AN INVESTIGATION OF THE POTENTIAL SAFETY BENEFITS OF VEHICLE BACKUP PROXIMITY SENSORS

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ABSTRACT

An increasing number of new vehicles are being equipped with backup proximity sensors. These sensors detect the presence and proximity of objects in the pathway of the reversing vehicle and warn the driver through an audible signal. This report investigates the performance capabilities and potential safety effectiveness of these systems in reducing the risks to small children and other pedestrians from reversing vehicles. These sensor systems are primarily designed and marketed as parking aids. However, some are being promoted as safety systems with the potential to reduce or prevent collisions with pedestrians, especially small children. The performance capabilities of six commercial reversing aid systems were evaluated in laboratory tests. Four systems were fitted to the vehicles as standard equipment. Two systems were purchased from aftermarket companies and installed on the test vehicles. All six systems used ultrasonic sensor technology. Laboratory tests consisted of 3-dimensional mapping of the detection zones, the system response time, and the effects of dust / dirt on sensor performance. In terms of detection area performance, parking aid systems sacrificed detection distance and height in order to suppress false or nuisance alarms. The durability and reaction time results revealed there were no substantial performance differences between the systems. The safety benefits of these devices were then estimated based on these test results.

INTRODUCTION

There are approximately 900 (Transport Canada[1]) pedestrians struck and injured by reversing vehicles each year in Canada. However, this is likely an underestimate as this figure only represents those pedestrians struck in traffic situations. It does not account for pedestrians injured or killed in private driveways or parking lots for example. Therefore, the exact number of pedestrians injured or killed in Canada is not known but studies in other jurisdictions have highlighed this problem. An Australian study by Henderson[2] found an average of 12 fatalities per year during the study period 1996-1999. The study also found that most of these non-traffic collisions involved toddlers. Among the recommendations made by Henderson was to investigate the potential of rear proximity sensors in detecting the presence of nearby children.

This paper reports on the performance of backup proximity sensor systems. The purpose was not to set out performance criterea but rather to investigate the capabilities of commercially available systems and to asses their potential effectiveness in reducing pedestrian collisions. The main performance parameters to be evaluated were:

- size and shape of the detection zones, with clean and dusty sensors
- lower detection zones height, with clean and dusty sensors
- sensor system's response time, with clean and dusty sensors

All six systems tested were commercially available. They are listed in Table 1. Four were installed as original vehicle equipment (OEM) and the two were aftermarket units designed to fit all types of passenger vehicles. The OEM systems had 4 sensors embeded into the bumper facias. One aftermarket system had single sensor (E) and the other had three sensors (F). The same vehicle was used to test the two aftermarket sensors.

Table 1.
Proximity sensor systems tested

Sensor ID	Vehicle Type	Vehicle Length (m)
A (OEM)	Minivan	1.946
B (OEM)	Convertible	1.777
C (OEM)	Sedan	1.739
D (OEM)	Pickup	2.029
E (Aftermarket)	SUV	2.002
F (Aftermarket)	SUV	2.002

PERFORMANCE TEST PROCEDURES

The performance tests were conducted in a laboratory. The ultrasonic sensors did not require relative motion between the vehicle and the test object. The engines needed to be kept running in order for the systems to operate but vehicles were stationary during the tests and with reverse gear activated the sensors.

Detection Zones

The detection zones were mapped on a 3.60 m x 3.60 m test surface. The test surface was divided into grids. Each cell was 15 cm x 15 cm in size. The test object was a 9 cm diameter and 100 cm tall PVC tube (Figure 1).

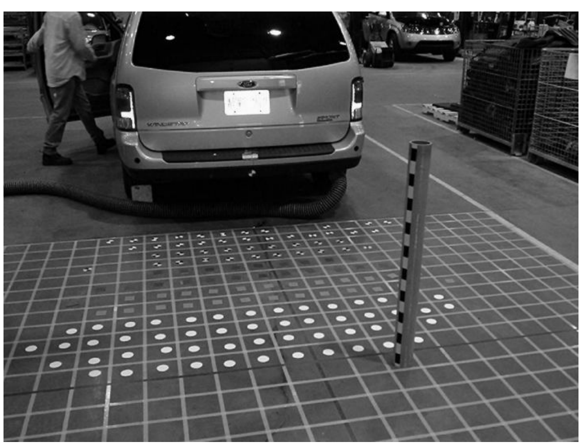


Figure 1.
Detection zone test surface and test object.

With the vehicle stationary, the test cylinder was moved manually and placed in each cell. Once a continuous detection signal from the system was received, the cell was marked corresponding to the frequency of the signal.

Figure 2.
Grid cell markings

In addition to the 100 cm test tube, tubes of different heights, ranging from 5 to 95 cm, in 5 cm increments, were used to map the bottom edge of the detection zone.

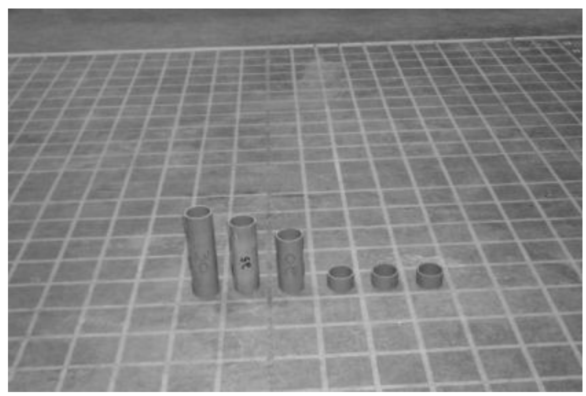


Figure 4.
Tubes used to map lower edge of detection zone

Response Time

The time delay between the appearance of the test object in the detection zone and the initiation of the audio signal was recorded on a chart recorder that was connected to an optical sensor and a microphone. The 100 cm test cylinder was suspended from above the detection zone just behind the rear bumper. The top of the detection zone was marked with the optical sensor. As the cylinder entered the top of the detection zone it triggered the optical sensor. The reaction time of the sensor system was the difference between this event and the audible signal given by the sensor. This test was repeated ten times for each system.

The response time was taken as the average of the 10 runs.

Figure 5.
Response time test set up

Dust Application

The detection zone area mapping and system response time were measured first with clean sensors and then with the sensors covered with a mixture of dust and water. The application and composition of the dust and water mixture used followed the Canadian Motor Vehicle Safety Standard 104 – *Windshield Wiping and Washing System* test procedure[3].

PERFORMENCE TEST RESULTS

Detection Zone

The detection zone dimensions, in the horizontal plane, are shown in Table 2. The maximum detection distances from the rear of the bumper ranged from 1.05 m (system B) to 2.25 m (system E). Aftermarket system E displayed the largest detection zone size in the horizontal plane.

Table 2.
Detection zone dimensions in the horizontal plane

Sensor System	Total Area (m^2)	Width (m)	Depth (m)
A	3.42	2.55	1.80
B	1.53	1.80	1.05
C	2.57	2.25	1.50
D	3.38	2.70	1.80
E	5.72	3.30	2.25
F	2.07	2.40	1.20

The measured detection zone patterns for each system are set out in Appendix A. Figure 6 shows an example of a mapped detection zone in the horizontal plane using the 100 cm tall test cylinder. The number in the cell represents the height of the test object used for detection. The vehicle would have been situation on the left side with the bumper aligned with first column.

The detection zones patterns displayed two basic shapes. Systems A and D had an hourglass shape with a narrower width near the centre. The other systems had more of a teardrop shape with a gradually increasing width towards the rear.

All systems had audible signals with distinct levels of warning corresponding to distance of the test object from the rear bumper. The number of detection warning levels ranged from 3 to 5. The total frequency range of the intermittent audible warnings was 3 to 8 Hertz. The audible warning was a continuous beep for the zone closest to the bumper for all systems. System E had a 3-level led display in addition to the audible warnings.

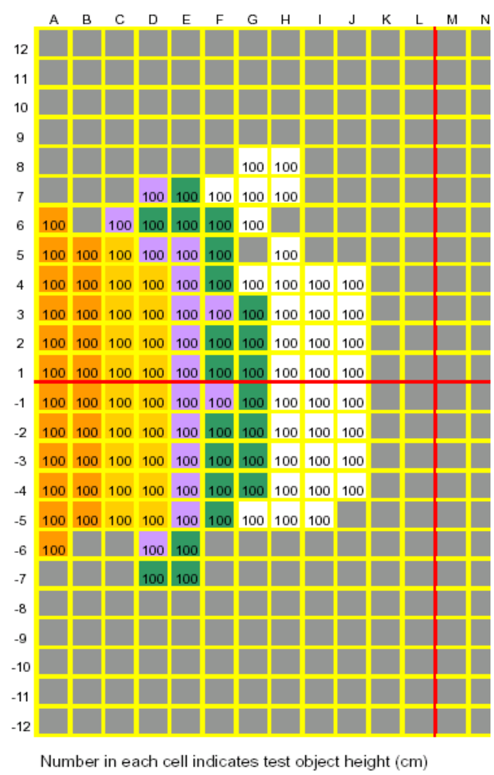


Figure 6.
Mapped horizontal detection zone using 100 cm tall test cylinder (system C)

All sensor systems except system C had a least one cell in the row nearest to the rear bumper (row A) where there was no detection of the test object – so-called "dead spots". System F was able to detect the 100 cm tall test cylinder in only two cells in this row (Figure 7).

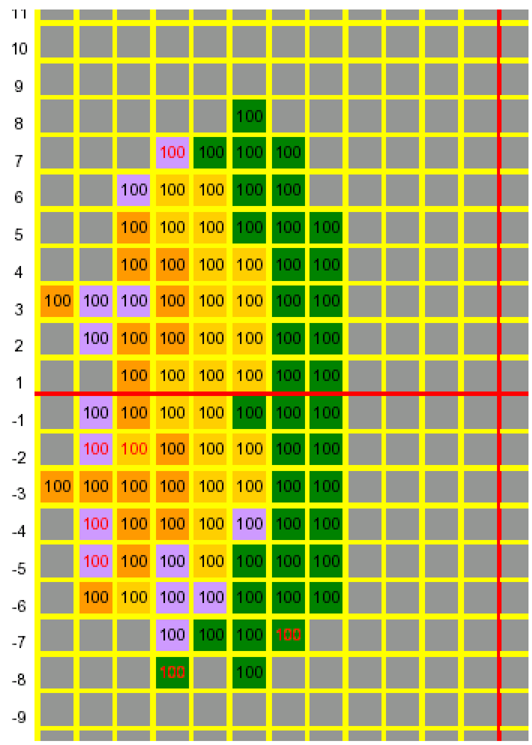


Figure 7.
Mapped detection zone showing "dead cells" near bumper edge. (System F)

Figure 8 shows a plot of the bottom edge of the detection zones measured along the central longitudinal axis. The sensors did not detect the area below the lines. All the profiles began at bumper height. System D was from a pickup truck, which had a high bumper height. The OEM systems tended to remain at bumper height level right to the end except system A, which dipped toward the ground near the end of its detection distance. The profiles of the two aftermarket systems exhibited different shapes. System E displayed the lowest cut-off. The bottom edge of the detection zone was very close to the ground at 75 cm behind the bumper. System F's profile dipped towards the rear but then went up again at the very end of the detection zone.

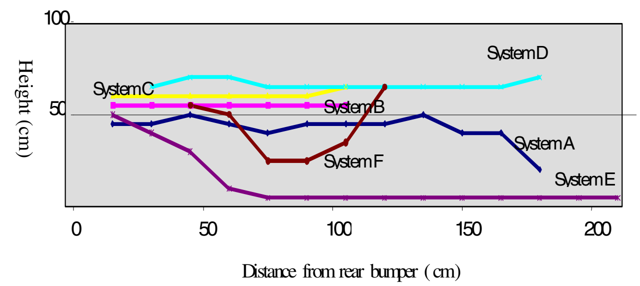


Figure 8.
Average height of the lower edge of detection zones

Response Time

The recorded response times are listed in Table 4. These results were the averages of 10 drop tests. The times ranged from 80 milliseconds for system A to 227 milliseconds for system D. All systems displayed response times that were within the ISO recommended limit for low-speed sensor systems[4] of 350 milliseconds.

Table 3.
System response time results

Sensor System	Response Time (ms)
A	80
B	187
C	135
D	227
E	199
F	105

Dusty Sensors

Table 4 shows the changes in sensor performance with the sensors covered with the dust and water mixture. There was no large reduction in the detection zones for any of the sensors. There was no significant change in the width of the detection zones in the horizontal plane. The maximum detection distance increased slightly for all of the systems except system C, which had a 9% reduction. The reaction times increased for all systems. The maximum increase was 25% (system A). However, all of the reaction times were still within the ISO accepted level of 350 ms.

Table 4.
Change in sensor performance with dirt application

Sensor System	Width (%)	Depth (%)	Reaction Time (%)
A	0	5	25
B	0	1	11
C	0	1	3
D	0	-9	3
E	0	17	13
F	0	3	15

The dust application did cause some minor performance reductions that are worth mentioning. The detection zone levels were less clearly defined. That is, the stages were more dispersed with one another with one row having more than one detection level present. There were also some loss of detection in one case (system D), there was two lower priority level signals given in the row closest to the bumper – where a continuous high level signal was given with clean sensors.

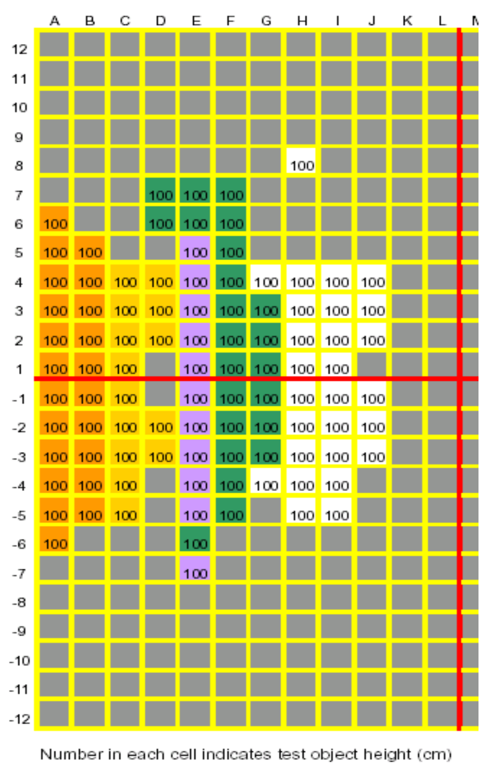


Figure 9.
Mapped horizontal detection zone using 100 cm tall test cylinder with dusty sensors (system C)

DISCUSSION

General Performance

The six sensor systems evaluated used similar technologies and it was not surprising then to discover that their performance was also quite similar. The performance of system E stood out the most from the others. System E displayed a larger detection zone area - in terms of both width and length - and the bottom edge of the zone started much closer to the ground.

Estimates of Potential Effectiveness

The systems must warn the driver of the presence of a pedestrian behind the vehicle quickly enough so that the driver has enough time to react and stop the vehicle before it strikes the pedestrian. The effectiveness of these systems is dependent on a number of vehicle and human factors. NHTSA (Harpster et al[5]) conducted studies of driver reaction times to acoustic signals during backing maneuvers. In this experiment the drivers were alerted to the fact that an alarm would be sounded. The authors reasoned that these ‘alert’ driver reaction times were suitable for backing maneuvers since it is a brief maneuver and drivers would be more cautions relative to driving forward. Williams[6] used this data to determine the probability of avoiding a collision when a vehicle is moving at a constant speed. Paine and Henderson[7] calculated the percentage of collisions that would be avoided for a range of collision speeds and sensor detection distances. These are illustrated in Figure 10.

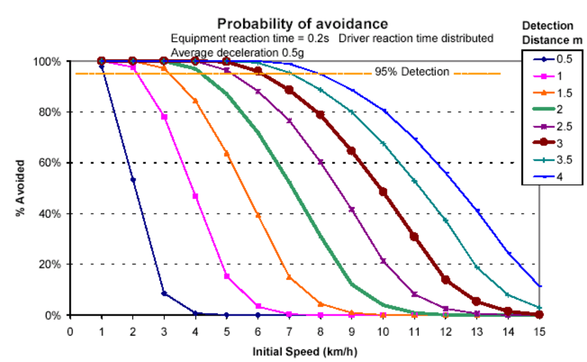


Figure 10.
Percentage of collisions avoided as derived by Paine and Henderson[7] for various vehicle speeds and detection distances

Figure 10 shows that effectiveness is highly sensitive to vehicle speed. For example, a 1 km/h increase in vehicle speed can reduce the effectiveness by as much as 20%.

Applying the same analysis to the maximum detection distance and response time results obtained for the systems tested yielded the following estimates. The maximum speeds at which the systems achieve 25%, 50% and 95% avoidance levels are tabulated below.

Table 5.
Maximum vehicle speeds for 25%, 50% and 95% collision avoidance levels

Sensor System	25% Avoided	50 % Avoided	95% Avoided
A	8 km/h	7 km/h	4 km/h
B	5 km/h	4 km/h	3 km/h
C	8 km/h	6 km/h	4 km/h
D	8 km/h	7 km/h	4 km/h
E	9/km/h	8 km/h	4 km/h
F	6 km/h	5 km/h	3 km/h

At the 50% level, the maximum vehicle speed possible ranges from 5 km/h (system B) to 9 km/h (system E). At vehicle speeds greater than 10 km/h, none of the systems tested would be very effective under ideal conditions.

At the 50% avoided level, the maximum vehicle speed ranged between 4 km/h and 8 km/h. At the 95% level there was no significant difference in maximum speeds. None of the systems would be 95% effective above a speed of 4 km/h.

Eberhard et al[8] estimated that 90% of backing collisions involving pedestrians were at a speed of 8 km/h or more. This would suggest that the systems would be less than 25% effective in these types of collisions due to their short detection distance capabilities.

Paine and Henderson concluded that a 4 m detection distance would be most appropriate for a vehicle traveling at 8 km/h (95% avoidance).

The above estimates are based on theoretical estimates under ideal conditions. However, there are other factors that will have an effect on the sensor system's effectiveness in preventing collisions. For example, it is assumed that once a warning is given the vehicle driver will always react to it immediately. However, there may be scenarios such as the one raised by Huey[9] – where "a driver may see a vehicle eight feet behind him but not be aware that there is a child only two feet behind. The driver could receive a warning but misinterpret it to be related to the more distant object".

Another aspect to consider is the detection height. In the analysis it is assumed that the object behind the vehicle has sufficient height so that the bottom of the sensor detection zone does not pass over it. Five of the six sensor systems tested had a minimum detection zone heights ranging from 45 to 65 cm. Sensor system E had a detection zone very close to ground level for most of its depth. Paine and Henderson recommended a minimum detection height of 60 cm in their analysis. They reasoned that the driver would have visual contact of a standing child of this height through the rear window. They also recognized that there would be some instances where a detection height of 60 cm may be insufficient (such as a child crawling or bending down) and detection would not be possible but reasoned that this was a fair trade-off against nuisance alarms. Indeed, it is very likely that sensor system E would display more false alarms than the other systems for objects close to the ground such as curbs. Nevertheless, this trade-off detection zone height still leaves the potential for the above scenario to exist thereby further reducing real world effectiveness of these sensor systems.

Overall, it would be safe to assume that the real world effectiveness of the systems would be even lower than that estimated by theoretical analysis.

CONCLUSIONS

All of the six sensor systems tested displayed reliable performance characteristics. Their performance did not decrease significantly even with the sensors covered with dust.

However, their effectiveness in preventing pedestrian strikes appears to be low due primarily to their limited detection distances. Since most of these systems were primarily designed as parking aids they have relatively short detection distances. Even under ideal conditions, their effectiveness is limited to vehicle speeds that are likely lower than those at which most pedestrian collision occur. The sensor systems under evaluation are unlikely to provide significant collision reduction in most situations where a reversing vehicle strikes a pedestrian.

There are other sensor technologies which could provide enough detection distance capability to be effective at higher vehicle speeds and could be worth investigating. Microwave-based sensors are capable of greater detection distances than ultrasonic sensors. However, they are also susceptible to giving false detections. Video cameras for aid in reversing are currently being made available on some vehicles as standard equipment. With the cost of video systems steadily decreasing they could become the basis of a viable countermeasure. Paine and Henderson[7] tested a prototype combination video camera and short-range proximity sensor with some success.

More research is needed into the causes of pedestrian collisions to more accurately determine the potential effectiveness of any type of collision avoidance system. Present Canadian national data does not provide sufficient collision detail such as vehicle speed, pedestrian action, and other human, vehicular and environmental factors to evaluate possible countermeasures thoroughly. Most studies into backing up collisions have focused only on small children. Collisions with other older and larger pedestrians may have very different dynamics. In-depth collision investigations targeting all pedestrians injured or killed of collisions could provide adequate data.

REFERENCES

[1] Transport Canada. 2004. “Pedestrian Fatalities and Injuries 1992-2001.” Fact Sheet TP 2436E, RS-2004-01E (http://www.tc.gc.ca/roadsafety/menu.htm)

[2] Henderson, M. 2000. “Child Deaths and Injuries in Driveways.” Prepared for the Motor Accidents Authority of NSW Australia, October 2000.

[3] Transport Canada, 1995. “Test Procedure for: Canadian Motor Vehicle Safety Standard No. 104: Windshield Washing and Wiping Systems.” Transport Canada Reference Laboratory, January 1995.

[4] International Organization for Standardization, 2002. “Transport information and control systems – Maneuvering Aids for Low Speed Operation (MALSO) – Performance requirements and test procedures.” Draft ISO/DIS 17386

[5] Harpster J., Huey R., Lerner N., and Steinberg G. 1996 “Backup Warning Signals: Driver Perception and Response.” National Highway Safety Administration, DOT HS 808 536, August 1996.

[6] Williams H. 1999 “Microwave Motion Sensors for Off-Road Vehicle Velocity Data and Collision Avoidance.” Sensors Magazine, December 1999.

[7] Paine M., Henderson M., 2001 “Devices to Reduce The Risk to Young Pedestrians from Reversing Vehicles.”, Motor Accidents Authority of NSW Australia, March 2001.

[8] Eberhard C., Moffa P., Young S and Allen R., 1995, “Development of Performance Specifications for Collision Avoidance Systems for Lane Change, Merging and Backing, Development of Preliminary Performance Spec., NHTSA, DOT HS 808 430, September 1995.

[9] Huey R., Harpster J. and Lerner N., 1996, “Summary Report on In-Vehicle Crash Avoidance Warning Systems: Human Factors Considerations, NHTSA, DOT HS 808 531, September 2001.

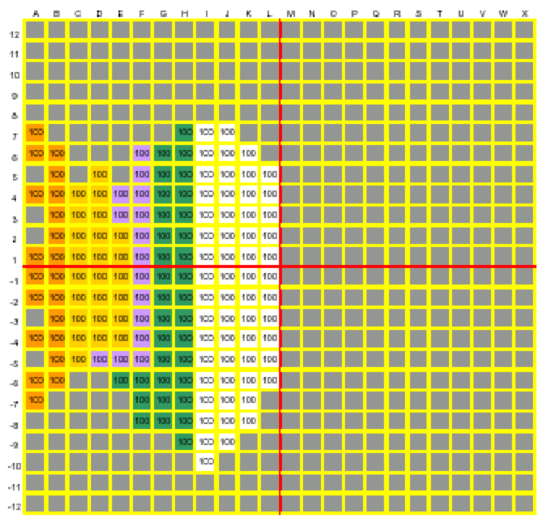
APPENDIX A –DETECTION ZONE PATTERNS IN THE HORIZONTAL PLANE

Test Number: I - Detection zones with clean sensors Date: 2003-10-23

Test obstacle: GRAY PVC TUBE Height (cm): 100 Width (cm): 9

Detection system make/model: OEM Test Location: Front ☐ Rear ☒

1st	detection zone:	Visual	None	audible	intermittent	color	white	2-3 Hz
2nd	detection zone:	Visual	None	audible	intermittent	color	green	3-4 Hz
3rd	detection zone:	Visual	None	audible	intermittent	color	violet	4-5 Hz
4th	detection zone:	Visual	None	audible	intermittent	color	yellow	5-8 Hz
5th	detection zone:	Visual	None	audible	continuous	color	orange	DC



Number in each cell indicates test object height (cm)

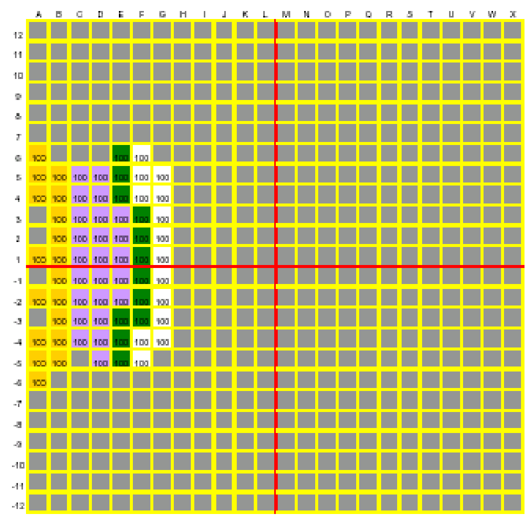
Sensor System A

Test Number: I - Detection zones with clean sensors Date: 2003-11-19

Test obstacle: GRAY PVC TUBE Height (cm): 100 Width (cm): 9

Detection system make/model: OEM Test Location: Front ☐ Rear ☒

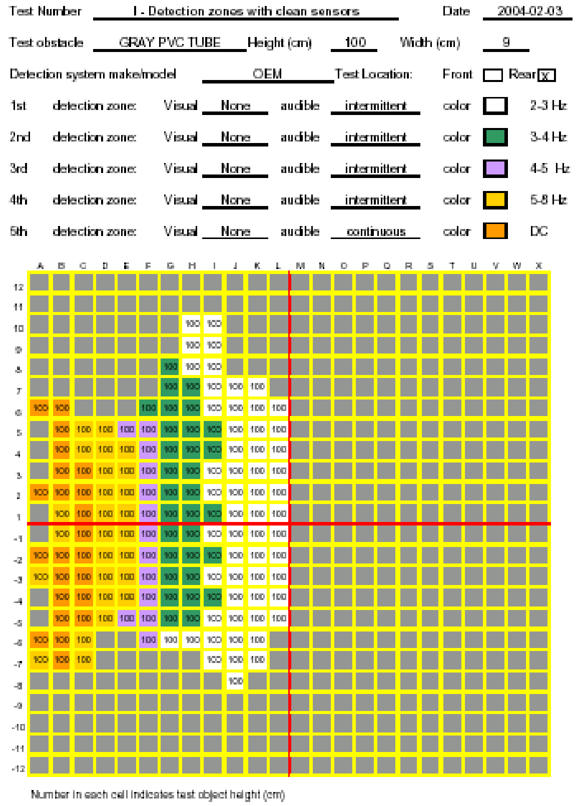
1st	detection zone:	Visual	None	audible	intermittent	color	white	3-4 Hz
2nd	detection zone:	Visual	None	audible	intermittent	color	green	4-5 Hz
3rd	detection zone:	Visual	None	audible	intermittent	color	violet	5-8 Hz
4th	detection zone:	Visual	None	audible	continuous	color	yellow	DC



Number in each cell indicates test object height (cm)

Sensor System B

System C



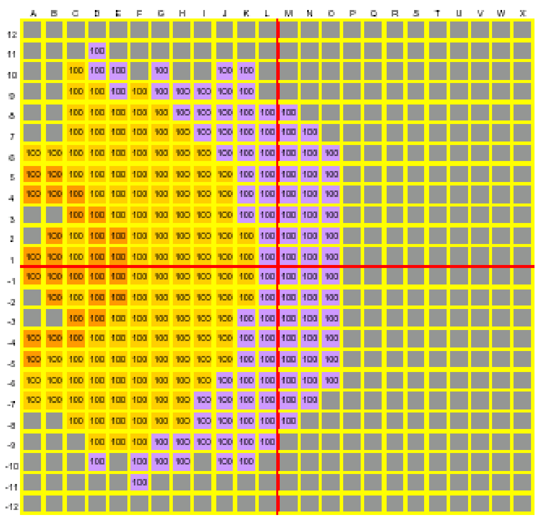
System D

Test Number: I - Detection zones with clean sensor — Date: 2003-12-15

Test obstacle: GRAY PVC TUBE — Height (cm): 100 — Width (cm): 9

Detection system make/model: C-Back — Test Location: Front ☐ Rear ☒

1st	detection zone:	Visual: 1 led	audible: intermittent	color
2nd	detection zone:	Visual: 2 leds	audible: intermittent	color
3rd	detection zone:	Visual: 3 leds	audible: continuous	color



Number in each cell indicates test object height (cm)

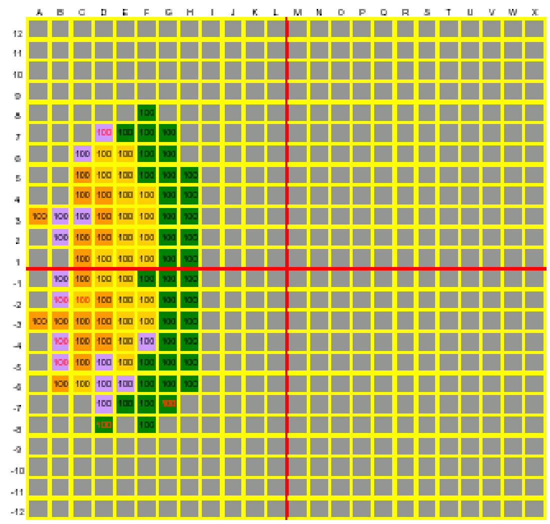
System E

Test Number: I - Detection zones with clean sensors — Date: 2003-12-08

Test obstacle: GRAY PVC TUBE — Height (cm): 100 — Width (cm): 9

Detection system make/model: SafeReverse — Test Location: Front ☐ Rear ☒

1st	detection zone:	Visual: None	audible: intermittent	color	3 Hz
2nd	detection zone:	Visual: None	audible: intermittent	color	5 Hz
3rd	detection zone:	Visual: None	audible: intermittent	color	7.5 Hz
4th	detection zone:	Visual: None	audible: continuous	color	DC



Number in each cell indicates test object height (cm)

System F