Final Report

Stationary Vehicle Detection System (SVD) Monitoring

Prepared for Highways England
by IBI Group

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EXECUTIVE SUMMARY

Executive Summary

To determine whether a ‘stationary vehicle detection’ (SVD) system would provide sufficient additional safety benefit to warrant inclusion either as part of the smart motorways all lane running (ALR) design, or on other parts of the network which exhibit similar physical characteristics, Highways England commissioned a trial of roadside SVD technology. The results of the trial will allow Highways England to make an informed decision on whether to roll-out SVD solutions to other parts of the network. This decision requires an assessment of not only the effectiveness of the system and the benefits it could bring, but also the costs and any potential dis-benefits of implementation.

The trial was delivered in two phases: the first phase of the trial took place on the M62 in the North East region; the second phase was conducted on the M25, over the 13km from J5-J6. This approach allowed the SVD system to be evaluated in RCC environments using different Traffic Management Systems (Cubic and Imtech versions of COBS), and at locations experiencing varying traffic patterns and operational demands, and for enhancements to be identified during phase one and evaluated during phase two. This report relates largely to phase two on the M25. The SVD system consists of scanning radar approximately every 500m, sending data to a central server. An algorithm on the server identifies and locates potential stopped vehicles to 100m blocks in each lane. The system then presents an alert to the RCC via a COBS interface. Each alert contains a location reference and a timestamp. We were able to obtain and review the relevant CCTV footage, and classify the validity of the alert.

The SVD system in phase two had a detection rate of 82.5%-90.3 % (at 95% confidence level), which equates to missing approximately 1 valid event per day over the 13km trial site. 3346 alerts were raised during the 57 day trial period, averaging 59 alerts per day split almost evenly over the three different shift patterns. Of the 2292 classified SVD alerts, 2673 (91.4%) were True Positives. This equates to 0.34 False Alerts per km per day (well under the 1 False Alarm per km per day requirement). 35.1% of all SVD alarms were generated during the low flow period (defined as between 20:00 and 06:00).

Of the evaluated True Positive alarms, 54.6% - (28 per day) related to vehicles stopping within ERAs; 8.1% (4.3 per day) were clustered in hot spots around Clacket Lane Motorway Service Area and 9.7% (5 per day) related to genuine live lane alarms. False alarms were clustered close to only 11 of the 294 marker posts within the coverage area, which contributed to 72% of the ‘False Positive – No source found’ alarms. Targeted fine tuning could potentially reduce the number of false alarms by up to 2.5 per day.

The evaluation covered specific requirements from 19 tasks (Tasks A to S) and a summary of the findings of each sub task is given in the table overleaf. Besides the detection and false alarm rates already mentioned, key findings of interest include:

- Roadworks had no significant impact on the effectiveness of the SVD system. The manual suppression functionality worked as required.
- Against the target detection zone coverage of >90% the trial achieved a calculated coverage zone of 96.7%. There is some evidence that vehicles tend to stop near structures, hence these should not be used for mounting radar.
- Over 90% of SVD alarms are maintained while the vehicle is stationary. However for just under 10% of incidents the system incorrectly states that the vehicle has departed.
- The system reports to RCC operators in under 1 second. RCC Operators only responded to 53.4% of alarms before the system detected the vehicle had moved and auto cleared the alarm.
- Key recommendations to reduce operator workload include the removal or reclassification of ERA/MSA areas; and increasing the time that a vehicle is stopped before alerting (12 sec in the trial). Other proposed enhancements include providing formal TOS procedures, regularly updating the clutter maps, and separating the audible alarms from other audible COBS alarms

We have developed a BCR based on design data for the rate of KSI on smart motorway schemes, and assuming that the overall duration of each stopped vehicle incident is reduced because the incident is detected more quickly. This provides a potential positive BCR value of 1.42 for a 20km scheme. To realise these benefits, the TOS must continue to have the resource to be able to react in a timely fashion to the alerts, and despatch resource as soon as they detect an event, reducing the overall duration of the event when compared to that expected without the SVD system.

Sub task reference	Description	Evaluation result
A/B	Record instances of events and ground truth verification	Against the target false detection frequency of 1.6 alerts per motorway mile per day, the trial achieved a level of 0.2 which is significantly better than required. A very high proportion of SVD alarms (54.6%) related to vehicles within ERA.
C/D	Additional ground truth verification by review of sample CCTV footage / propose locations for ground truth coverage	
E	Review sample footage to check for false positives	Over 1,700 hours of CCTV footage were reviewed to confirm an incident detection rate of 86.4% +/- 3.9% (at 95% confidence level) compared to the required incident detection rate of 80%.
F	Replicate stationary vehicles	N/A
G	Understanding the impacts of roadworks on SVD	Roadworks had no significant impact on the effectiveness of the SVD system. The manual suppression functionality worked as required.
H	Identify blind spots	Against the target detection zone coverage of >90% the trial achieved a calculated coverage zone of 96.7%. We have detailed calculations on the effect of road curvature, gradient and central reserve light on the SVD system with recommendations being made for maximum radar radii.
I	Recommend optimum coverage	We have assessed the number of radar needed to achieve optimum coverage, taking into account the effect of azimuth errors, road gradient, road curvature and the requirements for ERA and hot spot monitoring.
J	Test ability of system to clear alert	Over 90% of SVD alarms are maintained while the vehicles are still present at the roadside. However for just under 10% of incidents the system incorrectly states that the vehicle has departed.
K	Record traffic flows	Against the detection requirement of >80% of the total number of isolated stationary vehicles in < 1000vph per lane conditions the SVD system identifies 86.4% +/- 3.9% of these incidents. The SVD also is able to function at higher flow rates with valid alerts being raised at flow rates in excess of 7000vph and to report these to operators before MIDAS alerts are raised.
L	Record system timeliness	Against the detection requirement of <20 sec from vehicle stopping the SVD system identifies vehicles that have been stopped for >12 sec and reports to RCC operators almost instantly (<1 seconds) compared to the requirement of <10 sec. RCC Operator were only able to respond to 53.4% of alarms before the system auto cleared them (because the vehicle had moved off). Of the alarms investigated and classified as an event, the process takes an average of 50 sec for an

Sub task reference	Description	Evaluation result
		event to be verified; 90% of events are verified within 2 minutes of an alert being presented to the operator.
M	Test usability	Operator feedback has been positive towards the trial with areas for improvement being identified including the separation of COBS and SVD audible alarms and updates to the user interface
N	Recommend reductions on resource impact	Key recommendations include the removal or reclassification of ERA & MSA areas; and Increasing the time that a vehicle is stopped before alerting the operator (12 sec in the trial).
O	Recommend priority of elements from issue 1 of SVD specification	We have reviewed the specification of the SVD system and have suggested alterations based on the trial results and operational requirements for 10 of 27 requirements.
P	Quantify speed of detection over current methods	Comparison with the speed of detection of a sample of breakdown live lane events on the M25 J25-27 ALR scheme showed the SVD radar system detects an average of 16 minutes more quickly.
Q	Identify likely future requirements	We have proposed future requirements to the system categorized as essential, desirable and possible. Essential include providing formal TOS procedures, regularly updating the clutter maps, removal of ERA/hotspot alerts and separating the audible alarms from other audible COBS alarms.
R	Develop likely BCR	We have developed a BCR based on design data for the rate of KSI on smart motorway schemes, and assuming that the overall duration of each stopped vehicle incident is reduced because the incident is detected more quickly. This provides a potential positive BCR value between 1.49 and 1.72 depending on scheme length, where the longer the scheme the greater the value.
S	Define / measure other qualitative benefits	We have defined other qualitative benefits including improved customer and stakeholder confidence, detection of small objects and detection of stationary vehicles in high flows more quickly than via MIDAS

1. Introduction

To determine whether a ‘stationary vehicle detection’ (SVD) system would provide sufficient additional safety benefit to warrant inclusion either as part of the smart motorways all lane running (ALR) design, or on other parts of the network which exhibit similar physical characteristics, Highways England commissioned a trial of roadside SVD technology.

IBI Group were appointed to evaluate the trial data to determine the effectiveness of the system; establishing whether such technology would help to mitigate the safety risk associated with live lane breakdowns. The SVD system alerts RCC operators to the presence of a live lane obstruction, enabling them to set signs and signals and despatch on road support more quickly.

The results of the trial will allow Highways England to make an informed decision on whether to roll-out SVD solutions to other parts of the network. This decision requires an assessment of not only the effectiveness of the system and the benefits it could bring, but also the costs and any potential dis-benefits of implementation.

The trial was delivered in two phases: the first phase of the trial took place on the M62 in the North East region; the second phase was conducted on the M25 in the South East Region. The initial findings from Phase One are summarised in an interim report [Ref: Stationary Vehicle Detection System (SVD) Monitoring Final Report, Dec 2015], and were used to refine the approach to delivering Phase Two.

In this report we summarise the key findings from both phases of the trial, but provide more details on the final outcomes from Phase Two. As well as describing the overall results, this report evaluates the performance of the SVD system against a set of specific task requirements (referenced as Tasks A to S in the specification).

The remainder of this report is structured as follows:

- Section 2 provides the background to this trial;
- Section 3 sets out the scope of the trial;
- Section 4 contains an overview of the trial methodology;
- Section 5 outlines the key findings from Phase Two;
- Section 6 provides a more detailed response to each of the specific task objectives;
- Section 7 summarises the conclusions made so far;
- Section 8 recommends next steps.

2. Background

The smart motorway – all lane running (ALR) design involves the replacement of the hard shoulder with a controlled running lane. While the ALR concept is expected to deliver overall safety benefits, one consequence of the removal of the hard shoulder is an increase in the frequency of live lane stops (when compared to the D3M baseline). Although the ALR design includes the provision of emergency refuge areas at regular intervals, the lack of a dedicated hard shoulder will mean that a subset of vehicles who do need to stop in an emergency will be unable to leave the network, and so will be forced to stop in a live lane.

A stationary live lane obstruction creates a particular hazard during off-peak conditions (when flows are low and speeds are high) due to the increased severity associated with collisions involving large speed differentials. This is captured in the ALR generic hazard log as hazard H135: *"vehicle stops in a running lane – off peak"*. Compared to the D3M design used as the safety baseline, the assumption in the hazard log is that the H135 risk increases by 216%, making it the fourth highest scoring residual hazard.

Although the risk arising from this hazard can, to some extent, be mitigated through the setting of lane closure signals and by lowering the variable mandatory speed limits displayed, this mitigation is only possible once the presence and location of a stationary vehicle has been detected and confirmed by the RCC operator. The hazard is only fully eliminated once the obstruction is cleared from the carriageway.

During high flow conditions, a live lane obstruction will quickly create congestion behind it. This allows the resulting queues to be detected by the MIDAS queue detection system required as part of the ALR design, and the system will automatically request appropriate mandatory speed limits on the approach to the queue. If congestion is detected an alert will be generated to prompt the RCC operator to investigate and determine whether any further response is warranted.

In a low flow environment, where the volume of traffic around the live lane obstruction is insufficient to trigger the queue protection system, no alert is raised and signs and signals are not automatically requested, causing the hazard to remain unmitigated for a longer period of time.

Radar-based technology has the potential to provide additional mitigation for hazard H135. An SVD system works by raising an alert to the RCC, via the Control Office Based System (COBS) interface, once it has detected the presence of a stationary vehicle. This allows the operator to confirm the alert is genuine (e.g. using Pan Tilt Zoom (PTZ) CCTV), before setting appropriate signs and signals to warn approaching traffic of the hazard. This provides a degree of mitigation until the scene can be attended and the stationary vehicle (and any occupants) protected with emergency traffic management and, ultimately, cleared from the carriageway.

For a radar based SVD solution to be viable, it must have a sufficiently high detection rate coupled with a sufficiently low false alarm rate. This will ensure that the system works well enough to provide the anticipated level of mitigation to the hazard, without creating an undue amount of additional work for RCC operators. Any unnecessary work would prevent operators from dealing with other more critical tasks and potentially cause them to lose faith in the systems' ability to deliver to the desired safety benefits.

3. Trial Scope

Highways England agreed to trial the stationary vehicle detection system at two locations (M62 and M25), in two regions (NE and SE), over two time periods.

This approach allowed the SVD system to be evaluated in RCC environments using different Traffic Management Systems (Cubic and Imtech versions of COBS), and at locations experiencing varying traffic patterns and operational demands.

The specific details of each phase of the trial are summarised below:

Phase One:

- Trialled on the M62 CALR[1] section, between junctions 25 and 26.
- The link is approximately 4km (2.5 miles) in length.
- Deployed 6 x **TS-350X** radar over two sections, with an average spacing of 700 metres.
- Radar cover approximately 2.9km (1.8 miles) of carriageway, including:
  - four emergency refuge areas (ERAs),
  - one motorway service area exit and entry slip road on each carriageway, and
  - one motorway exit and entry slip road on each carriageway.
- The evaluation period commenced on 30th July 2015, and ran for three months, until 29th October 2015.

Phase Two:

- Trialled on the M25 ALR section, between junctions 5 and 6.
- The link is approximately 13km (8.1 miles) in length.
- Deployed 27 x **CTS-350X** [2]radar over two sections, with an average spacing of 500 metres.
- Radar cover approximately 13km (8.1 miles) of carriageway, including:
  - ten emergency refuge areas (ERAs),
  - one motorway service area exit and entry slip road on each carriageway, and
  - one motorway exit and entry slip road on each carriageway.
- The evaluation period commenced on 5th December 2015, and ran for two months until 2nd February 2016.

We have included the results of the Phase Two trial in this final report. We refer back to the Phase One trial results (detailed within the interim report) where appropriate.

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[1] Controlled All Lane Running (CALR) is a variant of smart motorways where the infrastructure is provided to HSR standards (i.e. gantries and ERA spacing according to IAN 111/09), but which do not feature a dynamic hard shoulder. They can effectively be considered as dynamic hard shoulder running schemes where the hard shoulder is always open.

[2] New version of radars installed on the M25 that addressed the TelNet security concern of the previous radars installed on the M62

4. Trial Methodology

The SVD system generates an alert each time it perceives an event. Each alert contains a location reference and a timestamp. Using this information we were able to obtain and review the relevant CCTV footage from the RCC, and assign each alert to one of the following categories:

- **True Positive** (i.e. the SVD system correctly identifies that there is an event).
- **False Positive** (i.e. the SVD system incorrectly detects an event when there is none)
- **False Negative** (i.e. the SVD system did not generate an alert when there was a genuine event)
    - Section 6.2 details our findings in respect of those instances when the SVD system failed to generate an alert despite the presence of an operator verified incident.

These categories can be further subdivided into the classifications shown in table 1, below.

Classification	Description
False Positives	
01 - No Source	Nothing seen on CCTV footage to indicate a stationary vehicle
02 - Wrong Carriageway - (Maintenance Related)	As above, where the alert is related to a maintenance activity
03 - Wrong Carriageway	A valid stopped/slow moving vehicle is observed on the opposite carriageway to the location provided by the SVD alert
04 - Off Carriageway	Those 'objects' that are out of scope but we identified them as being stationary – e.g. stopped vehicle on overbridge, a cow in a field
True Positives	
05 - Maintenance Related	A valid stopped/slow moving vehicle related to a maintenance activity
06 - ERA Stop	A valid detection of a stationary vehicle in an ERA
07 - Congestion – Main Carriageway	A valid stopped/slow moving vehicle related to congestion on the main carriageway
08 - Congestion – Slip Road	A valid stopped/slow moving vehicle related to congestion on one of the exit / entry slip roads
09 - Repeat Alarm	A valid alarm, which can be related to a previously identified SVD event
10 - MSA Hotspot	A valid detection of a stationary vehicle within the Motorway Service Area's slip roads
11 - Genuine Alarm	A valid stopped/slow moving vehicle

Table 1 - SVD Alert Classification Matrix

It is important to note that not all genuine SVD events will result in an alert being presented to an operator. There are several reasons why an alert might be suppressed, including:

- **Manual suppression**: RCC operators can choose to disable alerts, for example to prevent alerts being created which relate to maintenance activities;
- **Congestion suppression**: Alerts are suppressed when the system detects more than four vehicles travelling below 20mph within 100m of each other;
- **Automatic suppression**: The SVD alerts are automatically suppressed whenever signs and signals are set in the vicinity due to incident management or congestion on the network.

Additionally, the SVD radar have known limitations in relation to their detection zones, which can result in 'blind spots'. SVD events which occur in these locations may not be detected. Further details are provided in Section 0.

5. Results

5.1. Phase Two Results

During the two month trial on the M25[3], the SVD system generated a total of 3346 alerts for the RCC operators to investigate. This equates to an average of 59 per day. By analysing the available CCTV footage, Command & Control Logs and reviewing RCC operator responses to the SVD alerts we were able to allocate 2925 (87.3%) of alerts to the appropriate subcategory.

Categorisation of Alarms (24/7)

Table 2 & Figure 1 provides a breakdown of both the absolute number of alerts received, and the proportion of alerts measured during 24/7 operation.

SVD (M25) Phase Two Evaluation	24/7 Operational
Total SVD alerts analysed	**2925**
False Positives (FP)	252 (8.6%)
01. False Positive - No Source	197 (69.4% of FP)
02. False Positive - Wrong Carriageway (Maintenance Related)	29 (10.2% of FP)
03. False Positive - Wrong Carriageway	18 (6.3% of FP)
04. False Positive - Off Carriageway	8 (2.8% of FP)
True Positives TP)	2673 (91.4%)
05. True Positive - Maintenance Related	63 (2.2% of TP)
06. True Positive - ERA Stop	1596 (54.6% of TP)
07. True Positive - Congestion - Main Carriageway	4 (0.1% of TP)
08. True Positive - Congestion - Slip Road	32 (1.1% of TP)
09. True Positive - Repeat Alarm	456 (15.6% of TP)
10. True Positive – MSA Hot Spot	238 (8.1% of TP)
11. True Positive - Genuine Alarm	284 (9.7% of TP)

Table 2 - Categorised results of Phase Two Evaluation (24/7 Operational)

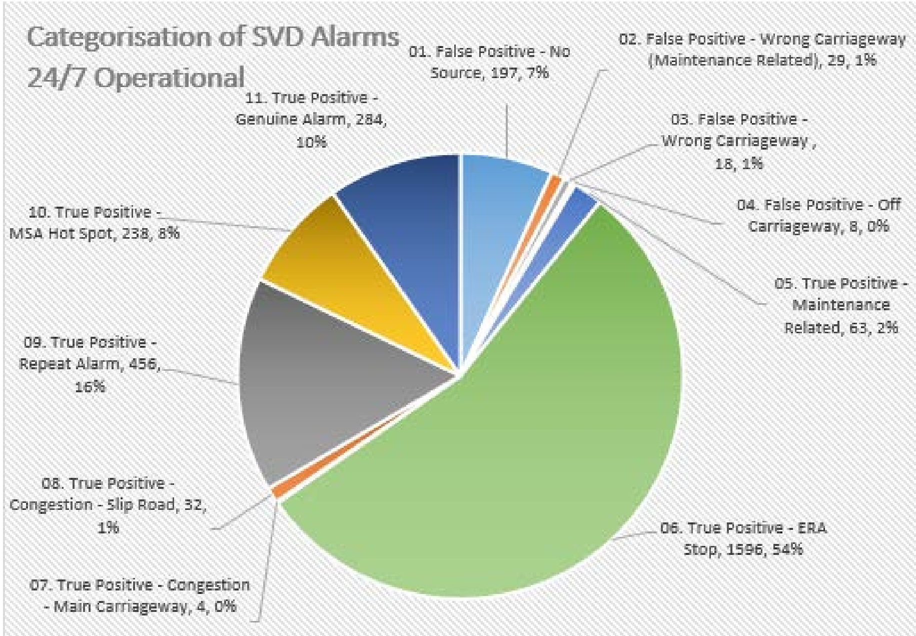

Figure 1 - Categorised results of Phase Two Evaluation (24/7 Operational)

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[3] 5th December 2015 to 2nd February 2016 (Excluding 14-16th January 2016 due to technical problem gathering CCTV footage) – 57 Days

Categorisation of Alarms (Low Flow)

Table 3 & Figure 2 provide a breakdown of both the absolute number of alerts received, and the proportion of the total that these alerts account for when measured across the low flow time period (20:00 – 06:00):

SVD (M25) Phase Two Evaluation	Low Flow
Total SVD alerts analysed	**1105**
False Positives	168 (15.2%)
01. False Positive - No Source	124 (114.8%)
02. False Positive - Wrong Carriageway (Maintenance Related)	29 (26.9%)
03. False Positive - Wrong Carriageway	14 (13%)
04. False Positive - Off Carriageway	1 (0.9%)
True Positives	937 (84.8%)
05. True Positive - Maintenance Related	59 (5.3%)
06. True Positive - ERA Stop	509 (46.1%)
07. True Positive - Congestion - Main Carriageway	0 (0%)
08. True Positive - Congestion - Slip Road	0 (0%)
09. True Positive - Repeat Alarm	159 (14.4%)
10. True Positive – MSA Hot Spot	102 (9.2%)
11. True Positive - Genuine Alarm	108 (9.8%)

Table 3 - Categorised results of Phase Two Evaluation (Low Flow)

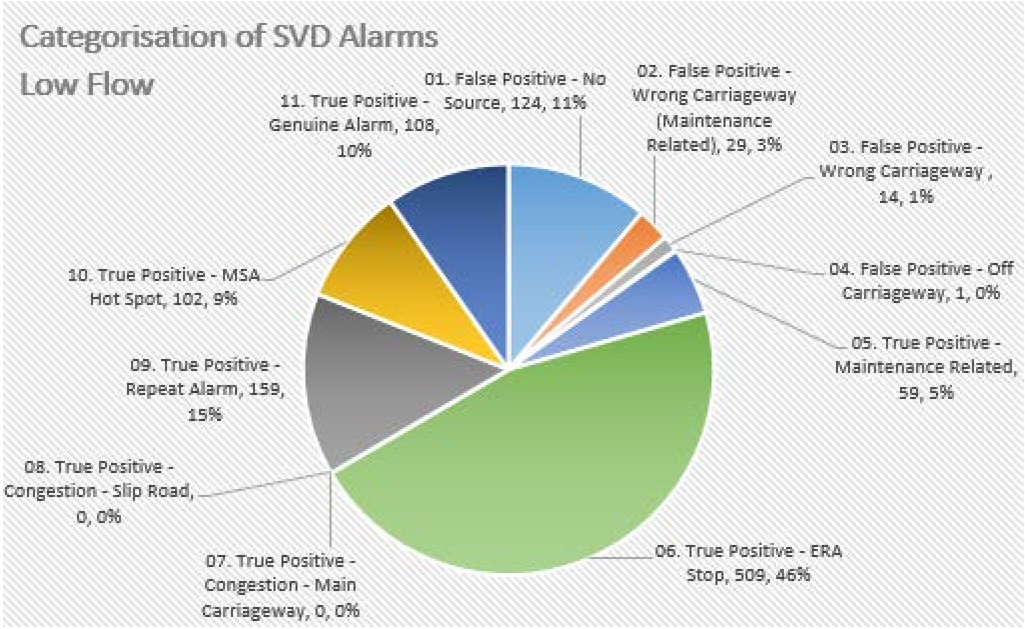

Figure 2 - Categorised results of Phase Two Evaluation (Low Flow)

5.2. Phase Two - Key Findings

Requirements	Results
Detection of 80% of live lane incidents	86.4% ±3.9%
False detection frequency <1.6 per day per motorway mile	0.21 per motorway mile per day

Table 4 - Key SVD Requirement vs Results

- The SVD system had a detection rate of between 82.5% and 90.3% (see Task E for details)
    - This equates to between 6.3 and 12.5 missed events per day
    - 9.7% of all SVD alarms in the 24/7 period related to 'TP – Genuine Alerts' meaning that between 0.6 and 1.2 'TP – Genuine Alerts' would be missed per day (9.7% of 6.3 and 12.5).
- A total of 3346 alerts were raised during the two month trial period, averaging 59 alerts per day split almost evenly over the three different shift patterns within the SERCC.
- Of the 2292 classified SVD alerts, we classified 2673 (91.4%) as True Positive with the remaining 252 (8.6%) classified as False Positives.
    - This equates to just over 4 False Positive alerts per day, 0.34 per km per day (well under the 1 False Alarm per km per day requirement)
- 35.1% of all SVD alarms were generated during the low flow period (defined as between 20:00 and 06:00).
    - The low flow period had a higher proportion of False Positives at 15.2% than the 24/7 proportion. We have recorded a higher number of maintenance related alarms in the low flow period than the 24/7 average (because maintenance is predominantly undertaken at night), and this largely accounts for the higher proportion of False Positives.
- Of the evaluated True Positive alarms:
    - 1563 (54.6% - 28 per day) related to SVD incidents within ERAs
    - 238 (8.1% - 4.3 per day) were clustered in several hot spots around Clacket Lane Motorway Service Area (MSA)
    - 284 (9.7% - 5 per day) related to Genuine Live Lane alarms
- Alarms closest to only 11 of the 294 marker posts within the coverage area contributed to 141 (72%) of the 'False Positive – No source found' alarms
    - Targeted fine tuning could potentially reduce the number of false positive alarms by up to 2.5 per day.

6. Specific Task Requirements – Key findings from Phase Two (M25)

This section summarises the key findings and observations for the specific task requirements as outlined in the specification. Findings are based on evidence drawn from both Phase One and Phase Two of the trial, unless otherwise stated.

6.1. Task A/B: Record instances of Events & Ground Truth Verification

Evaluation Requirements

A: To record instances of Events on the trial sites. There are three classifications in terms of the SVD system recording and Event:

i. True Positive (Event correctly detected by the system) – for this the monitoring will record number/date/time of day of system alerts that are subsequently operator verified.
ii. False Positive (Event incorrectly detected) – the monitoring will record the number/date/time of day of system alerts generated where the operator cannot verify the Event.
iii. False negative (Event not detected) – the monitoring will record the number/date/time of day of Events where there is no system alert generated but there is an operator verified incident related to a stopped vehicle recorded in C&C logs.

B: To provide additional ground truth verification of events using the Agency's Command & Control system and other data sources e.g. accident data.

The results already presented in Section 5.1 give the breakdown of the frequency of each classification of event observed during Phase Two of the trial, together with the method used to classify and verify the different event types.

6.2. Task C/D: Additional ground truth verification by review of sample CCTV footage/Propose locations for ground truth coverage

Evaluation Requirements

C: To provide additional ground truth verification of events by reviewing appropriate digital images captured at the time of the event (CCTV).

D: Propose locations for collection of footage

We used the footage from the PTZ CCTV cameras installed as part of the smart motorway design to perform the ground truth verification of the events raised by the SVD system. Our approach interrogated the HATMS logs to establish the date, time, marker post of the SVD alert, this was then cross matched to the corresponding CCTV camera via IBI's internal lookup database to determine the CCTV camera(s) that contain the imagery necessary to verify the details associated with each SVD alert.

In Phase Two, the terms of our code of connection agreement (CC00153) allowed us to have a second National Video Recording (NVR) system installed at the SERCC, which provided the facility to duplicate the CCTV footage recorded. This footage was then made available via a link to the WMRCC, where we were able to download the CCTV onto a secured external hard disk drive.. We visited the RCC twice per week to retrieve the external hard disk drive containing the relevant CCTV footage for off-line review.

6.3. Task E: Review sample footage to check for False Negatives:

Evaluation Requirements

To undertake a review of sample Highways England CCTV footage to further support the evidence on Events, particularly False Negatives.

Highways England has a requirement for the SVD system to have a rate of detection 'greater than 80% of the total number of isolated stationary vehicles (in less than 1000vph per lane conditions)'.

In order to evaluate this requirement, our team reviewed CCTV footage to manually identify SVD events that occurred within the low flow periods (20:00 and 06:00) for all of the Phase Two SVD trial area. We reviewed over 1,700 hours of CCTV footage covering six days of SVD operations, resulting in the identification of 294 stationary vehicle events. This figure is well in excess of the 100 events we initially planned to review. We categorised the 294 events as shown in table 5 below, which also gives the proportion of occurrence of each category. This proportion is also illustrated in figure 3:

Ref	Stationary Vehicle Classification	Number
1	All stationary Vehicle Events identified via Ground Truthing	294
Of which….		
2	SVD System Detected Events	192 (65.3%)
3	Allowable Missed Detection – Short Stop	1 (0.3%)
4	Allowable Missed Detection – Secondary Vehicles	5 (1.7%)
5	Allowable Missed Detection – Signs Suppressed	25 (8.5%)
6	Allowable Missed Detection – Manually Suppressed	11 (3.7%)
7	Allowable Missed Detection – Out of radar range	16 (5.4%)
8	Allowable Missed Detection – Congestion Suppressed	4 (1.4%)
9	Missed Detection – Unknown Reason	33 (17.2%)
10	Missed Detection – Blind Spots	7 (2.4%)

Table 5 - Ground truthing categorisation of stationary vehicle instances

Definitions of 'Allowable Missed Detection' categories:

- Short Stops: a vehicle stopped for less than 12 seconds. The radar are not configured to raise alerts for these vehicles.
- Secondary Vehicles: a second (or subsequent) vehicle stops at the site of the first vehicle. The radar are configured to only send one alert per marker post while the first vehicle is still present.
- Sign Suppressed: a valid stationary vehicle, where signs and signals had been set (e.g. by MIDAS or Operators). The SVD system prevents these alarms from being displayed to the operator.
- Manually Suppressed: a valid stationary vehicle when the system has been manually suppressed. This prevents alarms from being displayed to the operator for known stationary vehicles e.g. maintenance vehicles.
- Out of Radar Range: a valid stationary vehicle which falls outside of the coverage area of the radar. This includes maintenance access areas, and locations at the extremity of the SVD trial area.
- Congestion Suppressed: a valid stationary vehicle when there are high traffic levels at low speed. This would cause the radar to believe there is congestion present, and so suppress the alarms.

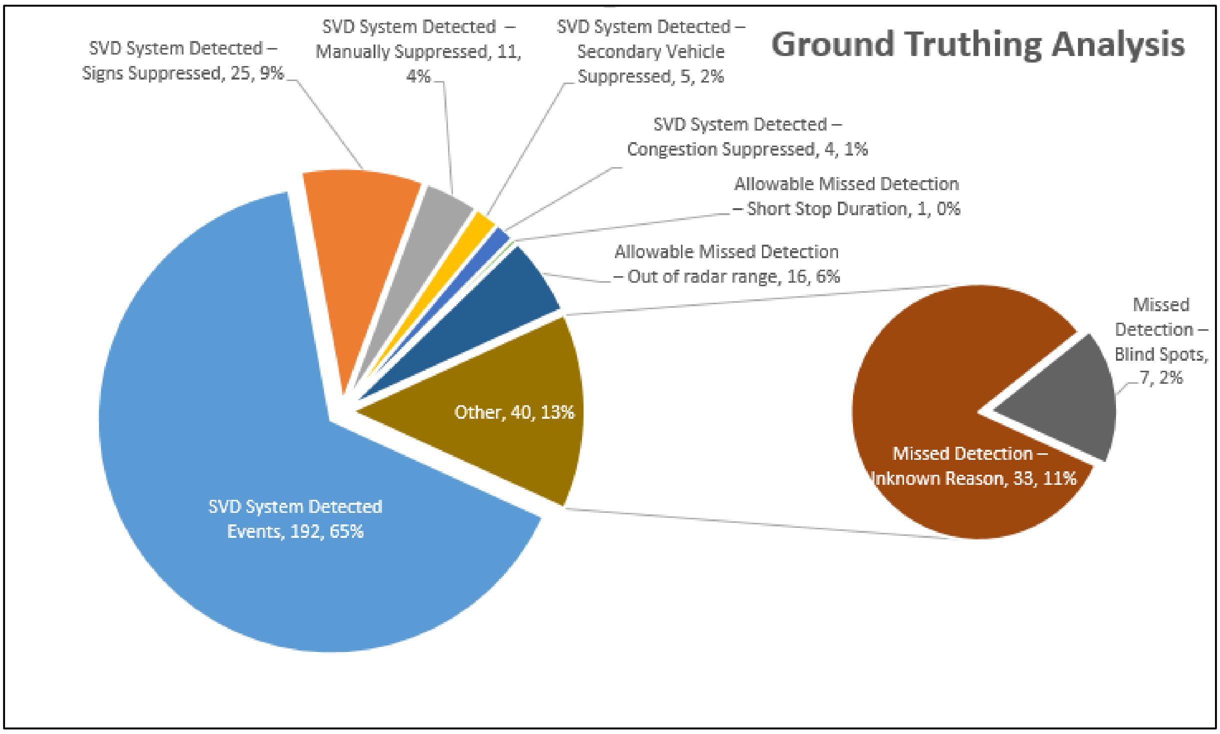

Figure 3 - Ground truthing categorisation of stationary vehicle instances

Our analysis found that in addition to the 192 events detected by the system, we were able to categorise a further 62 as ‘allowable missed detection’. This means that 254 of the 294 ground truthing SVD events were successfully detected by the SVD radar system, equivalent to 86.4%.

Highways England require a 95% Confidence Interval. From our analysis, this equates to +/- 3.9%. Therefore we can say with 95% confidence that Phase Two of the trial delivered a vehicle detection rate of between 82.5% and 90.3% which meets the minimum requirement of the SVD specification item 3 “Traffic flow range for detection and rate of detection >80% of the total number of isolated stationary vehicles”

Missed Detection – Radar Blind Spots

Of the 40 missed detections, seven (17.5%) were attributed to vehicles stopping directly under the radar and within the ‘near device’ blind spot. This amounts to approximately one per day. The issue of blind spots is discussed under Task H later in this section.

One potential explanation for this observation could be due to the installation of the radar detectors on large infrastructure items, such as dual span or cantilever gantries. It is possible that road users needing to stop in a live lane would assume by stopping under these infrastructure items they would stand more chance of being ‘seen’ by other traffic

Assuming this is the case, we recommend that radar are **not** co-located on large infrastructure items to reduce the likelihood that these events are missed due to blind spots.

Requirement: detection rate >80%

Observation: detection rate in the range 82.5% – 90.3%

6.4. Task F: Replicate stationary vehicles

Evaluation Requirements

To provide additional evidence as to the level of False Negatives.

Task F (to replicate stationary vehicles) was initially included to mitigate the risk that insufficient 'genuine' events would occur within the evaluation period to allow statistically significant conclusions to be drawn.

During the initial trials we found that approximately 60 SVD alerts were triggered each day, with a high percentage of these attributable to valid SVD events. This frequency was higher than we had expected, removing the need to introduce additional stationary vehicles in order to increase the sample size.

With the agreement of the project sponsor, task F was removed from scope.

6.5. Task G: Understanding the Impact of Road Works on the SVD system

Evaluation Requirements

To understand what, if any, is the impact of road works upon the effectiveness of the radar and / or RCC operations.

To provide a safer working environment for road workers, all maintenance activities performed on ALR sections require Temporary Traffic Management (TTM). The provision of TTM can be considered in three distinct phases: setting out TTM; conducting the maintenance activities under TTM; and removing the TTM once the works are complete. Each phase introduces specific challenges.

Key observations:

- The modified traffic patterns associated with TTM (lower speeds and alternative lane use) had no material impact on the ability of the SVD system to identify stationary or slow moving objects.
- The SVD system correctly identified slow-moving cone-laying vehicles during the setting out and removal of TTM, raising multiple alerts as each vehicle passed through the SVD section.
- When maintainers stopped in ERAs (e.g. prior to setting out or removing TTM), the SVD system detected these as stationary vehicles and raised appropriate alerts.
- The presence of stationary / slow moving resources (e.g. equipment and vehicles) on the network required to carry out the maintenance activities correctly raised multiple SVD alerts.
- Large TTM vehicles can, on occasion, incorrectly generate a false positive alarm on the opposite carriageway to the one on which the works are being conducted. Navtech have attributed this issue to the radar reflecting off the central reserve barrier.
- Maintenance related SVD alerts occur in relatively high numbers (5+) but condensed into short durations of time while TTM activities are being performed prior to system manual suppression.

Although 'True Positives' represent genuine instances of the system correctly identifying stationary or slow moving vehicles present on the network; some of the alerts are unwanted – for example because the RCC operator is already aware of planned maintenance activities on the network, and so has no need to be alerted to their presence.

The RCC operators have introduced procedures to manually suppress alerts from relevant parts of the network while maintenance activities are undertaken. As the Navtech SVD system does not allow lane specific alerting to be enabled/disabled; alerts were suppressed for all lanes – even those remaining open to traffic. However as observed in Phase One of the trial this procedure can result in the SVD system being manually suppressed longer than required, for example if the TTM is taken off early or the RCC operators do not re-enable the system once the TTM has been removed.

Following the Phase One trial, a number of changes were introduced to the SVD software prior to the start of Phase Two to assist in mitigating this risk. These changes included a Manual

Suppression Reminder to advise the operators to re-enable the SVD system (when the system is suppressed) at pre-determined time intervals throughout the day. Operational feedback from Phase Two of the trial confirms that this helped to remind operators to re-enable the manually suppressed sections.

Despite suppressing the SVD during periods of maintenance, 2.7% of the SVD alarms generated were related to maintenance activities taking place 'early' – i.e. before the alarms were manually suppressed.

Although not a large percentage, these alerts all occur in clusters when the maintenance activities were taking place, with a peak of thirty alarms being observed on one day of the trial. Ideally, a SVD system should have the ability to suppress unwanted alerts. Updated RCC operator and maintenance procedures would then ensure relevant alerts are suppressed for any/all affected sections prior to the deployment of maintenance vehicles being present on the network; and re-enabled after the works have been lifted.

It's worth highlighting that while the alerts are off due to manual suppression, we have eyes on the ground (maintenance providers) who would raise any stationary vehicle incidents identified and reduced speed limits would be in place due to the roadworks themselves, so risk is substantially reduced (but not eliminated).

The Phase One trial found that 14% of the SVD alarms were related to 'False Positives' caused by the system incorrectly detecting maintenance vehicles on the opposite carriageway. In Phase Two this figure fell to less than 1%. However, the improvement between Phases One and Two cannot be attributed to changes in the implementation design alone, as physical attributes on road (such as gradient, central reserve barriers, bridges, etc.) may also have contributed to the change. As such, these False Positive alerts may occur in future implementations if not specifically addressed. We recommend that a link should be created between the COBS manual suppression state and the SVD system, which would allow the SVD system to establish whether these are reflection alarms or not.

6.6. Task H: Identify blind spots

Evaluation Requirements

To liaise with the Supplier, using preliminary design data, to identify radar blind spots and the impact of roadside furniture in creating shadows or blind spots in radar coverage, particularly central reservation lighting columns.

There are two reasons for "radar shadow" or "blind spots", i.e. regions where a scanning radar cannot detect objects:

- Regions that are in close proximity to the device; where the shape of the beam means that the device does not scan in its immediate vicinity.
- The presence of objects in the scanning zone of a radar; these will partially or completely obscure other objects that are beyond them.

We adopted a simple geometric approach to estimate the potential extent of the types of radar shadow and the implications that has for stationary vehicle detection using scanning radar. We have provided a summary of this approach below; the full details of these calculations are given in Appendix 01.

Near Unit Shadow

For a device mounted at 5m, there is a zone directly underneath the unit with a radius of about 20m (at ground level), where objects will not be detected. The detection zone is shaded in Figure 4 with the 'blind spot' near the unit left unshaded.

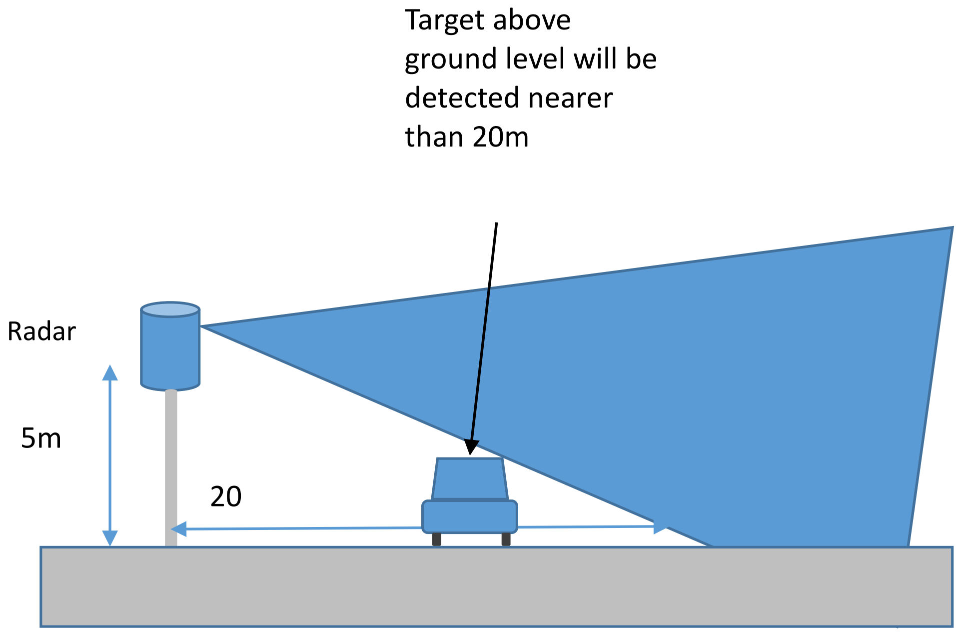

Figure 4 - Near-unit shadow zone

Objects that have some vertical height, e.g. vehicles, may be detected nearer than 20m. The radius at which they are detected is directly proportional to the relative height of the object to the height of the radar above the ground. Our analysis has calculated that this near unit shadow has created a blind spot of approximately 3.3% of the coverage zone (i.e. 96.7% detection zone) in the Phase Two trial which is within the minimum requirements of the SVD specification item 2 of "90% of the carriageway where no hard shoulder exists".

Central Reservation Shadow

Smart motorway ALR schemes usually have solid concrete barriers along the central reserve which will block the radar signal, and create a "radar shadow" on the far carriageway from where the radar unit is installed. Large vehicles parked in an ERA will also cast a shadow, which, depending on the relative positions of the radar and vehicle, may fall within the carriageway.

In most layouts, the central barrier is lower than the height of vehicles, meaning there is little chance of the barrier obscuring the opposite carriageway. In certain exceptional circumstances, such as near an uphill gradient, or on low radius curves where the radar is mounted on the inside of the curve, the geometry will cause the extent of the radar shadow to increase compared to a flat, straight section. Alternatively, downhill gradients away from the radar will reduce the extent of the radar shadow compared to a flat section; while if the radar is on the outside of the curve then the comparative effect on the shadow is minimal. Depending on the actual values, one of these two factors (gradient or curvature) will be dominant.

Usually, the dominant factor is gradient, but this may not be fully obvious to those responsible for the positioning of the radar. At the location where a blind spot has been observed on the M25, the available data suggests that the top of the central reserve barrier is in fact higher (in absolute terms) than the radar at that point. This means that the blind spot covers all the lanes on the carriageway away from the radar.

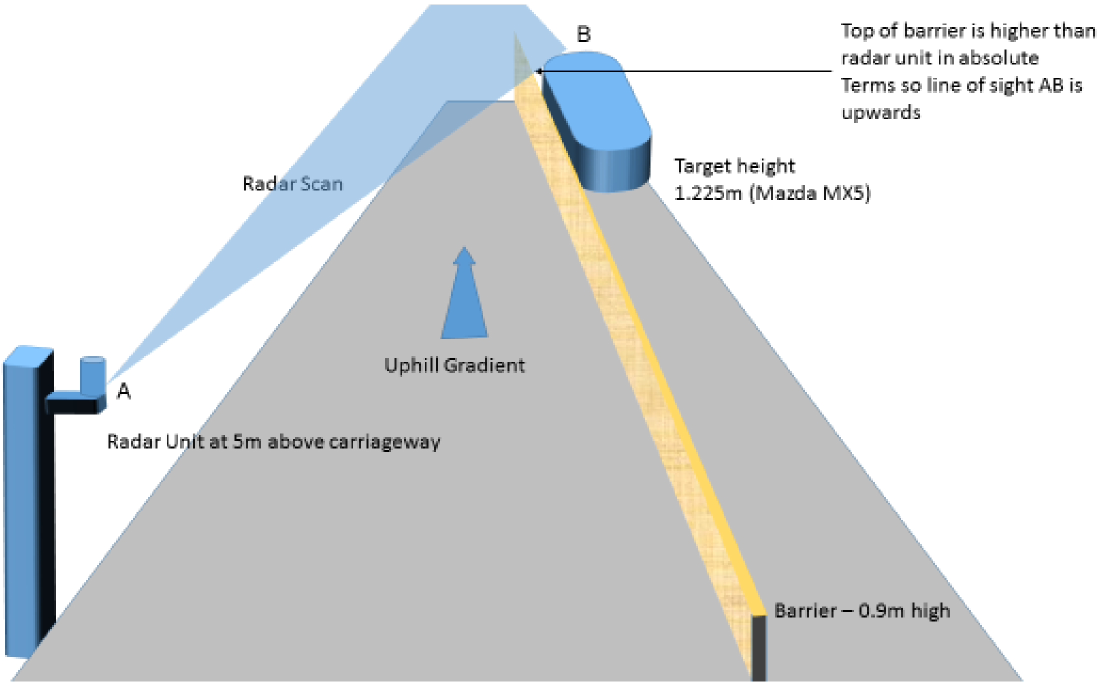

Figure 5 - Vehicle taller than barrier but with an uphill gradient

The alignment of the radar beam cannot eliminate or even reduce the extent of the shadow. Tilting the radar only changes the proportion of the beam either side of the barrier. This changes the location of the shadow within the radar image but does not affect its extent.

Mounting the radar higher would mitigate the issue to some extent. If the radar was mounted at 10m then the radar shadow for a 2% gradient would not become a problem until well over 450m from the device. However, this would also increase the size of the “non-detect” zone in the immediate vicinity of the radar up to 40m radius at ground level.

Reducing the distance between the radar and the edge of the carriageway would only offer a small reduction in the extent of the shadow.

Vehicle Shadow

Any stationary object, including vehicles, will cast a shadow. If Radar are positioned adjacent to ERAs where stopped vehicles, particularly HGVs, may be a common occurrence, then the device needs to be near enough to the carriageway edge that vehicles parked in the ERA are outside of its view along the carriageway beyond the ERA.

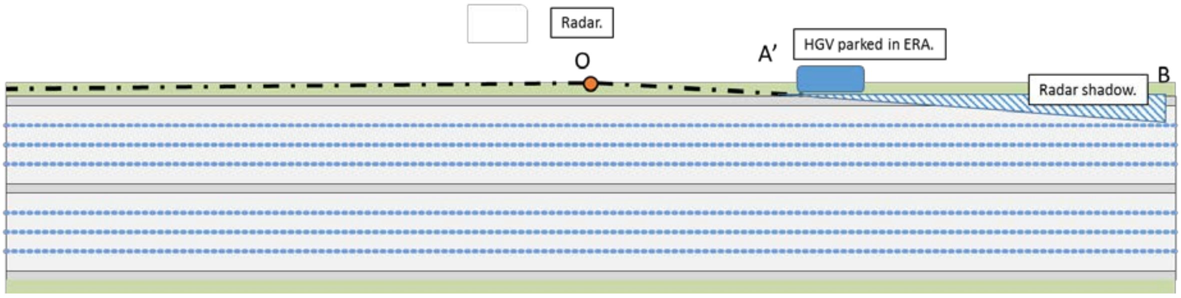

Figure 6 - Plan view of radar shadow from large vehicle in ERA

Central Reservation Lighting Shadows

Where a section of motorway is lit by luminaires mounted on columns in the centre reserve there is the potential for interference with the scanning radar beam in two ways; either the shadow cast by an individual column or by the apparent spacing of columns being too close to discriminate between when viewed from the position of the radar.

The further the lighting column from the radar the further away the shadow is cast and the longer the shadow is in the longitudinal direction. Additionally, the difference in bearing between successive columns will reduce the further away from the radar detector they are. If this bearing between lighting columns becomes less than the radar azimuth angle, then the radar will not be able to distinguish between them and anything on the far carriageway. From that point onwards the lighting columns effectively obscure the far carriageway.

For motorways that have lighting columns in the central reserve, radar will be required with radius ranges between 120-145m or on both sides of the carriageway.

The above issues are not unique to radar detection, they exist for any “point” detection method positioned only on one side of the road, including CCTV and LIDAR.

Requirement: detection zone coverage >90%
Observation: detection zone coverage 96.7%

6.7. Task I: Recommend optimum coverage

Evaluation Requirements

To assess the impact of radar coverage, and hence to recommend an optimum level of coverage based upon a critical point at which there are diminishing returns for increasing coverage.

To ascertain the optimum coverage level for radar based SVD implementation, we used the detection zone requirement (90% of carriageway where no hard shoulder exists) and the detection rate requirement (80% of the total number of isolated stationary vehicles) cited as part of the requirements for the SVD system.

The table below indicates the quantity of radar required for different scheme lengths, for a range of radar radii.

Radar Radius Range (m)	5 km Scheme	10 km Scheme	13 km Scheme	20 km Scheme
150	17	34	44	67
175	15	29	38	58
200	13	25	33	50
225	12	23	29	45
250	**10**	**20**	**26**[4]	**40**
275	10	19	24	37
300	9	17	22	34
325	8	16	20	31
350	8	15	19	29

Table 6 - Number of radar required at various radar radii

- **Spacing – Trial analysis**

The Phase One trial used SVD radar which had an operational radius of approximately 350m, resulting in a detection accuracy rate of 55%. The Phase Two trial used SVD radar with an operational radius of approximately 250m, giving a detection accuracy rate of 91.4%. Assuming a linear relationship between radar radius and detection accuracy would suggest that the maximum radar radius required to deliver the target 80% detection rate would be around 275m.

- **Azimuth error**

Azimuth error is the bearing error due to horizontal diffraction. It represents the accuracy with which the radar can place the SVD object on the carriageway. The **CTS-350X** SVD radar used in Phase Two have an azimuth error of 2'.

At the outer extent of the radar range on the Phase Two trial (250m), a 2' error equates to 4.37m azimuth range – meaning a detected object may be reported up to 4.37m away from its true location. This could result in a vehicle which stops in LBS4 on the alpha carriageway being (incorrectly) detected on the bravo carriageway.

New radar proposed by the current trial supplier, Navtech, are reported to have an improved azimuth error value of 1.6', which equates to 3.5m azimuth range at 250m. However, this could still result in stationary vehicles in the lane nearest the central reservation being incorrectly detected on the opposite carriageway.

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[4] 27 Radar have been installed on the M25 due to line of sight issues, a 'generic' 13km scheme would only require 26 radar with radius range of 250m

Our analysis has shown that if the new radar are used, accurately detecting SVD incidents, which occur in the lane nearest the central reservation at the extremity of the radar ranges, would require the radius to be reduced to 200m[5]. This would increase the number of radar on a 13km scheme from 26 to 33 (an increase of 25%).

While there is a small possibility that a valid SVD event will happen in the lane nearest the central reservation at the extremes of coverage, we suggest that a 25% increase in the number of radar required is not a cost effective mitigation. RCC operators will still receive an SVD alarm for the incident, and following confirmation of the exact location, the appropriate signs and signals could be set.

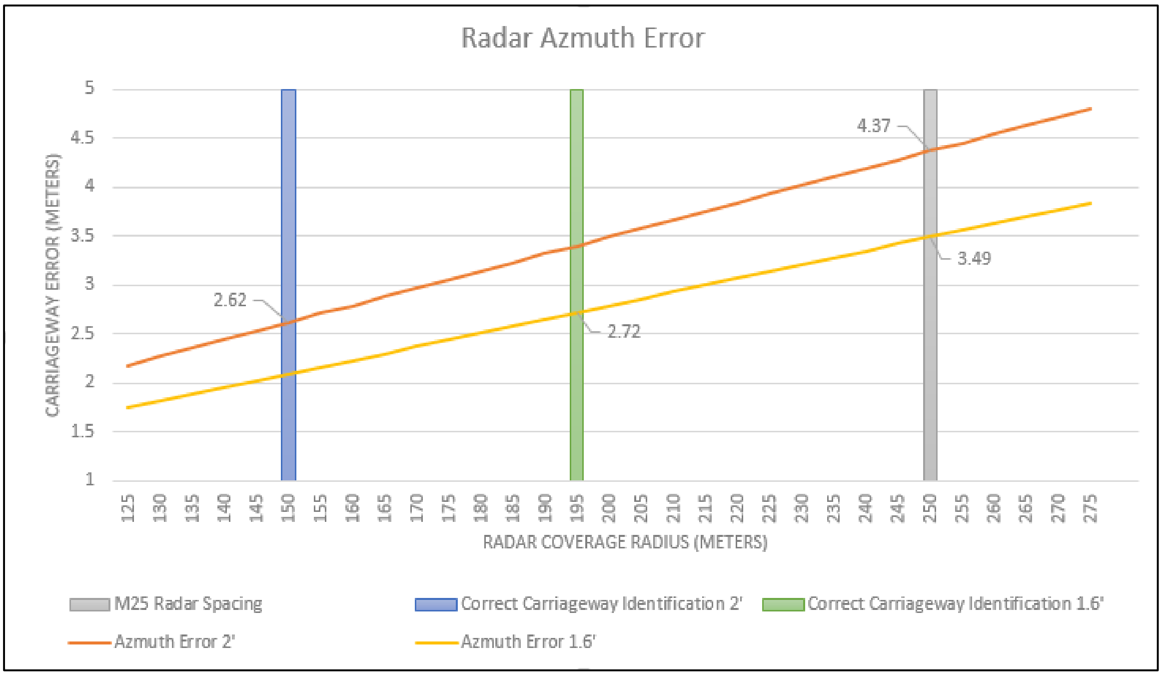

Figure 7 - Radar Azimuth Error Calculations

- **Road curvature, Gradient**

As described in Appendix 01 road curvature and gradient has a significant effect on radar spacing. As these are location specific a site survey will be required for each proposed SVD scheme in order to establish whether a spacing of less than 250m is required to ensure SVD coverage is maintained.

- **Blind Spots – Radar Spacing**

Phase Two radar have an approximate 3.3% drop in coverage area due to ‘near device’ blind spot (as described in appendix 01). We have assumed that if the radius range of the radar is 250m; to eliminate this blind spot would require radar to be spaced 250m apart (doubling the amount of radar required). Given the 96.7% coverage is well within the 90% coverage requirement we would not recommend changing the radar spacing to fill in these blind spots.

Task E showed that 17.5% of the missed detections occurred due to vehicles stopping within the near device blind spot of radar co-located with large infrastructure items. We suggest that, to help reduce the number of missed events, any subsequent installation avoids mounting SVD detectors on existing gantries and similar structures.

- **ERA coverage**

Although automatic detection of vehicles entering an ERA is not a requirement of the ALR design, Phases One and Two of the SVD trial demonstrated that such detection is possible using the SVD

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[5] Assuming the Central reserve is 2m wide (1m with a single carriageway) and LBS4 is 3.2m wide, this equates to an allowance of 2.6m for a car stopping in LBS4 to be detected in the correct carriageway.

system. This could be considered an additional benefit in future, however during the trial these alerts were not distinguished from ‘genuine’ live lane stops, meaning operators were expected to treat ERA alerts as potential live lane events.

In order for the system to distinguish between ERA SVD events and Live Lane SVD events we recommend that an SVD radar is located within 50m of the ERA which would enable the ERAs to be marked out of the detection area. A similar approach is to locate radar near other areas known to generate unwanted alerts, such as motorway service areas, slip roads, and maintenance access areas.

Determining the optimum positioning of SVD radar is a location specific exercise. A site survey is required to identify the necessary coverage near structures such as overbridges. Using a maximum radar radius of 250-275m would provide the required 80% detection rate and 90% coverage detection zone requirements.

6.8. Task J: Test ability of system to "clear" alert

Evaluation Requirements

To test the ability of the SVD system to mark an alert as "cleared" if the vehicle moves off before the operator has dealt with the alert.

The ability of the SVD system to clear an alert once the stationary vehicle moves off is important in terms of both eliminating unnecessary operator workload and maximising operator confidence in the system. Highways England have specified the requirement for the SVD system is to "be able to maintain a continuous alert until either the vehicle moves or an operator classifies the alert as "clear" or "confirmed"."

Whenever a stationary vehicle is detected by the SVD system, an "Alarm On" record is created. When the SVD radar detect that the vehicle has moved off, an "Alarm Off" record is created. Analysing Phase One and Two data, we found no instances where an "Alarm On" record did not have a corresponding "Alarm Off" entry, and no instances where a new alert was generated at the same location while a previous alert remained active. This demonstrates that the SVD system does not create multiple alarms for the same marker post section when the original stationary vehicle is present.

The NVR and HATMS date and time records do not match directly, meaning that manipulation of the HATMS dataset is required to enable correlation between the two data sources. As a result, definitive time differences between the timestamps for the system to 'deactivate' the alert after the previously stationary vehicle moved off cannot be made directly. However, by comparing the different values of incident duration as calculated through CCTV analysis and via the HATMS logs we are able to give an indication of effectiveness of the SVD system in clearing the alerts when appropriate to do so. A breakdown is provided in the table below.

Number of SVD Events analysed	1492
SVD Event classified by RCC Operator before the SVD radar cleared the alert	539 (36.1%)
SVD Not Classified by Operator	
• Up to 2 minutes difference between CCTV and HATMS event durations	827 (55.4%)
• Up to 5 minutes difference between CCTV and HATMS event durations	66 (4.4%)
• Up to 10 minutes difference between CCTV and HATMS event durations	23 (1.5%)
• Up to 30 minutes difference between CCTV and HATMS event durations	23 (1.5%)
• Up to 60 minutes difference between CCTV and HATMS event durations	12 (0.8%)
• Greater than 1 hour difference between CCTV and HATMS event durations	2 (0.1%)

Table 7 - HATMS vs CCTV SVD event duration

If an operator has not classified the event within a period of one minute after the radar detect that the vehicle has moved away, the SVD system records an alarm as 'auto cleared'. Applying a threshold of 1 minute[6], our analysis of the CCTV footage indicates that the system correctly clears 91.5% of the alerts.

This leaves 8.5% of the SVD alerts which are incorrectly stated as "auto cleared" when the event is still present. The most likely causes of this discrepancy are either the radar losing the track data from the stationary vehicle (e.g. due to other vehicles passing close by) or where the event has been captured in the dynamic update to the clutter map.

The evaluation project therefore recommends that the operational procedure should state that all alarms (including those due to be auto-cleared) must be reviewed, as this will help ensure that all genuine SVD incidents are properly investigated.

Requirement 90% Met

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[6] 30 seconds added to start & end of the CCTV analysis times to take into account human / computer detection accuracy.

6.9. Task K: Record Traffic flows

Evaluation Requirements

To record traffic flows when the system is on and off.

Requirement 3 of the 'Stopped Vehicle Detection Trial – System requirements' states that the traffic flow range for detection and rate of detection should be *'>80% of the total number of isolated stationary vehicles (in <1000vph per lane conditions)*'. As the section is four lanes in each direction, this equates to 4000vph for the whole carriageway.

During both Phases One and Two of the trial, there has been no mechanism which would allow flow data from HATMS to drive the suppression of the system, such as when a particular flow threshold has been reached. Instead, the SVD system monitors traffic volumes itself, and suppresses alerts according to the following rule: *"when more than 4 vehicles within a 100m section are moving slower than 20mph, the system is classified as congested / in queue and no alarms will be raised for that section while this condition is still present".*

Our evaluation used MIDAS data from the corresponding section of the M25 to determine the equivalent flow figures at the time each genuine alert was raised. The graph below shows the distribution of valid live lane true positive alerts generated under various flow conditions, and this indicates that around 15% of the alerts were created when flows exceeded the 4000vph threshold.

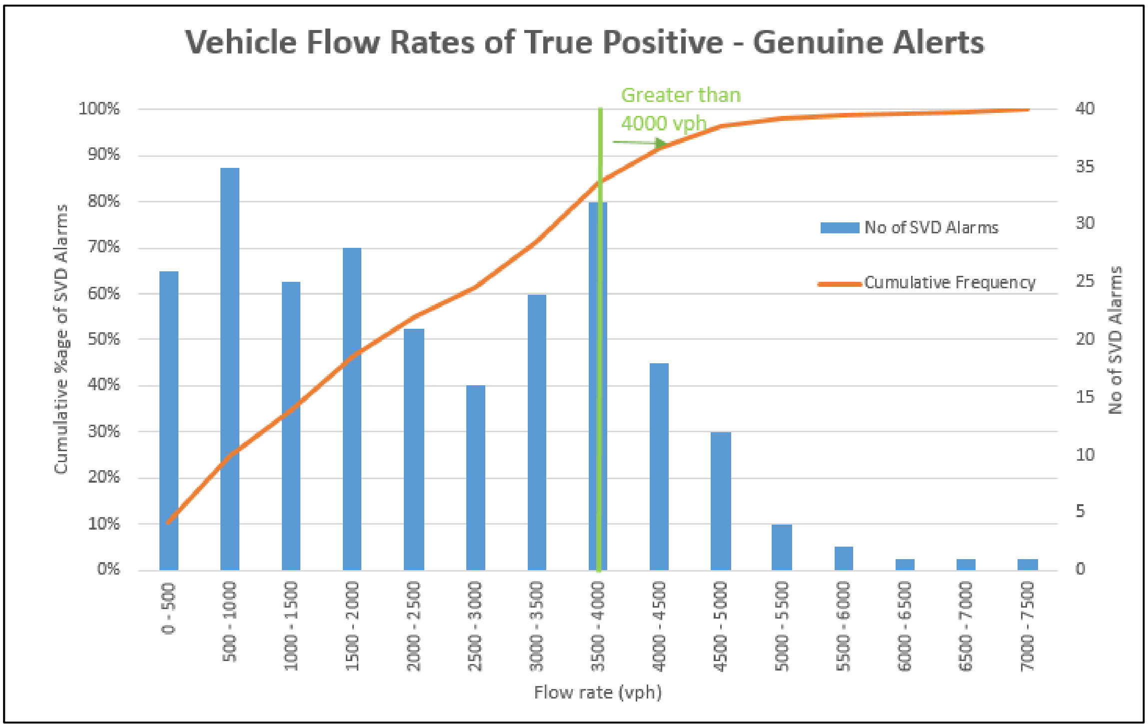

Figure 8 - Vehicle Flow rates of SVD Alerts

Although this does not strictly meet the requirements of the trial it has allowed us to test one of the operational assumptions used during the SVD trial, specifically;

- During high flow conditions, a live lane obstruction will quickly create congestion behind it. This allows the resulting queues to be detected by the queue detection system required by the ALR design, and the system automatically requests reduced speed limits on the approach to the scene.

Reviewing a sample of the 15% of alerts created when flows exceeded the 4000vph threshold, the high flow conditions did usually result in congestion being created behind the incident, however this was often only short in both duration and length, and would only have triggered the MIDAS queue protection if the incident happened in close proximity to the MIDAS loop sites, contrary to the initial assumptions of the trial.

6.10. Task L: Record system timeliness

Evaluation Requirements

To test the timeliness of the system as per the below four components:

(i) Time between the detection at the roadside and setting the Alert in the OIF i.e. delay within the system from detection of event to presentation of the information.
(ii) End to end time from when a vehicle has stopped (validated by image verification and or CCTV or other means) to an alert being received on the OIF.
(iii) Time from when the alert is available to when it is first processed as an event by the operator
(iv) Time from when the alert is first process by the operator to when the appropriate outcome is achieved, if at all.

During Phase Two of the trial, the activity of responding to the SVD alerts was shared between up to three RCC operators performing the Traffic Management Desk (TMD) role within the SE RCC. Visual alerts were provided to operators via COBS throughout the trial, augmented by audible alarms from 23/12/15. The RCC Operator process for responding to SVD alarms involved:

a) Acknowledging the SVD alarm (by pressing the SVD icon or selecting it from the menu) to show the alert status screen;
b) Reviewing the alert status screen to establish the location of the SVD event, and the CCTV camera(s) which can be used to view the event;
c) Initiating the Investigation of the SVD alarm (by pressing the Under Investigation Button for the applicable marker post on the alert status screen).Selecting the relevant CCTV camera to ‘scan’ the road for an object that could have caused the SVD alert.
d) Upon identification of an incident, notifying other operators in the room and setting appropriate signs and signals; and
e) Classifying the event on the SVD alert status screen.

The NVR CCTV system used by the RCC operators uses an independent date / time logging method to HATMS, meaning that directly matching HATMS logs with the timestamps from the NVR CCTV system was not possible. Instead, we determined the time delay between detection at the roadside and the alert being presented via the OIF as part of our evaluation for Tasks A-D. Our method was to:

- Gather the CCTV footage for a sample of True Positive Events (those where the CCTV camera was positioned to allow the stopped vehicle to be seen);
- Note the timestamp on the CCTV camera when the vehicle originally came to rest; and
- Compare with the timestamp when the PTZ camera started to move (indicating that an operator had responded to the alert).

Responding to SVD alarms

During Phase Two, we found that when audible alarms were not enabled only 19.7% of the 1147 alarms presented to operators were investigated (activities a) to c)) before the SVD system classified the incident as auto-cleared[7]. When audible alarms were enabled this increased to 53.4% (of the 2415 alarms), however in comparison, the alerts raised during the Phase One trial had an 87% investigation rate with no audible alarms.

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[7] The SVD system sets alarms as auto-cleared 60 seconds after detecting the root cause of the SVD alarm has gone i.e. vehicle has moved off.

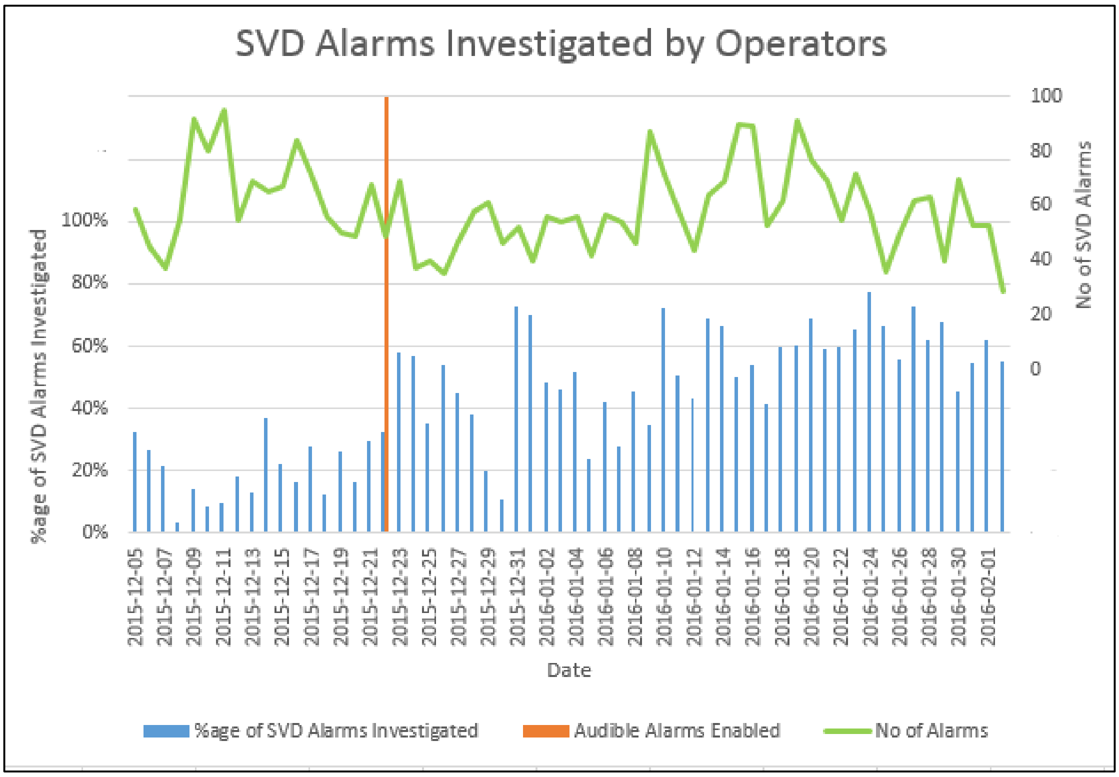

Figure 9 - SVD Alarms Investigation Rate

Our investigation indicates that this may be due to operators in the SERCC performing other activities, which impacted the response time to SVD alerts. Additionally, due to the greater geographic extent in Phase Two, there were approximately 200% more alarms raised per day than during the Phase One trial.

Reviewing the True Positive events where operators were able to investigate the cause of the SVD alarms when the audible alarms were enabled showed that the four stages of the above process (a-d) took an average of 11 seconds. The shortest time recorded was 4 seconds, and 75% of alarms were being investigated by operators within 30 seconds of the alarm being raised.

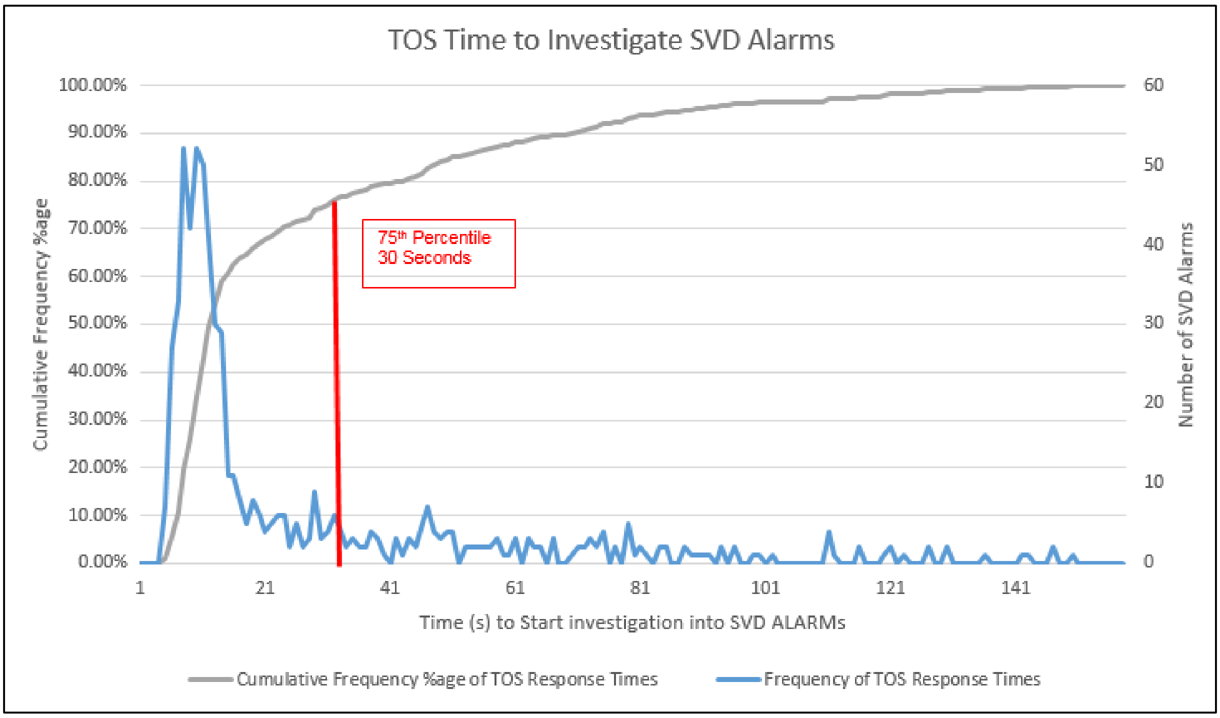

Figure 10 - Time to Investigate SVD Alarms

Classification Time

The shortest time observed for all five stages of the above process (activities a-e) was 6 seconds. As the radar system is configured such that an alert is not raised on the OIF until a vehicle has been stationary for 12 seconds, this means that in the best case scenario, the vehicle was stationary for only 18 seconds until an operator had verified its presence.

When compared to the requirements specified for the trial (replicated in the table below, as <20 seconds to detect, plus 10 seconds to notify) the quickest responses observed during the trial confirm these requirements have been met.

Ref	Category	Minimum Requirement
4	Time to detect	<20 seconds from vehicle stopping
5	Time to notify	An alert must be presented to the operator within 10 seconds of being received from the SVD system.

Table 8 - SVD Detection and Notification Requirements

The evaluation has observed that on average, the process takes 50 seconds for a SVD event to be verified and 90% of events are verified within 2 minutes of an alert being presented to the operator. The graph below plots both the individual and cumulative frequencies of events classified, against the time taken for RCC operators to do so.

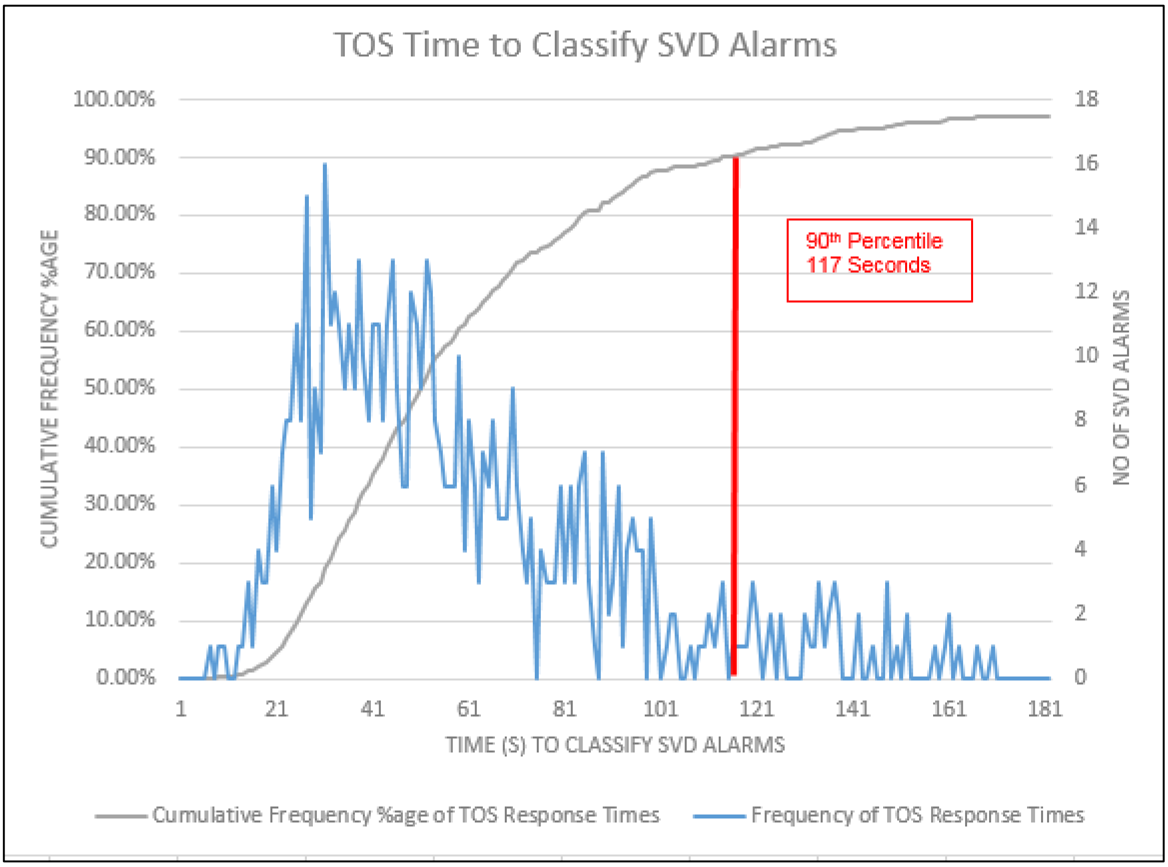

Figure 11 - Time to Classify SVD Alarms

The data shows that over 90% of all the SVD alerts investigated during Phase Two were classified within two minutes of being presented to the operators. By way of comparison, the Phase One trial results showed an average classification time of 64 seconds. Our investigation again indicates that this may be due to operators in the Phase Two trial having other tasks to perform that meant they were unable to respond as quickly to the SVD alerts.

The SVD system can only provide a safety benefit in the event of a genuine incident by enabling operators to set signs and signals to protect the scene earlier in the incident lifecycle than would be possible if the SVD system were not present.

The RCCs have a Key Performance indicator to set signs and signals within 3 minutes of an incident being verified. Assuming that once a broken down vehicle (or other incident) has been detected on the network by any means, the corresponding actions required to set signs and signals take the same amount of time regardless of the detection methods; the overall time from the detection of an SVD event to the setting of appropriate signs and signals would take less than 5 minutes on average.

6.11. Task M: Test usability

Evaluation Requirements
To test the usability of the system.

Unlike some of the other evaluation criteria, assessing the usability of a system is subjective, as it relies on obtaining and interpreting operational feedback. This system was implemented on a trial basis and the processes and procedures adopted reflect this.

For example, during Phase One in the NE RCC, the responsibility for responding to the SVD alerts was given to a single resource per shift; whereas in the SE RCC, the responsibility was spread between three operators performing the TMD role.

The specification for any fully-implemented SVD system must seek to address the concerns raised by those participating in the trial, so during the course of the trial we conducted interviews with, and reviewed answers to questionnaires submitted to, control room operators, team leaders and operations managers. This gave them the opportunity to comment on the trial, and to provide feedback and suggestions as to how the system could be improved. A summary of their key comments and concerns is provided below:

- **Perceived Detection Rate –** The perception of the operators is that the system detects between 40-70% of all SVD incidents. Task E highlighted that the system has a detection rate of between 82.5% – 90.3% and Tasks A-D advise an accuracy rate of 91%, so the actual detection rate observed by our evaluation team is substantially higher than the operators' perception. One possible explanation emerged with the finding from Task L that only 53.4% of events were responded to before the vehicle resumed its journey. This means that for almost half of all valid event detections, the operators might perceived them as false detections as they would not realise that a vehicle had been present for a short time.

  Operators were not always aware of the reasons why SVD alerts were suppressed or not raised through the system, highlighting a potential training need.

- **Weather** – Operators advised that they observed the SVD working effectively in a variety of weather conditions and that the system would provide benefit in foggy conditions, where CCTV monitoring might not be able to detect a vehicle on the network without additional SVD support.

- **Alerts in ERAs -** Phase One of the SVD trial took place on a CALR section, where the ERAs contain loop detectors. Operator feedback suggests that the SVD system appears to perform better than the existing loop system at detecting the presence of stationary vehicles in ERAs.

- **SVD Alerts –** Feedback from the operators confirms that the combination of the visual SVD icon alert and the SVD audible alerts are sufficient to advise them of an incident to investigate. However operators also felt that COBS audible alarms (that have been enabled in addition to the SVD alarms) are an annoyance, detracting from their day to day tasks and incident management activities.

- **SVD User Interface –** Following Phase One of the trial, the OIF was updated to take account of feedback gained from that phase of the trial. Feedback from Phase Two operators indicated they were generally happy with the level of detail provided when a new SVD alarm was generated (Marker post position, CCTV camera to use) and knew how / why SVD alarms should be categorised.
  A significant amount of negative feedback (90%) related to an issue which caused the SVD alert window to automatically scroll to the bottom of the list following any interaction with the screen (This was noted in the FAT tests of the IMTECH SVD software release and subsequently used in Phase Two of this evaluation).

- **Hot Spot Alerts –** Operators also commented on the relatively high level of alarms received relating to stops in or near the Clacket Lane MSA as well as stops in ERAs, and suggested that future alerts from these locations should be omitted, or given a different priority.

6.12. Task N: Recommend reductions on resource impact:

Evaluation Requirements

To make recommendations on how the resource impact of using the system could be reduced, if it were to be further rolled out by Highways England.

We observed the end to end process of detecting stationary vehicles and taking appropriate actions. Task L highlighted that only 53.4% of events were investigated before the SVD system indicated that the cause of the alarm had gone. This has led us to propose the following actions to reduce the impact on RCC resources which should enable the source of all SVD alarms to be investigated:

Reduce Number of SVD Alarms

To reduce the impact on RCC resources required to respond to SVD alerts, one option is to reduce the number of SVD alarms presented to them. (During Phase Two of the trial, an average of 59 alerts were generated per day). The following options are available:

- **Remove ERA coverage**

  The Phase Two trial found that 54.6% of all analysed SVD alarms were related to ERA stops, an average of 28 per day. While valid True Positive alarms, the ALR design does not require any particular operator response to an ERA stop, and does not require any vehicle detection technology to be provided in ERAs. These alarms are therefore not operationally essential, and on that basis the radar coverage would not need to include ERAs. If these events were supressed from generating alerts, this would reduce the number of alarms generated to around 27 per day, a reduction of over 50%.

- **Hot Spots**

  Phase Two of the trial covered the Clacket Lane MSA. 8.1% (4.2 per day) of the SVD alarms related to vehicles stopping on the exit/entry slip roads for the services. As above, while these events represent genuine True Positive alarms, they are not main carriageway live lane events and could be suppressed.

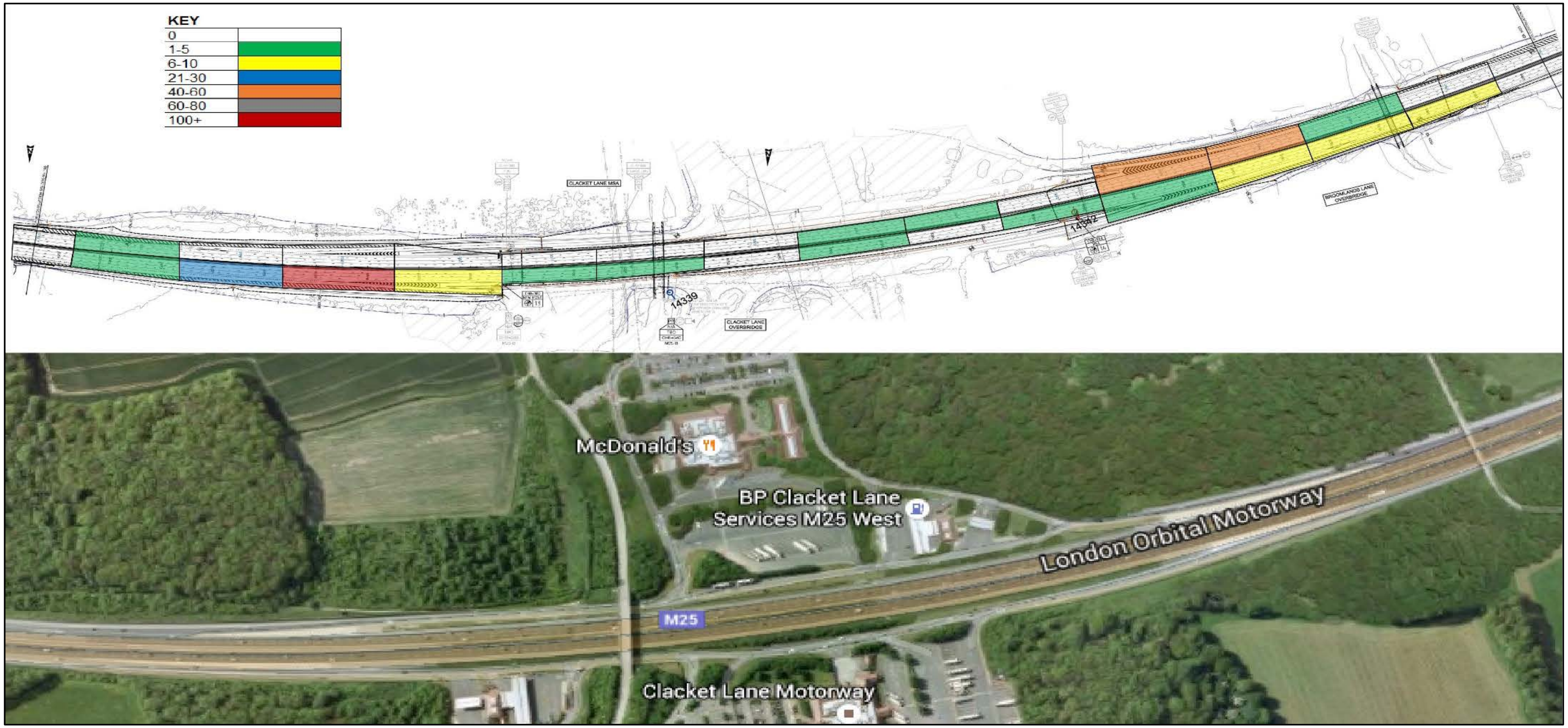

Figure 12 - SVD Alarms around Clacket Lane MSA

The MSA alarms would obviously only occur where there is a MSA on the link, therefore removing these would reduce the number of SVD alarms to circa 22 per day.

- **Stopped Vehicle Durations**

  Both Phase One and Two trials were configured to provide alarms if a vehicle was stationary for greater than 12 seconds. Increasing this time to 30 seconds or more would remove the alarms for vehicles that only stopped temporarily, however this increase in detection time would also increase the time a vehicle is 'at risk' without any mitigating actions taking place. Increasing this threshold from 12 seconds to 30 seconds for the duration of the trial would have removed approximately an additional 148 alarms from the system (~.2.5 per day).

Taking into account all of the above, suppressing alerts from ERAs, MSAs, slip roads and stops of less than 30 seconds, would have reduced the number of SVD alarms raised during the Phase Two trial from 59 per day to 25 per day, or by a reduction of over half.

Reduce Operator Interactions Requirements

A reduction in the number of SVD alarms generated doesn't necessarily mean that all SVD alarms will be investigated promptly, as the RCC operator's workload / responsibilities may mean their attention is not focused on the SVD system.

If the SVD system were to be rolled out to other parts of the network, extending the coverage would result in a scaling up of the number of SVD alarms generated, which would eventually exceed the level of alarms experienced during the Phase Two trial. Without additional changes to operations/system or the provision of additional resource it will not be possible for the RCC to respond promptly to all SVD alarms created.

Some potential methods for improving the responsiveness of RCC operators to each SVD alarm include:.

- **Dedicated Resource**
  The quickest way to resolve this issue without any system changes would be to provide a dedicated RCC resource whose primary role would be to respond to SVD alarms. Note, multiple SVD alarms may be raised at the same time meaning that the dedicated SVD resource may not be able to investigate all alarms promptly so additional measures may still be required.

- **Link to DDS – CCTV auto positioning**
  To assist in reducing the verification time for SVD alarms, the SVD/COBS/CCTV could be configured to auto position the PTZ CCTV to pre-set positions relating to the marker post of the SVD alarm. Having this footage displayed in a section of the Digital Display Screen (DDS) would bring the incident to the operator's attention and would enable a more efficient verification of incidents.

- **Link to COBS**
  To assist in reducing the time in setting signs and signals following the verification of an incident the SVD Alert interface could auto position the COBS window's view so that it focuses on the marker post section where the SVD alert was raised to enable operators to quickly select and set appropriate signs and signals.

- **Automatic Signalling**
  The Phase Two trial resulted in a very high incident detection accuracy rate of 91%. If ERA and the other non- live lane hotspot areas can be omitted from the detection zone, the system could be configured to automatically request reduced speed limits (similar to the functionality of MIDAS) while the SVD alarm is present. With the requirement for automatic signs to be displayed for a minimum time of 4 minutes[8] this would provide operators additional time to investigate these alarms.

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1. Once a MIDAS alert has requested signals and message signs to be set, the request remains live for a minimum time of 4 minutes. If MIDAS raises an alert and the queue disperses in less than 4 minutes, the signals and message signs will stay set (or the request stored) for 4 minutes.

However, enabling automatic signalling would require a very high level of confidence that there is a genuine SVD event requiring signals to be set. The two trials have only been live for a very short duration with no long term performance history available and with the functionality to remove/re-classify ERA and hotspots being untested this level of automation is a long term ambition of the system.

Current

- The SVD investigation responsibility is split between 3 operators
- SVD coverage area includes ERA, Main Carriageway and Entry/Exit Slips
- All SVD incidents in the coverage area are presented as SVD alarms.
- Operators verify SVD events by manually using CCTV
- Operators set signs and signals upon identification of live lane incidents
- COBS & SVD audible alarms enabled

Better

- Dedicated operators asigned to SVD role
- ERA and Hot Spots removed from coverage area
- CCTV & COBS auto position to incident location
- Only SVD audible alarms enabled

Best

- SVD, ERA and Hot Spot alarms presented differently to operators
- Automated signalling for SVD alarms

6.13. Task O: Recommend priority of elements from issue 1 of the SVD specification:

Evaluation Requirements
Make recommendations based upon the desirable requirements identified within issue 1 of the SVD specification

Where changes to the requirements are suggested the reference number is followed by * to indicate this, and the row is shaded.

Ref	Category	Minimum requirement	Target requirement	Trial Results	Comments
1	Minimum size of object detected	To detect vehicles that have stopped in a live lane. Vehicle dimensions 2.9m (L) x 1.6m (W) x 1.2m (H)	To be determined by the trial. Examples include motorcycles, vehicles hard against the barrier.	The trial detected a range of different sized vehicle (small cars to HGV) and pedestrians. Vehicles were detected in all lanes, hash marked areas, slip roads, verges and ERA. Pedestrians were also detected behind the safety barrier.	No changes suggested for this requirement
2	Coverage of detection zones	90% of carriageway where no hard shoulder exists.	95% of carriageway where no risk mitigations are in place e.g. ERA in close proximity.	Task H advised on numerous causes for blind spots and the near device blind spots mean that Phase Two of the trial had a detection zone of approximately 96.7%. Note, other blind spots may exist on the trial due to site specific items however these are difficult to identify and quantify.	No changes suggested for this requirement Although the higher target requirement was achieved in the Phase Two trial we would not recommended that this level becomes the minimum requirement as this would potentially increase the number of radar installed to mitigate the risk of multiple units fail at the same time and reducing the coverage zone under the minimum requirement.
3*	Traffic flow range for detection and rate of detection	>80% of the total number of isolated stationary vehicles (in < 1000vph per lane conditions	To be determined by the trial. Examples include increase % detection or increase flow rate where detection system works.	Task E (Ground Truthing) identified that between 82.5% and 90.3% of isolated stationary vehicles (in <1000vph per lane conditions) have been observed in Phase Two of the trial. Task K identified that the SVD system identified valid events at flows greater than 1000 vph per lane condition.	Remove the "< 1000vph per lane conditions" condition to enable the device to function at all traffic levels
4*	Time to detect	< 20 seconds from vehicle stopping	To be determined by the trial.	The system in both phases of the trial has been configured to report vehicles that have been stationary for longer than 12 seconds.	To remove SVD notifications for very short stops this requirement should be relaxed to only report SVD events for vehicles that have been stationary for a minimum of 30 seconds.

Ref	Category	Minimum requirement	Target requirement	Trial Results	Comments
				CCTV analysis in Task L confirms that the system detects vehicles and presents alerts after 12 seconds of them stopping.	
5	Time to notify	An alert must be presented to the operator within 10 seconds of being received from the SVD system		See above	No changes suggested.
6	False detection frequency	<1.6 per day per motorway mile	<0.2 per day per motorway mile	Tasks A-D observed a False Detection Frequency of 0.56 per day per motorway mile.	No changes suggested.
7	Localisation of detected object	±25 meters of its longitudinal position and carriageway	To be determined by the trial. Examples include determining lane.	The trial was configured to report SVD events ±50 meters of its longitudinal position and carriageway Operators feedback confirm that this level of reporting was acceptable	No changes suggested.
8	Continuity of alert	The SVD system must be able to maintain a continuous alert until either the vehicle moves (see ref 9) or an operator classifies the alert as “clear” or “confirmed”		Task J confirms that over 90% of alarm are maintained while the vehicle is still present or the operator has classed them appropriately.	Approximately 10% of all alarms were stated as clear before the vehicle has left. In some cases this was due to other traffic affecting the radar’s ability to keep a ‘lock’ on the stationary vehicle. We recommend that RCC operator procedures are updated to include a review of all events (even Auto-cleared) to overcome this issue.
9	Clearance of detection	If a detected stationary vehicle moves off the SVD system must automatically clear the detection in < 60 seconds without any need for an external intervention. This SVD must continue to be displayed in the Status List and the SVD status icon must change to a non-flashing red if no other active alerts are present.	To be determined by the trial.	Task J confirms that following a vehicle moving off an Alarm Off record is logged by the system. The functionality of SVD Status List and SVD Status Icon works are required and has been observed during FAT tests and during live trials.	No changes suggested.
10	TR1100 Compliance	The equipment shall meet the relevant requirements set out in Section 10.3 and Section 12 of TR1100 and have a 15 year service life	Compliance with all relevant requirements set out in TR1100	Not covered within evaluation task.	N/A

Ref	Category	Minimum requirement	Target requirement	Trial Results	Comments
11	Weather Conditions	All conditions, day or night that might be reasonably expected given the UK weather patterns, including fog, spray, heavy rain, snow, extreme temperatures, wind and the effects of low sun angles.			No changes suggested.
12	Communications interface	The SVD system must be capable of being interfaced with NRTS system		The radar successfully utilised the NRTS network to communicate data to/from the RCC.	No changes suggested.
13*	Remote Calibration	The SVD system must be able to maintain all other requirements whilst calibrating the system less than once in 12 months	Maintain all other requirements whilst calibrating the system less than once in 36 months	Following the initial set up of the radar no additional calibrating was observed or planned	The background clutter map may needed to be updated over time as new infrastructure is installed or when vegetation's grows / recedes. This activity may be triggered follow a certain number of unknown / invalid SVD alerts being provided to operators.
14*	Roadside Maintenance	Routine Maintenance of equipment that requires access to roadside must be less than 1 in 12 months and device swap out and set up must be able to be performed within 2 hours of reaching roadside location		No routine maintenance of equipment has observed during the trial.	Navtech have advised that routine maintenance of the Radar devices is required every 5 years.
15	Remote Fault Maintenance	The SVD system must remotely fault diagnosis all predictable faults on roadside equipment The operator must be able to view the "health" of the overall system and each unit	Remotely fault diagnosis all predictable faults on roadside equipment and log in HALOGEN	The evaluation team believe this functionality was provided but was not specifically tested within the evaluation.	No changes suggested.
16*	Mean Time Between Failures (MTBF)	70,000 hrs	130,000 hrs	No hardware faults have been observed during the course of the trial	Navtech have advised that their equipment will have a 10 year life span (assuming 1 maintenance visit at year 5) this would suggest a minimum requirement of 90,000 hrs.

Ref	Category	Minimum requirement	Target requirement	Trial Results	Comments
17	Manual suppression	The operator must be able to suppress alerts in 100m sections (using Marker Posts as the reference). This is to prevent false or unnecessary alerts occurring during roadworks or other carriageway operations		Task G confirms that this functionality was enabled.	No changes suggested.
19*	Automatic suppression during congestion	The SVD system must suppress alerts if the presence of congestion or queues is detected. This must be done in 100m sections.		Task K confirms that internal rules of the radar mean that "when more than 4 vehicles within a 100m section are moving slower than 20mph, the system is classified as congested / in queue and no alarms will raised for that section while this condition is still present".	No changes suggested. However, this information is not provided back to operators so they incorrectly think the system is working/enabled when it is not.
20	Automatic suppression in the presence of Signal alerts	The SVD system must be able to automatically disable alerts to operators when Signal Alerts are present over the same location		Task A-E confirmed that several SVD events were correctly identified but not reported to operators due to signals already being set in the area.	No changes suggested.
21	Unacknowledged alerts during deactivation	When the SVD system is deactivated unacknowledged alerts must remain on the system for the operator to classify (as per the Operator Interface Requirements). This requirement must be able to be disabled by Cubic if no longer required		This was not specifically observed during the trial this was observed during the Factory Acceptance Testing of the IMTECH release of the SVD software.	No changes suggested.
22	Alert logging	The SVD system must create a log of all detections of stationary vehicles with time and location of detection, time and reference of operator input, time of clearance and whether automatic or in response to manual input.	Data available in HALOGEN	The HALOGEN data was used as a source for the evaluation and therefore confirms this requirement has been met.	No changes suggested.
23*	Log duration	Logs must be held by the SVD system for ?? days		The data is stored in HALOGEN and therefore local logging is not required	Remove from requirements

Ref	Category	Minimum requirement	Target requirement	Trial Results	Comments
24*	Tracking data retention	Tracking logs must be available for ? days and ? days if flagged by RCC as required data		Navtech have advised that this is only available for 3 days which has proven acceptable for the investigation into issues identified.	Longer periods of data retention would require larger servers/databases and if the SVD system is to be rolled out extensively this could soon prove to be very expensive. However, this data may only be used to confirm why alerts occurred and high priority incidents for investigation should be notified to the supplier within this period so this data can be 'tagged' and evaluated off line.
25	CCTV referencing	The SVD system must direct the operator to the PTZ cameras that present the best and 2nd best CCTV coverage. This information must be displayed to the operator in the Status List. This data must be configurable		A configuration file has been provided to the evaluation team and through operator feedback and interactions with the system we confirm that this functionality has been provided.	No changes suggested
26*	Mapping	The SVD system must be visible on the OIF map		This functionality has not been provided	If a wider rollout of the SVD system were procured then this would become a requirement of CHARM
27*	Slow moving vehicle prior to blind spot	Slowing down vehicles to be detected and raise an alert prior to known blindspots		The trial observed several vehicles stopping under the radar blind spots with no alerts being provided. However, we are unable to confirm whether these missed events met the criteria for the slow moving detection rule to confirm if this requirement has been met or not.	Further consultation / requirement analysis is required to confirm whether this functionality if possible. Repositioning of radar away from large infrastructure may reduce the requirement for this functionality.

Table 9 - SVD Requirements Specification

6.14. Task P: Quantify speed of detection over current methods

Evaluation Requirements

To quantify whether the system is able to detect stopped vehicles more quickly and/or more often than the methods currently used (predominantly via emergency calls).

In this part of the evaluation we establish whether the SVD system is able to speed up the detection and validation of an event such that signs and signals can be set and on road support dispatched to protect a vehicle more quickly. The figure below illustrates the two main elements of the risks associated with the hazard of a stationary vehicle, H135:

- the time between the Event occurrence ① and the verification of the location of the obstruction ②, where the risk is greatest because it is unmitigated, and
- the time between verification ② and attendance by the police or RCC Operator ③, when the risk is somewhat reduced by setting lane specific signs and signals, for example, to warn of the obstruction, lower the speed limit, remotely close the blocked lane(s) and direct other motorists into open lanes.

After time ③, the vehicle is protected by both signs and signals and Emergency Traffic Management set out by the police or RCC Operator, and the risk reduces again.

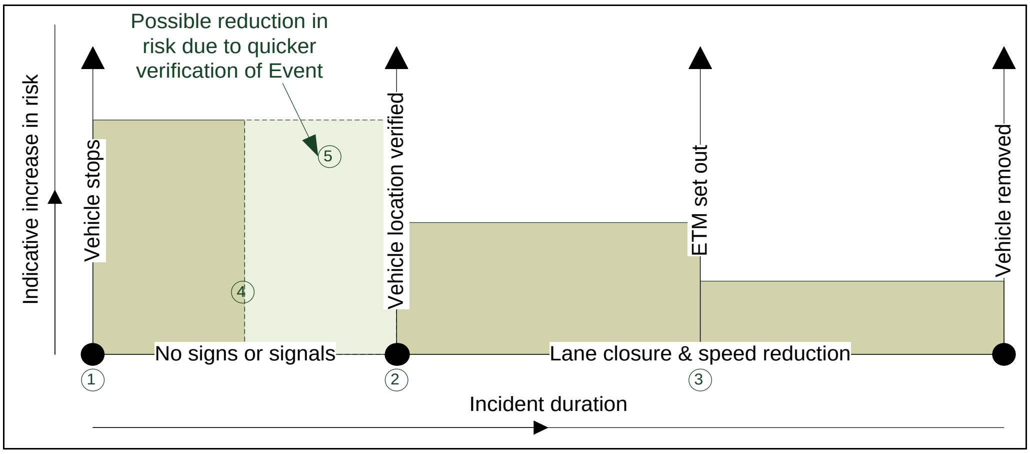

Figure 13 - Representation of the risks in hazard H135

The test is whether the SVD system can reduce the overall level of risk, by alerting the RCC operator more quickly than other methods (say at time ④). This would help to reduce the elapsed time between ① and ②, so that the risk levels can be reduced sooner, by removing block ⑤ in the diagram and shifting the remainder of the event to the left. This will also have secondary benefits of speeding up the clearance of the Event, all other things being equal.

SVD non-detection times

Command and Control (C&C) does not record the actual time the vehicle stopped as this information is not available to operators. Only the time that the incident is reported is recorded at the first instance. In order to establish the time the event occurred ① we undertook an analysis of CCTV footage.

Using C&C data for breakdown live lane incidents for the M25 J25-26 ALR scheme we reviewed CCTV footage to identify incidents where the event occurrence time ① could be recorded. We then used the corresponding C&C data to establish the elapsed time between ① and ②. Removing the outliers from our datasets, our analysis found the average time between ① and ② was 17 minutes and 1 second.

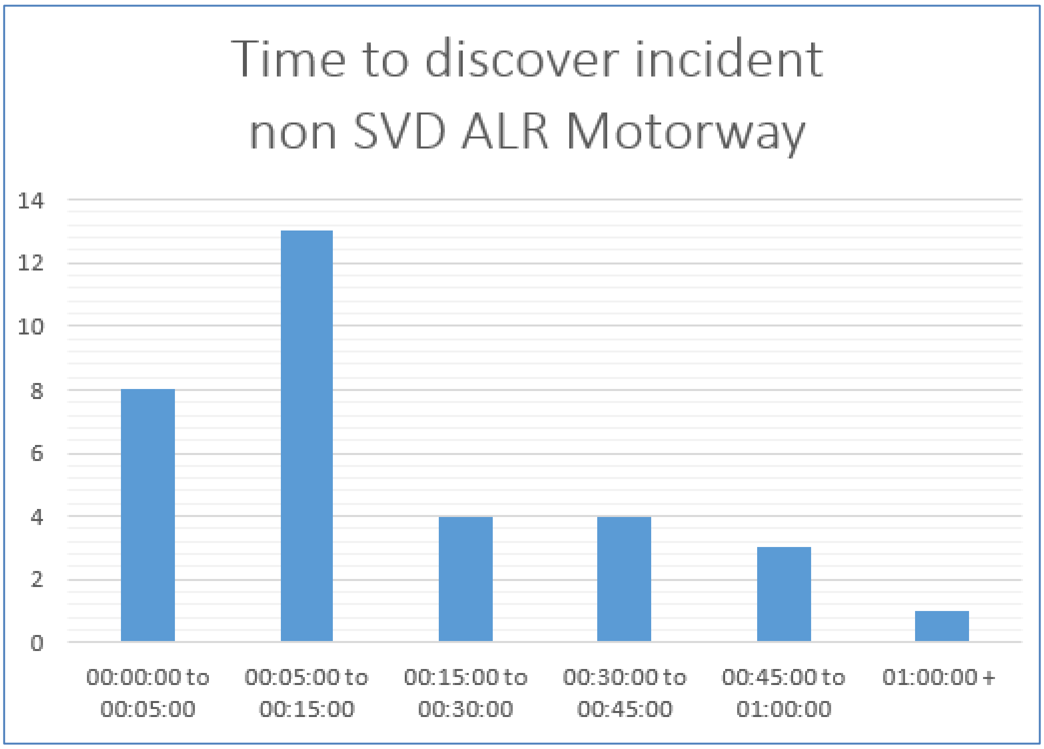

Figure 14 - Time to discover incident with no SVD

SVD Detection times

Task L showed that the SVD system is able to detect and report a stationary vehicle on the OIF within 10 seconds of the event occurring①. We could then verify and classify the event ② in an average 50 seconds. This gives a mean average time between ① and ② of 60 seconds.

This suggests that the SVD system could enable operators to set signs and signals 16 minutes earlier for live lane breakdowns, compared to locations where SVD is not installed.

6.15. Task Q: Identify likely future requirements

Evaluation Requirements

To identify the likely forward development, implementation and maintenance requirements if the system were to be permanently adopted; this will consider both the in-station and the roadside requirements.

Throughout this report, we have made a number of suggestions that we believe would improve the functionality of an SVD system. For clarity, we have repeated the improvements we believe to be essential to a wider deployment of the SVD system below, along with some additional recommendations that are considered desirable or possible.

Essential Requirements

We have identified the following items that we believe must be implemented to enable a successful extension to the trial, and support any future roll out of an SVD system:

- **Formal Procedures**
  During the trial, formal RCC operator procedures to support RCC operators using the system were not provided. Developing standardised procedures, and delivering the associated training in their use, would help to increase the number of incidents investigated before the incident has cleared, which in turn would reduce the time that a vehicle is left undiscovered without any mitigating actions taking place.

- **Regular Clutter Map Updates**
  The physical environment of the SVD detection area will change over time, for example due to seasonal vegetation growth. Any changes in the detection area can cause the radar to incorrectly identify stationary objections on the network, an observation supported by evidence from Phase One, which returned an increasing number of False Positive alarms as the trial progressed. Regularly updating the Clutter Map (i.e. the background image used as the baseline by the radar, against which it attempts to identify a stationary vehicle) would alleviate this problem. The optimum update frequency would need to be determined following a longer trial period – the durations of both Phases One and Two were too short to allow firm conclusions to be drawn.

- **Removal of ERA / Hotspot Alerts**
  As detailed in Task N, the removal (or suppression) of ERA and Hotspot alerts has the potential to significantly reduce the number of alarms presented to the operator each day, although it does increase the risk that some genuine live lane incidents are not detected. Further evidence is required to determine the optimum balance between ensuring successful detection and minimising unnecessary operator workload.

- **Audible Alarm Separation**
  Task M highlighted that audible COBS alarms are an annoyance in the control room, and can distract operators from other activities. In order for the system to be successful, the COBS alarms need to be disabled, while the SVD audible alarms are retained.

Desirable

We have identified the following items that we believe would further help maximise the benefits of any future trials or wider roll out of the system:

- **Alert Classification**
  Although we recommend above that the ERA and Hotspot alert areas are removed from the detection zones to reduce the number of alerts raised, they can provide useful information to operators (such as notification that a vehicle has entered an ERA). As there is no requirement for operators to respond to these alerts, an improved system would be able to differentiate between a ‘genuine’ alert, and an ERA/Hotspot alert, and present them in a different way. This would mean the operator can focus their attention on the most critical alerts, and would be free to investigate and respond to lower priority alerts when resources allow.

- **Trend analysis**
  Analysing the pattern of SVD alerts could help to identify localised trends in road user behaviour. Monitoring factors such as ERA usage would help identify issues and develop suitable mitigation strategies. As the data is already stored in HALOGEN, the only additional costs associated with this activity would the resource required to access and analyse the data.

Possible
The following is expected to further increase the benefits of any future trial or system roll out, although additional work would be required to implement the necessary changes:

- **Fused Data**
  The SVD system produces a large amount of real time data concerning traffic movements within the detection area. This data could be fused with other data sources, including those already used by the National Traffic Information Service (NTIS) or RCCs to provider greater granularity. It may also be possible to use the data to supplement, or even replace some data collected by MIDAS. Further investigation is required into the potential for data fusion, which should be addressed by the Common **Highways** Agency Rijkswaterstaat Model (CHARM) implementation team.

Task R: Develop likely Benefit Cost Ratio

Evaluation Requirements

To develop a likely BCR for the system, given the data coming out of the evaluation and the quantification of the risk level against the cost in accordance with GD04 safety risk assessment [Design Manual for Roads and Bridges].

Background

The primary objective of a SVD system is to alert the RCC operator of a vehicle stopped in a live-lane which might not be detected by existing means. Reducing the "time to discover" element of the incident lifecycle (i.e. the time between a vehicle stopping and the time the RCC is made aware of it), enables upstream warning signals to be set earlier, meaning that approaching drivers are warned sooner, thereby reducing the time period that the stopped vehicle (and any occupants) are exposed to the unmitigated risk.

The SVD trial Stage 0 Report[9] from 2013 described an outline business case for the deployment of a stopped vehicle detection system based solely on the anticipated reduction in deaths and serious injuries (KSIs). This is a simplified view which only gave an initial estimate of the benefits that can be expected since, in addition to reducing the risk of an actual collision, early notification also serves to reduce the likelihood of a near miss, such as one where due to the absence of any advance warning, an approaching vehicle makes a last minute lane change to avoid a collision. Reducing the near miss frequency also provides a benefit, and this report attempts to also quantify that benefit as part of the wider business case.

Approach

The results from Task P quantify the change in "time to discover" that we have observed when using the SVD system. The 2013 analysis of the safety risks associated with stopped vehicles on ALR[10] estimated the rates of KSI categories expressed per carriageway mile and, of more relevance here, per live lane stop. By combining these values with information on the duration of the time to discover (TD) for live lane stops on the M25 recorded in the Command and Control logs, we are able to determine a rate per "TD-minute" for each of the KSI categories.

The analysis in Task P of current methods of detection has given us the distribution of TD durations in an environment where SVD is not deployed, and we have used this frequency distribution to estimate the number of stopped vehicle incidents in each time band. Only around one quarter of such incidents are detected within five minutes using current methods, and in comparison, the TD when SVD is deployed is typically less than 1 minute (see Task P for full details). For the purpose of the analysis we have selected a value of 1 minute for TD with SVD deployed.

Using this value and multiplying by the KSI rates per exposure minute, we can estimate the number of KSI per stop avoided by the improved response time and reduction in exposure. We can then estimate the number in each category of KSI and, in turn, apply the monetary value for prevention of each category used in standard transport scheme appraisal to determine a quantified benefit.

The full working is given in Appendix 02.

The MM_ALR Hazard Log[11] estimates that setting signs and signals reduces the incident risk by 40%, which allows us to estimate a rate of occurrence per minute of each of the accident types when no signals are set as shown in the table below.

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[9] 20130913 - SVD trial Stage 0 Report v1.1

[10] Managed Motorways All lanes running: Managing the risk of vehicle stops in the carriageway, 18th April 2013, Version 1.00, Ref: 1049773_DOC_VSC

	Rate per minute with no signals set
Near miss rate - fatal	5.22E-06
Near miss rate serious injury	1.24E-05
Near miss rate slight injury	1.01E-04
Near miss rate damage only	1.01E-03

Table 10

Assumptions

KSI rates: The values for the rates in Table 10 above are based on those used in the MM-ALR design analysis. Although data is now available for the first year of operation on the M25 ALR sections this is too short a time period, and the total length of carriageway is also too short, to generate statistically robust values. Therefore, we have elected to remain with the design values. The initial data from the M25 does show lower KSI rates than anticipated which means that the estimates of benefits are likely to be high and can be regarded as the maximum benefits that can be realized.

Breakdown rates: The initial data from analysis of the C&C logs for J5 to J6 by the M25 Operational Impact study reported 1616 live lane breakdowns in 580 days, a rate of 2.8 per day. The observed rate in the trial was substantially higher at 5 per day. This difference may be in part due to the way data is recorded in C&C logs and because the SVD system identified a number of short duration stops that are not currently discovered by TOS and hence not in the logs. We have not been able to set these values against traffic data to obtain a value for Vehicle stops per 10^6 miles. Again, this ambiguity in the data means that we have elected to work with the design data for the purposes of estimating the benefits and this may mean that the values are over-estimated. These areas should be subject to further work to provide robust estimates from actual data.

Reduction in overall incident duration: We have assumed that the overall duration of each incident is reduced when using the SVD system, because it is detected more quickly, the RCC operators react to the alerts and dispatch resources as soon as they are aware of the incident. However in the Appendix we have also calculated the (worst case) impact of assuming that the incident duration is not reduced at all, where the benefit is only derived from the protection given because signs and signals are set more quickly. This is what would occur if there was not sufficient resource be able to despatch to scene more quickly. It does not give a positive BCR, but we consider it to be an unlikely scenario.

Exposure to near misses

The total exposure to near misses is the number of stopped vehicle events multiplied by the duration of exposure, TD. Instead of using a single average value we used the distribution from Task P to determine the exposure in each band and then sum across all bands to get the total.

During the trial we observed that the traffic levels fall into two distinct groupings – low flow overnight between 20:00 and 06:00 and high flows during the rest of the day, 06:00 to 20:00. There are different rates of vehicles stopping in these two periods, so we have analysed them separately and then added together to get the final value.

For each of the two flow periods (high and low) we can use the trial data to determine the stopped vehicle rate per carriageway km per day, as shown in Table 11.

No of stops in high flow period during trial	151
No of stops in low flow period during trial	98
Length of trial (days)	57
Length of site in km	13
Stops in high flow per carriageway km/day	0.102
Stops in low flow per carriageway km/day	0.066

Table 11

If we take the example of an indicative 20km scheme using the method described in the appendix we estimate the following benefits:

	(a) WEBTAG Value adjusted to 2016	(b) Benefit (2016 values)
Valuation of accident- fatal	£ 2,087,399	£ 223,404
Valuation of accident- serious injury	£ 238,149	£ 60,668
Valuation of accident- slight	£ 25,136	£ 51,909
Valuation of accident- damage only	£ 2,226	£ 45,971
	Total	**£ 381,951**

Table 12

Costs

We have analysed the capital and maintenance costs of installing a system based on the Navtech radar. The costs include civil engineering and the computers at the RCC. We have then scaled the costs to estimate values for schemes of 5, 20 and 100km in length, to account for economies of scale in the costs. Appendix 2 shows the breakdown of costs.

Net present value (NPV) analysis

In order to assess benefits and cost on an equitable basis we need to consider each of the scheme sizes (5, 20 and 100 km) over a 10 year period. This involves calculating the benefits and costs for each year.

Finally, we apply a “discount factor” to bring all future year values back to the base year, 2016 values. The discount factor applied is 3.5%, this being the value for schemes of 0-30 years given in DfT: WebTAG: TAG data book, December 2015.

We then divide the NPV value for benefits by the NPV value for cost to give a Benefit Cost Ratio (BCR). We have calculated BCR values over each indicative scheme length as shown below. Table 14

Scheme length (km)	Benefits	Costs	**BCR**
5	£ 2.4M	£ 1.6M	**1.49**
20	£ 9.6M	£ 6.8M	**1.42**
100	£ 47.9M	£ 27.9M	**1.72**

Table 13

Conclusion

From Table 13 it is clear that the positive benefits exceed the costs of the implementation when the overall duration of stopped vehicle incidents reduces by the same amount as the reduction in the time to discover, TD. The BCR ratio improves with size of scheme.

To realise these benefits, the TOS must continue to have the resource to be able to react in a timely fashion to the alerts, and despatch resource as soon as they detect an event, reducing the overall duration of the event when compared to that expected without the SVD system. As discussed in the assumptions section, these benefits will also be less if the ALR schemes prove to have fewer KSI and breakdowns than the rate assumed in the design data, because there will be fewer events that require the early detection afforded by an SVD system.

6.16. Task S: Define and measure other qualitative benefits

Evaluation Requirements

Define and objectively measure any qualitative benefits associated with SVD such as improvements in the Agency's reputation.

We have identified the following additional benefits associated with the inclusion of a radar based SVD detection system on ALR schemes. Where these benefits had a quantifiable monetary value they have been included within Task R (BCR) above.

Customer Confidence

In the lead up to the introduction of the first ALR schemes, and since they commenced operation, there have been negative press reports and negative comments from stakeholders related to the removal of the hard shoulder and the perceived 'risks' this brings to the road user. For example, the Daily Mail on the 11th April 2014 reported that "…motoring groups say it will put motorists at 'added risk'. They say the distances between new safety 'refuges' are too far apart …"[12]

The introduction of an SVD system on ALR schemes is likely to improve the public perception of Highways England that, as an organisation, it understands the concerns of customers and road workers, and seeks to minimize the risks to them through use of the latest technology. It is likely to also provide improved customer confidence when using smart motorways, arising from the knowledge that they will be rapidly detected if they stop in a live lane, and that assistance will be provided as quickly as possible.

Improved Operational confidence

Similarly, the system may provide improved RCC operator confidence in working on smart motorways, as staff understand that they will be alerted to stopped vehicles quickly and can set signs to improve the protection of the public and their colleagues.

Other Objects Detected

The requirements of the SVD system specify that the smallest objects the SVD system must detect are small vehicles. However during the course of the two trials instances of pedestrians walking along the verge, wildlife and large debris items in the main carriageway have also been detected by the radar providing additional valid alerts for the RCC operators to respond to.

SVD detection in High Flow Rates

The requirements of the SVD system specify that the system should detect >80% of the total number of isolated stationary vehicles in < 1000vph per lane conditions. Our analysis of Task K has shown that the system is capable of identifying live lane stationary vehicles in flow rates in excess of 1700vph, with 9% of the true positive genuine alerts being raised above the 1000vph requirement. We observed that in certain instances MIDAS didn't detect the incident (as sufficient queues had not formed) before RCC operators were made aware via SVD alarm providing an earlier warning of vehicles at risk.

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[12] http://www.dailymail.co.uk/news/article-2602746/Road-safety-row-hard-shoulder-shut-permanently-time-M25-smart-motorway-ease-gridlock-dont-forget-speed-cameras.html

Detection within Emergency Refuge Areas

In the ALR smart motorway design, ERA loops are not a requirement as they do not provide mitigation to any specific hazard, and instead introduce a maintenance liability and an associated operational cost.

The SVD system can detect vehicles stopped in ERAs in addition to its main carriageway detection area, with no additional maintenance liability. Although they are not required to mitigate a specific hazard, RCC operator feedback has confirmed that these alerts provide a beneficial increase in the operational awareness of the RCC. If the ERA alerts can be easily distinguished from the main carriageway alerts they will not create an unwanted resource impact on the RCC.

Early provision of some E-Call-like benefits

eCall is an in-vehicle safety device which manually or automatically generates a phone call in the event of an accident. On 28 April 2015 the European Parliament voted in favour of eCall regulation which requires all new cars be equipped with eCall technology from April 2018. This functionality will provide very similar benefits to that of the SVD system without the need to install any roadside technology. However the requirement for this technology is only for new vehicles and is not mandated for existing vehicles, therefore the timeframes for widespread adoption of this technology are very long term (estimated 10 years+). Hence SVD will provide some parts of e-Call functionality (automated detection of stopped vehicles) well in advance of the UK vehicle fleet being fully equipped with e-Call. Given the estimated lifespan of the SVD system being 10 years + the business case for SVD will not be undermined by e-call in the short to medium term.

7. Summary

The table below summarises the findings of each of Tasks A to S:

Sub task reference	Description	Evaluation result
A/B	Record instances of events and ground truth verification	Against the target false detection frequency of 1.6 alerts per motorway mile per day, the trial achieved a level of 0.2 which is significantly better than required. A very high proportion of SVD alarms (54.6%) related to vehicles within ERA.
C/D	Additional ground truth verification by review of sample CCTV footage / propose locations for ground truth coverage	
E	Review sample footage to check for false positives	Over 1,700 hours of CCTV footage were reviewed to confirm an incident detection rate of 86.4% +/- 3.9%(at 95% confidence level) compared to the required incident detection rate of 80%.
F	Replicate stationary vehicles	N/A
G	Understanding the impacts of roadworks on SVD	Roadworks had no significant impact on the effectiveness of the SVD system. The manual suppression functionality worked as required.
H	Identify blind spots	Against the target detection zone coverage of >90% the trial achieved a calculated coverage zone of 96.7%. We have detailed calculations on the effect of road curvature, gradient and central reserve light on the SVD system with recommendations being made for maximum radar radii.
I	Recommend optimum coverage	We have assessed the number of radar needed to achieve optimum coverage, taking into account the effect of azimuth errors, road gradient, road curvature and the requirements for ERA and hot spot monitoring.
J	Test ability of system to clear alert	Over 90% of SVD alarms are maintained while the vehicles are still present at the roadside. However for just under 10% of incidents the system incorrectly states that the vehicle has departed.
K	Record traffic flows	Against the detection requirement of >80% of the total number of isolated stationary vehicles in < 1000vph per lane conditions the SVD system identifies 86.4% +/- 3.9% of these incidents. The SVD also is able to function at higher flow rates with valid alerts being raised at flow rates in excess of 7000vph and to report these to operators before MIDAS alerts are raised.
L	Record system timeliness	Against the detection requirement of <20 sec from vehicle stopping the SVD system identifies vehicles that have been stopped for >12 sec and reports to RCC operators almost instantly (<1 seconds) compared to the requirement of <10 sec. RCC Operator were only able to respond to 53.4% of alarms before the system auto cleared them (because the vehicle had moved off).

Sub task reference	Description	Evaluation result
		Of the alarms investigated and classified as an event, the process takes an average of 50 sec for an event to be verified; 90% of events are verified within 2 minutes of an alert being presented to the operator.
M	Test usability	Operator feedback has been positive towards the trial with areas for improvement being identified including the separation of COBS and SVD audible alarms and updates to the user interface
N	Recommend reductions on resource impact	Key recommendations include the removal or reclassification of ERA & MSA areas; and Increasing the time that a vehicle is stopped before alerting the operator (12 sec in the trial).
O	Recommend priority of elements from issue 1 of SVD specification	We have reviewed the specification of the SVD system and have suggested alterations based on the trial results and operational requirements for 10 of 27 requirements.
P	Quantify speed of detection over current methods	Comparison with the speed of detection of a sample of breakdown live lane events on the M25 J25-27 ALR scheme showed the SVD radar system detects an average of 16 minutes more quickly.
Q	Identify likely future requirements	We have proposed future requirements to the system categorized as essential, desirable and possible. Essential include providing formal TOS procedures, regularly updating the clutter maps, removal of ERA/hotspot alerts and separating the audible alarms from other audible COBS alarms.
R	Develop likely BCR	We have developed a BCR based on design data for the rate of KSI on smart motorway schemes, and assuming that the overall duration of each stopped vehicle incident is reduced because the incident is detected more quickly. This provides a potential positive BCR value between 1.49 and 1.72 depending on scheme length, where the longer the scheme the greater the value.
S	Define / measure other qualitative benefits	We have defined other qualitative benefits including improved customer and stakeholder confidence, detection of small objects and detection of stationary vehicles in high flows more quickly than via MIDAS

Table 14 - Summary of Task A-S

8. Conclusions and Next Steps

The SVD system is able to meet the requirements that were set out in the functional specification: in terms of the percentage of vehicles detected, detection accuracy (false alert rates) and coverage.

From the BCR it is clear that the positive benefits exceed the costs of the implementation when the overall duration of each stopped vehicle incident is reduced because the incident is detected more quickly.

To realise these benefits, the TOS must continue to have the resource to be able to react in a timely fashion to the alerts, and despatch resource as soon as they detect an event, reducing the overall duration of the event when compared to that expected without the SVD system.

In order to ensure that the TOS are supported in this, we recommend that the following are prerequisites for the further roll out of a SVD system:

- The TOS will require **formalised RCC Procedures**, and the resource to increase the response rate to SVD alarms (in this trial only 53% were responded to before the system auto cleared them. This includes putting a KPI put in place to monitor response, but also sufficient training and engagement to ensure that the TOS have confidence in the system.

- **Removal of ERA / Hotspot Alerts** – this will reduce the overall number of alarms, but a trial would be required to understand how effective it could be. Again, this would be key in ensuring that TOS have confidence that the system is detecting actual events.

- **Audible Alarm Separation** – this would allow the SVD system to have an audible alarm, without other COBS alarms sounding audibly. These latter alarms are not critical alarms, and are an irritation in the control room as well as detracting from the SVD alarms.

- **Regular Clutter Map Updates** – this will improve system performance, by reducing the number of false alarms due to changing conditions at the roadside (e.g. growth in foliage)

- **Increase stationary vehicle time requirement** – this would increase the time that a vehicle must be stopped before the operator is alerted. Although there is some increase in risk, it would "filter" out more of the very short stops, allowing the RCC to focus on the most operationally critical incidents, by reducing the number of alarms.

Appendix 01

Technical Note on radar shadows

Stationary Vehicle Detection (SVD) Trials M62 & M25

Technical note on “radar shadow”

Introduction

There are two causes of “radar shadow” or “blind spots”, i.e. regions where a scanning radar cannot detect objects. One is near to the device itself because the shape of the beam means that it does not scan in its immediate vicinity.

The other cause it that the presence of objects in the scanning zone of a radar will partially or completely obscure other objects that are beyond them. SM-ALR schemes have solid concrete barriers along the central reserve that will block the radar signal and create a “radar shadow” on the far carriageway from where the radar unit is installed. Large vehicles parked in an ERA will also cast a shadow which maybe within the carriageway depending on the relative positions of the radar and vehicle.

This paper uses a simple geometric approach to estimate the potential extent of the types of radar shadow and the implications that has for stationary vehicle detection using scanning radar.

Near the device.

The device is known to have a zone with a radius of about 20m at ground level, for a device mounted at 5m, directly underneath the unit where it will not detect, as shown in Figure 1.

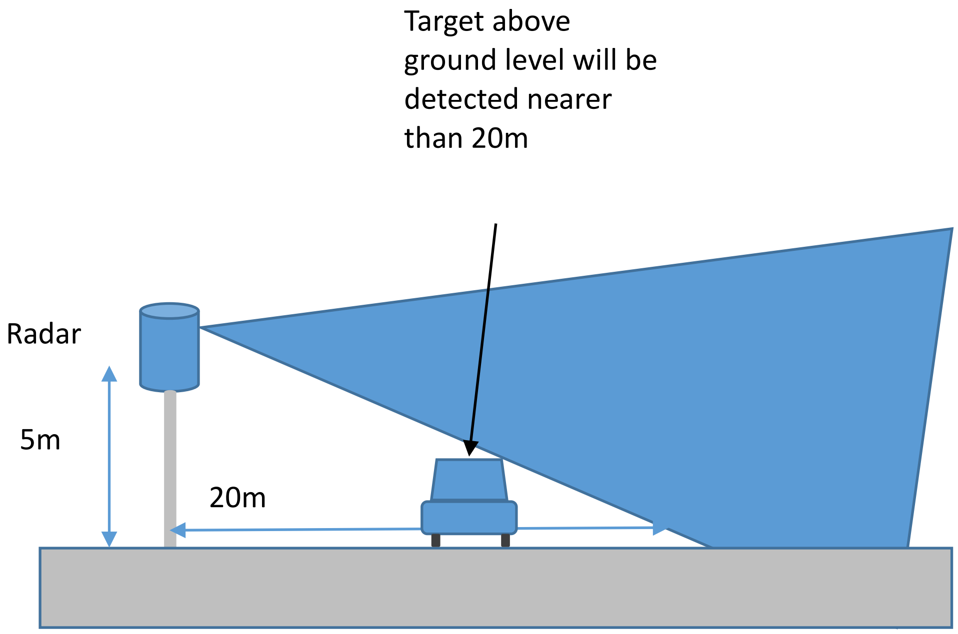

Figure 1 Near-unit shadow zone

Objects that have some vertical height, e.g. vehicles, may be detected nearer than 20m. The radius they are detected is directly proportional to the relative height of the object to the height of the radar above the ground. For example a 1.25m high car will be detected at (1- 1.25/5)*20 = 15m.

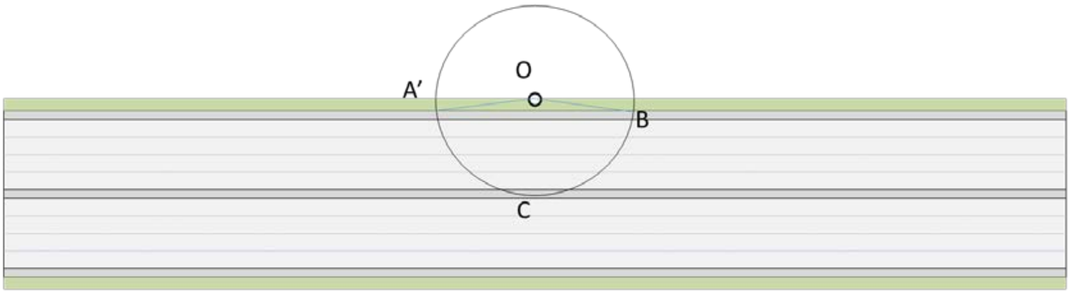

Figure 2 Plan view of near unit shadow zone.

We can calculate the size of the shadow zone using geometry based on the plan view shown in Figure 2 as follows

<u>Calculate area of near blind spot in carriageway</u>

angle AOA' = angle BOB' = arcsin (2+1.5)/20 = 10.0786°

Angle AOB = 180 – (angle AOA' + angle BOB') = 159.843°

Length of ACB = 2π(20) (Angle AOB)/360= 55.8m

Area of Sector OACB = Length of ACB π $(20)^2$/2 π(20)= 558m^2
Area of triangle AOB = ½ AB * Radar to road= ½ (2*20) (2+1.5)= 70m^2
Area of Segment ABC = Area of Sector – area of triangle = 558-70 = 488m^2

If radar range is 250m

Total area = 2*250* carriageway width = 2*250*29.5 = 14750m^2

Near range blind spot % = 488/14750*100 =3.3%

<u>Calculate area of near blind spot in LBS1</u>

Length mid LBS1 in blind spot = 2(OA^2 – Radar to mid $LBS1^2$) ^{½} = 2(20^2 – $(2+1.5+1.8)^2$) ^{½} = 38.56m
Area of blind spot = 38.56 * 3.6 = 138.85m^2
Area of LBS1 in range = 3.6*300*2 = 2160m^2

Near range blinds spot in LBS1 = 138.85/2160 = 7.7%

This is the worst case assumption because this is the area at ground level. As we have seen from Figure 1 at vehicle roof height the area of the blind spot will be smaller.

Vehicle parked in ERA on same carriageway as radar

If a large vehicle whose height is close to that of the mounted radar, e.g. a box body or curtain-sided HGV, is parked in an ERA then it may cast a shadow into the carriageway as illustrated by the cross hatched area in Figure 3. If the vehicle has a low profile then the radar will see over the top of it and the shadow will be minimal. If it is relatively tall, say >50% of the radar mounting height then the shadow it casts may be substantial.

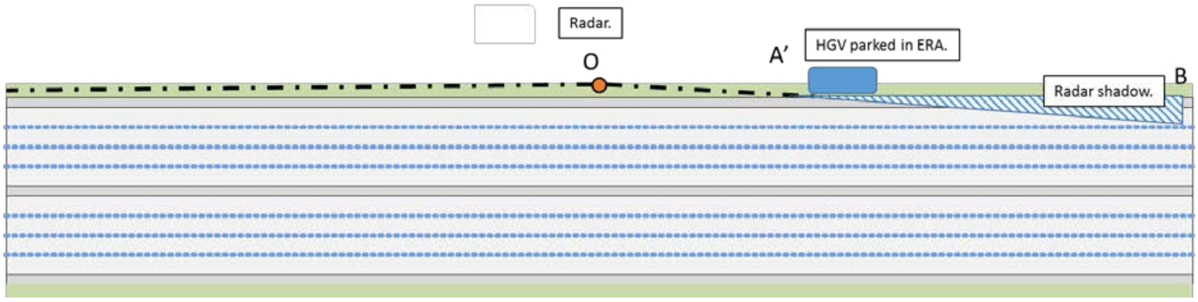

Figure 3 – Plan view of radar shadow from large vehicle in ERA

The extent of the shadow is a function to the amount the vehicle at A’ intrudes into the radar detection zone, the distance 0A’ and will increase as OB increases. If the radar is closer to the edge of the carriageway than the edge of the vehicle, then the shadow will only cut into the road if the radar is on the inside of a curve. Otherwise, the closer the vehicle is to the radar, i.e. the shorter OA’, the bigger the angle at A’ and the more the shadow will intrude into the carriageway. Therefore, radars should not be sighted adjacent to ERAs as a large vehicle may cast a significant radar shadow whilst it is present.

The shadow will be larger in extent in the carriageway if the radar at O is on the inside of a curve but will be less of a problem if the radar is on the outside of a curve.

Target vehicle

In order to calculate the extent of any shadow we need to decide on a target object. The purpose of the SVD device is to detect stopped vehicles so pedestrians or debris have been deliberately ruled out. Using a low vehicle as a target will enable the calculation to show the maximum extent of the shadow, i.e. the area that a vehicle lower than the target would not be detected and, conversely, in the non-shadow area the majority of vehicles will be visible to the radar. This approach is similar to that used for determining the spacing of hard shoulder monitoring cameras. In that case the target chosen was a vehicle that had the smallest cross-section (i.e. a Smart) and hence would have the smallest area within the CCTV image

One of the lowest cars is the Mazda MX5 sports coupe which has a height of 1.225m[1]. This is lower than a motorcycle with a rider so represents about the lowest vehicle that might be expected. The SVD radar tracks detected targets and identifies “stops” as when a vehicle has dropped below a threshold speed. Therefore, it will detect motorcycle and rider combinations so the Mazda is still likely to be the more testing target.

Vehicle taller than the barrier

Typically, the concrete barrier in an SM-ALR scheme is 0.9m high. This is lower than the roof height for all cars found on the roads today.

The concrete barrier will not obscure a vehicle in the opposite carriageway from the radar scan unless the barrier is higher in absolute terms than the radar. This can occur if there is an uphill gradient away from the radar site. Under such circumstances the “line of sight” from the radar over the barrier will be upwards and objects may be hidden from the radar despite being relatively taller than the barrier. Figures 4 and 5 illustrate the situation.

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[1] Source –https://www.mazda.co.uk/assets/uk/cars/brochures/mx-5/all-new-mx-5-brochure.pdf

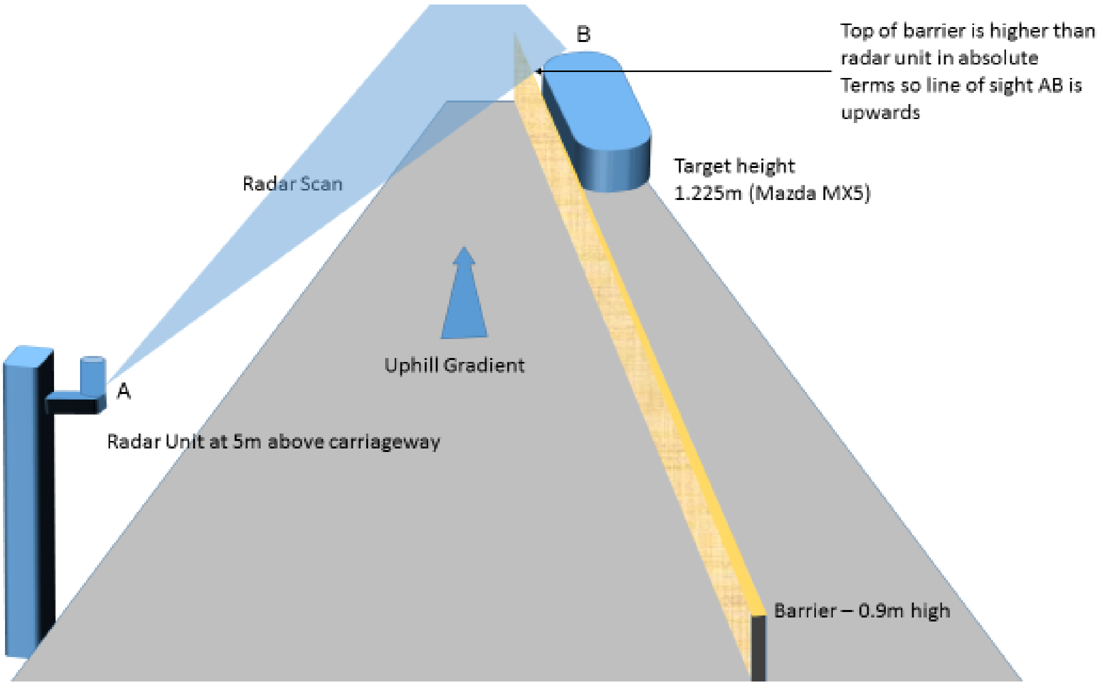


Figure 4 – Vehicle taller than barrier but with an uphill gradient

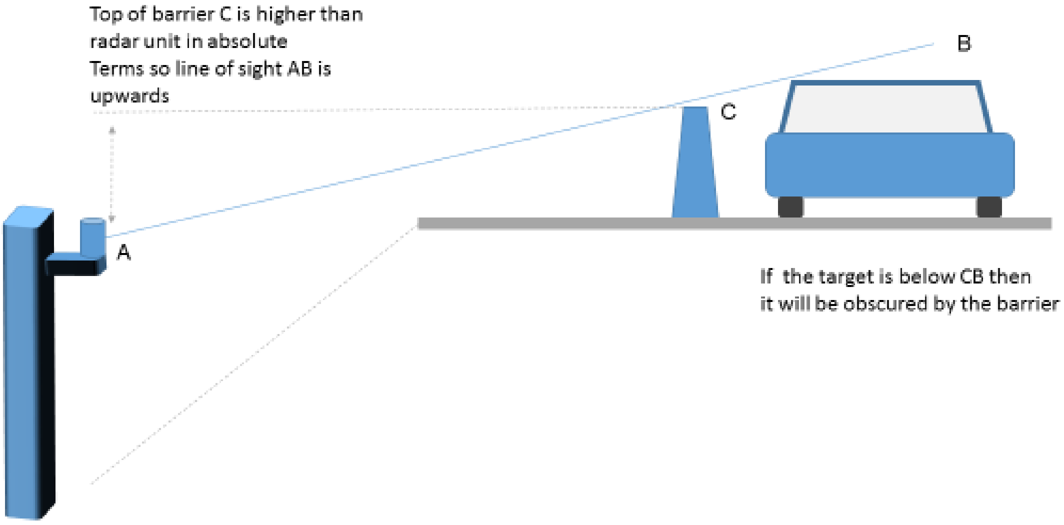


Figure 5 Detail of line of sight for Figure 3

We can see from Figure 5 that it will be vehicles furthest away, i.e. in LBS1 on the opposite carriageway, that become hidden first.

Using simple triangular geometry, it is possible to calculate the distance from the barrier to the shadow (y) along the carriageway from the radar position (x). In order to perform the calculations, we need to make the following assumptions:

- Radar height above the carriageway – assume 5m
- Radar distance to the edge of the carriageway 2m
- Barrier height – assume 0.9m
- Target height – assume 1.225m which is the height of a low vehicle such as a Mazda MX5
- Lane width = 3.6m
- Distance from edge of lane to barrier 1m

We also need to make assumptions about longitudinal gradient. Horizontal curvature does not of itself have this form of shadow.

Figure 6 shows the shadow for a straight road with a gradient of +2.0% from the radar.

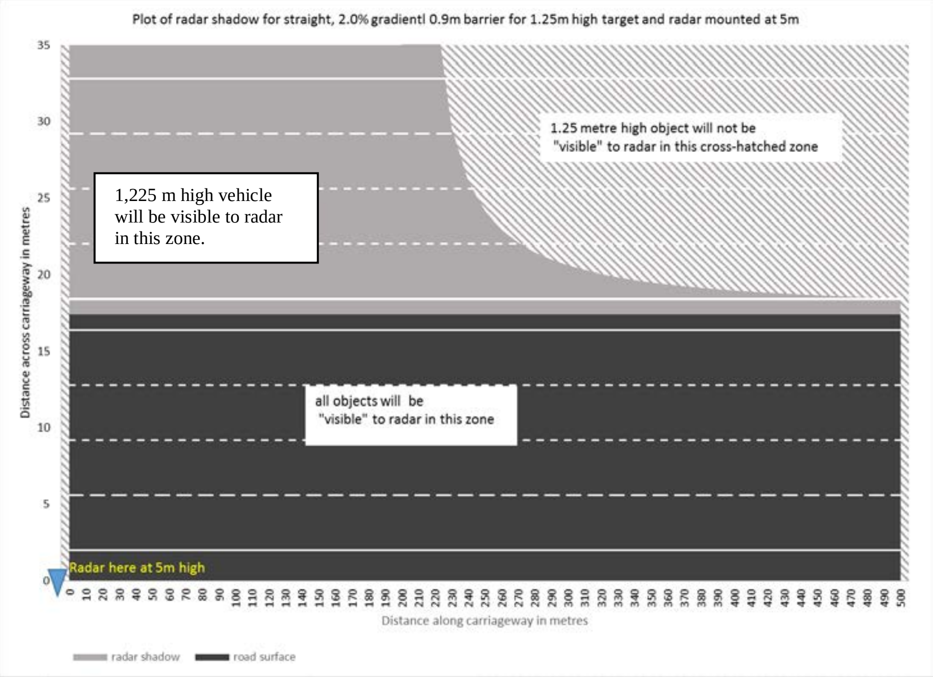


Figure 6 Radar shadow for vehicle taller than barrier

LBS1 and LBS2 on the opposite carriageway become obscured around 230m from the radar. LBS3 is completely hidden by 300m but LBS4 remains partially visible to the radar to beyond 350m. As the practical range is 250m there will be some loss of detection at the far end of the range.

If the gradient is less than 2.1% then there is no shadow effect for the range of 250m. At steeper gradients the effect increases, for example, at 4% for the shadow to be 100m from the radar.

Barrier taller than vehicle

In some circumstances a taller barrier may have been installed (e.g. if it contains the leg of a gantry or if it forms part of a bridge parapet) in which case the nature of the shadow is different and will be affected both by gradient and horizontal curvature.

Figure 7 shows a simplified sketch of how the radar shadow is formed by a solid barrier. The “target” vehicle on the right is partially hidden from the radar on the left because the edge of the shadow cuts across it. If the target was further to the left it could become completely hidden from the radar scan.

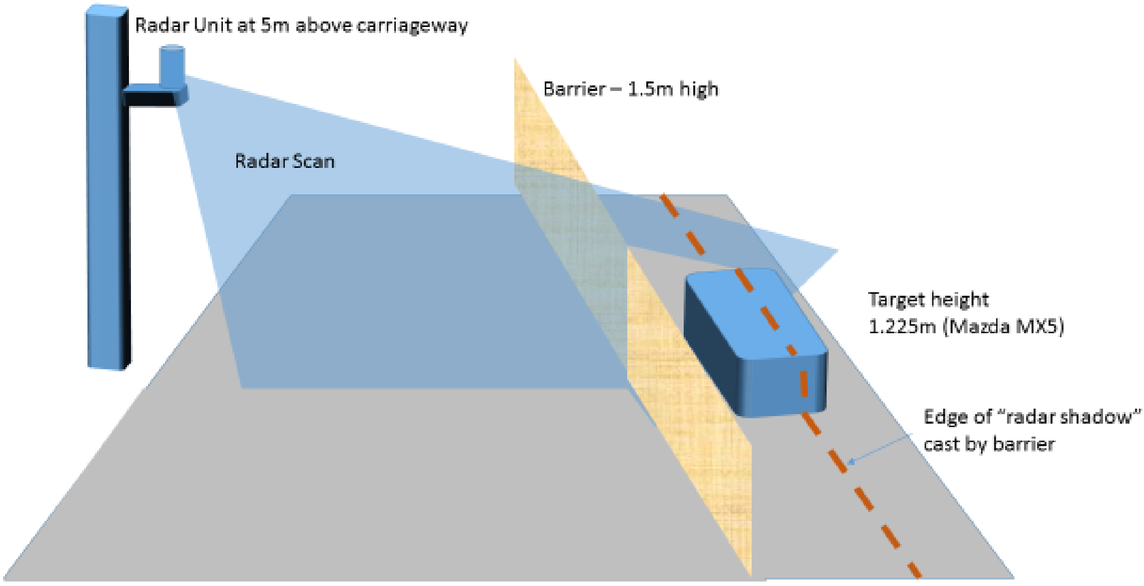


Figure 7 Barrier taller than vehicle

Using simple triangular geometry, it is possible to calculate the distance from the barrier to the shadow (y) along the carriageway from the radar position (x). In order to perform the calculations, we need to make the following assumptions:

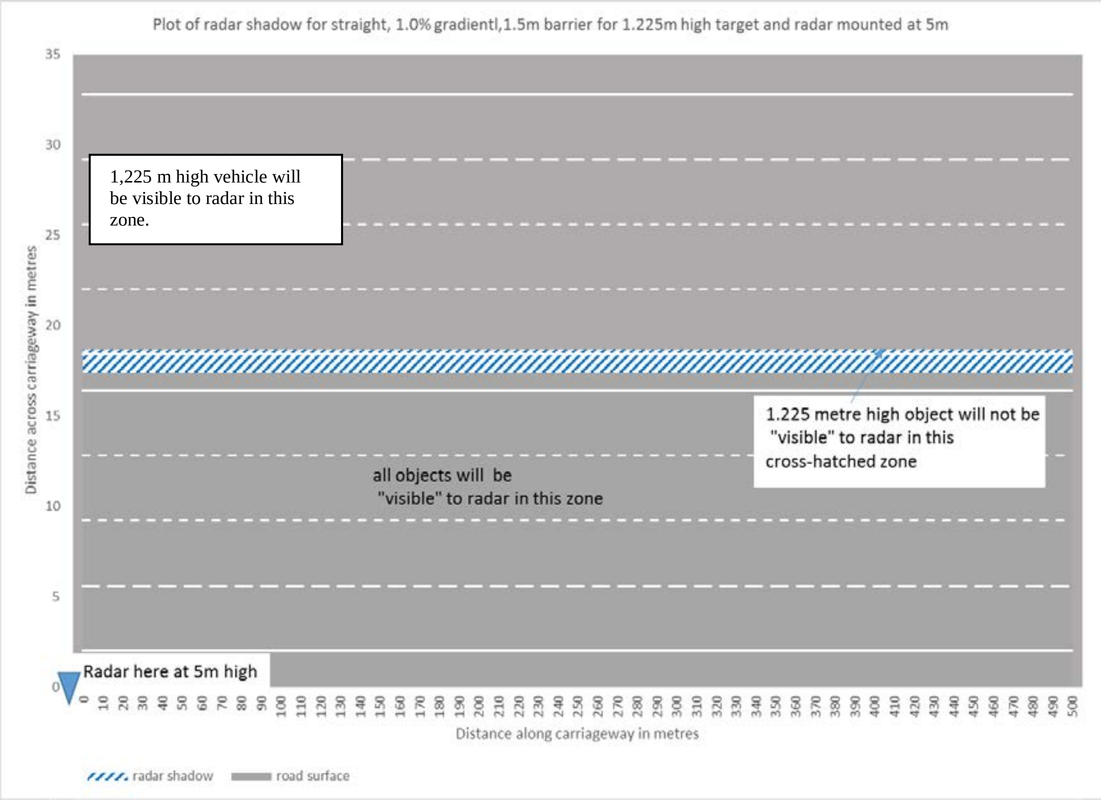
- Radar height above the carriageway – assume 5m
- Radar distance to the edge of the carriageway 2m
- Barrier height – assume 1.5m
- Target height – assume 1.225m which is the height of a low vehicle such as an Mazda MX5
- Lane width = 3.6m
- Distance from edge of lane to barrier 1m

We also need to make assumptions about longitudinal gradient and horizontal curvature. The following examples look at a number of different scenarios of road geometry.

Shadow extents

Example 1

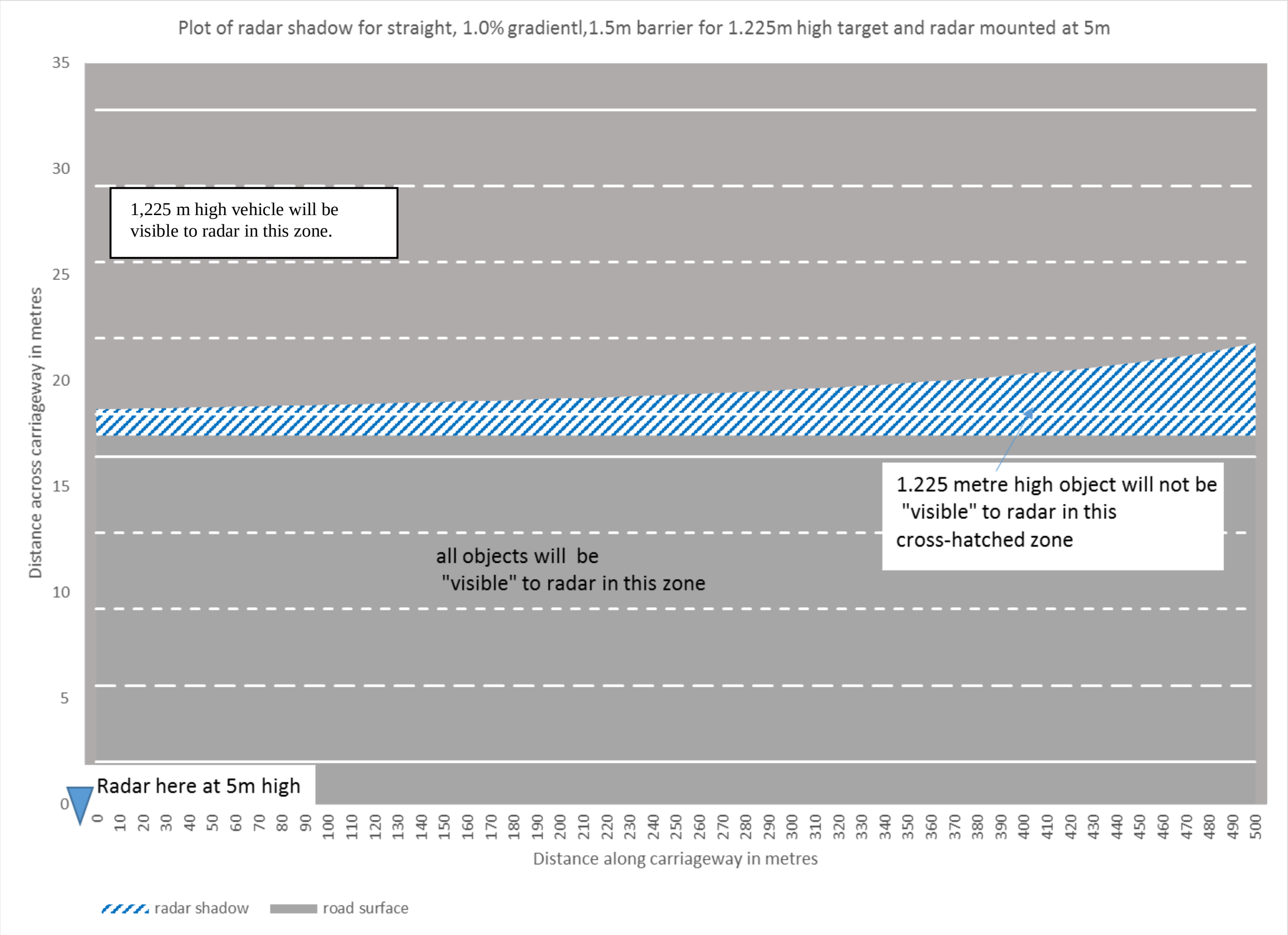
Gradient = 0% (i.e. level), no horizontal curvature



In this case the radar shadow is minimal and does not cover any traffic lanes to any extent, in fact it barely enters LBS4. All vehicles would be visible to the radar.

Example 2

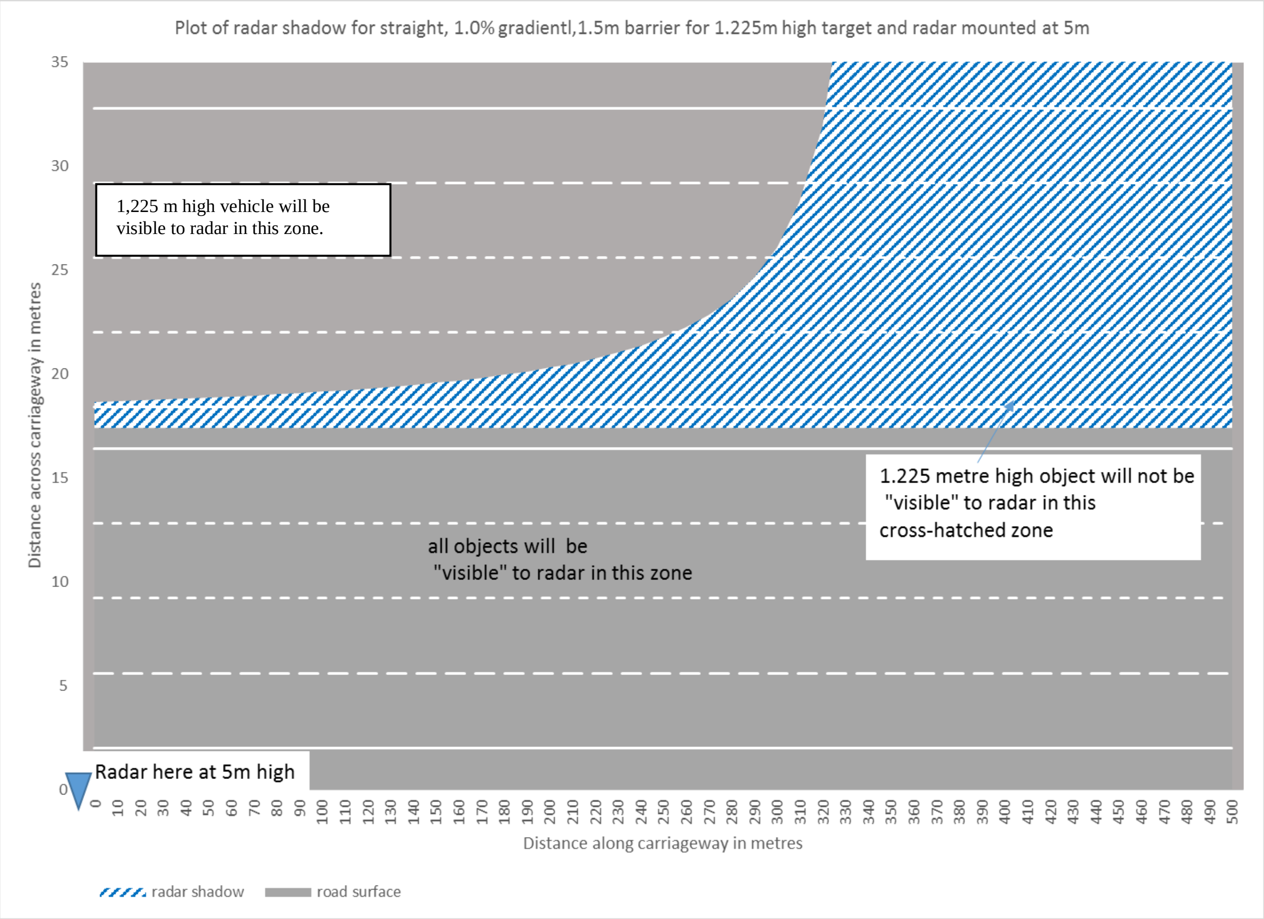
Gradient = 0.5% uphill from the radar position. Gradient assumed to be constant. No horizontal curvature



In this case the radar shadow is minimal nearer the radar and does not cover any traffic lanes to any extent, in fact it barely enters LBS4 by the time the practical range of 250m is reached. It is from 400m that a significant part of LBS4 is hidden and by 500m all of the lane is in the shadow.

Example 3

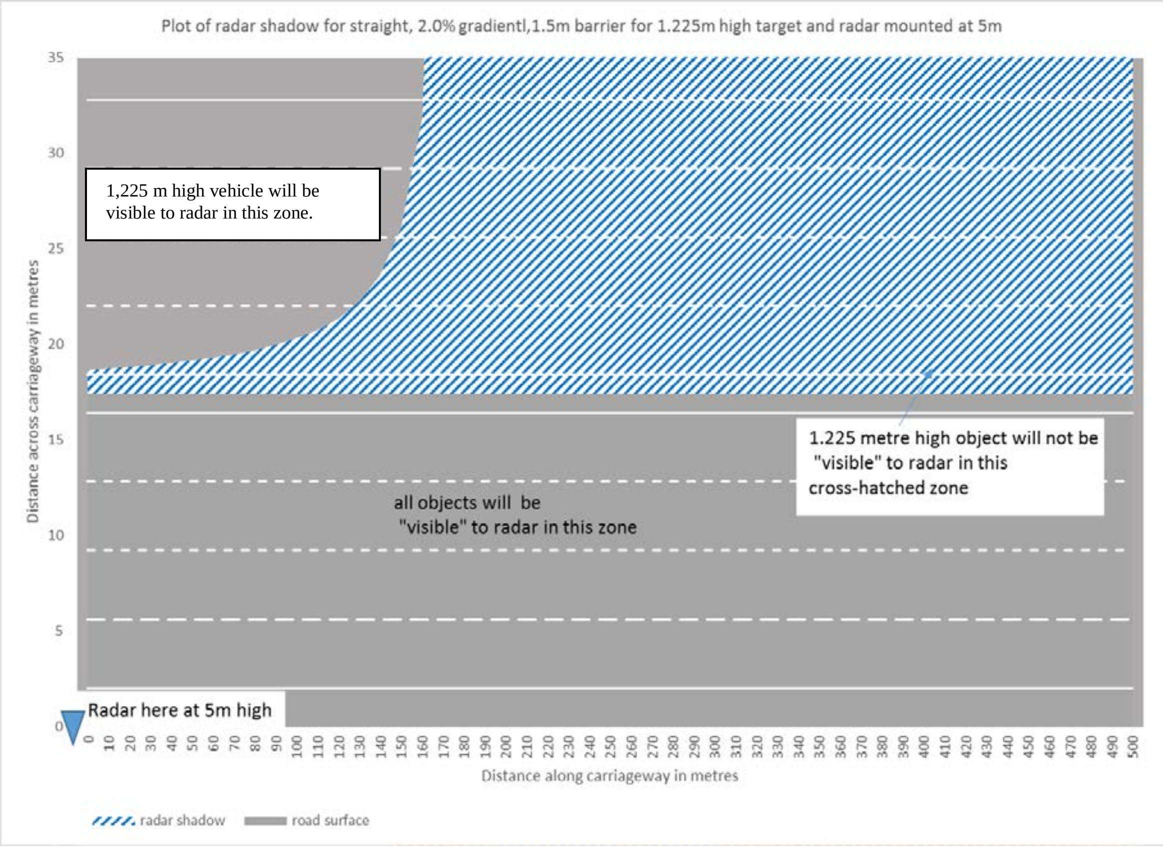
Gradient = 1.0% no horizontal curvature



In this case the radar shadow is minimal for a much shorter distance, around 150m. The shadow increases rapidly in extent such that at the practical range of 250m all of LBS4 on the far carriageway is obscured, and by 330m all the far carriageway is obscured. This is because the relative height of the radar and the top of the barrier is an important factor. The size of the gradient means that this relative height is much reduced by 300m from the radar position such that any radar that passes over the barrier does not get below 1.225 m by the time it has passed the far edge of LBS1.

Example 4

Gradient = 2.0% no horizontal curvature



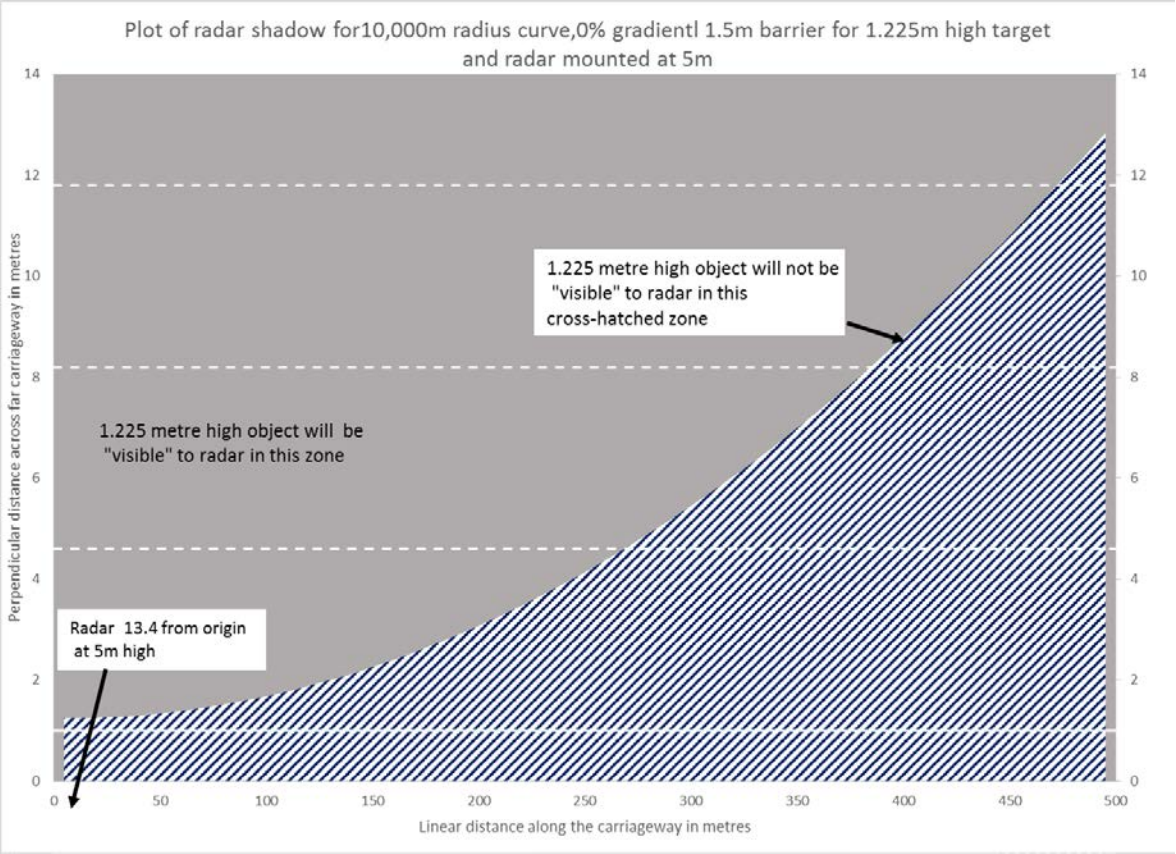
In this case the radar shadow is minimal for a much shorter distance, around 50m. The shadow increases rapidly in extent and by 160m all the far carriageway is obscured, well inside the detection range. This is because the relative height of the radar and the top of the barrier is an important factor. The size of the gradient means that this relative height is much reduced by 250m from the radar position such that any radar that passes over the barrier does not get below 1.225 m by the time it has passed the far edge of LBS1.

Example 5

Horizontal curvature = 10,000m; Gradient = 0%.

In the case of this example the plot shows the road straightened out and the perpendicular distance from the barrier to the edge of the radar shadow. Only the far carriageway has been plotted. The radar is located at the (0, -13.4m).

The radar is on the inside of the curve. In order to simplify the calculations it is assumed that the radar is on the radius of the curve and the curve is circular not a transition curve. This is a harsh assumption and the shadow cast along a transition curve would probably be less in extent.

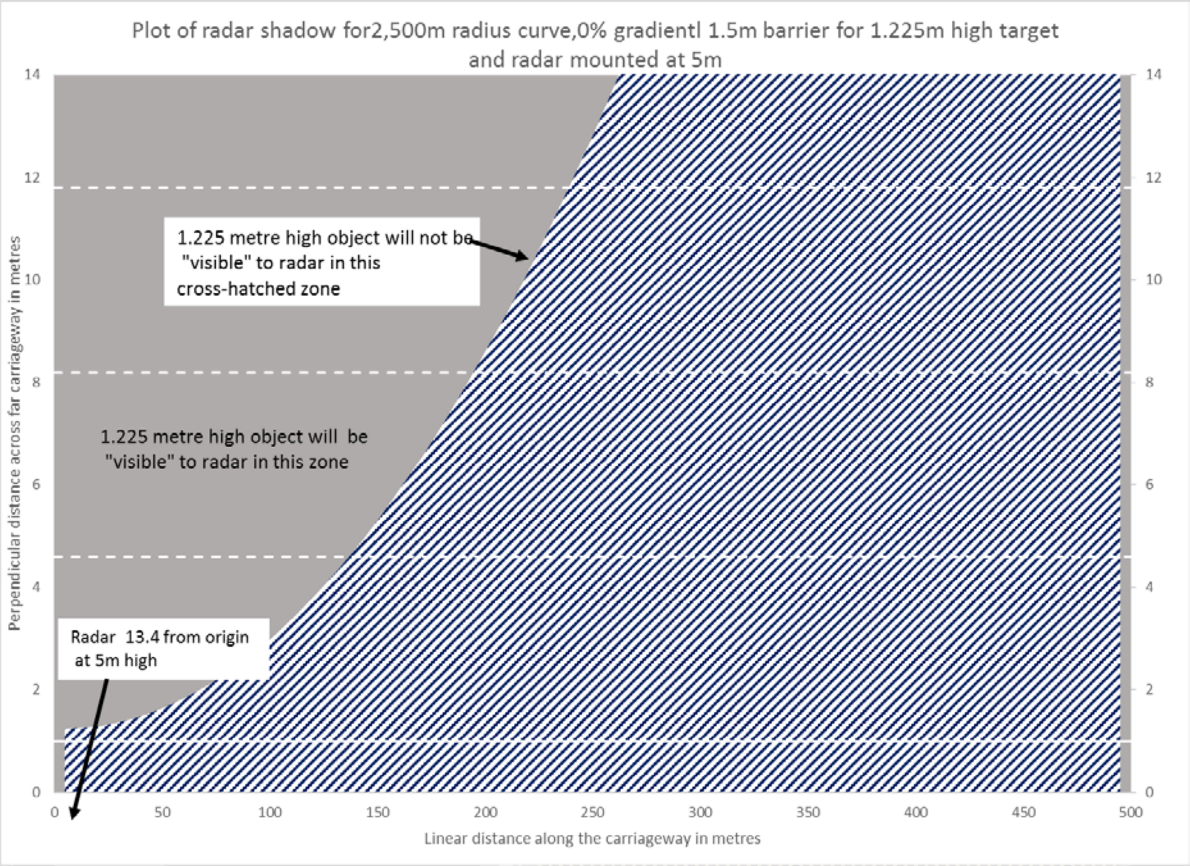


In this case the radar shadow increases to cover LBS4 after 250m. LBS4 is significantly obscured by 200m so there is a high possibility of low profile vehicles not being visible to the radar in LBS4 from 200m. More of the lanes fall into the shadow as the distance from the radar increases until all lanes in the opposite carriageway are in the shadow by 500m.

The effect is because the increasing curve means the angle between the radar beam and the barrier does not decrease at the same rate as for a straight barrier. For a straight barrier as the view becomes more oblique this compensates for the more horizontal view such that the shadow extent remains constant. For a radar mounted on an inside barrier this effect is reduced because the obliqueness of the barrier reduces as well.

Example 6

Horizontal curvature = 2,500m; Gradient = 0%.



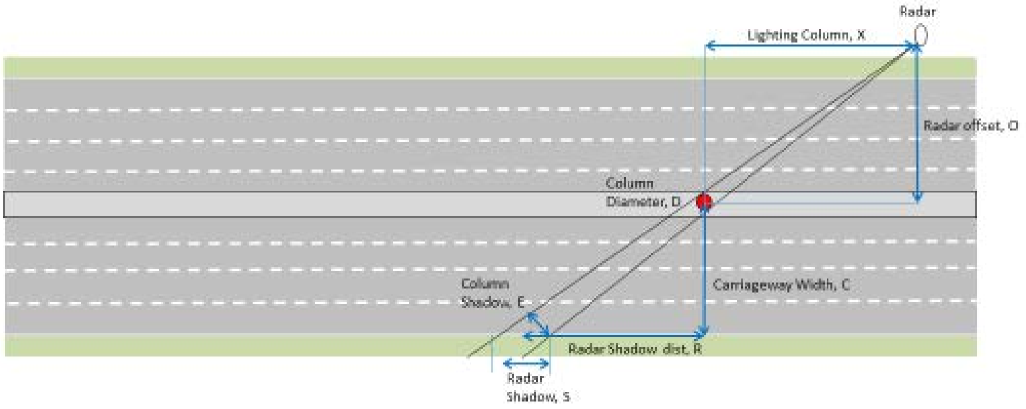
In this case the radar shadow substantially covers LBS4 from 100m and the shadow increases to cover all lanes after 250m. However, this is an extreme case as this radius is near the lowest permitted radius for a motorway.

Lighting Columns

Where a section of motorway is lit by luminaires mounted on columns in the centre reserve there is the potential for interference with the scanning radar beam in two ways; either the shadow cast by an individual column or by the apparent spacing of columns being too close to discriminate between when viewed from the position of the radar. The two effects are analysed separately in the next sub-sections.

Shadow of column

Each individual column will cast a radar shadow across the opposite carriageway whose horizontal size depends on the width of the column. For a 12m high column the typical diameter is 168mm[2]. The main question is what size is this shadow when projected onto LBS1 of the opposite carriageway to where the radar is sited? The diagram below shows the geometry of the situation.



Radar to light column, a = (X² + O²)½

Light column to far edge, b = (C² + R²)½

$^{O}/_{X} = {}^{C}/_{R} \Rightarrow R = {}^{XC}/_{O}$

$\frac{D}{a} = \frac{E}{(a+b)} \Rightarrow E = \frac{(a+b)D}{a}$

As D and E are small then

$\frac{E}{S} \cong \frac{(O+C)}{(a+b)} \Rightarrow S \cong \frac{E(a+b)}{(O+C)}$

The further the lighting column is along the road from the radar (X in the diagram) the further away the shadow is cast (R) and the longer the shadow is in the longitudinal direction (S). Using the equations in the diagram we can calculate S for every value of X+R up to the range of 250m. The results are plotted in the graph below.

The maximum value for the longitudinal shadow at 250m is around 2.3m. This is shorter than most vehicles so we can conclude that the shadow cast by a light column will not completely obscure vehicles on the opposite carriageway. The shadow dimension in the lateral direction (i.e. across the carriageway) is much smaller and does not exceed twice the lighting column width of 340mm.

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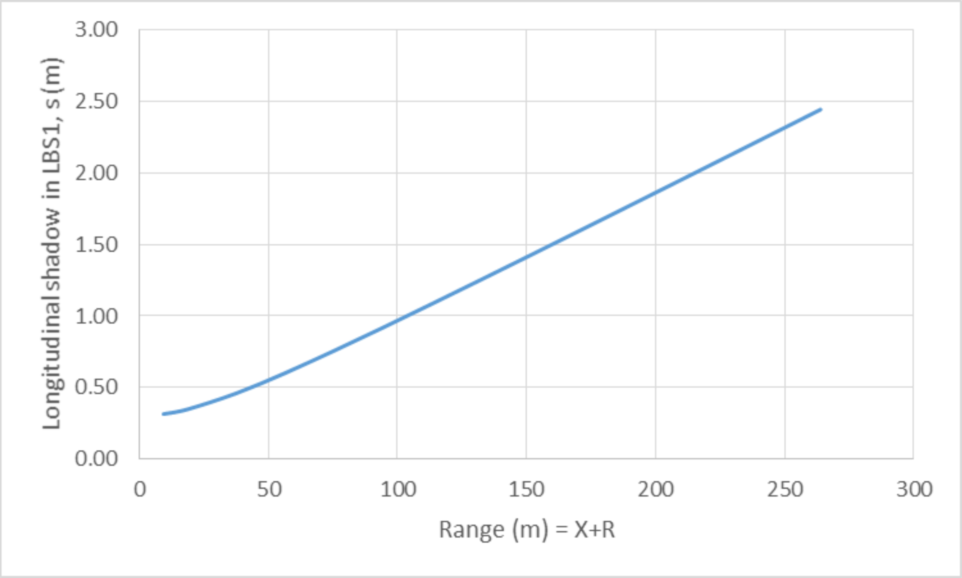
[2] http://www.abacuslighting.com/pdf/brochure-lighting-columns.pdf



Effect of column spacing

For devices such as radar detectors that are scanning a 3-D world onto a 2-D plane the apparent horizontal distance between two objects depends on the angle subtended between them at the detector. This angle is not necessarily dependent on the actual distance between the objects, as each one may be at a different distance from the detector. However, they appear to be close together because they are on similar bearings from the detector. For radar detectors there is a minimum subtended angle, often referred to as the “azimuth angle”, below which the device cannot tell if there is more than one object or not. That is to say, if the difference in absolute bearing of two objects is less than the azimuth angle then only one object will be detected.

If a motorway has lighting columns in the centre reservation the difference in bearing between successive columns will reduce the further away from the radar detector they are. The diagram below illustrates the geometry. For a given value of column spacing, s, the subtended angle (Angle B in the diagram) decreases as the distance from the radar, X, increases. If Angle B becomes less than the radar azimuth angle, then the radar will not be able to distinguish between them and anything on the far carriageway. From that point onwards the lighting columns effectively obscure the far carriageway.

The spacing of lighting columns on motorways varies between 30m and 45m[3]. Using the geometry set out in the diagram it is possible to calculate values for Angle B for differing values of X and spacing, s. The graph below shows the plots of those values for spacing of 30m and 45m. Overlaid on that is a horizontal line showing the quoted azimuth angle for the future versions of the Navtech radar, 1.6°. This shows that the limiting range for detection on the far carriageway is around 120m for 30m column spacing and 145m for 45m spacing.

The conclusion from this is that radars will be required with radius ranges between 120-145m or on both sides of the motorway on sections that have lighting columns in the central reserve.

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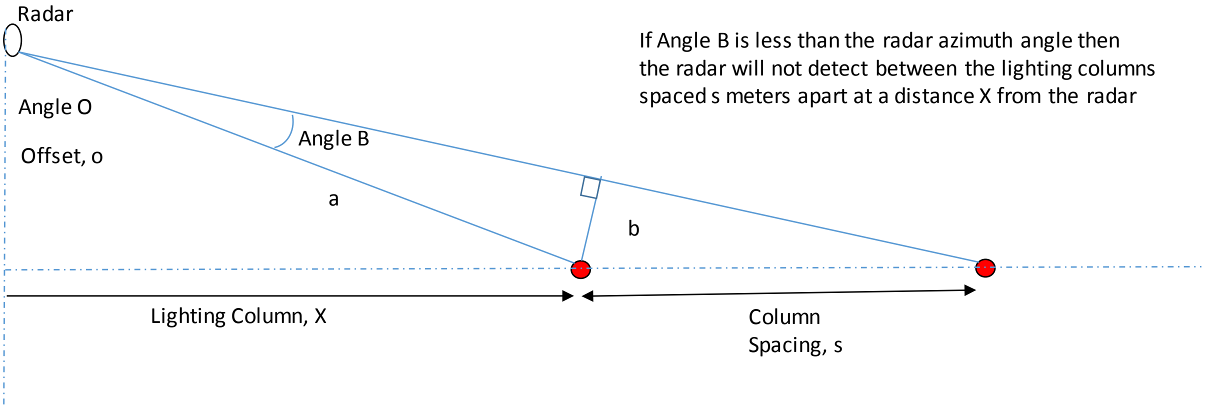
[3] http://webarchive.nationalarchives.gov.uk/20120810121037/http:/www.highways.gov.uk/customer/25238.aspx

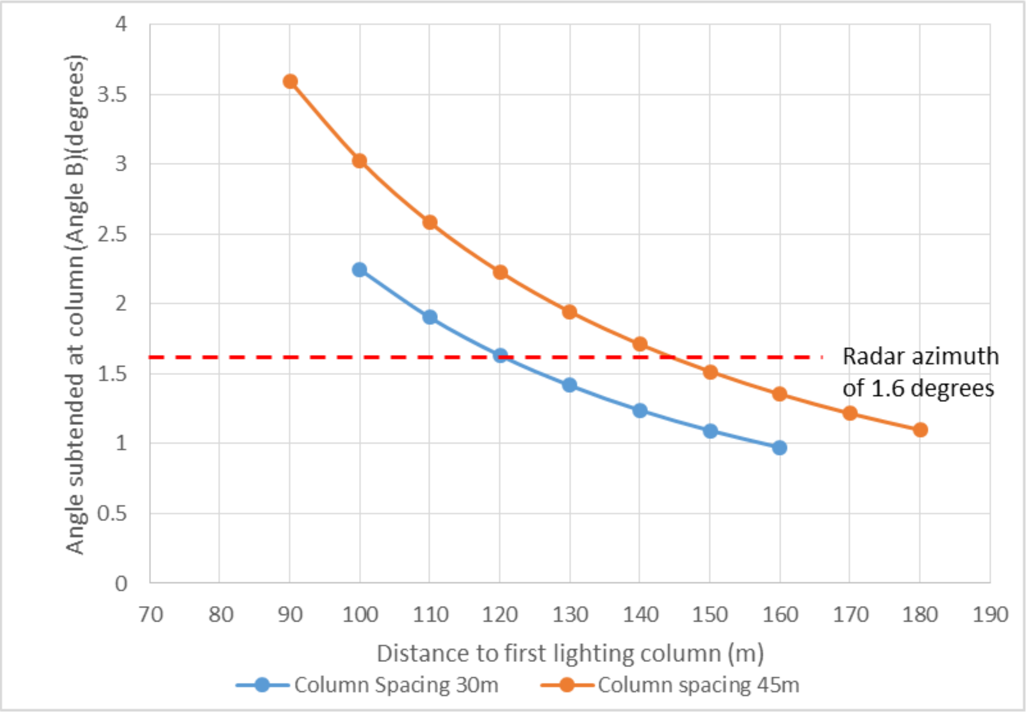


If Angle B is less than the radar azimuth angle then the radar will not detect between the lighting columns spaced s meters apart at a distance X from the radar

Angle O = atan(X/o)

Angle (B+O) = atan((X+s)/o)

Angle B = atan((X+s)/o) - atan(X/o)



Conclusions

In most layouts where the barrier is lower than the height of vehicles there is little obscuration of the opposite carriageway by the central barrier unless there is an uphill gradient of greater than 1%.

If the barrier is taller than vehicles the both uphill gradients and low radius curves where the radar is on the inside of the curve will both cause the extent of the radar shadow to increase compared to a flat, straight section. Depending on the actual values one of the two factors will be dominant. Downhill gradients away from the radar will reduce the extent of the radar shadow compared to a flat section. If the radar is on the outside of the curve, then the comparative effect on the shadow is minimal.

Therefore, the dominant factor is gradient and this may not be fully realised when setting out radars. At the location where a blind spot has been observed on the M62 the available data suggests that the top of the central reserve barrier is in fact higher (in absolute terms) than the radar at that point. This means the blind spot covers all the lanes on the carriageway away from the radar.

Radars need to be alternated along the carriageway in order to minimise the effect of gradient even if the road is straight or nearly straight. The linear spacing between radars will also have to be reduced in response to gradient.

To achieve 100% coverage more radars will be needed and designers will need to assess the relative height of the barrier to the proposed radar position to minimise shadows.

The alignment of the radar beam cannot eliminate or even reduce the extent of the shadow. Tilting the radar only changes the proportion of the beam either side of the barrier. This changes the location of the shadow within the radar image but does not affect its extent.

Mounting the radar higher would mitigate the issue to some extent. If the radar was mounted at 10m then the radar shadow for a 2% gradient would not become a problem until over 450m from the device, well beyond the current practical detection range of 250m. However, this would also increase the size of the “non-detect” zone in the immediate vicinity of the radar up to 40m radius at ground level.

Reducing the distance from the radar to the edge of the carriageway would be of some help but the reduction in extent is small.

It is worthwhile remembering that any stationary object, including vehicles, will cast a shadow. If Radars are positioned adjacent to ERAs where stopped vehicles, particularly HGVs, may be a common occurrence, then the device needs to be near enough to the carriageway edge that vehicles parked in the ERA are outside of its view along the carriageway beyond the ERA.

For motorway that have lighting columns in the central reserve radars will be required with radius ranges between 120-145m or on both sides of the carriageway.

It should be noted that these issues exist for any “point” detection method positioned on one side of the road, e.g. CCTV, LIDAR, not just for Radar.

Appendix 02

Outline Benefit Costs Ratio for Stopped Vehicle Detection

Stationary Vehicle Detection (SVD) Trials M62 & M25

Outline Benefit Cost Ratio for Stopped Vehicle Detection

Introduction

The SVD trial Stage 0 Report[1] described an outline business case based on the deployment of stopped vehicle detection preventing KSIs. This is an optimistic view and, as the report stated, gives an upper bound to the benefits that can be expected.

The primary effect of the stopped vehicle detection system is to raise awareness sooner in the RCC of the presence of a vehicle stopped in a live-lane. This reduction in the "time to discover", i.e. the time between a vehicle stopping and upstream warning signals being set, means that warning to approaching drivers are set sooner and hence the time period that the stopped vehicle is without the mitigation offered by the signs and signals is reduced.

The results from the trial quantify the change in time to discover. A reduction in this time results in a reduction in exposure to near misses as vehicles approaching in the same lane will have to change lane without having received any prior warning.

From the analysis of the risks associated with stopped vehicles on ALR[2] estimates have been made for the rates of KSI categories per carriageway mile and, of more relevance here, per live lane stop. By combining these values with information on the duration of the time to discover (TD) for live lane stops on the M25 recorded in the Command and Control logs it is possible to determine a rate per "TD-minute" for each of the KSI categories.

The next factor we need to determine is how many stops are there with different TD durations when SVD is not deployed. A detailed analysis of 33 stopped vehicle incidents was carried out and gives the distribution shown in the figure below.

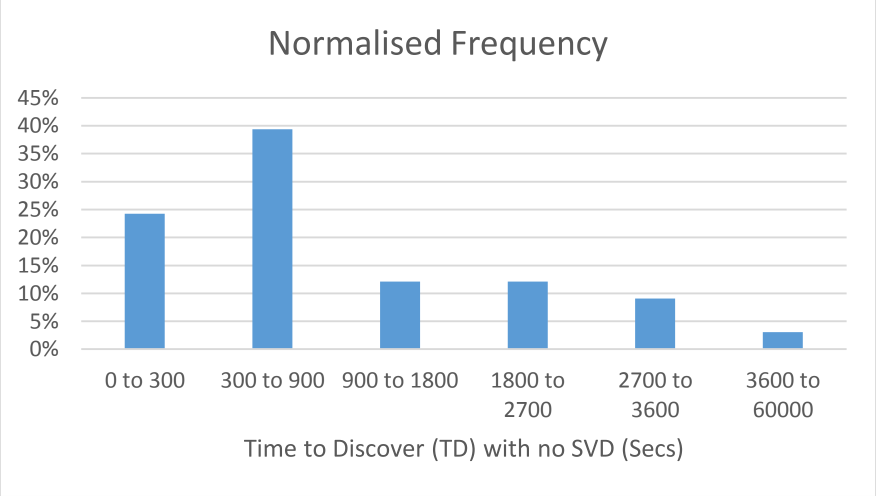


Figure 1

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[1] 20130913 - SVD trial Stage 0 Report v1.1

[2] Managed Motorways All lanes running: Managing the risk of vehicle stops in the carriageway, 18th April 2013, Version 1.00, Ref: 1049773_DOC_VSC

We can use this frequency distribution to estimate the number of stopped vehicle incidents in each time band.

The trial showed that the TD when SVD was deployed was more or less constant and less than 1 minute. For the purpose of the analysis we have selected a value of 1 minute for TD with SD deployed. If we remove this value from the midpoint of the bands in the distribution of TD without SD, and multiply by the KSI rates per exposure minute, we can estimate the number of KSI per stop avoided by the improved response time and reduction in exposure. Using the frequency distribution from figure 1, we can estimate the number in each category of KSI and then, in turn, apply the monetary value for prevention of each category used in standard transport scheme appraisal to determine a quantified benefit.

KSI Rates

Table 1 sets out the casualty rates for the three different categories of KSI. The values for KSI rates are those used in the MM-ALR design analysis. Although data is now available for the first year of operation on the M25 ALR sections this is too short a time period, and the total length of carriageway is also too short, to generate statistically robust values. Therefore, we have elected to remain with the design values. The initial data from the M25 does show lower KSI rates than anticipated which means that the estimates of benefits are likely to be high and can be regarded as the maximum benefits that can be realized.

The initial data from analysis of the C&C logs for J5to J6 by the M25 Operational Impact study reported 1616 live lane breakdowns in 580 days, a rate of 2.8 per day. The observed rate in the trial was substantially higher at 5 per day. This difference may be in part due to the way data is recorded in C&C logs and because the SVD system identified a number of short duration stops that are not currently discovered by TOS and hence not in the logs. We have not been able to set these values against traffic data to obtain a value for Vehicle stops per 10^6 miles. Again, this ambiguity in the data means that we have elected to work with the design data for the purposes of estimating the benefits and this may mean that the values are over-estimated.

Table 1

Item	Rate	Source
Killed rate (per 10^{11} vehicle-mile)	7.1	Managed Motorways All lanes running: Managing the risk of vehicle stops in the carriageway
Seriously injured rate (per 10^{11} vehicle-mile)	16.9	18th April 2013, Version 1.00, Ref: 1049773_DOC_VSC
Slightly injured rate (per 10^{11} vehicle-mile)	137	
Vehicle stops per 10^6 miles	1.7	
Killed rate per stopped vehicle	0.0000418	Relevant rate divided by vehicle stops per 10^6 miles
Seriously injured rate per stopped vehicle	0.0000994	
Slightly injured rate per stopped vehicle	0.0008059	

These are the average values across the whole duration of the stopped vehicle events, i.e. they do not differentiate as to when signs and signals were set. From the MM_ALR Hazard Log[3] setting signs and signals is estimated to reduce the risk by 40%.

Let:

R = rate of killed per stop (= 0.0000418 in table 1)

R is the average of two rates

R_1= rate of killed when signs are not set per stop and R_2 = rate of killed when signs are set.

R_2 is 40% less than R_1 (Hazlog estimate) then $R_2 = 0.6\,R_1$

Hence $R = (R_1+R_2)/2 = 1.6R_1/2 = 0.8R_1$ and therefore $R_1 = 1.25R$

There are then two cases to be considered

Case 1

The duration of the stopped vehicle incident as whole is reduced by the same amount as the reduction in exposure to near miss duration. In this case the KSI rate of $1.25R$, where R is the rate of KSI category per stop, can be applied. This case will give the maximum level of benefit

Case 2

The duration of the stopped vehicle incident as whole remains the same. Therefore, on the change in rate can be applied to the reduction in exposure to near miss duration. In this case the KSI rate of R_1-R_2 , where R_x is the rate of KSI category per stop, can be applied. Substituting $1.25R$ for R_1 and $0.6R_1$ for R_2 gives a rate of $0.5R$. This represents the case of minimal benefit.

Calculations for benefits have been made for both cases.

A further assumption has been made regarding damage only accidents. It has been assumed that the ratio of slight to damage only is approximately the same as that for serious to slight, i.e. 1 to 10. So for every 1 slight injury accident there will have been 10 damage only accidents.

In the tables 2 and 3 column (a) are the values for KSI per stopped vehicle given in the earlier table, column (b) is column (a) multiplied by 1.25 in Case 1 and 0.5 in Case 2. The value for (c) is the mid-point of the mode value of the distribution shown in figure 1. This has been chosen as a more typical value than, for example, the arithmetic mean or the median. Finally, column (d) is (b) divided by (c) expressed in minutes rather than seconds.

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[3] SMOps - WP17 Generic hazard log for ALR 20150107 colour

Case 1

Table 2

	(a) Rate per stopped vehicle	(b) No signals set	(c) Average duration with no signals set (seconds)	(d) Rate per minute with no signals set
Near miss rate - fatal	0.0000418	5.22E-05	600	5.22E-06
Near miss rate serious injury	0.0000994	1.24E-04	600	1.24E-05
Near miss rate slight injury	0.0008059	1.01E-03	600	1.01E-04
Near miss rate damage only	Assume 10 x slight	1.01E-02	600	1.01E-03

Case 2

Table 3

	Rate per stopped vehicle	No signals set	Average duration with no signals set	Rate per minute with no signals set
Near miss rate - fatal	0.0000418	2.09E-05	600	2.09E-06
Near miss rate serious injury	0.0000994	4.97E-05	600	4.97E-06
Near miss rate slight injury	0.0008059	4.03E-04	600	4.03E-05
Near miss rate damage only	Assume 10 x slight	4.03E-03	600	4.03E-04

Exposure to near misses

The total exposure to near misses is the number of stopped vehicle events multiplied by the duration of exposure, TD. Instead of using a single average value we can use the distribution shown in figure 1 to determine the exposure in each band and then sum across all bands to get the total.

During the trial it was observed that the traffic levels fall into two distinct groupings – low flow overnight between 20:00 and 06:00 and high flows during the rest of the day, 06:00 to 20:00. There are different rates of vehicles stopping in these two periods so they have been analysed separately and then added together to get the final value.

We have assumed that the distribution of TD is the same for both periods because the available data did not give us enough detail to have a robust distribution for both. It is quite likely that they are different because of different resource and workload during these periods. However, the effects of lower resource levels during the night may be offset by increased workload during the day so the difference may not be too great. Future work should test whether this assumption has a material effect on the calculations or not.

For each of the two flow periods (high and low) we can use the trial data to determine the stopped vehicle rate per carriageway km per day, as shown in table 4.

Table 4

No of stops in high flow period during trial	176
No of stops in low flow period during trial	108
Length of trial (days)	57
Length of site in km	13
Stops in high flow per carriageway km/day	0.119
Stops in low flow per carriageway km/day	0.073

If we now take the example of a 20km scheme

Table 5

Scheme length km	**20**				
Exposure to near miss duration	No of stops high flow - 12 months	No of stops low flow - 12 months	Reduction in exposure to near misses (secs)	Reduction in minutes with no signals set, high flow	Reduction in near misses low flow
0 to 300	420	258	90	630	387
300 to 900	683	419	540	6147	3772
900 to 1800	210	129	1290	4519	2773
1800 to 2700	210	129	2190	7671	4707
2700 to 3600	158	97	3090	8118	4981
3600 to 60000	53	32	5340	4676	2869
total	**1734**	**1064**		**31761**	**19490**

The value in column (c) is the scheme length multiplied by the stops in high flow per carriageway km/day then by 365 and then by the frequency value in column (b). Column (d) is the same but for low flow conditions.

The value in column (e) is the mid-point of the duration in column (a) minus the value of TD with SVD deployed, i.e. 60 seconds. Note that in the final row we have not taken the midpoint as the band is very wide. Instead we have taken 1.5 x the lower limit as the mid-point value. This is a slightly conservative approach as it underestimates the reduction in exposure to near misses for this band.

Column (f) is the product of (c) and (e) and represent the total number of minutes in the year that exposure has been reduced. As before, column (f) is for high flow and column (g) for low flow.

Estimating avoided KSI

We can calculate our estimate for the numbers of KSI and damage only incidents avoided by multiplying the values in column (d) of tables 2 and 3 with the total value from the bottom of columns (f) or (g) in table 5 depending on which time of day we are analyzing. These are shown in table 6.

If we then add the two values for the same KSI category we can multiply this sum by the values for prevention of injuries used the WEBTAG appraisal methodology to give monetary values for the benefits from reducing the exposure time to near misses. Table 7 shows the outcome. Column (a) are the unit values for each accident type and column (b) are the values for a single year on a 20km scheme.

Table 6

Estimated reduction in casualties, high flow	
Fatal	0.06633
Serious	0.15787
Slight	1.27980
Damage only	12.79798
Estimated reduction in casualties, low flow	
Fatal	0.04070
Serious	0.09688
Slight	0.78533
Damage	7.85330

	(a) WEBTAG Value adjusted to 2016	(b) Benefit (2016 values)
Valuation of accident- fatal	£ 2,087,399	£ 223,404
Valuation of accident- serious injury	£ 238,149	£ 60,668
Valuation of accident- slight	£ 25,136	£ 51,909
Valuation of accident- damage only	£ 2,226	£ 45,971
	Total	**£ 381,951**

Costs

A detailed analysis has been made of the capital and maintenance costs of installing a system based on the Navtech radar. The costs include civil engineering and the computers at the RCC. The costs have then been scaled to estimate the costs for schemes of 5, 20 and 100km in length. Appendix 3 shows the breakdown of costs.

Net present value (NPV) analysis

In order to assess benefits and cost on an equitable basis we need to consider each case for each scheme size (5, 20 and 100 km) over a 10 year period. This involves calculating the benefits and costs for each year.

For each year we need to take into account any changes over time, such as inflation and traffic growth. We have assumed an inflation of 3%p.a. using government forecasts[4] and applied these to both the value of KSI and damage accidents and to the annual costs of maintaining the system. We have assumed that growth in traffic will cause an increase in the number of stops of the same magnitude. Based on Department for Transport data[5] we have adopted an annual increase of 1.5% p.a. for the 10-year period.

Finally, we apply a “discount factor” to bring all future year values back to the base year, 2016 values. The discount factor applied is 3.5%, this being the value for schemes of 0-30years given in DfT: WebTAG: TAG data book, December 2015.

The NPV value for benefits is then divided by the NPV value for cost to give a Benefit Cost Ratio (BCR). BCR values have been calculated for each of the two options over each scheme to give a table of 6 values.

Table 7

	Case 1				Case 2		
Scheme length (km)	Benefits	Costs	**BCR**		Benefits	Costs	**BCR**
5	£2,395,701	£1,611,287	**1.49**		£958,280	£1,611,287	**0.59**
20	£9,582,805	£6,750,783	**1.42**		£3,833,122	£6,750,783	**0.57**
100	£47,914,024	£27,856,717	**1.72**		£19,165,610	£27,856,717	**0.69**

From Table 7 it is clear that the positive benefits exceed the costs of the implementation when the overall duration of stopped vehicle incidents reduces at the same magnitude as the reduction the time to discover, TD. The BCR ratio improves with size of scheme. However, if the only outcome is that signs are set earlier then the costs outweigh the quantifiable benefits.

Therefore, to fully benefit from deploying SVD there must be changes in TOS operations that use the improved time to discover to reduce overall stopped vehicle durations by a comparable amount.

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[4] HM Treasury: Forecasts for the UK economy: a comparison of independent forecasts

[5] Road Traffic Forecasts 2015 - DfT

Appendix 03

Outline Benefit Costs Ratio for Stopped Vehicle Detection

Case 1 Datasheets

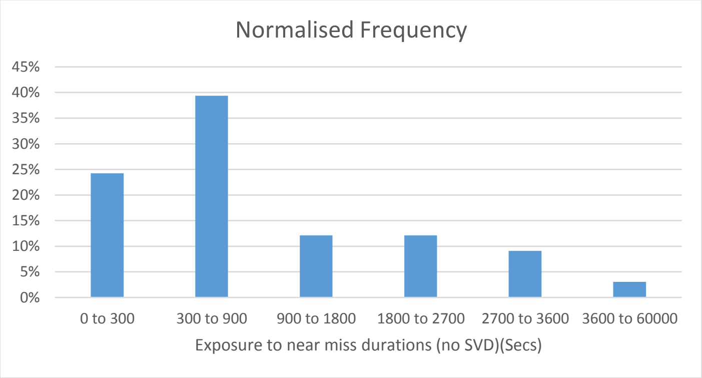
Base Data

Item		Rate	Source	
Killed rate (per 10^{11} vehicle-mile)		7.1	Managed Motorways All lanes running: Managing the risk of vehicle stops in the carriageway	
Seriously injured rate (per 10^{11} vehicle-mile)		16.9	18th April 2013, Version 1.00, Ref: 1049773_DOC_VSC	
Slightly injured rate (per 10^{11} vehicle-mile)		137		
Vehicle stops per 10^6 miles		1.7		
Killed rate per stopped vehicle		0.0000418	Relevant rate divided by vehicle stops per 10^6 miles	
Seriously injured rate per stopped vehicle		0.0000994		
Slightly injured rate per stopped vehicle		0.0008059		
Factor for risk before signs and signals set		0.5	Hazlog estimate of effect of settings signs and signals is a reduction of 40%. Therefore R=(r1 + r2)/2 = (r1 +(1-0.4)r1)/2=4/5r1 and r1=1.25R	
			This the pessimistic assumption that only KSI will be avoided because of lower risk rate (incident duration remains unchanged)	
Typical average flow per carriageway 06:00-20:00				
ppn average flow in LBS1 per carriageway 06:00-20:00				
Typical average flow in LBS1 per carriageway 06:00-20:00 (vph)		529		
Typical average flow per carriageway 20:00-06:00				
ppn average flow in LBS1 per carriageway 20:00-06:00				
Typical average flow in LBS1 per carriageway 20:00-06:00 (vph)		220		
Forecast traffic growth on SRN 2010-2040 low		29.0%	Road Traffic Forecasts 2015 - DfT	
Forecast traffic growth on SRN 2010-2040 high		60.0%	Road Traffic Forecasts 2015 - DfT	
Forecast annual traffic growth on SRN 2010-2040 low		1.0%	Above divided by 30 years	
Forecast traffic annual growth on SRN 2010-2040 high		2.0%		
Forecast traffic annual growth on SRN 2010-2040 mid		1.50%	Average of high-low	
		2014	2016	
Valuation of prevention of accident- fatal		£ 2,066,732	£ 2,087,399	DfT
Valuation of prevention of accident- serious injury		£ 235,791	£ 238,149	Reported Road Casualties in Great Britain: 2011 Annual Report
Valuation of prevention of accident- slight		£ 24,887	£ 25,136	A valuation of road accidents and casualties in Great Britain in 2011
Valuation of prevention of accident- damage only		£ 2,204	£ 2,226	
Inflation rate (RPI)				
	2011	5.2%	520%	Office for national statistics: RPI: Retail Price Index (% change)
	2012	3.2%	320%	
	2013	3.0%	300%	
	2014	2.4%	240%	
	2015	1.0%	100%	
Forecast inflation rate				
	2016	2.6%	HM Treasury: Forecasts for the UK economy:a comparison of independent forecasts	
	2017	3.2%		
	2018	3.2%		
	2019	3.0%		
	2020+			
Discount rates		3.50%	DfT: WebTAG: TAG data book, December 2015	
No of stops in high flow period during trial		176		
No of stops in low flow period during trial		108		
Length of trial (days)		57		

Base Data

Length of site in km	13
Stops in high flow per carriageway km/day	0.119
Stops in low flow per carriageway km/day	0.073
Time to discover with SVD (secs)	60

exposure to near miss durations (no SVD)(Secs)	No of stop vehicle Incidents	Normalised Frequency	Mid point of time to discover
0 to 300	8	24%	150
300 to 900	13	39%	600
900 to 1800	4	12%	1350
1800 to 2700	4	12%	2250
2700 to 3600	3	9%	3150
3600 to 60000	1	3%	5400
		100%	
Average duration with no signals set (secs)	600	Mode of above distribution	



BCR Summary

	Case 1				Case 2		
Scheme length (km)	Benefits	Costs	**BCR**		Benefits	Costs	**BCR**
5	£ 2,395,701	£ 1,611,287	**1.49**		£ 958,280	£ 1,611,287	**0.59**
20	£ 9,582,805	£ 6,750,783	**1.42**		£ 3,833,122	£ 6,750,783	**0.57**
100	£ 47,914,024	£ 27,856,717	**1.72**		£ 19,165,610	£ 27,856,717	**0.69**

Costs

PROJECT AND SCHEME DETAILS			
Scheme Type	Fill-in e.g. M62	New Build e.g. M25	Major e.g. M1
Scheme Length (km)	5	20	100
Operational Life (yrs)	10	10	10
Service Interval (yrs)	5	5	5
Support Contract renewal period (yrs)	5	5	5
Distance between radar (km)	0.5	0.5	0.5
Number of radar per scheme	10	40	200

CAPITAL COSTS			
HARDWARE			
Radar unit cost (£)	15,750	15,035	13,388
Additional EPU functionality unit cost (£)	1,000	1,000	850
24V DC Power Supply unit cost (£)	227	227	193
Onboard tracking software unit cost (£)	1,200	1,200	1,020
Total hardware cost per unit	18,177	17,462	15,450
Total hardware cost per scheme	*181,770*	*698,480*	*3,090,090*

Instation			
Number of Server (Rule Engine)	1	1	5
Number of Server (Database)	0	1	5
Number of Server (Alarm Management)	1	1	1
Total Server requirement	2	3	11
Number of Witness Software	1	1	5
Number of Database SW	1	1	5
Server unit cost (£)	3,998	3,998	3,998
Witness Software unit cost (£)	2,055	2,055	2,055
Database unit cost (£)	1,700	1,700	1,700
Standard XML alarm integration (£)	5,150	5,150	5,150
Total software cost per scheme	*16,901*	*20,899*	*67,903*

PROJECT DELIVERY SERVICES			
Site Survey (days)	3	10	50
System Design (days)	0	2	2
System Preparation (days)	1	1	3
Interface Support (days)	0	0	0
Factory Acceptance Test (days)	5	5	5
Radar Install (days)	0	0	0
Onsite Commissioning (days)	4	14	66
Remote Software Commissioning	5	20	100
Site Acceptance Test	2	7	33
Fine Tuning (over 8 weeks)	5	20	100
Alarm Monitoring (over 4 weeks)	0	0	0
Operational Acceptance Test			
Project Management	5	15	67
Documentation	0	0	0
Onsite Training	0	1	1
Total onsite man days	9	31	149
Total office man days	21	63	277
Total man days	30	94	426
Total man days per radar	3	2.35	2.13
Unit cost per onsite day	£1,050	£1,050	£1,050
Unit cost per office day	£800	£800	£800
Total cost of manpower	£26,250	£82,950	£378,050
Travel (no of trips)	3	6	30
Accommodation & subsistence (days)	12	37	179
Cost of Travel	£100	£100	£100
Cost of Accommodation & subsistence	£150	£150	£150
Total cost of travel & subsistence	£2,100	£6,150	£29,850
Total project services cost per scheme(£)	*28,350*	*89,100*	*407,900*

TOTAL PROJECT COST PER SCHEME(£)	*227,021*	*808,479*	*3,565,893*
TOTAL COST PER RADAR (£)	£ 22,702	£ 20,212	£ 17,829

SPARES			
Total spares cost per scheme (£)	*17,950*	*68,940*	*305,150*

Costs

Road Side Civils						
Poles Required		10		40		200
Mounting Pole Unit Costs	£	500	£	500	£	500
Base for Pole Unit Costs	£	2,500	£	2,500	£	2,500
Sub Total	£	30,000	£	120,000	£	600,000
NRTS Connection & Enablement Units		10		40		200
NRTS Connection & Enablement Unit Cost	£	4,000	£	4,000	£	4,000
Sub Total	£	40,000	£	160,000	£	800,000
Ducting & Cabling Units		250		1000		5000
Ducting & Cabling Unit Cost	£	20	£	20	£	20
Sub Total	£	5,000	£	20,000	£	100,000
Unit Installation		4		14		67
Unit cost per onsite day		£1,050		£1,050		£1,050
	£	4,200	£	14,700	£	70,350
Total Road Side Civils costs per scheme (£)		*79,200*		*314,700*		*1,570,350*

TRAFFIC MANAGEMENT						
Number of radar installed per TM		1.5		1.5		1.5
Traffic Management Activities Required		7		27		134
Traffic Management Costs (inc plant, lighting etc..)	£	5,000	£	5,000	£	5,000
Total Traffic Management costs per scheme (£)		*35,000*		*135,000*		*670,000*

TOTAL SCHEME CAPITAL COSTS	*£*	*359,171*	*£*	*1,327,119*	*£*	*6,111,393*

EXTENDED WARRANTY, TECHNICAL SUPPORT AND SERVICING (GROUPED AS SUPPORT)			
Support costs per radar per annum	£2,043	£1,819	£1,605
Support costs per scheme per annum	£20,432	£72,763	£320,930
Support costs per scheme first 5 years	£81,728	£291,052	£1,283,721
Support costs per scheme first 5 years	£69,468	£247,395	£1,091,163
Support costs per scheme first 5 years	£57,209	£203,737	£898,605
Support costs per scheme first 5 years	£102,159	£363,816	£1,604,651.85
Support costs per scheme first 5 years	£86,836	£309,243	£1,363,954
Support costs per scheme first 5 years	£71,512	£254,671	£1,123,256
Total support costs per scheme (£)	*£128,721*	*£458,408*	*£2,021,861*
Additional Operating Resources	0	2	4
Cost per resource	£50,000	£50,000	£50,000
	£0	£100,000	£200,000
First line maintenance by RTMC costs	500	500	500
	£5,000	£20,000	£100,000
Resource Totals	*£5,000*	*£120,000*	*£300,000*
Totals Annual costs	*£133,721*	*£578,408*	*£2,321,861*
Total support costs per scheme, per year (£)	£133,720.91	£57,840.76	£232,186.13
Total support costs per year, per radar (£)	£13,372.09	£1,446.02	£1,160.93

TOTAL COSTS Over 10 Years	£1,696,380	£1,905,527	£8,433,254
Annual cost per km of motorway	£7,183	£6,636	£6,111
Annual cost per km of motorway(rounded)	£7,200	£6,600	£6,100

NPV Claculations for 5km Scheme

Scheme length km	**5**				
Time to Discover	No of stops high flow - 12 months	No of stops low flow - 12 months	Reduction in exposure to near misses (secs)	Reduction in minutes with no signals set, high flow	Reduction in near misses low flow
0 to 300	105	64	90	158	97
300 to 900	171	105	540	1537	943
900 to 1800	53	32	1290	1130	693
1800 to 2700	53	32	2190	1918	1177
2700 to 3600	39	24	3090	2029	1245
3600 to 60000	13	8	5340	1169	717
total	**433**	**266**		**7940**	**4872**

	No signals set	Average duration with no signals set	Rate per minute with no signals set
Near miss rate - fatal	2.09E-05	600	2.09E-06
Near miss rate serious injury	4.97E-05	600	4.97E-06
Near miss rate slight injury	4.03E-04	600	4.03E-05
Near miss rate damage only	4.03E-03	600	4.03E-04

	1	2	3	4	5	6	7	8	9	10
Valuation of accident- fatal	£ 2,087,399	£ 2,141,672	£ 2,210,205	£ 2,280,932	£ 2,349,360	£ 2,419,841	£ 2,492,436	£ 2,567,209	£ 2,644,225	£ 2,723,552
Valuation of accident- serious injury	£ 238,149	£ 245,770	£ 253,634	£ 261,243	£ 269,081	£ 277,153	£ 285,468	£ 294,032	£ 302,853	£ 311,938
Valuation of accident- slight	£ 25,136	£ 25,940	£ 26,718	£ 26,718	£ 27,520	£ 28,346	£ 29,196	£ 30,072	£ 30,974	£ 31,903
Valuation of accident- damage only	£ 2,226	£ 2,293	£ 2,293	£ 2,293	£ 2,362	£ 2,432	£ 2,505	£ 2,581	£ 2,658	£ 2,738
Estimated reduction in casualties, high										
Fatal	0.01658	0.01683	0.01708	0.01734	0.01760	0.01786	0.01813	0.01840	0.01868	0.01896
Serious	0.03947	0.04006	0.04066	0.04127	0.04189	0.04252	0.04316	0.04380	0.04446	0.04513
Slight	0.31995	0.32475	0.32962	0.33456	0.33958	0.34468	0.34985	0.35509	0.36042	0.36583
Damage only	3.19949	3.24749	3.29620	3.34564	3.39583	3.44676	3.49847	3.55094	3.60421	3.65827
Estimated reduction in casualties, low										
Fatal	0.01017	0.01033	0.01048	0.01064	0.01080	0.01096	0.01113	0.01129	0.01146	0.01163
Serious	0.02422	0.02458	0.02495	0.02533	0.02571	0.02609	0.02648	0.02688	0.02728	0.02769
Slight	0.19633	0.19928	0.20227	0.20530	0.20838	0.21151	0.21468	0.21790	0.22117	0.22448
Damage	1.96333	1.99278	2.02267	2.05301	2.08380	2.11506	2.14679	2.17899	2.21167	2.24485
Value										
Fatal	£ 55,851	£ 58,163	£ 60,924	£ 63,817	£ 66,717	£ 69,750	£ 72,920	£ 76,234	£ 79,699	£ 83,321
Serious	£ 15,167	£ 15,887	£ 16,642	£ 17,398	£ 18,189	£ 19,015	£ 19,880	£ 20,783	£ 21,728	£ 22,715
Slight	£ 12,977	£ 13,593	£ 14,211	£ 14,424	£ 15,080	£ 15,765	£ 16,482	£ 17,231	£ 18,014	£ 18,833
Damage	£ 11,493	£ 12,015	£ 12,195	£ 12,378	£ 12,941	£ 13,529	£ 14,144	£ 14,787	£ 15,459	£ 16,161
Total	**£ 95,488**	**£ 99,658**	**£ 103,972**	**£ 108,017**	**£ 112,927**	**£ 118,059**	**£ 123,425**	**£ 129,035**	**£ 134,899**	**£ 141,030**
Total for 10 years	£ 1,166,509.78									
NPV for 10 years	**£ 958,280.48**									
Costs										
Capital	£ 359,171									
Annual	£ 133,721	£ 137,733	£ 141,865	£ 146,120	£ 150,504	£ 155,019	£ 159,670	£ 164,460	£ 169,394	£ 174,475
Total	**£ 492,892**	**£ 137,733**	**£ 141,865**	**£ 146,120**	**£ 150,504**	**£ 155,019**	**£ 159,670**	**£ 164,460**	**£ 169,394**	**£ 174,475**
Total for 10 years	£ 1,892,131.34									
NPV for 10 years	**£ 1,611,286.62**									
BCR	**0.59**									

NPV Calculations for 20km Scheme

Scheme length km **20**

Exposure to near miss duration	No of stops high flow - 12 months	No of stops low flow - 12 months	Reduction in exposure to near misses (secs)	Reduction in minutes with no signals set, high flow	Reduction in near misses low flow
0 to 300	420	258	90	630	387
300 to 900	683	419	540	6147	3772
900 to 1800	210	129	1290	4519	2773
1800 to 2700	210	129	2190	7671	4707
2700 to 3600	158	97	3090	8118	4981
3600 to 60000	53	32	5340	4676	2869
total	**1734**	**1064**		**31761**	**19490**

	No signals set	Average duration with no signals set	Rate per minute with no signals set
Near miss rate - fatal	2.09E-05	600	2.09E-06
Near miss rate serious injury	4.97E-05	600	4.97E-06
Near miss rate slight injury	4.03E-04	600	4.03E-05
Near miss rate damage only	4.03E-03	600	4.03E-04

Year	1	2	3	4	5	6	7	8	9	10
Valuation of accident- fatal	£ 2,087,399	£ 2,141,672	£ 2,210,205	£ 2,280,932	£ 2,349,360	£ 2,419,841	£ 2,492,436	£ 2,567,209	£ 2,644,225	£ 2,723,552
Valuation of accident- serious injury	£ 238,149	£ 245,770	£ 253,634	£ 261,243	£ 269,081	£ 277,153	£ 285,468	£ 294,032	£ 302,853	£ 311,938
Valuation of accident- slight	£ 25,136	£ 25,940	£ 26,718	£ 26,718	£ 27,520	£ 28,346	£ 29,196	£ 30,072	£ 30,974	£ 31,903
Valuation of accident- damage only	£ 2,226	£ 2,293	£ 2,293	£ 2,293	£ 2,362	£ 2,432	£ 2,505	£ 2,581	£ 2,658	£ 2,738
Estimated reduction in casualties, high flow										
Fatal	0.06633	0.06732	0.06833	0.06935	0.07040	0.07145	0.07252	0.07361	0.07471	0.07584
Serious	0.15787	0.16024	0.16264	0.16508	0.16756	0.17007	0.17263	0.17521	0.17784	0.18051
Slight	1.27980	1.29899	1.31848	1.33826	1.35833	1.37871	1.39939	1.42038	1.44168	1.46331
Damage only	12.79798	12.98995	13.18480	13.38257	13.58331	13.78706	13.99386	14.20377	14.41683	14.63308
Estimated reduction in casualties, low flow										
Fatal	0.04070	0.04131	0.04193	0.04256	0.04320	0.04385	0.04450	0.04517	0.04585	0.04654
Serious	0.09688	0.09833	0.09980	0.10130	0.10282	0.10436	0.10593	0.10752	0.10913	0.11077
Slight	0.78533	0.79711	0.80907	0.82120	0.83352	0.84602	0.85871	0.87159	0.88467	0.89794
Damage	7.85330	7.97110	8.09067	8.21203	8.33521	8.46024	8.58714	8.71595	8.84669	8.97939
Benefits										
Fatal	£ 223,404	£ 232,650	£ 243,697	£ 255,267	£ 266,869	£ 278,998	£ 291,679	£ 304,936	£ 318,795	£ 333,284
Serious	£ 60,668	£ 63,549	£ 66,566	£ 69,592	£ 72,754	£ 76,061	£ 79,518	£ 83,132	£ 86,911	£ 90,861
Slight	£ 51,909	£ 54,373	£ 56,845	£ 57,697	£ 60,320	£ 63,061	£ 65,927	£ 68,924	£ 72,056	£ 75,331
Damage	£ 45,971	£ 48,060	£ 48,781	£ 49,513	£ 51,763	£ 54,116	£ 56,575	£ 59,146	£ 61,835	£ 64,645
Total	**£ 381,951**	**£ 398,633**	**£ 415,888**	**£ 432,069**	**£ 451,706**	**£ 472,236**	**£ 493,699**	**£ 516,138**	**£ 539,597**	**£ 564,121**

Total for 10 years	£ 4,666,039.12
NPV for 10 years	**£ 3,833,121.94**

Costs										
Capital	£ 1,327,119									
Annual	£ 578,408	£ 595,760	£ 613,633	£ 632,042	£ 651,003	£ 670,533	£ 690,649	£ 711,368	£ 732,709	£ 754,691
Total	**£ 1,905,527**	**£ 595,760**	**£ 613,633**	**£ 632,042**	**£ 651,003**	**£ 670,533**	**£ 690,649**	**£ 711,368**	**£ 732,709**	**£ 754,691**

Total for 10 years	£ 7,957,913.84
NPV for 10 years	**£ 6,750,782.98**

BCR **0.57**

NPV Calculations for 100km Scheme

Scheme length km	**100**				
Time to Discover	No of stops high flow - 12 months	No of stops low flow - 12 months	Reduction in exposure to near misses (secs)	Reduction in minutes with no signals set, high flow	Reduction in near misses low flow
0 to 300	2102	1290	90	3152	1934
300 to 900	3415	2096	540	30737	18861
900 to 1800	1051	645	1290	22593	13864
1800 to 2700	1051	645	2190	38355	23536
2700 to 3600	788	484	3090	40588	24907
3600 to 60000	263	161	5340	23381	14347
total	**8669**	**5320**		**158807**	**97450**

	No signals set	Average duration with no signals set	Rate per minute with no signals set
Near miss rate - fatal	2.09E-05	600	2.09E-06
Near miss rate serious injury	4.97E-05	600	4.97E-06
Near miss rate slight injury	4.03E-04	600	4.03E-05
Near miss rate damage only	4.03E-03	600	4.03E-04

	1	2	3	4	5	6	7	8	9	10
Valuation of accident- fatal	£ 2,087,399	£ 2,141,672	£ 2,210,205	£ 2,280,932	£ 2,349,360	£ 2,419,841	£ 2,492,436	£ 2,567,209	£ 2,644,225	£ 2,723,552
Valuation of accident- serious injury	£ 238,149	£ 245,770	£ 253,634	£ 261,243	£ 269,081	£ 277,153	£ 285,468	£ 294,032	£ 302,853	£ 311,938
Valuation of accident- slight	£ 25,136	£ 25,940	£ 26,718	£ 26,718	£ 27,520	£ 28,346	£ 29,196	£ 30,072	£ 30,974	£ 31,903
Valuation of accident- damage only	£ 2,226	£ 2,293	£ 2,293	£ 2,293	£ 2,362	£ 2,432	£ 2,505	£ 2,581	£ 2,658	£ 2,738
Estimated reduction in casualties, high										
Fatal	0.33163	0.33660	0.34165	0.34677	0.35198	0.35726	0.36261	0.36805	0.37357	0.37918
Serious	0.78936	0.80120	0.81322	0.82542	0.83780	0.85037	0.86313	0.87607	0.88921	0.90255
Slight	6.39899	6.49497	6.59240	6.69128	6.79165	6.89353	6.99693	7.10188	7.20841	7.31654
Damage only	63.98989	64.94973	65.92398	66.91284	67.91653	68.93528	69.96931	71.01885	72.08413	73.16539
Estimated reduction in casualties, low										
Fatal	0.20350	0.20655	0.20965	0.21279	0.21599	0.21923	0.22251	0.22585	0.22924	0.23268
Serious	0.48438	0.49165	0.49902	0.50651	0.51411	0.52182	0.52964	0.53759	0.54565	0.55384
Slight	3.92665	3.98555	4.04534	4.10602	4.16761	4.23012	4.29357	4.35797	4.42334	4.48969
Damage	39.26652	39.85552	40.45335	41.06015	41.67605	42.30120	42.93571	43.57975	44.23345	44.89695
Value										
Fatal	£ 1,117,018	£ 1,163,252	£ 1,218,483	£ 1,276,337	£ 1,334,346	£ 1,394,992	£ 1,458,394	£ 1,524,679	£ 1,593,975	£ 1,666,421
Serious	£ 303,341	£ 317,744	£ 332,831	£ 347,958	£ 363,772	£ 380,306	£ 397,591	£ 415,661	£ 434,553	£ 454,304
Slight	£ 259,544	£ 271,867	£ 284,223	£ 288,487	£ 301,599	£ 315,306	£ 329,637	£ 344,619	£ 360,282	£ 376,657
Damage	£ 229,853	£ 240,300	£ 243,904	£ 247,563	£ 258,814	£ 270,578	£ 282,875	£ 295,732	£ 309,173	£ 323,225
Total	**£ 1,909,757**	**£ 1,993,163**	**£ 2,079,441**	**£ 2,160,344**	**£ 2,258,532**	**£ 2,361,182**	**£ 2,468,497**	**£ 2,580,691**	**£ 2,697,983**	**£ 2,820,606**

Total for 10 years	£ 23,330,195.62
NPV for 10 years	**£ 19,165,609.69**

Costs										
Capital	£ 6,111,393									
Annual	£ 2,321,861	£ 2,391,517	£ 2,463,263	£ 2,537,161	£ 2,613,275	£ 2,691,674	£ 2,772,424	£ 2,855,597	£ 2,941,264	£ 3,029,502
Total	**£ 8,433,254**	**£ 2,391,517**	**£ 2,463,263**	**£ 2,537,161**	**£ 2,613,275**	**£ 2,691,674**	**£ 2,772,424**	**£ 2,855,597**	**£ 2,941,264**	**£ 3,029,502**

Total for 10 years	£ 32,728,931.08
NPV for 10 years	**£ 27,856,716.56**
BCR	**0.69**

NPV Claculations for Trial Site

Time to Discover	No of stops high flow - trial period	No of stops low flow - trial period	No of stops high flow - 12 months	No of stops low flow - 12 months	Reduction in time to discover (secs)	Reduction in minutes with no signals set, high flow	Reduction in near misses low flow
0 to 300	43	26	273.2163743	168	90	410	251
300 to 900	69	43	443.9766082	272	540	3996	2452
900 to 1800	21	13	136.6081871	84	1290	2937	1802
1800 to 2700	21	13	136.6081871	84	2190	4986	3060
2700 to 3600	16	10	102.4561404	63	3090	5276	3238
3600 to 60000	5	3	34.15204678	21	5340	3040	1865
total	**176**	**108**	**1127.017544**	**692**		**20645**	**12668**

	No signals set	Average duration with no signals set	Rate per minute with no signals set
Near miss rate - fatal	2.09E-05	600	2.09E-06
Near miss rate serious injury	4.97E-05	600	4.97E-06
Near miss rate slight injury	4.03E-04	600	4.03E-05
Near miss rate damage only	4.03E-03	600	4.03E-04

	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Valuation of accident- fatal	£ 2,390,222	£ 2,452,367	£ 2,530,843	£ 2,611,830	£ 2,690,185	£ 2,770,890	£ 2,854,017	£ 2,939,638	£ 3,027,827	£ 3,118,662
Valuation of accident- serious injury	£ 272,698	£ 281,424	£ 290,429	£ 299,142	£ 308,117	£ 317,360	£ 326,881	£ 336,687	£ 346,788	£ 357,192
Valuation of accident- slight	£ 28,782	£ 29,703	£ 30,595	£ 30,595	£ 31,512	£ 32,458	£ 33,431	£ 34,434	£ 35,467	£ 36,531
Valuation of accident- damage only	£ 2,549	£ 2,625	£ 2,625	£ 2,625	£ 2,704	£ 2,785	£ 2,869	£ 2,955	£ 3,044	£ 3,135
Estimated reduction in casualties, high										
Fatal	0.04311	0.04376	0.04441	0.04508	0.04576	0.04644	0.04714	0.04785	0.04856	0.04929
Serious	0.10262	0.10416	0.10572	0.10730	0.10891	0.11055	0.11221	0.11389	0.11560	0.11733
Slight	0.83187	0.84435	0.85701	0.86987	0.88291	0.89616	0.90960	0.92325	0.93709	0.95115
Damage only	8.31869	8.44347	8.57012	8.69867	8.82915	8.96159	9.09601	9.23245	9.37094	9.51150
Estimated reduction in casualties, low										
Fatal	0.02645	0.02685	0.02725	0.02766	0.02808	0.02850	0.02893	0.02936	0.02980	0.03025
Serious	0.06297	0.06391	0.06487	0.06585	0.06683	0.06784	0.06885	0.06989	0.07093	0.07200
Slight	0.51046	0.51812	0.52589	0.53378	0.54179	0.54992	0.55816	0.56654	0.57503	0.58366
Damage	5.10465	5.18122	5.25894	5.33782	5.41789	5.49916	5.58164	5.66537	5.75035	5.83660
Value										
Fatal	£ 166,279	£ 173,161	£ 181,383	£ 189,995	£ 198,630	£ 207,658	£ 217,096	£ 226,963	£ 237,278	£ 248,062
Serious	£ 45,155	£ 47,299	£ 49,545	£ 51,797	£ 54,151	£ 56,612	£ 59,185	£ 61,875	£ 64,687	£ 67,627
Slight	£ 38,636	£ 40,470	£ 42,309	£ 42,944	£ 44,896	£ 46,936	£ 49,070	£ 51,300	£ 53,631	£ 56,069
Damage	£ 34,216	£ 35,771	£ 36,307	£ 36,852	£ 38,527	£ 40,278	£ 42,109	£ 44,022	£ 46,023	£ 48,115
Total	**£ 284,285**	**£ 296,701**	**£ 309,544**	**£ 321,587**	**£ 336,203**	**£ 351,484**	**£ 367,459**	**£ 384,160**	**£ 401,620**	**£ 419,873**

Total for 10 years	£ 3,472,916.58
NPV for 10 years	**£ 2,852,979.23**

Appendix 04

Outline Benefit Costs Ratio for Stopped Vehicle Detection

Case 2 Datasheets

Base Data

Item		Rate	Source	
Killed rate (per 10^{11} vehicle-mile)		7.1	Managed Motorways All lanes running: Managing the risk of vehicle stops in the carriageway	
Seriously injured rate (per 10^{11} vehicle-mile)		16.9	18th April 2013, Version 1.00, Ref: 1049773_DOC_VSC	
Slightly injured rate (per 10^{11} vehicle-mile)		137		
Vehicle stops per 10^6 miles		1.7		
Killed rate per stopped vehicle		0.0000418	Relevant rate divided by vehicle stops per 10^6 miles	
Seriously injured rate per stopped vehicle		0.0000994		
Slightly injured rate per stopped vehicle		0.0008059		
Factor for risk before signs and signals set		1.25	Hazlog estimate of effect of settings signs and signals is a reduction of 40%. Therefore R=(r1 + r2)/2 = (r1 +(1-0.4)r1)/2=4/5r1 and r1=1.25R	
			This the optimistic assumption that overall stop duration reduces by the the same amount of time and hence all KSI will be avoided	
Typical average flow per carriageway 06:00-20:00				
ppn average flow in LBS1 per carriageway 06:00-20:00				
Typical average flow in LBS1 per carriageway 06:00-20:00 (vph)		529		
Typical average flow per carriageway 20:00-06:00				
ppn average flow in LBS1 per carriageway 20:00-06:00				
Typical average flow in LBS1 per carriageway 20:00-06:00 (vph)		220		
Forecast traffic growth on SRN 2010-2040 low		29.0%	Road Traffic Forecasts 2015 - DfT	
Forecast traffic growth on SRN 2010-2040 high		60.0%	Road Traffic Forecasts 2015 - DfT	
Forecast annual traffic growth on SRN 2010-2040 low		1.0%	Above divided by 30 years	
Forecast traffic annual growth on SRN 2010-2040 high		2.0%		
Forecast traffic annual growth on SRN 2010-2040 mid		1.50%	Average of high-low	
		2014	2016	
Valuation of prevention of accident- fatal		£ 2,066,732	£ 2,087,399	DfT
Valuation of prevention of accident- serious injury		£ 235,791	£ 238,149	Reported Road Casualties in Great Britain: 2011 Annual Report
Valuation of prevention of accident- slight		£ 24,887	£ 25,136	A valuation of road accidents and casualties in Great Britain in 2011
Valuation of prevention of accident- damage only		£ 2,204	£ 2,226	
Inflation rate (RPI)				
	2011	5.2%	520%	Office for national statistics: RPI: Retail Price Index (% change)
	2012	3.2%	320%	
	2013	3.0%	300%	
	2014	2.4%	240%	
	2015	1.0%	100%	
Forecast inflation rate				
	2016	2.6%	HM Treasury: Forecasts for the UK economy:a comparison of independent forecasts	
	2017	3.2%		
	2018	3.2%		
	2019	3.0%		
	2020+			
Discount rates		3.50%	DfT: WebTAG: TAG data book, December 2015	
No of stops in high flow period during trial		176		

Base Data

No of stops in low flow period during trial	108
Length of trial (days)	57
Length of site in km	13
Stops in high flow per carriageway km/day	0.119
Stops in low flow per carriageway km/day	0.073

Time to discover with SVD (secs)	60

Time to Discover (no SVD)(Secs)	No of stop vehicle Incidents	Normalised Frequency	Mid point of time to discover
0 to 300	8	24%	150
300 to 900	13	39%	600
900 to 1800	4	12%	1350
1800 to 2700	4	12%	2250
2700 to 3600	3	9%	3150
3600 to 60000	1	3%	5400
		100%	
Average duration with no signals set (secs)	600	Mode of above distribution	

NPV Calculations for 5km Scheme

Scheme length km **5**

Time to Discover	No of stops high flow - 12 months	No of stops low flow - 12 months	Reduction in time to discover (secs)	Reduction in minutes with no signals set, high flow	Reduction in near misses low flow
0 to 300	105	64	90	158	97
300 to 900	171	105	540	1537	943
900 to 1800	53	32	1290	1130	693
1800 to 2700	53	32	2190	1918	1177
2700 to 3600	39	24	3090	2029	1245
3600 to 60000	13	8	5340	1169	717
total	**433**	**266**		**7940**	**4872**

	No signals set	Average duration with no signals set	Rate per minute with no signals set
Near miss rate - fatal	5.22E-05	600	5.22E-06
Near miss rate serious injury	1.24E-04	600	1.24E-05
Near miss rate slight injury	1.01E-03	600	1.01E-04
Near miss rate damage only	1.01E-02	600	1.01E-03

	1	2	3	4	5	6	7	8	9	10
Valuation of accident- fatal	£ 2,087,399	£ 2,141,672	£ 2,210,205	£ 2,280,932	£ 2,349,360	£ 2,419,841	£ 2,492,436	£ 2,567,209	£ 2,644,225	£ 2,723,552
Valuation of accident- serious injury	£ 238,149	£ 245,770	£ 253,634	£ 261,243	£ 269,081	£ 277,153	£ 285,468	£ 294,032	£ 302,853	£ 311,938
Valuation of accident- slight	£ 25,136	£ 25,940	£ 26,718	£ 26,718	£ 27,520	£ 28,346	£ 29,196	£ 30,072	£ 30,974	£ 31,903
Valuation of accident- damage only	£ 2,226	£ 2,293	£ 2,293	£ 2,293	£ 2,362	£ 2,432	£ 2,505	£ 2,581	£ 2,658	£ 2,738
Estimated reduction in casualties, high										
Fatal	0.04145	0.04208	0.04271	0.04335	0.04400	0.04466	0.04533	0.04601	0.04670	0.04740
Serious	0.09867	0.10015	0.10165	0.10318	0.10473	0.10630	0.10789	0.10951	0.11115	0.11282
Slight	0.79987	0.81187	0.82405	0.83641	0.84896	0.86169	0.87462	0.88774	0.90105	0.91457
Damage only	7.99874	8.11872	8.24050	8.36411	8.48957	8.61691	8.74616	8.87736	9.01052	9.14567
Estimated reduction in casualties, low										
Fatal	0.02544	0.02582	0.02621	0.02660	0.02700	0.02740	0.02781	0.02823	0.02865	0.02908
Serious	0.06055	0.06146	0.06238	0.06331	0.06426	0.06523	0.06621	0.06720	0.06821	0.06923
Slight	0.49083	0.49819	0.50567	0.51325	0.52095	0.52876	0.53670	0.54475	0.55292	0.56121
Damage	4.90832	4.98194	5.05667	5.13252	5.20951	5.28765	5.36696	5.44747	5.52918	5.61212
Value										
Fatal	£ 139,627	£ 145,406	£ 152,310	£ 159,542	£ 166,793	£ 174,374	£ 182,299	£ 190,585	£ 199,247	£ 208,303
Serious	£ 37,918	£ 39,718	£ 41,604	£ 43,495	£ 45,472	£ 47,538	£ 49,699	£ 51,958	£ 54,319	£ 56,788
Slight	£ 32,443	£ 33,983	£ 35,528	£ 36,061	£ 37,700	£ 39,413	£ 41,205	£ 43,077	£ 45,035	£ 47,082
Damage	£ 28,732	£ 30,037	£ 30,488	£ 30,945	£ 32,352	£ 33,822	£ 35,359	£ 36,967	£ 38,647	£ 40,403
Total	**£ 238,720**	**£ 249,145**	**£ 259,930**	**£ 270,043**	**£ 282,316**	**£ 295,148**	**£ 308,562**	**£ 322,586**	**£ 337,248**	**£ 352,576**

Total for 10 years £ 2,916,274.45

NPV for 10 years **£ 2,395,701.21**

Costs										
Capital	£ 359,171									
Annual	£ 133,721	£ 137,733	£ 141,865	£ 146,120	£ 150,504	£ 155,019	£ 159,670	£ 164,460	£ 169,394	£ 174,475
Total	**£ 492,892**	**£ 137,733**	**£ 141,865**	**£ 146,120**	**£ 150,504**	**£ 155,019**	**£ 159,670**	**£ 164,460**	**£ 169,394**	**£ 174,475**

Total for 10 years £ 1,892,131.34

NPV for 10 years **£ 1,611,286.62**

BCR **1.49**

NPV Claculations for 20km Scheme

Scheme length km 20

Time to Discover	No of stops high flow - 12 months	No of stops low flow - 12 months	Reduction in time to discover (secs)	Reduction in minutes with no signals set, high flow	Reduction in near misses low flow
0 to 300	420	258	90	630	387
300 to 900	683	419	540	6147	3772
900 to 1800	210	129	1290	4519	2773
1800 to 2700	210	129	2190	7671	4707
2700 to 3600	158	97	3090	8118	4981
3600 to 60000	53	32	5340	4676	2869
total	**1734**	**1064**		**31761**	**19490**

	No signals set	Average duration with no signals set	Rate per minute with no signals set
Near miss rate - fatal	5.22E-05	600	5.22E-06
Near miss rate serious injury	1.24E-04	600	1.24E-05
Near miss rate slight injury	1.01E-03	600	1.01E-04
Near miss rate damage only	1.01E-02	600	1.01E-03

Year	1	2	3	4	5	6	7	8	9	10
Valuation of accident- fatal	£ 2,087,399	£ 2,141,672	£ 2,210,205	£ 2,280,932	£ 2,349,360	£ 2,419,841	£ 2,492,436	£ 2,567,209	£ 2,644,225	£ 2,723,552
Valuation of accident- serious injury	£ 238,149	£ 245,770	£ 253,634	£ 261,243	£ 269,081	£ 277,153	£ 285,468	£ 294,032	£ 302,853	£ 311,938
Valuation of accident- slight	£ 25,136	£ 25,940	£ 26,718	£ 26,718	£ 27,520	£ 28,346	£ 29,196	£ 30,072	£ 30,974	£ 31,903
Valuation of accident- damage only	£ 2,226	£ 2,293	£ 2,293	£ 2,293	£ 2,362	£ 2,432	£ 2,505	£ 2,581	£ 2,658	£ 2,738
Estimated reduction in casualties, high flow										
Fatal	0.16581	0.16830	0.17082	0.17339	0.17599	0.17863	0.18131	0.18403	0.18679	0.18959
Serious	0.39468	0.40060	0.40661	0.41271	0.41890	0.42518	0.43156	0.43804	0.44461	0.45128
Slight	3.19949	3.24749	3.29620	3.34564	3.39583	3.44676	3.49847	3.55094	3.60421	3.65827
Damage only	31.99494	32.47487	32.96199	33.45642	33.95827	34.46764	34.98466	35.50942	36.04207	36.58270
Estimated reduction in casualties, low flow										
Fatal	0.10175	0.10328	0.10482	0.10640	0.10799	0.10961	0.11126	0.11293	0.11462	0.11634
Serious	0.24219	0.24582	0.24951	0.25325	0.25705	0.26091	0.26482	0.26879	0.27283	0.27692
Slight	1.96333	1.99278	2.02267	2.05301	2.08380	2.11506	2.14679	2.17899	2.21167	2.24485
Damage	19.63326	19.92776	20.22668	20.53008	20.83803	21.15060	21.46786	21.78987	22.11672	22.44847
Benefits										
Fatal	£ 558,509	£ 581,626	£ 609,241	£ 638,168	£ 667,173	£ 697,496	£ 729,197	£ 762,339	£ 796,988	£ 833,211
Serious	£ 151,671	£ 158,872	£ 166,415	£ 173,979	£ 181,886	£ 190,153	£ 198,795	£ 207,831	£ 217,277	£ 227,152
Slight	£ 129,772	£ 135,934	£ 142,112	£ 144,243	£ 150,799	£ 157,653	£ 164,818	£ 172,309	£ 180,141	£ 188,328
Damage	£ 114,926	£ 120,150	£ 121,952	£ 123,781	£ 129,407	£ 135,289	£ 141,438	£ 147,866	£ 154,587	£ 161,612
Total	**£ 954,878**	**£ 996,581**	**£ 1,039,721**	**£ 1,080,172**	**£ 1,129,266**	**£ 1,180,591**	**£ 1,234,249**	**£ 1,290,345**	**£ 1,348,992**	**£ 1,410,303**

Total for 10 years £ 11,665,097.81
NPV for 10 years £ 9,582,804.85

Costs										
Capital	£ 1,327,119									
Annual	£ 578,408	£ 595,760	£ 613,633	£ 632,042	£ 651,003	£ 670,533	£ 690,649	£ 711,368	£ 732,709	£ 754,691
Total	**£ 1,905,527**	**£ 595,760**	**£ 613,633**	**£ 632,042**	**£ 651,003**	**£ 670,533**	**£ 690,649**	**£ 711,368**	**£ 732,709**	**£ 754,691**

Total for 10 years £ 7,957,913.84
NPV for 10 years £ 6,750,782.98

BCR 1.42

NPV Claculations for 100km Scheme

Scheme length km	**100**				
Time to Discover	No of stops high flow - 12 months	No of stops low flow - 12 months	Reduction in time to discover (secs)	Reduction in minutes with no signals set, high flow	Reduction in near misses low flow
0 to 300	2102	1290	90	3152	1934
300 to 900	3415	2096	540	30737	18861
900 to 1800	1051	645	1290	22593	13864
1800 to 2700	1051	645	2190	38355	23536
2700 to 3600	788	484	3090	40588	24907
3600 to 60000	263	161	5340	23381	14347
total	**8669**	**5320**		**158807**	**97450**

	No signals set	Average duration with no signals set	Rate per minute with no signals set
Near miss rate - fatal	5.22E-05	600	5.22E-06
Near miss rate serious injury	1.24E-04	600	1.24E-05
Near miss rate slight injury	1.01E-03	600	1.01E-04
Near miss rate damage only	1.01E-02	600	1.01E-03

	1	2	3	4	5	6	7	8	9	10
Valuation of accident- fatal	£ 2,087,399	£ 2,141,672	£ 2,210,205	£ 2,280,932	£ 2,349,360	£ 2,419,841	£ 2,492,436	£ 2,567,209	£ 2,644,225	£ 2,723,552
Valuation of accident- serious injury	£ 238,149	£ 245,770	£ 253,634	£ 261,243	£ 269,081	£ 277,153	£ 285,468	£ 294,032	£ 302,853	£ 311,938
Valuation of accident- slight	£ 25,136	£ 25,940	£ 26,718	£ 26,718	£ 27,520	£ 28,346	£ 29,196	£ 30,072	£ 30,974	£ 31,903
Valuation of accident- damage only	£ 2,226	£ 2,293	£ 2,293	£ 2,293	£ 2,362	£ 2,432	£ 2,505	£ 2,581	£ 2,658	£ 2,738
Estimated reduction in casualties, high										
Fatal	0.82907	0.84150	0.85412	0.86694	0.87994	0.89314	0.90654	0.92013	0.93394	0.94795
Serious	1.97341	2.00301	2.03306	2.06355	2.09451	2.12592	2.15781	2.19018	2.22303	2.25638
Slight	15.99747	16.23743	16.48100	16.72821	16.97913	17.23382	17.49233	17.75471	18.02103	18.29135
Damage only	159.97472	162.37434	164.80995	167.28210	169.79133	172.33820	174.92328	177.54712	180.21033	182.91349
Estimated reduction in casualties, low										
Fatal	0.50875	0.51638	0.52412	0.53198	0.53996	0.54806	0.55628	0.56463	0.57310	0.58169
Serious	1.21096	1.22912	1.24756	1.26627	1.28527	1.30454	1.32411	1.34397	1.36413	1.38460
Slight	9.81663	9.96388	10.11334	10.26504	10.41901	10.57530	10.73393	10.89494	11.05836	11.22424
Damage	98.16630	99.63880	101.13338	102.65038	104.19014	105.75299	107.33928	108.94937	110.58361	112.24237
Value										
Fatal	£ 2,792,546	£ 2,908,130	£ 3,046,207	£ 3,190,841	£ 3,335,865	£ 3,487,480	£ 3,645,986	£ 3,811,696	£ 3,984,938	£ 4,166,053
Serious	£ 758,354	£ 794,360	£ 832,076	£ 869,894	£ 909,431	£ 950,765	£ 993,977	£ 1,039,153	£ 1,086,383	£ 1,135,759
Slight	£ 648,860	£ 679,668	£ 710,559	£ 721,217	£ 753,996	£ 788,266	£ 824,092	£ 861,547	£ 900,704	£ 941,642
Damage	£ 574,632	£ 600,749	£ 609,761	£ 618,907	£ 647,036	£ 676,444	£ 707,188	£ 739,330	£ 772,933	£ 808,062
Total	**£ 4,774,392**	**£ 4,982,907**	**£ 5,198,603**	**£ 5,400,860**	**£ 5,646,329**	**£ 5,902,954**	**£ 6,171,244**	**£ 6,451,727**	**£ 6,744,958**	**£ 7,051,516**
Total for 10 years	£ 58,325,489.04									
NPV for 10 years	**£ 47,914,024.23**									
Costs										
Capital	£ 6,111,393									
Annual	£ 2,321,861	£ 2,391,517	£ 2,463,263	£ 2,537,161	£ 2,613,275	£ 2,691,674	£ 2,772,424	£ 2,855,597	£ 2,941,264	£ 3,029,502
Total	**£ 8,433,254**	**£ 2,391,517**	**£ 2,463,263**	**£ 2,537,161**	**£ 2,613,275**	**£ 2,691,674**	**£ 2,772,424**	**£ 2,855,597**	**£ 2,941,264**	**£ 3,029,502**
Total for 10 years	£ 32,728,931.08									
NPV for 10 years	**£ 27,856,716.56**									
BCR	**1.72**									

NPV Claculations for Trial Site

Time to Discover	No of stops high flow - trial period	No of stops low flow - trial period	No of stops high flow - 12 months	No of stops low flow - 12 months	Reduction in time to discover (secs)	Reduction in minutes with no signals set, high flow	Reduction in near misses low flow
0 to 300	43	26	273.2163743	168	90	410	251
300 to 900	69	43	443.9766082	272	540	3996	2452
900 to 1800	21	13	136.6081871	84	1290	2937	1802
1800 to 2700	21	13	136.6081871	84	2190	4986	3060
2700 to 3600	16	10	102.4561404	63	3090	5276	3238
3600 to 60000	5	3	34.15204678	21	5340	3040	1865
total	**176**	**108**	**1127.017544**	**692**		**20645**	**12668**

	No signals set	Average duration with no signals set	Rate per minute with no signals set
Near miss rate - fatal	5.22E-05	600	5.22E-06
Near miss rate serious injury	1.24E-04	600	1.24E-05
Near miss rate slight injury	1.01E-03	600	1.01E-04
Near miss rate damage only	1.01E-02	600	1.01E-03

	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Valuation of accident- fatal	£ 2,390,222	£ 2,452,367	£ 2,530,843	£ 2,611,830	£ 2,690,185	£ 2,770,890	£ 2,854,017	£ 2,939,638	£ 3,027,827	£ 3,118,662
Valuation of accident- serious injury	£ 272,698	£ 281,424	£ 290,429	£ 299,142	£ 308,117	£ 317,360	£ 326,881	£ 336,687	£ 346,788	£ 357,192
Valuation of accident- slight	£ 28,782	£ 29,703	£ 30,595	£ 30,595	£ 31,512	£ 32,458	£ 33,431	£ 34,434	£ 35,467	£ 36,531
Valuation of accident- damage only	£ 2,549	£ 2,625	£ 2,625	£ 2,625	£ 2,704	£ 2,785	£ 2,869	£ 2,955	£ 3,044	£ 3,135
Estimated reduction in casualties, high										
Fatal	0.10778	0.10940	0.11104	0.11270	0.11439	0.11611	0.11785	0.11962	0.12141	0.12323
Serious	0.25654	0.26039	0.26430	0.26826	0.27229	0.27637	0.28052	0.28472	0.28899	0.29333
Slight	2.07967	2.11087	2.14253	2.17467	2.20729	2.24040	2.27400	2.30811	2.34273	2.37788
Damage only	20.79671	21.10866	21.42529	21.74667	22.07287	22.40397	22.74003	23.08113	23.42734	23.77875
Estimated reduction in casualties, low										
Fatal	0.06614	0.06713	0.06814	0.06916	0.07020	0.07125	0.07232	0.07340	0.07450	0.07562
Serious	0.15742	0.15979	0.16218	0.16462	0.16708	0.16959	0.17213	0.17472	0.17734	0.18000
Slight	1.27616	1.29530	1.31473	1.33445	1.35447	1.37479	1.39541	1.41634	1.43759	1.45915
Damage	12.76162	12.95304	13.14734	13.34455	13.54472	13.74789	13.95411	14.16342	14.37587	14.59151
Value										
Fatal	£ 415,696	£ 432,902	£ 453,456	£ 474,986	£ 496,575	£ 519,144	£ 542,739	£ 567,406	£ 593,195	£ 620,156
Serious	£ 112,888	£ 118,248	£ 123,862	£ 129,492	£ 135,377	£ 141,530	£ 147,963	£ 154,688	£ 161,718	£ 169,068
Slight	£ 96,589	£ 101,175	£ 105,773	£ 107,360	£ 112,239	£ 117,341	£ 122,674	£ 128,249	£ 134,078	£ 140,172
Damage	£ 85,539	£ 89,427	£ 90,769	£ 92,130	£ 96,317	£ 100,695	£ 105,272	£ 110,056	£ 115,058	£ 120,288
Total	**£ 710,713**	**£ 741,752**	**£ 773,860**	**£ 803,968**	**£ 840,509**	**£ 878,710**	**£ 918,647**	**£ 960,400**	**£ 1,004,050**	**£ 1,049,684**

Total for 10 years	£ 8,682,291.44
NPV for 10 years	**£ 7,132,448.08**