

Forklift truck reverse sensor systems assessment

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Counterbalance forklift trucks (FLT) are widely used in a variety of industry sectors for material handling. Incidents involving FLT are typically vehicle/pedestrian, vehicle/vehicle, or vehicle/structure collisions. Of these, vehicle/pedestrian incidents have the most potential for reportable injury and around 500 incidents a year involving moving FLT are reported to HSE.

Measures to improve or augment the operator's field of vision can include: mirrors and CCTV systems (which rely on the operator's observations) and sensor systems (including ultrasonic, radar, and Radio Frequency Identification (RFID)), similar to those commonly fitted to passenger vehicles; or simply improving the driver's operating position.

This report describes work undertaken to assess the active sensor systems (ultrasonic and radar) commonly used to reduce the risk of collisions. The systems tested appeared to provide a useful function in mitigating the risk of collision by stopping the truck when an obstruction was detected. However, certain configurations produced blind spots in the detection zones that could allow a pedestrian to approach the truck without being detected. The sensors also needed to be mounted to give an appropriate detection zone without producing a large number of false detections.

Companies should establish the conditions under which they will be operating an FLT and select a system that best fits their particular operating environment. Consideration should be given in the first instance to the practicability of removing pedestrians from the working area, although it is acknowledged that this is not always possible.

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Forklift truck reverse sensor systems assessment

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KEY MESSAGES

- Counterbalance forklift trucks are widely used in a variety of industry sectors for material handling. Incidents involving forklift trucks are typically vehicle/pedestrian, vehicle/vehicle, or vehicle/structure collisions. Of these, vehicle/pedestrian incidents have the most potential for reportable injury.
- Measures to increase or augment the operator's field of vision can include mirrors, CCTV systems, and sensor systems similar to those commonly fitted to passenger vehicles. Sensor systems include ultrasonic, radar, and Radio Frequency Identification (RFID) systems. Mirrors and CCTV systems rely on the operator's observations. This project assessed the active sensor systems (ultrasonic and radar) commonly used to reduce the risk of collisions to determine if they helped reduce risk.
- Pedestrians and moving vehicles should be kept separate whenever this is practicable.
- Where separating people and vehicles is not practicable, we concluded that the systems tested provide a useful function in mitigating the risk of collision when well positioned on the truck.
- Certain configurations produced blind spots in the detection zones that could allow a pedestrian to approach the truck without being detected. It was important to mount the sensors to create a suitable detection zone while avoiding false detections.
- Environmental factors that could affect the effectiveness of the systems included engine and background noise that could potentially 'drown out' the on-board alarm, and adverse environmental conditions such as dust and water and oil contamination that could damage or inhibit the sensors. It is essential to identify such issues when assessing risks in order to select the most appropriate system for the site conditions.
- Overall, the research concluded that ultrasonic and radar detection systems can provide a useful function in ensuring site safety where the assessment of risks has identified particular hazards with FLT's operating in close quarters with personnel, other vehicles, or vulnerable infrastructure.
- Detection systems may not be suitable for all applications and companies should consider whether other means of risk mitigation may be more practicable.

EXECUTIVE SUMMARY

Counterbalance forklift trucks (FLT) are the most commonly-used type of industrial lift trucks in the UK and operate in a wide variety of industrial material handling applications.

Counterbalance FLT may be electric, gas, or diesel-powered. The forks protrude from the front of the chassis, mounted on a mast that may incorporate sideshift or mast tilt facilities, so that the FLT can be driven right up to the load to be transported or storage system without the need for a reach facility. Counterbalance FLT are available in a range of load handling capabilities, from small trucks capable of moving loads of 1 to 2 tonnes, to larger trucks capable of moving loads of 8 tonnes or more.

Counterbalance FLT operate in a variety of working environments, from the relatively narrow confines of a busy warehouse or manufacturing facility, to the open spaces of an outdoor storage facility or marshalling yard. The working environment may be closed to pedestrians and other traffic, or there may be multiple traffic routes in the immediate vicinity of the FLT. Excluding overturning incidents, incidents involving FLT are typically one of three types of collision:

- Vehicle/pedestrian
- Vehicle/vehicle
- Vehicle/object.

Vehicle/pedestrian collisions typically result in injury to the pedestrian, with the severity ranging from the relatively minor (broken toes if a foot is run over) to serious injury or death if a pedestrian is crushed against the floor or a solid object.

Vehicle/vehicle collisions may involve two FLT, or a FLT colliding with a passenger car, van, HGV, or other vehicle.

Vehicle/object collisions typically involve a FLT colliding with warehouse racking, barriers set up to protect pedestrian walkways, or more substantial infrastructure such as walls and doorways.

Improving safety in reversing is a priority by HSE to ensure the safe operation of lift trucks and reduce injury. HSL: HSE's Health & Safety Laboratory carried out research to identify commercially-available reversing sensor systems that can be fitted to counter-balance FLT to provide protection for personnel working in the vicinity of the trucks, and assess their effectiveness and practicality in a range of working environments.

Objectives

- Undertake an analysis of up to 1000 FLT-related incidents reported under RIDDOR¹, starting with the most recent and working backwards in time, to identify risk factors where the FLT is reversing or where collision occurs as a result of tail swing during forward movement.
- Identify, document, and assess ultrasonic and radar systems currently on the market, and identify a sample to be taken forward for detailed evaluation and testing.
- Develop and apply an evaluation methodology for sensor system in open and confined test environments

Main findings

Analysis of injury incidents reported to HSE indicated that there were 1117 incidents involving a moving FLT between April 2011 and September 2013. In many cases it was not possible to identify the direction of travel based on the information in the RIDDOR report; however 328 incidents explicitly involved a reversing FLT.

Historically, safety during reversing manoeuvres relied solely on an operator visually scanning the area behind the FLT. The necessity to look over the shoulder or partially turn around in the seat could, with repeated operation, results in musculoskeletal disorders (MSDs). To reduce the discomfort, inconvenience and potential health effects of the operator having to physically rotate themselves in their seat, some companies installed additional mirrors in the cab or closed circuit television (CCTV) systems that relay images from behind the truck to a display panel mounted in the cab in front of the operator. Wired or wireless CCTV systems may also feature additional cameras mounted on the mast for improved visibility when working with high-level stacks or racking.

The use of additional mirrors and/or CCTV may help to reduce the risk of injury by increasing the operator's ability to see the area around the FLT. These methods, however, rely on the operator having clear sight of the mirrors/display panel and responding appropriately to detected hazards. They are also sensitive to the siting and number of the mirrors/cameras on the FLT, and the need to achieve a balance between ensuring adequate coverage of blind spots around the truck and overloading the operator with information to the point where he or she cannot react promptly to detected hazards.

The radar and ultrasonic systems tested as part of this research displayed a similar sensitivity to both siting points and environmental conditions. Appropriate mounting of user-fitted systems proved to be particularly important in avoiding blind spots in the detection zone where a pedestrian could approach the FLT without being detected by the sensors. The choice of siting points is likely to vary considerably depending on the specific operating environment. This is because of the need to strike a balance between reliable detection and avoiding false positives from site structures and other vehicles. The characteristics of the FLT itself may also have an effect on suitable siting points to avoid blind spots.

We observed that some siting points and operating environments might result in the sensors being exposed to environmental factors such as water, oil, and dust, potentially reducing their effectiveness over time. End users should be aware of the potential for contamination and ensure that manufacturers' maintenance recommendations are followed.

¹ *Reporting of Injuries, Diseases and Dangerous Occurrences Regulations 2013*

Environmental noise was a factor in the usefulness of warning alarms utilised by the systems tested. Engine noise, in addition to background noise such as machinery and vehicle movements on a busy work site, or radio in the cab or in the work area, could result in the alarm either going unheard or not being distinctive from the background noise.

A system that brought the truck to a halt when an object was detected was less optimal than a system that reduced the speed of the truck without bringing it to a complete stop. This is because operators might become exasperated with abrupt halts in a confined working environment, and either override the system and restart operation without checking for hazards or seek to disable the system entirely.

Recommendations

Ultrasonic and radar detection systems can provide a useful function in ensuring site safety where assessment of risks identifies hazards with FLT's operating in close quarters with personnel, other vehicles, or vulnerable infrastructure. Potential controls in such environments might consist of one or more of:

- Removing the risk – e.g. by rerouting pedestrian walkways and implementing guard rails and similar barriers to physically separate pedestrians and vehicles so that there is no risk of pedestrians being struck by vehicles;
- Sensor systems to detect hazards in the working area of the FLT;
- Augmented visibility systems – e.g. CCTV or additional mirrors;
- PPE e.g. specific high visibility clothing for pedestrians in the working area.

In each case, it is important that the company establish the conditions under which they will be operating the FLT and select a system that best fits their particular operating environment.

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1. INTRODUCTION

1.1 BACKGROUND

Forklift trucks are commonly involved in workplace incidents. HSE believe that the majority of those incidents involve counterbalance forklift trucks (FLTs), the most common type of lift truck. Around 70% of FLT incidents are classified as ‘struck by’ or collision incidents, where a person has been injured as a result of an impact by an FLT.

1.2 METHODOLOGY

HSE’s RIDDOR database² was interrogated to collate incident summary data relating to forklift trucks.

International Standards relating to the fitting and use of sensor systems for vehicles were reviewed to identify appropriate test methods for reversing sensor systems.

Two Standards were identified as particularly relevant in devising the test method; BS ISO 16001:2008 *Earth-moving machinery – Hazard detection systems and visual aids – Performance requirements and tests*, and BS ISO 22840:2010 *Intelligent transport systems – Devices to aid reverse manoeuvres – Extended-range backing aid systems (ERBA)*.

Both Standards are not aimed specifically at testing reversing sensor systems on FLTs, and were therefore used only as a guide for recommendations on how to potentially select and test the systems.

After reviewing BS ISO 16001:2008, and BS ISO 22840:2010, it was decided that two tests would be conducted on the reversing sensor systems, a static test, and a dynamic test.

A number of commercially-available reversing sensor systems were then identified, with some systems specifically aimed at use on FLTs and others designed to be used on a range of work vehicles and plant machinery.

The following criteria were used to determine which of the available reversing sensor systems should be tested using the methods identified by the literature review:

- History of the systems having been fitted to FLTs
- The features of the operator warning system fitted such as whether it had active speed control, audible warning, visual warning, or a combination of all three
- The appropriateness of the detection area size³, i.e. would the detection area be too big and regularly trigger false alarms, or be too small to be of practical use
- System cost.

Four reversing sensor systems were selected for testing, two radar systems and two ultrasonic systems. No RFID systems were tested as part of this research project, as it was solely focused on systems that actively detect their surroundings.

² A database of accidents reported to HSE by Employers as part of their duties under the Reporting of Injuries, Diseases and Dangerous Occurrences 1995 Regulations.

³ The detection area size is the size of the detection area as set by the operator or installer

One system (TBM ultrasonic) with active speed reduction had already been identified by the customer as falling into the scope of this project and being suitable for testing. The system had been identified as being supplied with certain models of Linde FLT's in the U.K.

The systems identified during the initial research as being appropriate for use on FLT's were ranked against each of the four main requirements, with 1 being least suitable, and 3 being most suitable. A weighting was then given to each of the four requirements based on the importance of that requirement, as agreed with the customer, again with 1 being least important, and 3 being the most important requirement. The three systems that had the highest weighted scores were then selected for testing.

Table 1 provides details of the four systems that were selected to be tested. The full weighted analysis table can be found in Appendix A.

Table 1 Reversing sensor systems selected for testing

<i>Sensor type</i>	<i>Manufacturer/Model</i>	<i>Cost (£)</i>	<i>Warning system</i>
Radar	Ogden Intelligent (VMS active)	£5,875.00	Active/audible/visual
Radar	Brigade Electronics Backsense – Workzone	£825.00	Audible/visual
Ultrasonic	TBM Hightech Control (fitted to Linde H50D FLT)	£ ⁴	Active/audible/visual
Ultrasonic	Brigade Electronics Backscan – BS4000W	£186.05	Audible/visual

The static test was based on the test procedure recommended in BS ISO 16001:2008 – Annex C, and was used to determine the approximate shape and size of the reversing systems' detection area. The static test also established whether there were any limitations to the detection area that would impact upon the capability of the system.

For the two reversing sensor systems that had active speed control, an additional dynamic test was conducted. The purpose of the dynamic test was to establish how the active speed control component functioned in practice.

⁴ This system was supplied pre-fitted to the FLT tested

2. RIDDOR ANALYSIS

2.1 BACKGROUND

This section provides summary statistics relating to forklift truck accidents reported to HSE over the period of 1 April 2011 to 30 Sept 2013. Information is provided on the nature of the accident and contributing factors, based on a review of the descriptor recorded for each accident.

The search criteria used to flag cases from the RIDDOR dataset were as follows:

1. Reportability – reportable accidents only
2. Kind of accident – accidents where the injured person was reportedly struck by a moving vehicle
3. Descriptor – mention of a forklift truck in the incident descriptor
4. Date of accident – occurring between 1 April 2011 and 30 Sept 2013.

These filters resulted in a total of 1203 records, which were then manually reviewed in order to establish the following (data allowing):

1. The direction of travel of the truck at the time of the accident (e.g. whether moving forwards, backwards etc.)
2. Where the injured person impacted with the truck (e.g. with the front, rear or side of the truck etc.).

Those accidents not involving a moving forklift truck were excluded from the filtered dataset, leaving 1117 relevant records. Contextual information regarding the accidents for the remaining records is provided in the tables on the following pages.

2.2 DESCRIPTIVE SUMMARY OF ACCIDENTS FLAGGED

Table 2 Direction of travel

Direction of travel of truck	Count
Rolled forwards/backwards (uncontrolled)	55
Moving backwards	328
Moving forwards	240
Moving (direction not clear)	494

Table 3 All accidents (n=1117)

Impact with truck	Count
Front of truck	25
Rear of truck	60

Side of truck	18
Front wheel	27
Rear wheel	80
Forks	41
Two trucks collide	76
Load	89

Unclear from information available = 701

Table 4 Rolled forwards/backwards (uncontrolled) (n=55)

Impact with truck	Count
Front of truck	4
Rear of truck	4
Side of truck	
Front wheel	2
Rear wheel	3
Forks	6
Two trucks collide	1
Load	1

Unclear from information available = 34

Table 5 Moving backwards (n=328)

Impact with truck	Count
Front of truck	3
Rear of truck	43
Side of truck	5
Front wheel	3
Rear wheel	25
Forks	4
Two trucks collide	14
Load	8

Unclear from information available = 223

Table 6 Moving forwards (n=240)

Impact with truck	Count
Front of truck	16
Rear of truck	6
Side of truck	8

Front wheel	11
Rear wheel	32
Forks	20
Two trucks collide	13
Load	37

Unclear from information available = 97

Table 7 Moving (direction not clear) (n=494)

Impact with truck	Count
Front of truck	2
Rear of truck	7
Side of truck	5
Front wheel	11
Rear wheel	20
Forks	11
Two trucks collide	48
Load	43

Unclear from information available = 347

2.3 DISCUSSION

A number of observations relating to the data collected are worthy of mention.

The above statistics highlight that a significant number of accidents did involve a truck reversing when collision occurred (i.e. 328 or 58%, see Table 2). Of those accidents where the truck was in controlled travel and the direction of travel was explicitly mentioned (the latter numbering 568 in total), in 295 cases, the truck was either moving forwards when collision occurred, or was rolling uncontrollably. Neither of these represent situations where, had the truck been fitted with reversing sensors, the risk of the collision occurring would have been significantly reduced.

Close examination of the accident counts where the truck was moving backwards when collision occurred (see Table 5) revealed that in 28 cases the injured person impacted with the wheel of the truck, often with the truck running over the injured person's foot whilst standing adjacent to it. In this position, it is possible that the injured person would have been standing in a location not covered by sensor systems.

3. LITERATURE REVIEW

3.1 BS ISO 16001:2008

The scope of BS ISO 16001:2008 states that *'...this international standard specifies general requirements and describes methods for evaluating and testing the performance of Hazard Detection Systems (HDS) and visual aids (VA) used on earth-moving machines.'*

Although BS ISO 16001:2008 is primarily aimed at earth-moving machinery (significantly larger than FLT's), it does provide useful guidance that is relevant regardless of vehicle size on how to test different types of reversing sensor systems.

The Standard provides a Table (Table A.1 – *Some advantages and disadvantages of HDS and VA*) that compares the different types of HDS and VA that can be used on earth-moving machines, and lists the advantages and disadvantages of each particular system. Table A.1 has been reproduced in Appendix B of this report, as the majority of the HDS and VA listed would also be compatible for use on FLT's.

Section A.2 *Consideration of the functional aspects of HDS and VA* provided some useful points as to what to consider when selecting a HDS to use on a piece of plant equipment, such as:

- *Operator needs and ability to interface and use the system*
- *Operating environment*
- *Machine functions*
- *Selection of HDS and VA.*

BS ISO 16001:2008 provides six annexes that detail how best to test the most common types of reversing sensor systems, with Annex C *'Test procedure for radar sensors'*, and Annex D *'Test procedure for ultrasonic detection systems'* being most relevant for this research.

3.1.1 Annex C - 'Test procedure for radar sensors'

Annex C.6.2 recommended the following test procedure for measuring the horizontal limits of a radar detection system.

'Move the test person 0.5 m away from the radar on the centreline of the anticipated detection zone. If the warning device indicates detection, move the test person sideways in each direction until detection does not occur. Record the last position where detection occurs on each side. Record any position between these points where detection does not occur. Move the test person a further 0.5 m away from the radar and repeat the above procedure. Repeat the procedure at 1 m intervals away from the radar until detection does not occur.'

Annex C.2 of BS ISO 16001:2008 states that the first part of the body to usually protrude into the detection zone⁵ will be the head, and that *'the consistency of results with real people of varying sizes has been found to be greater than those with artificial substitute objects.'*

Section C.3 *Test area*, recommends that an *'open space on flat terrain with a dry sand and/or gravel base'*, with no large objects within 25 m of either side of the radar system, be used as the test area.

⁵ The zone around the FLT in which an obstacle or person would be expected to be detected

3.1.2 Annex D – ‘Test procedure for ultrasonic detection systems’

Section D.1 highlights the following aspects of the system performance that should be considered during testing:

- *Overall performance criteria of the system*
- *The performance criteria and limits of the detection zone*
- *The criteria for location and fixing of the components*
- *The operational system’s reliability*
- *Deactivation of the system*
- *The detection time*
- *The physical environment conditions (vibration, shock, temperature, humidity).*

For horizontal testing of ultrasonic based systems the standard recommended using a plastic or metal ‘tube 75 mm in diameter and of length 1700 mm’ as the test body.

3.2 BS ISO 22840:2010

BS ISO 22840:2010 is primarily aimed at the use of reversing sensor systems in light duty vehicles, for example passenger cars, pick-up trucks, and light vans.

The test method recommended in BS ISO 22840:2010 is based around using an ‘*azimuth zone of regard*’ where ‘...a grid comprised of 10 cm squares drawn to fill a rectangle approximately 3 m x 6 m’ is placed on the floor. The grid should be aligned ‘...so that the rectangle is perpendicular to the vehicle bumper...’ and ‘the column of grid squares is uniformly 1.0 m from the rear edge of the bumper’. The test object (to be detected) is placed in each of the test squares in turn. The sensor system is then enabled, and the level of detection in each test square recorded.

BS ISO 22840:2010 recommends using a wood, metal or hard plastic test object for ultrasonic based systems, and a metal object for radar based systems, ‘...as it provides a consistent radar cross-section (RCS), over a wide range of radar frequencies, unlike the plastic pipe.’

The recommended size of the test object varies between 25 and 150 mm in diameter, with a nominal length of 1 m. The recommended size of the test object depends on factors including; what material the object is to be made of (wood, metal or plastic), where on the test grid the object is to be positioned, and the type of system being tested.

4. TEST VEHICLES AND TEST PROCEDURES

4.1 TEST VEHICLES USED

A 4 tonne Caterpillar (CAT) - 40 FLT at HSE's Buxton laboratory was selected as the test vehicle for three of the reversing sensor systems (see Figure 1).

The TBM Hightech Control system was tested as fitted to a 5 tonne Linde 50D FLT (Figure 2). The 50D model was chosen as it is a similar size to the CAT-40, and therefore offers some degree of comparison⁶ between the systems tested on the CAT-40, and the TBM system tested on the Linde 50D.



Figure 1 CAT-40 test vehicle

⁶ In terms of the practicalities of the detection area size, compared to the size of the FLT.



Figure 2 Linde 50D test vehicle

4.2 INSTALLING THE DETECTION SYSTEMS

The two Brigade systems tested were mounted temporarily on the CAT-40 FLT and were powered using an external 12 V battery. The Ogden Intelligent VMS system needed to be permanently installed onto the CAT-40 due to the installation of the active braking component. Installation of the VMS system was carried out by the supplier's approved installer.

4.3 TEST PROCEDURES

4.3.1.1 *Static test procedure*

The following static test procedure was used for all four reversing sensor systems.

The sensors were mounted on the FLT in the position recommended in the manufacturer's supplied installation guide. A human test subject was positioned on the centreline of the FLT at a distance of 0.5 m from the rear fascia. If the warning system detected the test subject, they then stepped horizontally (perpendicular to the FLT centreline) in both directions until they were no longer being detected. The last position where detection had occurred was measured back to the FLT centreline. Any position between these points where detection had not occurred was noted and measured. The test subject then moved a further 0.5 m away from the sensors, and repeated the above procedure until the test subject was no longer being detected on the FLT centreline.

For the static test the operator's warning device was positioned so it could be clearly heard and seen by the test subject. For the two systems where the warning device could not be repositioned (the VMS and TBM system), additional test personnel were used to monitor the warning device from within the FLT cab, and record the level of detection indicated.

4.3.1.2 *Dynamic test procedure*

For safety reasons, a fluorescent pole (Figure 3), previously used by HSE ergonomists for vehicle visibility studies, was used as the test object for dynamic tests. The test pole had a diameter of approximately 160 mm, and was placed over a cone for additional height and stability. When mounted on the cone the pole had a height of approximately 1872 mm.

BS ISO 22840:2010 section 7.1.1 states that some radar systems have difficulties with detecting plastic objects at certain radar frequencies. To make sure that the plastic test pole used was capable of being detected by the VMS system's Ogden radar sensor, a preliminary test was conducted, whereby the test pole was placed at known locations within the detection zone (established during the static test). The VMS system consistently detected the test pole.

This test was repeated with the other systems to check for consistency and the pole was found to perform comparatively to the human test subject in terms of sensor detection.



Figure 3 Test object used during the dynamic tests

For the dynamic test the test pole was located on the FLT centreline, 6 m from the rear fascia of the FLT. Markers were placed on the ground at 0.5 m intervals between the FLT and the test pole.

The first stage of testing was to reverse the FLT towards the test pole in order to determine the distance at which the speed reduction system was activated.

The second stage of testing was to determine whether the speed reduction system would be triggered unnecessarily by objects positioned outside the detection ‘footprint’ and, if so, how far away from the FLT centreline this detection would occur. To determine this, the FLT was driven along the marked out centreline towards the test pole. If the speed reduction system triggered, the distance from the FLT centreline to the test pole was measured.

How far away from the FLT centreline the test pole was positioned was determined from the results of the static test.

5. RESULTS

The following section provides an overview of how each of the detection systems functioned during testing, and includes the results from the static and dynamic tests.

5.1 TBM – HIGHTECH CONTROL – ULTRASONIC DETECTION SYSTEM

The TBM Hightech Control system was tested as fitted to a 5 tonne Linde 50D FLT. The TBM system was the only detection system we identified as being specifically designed for use on counterbalance FLTs.

The system consists of four ultrasonic sensor pods, with two pods located on the rear of the FLT, and two pods located on the side. The two rear pods both contained six ultrasonic sensors. Both rear pods were angled towards the centreline of the FLT (Figure 4). The two smaller side pods (both containing two sensors each) were set further back from the rear of the FLT, approximately in line with the centreline of the rear axle.

The side pods were angled downwards in order to limit the size of the detection area and to focus the sensors on monitoring the area adjacent to the rear wheels, of which the operator would have limited visibility when seated.

The TBM system was fitted with a speed reduction system, which was designed to activate when an object encroached on the detection zone. The system was capable of reducing the speed of the FLT to a minimum of 1 km/h.

A press release from Linde⁷ promoting the use of the TBM system on their FLTs stated that the detection area is divided into three distinct detection zones;

“...zone 1 acts as a preliminary warning area. If an obstacle is detected in this area, the LED lights flash in the driver’s cab and an acoustic warning signal sounds. Zone 2 is the main warning area; in this area, the LEDs flash in red and the warning signal sounds at shorter intervals. In zone 3 – the collision area – the red LEDs illuminate permanently and the warning signal emits a continuous sound. For all three zones, an automatic reduction in the driving speed can also be applied.”

The size of the three detection zones, distance from the object that the warning system is activated, and the distance that the active speed reduction is applied, can be altered depending on customer requirements and the operating environment.

⁷ Linde Press Release - Number 3/2012, 14 February 2012 ‘New assistance system from Linde MH facilitates rear-area monitoring and warns against collisions’



Figure 4a

Both side pods consisted of two sensors that were angled downwards.



Figure 4b

The two rear pods consisted of six sensors, which were angled inwards towards the centreline of the FLT.

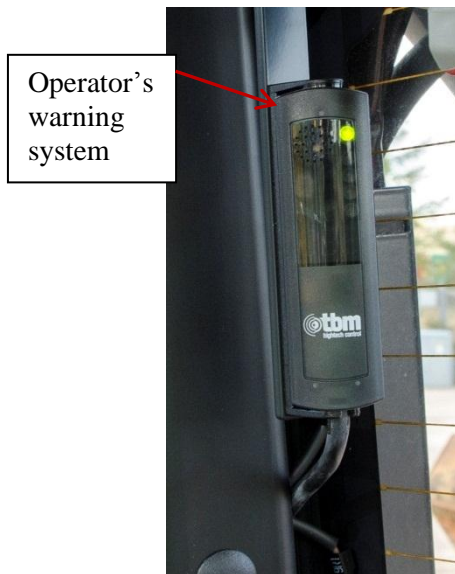


Figure 4c

Figure 4 Rear of the Linde truck showing the mounting position of the ultrasonic sensors

The operator's warning system consisted of an audible buzzer and a set of five LED lights (1 green, 2 amber, and 3 red). The warning system was positioned behind the FLT operator's right shoulder (Figure 5), meaning that when the operator was turned for reversing, the warning system would be within their field of vision.

Upon inspecting the FLT cab it was noted that there were no warning override, or volume adjustment controls to allow the operator to adjust the warning system.



Operator's
warning
system

Figure 5a



Figure 5b

Figure 5 Position of the warning system within the FLT cab

Section 2 - '*Reverse proximity alarm*' of the FLT operating manual stated that the standard pre-set for the operator warning system was for two steady green lights to show when an object was > 4 m away.

When an object was < 4 m to 3 m away, an additional two yellow LEDs would start to flash, and the audible warning would start to sound. When an object was < 3 m to 2 m away, two red LEDs would start to flash, and the audible warning would increase in frequency. The speed reduction system would also be activated, slowing the FLT to a pre-set speed. At less than < 2 m to 0 m the red LEDs would stay on steady, and the audible warning would sound continuously.

5.1.1 Static test results

The maximum width of the detection area was found to be approximately 2.8 m, and was located 3.5 m from the rear fascia of the FLT. The maximum distance from the FLT that the test person could be detected was approximately 4 m, with a detection width of approximately 1.7 m at this distance. Due to the configuration of the sensors, there is a blind spot on both the right and left hand side of the FLT (Figure 6a). This was further compounded by the operator's warning system being located on the right hand side, which meant that the driver would have to turn to the right when reversing in order to view the warning system.

The detection area narrowed considerably around the rear quarters of the FLT counterweight, with an area large enough for the test person to stand and not be detected, being formed in the area between the rear and side sensor pods (Figure 6b).



Figure 6a

Air intake canister obscured the view the FLT operator had of the LHS of the vehicle.



Figure 6b

Location of the LHS sensor blind spot

Figure 6 Location of reversing sensor blind spot

The detection area exceeded the width of the FLT footprint by a maximum of 0.7 m on both sides. The maximum width of the detection area at the distance the speed reduction system was activated exceeded the width of the FLT by approximately 0.5 m.

By positioning both of the rear sensor pods towards the centreline of the FLT, the size of the detection area that exceeded the width of the FLT, was minimised, helping to limit the potential for false detections triggered by objects of no concern located outside the path of the reversing FLT.

5.1.2 Dynamic test results

The test pole was initially positioned on the FLT centreline, 6 m from the rear fascia. The FLT was then reversed towards the test pole. After each light had been activated on the operator's warning system, the FLT was stopped and the distance from the rear fascia to the test pole measured.

The first green LED warning light was activated at approximately 4 m from the test pole, and was a steady light. At approximately 2.5 m the two amber warning LEDs started flashing and the audible warning started to sound. The speed reduction system activated approximately 2.3 m from the test pole, with the FLT noticeably slowing down to crawling speed. At approximately 1.5 m the two red LEDs activated, and the audible warning sounded continuously.

To test whether the speed reduction system would be activated by objects placed outside the path of the FLT, the test pole was placed 0.8, 1.5, and 2 m to the side of the FLT's centreline.

When the test pole was positioned 0.8 m to the side of the FLT centreline (0.1 m outside the width of the FLT), it was found that the speed reduction system activated at a distance of approximately 2.5 m from the test pole (see Figure 7).

When the test pole was positioned 1.5 and 2 m from the FLT centreline, neither the speed reduction system, nor the operator's warning system was activated. This correlated with the 'map' of the detection area (Figure 8) obtained from static detection test.

Figure 8 shows that the visual and audible warning system would not be activated if an object was located further than approximately 1.4 m to the side of the FLT centreline, and the speed reduction system would not be activated if an object was located further than approximately 1.1 m to the side of the FLT centreline.



Figure 7a



Figure 7b

Figure 7 Test pole positioned 0.8 m to the side of the FLT centreline

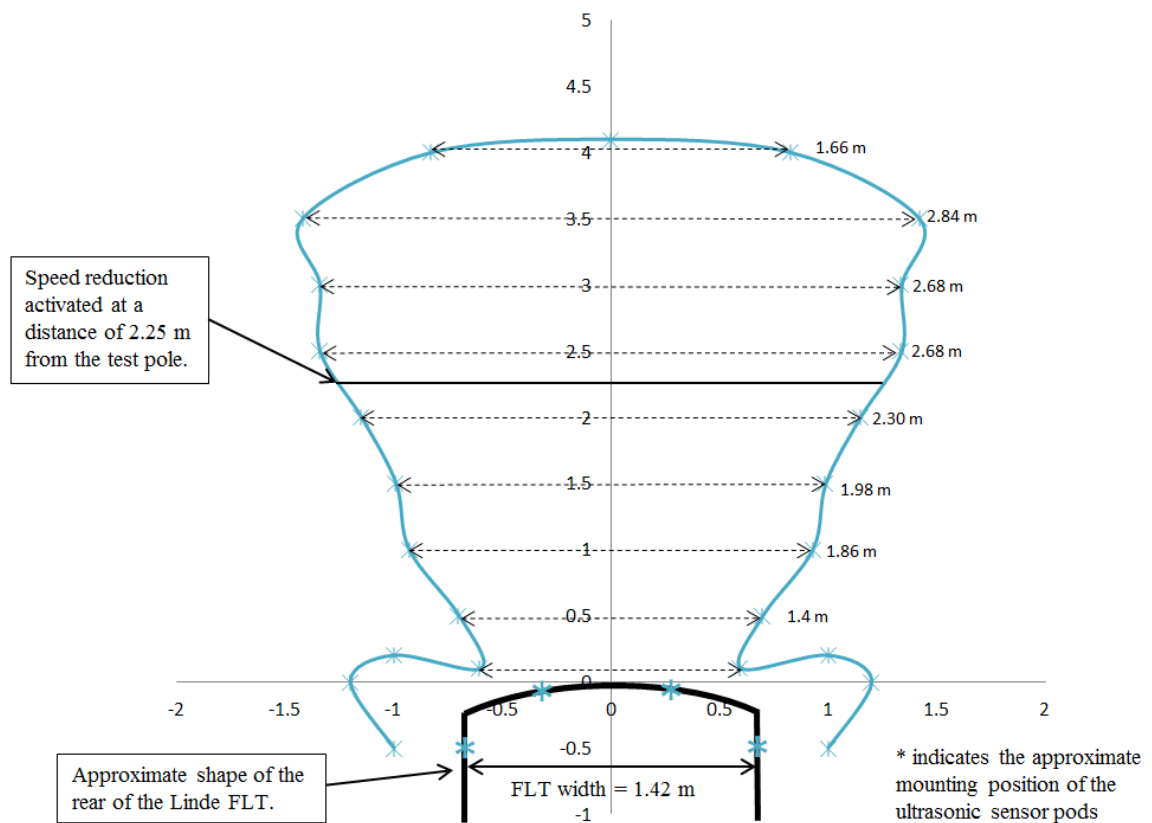


Figure 8 Diagram showing the approximate size of the TBM system's detection area

Table 8 TBM System - static test results

<i>Centreline distance from the rear of the FLT (m)</i>	<i>Approximate width of the detection area (m)</i>
0.5	1.4
1	1.86
1.5	1.98
2	2.30
2.5	2.68
3	2.68
3.5	2.84
4	1.66

5.2 BRIGADE ELECTRONICS – BACKSCAN (BS-4000W) ULTRASONIC SYSTEM

The Backscan BS-4000W ultrasonic system consisted of a four sensor array. The system was primarily marketed for use on Heavy Goods Vehicles (HGVs); although there was nothing in the system specification that prevented it from being fitted to a range of other vehicle types including FLTs.

The system was quoted as having a maximum detection range of approximately 2.5 m. The system came fitted with an output trigger cable, which could be used to switch on additional warning devices (for example, a pedestrian warning beacon) as soon as an object had been detected.

The operator's warning system consisted of two sets of seven LED warning lights, which represented either side of the FLT. By using two sets of lights, a visual indication as to which side of the FLT the object being detected was located, could be provided to the FLT operator. The change in colour (from green to amber, and then finally to red), and the increasing size of the LEDs, denoted the proximity of the detected object to the sensors. An approximation (in metres) of how close the object being detected was to the FLT was also provided in the centre of the warning system display (see Figure 9). The operator's warning system was fitted with a built in audible warning that increased in repetition rate depending on how close the object was to the sensors. There were no controls available to adjust the volume of the audible warning.

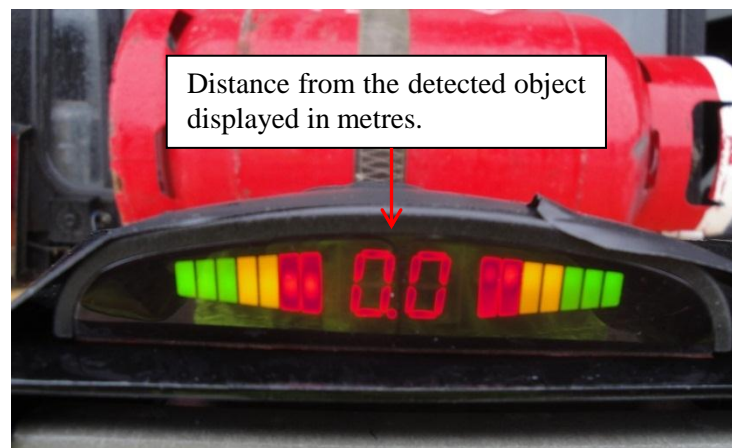


Figure 9 Backscan – operator's warning system

The ultrasonic sensors were attached to the FLT's rear counterweight, using the plastic brackets supplied with the detection system. The sensors were attached to the counterweight temporarily using Loctite adhesive. If the sensors were to have been mounted permanently to the FLT, then it was possible for the brackets and cables to have been attached to the counterweight using appropriate fasteners.

The sensors were mounted at a height of approximately 1 m from the ground, as recommended in the manufacturer's installation guidance. Two of the four sensors were positioned in the ventilation gap in the rear of the FLT counterweight. The other two sensors were mounted to the sides of the counterweight (Figure 10). The sensors were mounted symmetrically, to ensure the detection area had an even shape.

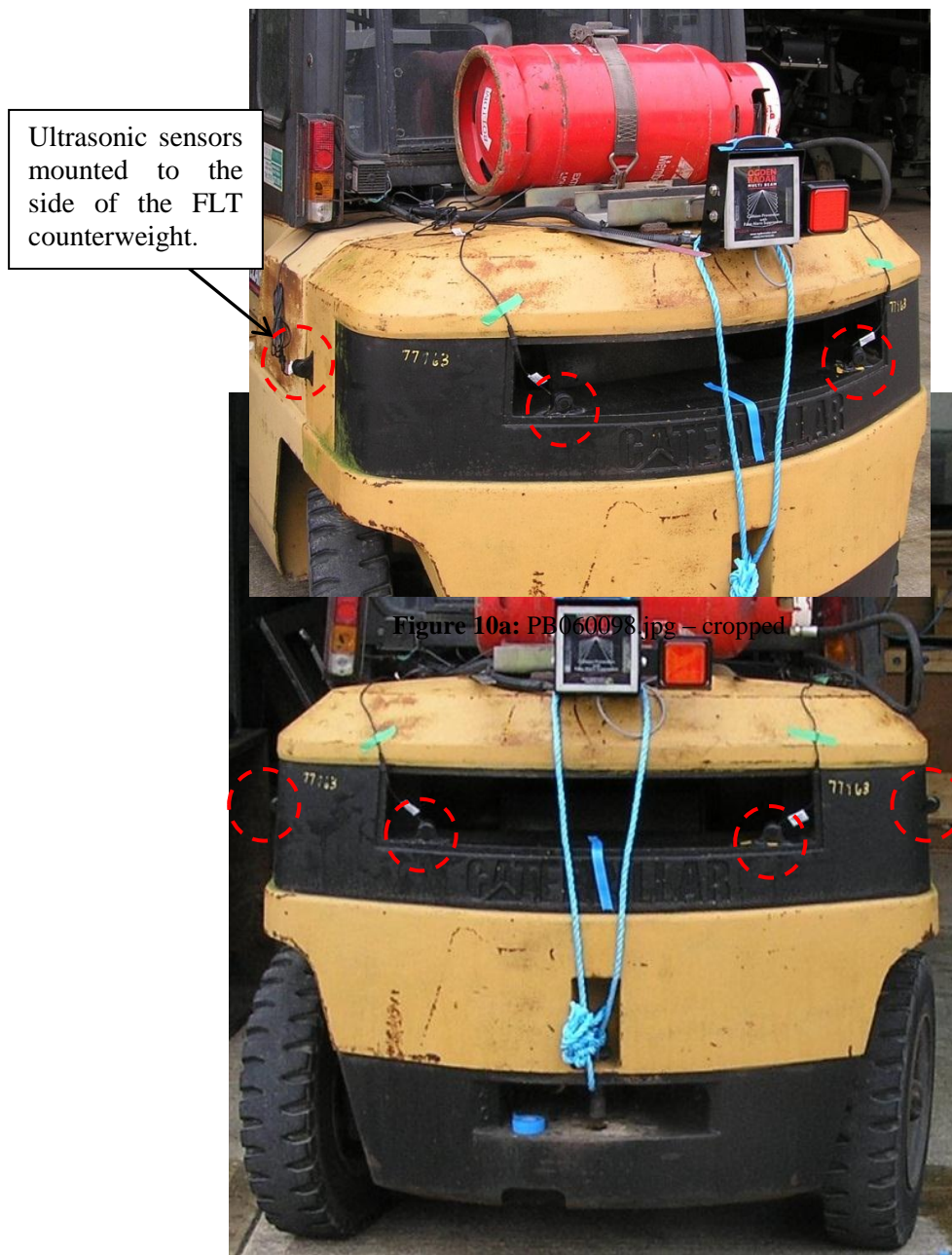


Figure 10 Mounting position for the ultrasonic sensors on the FLT counterweight

5.2.1 Static test results

In order to establish what effect moving the mounting position of the side sensors (attached to the outside of the counterweight) forward and back had on the overall shape of the detection area, the static test was conducted twice using two different mounting positions.

As can be seen in Figure 11, with the side sensors mounted further back (in the position shown in Figure 10b), the widest part of the detection area was positioned closer to the rear of the FLT. The rear mounting position was initially wider than the forward mounting position but after approximately 1.2 m became slightly narrower. The rear mounting position also had a slightly shorter maximum detection distance of 2.3 m, compared to the forward mounting positions maximum detection distance of 2.6 m.

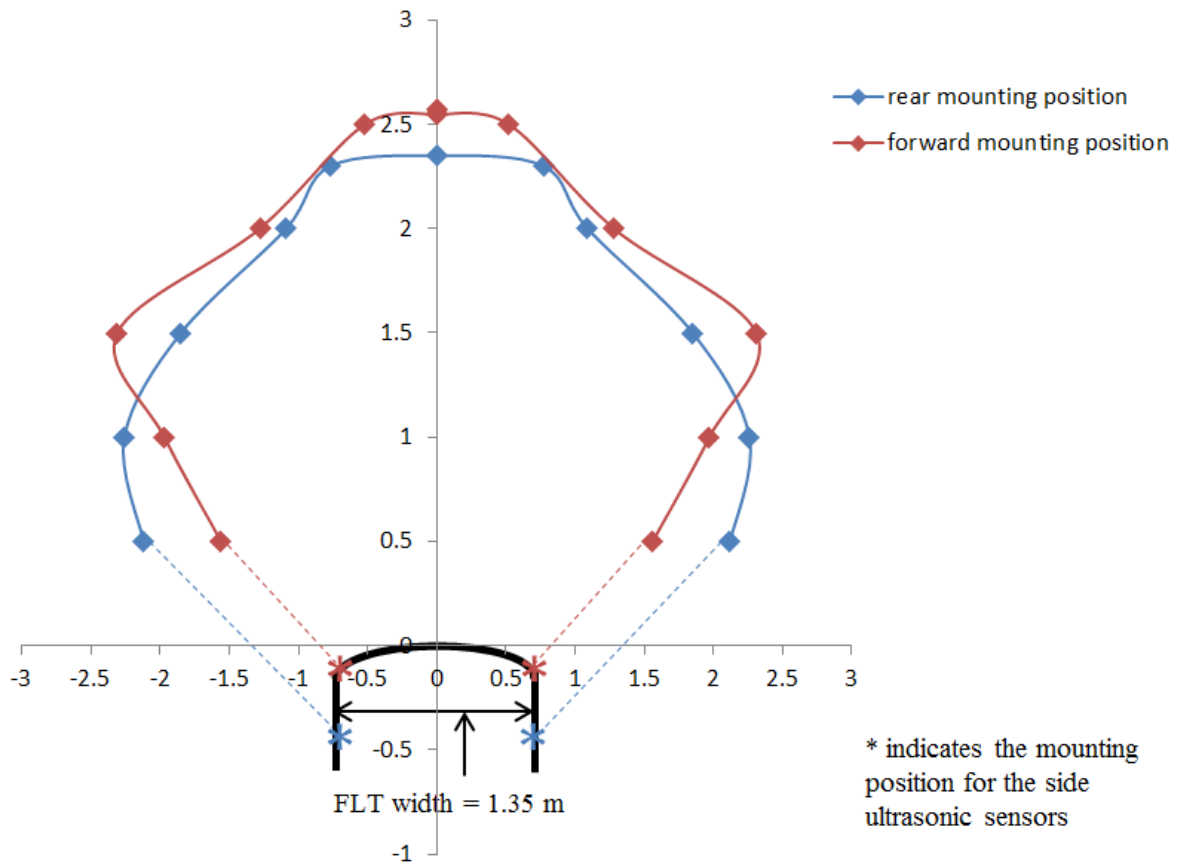


Figure 11 Plot of the Backscan detection area - comparing the forward and rear mounting positions for the side sensors

As counterweight FLT's have a particularly tight turning circle, with the counterweight usually overhanging the rear (steering) axle, the rear has a tendency to swing rapidly round when manoeuvring. Increasing the width of the detection area closer to the rear of the FLT would therefore be the preferential option over increased detection width further away.

Figure 12 and Table 9 provide detailed measurements for the size of the detection area when the side sensors were mounted further back on the counterweight.

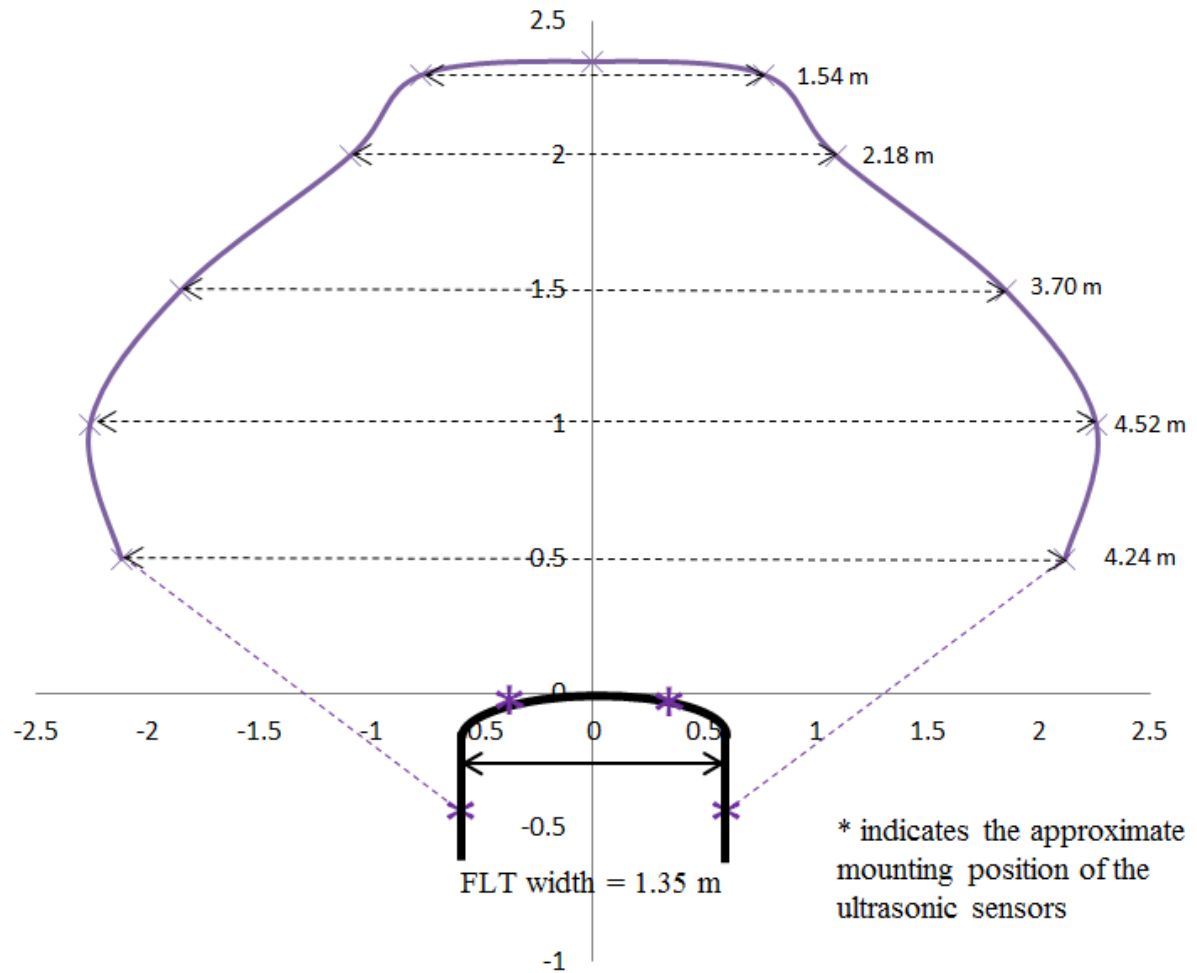


Figure 12 Diagram showing the plot of the detection area when the side sensors are positioned further back on the FLT counterweight

Table 9 Backscan – static test results

<i>Centreline distance from the rear of the FLT (m)</i>	<i>Approximate width of the detection area (m)</i>
0.5	4.24
1	4.52
1.5	3.70
2	2.18
2.3	1.54

As can be seen in Figure 12, the maximum distance that the system could detect the test person was approximately 2.3 m from the rear of the FLT. The maximum width of the detection area was approximately 4.5 m, which was located approximately 1 m away from the rear of the FLT. The maximum width of the detection area exceeded the width of the FLT by approximately 1.6 m either side of the FLT.

5.3 VISION TECHNIQUES – VMS ACTIVE – (OGDEN INTELLIGENT RADAR)

The VMS active system consisted of an FMCW radar sensor⁸, and a mechanical active braking component. The size and shape of the radar's detection area could be tailored to suit different working environments. The system had the ability to store up to three different detection area profiles in its memory, from which the FLT operator could then choose, depending on the environment that the FLT would be operating in. Each detection area was segregated into three distinct detection zones. The size of the detection zones within the detection area could also be altered.

The Ogden radar sensor was capable of determining whether an object was moving towards the sensor. When an object was detected in the zone closest to the sensor (detection zone 1) the active braking component applied the brakes, bringing the FLT to a halt.

In the outer two zones of the detection area, the warning system had been programmed to respond only to objects moving towards the sensor. In detection zone 1, the warning system had been programmed to react to the movement of any object, regardless of which direction it was travelling. The system's capability of being able to determine whether an object is approaching the sensor, helps to limit the number of false detections caused by objects of no concern encroaching on the detection area.

The VMS active system had been primarily designed and marketed towards use on quarry vehicles, although the system had been previously fitted to FLT's of a similar size to the CAT-40 test vehicle.

As the system was fitted with an active braking component, it needed to be permanently installed on the CAT-40. Installation of the system was completed by the suppliers recommended installer.

The Ogden radar sensor was mounted on the edge of the FLT counterweight at a height of approximately 1.2 m (Figure 13).

⁸ *Manufactured by Ogden Safety Systems*

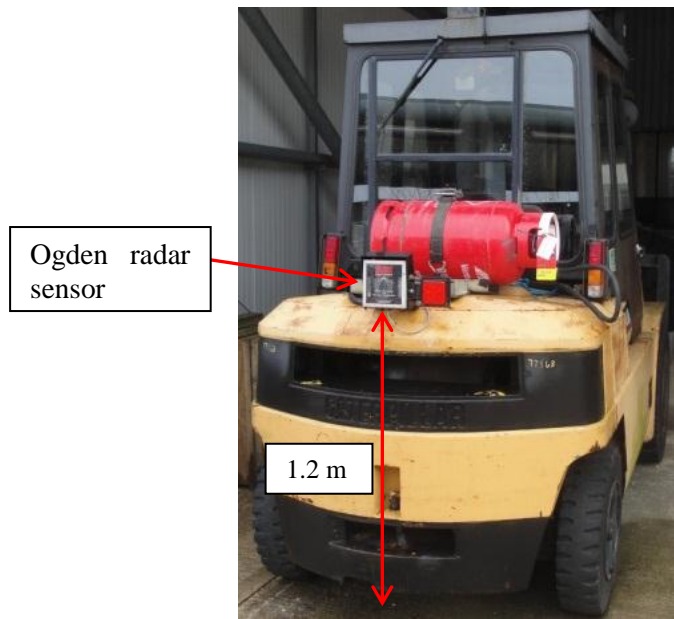


Figure 13 Installation of the Ogden radar sensor

As can be seen in Figure 14, the active braking system consisted of a Bowden cable that joined the brake pedal (Figure 14a), to an actuator mounted on a chassis cross-member underneath the FLT (Figure 14b). When the system was activated, the actuator pulled on the Bowden cable which in turn depressed the brake pedal bringing the FLT to a halt.

Once the active braking component had stopped the FLT, the operator was required to press an over-ride button located next to the seat in order to reset the actuator and release the brakes.

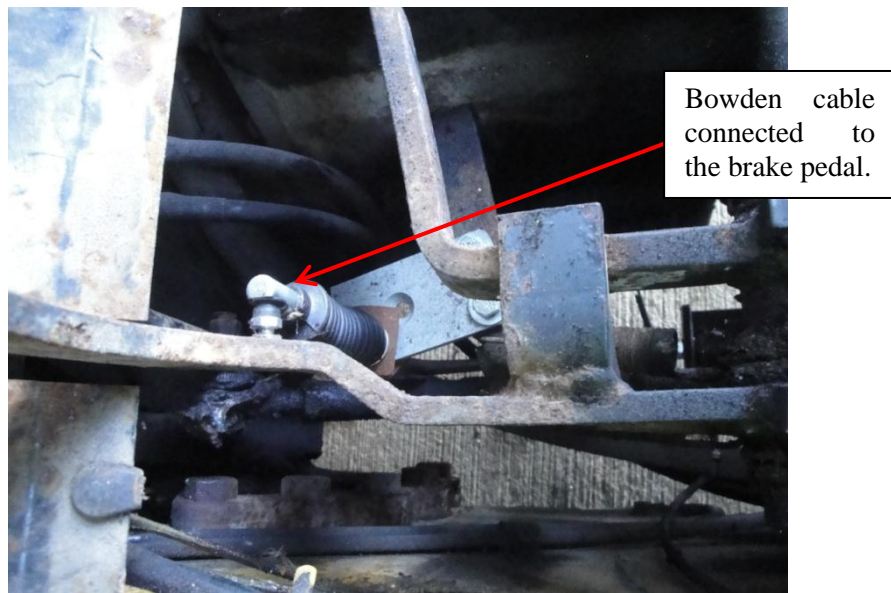


Figure 14a

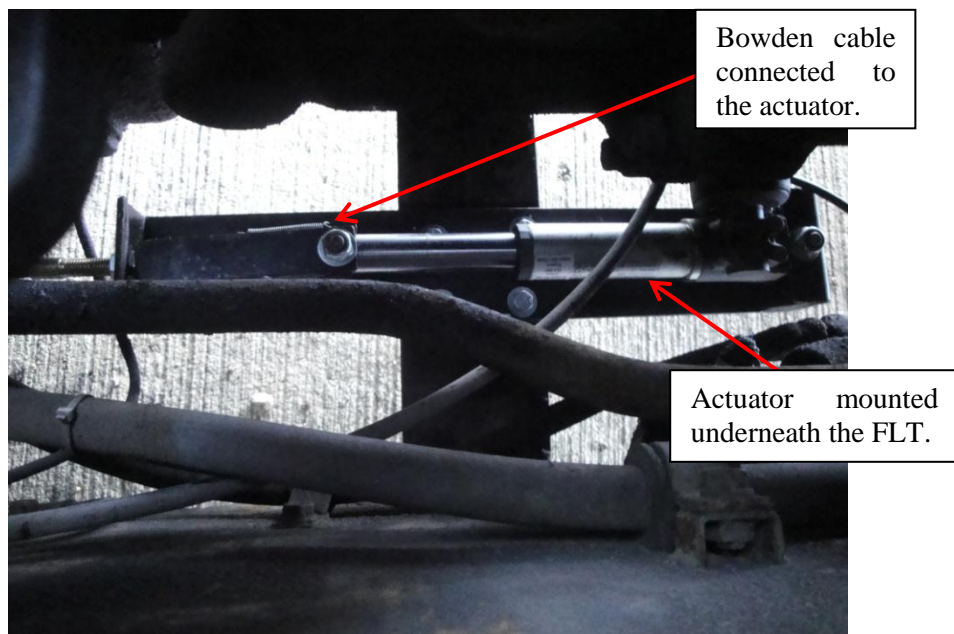


Figure 14b

Figure 14 Installation of the active braking component on the FLT

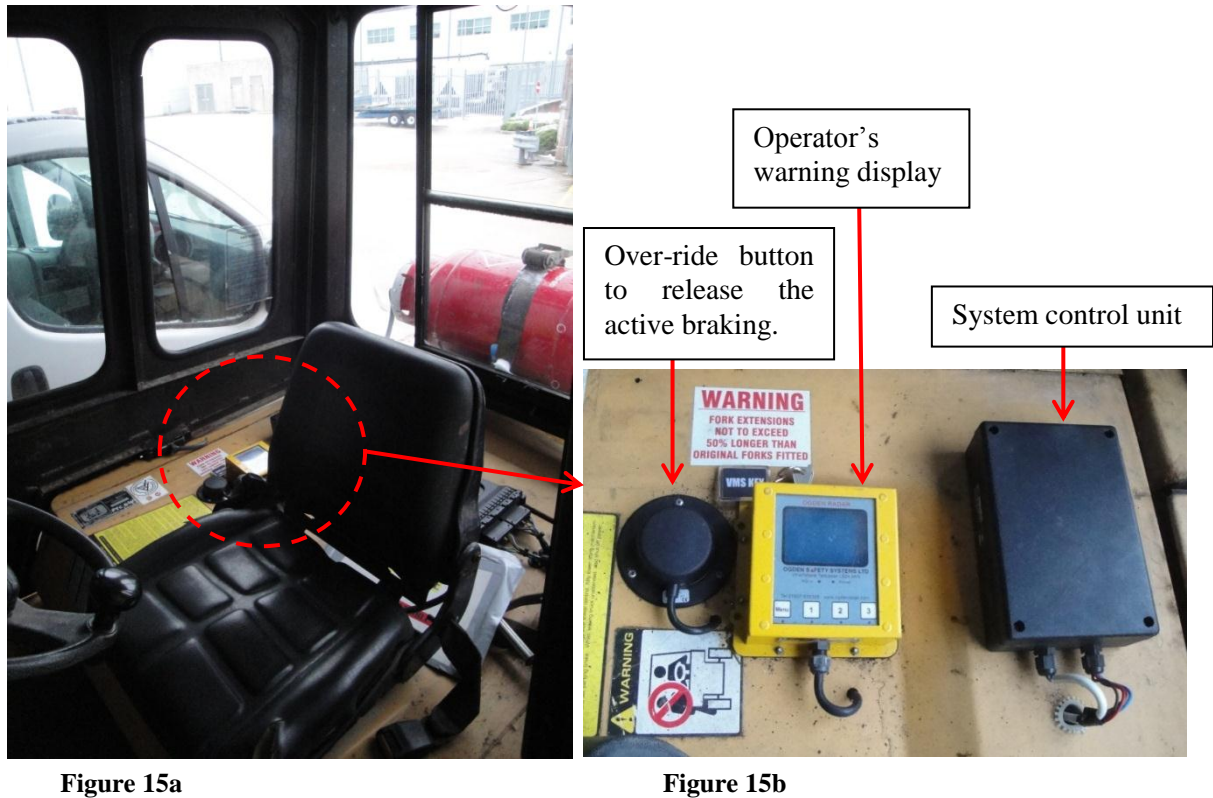


Figure 15a

Figure 15b

Figure 15 Installation of the warning system in the FLT cab

As can be seen in Figure 15, the warning display (yellow box) was mounted next to the operator's seat. The selected detection area could be changed from the display box. If the active braking component was not required, it could be turned off using the supplied key.

The warning system consisted of an LED screen which showed diagrammatically the shape of the detection area selected, and in which of the three detection zones an object had been detected (Figure 16).

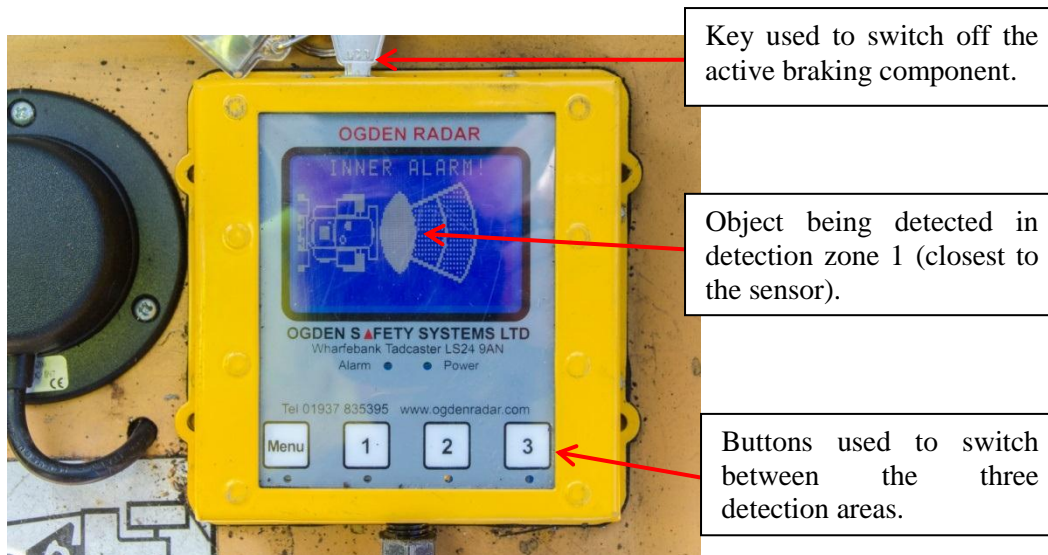


Figure 16 Operator's warning display, indicating that an object has been detected in detection zone 1

5.3.1 Static test

The static test was completed for all three detection areas, demonstrating the differences in detection area size and shape available.

5.3.1.1 Detection area one

The first detection area had been designed to be approximately the same width as the FLT (Figure 17), in order to operate in confined areas. The widest point of the detection area was only 1.9 m wide, which exceeded the width of the FLT by approximately 0.3 m (either side), and therefore limited the potential for false detections. The widest point was located approximately 1 m from the rear of the FLT (within detection zone 1). Detection zones 2 and 3 were both approximately 1.4 m wide (slightly wider than the width of the FLT).

The furthest point that the test person could be detected was approximately 3.5 m on the centreline.

5.3.1.2 Detection area two

The second detection area was larger than the first (Figure 18), and had been designed to be used in an environment with a high potential for collisions (for example, a HGV unloading area). Detection zone 1 within this area had been made significantly larger than zones 2 and 3, and contained more than half of the whole detection area.

The maximum width of detection area two was approximately 3.6 m (located approximately 1.5 m from the sensor in detection zone 1). This exceeded the width of the FLT by approximately 1.1 m on both sides. Zones 2 and 3 were significantly narrower than the first, with a maximum width of approximately 2.4 m.

The furthest point that the test person could be detected was approximately 4.7 m on the centreline.

5.3.1.3 Detection area three

The third detection area was by far the largest (Figure 19), and had been designed to be used in large open environments such as those found in quarries. The size of the three detection zones within area three varied significantly, with detection zone 1 being the largest. The maximum width of the detection zone was approximately 6.8 m which exceeded the width of the FLT by approximately 2.7 m (either side). The maximum width of the detection area was located approximately 1 m from the sensor.

The furthest point that the test person could be detected was approximately 6.9 m from the centreline.

In the majority of operating environments it would most likely not be practical to use such a large detection area on a vehicle as narrow as the CAT-40 FLT. However, the size of detection area three does demonstrate the flexibility available between the detection areas.

5.3.1.4 VMS system – detection area one

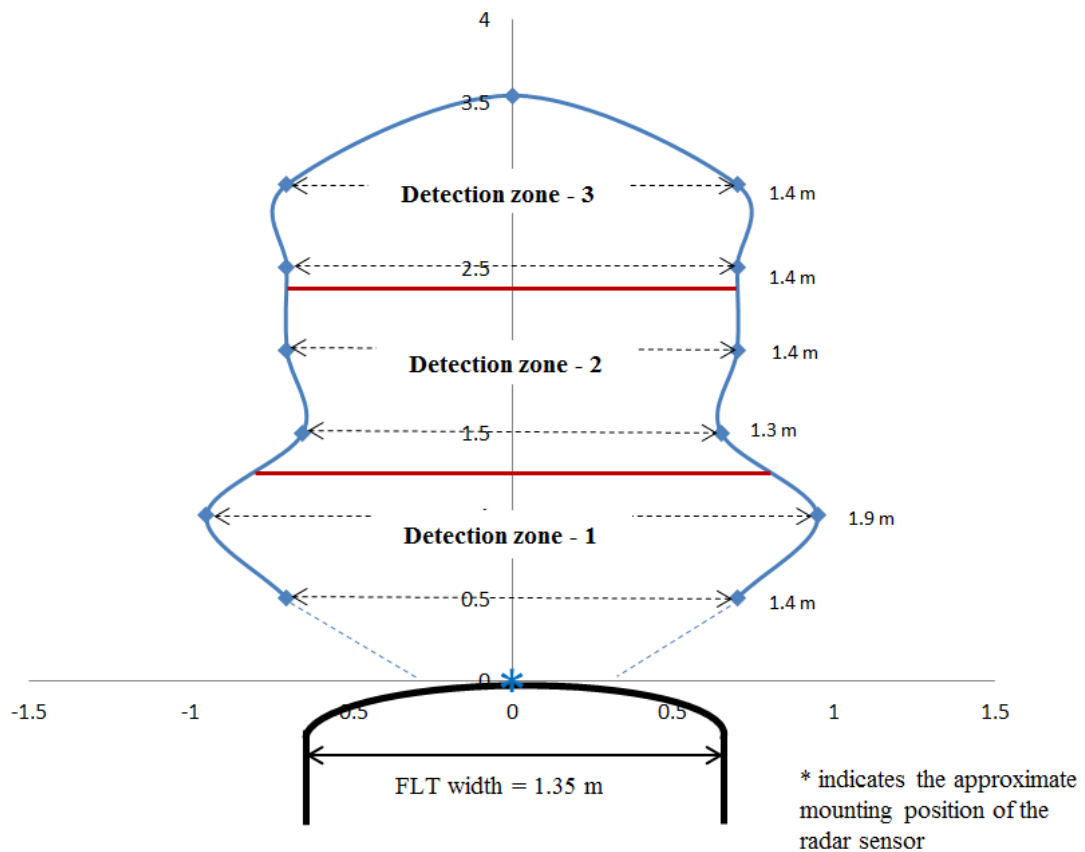


Figure 17 Plot of the detection area for the VMS system – setting one

Table 4 VMS System (detection area one) – static test results

<i>Centreline distance from the rear of the FLT (m)</i>	<i>Approximate width of the detection area (m)</i>
0.5	1.4
1	1.9
1.5	1.3
2	1.4
2.5	1.4
3	1.4
3.5	----

5.3.1.5 VMS System – detection area two

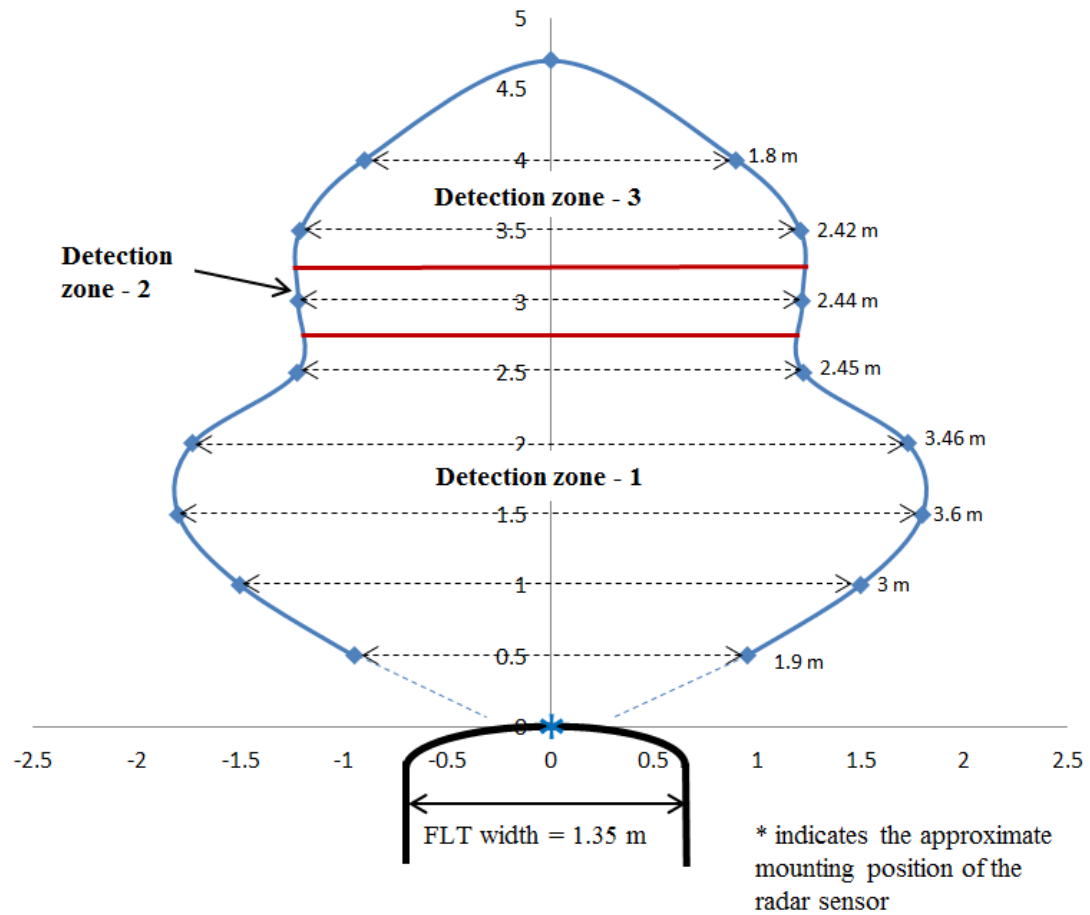


Figure 18 Plot of the detection area for VMS system - setting two

Table 5 VMS System (detection area two) – static test results

<i>Centreline distance from the rear of the FLT (m)</i>	<i>Approximate width of the detection area (m)</i>
0.5	1.9 m
1	3 m
1.5	3.6 m
2	3.46 m
2.5	2.45 m
3	2.44 m
3.5	2.42 m
4	1.8 m
4.7	-----

5.3.1.6 VMS System – detection area three

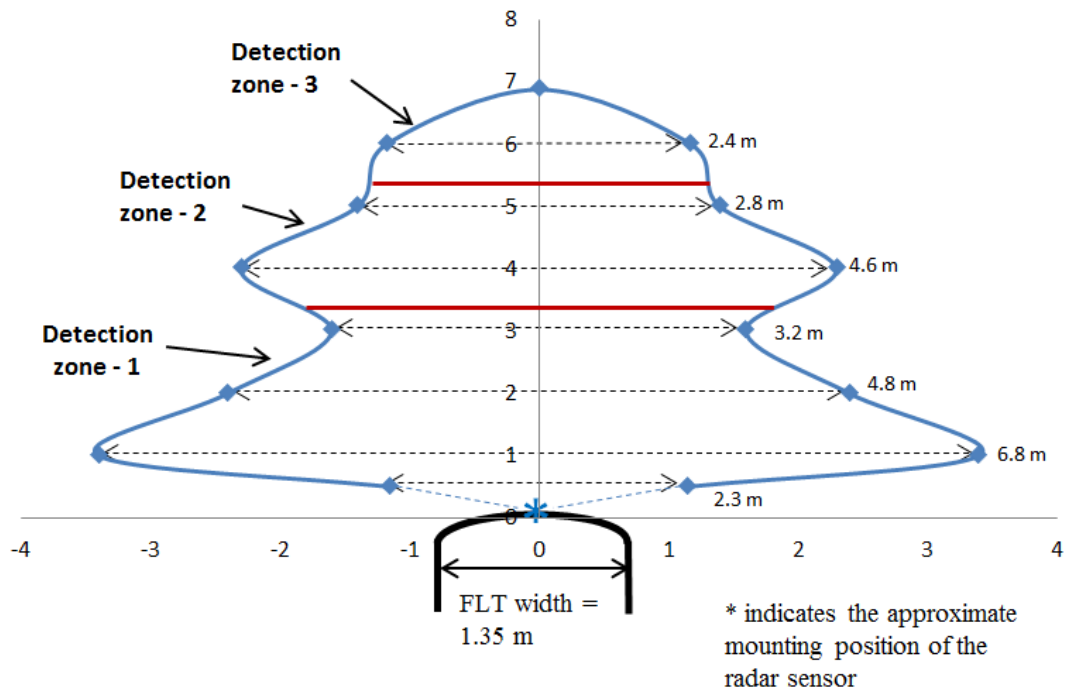


Figure 19 Plot of the detection area for VMS system - setting three

Table 6 VMS System (detection area three) – static test results

<i>Centreline distance from the rear of the FLT (m)</i>	<i>Approximate width of the detection area (m)</i>
0.5	2.3
1	6.8
2	4.8
3	3.2
4	4.6
5	2.8
6	2.4
6.9	---

5.3.2 VMS system – dynamic test

The test pole was positioned on the FLT centreline, 6 m from the FLT's rear fascia. The FLT was then reversed towards the pole in order to establish at what distance the automatic braking system activated. The dynamic test was conducted using the second detection area.

With the test pole positioned on the FLT centreline, the automatic braking system was activated 1.8 m from the test pole. The test pole was then placed 1.5 m to the side of the FLT centreline. The braking system was activated when the FLT was 1.2 m from the test pole (Figure 20). When the test pole was positioned 2 m from the FLT centreline (approximately 1.3 m outside the footprint of the FLT), the automatic braking system was not activated.

The documents supplied with the detection system state that the automatic braking system should activate when the test object enters the final detection zone. The reason for the delay in response during testing could be due to the fact that the test pole being used was a 'worst case detection scenario' for radar based systems, as it was made of plastic and had a curved surface. A metal object should ordinarily be used to test the functionality of the system. For the purpose of this research, however, testing the 'worst case scenario' was deemed beneficial.

The automatic braking system was considered to be working effectively, as the FLT stopped within 1.2 metres of the test pole.



Figure 20a

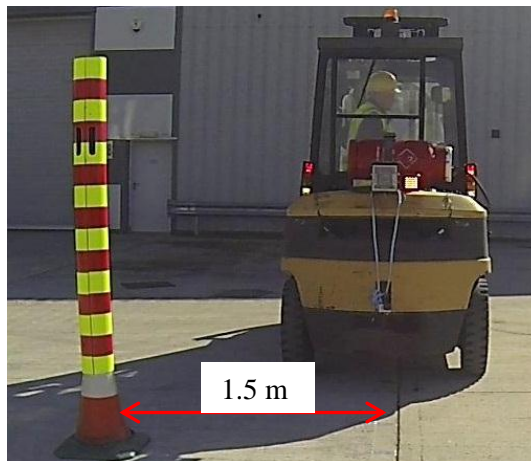


Figure 20b

Figure 20 VMS system - dynamic testing

5.4 BRIGADE ELECTRONICS – BACKSENSE WORKZONE (RADAR)

The Backsense – Workzone consisted of a single FMCW radar sensor, which had been designed to be mounted centrally onto the rear of a vehicle. The system had been primarily aimed for use on plant equipment and refuse vehicles, although was also suitable for use on other vehicle types such as FLT's.

The sensor had a stated maximum detection range of approximately 3 m. As with the Backscan ultrasonic system, the Backsense came fitted with an output trigger that could be used to activate additional warning devices on the FLT. The output trigger would be activated as soon as an object entered into the detection area.

The sensor was mounted centrally on the FLT counterweight, approximately 1 m from the ground (as recommended in the manufacturers installation guide). The sensor unit was attached temporarily to the FLT using zip-ties and nylon rope (Figure 21), which allowed for adjustment of the sensor height during testing (if required).

A bracket could be fabricated allowing for the sensor to be mounted over the counterweight's ventilation gap if the sensor was to be attached permanently to the FLT.

The operator's warning system consisted of a set of five LED warning lights (Figure 22), with an audible warning system also incorporated into the unit. The number of LEDs that were activated, and the repetition rate of the audible warning, increased the nearer an object came to the sensor unit. The volume of the audible warning could be adjusted by the FLT operator, with three distinct volume levels to choose from.

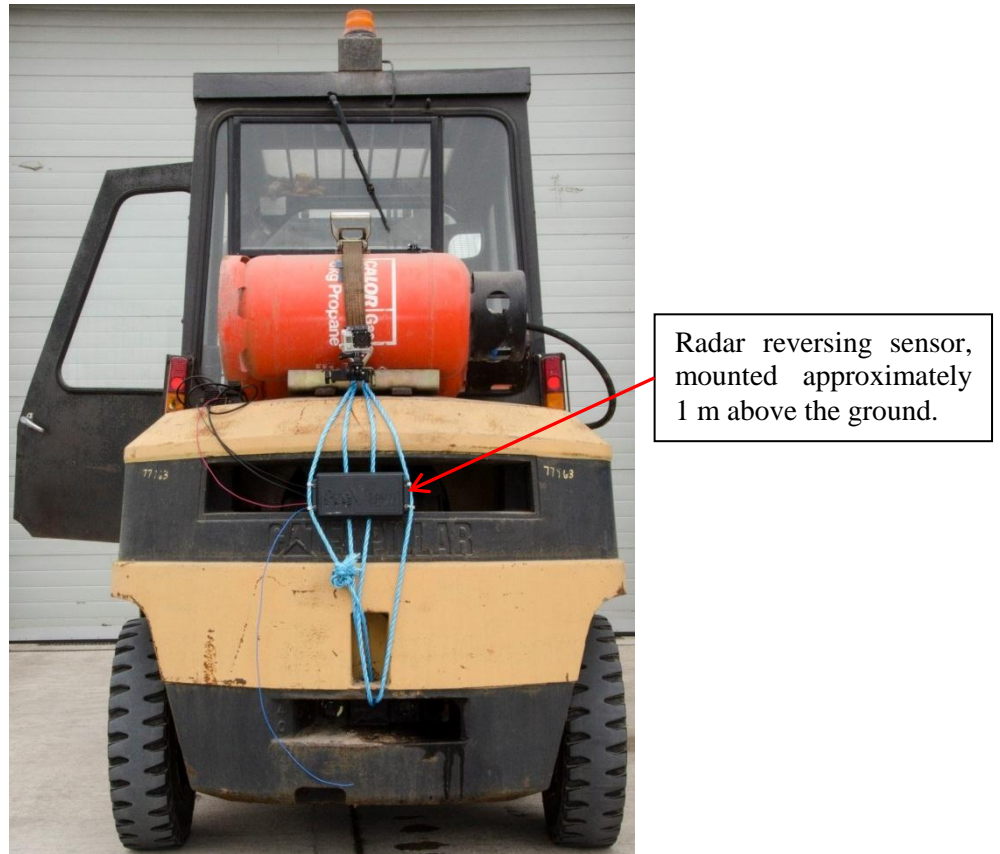


Figure 21 Rear of the CAT – 40 FLT, with the radar sensor mounted centrally

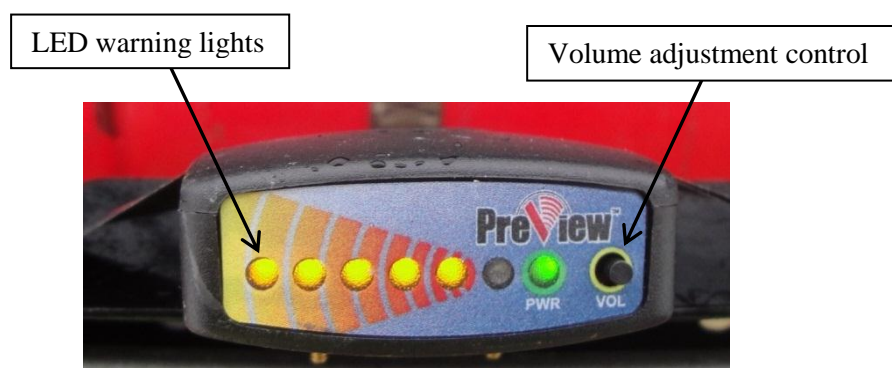


Figure 22 Backsense - operator warning system

5.4.1 Backsense - static test results

The Backsense system had a maximum detection width of approximately 3.3 m, located approximately 2 m from the sensor. The maximum width of the detection area exceeded the width of the FLT by approximately 0.8 m on either side of the FLT. The maximum distance that the system could detect the test person was approximately 3 m.

As can be seen in Figure 23 the detection area was cone shaped, which left two areas close to the FLT either side of the sensor where there would be no detection coverage as indicated by the dotted green line.

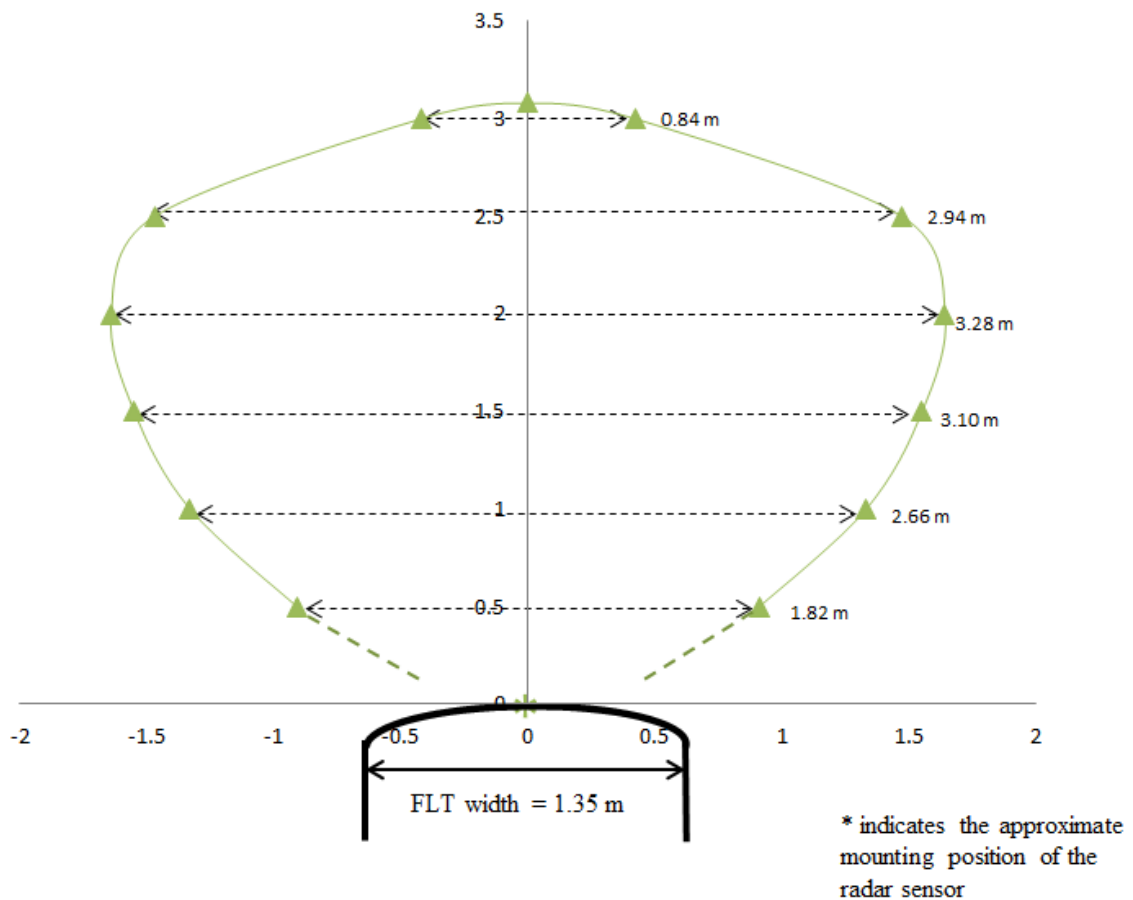


Figure 23 Plot of the detection area for the Backsense radar system

Table 7 Backsense – static test results

<i>Centreline distance from the rear of the FLT (m)</i>	<i>Approximate width of the detection area (m)</i>
0.5	1.82
1	2.66
1.5	3.10
2	3.28
2.5	2.94
3	0.84

6. ASSESSMENT

Testing established that all four of the reversing sensor systems had advantages and disadvantages when fitted to FLT's.

Below is a brief assessment of the efficacy of each of the four systems.

6.1 TBM HIGHTECH CONTROL (SPEED REDUCTION - ULTRASONIC SYSTEM)

The TBM Hightech Control system was the only system designed specifically for use on counterbalance FLT's and small plant vehicles. The size and shape of the detection chosen was suitable for use in confined environments, with little overhang of the detection area past the width of the FLT.

The dynamic test confirmed that the speed reduction system would not activate when the test pole was positioned at 1.5 m from the FLT centreline, but did activate when the pole was positioned at 0.8 m from the centreline.

The static test revealed that the positioning of the ultrasonic sensor pods created two blind spots either side of the FLT counterweight. The blind spots were large enough for the test person to stand and not be detected. The blind spot on the left hand side also corresponded with a visual blind spot caused by the air intake canister. As the test person had to approach the FLT from a specific angle in order to remain undetected, however, it is uncertain how significant these blind spots would be in practice.

The warning display had been well positioned behind the operator's right shoulder, which meant that the operator could observe the warning display when positioned for reversing.

6.2 BACKSCAN - BS-4000W (ULTRASONIC SYSTEM)

As tested, the widest point of the Backscan's detection area had exceeded the width of the FLT by approximately 1.6 m (on both sides). By positioning the two sensors that were attached to the side of the counterweight further back, the widest part of the detection area was moved closer to the rear of the FLT. This was deemed to be more beneficial for FLT operations.

The width of the Backscan's detection area can be attributed to the fact that the system had primarily been designed to be used on vehicles wider than the CAT-40 FLT. How much of a problem the additional width of the detection area would be (in terms of false detections) would depend upon what sort of environment the FLT would be operating within. The shape and size of the detection area could potentially be altered by adjusting the angle and mounting position of the sensors, although this was not tested.

In order for the system to be mounted onto the FLT at the height recommended in the manufacturer's installation guidance, two of the sensors had to be mounted onto the side of the FLT counterweight. A potential problem with using this mounting configuration is that the sensors are exposed to environmental conditions such as mud and dirt, and the potential for impact damage to them is increased.

The operator's warning system displayed clearly which side of the vehicle an object had been detected, and included the approximate distance to the object numerically in metres.

The warning display had been designed for mounting on a dashboard. If the warning system was to be mounted permanently in the FLT cab, a bracket would potentially need to be fabricated so that the display could be mounted behind the operator's seat in a similar fashion to the TBM system.

6.3 VISION TECHNIQUES - VMS (ACTIVE BRAKING - RADAR SYSTEM)

The VMS active system had been primarily designed for use on quarry vehicles; significantly larger than the CAT-40 test vehicle although, according to the supplier, the system had been previously fitted to FLTs of a similar size to the CAT-40.

The system was able to store up to three different detection area designs in its memory, and was the only detection system tested in which the operator could change the size of the detection area, whilst operating the FLT. This meant that if the operator moved from a confined space to a more open environment, the size of the detection area could be easily altered at the push of a button.

The VMS system was also the only system tested that could be programmed to disregard objects in the outer two detection zones that were either static, or moving away from the sensor. When an object entered into the detection zone closest to the sensor, the active braking component would apply the brakes, bringing the FLT to a halt. A reset button next to the driver would need to be pressed in order for the FLT to continue reversing. Depending on the operating environment of the FLT this could prove to be a nuisance if the FLT was continually being stopped. The active braking component could be switched off (using the supplied key), a system similar to the TBM's that just slows the vehicle down could be more suitable for the majority of FLT operational environments.

As can be seen from the static test results, each of the three detection areas had areas either side of the sensor that were not covered by the detection area. This was due to the single sensor having been positioned on the centre edge of the counterweight. Potentially the sensor could be set further back, meaning that more of the counterweight would potentially be included within the detection area, therefore mitigating the size of these areas.

The warning display had been fitted next to the driver's seat, which meant that the operator would have to look down to monitor the warning display when reversing. The built in audible warning was also potentially too quiet to be heard over the noise of the engine in the FLT cab. An additional warning device that could be positioned more appropriately, and has a louder audible warning could be used.

6.4 BACKSENSE – WORKZONE (RADAR SYSTEM)

The Backsense – Workzone had a maximum detection width of approximately 3.3 m, which exceeded the width of the FLT footprint by approximately 0.8 m on either side. The static test showed that the detection area was a cone shape, with two areas either side of the sensor that were not covered by the detection area. Similarly to the VMS system, this was a product of having to mount the single sensor onto the centre edge of the counterweight. By moving the mounting position of the sensor so that it was sat further back, the corners of the counterweight could be included within the detection area.

The warning display supplied with the Backsense system consisted of a basic 5 LED light display, and an audible warning.

Similarly to the Backscan system, the Backsense's warning display had been designed primarily for dash mounting. The display could, however, be mounted behind the operator's seat through the fabrication of a mounting bracket.

Forklift truck reverse sensor systems assessment

Counterbalance forklift trucks (FLT) are widely used in a variety of industry sectors for material handling. Incidents involving FLT are typically vehicle/pedestrian, vehicle/vehicle, or vehicle/structure collisions. Of these, vehicle/pedestrian incidents have the most potential for reportable injury and around 500 incidents a year involving moving FLT are reported to HSE.

Measures to improve or augment the operator's field of vision can include: mirrors and CCTV systems (which rely on the operator's observations) and sensor systems (including ultrasonic, radar, and Radio Frequency Identification (RFID)), similar to those commonly fitted to passenger vehicles; or simply improving the driver's operating position.

This report describes work undertaken to assess the active sensor systems (ultrasonic and radar) commonly used to reduce the risk of collisions. The systems tested appeared to provide a useful function in mitigating the risk of collision by stopping the truck when an obstruction was detected. However, certain configurations produced blind spots in the detection zones that could allow a pedestrian to approach the truck without being detected. The sensors also needed to be mounted to give an appropriate detection zone without producing a large number of false detections.

Companies should establish the conditions under which they will be operating an FLT and select a system that best fits their particular operating environment. Consideration should be given in the first instance to the practicability of removing pedestrians from the working area, although it is acknowledged that this is not always possible.

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