazard.co.uk

Vision Technologies www.vision-techniques.com

Global Vehicle Systems www.global-vs.com

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Appendix A Traffic Officer Manual Version 3.2. Extract: Guidance: Vehicle Orientation - In Line, Fend in, Fend off - Applicable to Motorways and All Purpose Trunk Roads Navigation and Information

This guidance is for the use of personnel involved in the Management of Traffic and applicable to:

Traffic Officers including those that supervise their activity.

There are three positions to place a TO Vehicle when stationary and dealing with an incident: In Line, Fend In, and Fend Off.

TOs will need to position the vehicle in the most appropriate orientation to deal with the incident as indicated by a Dynamic risk assessment, taking into account the detailed advantages and disadvantages described below.

1. Vehicle parked in "Fend Off" position.

Advantages: -

- Fills the lane and therefore provides a line of defence.
- Approaching drivers tend to want to pass by driving around the front.
- Provides a forewarning that the vehicle is stationary.
- Visually the vehicle tends to get larger as approaching vehicles draw nearer.
- When parked on the Hard Shoulder the vehicle tends to encourage people away from it, appears as though it could be emerging from the Hard Shoulder and is more likely to arouse caution from an approaching motorist.
- Provides the TO with a better view of approaching traffic when looking to egress the vehicle
- Provides a better view of approaching traffic over the TO vehicles bonnet and enables TO to be better aware of approaching danger.

Disadvantages: -

- Rear lights aimed towards the Hard Shoulder.
- When parked on the Hard Shoulder approaching motorists may be inclined to react by slowing or changing lanes having wrongly assumed that the TO vehicle is emerging from the Hard Shoulder. Driver is exposed to a direct impact from an errant vehicle.
- When on the Hard Shoulder, if struck, the vehicle is more likely to be projected into live lanes; an errant vehicle having struck the ATO vehicle may then breach the safety zone.
- If there are narrow h/s, using the fend off may result in part of the TO Vehicle obstructing a live carriageway lane, or being so close to lane 1 as to cause danger.

- If there is significant road curvature to the left (e.g. on intersection slip road) using the fend off may reduce the side visibility of the TO Vehicle to approaching drivers.
- If there are narrow h/s using the fend off may result in part of the TO vehicle obstructing a live carriageway lane or being so close to lane 1 as to cause danger.
- If there is significant road curvature to the left (e.g. on intersection slip road) using the fend off may reduce the side visibility of the TO vehicle to approaching drivers.

2. Vehicle parked in "Fend In" position.

Advantages: -

- Fills the lane and therefore provides a line of defence.
- Provides a forewarning that the vehicle is stationary.
- Driver not exposed to direct impact on exiting vehicle.
- When parked on the Hard Shoulder, if struck, it will minimise the likelihood of the vehicle being projected into the live carriageway.

Disadvantages: -

- Rear lights are aimed towards the central reservation.
- When "fend in" is used whilst parked on the Hard Shoulder, and a nearside barrier or wall is present, if the vehicle is struck it is more likely to collide with the barrier and then continue to travel along the Hard Shoulder alongside the barrier. At high speeds this could result in the TO vehicle breaching the 25m safety zone.
- Visually the vehicle tends to get smaller as approaching vehicles draw nearer.
- With the vehicle in the "fend in" position it tends to obstruct the TO view of approaching traffic when returning to the vehicle.
- Approaching drivers tend to want to pass by driving around the front.
- If there are narrow h/s, using the fend off may result in part of the TO Vehicle obstructing a live carriageway lane, or being so close to lane 1 as to cause danger.
- If there is significant road curvature to the right (e.g. on intersection slip road) using the fend in may reduce the side visibility of the TO Vehicle to approaching drivers.

3. Vehicle parked "In line".

Advantages: -

- Rear facing red lights and amber bar lights are most visible.
- Rear vehicle markings most visible.
- Driver of vehicle is not exposed to direct impact on exiting vehicle.

Disadvantages: -

- May appear to approaching drivers that the vehicle is moving.
- Does not fill the lane, therefore offering only a limited line of defence.

- If the vehicle is struck it will travel forward and may strike TO in the 25m safety zone.

Whatever position is adopted, in all cases the vehicle should be left with its front wheels steered straight ahead parallel to the vehicle, and in the case of an automatic gearbox, with the gear selector in park. The handbrake must be set and the four-wheel drive mode engaged. If it is necessary to leave the engine running "Run Lock" should be used.

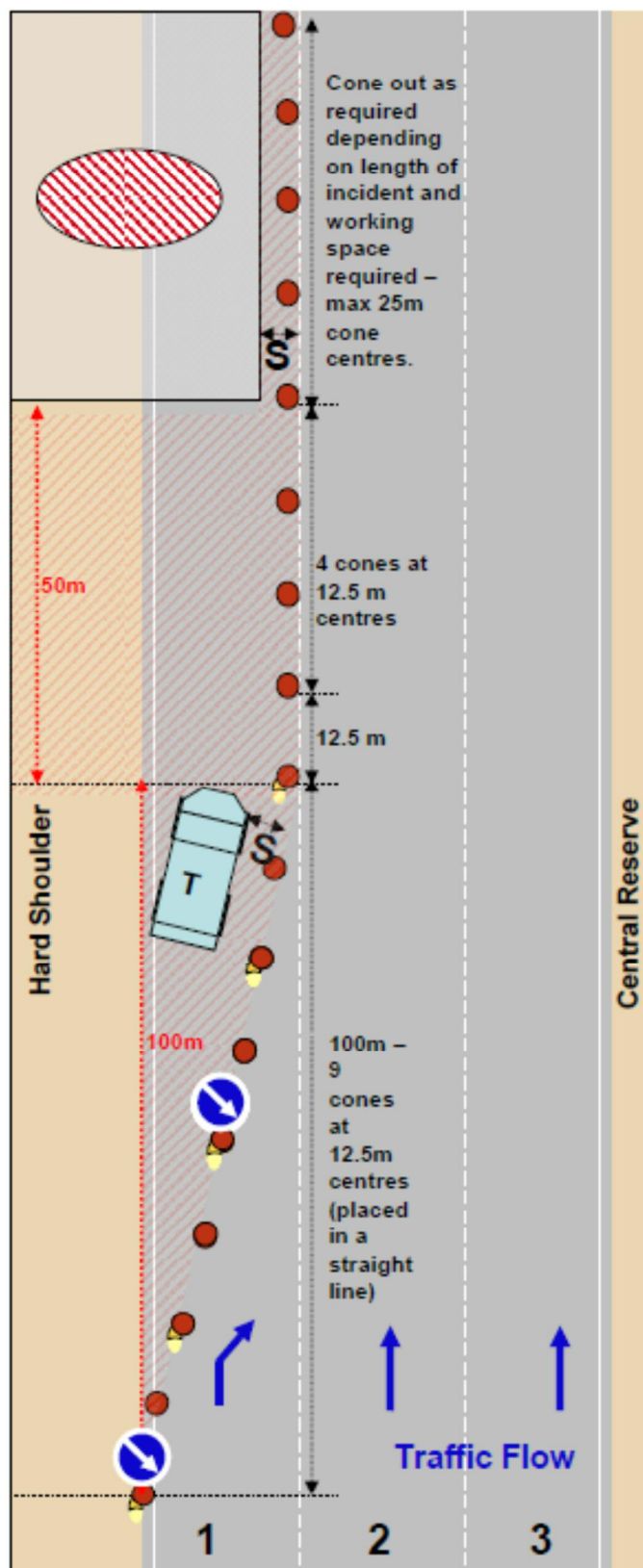
The "fend" angle is when the vehicle is parked at a 10 degree angle to the direction of flow e.g. in a 10 degree fend off position (subject to dynamic risk assessment)), i.e. the vehicle at a slight angle with the front of the vehicle pointing away from the verge with the front wheels in the straight ahead position (parallel to the vehicle). When the vehicle is parked adjacent to the central reserve, the front of the vehicle should point away from the central reserve at an angle of 10 degrees with the front wheels in the straight ahead position (parallel to the vehicle).

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Appendix B Traffic Officer Manual Version 3.2. Extract: ETM Diagram 2 (V10) Lane 1 Closure

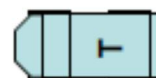


Notes:

1. On-scene Recovery Operators, ISU / Service Providers and supporting TO / TM resources should be directed to park within the working space in the most appropriate position for the circumstances.
2. If, due to the length required, the longitudinal coning parallel to the incident and working space has been initially set at 25m centres; when a second TO vehicle or an ISU or other HA Service Provider vehicle is on-scene, back fill to 12.5m centres.

Key:

TO Vehicle: Final position shown - orientation depends on dynamic risk assessment.



Safety Clearance - minimum 1.2m.

S

Diagram 610 Sign: Placed adjacent to cone and within cone line.



500 mm Traffic Cone.



500 mm Traffic Cone with Sequentially Flashing Warning Light placed immediately adjacent to the cone base on the inside of the taper.



Incident and working space.



Safety Zone for access only - no working to take place except setting out, maintaining or removing ETM.

