Heavy duty vehicle rear-view camera systems: phase II
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Heavy-Duty Vehicle Rear-View Camera Systems – Phase II

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Technical Report

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ABSTRACT

Transport Canada, through its ecoTECHNOLOGY for Vehicles program, retained the services of the National Research Council Canada, as represented by the portfolio for Automotive and Surface Transportation to undertake a test program to examine the operational and human factors considerations concerning the use of a prototype camera-based indirect vision system on a heavy duty vehicle. The primary objective of the camera-based indirect vision system test program was to conduct a preliminary evaluation of the use of cameras in replacement of a mirror-based indirect vision system on a heavy duty vehicle by performing comparative testing in simulated driving scenarios on a closed course test track using commercial drivers as test subjects. A total of four test subjects were asked to perform six tests, although not all of the test subjects completed all of the available tests.

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EXECUTIVE SUMMARY

Transport Canada, through its ecoTECHNOLOGY for Vehicles program, retained the services of the National Research Council Canada (NRC), as represented by the portfolio for Automotive and Surface Transportation (AST) to undertake a test program to examine the operational and human factors considerations concerning the use of a prototype camera-based indirect vision system on a heavy duty vehicle. Indirect vision systems are used by drivers to identify objects that do not fall directly within their line of sight. This can be accomplished through the use of a conventional mirror-based indirect vision system or by a camera-based indirect vision system.

The test program to date has been divided into two phases. In the first phase of the program, NRC-AST evaluated the design factors surrounding the use of camera-based indirect vision systems, quantified the possible fuel savings associated with the use of such a system, and designed and installed a prototype camera-based indirect vision system on a commercial highway tractor. The primary objective of the second phase of the camera-based indirect vision system test program was to conduct a preliminary evaluation of the use of cameras in replacement of a mirror-based indirect vision system on a heavy duty vehicle by performing comparative testing in simulated driving scenarios on a closed course test track using commercial drivers as test subjects.

Two vehicles were used to test the camera-based indirect vision system: the subject vehicle and the target vehicle. The subject vehicle was a Volvo VN780 highway tractor with a 53 foot dry van semi-trailer. The camera-based indirect vision system installed in the subject vehicle consisted of four Panasonic WV-CP624 cameras, two cameras mounted on either side of the subject vehicle on the front fender. Four monitors were mounted on the A-pillars of the subject vehicle, one for each camera. The vehicle was prepared such that the camera-based indirect vision system and the mirror-based indirect vision system could be interchanged, allowing for comparison testing of the two systems. The target vehicle was a 2013 black Ford Focus Model SE.

A total of four test subjects were asked to perform six tests, although not all of the test subjects completed all of the available tests. The six tests were an object identification test, a blind spot comparison test, a coupling and uncoupling test, a quasi-static lane change test, a dynamic lane change test and an evasive manoeuvres test.

The purpose of the object identification test was to compare the test subjects' ability to locate and identify targets while using both the conventional mirror-based indirect vision systems as well as the camera-based indirect vision system. The test was completed in both daytime and nighttime lighting conditions. Four test objects were used for the object identification test: a person, a road cone, a stop sign and a bicycle. Each object was presented four times for a total of sixteen tests per test condition. All four of the test subjects performed the test.

The results of the object identification test suggest that there is an increased ability to locate an object using the camera-based indirect vision system over the mirror-based indirect vision system. However, there is an increased ability to identify an object using a mirror-based indirect vision system over a camera-based indirect vision system.

The purpose of the blind spot comparison test was to compare the ability of the test subject to detect the presence of a target vehicle located alongside the subject vehicle. The test was performed both with the conventional mirror-based indirect vision system as well as the camera-based indirect vision system during daytime lighting conditions. All four of the test subjects performed the test.

The blind spot comparison tests did not reveal any significant differences between the size or location of the blind spots associated with either indirect vision system. Although the final position of the target vehicle varied with the test subject as well as between systems, the size of the variation was not large enough to make a vehicle not visible to the test subject while using either system.

The purpose of the coupling and uncoupling test was to determine whether or not the test subject could adequately perform a series of simple coupling manoeuvers which they may be expected to perform during typical transport operations. The test was performed both with the conventional mirror-based indirect vision system as well as the camera-based indirect vision system during daytime and nighttime driving conditions. Two of the four test subjects performed the test.

The results of the coupling and uncoupling test revealed that the test subjects were capable of positioning the subject vehicle's trailer within the cones of the simulated loading dock with the camera-based indirect vision system and with the mirror-based indirect vision system. In general, both test subjects took more time performing the required manoeuvres during daytime conditions with the camera-based indirect vision system compared to the mirror-based indirect vision system, but showed significant improvement during nighttime tests when using the camera-based indirect vision system compared to the mirror-based indirect vision system.

The purpose of the quasi-static lane change test was to quantify the ability of the driver to perceive the location of the zero clearance distance position of the target vehicle. The zero clearance distance position of the target vehicle occurs when the front bumper of the target vehicle contacts the imaginary plane extending laterally from the end of the subject vehicle trailer. The test was performed both with the conventional mirror-based indirect vision system as well as the camera-based indirect vision system during daytime and nighttime lighting conditions. Three of the four test subjects performed the test.

The results of the quasi-static lane change test may be summarized by two findings. Firstly, the test subjects were not able to accurately locate the zero clearance distance position with either the mirror-based or camera-based indirect vision systems. Secondly, there were significant differences in the perceived location of the zero clearance distance position between the mirror-based and camera-based indirect vision systems. The noted differences in the perceived location of the zero clearance distance position between indirect vision systems were not consistent with the system under test, but varied between tests and test subjects. These differences in the perceived location of the zero clearance distance position revealed that the careful calibration of the camera fields of view to provide a similar sense of depth as is available with the use of a mirror-based indirect vision system was ineffective.

The purpose of the dynamic lane change test was to compare the ability of the driver to perform lane change maneuvers with each of the tested indirect vision systems. The test was performed both with the conventional mirror-based indirect vision system as well as the camera-based indirect vision system during daytime and nighttime lighting conditions. Two test speeds were used for the target vehicle: 40 km/h and 74 km/h. The subject vehicle's passing speeds were 50 km/h and 80 km/h. Two of the four test subjects performed the test.

The results of the dynamic lane change test revealed that the test subjects allowed for much more clearance distance between the subject vehicle and the target vehicle while using the camera-based indirect vision system than they did while using the mirror-based indirect vision system. The larger allowance of clearance distance while changing lanes with the camera-based indirect vision system was likely a result of the test subject not knowing the location of the end of the subject vehicle trailer.

The purpose of the evasive maneuvers test was to assess the ability of the test subject to determine whether a lane change could be successfully completed in the event of a sudden and unforeseen road obstruction. The test was performed both with the conventional mirror-based indirect vision system as well as the camera-based indirect vision system during daytime and nighttime lighting conditions. Two of the four test subjects performed the test.

The results of the evasive manoeuvres test revealed that the test subjects had difficulty in determining the location of the rear of the subject vehicle's trailer, similar to the results of the quasi-static lane change and dynamic lane change tests. Determining the location of the rear of the subject vehicle's trailer was made even more difficult at night as a result of the camera bloom emanating from the target vehicle's headlights. The test subjects were much more hesitant in their lane changing manoeuvres during nighttime operations with the camera-based indirect vision system compared to similar lane change manoeuvres with the mirror-based indirect vision system as a result of the blooming effect of the digital cameras. However, at no point during testing did the test subjects attempt to perform a lane change manoeuvre which would have caused a collision.

After each test, the test subjects were provided with questionnaires as a way to gather both qualitative and quantitative user data. The test subjects were asked to rate the level of ease or difficulty they associated with each test manoeuvre for both the camera-based indirect vision system and the mirror-based indirect vision system. The test subjects were also asked to provide comments on what they liked and did not like about the camera-based indirect vision system. In addition, they were encouraged to provide feedback on ways to improve the camera-based indirect vision system.

In general, the test subjects rated the camera-based indirect vision system as more difficult to use than the mirror-based indirect vision system. In terms of the comments received from the test subjects, the most frequent concern was that of blooming in the monitors as a result of viewing bright lights during nighttime operations. Test subjects were also concerned about the resolution of the system, difficulties in proper depth perception, and the lack of control over the cameras fields of view and monitor brightness. However, test subjects did enjoy the greater forward field of view associated with the use of a camera-based indirect vision system as result of the removal of the mirrors, as well as the smaller scan area associated with such a system.

The preliminary comparison of the camera-based indirect vision system with a conventional mirror-based indirect vision system revealed that the camera-based indirect vision system provided potential advantages in locating and identifying objects during nighttime operations. This was shown in the object identification test as well as the coupling and uncoupling test. However, it was during nighttime operations when the camera-based indirect vision system was at its most vulnerable due to image blooming as a result of bright objects within the camera fields of view. This was also the most frequent concern about the system listed by the test subjects on the questionnaires. It will be important to resolve the issue of image blooming in any subsequent revision of the camera-based indirect vision system.

The quasi-static lane change test, the dynamic lane change test and the evasive manoeuvre test all revealed that the test subject's inability to locate the end of their trailer resulted in hesitation to perform lane changes which could be deemed as safe to perform. However, the quasi-static lane change test revealed that the test subjects were not any better in locating the actual position of their trailer with a mirror-based indirect vision system. The hesitation in performing lane change manoeuvres, especially during daytime conditions, could be the result of unfamiliarity with the use of a camera-based indirect vision system. During nighttime conditions, it is likely a combination of this unfamiliarity and the aforementioned issue of image blooming.

It was found that the careful calibration of the camera fields of view to provide a similar sense of depth as is available with the use of a mirror-based indirect vision system was ineffective. This finding allows for the placement of the cameras in locations other than the front fender of the equipped vehicle. This will allow for cameras to be mounted in locations which are less susceptible to road debris and soiling. This will also allow for placement of the cameras in the location which results in the greatest reduction in aerodynamic drag, the potential for aerodynamic drag reduction and the resultant fuel savings being the main driver for the adoption of camera-based indirect vision systems. The attempt at simulating depth perception through careful selection of camera fields of view was also an important consideration in choosing the size of the system monitors in the first phase of this program. The finding that this methodology is ineffective allows for greater flexibility in the sizing of the monitors. Although there is an upper practical limit on the size of the monitors, the larger the monitor, the more visual information may be provided to the vehicle operator.

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1 INTRODUCTION

1.1 Purpose

Transport Canada (TC), through its ecoTECHNOLOGY for Vehicles (eTV) program, has retained the services of the National Research Council Canada (NRC), as represented by the portfolio for Automotive and Surface Transportation (AST), hereafter known as NRC-AST, to undertake a test program to examine the operational and human factors considerations concerning the use of a prototype camera-based indirect vision system on a heavy duty vehicle.

1.2 Background

Indirect vision systems are used by drivers to identify objects that do not fall directly within their line of sight. This can be accomplished through the use of a conventional mirror-based indirect vision system or by a camera-based indirect vision system.

Conventional mirror-based indirect vision systems require large structures to be placed in the airflow passing the vehicle creating a significant amount of drag. The use of a camera-based indirect vision system requires smaller support structures, thereby reducing the overall drag coefficient of the vehicle on which they are mounted. The reduction in drag results in fuel savings and a corresponding reduction in emissions.

In Phase I of this study, NRC-AST evaluated the design factors surrounding the use of camera-based indirect vision systems, quantified the possible fuel savings associated with the use of such a system, and designed and installed a prototype camera-based indirect vision system on a Volvo VN780 highway tractor. [1]

1.3 Objectives

The primary objective of the camera-based indirect vision system test program is to conduct a preliminary evaluation of the use of cameras in replacement of a mirror-based indirect vision system on a heavy duty vehicle. In order to evaluate whether there are any significant changes to the operating environment in which the driver is situated as a result of removing the mirrors from the vehicle, the driver was placed in simulated driving scenarios on a closed course test track. The driver's ability to efficiently operate the test vehicle with the use of the camera-based indirect vision system will be compared to the ability to efficiently operate the vehicle with the conventional mirror-based indirect vision system.

1.4 Limitations

There were several limitations concerning the testing of the camera-based indirect vision system. Firstly, the sample size of test subjects used for the testing was small meaning that the results may not be representative of the entire population of commercial drivers. Secondly, there was no training given to the test subjects for them to adjust to the use of a camera-based indirect vision system. The test sequence was designed so that the tests became progressively more difficult, but no time was allotted for training of the test subjects. Thirdly, all tests were performed on a closed course in controlled conditions, removing the test subject from the environment in which they normally operated. Finally, there was no control over environmental factors. All tests occurred in conditions which were free of precipitation. Only once did condensation form on the camera-based indirect vision system.

2 APPARATUS

2.1 Test Vehicles

Two vehicles were used to test the camera-based indirect vision system: the subject vehicle and the target vehicle.

2.1.1 Subject Vehicle

The subject vehicle was a Volvo VN780 highway tractor with a 53 foot dry van semi-trailer. The vehicle was prepared such that the camera-based indirect vision system and the mirror-based indirect vision system could be interchanged, allowing for comparison testing of the two systems. The subject vehicle with the camera-based indirect vision system may be seen in Figure 1.

Figure 1: Subject vehicle

The camera-based indirect vision system installed in the subject vehicle consisted of four Panasonic WV-CP624 cameras housed inside a temporary steel box to protect the cameras from any debris but still allow accessibility for the test team. The driver side and passenger side camera housings may be seen in Figure 2 and Figure 3, respectively.

Four monitors were mounted on the A-pillars of the subject vehicle, one for each camera. The monitors mounted on the left A-pillar (as shown in Figure 4) were a ToteVision LCD-562 mounted above a ToteVision LCD-642. The monitors mounted on the right A-pillar (as shown in Figure 5) were a ToteVision LCD-642 mounted above a ToteVision LCD-842HD.

Further details of the design and installation of the camera-based indirect vision system used in the testing described within this document may be found in the previously issued report [1].

Figure 2: Driver side camera housing

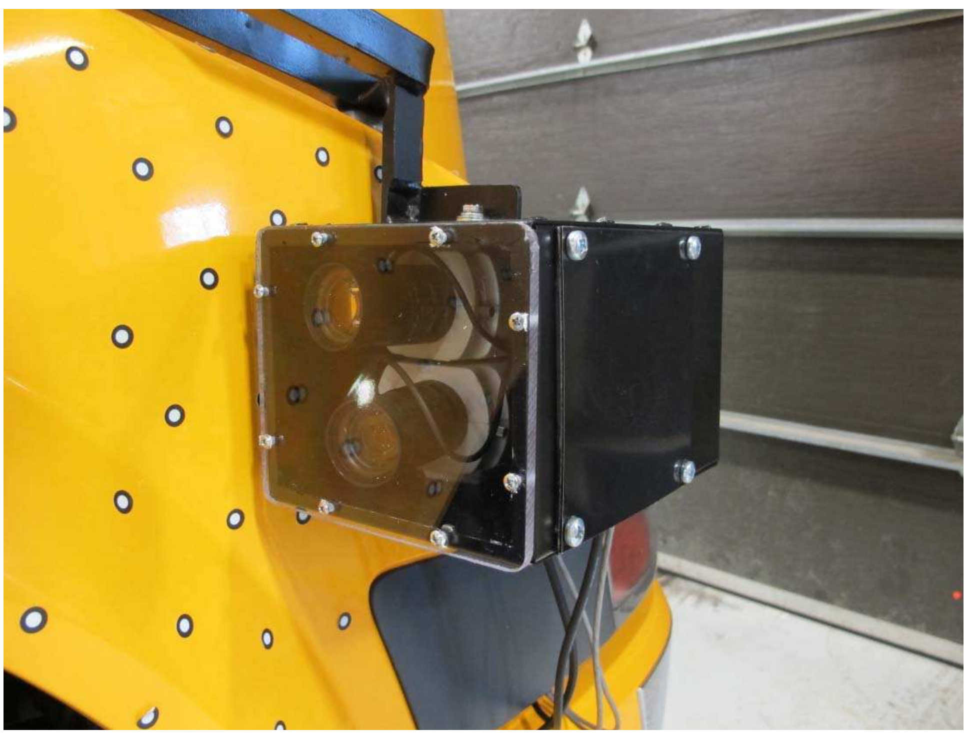

Figure 3: Passenger side camera housing

Figure 4: System monitors mounted on left A-pillar

Figure 5: System monitors mounted on right A-pillar

2.1.2 **Target Vehicle**

Four of the six tests which formed the test program required the use of a target vehicle. The target vehicle was a 2013 black Ford Focus Model SE. The target vehicle may be seen in Figure 6.

Figure 6: Target vehicle

2.2 Instrumentation

Table 1 provides details on the instrumentation installed during testing.

Table 1: List of instrumentation

Sensor	Location	Range	Accuracy
Linear transducer	Subject vehicle steering wheel (for steering input measurement)	0-750 mm	±2 mm
Laser distance meter	Various locations depending upon test	0.2-15 m	<5 mm
Global positioning	Target vehicle	∞	±3 m
Global positioning	Subject vehicle	∞	±3 m

2.3 Data Acquisition

Raw data were sampled at 100 Hz and filtered with a low pass Butterworth filter by an IMC data acquisition system. Data from each run were captured into memory and then stored onto the local hard drive. All recorded data were transferred to NRC-AST's network after the testing was completed.

3 TEST SUBJECTS

A small sample of test subjects was used to evaluate the camera-based indirect vision system. All of the test subjects were male. Table 2 provides additional pertinent information describing the test subjects. Table 3 provides details of which test subjects completed which tests.

Table 2: Test subject details

Test Subject	Age	Years of Commercial Driving Experience	Vision	Corrective Lenses
Driver 1	62	35	20/20	Bifocals
Driver 2	34	8	20/20	None
Driver 3	36	7	20/25	None
Driver 4	65	33	20/30	Bifocals

Table 3: Tests completed by test subjects

Test Subject	Completed Tests
Driver 1	Object Identification Blind Spot Comparison Coupling and Uncoupling Quasi-Static Lane Change
Driver 2	Object Identification Blind Spot Comparison Coupling and Uncoupling Quasi-Static Lane Change Dynamic Lane Change Evasive Manoeuvre
Driver 3	Object Identification Blind Spot Comparison Coupling and Uncoupling Quasi-Static Lane Change Dynamic Lane Change Evasive Manoeuvre
Driver 4	Object Identification Blind Spot Comparison

4 TEST PROCEDURES

4.1 Object Identification

The object identification test was performed on the premises of NRC-AST. The purpose of the object identification test was to compare the test subjects' ability to locate and identify targets while using both the conventional mirror-based indirect vision systems as well as the camera-based indirect vision system. The test was completed in both daytime and nighttime lighting conditions. Although weather was not a controlled factor, all tests took place in precipitation free conditions.

Four test objects were used for the object identification test: a person, a road cone, a stop sign and a bicycle. The four test objects used during testing may be seen in Figure 7. The test locations in which the test objects were placed may be seen in Figure 8. Prior to the testing, four test locations were randomly selected for each of the four test objects. Sixteen locations were tested in total. Each driver was subjected to the same set of test object locations and order of object presentation. The test locations and order of presentation for daytime testing may be found in Table 4. The test locations and order of presentation for nighttime testing may be found in Table 5.

The subject vehicle was positioned in a rear lot of NRC-AST with the test subject in the driver's seat. The test subject was asked to adjust the indirect vision system under test as they would under normal operating conditions. A grid was measured around the subject vehicle as shown in Figure 8 to locate the test objects.

To ensure the test subject could not see where the test object was being placed, the indirect vision system under test was obstructed. For the mirror-based indirect vision system, this was accomplished through the use of a spring loaded obstruction operated by a solenoid release mechanism, as shown in Figure 9. For the camera-based system, the video feed delivered to the monitors was interrupted via a toggle switch.

Once the test object was in position, the indirect-vision system was unobstructed and the time for the test subject to identify the test object was recorded using the data acquisition system.

Upon completion of the object identification test, the test subject was provided with brief questionnaires to collect additional data. The object identification test questionnaires may be found in Appendix A and Appendix B.

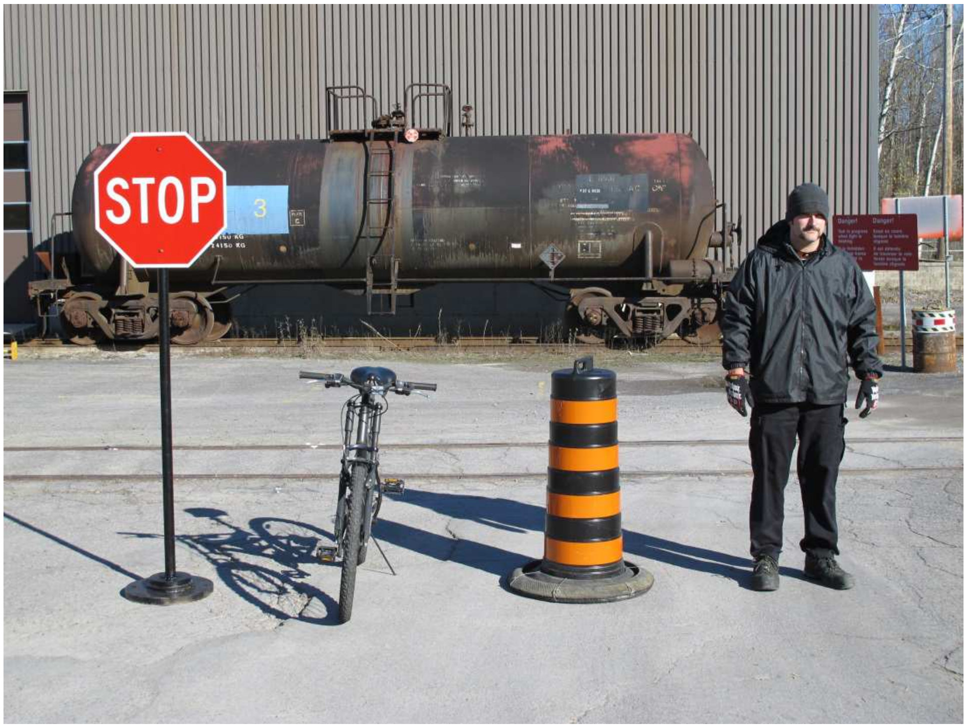

Figure 7: Objects used for object identification test (left to right: stop sign, bike, cone, person)

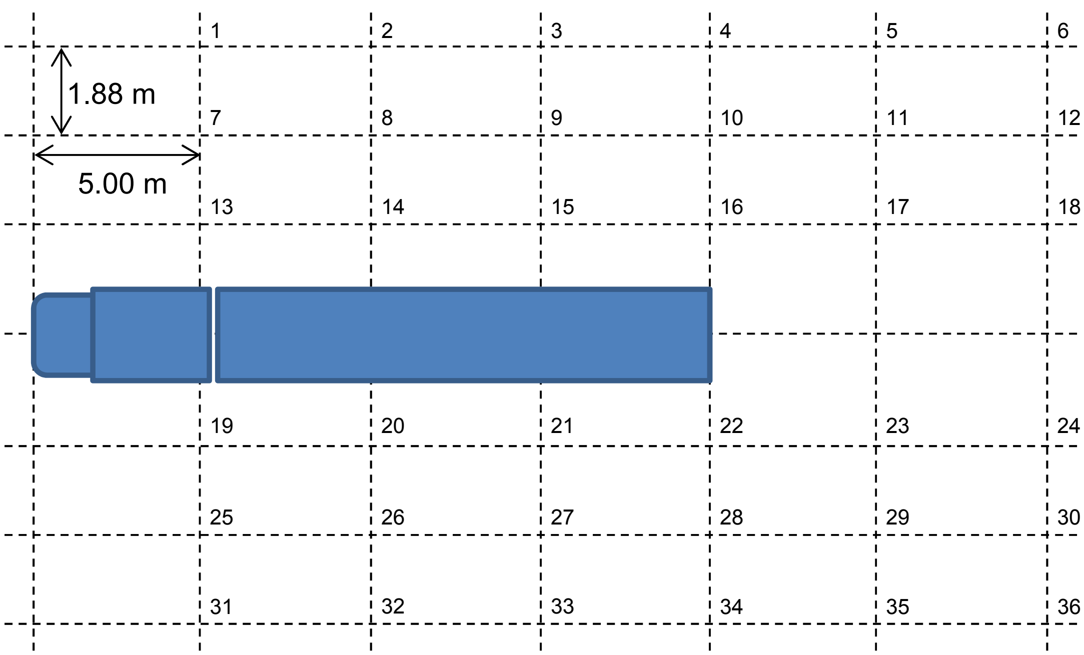

Figure 8: Object identification test object locations

Table 4: Daytime object identification test

Test	Camera Test Locations		Mirror Test Locations	
	Item	Location	Item	Location
1	Cone	5	Cone	19
2	Bike	35	Stop sign	30
3	Cone	36	Bike	25
4	Bike	25	Cone	5
5	Cone	13	Bike	35
6	Person	15	Stop sign	11
7	Stop sign	9	Person	24
8	Stop sign	21	Bike	13
9	Cone	19	Person	13
10	Stop sign	30	Person	14
11	Bike	13	Bike	29
12	Stop sign	11	Cone	13
13	Person	14	Person	15
14	Person	13	Cone	36
15	Bike	29	Stop sign	9
16	Person	24	Stop sign	21

Table 5: Nighttime object identification test

Test	Camera Test Locations		Mirror Test Locations	
	Item	Location	Item	Location
1	Stop sign	11	Cone	36
2	Bike	25	Bike	35
3	Cone	36	Stop sign	21
4	Person	24	Person	15
5	Stop sign	21	Stop sign	9
6	Person	13	Cone	13
7	Bike	29	Bike	13
8	Person	15	Bike	25
9	Person	14	Stop sign	11
10	Stop sign	9	Bike	29
11	Cone	5	Person	24
12	Cone	13	Cone	5
13	Bike	13	Person	13
14	Stop sign	30	Person	14
15	Cone	19	Stop sign	30
16	Bike	35	Cone	19

Figure 9: Mirror obstruction device closed (left) and open (right)

4.2 Blind Spot Comparison

The blind spot comparison test was performed on the premises of NRC-AST. The purpose of the blind spot comparison test was to compare the ability of the test subject to detect the presence of the target vehicle located alongside the subject vehicle. The test was performed both with the conventional mirror-based indirect vision system as well as the camera-based indirect vision system during daytime lighting conditions. Although weather was not a controlled factor, all tests took place in precipitation free conditions.

The subject vehicle was positioned in a rear lot of NRC-AST with the test subject in the driver's seat. The test subject was asked to adjust the indirect vision system under test as they would under normal operating conditions.

The target vehicle was positioned roughly 10 m behind the subject vehicle, leaving roughly 1 m of lateral clearance to simulate the target vehicle traveling in an adjacent lane. The test was first performed with the target vehicle on the passenger side of the subject vehicle, then with the target vehicle on the driver side of the subject vehicle. The starting position of the target vehicle in relation to the subject vehicle may be seen in Figure 10.

The target vehicle was then driven forwards at a speed of less than 2 km/h. The test subject was asked to notify the test team when they could no longer see the target vehicle in the indirect vision system under test. When the test subject could no longer see the target vehicle through the indirect vision system, the target vehicle was stopped and the relative position of the two vehicles was measured. The final position of the target vehicle may be seen in Figure 11.

Upon completion of the blind spot comparison test, the test subject was provided with brief questionnaires to collect additional data. The blind spot comparison test questionnaires may be found in Appendix C and Appendix D.

Figure 10: Starting position of target vehicle for blind spot comparison test (driver side test)

Figure 11: Final position of target vehicle for blind spot comparison test (driver side test)

4.3 Coupling and Uncoupling

The coupling and uncoupling test was performed at the Transport Canada test track in Blainville, Québec. The purpose of the coupling and uncoupling test was to determine whether or not the test subject could adequately perform a series of simple coupling manoeuvers which they may be expected to perform during typical transport operations. The test was performed both with the conventional mirror-based indirect vision system as well as the camera-based indirect vision system during daytime and nighttime driving conditions. Although weather was not a controlled factor, all tests took place in precipitation free conditions (the wet pavement shown in Figure 18 and Figure 19 was a result of an earlier rainfall and did not occur during testing).

Eight road cones were used to simulate a narrow passage leading to a loading dock. The opening of the narrow passage was 3 m. The positioning of the cones for the simulated loading dock and passage is shown schematically in Figure 12. The simulated loading dock may be seen in Figure 13.

The subject vehicle was positioned on the test track in the starting position, as shown in Figure 14. In the starting position, the subject vehicle was positioned roughly 17.75 m from the opening of the simulated loading dock. The test subject was then asked to reverse the subject vehicle into the simulated loading dock as they would do during normal operations, positioning the trailer in the docked position shown in Figure 14. Once the test subject was satisfied with the placement of the trailer in the simulated loading dock, the test subject was asked to decouple the trailer from the tractor and pull away from the trailer to the final position, as shown in Figure 14. The test subject was then asked to reverse the procedure, reversing the tractor into the trailer, coupling, then driving out of the simulated loading dock. The starting position and final position for the driver side approach may be seen in Figure 15 and Figure 16, respectively.

The subject vehicle was then repositioned at the starting position for a passenger side approach into the simulated loading dock, as shown in Figure 17. The test subject was asked to perform a similar manoeuvre, reversing into the simulated loading dock, uncoupling the tractor from the trailer and then pulling away from the trailer. The test subject was then asked to reverse towards the trailer, connect to the trailer and pull away from the simulated loading dock. The starting position and final position for the passenger side approach may be seen in Figure 18 and Figure 19, respectively.

This procedure was repeated both with the camera-based indirect vision system as well as with the mirror-based indirect vision system during daytime and nighttime lighting conditions.

Upon completion of the coupling and uncoupling test, the test subject was provided with brief questionnaires to collect additional data. The coupling and uncoupling test questionnaires may be found in Appendix E and Appendix F.

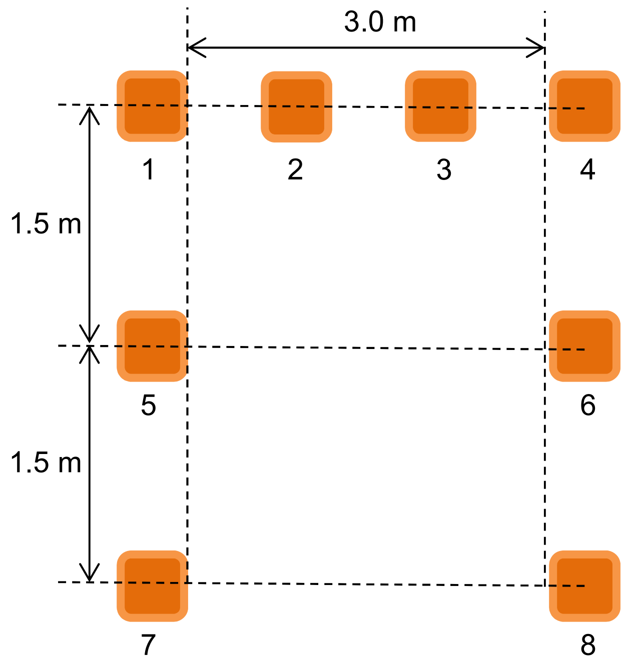

Figure 12: Postioning of cones for simulated loading dock for coupling and uncoupling test

Figure 13: Simulated loading dock for coupling and uncoupling test

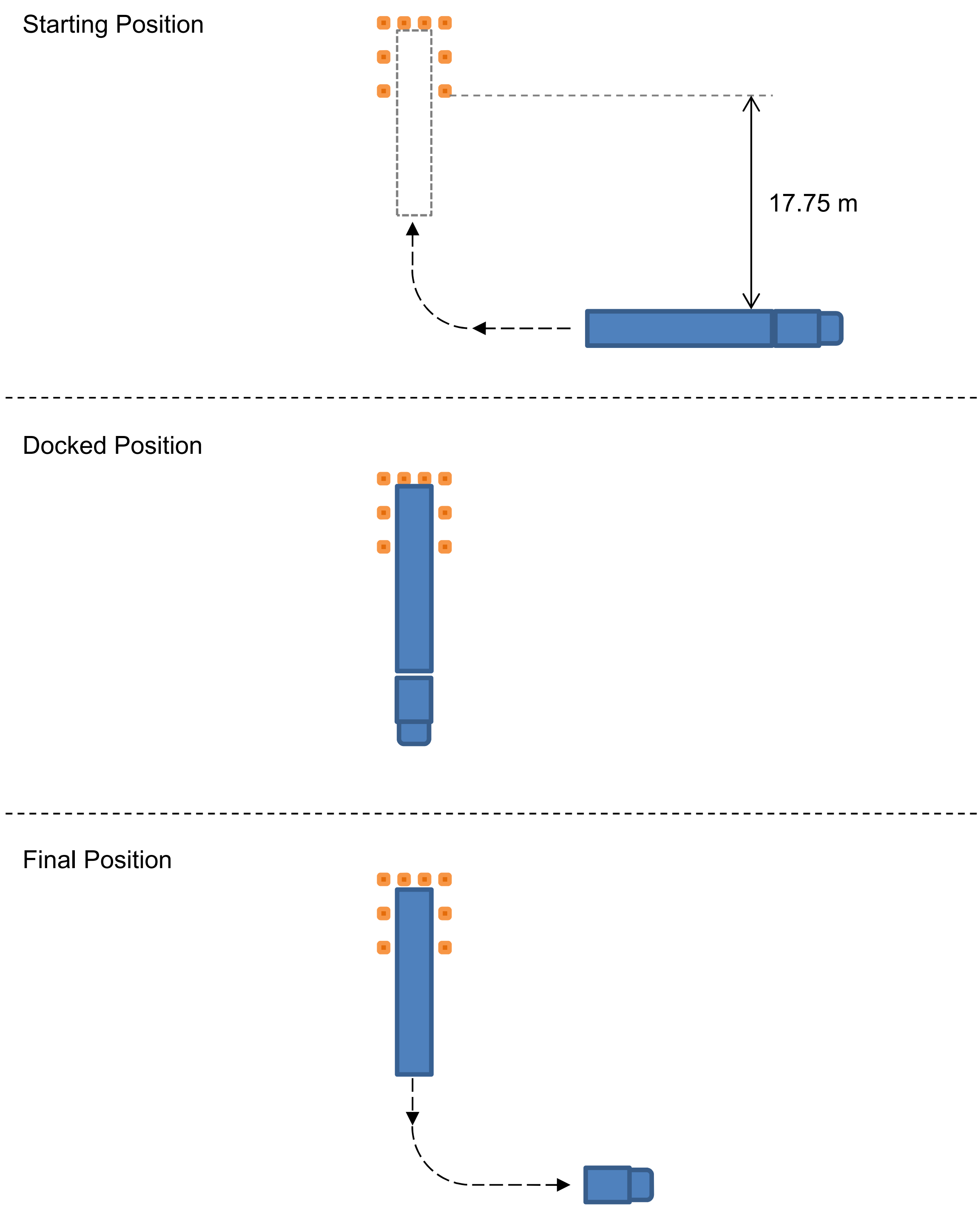

Figure 14: Coupling and uncoupling manoeuvre (driver side approach)

Figure 15: Starting position for coupling and uncoupling test (driver side approach)

Figure 16: Final position for coupling and uncoupling test (driver side approach)

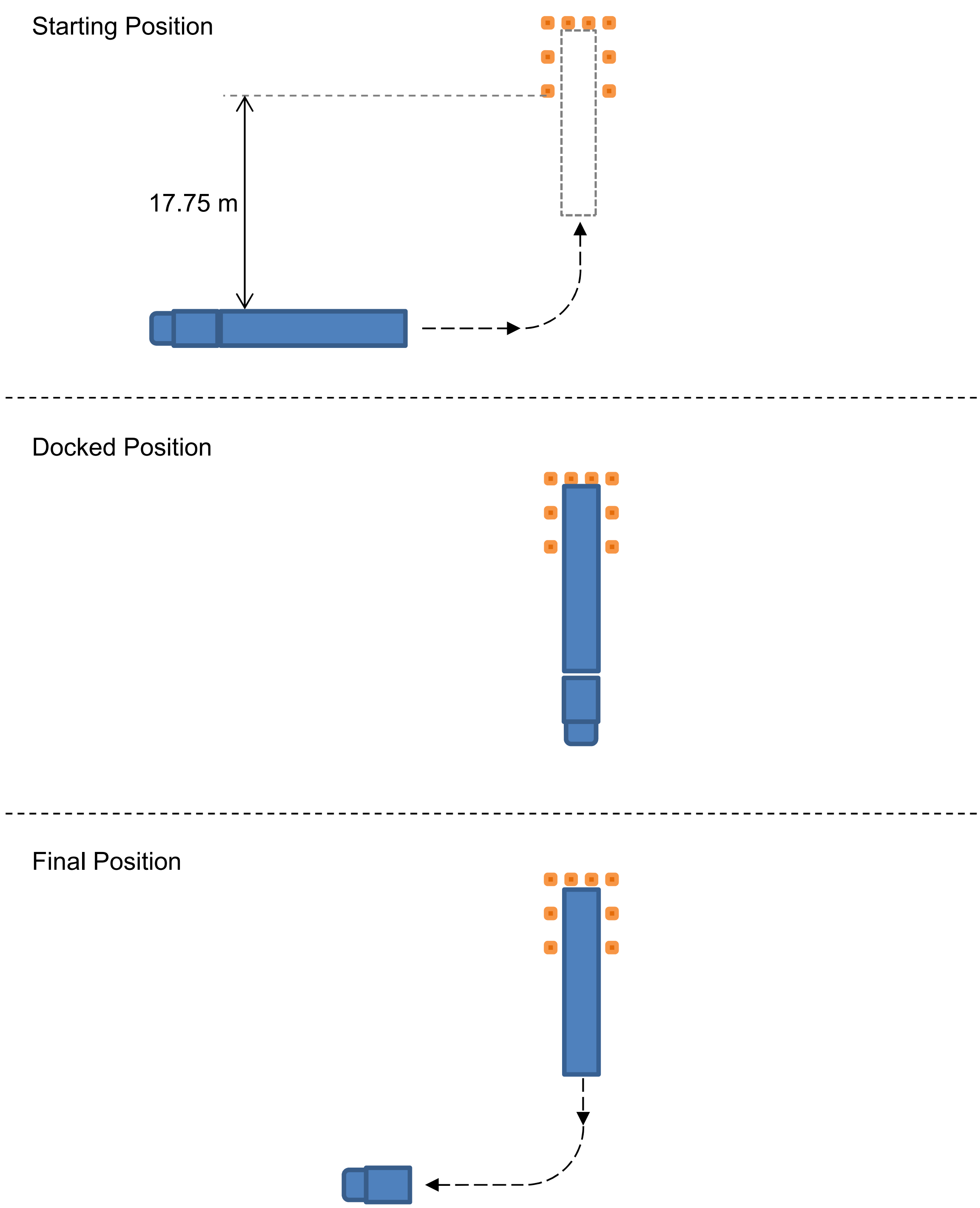

Figure 17: Coupling and uncoupling manoeuvre (passenger side approach)

Figure 18: Starting position for coupling and uncoupling test (passenger side approach)

Figure 19: Final position for coupling and uncoupling test (passenger side approach)

4.4 Quasi-Static Lane Change

The quasi-static lane change test was performed at the Transport Canada test track in Blainville, Québec. The purpose of the quasi-static lane change test was to quantify the ability of the driver to perceive the location of the zero clearance distance position of the target vehicle. The test was performed both with the conventional mirror-based indirect vision system as well as the camera-based indirect vision system during daytime and nighttime lighting conditions. Although weather was not a controlled factor, all tests took place in precipitation free conditions. However, at one point condensation did form on the protective housing surrounding the cameras as detailed in section 5.7.2.1.

The subject vehicle was positioned on the test track and remained stationary for the duration of the test. The target vehicle was positioned in an adjacent lane, leaving roughly 1.5 m of lateral clearance between the two vehicles. A laser distance meter was attached to the rear of the subject vehicle trailer to continuously measure the clearance distance between the rear of the trailer and a laser reflection panel mounted to the target vehicle. The target vehicle with the laser reflection panel may be seen in Figure 20. The laser reflection panel structure may be seen in Figure 21. The white panel in the right of Figure 21 was used to reflect the laser. The orange cone affixed to the structure was used along with the painted yellow line to maintain the separation distance between the target and subject vehicles.

Once the target and subject vehicles were in position, the target vehicle was driven slowly (<5 km/h) back and forth alongside the subject vehicle. The test subject was instructed to activate a pendant switch every time they perceived that the rear of the subject vehicle's trailer was flush with the front of the target vehicle's nose. The rearward and forward position of the target vehicle may be seen in the upper and lower images of Figure 22. The middle image of Figure 22 shows the position in which the test subject was asked to activate the pendant switch. The target vehicle continued driving forward and backward for a total of 20 minutes.

The same procedure was followed for both driver side and passenger side positioning of the target vehicle, daytime and nighttime conditions and with both the camera-based and mirror-based indirect vision systems.

Upon completion of the quasi-static lane change test, the test subject was provided with brief questionnaires to collect additional data. The quasi-static lane change test questionnaires may be found in Appendix G and Appendix H.

Figure 20: Laser reflection panel mounted to target vehicle

Figure 21: Laser reflection panel structure

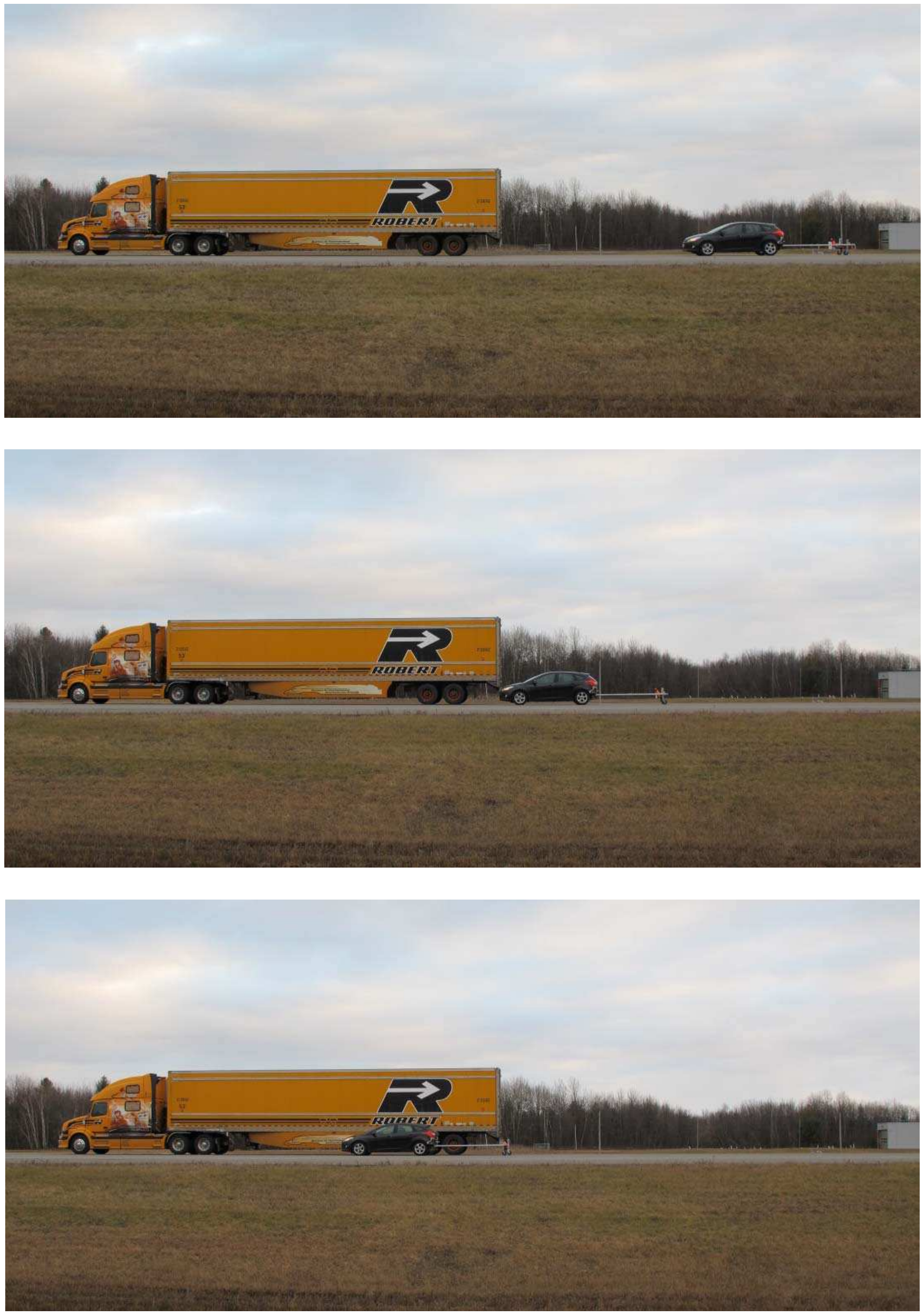

Figure 22: Rearmost (top), flush (middle) and foremost (bottom) target vehicle positions

4.5 Dynamic Lane Change

The dynamic lane change test was performed at the Transport Canada test track in Blainville, Québec. The purpose of the dynamic lane change test was to compare the ability of the driver to perform lane change maneuvers with each of the tested indirect vision systems. The test was performed both with the conventional mirror-based indirect vision system as well as the camera-based indirect vision system during daytime and nighttime lighting conditions. Although weather was not a controlled factor, all tests took place in precipitation free conditions.

Two test speeds were used for the target vehicle: 40 km/h and 74 km/h. The test speed of 74 km/h was chosen as the target vehicle's cruise control could only be set to 2 km/h increments. The subject vehicle's passing speeds were 50 km/h and 80 km/h, the latter being the nighttime speed limit of the test track.

To begin the test, the target vehicle was brought up to test speed, followed by the subject vehicle being operated by the test subject. Once at the test speed, the target vehicle engaged its cruise control to maintain that speed during the lane change manoeuvre. Once the target vehicle was locked into the test speed with the cruise control system, the subject vehicle passed the target vehicle and performed a lane change in front of the target vehicle. Three attempts at the lane change manoeuvre were performed on both the passenger side and the driver side of the target vehicle, at 40 km/h and 74 km/h target vehicle speeds, and during both daytime and nighttime driving conditions.

To measure the separation distance between the two vehicles at the time of the lane change, a laser distance meter was affixed to the side of the target vehicle. For lane change manoeuvres with the subject vehicle passing on the passenger side of the target vehicle, the laser was affixed to the passenger side of the target vehicle. For lane change manoeuvres with the subject vehicle passing on the driver side of the target vehicle, the laser was affixed to the driver side of the target vehicle. The laser affixed to the passenger side of the target vehicle is shown in Figure 23 and Figure 24. In order to provide a sizeable target with suitable reflective properties on the rear of the subject vehicle's trailer, large white reflection panels were affixed to the rear of the trailer. The laser reflection panels may be seen in Figure 25.

The effective range of the laser distance meter was 15 m. When the clearance distance between the two vehicles was greater than 15 m, the GPS units located on the vehicles were used to determine the clearance distance during lane change manoeuvres.

Upon completion of the dynamic lane change test, the test subject was provided with brief questionnaires to collect additional data. The dynamic lane change test questionnaires may be found in Appendix I and Appendix J.

Figure 23: Laser distance meter affixed to the side of the target vehicle

Figure 24: Laser reflection panels affixed to the rear of the subject vehicle

Figure 25: Laser reflection panels affixed to the rear of the subject vehicle

4.6 Evasive Manoeuvre

The evasive manoeuvres test was performed at the Transport Canada test track in Blainville, Québec. The purpose of the evasive maneuvers test was to assess the ability of the vehicle operator to determine whether a lane change could be successfully completed in the event of a sudden and unforeseen road obstruction. The test was performed both with the conventional mirror-based indirect vision system as well as the camera-based indirect vision system during daytime and nighttime lighting conditions. Although weather was not a controlled factor, all tests took place in precipitation free conditions.

The test subject was informed that they would be driving at 80 km/h with the indirect vision system under test deactivated. The test subject was instructed that once the indirect vision system was activated, they were to decide whether they felt they could perform an evasive lane change maneuver. At the same time of indirect vision system activation, the test team told the test subject to “move left” or “move right”, dependent upon where the target vehicle was located. If the test subject felt a lane change could be performed safely, they were to provide steering input to the subject vehicle in the required direction. The test subject was not asked to perform a full lane change to avoid a possible collision in the event there was insufficient clearance distance between the subject and target vehicles. They were merely asked to show intent of a lane change manoeuvre.

There were six predetermined locations for the target vehicle, as shown in Figure 26. The test subject was not informed as to the number or location of test positions. Test positions one, three and five are shown in Figure 27.

With the subject vehicle leading the target vehicle, both vehicles accelerated to test speed. Once at test speed, the target vehicle positioned itself in one of the six test positions. Once in position, the indirect vision system under test was activated and the test subject was asked to make the decision as to whether or not they should perform a lane change manoeuvre.

Ten tests were performed for each of the four test conditions: mirror-based indirect vision system during the day, mirror-based indirect vision system at night, camera-based indirect vision system during the day and camera-based indirect vision system at night. The order in which the tests took place may be found in Table 6.

Upon completion of the evasive manoeuvre test, the test subject was provided with brief questionnaires to collect additional data. The evasive manoeuvre test questionnaires may be found in Appendix K and Appendix L.

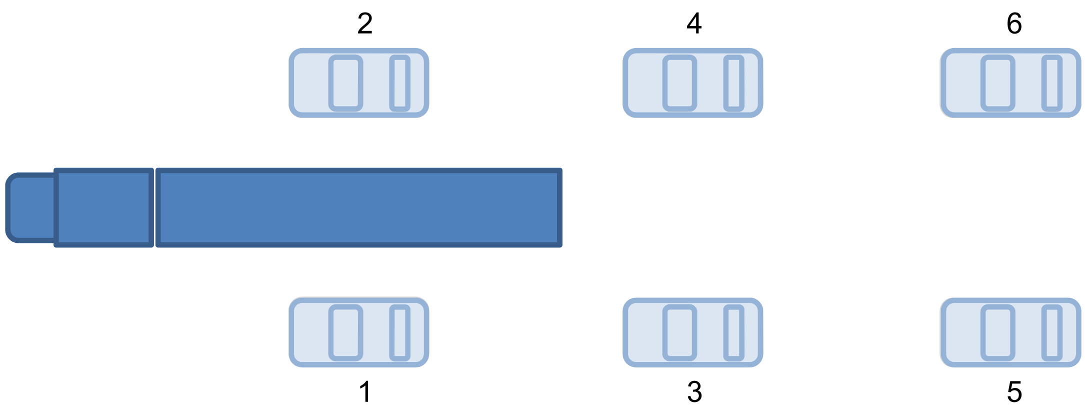

Figure 26: Evasive manoeuvre target locations

Table 6: Target vehicle positions for evasive manoeuvre test

Test	Target Vehicle Positions (Camera Tests)		Target Vehicle Positions (Mirror Tests)	
	Day	Night	Day	Night
1	3	3	3	4
2	3	5	3	3
3	2	4	5	4
4	6	5	1	5
5	2	4	6	1
6	4	6	2	1
7	5	4	3	5
8	1	2	4	4
9	6	1	2	6
10	3	1	6	2

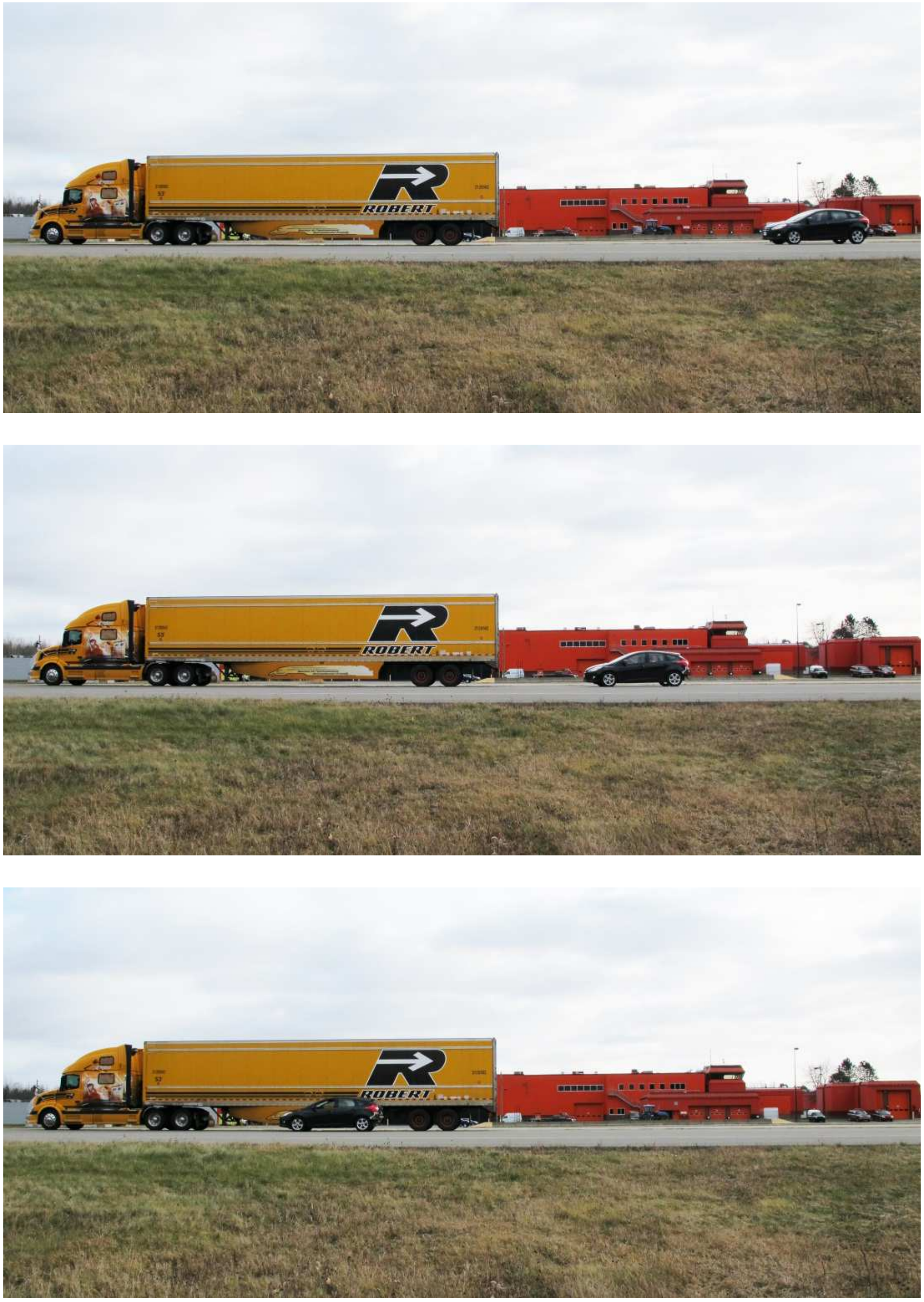

Figure 27: Evasive manoeuvre test positions one (top), three (middle) and five (bottom)

4.7 Questionnaires

The questionnaires were provided to the test subject after each test as a way to gather both qualitative and quantitative user data. The test subjects were asked to rate the level of ease or difficulty they associated with each test manoeuvre for both the camera-based indirect vision system and the mirror-based indirect vision system. The scale used to rate the level of difficulty is provided in Table 7.

The test subjects were also asked to provide comments on what they liked and did not like about the camera-based indirect vision system. In addition, they were encouraged to provide feedback on ways to improve the camera-based indirect vision system.

The questionnaires provided to the test subjects after each test may be found in Appendix A through Appendix L.

Table 7: Scale used to rate the indirect vision system under test

Ranking	Level of Ease/Difficulty
1	Extremely Difficult
2	Very Difficult
3	Difficult
4	Neutral
5	Easy
6	Very Easy
7	Extremely Easy

5 RESULTS

5.1 Object Identification

The list of test subjects who completed the object identification test along with the dates on which they completed the test may be found in Table 8.

Table 8: List of test subjects for object identification test

Test Subject	Date Test Performed
Driver 1	October 16, 2013
Driver 2	October 23, 2013
Driver 3	October 29, 2013
Driver 4	October 25, 2013

5.1.1 Driver 1

The results of the object identification test for Driver 1 may be found in Table 9 through Table 12.

For the object identification test occurring in the daytime with the camera-based indirect vision system (data presented in Table 9 on page 32), the test subject was unable to locate the test item for test number five. However, this was due to the fact that the driver failed to look to the right and focused their attention only on the left-hand monitors.

For the object identification test occurring in the daytime with the mirror-based indirect vision system (data presented in Table 10 on page 33), the test subject reported not being able to locate any test objects for tests number six and seven.

For the object identification test occurring in the nighttime with the camera-based indirect vision system (data presented in Table 11 on page 34), the test subject incorrectly identified the test item as a stop sign rather than a person for test number four.

For the object identification test occurring in the nighttime with the mirror-based indirect vision system (data presented in Table 12 on page 35), the test subject reported not being able to locate any test objects for tests number five, nine and twelve. For test number seven, the test subject incorrectly identified the test object as a cone rather than a bike.

Table 9: Driver 1 object identification test results for daytime with cameras

Test	Test Item	Test Item Location	Identified (Y/N)	Time to Identification (s)
1	Cone	5	Y	4.2
2	Bike	35	Y	2.5
3	Cone	36	Y	3.4
4	Bike	25	Y	2.6
5	Cone	13	N	--
6	Person	15	Y	4.2
7	Stop sign	9	Y	3.3
8	Stop sign	21	Y	1.8
9	Cone	19	Y	1.4
10	Stop sign	30	Y	1.7
11	Bike	13	Y	2.6
12	Stop sign	11	Y	3.8
13	Person	14	Y	3.0
14	Person	13	Y	2.8
15	Bike	29	Y	1.4
16	Person	24	Y	12.0
		Percent correctly identified:	**94%**	
			Average time to identification:	**3.4**

Table 10: Driver 1 object identification test results for daytime with mirrors

Test	Test Item	Test Item Location	Identified (Y/N)	Time to Identification (s)
1	Cone	19	Y	2.2
2	Stop sign	30	Y	5.4
3	Bike	25	Y	3.4
4	Cone	5	Y	4.4
5	Bike	35	Y	2.4
6	Stop sign	11	N	--
7	Person	24	N	--
8	Bike	13	Y	3.1
9	Person	13	Y	2.6
10	Person	14	Y	3.0
11	Bike	29	Y	1.4
12	Cone	13	Y	2.8
13	Person	15	Y	2.4
14	Cone	36	Y	4.2
15	Stop sign	9	Y	3.8
16	Stop sign	21	Y	1.4
		Percent correctly identified:	**88%**	
			Average time to identification:	**3.0**

Table 11: Driver 1 object identification test results for nighttime with cameras

Test	Test Item	Test Item Location	Identified (Y/N)	Time to Identification (s)
1	Stop sign	11	Y	3.2
2	Bike	25	Y	1.6
3	Cone	36	Y	7.0
4	Person	24	N	3.6
5	Stop sign	21	Y	2.2
6	Person	13	Y	3.2
7	Bike	29	Y	1.8
8	Person	15	Y	3.6
9	Person	14	Y	3.2
10	Stop sign	9	Y	4.0
11	Cone	5	Y	3.4
12	Cone	13	Y	3.4
13	Bike	13	Y	3.4
14	Stop sign	30	Y	1.8
15	Cone	19	Y	1.8
16	Bike	35	Y	1.8
		Percent correctly identified:	**94%**	
			Average time to identification:	**3.1**

Table 12: Driver 1 object identification test results for nighttime with mirrors

Test	Test Item	Test Item Location	Identified (Y/N)	Time to Identification (s)
1	Cone	36	Y	9.6
2	Bike	35	Y	2.1
3	Stop sign	21	Y	3.0
4	Person	15	Y	5.0
5	Stop sign	9	N	--
6	Cone	13	Y	3.6
7	Bike	13	N	4.2
8	Bike	25	Y	3.0
9	Stop sign	11	N	--
10	Bike	29	Y	1.8
11	Person	24	Y	2.0
12	Cone	5	N	--
13	Person	13	Y	3.2
14	Person	14	Y	2.8
15	Stop sign	30	Y	3.8
16	Cone	19	Y	1.8
		Percent correctly identified:	**75%**	
			Average time to identification:	**3.5**

5.1.2 **Driver 2**

The results of the object identification test for Driver 2 may be found in Table 13 through Table 16.

5.1.3 **Driver 3**

The results of the object identification test for Driver 3 may be found in Table 17 through Table 20.

For the object identification test occurring in the nighttime with the camera-based indirect vision system (data presented in Table 19 on page 43), the test subject incorrectly identified the test object as a person instead of a stop sign for the first test.

5.1.4 **Driver 4**

The results of the object identification test for Driver 4 may be found in Table 21 through Table 24.

For the object identification test occurring in the daytime with the camera-based indirect vision system (data presented in Table 21 on page 45), the test subject was unable to locate the test object for the first test. For the sixteenth test of the same test condition, the test subject incorrectly identified the test object as a stop sign instead of a person.

For the object identification test occurring in the daytime with the mirror-based indirect vision system (data presented in Table 22 on page 46), the test subject was unable to locate the test object for the third test. The test subject noted that the test object was outside their field of view, but they failed to check their convex mirror, in which the object was clearly visible.

For the object identification test occurring in the nighttime with the camera-based indirect vision system (data presented in Table 23 on page 47), the test subject incorrectly identified the test object as a stop sign instead of a person. For the seventh test of the same test condition, the test subject correctly identified the test object as a bike but wasn’t entirely certain that the test object was indeed a bike.

Table 13: Driver 2 object identification test results for daytime with cameras

Test	Test Item	Test Item Location	Identified (Y/N)	Time to Identification (s)
1	Cone	5	Y	2.6
2	Bike	35	Y	1.2
3	Cone	36	Y	1.2
4	Bike	25	Y	1.0
5	Cone	13	Y	4.1
6	Person	15	Y	1.2
7	Stop sign	9	Y	2.6
8	Stop sign	21	Y	1.0
9	Cone	19	Y	0.8
10	Stop sign	30	Y	1.4
11	Bike	13	Y	1.4
12	Stop sign	11	Y	1.6
13	Person	14	Y	2.2
14	Person	13	Y	2.2
15	Bike	29	Y	2.8
16	Person	24	Y	1.2
		Percent correctly identified:	**100%**	
			Average time to identification:	**1.8**

Table 14: Driver 2 object identification test results for daytime with mirrors

Test	Test Item	Test Item Location	Identified (Y/N)	Time to Identification (s)
1	Cone	19	Y	1.4
2	Stop sign	30	Y	2.8
3	Bike	25	Y	3.4
4	Cone	5	Y	2.2
5	Bike	35	Y	1.4
6	Stop sign	11	Y	1.8
7	Person	24	Y	5.0
8	Bike	13	Y	1.8
9	Person	13	Y	2.8
10	Person	14	Y	2.4
11	Bike	29	Y	1.4
12	Cone	13	Y	3.0
13	Person	15	Y	2.6
14	Cone	36	Y	3.6
15	Stop sign	9	Y	1.6
16	Stop sign	21	Y	1.6
		Percent correctly identified:	**100%**	
			Average time to identification:	**2.4**

Table 15: Driver 2 object identification test results for nighttime with cameras

Test	Test Item	Test Item Location	Identified (Y/N)	Time to Identification (s)
1	Stop sign	11	Y	3.0
2	Bike	25	Y	1.2
3	Cone	36	Y	2.4
4	Person	24	Y	7.8
5	Stop sign	21	Y	3.2
6	Person	13	Y	2.4
7	Bike	29	Y	1.2
8	Person	15	Y	2.6
9	Person	14	Y	2.6
10	Stop sign	9	Y	2.8
11	Cone	5	Y	3.4
12	Cone	13	Y	2.8
13	Bike	13	Y	3.0
14	Stop sign	30	Y	1.4
15	Cone	19	Y	2.4
16	Bike	35	Y	1.6
		Percent correctly identified:	**100%**	
			Average time to identification:	**2.7**

Table 16: Driver 2 object identification test results for nighttime with mirrors

Test	Test Item	Test Item Location	Identified (Y/N)	Time to Identification (s)
1	Cone	36	Y	1.8
2	Bike	35	Y	4.0
3	Stop sign	21	Y	4.0
4	Person	15	Y	4.2
5	Stop sign	9	Y	2.8
6	Cone	13	Y	4.4
7	Bike	13	Y	5.2
8	Bike	25	Y	2.2
9	Stop sign	11	Y	4.2
10	Bike	29	Y	4.0
11	Person	24	Y	4.2
12	Cone	5	Y	4.0
13	Person	13	Y	4.2
14	Person	14	Y	3.6
15	Stop sign	30	Y	6.2
16	Cone	19	Y	2.4
		Percent correctly identified:	**100%**	
			Average time to identification:	**3.8**

Table 17: Driver 3 object identification test results for daytime with cameras

Test	Test Item	Test Item Location	Identified (Y/N)	Time to Identification (s)
1	Cone	5	Y	3.8
2	Bike	35	Y	1.4
3	Cone	36	Y	1.6
4	Bike	25	Y	1.0
5	Cone	13	Y	2.4
6	Person	15	Y	2.6
7	Stop sign	9	Y	3.6
8	Stop sign	21	Y	1.2
9	Cone	19	Y	0.8
10	Stop sign	30	Y	1.4
11	Bike	13	Y	3.0
12	Stop sign	11	Y	10.2
13	Person	14	Y	2.8
14	Person	13	Y	3.4
15	Bike	29	Y	1.8
16	Person	24	Y	7.4
		Percent correctly identified:	**100%**	
			Average time to identification:	**3.0**

Table 18: Driver 3 object identification test results for daytime with mirrors

Test	Test Item	Test Item Location	Identified (Y/N)	Time to Identification (s)
1	Cone	19	Y	1.4
2	Stop sign	30	Y	5.8
3	Bike	25	Y	1.8
4	Cone	5	Y	4.8
5	Bike	35	Y	2.0
6	Stop sign	11	Y	3.6
7	Person	24	Y	7.2
8	Bike	13	Y	3.8
9	Person	13	Y	3.6
10	Person	14	Y	2.8
11	Bike	29	Y	1.8
12	Cone	13	Y	3.4
13	Person	15	Y	3.4
14	Cone	36	Y	1.8
15	Stop sign	9	Y	4.2
16	Stop sign	21	Y	2.2
		Percent correctly identified:	**100%**	
			Average time to identification:	**3.3**

Table 19: Driver 3 object identification test results for nighttime with cameras

Test	Test Item	Test Item Location	Identified (Y/N)	Time to Identification (s)
1	Stop sign	11	N	9.8
2	Bike	25	Y	1.6
3	Cone	36	Y	8.0
4	Person	24	Y	7.2
5	Stop sign	21	Y	3.0
6	Person	13	Y	2.4
7	Bike	29	Y	1.8
8	Person	15	Y	3.6
9	Person	14	Y	4.0
10	Stop sign	9	Y	3.6
11	Cone	5	Y	3.2
12	Cone	13	Y	4.2
13	Bike	13	Y	3.4
14	Stop sign	30	Y	1.4
15	Cone	19	Y	1.0
16	Bike	35	Y	1.4
		Percent correctly identified:	**94%**	
			Average time to identification:	**3.7**

Table 20: Driver 3 object identification test results for nighttime with mirrors

Test	Test Item	Test Item Location	Identified (Y/N)	Time to Identification (s)
1	Cone	36	Y	9.2
2	Bike	35	Y	2.4
3	Stop sign	21	Y	9.2
4	Person	15	Y	6.2
5	Stop sign	9	Y	8.6
6	Cone	13	Y	5.0
7	Bike	13	Y	5.4
8	Bike	25	Y	3.8
9	Stop sign	11	Y	7.0
10	Bike	29	Y	2.6
11	Person	24	Y	14.4
12	Cone	5	Y	7.8
13	Person	13	Y	6.2
14	Person	14	Y	6.8
15	Stop sign	30	Y	4.2
16	Cone	19	Y	2.4
		Percent correctly identified:	**100%**	
			Average time to identification:	**6.3**

Table 21: Driver 4 object identification test results for daytime with cameras

Test	Test Item	Test Item Location	Identified (Y/N)	Time to Identification (s)
1	Cone	5	N	--
2	Bike	35	Y	2.2
3	Cone	36	Y	5.0
4	Bike	25	Y	1.4
5	Cone	13	Y	1.4
6	Person	15	Y	4.4
7	Stop sign	9	Y	4.6
8	Stop sign	21	Y	2.2
9	Cone	19	Y	3.8
10	Stop sign	30	Y	4.0
11	Bike	13	Y	3.6
12	Stop sign	11	Y	6.4
13	Person	14	Y	1.2
14	Person	13	Y	1.0
15	Bike	29	Y	2.2
16	Person	24	N	3.8
		Percent correctly identified:	**88%**	
			Average time to identification:	**3.1**

Table 22: Driver 4 object identification test results for daytime with mirrors

Test	Test Item	Test Item Location	Identified (Y/N)	Time to Identification (s)
1	Cone	19	Y	1.4
2	Stop sign	30	Y	2.0
3	Bike	25	N	--
4	Cone	5	Y	6.2
5	Bike	35	Y	2.4
6	Stop sign	11	Y	10.8
7	Person	24	Y	5.0
8	Bike	13	Y	13.2
9	Person	13	Y	1.6
10	Person	14	Y	1.6
11	Bike	29	Y	5.2
12	Cone	13	Y	2.4
13	Person	15	Y	1.8
14	Cone	36	Y	5.6
15	Stop sign	9	Y	2.6
16	Stop sign	21	Y	4.4
		Percent correctly identified:	**94%**	
			Average time to identification:	**4.4**

Table 23: Driver 4 object identification test results for nighttime with cameras

Test	Test Item	Test Item Location	Identified (Y/N)	Time to Identification (s)
1	Stop sign	11	Y	6.8
2	Bike	25	Y	1.4
3	Cone	36	Y	13.2
4	Person	24	N	4.4
5	Stop sign	21	Y	1.4
6	Person	13	Y	4.8
7	Bike	29	Y	8.0
8	Person	15	Y	5.8
9	Person	14	Y	5.0
10	Stop sign	9	Y	4.6
11	Cone	5	Y	4.4
12	Cone	13	Y	3.8
13	Bike	13	Y	2.2
14	Stop sign	30	Y	2.2
15	Cone	19	Y	1.8
16	Bike	35	Y	1.8
		Percent correctly identified:	**94%**	
			Average time to identification:	**4.5**

Table 24: Driver 4 object identification test results for nighttime with mirrors

Test	Test Item	Test Item Location	Identified (Y/N)	Time to Identification (s)
1	Cone	36	Y	9.0
2	Bike	35	Y	2.6
3	Stop sign	21	Y	2.2
4	Person	15	Y	2.2
5	Stop sign	9	Y	6.4
6	Cone	13	Y	8.8
7	Bike	13	Y	3.0
8	Bike	25	Y	9.8
9	Stop sign	11	Y	7.8
10	Bike	29	Y	2.4
11	Person	24	Y	3.8
12	Cone	5	Y	1.0
13	Person	13	Y	7.2
14	Person	14	Y	4.6
15	Stop sign	30	Y	6.2
16	Cone	19	Y	6.8
		Percent correctly identified:	**100%**	
			Average time to identification:	**5.2**

5.1.5 **Summary of Results**

The results of the object identification test are summarized in Table 25.

Table 25: Summary of results for object identification test

		Proportion of Correctly Identified Test Objects				Average Elapsed Time to Object Identification (s)			
		Driver 1	Driver 2	Driver 3	Driver 4	Driver 1	Driver 2	Driver 3	Driver 4
Daytime Tests	Camera-Based Indirect Vision System	94%	100%	100%	88%	3.4	1.8	3.0	3.1
	Mirror-Based Indirect Vision System	88%	100%	100%	94%	3.0	2.4	3.3	4.4
Nighttime Tests	Camera-Based Indirect Vision System	94%	100%	94%	94%	3.1	2.7	3.7	4.5
	Mirror-Based Indirect Vision System	75%	100%	100%	100%	3.5	3.8	6.3	5.2

5.1.6 **Results of Questionnaire**

The results of the questionnaires provided to the test subjects after completion of the object identification test may be found in Table 26 and Table 27 on page 51. The scale used for the quantitative evaluation may be found in Table 7 on page 30.

Table 26: Quantitative results of object identification questionnaire

		Driver 1	Driver 2	Driver 3	Driver 4
Mirror-Based Indirect Vision System	Ease of object identification during daytime conditions	6	6	6	5
	Ease of object identification during nighttime conditions	6	5	4.5	5
Camera-Based Indirect Vision System	Ease of object identification during daytime conditions	6	6.5	5.5	5
	Ease of object identification during nighttime conditions	6	6.5	5	5

Table 27: Qualitative results of object identification questionnaire

Test Subject	Comment
Driver 1	• Complained about the resolution of the monitors • Suggested that bottom monitor on the passenger side A-pillar could be smaller • Enjoyed the idea of having two cameras on either side of the vehicle rather than three mirrors (two convex mirrors and one unit magnification mirror)
Driver 2	• Stated that bright objects at night caused glare in the monitors • Suggested that monitors should be more easily dimmable by the driver • Found that removal of the mirrors aided in adding additional direct line of sight through side windows
Driver 3	• Stated that bright objects at night caused glare in the monitors • Requested a higher definition camera and monitor • Suggested adding additional cameras in the system to augment normally obtainable field of view • Suggested that a system which could present colour during nighttime operations would be beneficial • Would prefer to see larger monitors • Suggested that IR may not be required as most nighttime driving environments are well lit
Driver 4	• Stated that the use of the camera system was easier at night than during the day but would like to have an easy way to dim the monitors to his preferred level

5.2 Blind Spot Comparison

The list of test subjects who completed the blind spot comparison test along with the dates on which they completed the test may be found in Table 28.

Table 28: List of test subjects for blind spot comparison test

Test Subject	Date Test Performed
Driver 1	October 16, 2013
Driver 2	October 23, 2013
Driver 3	October 29, 2013
Driver 4	October 25, 2013

5.2.1 Driver 1

The results of the blind spot comparison test for Driver 1 may be found in Table 29 and Table 30. Table 29 provides the results of the blind spot comparison test with the target vehicle on the driver side of the subject vehicle, Table 30 provides the results of the test with the target vehicle on the passenger side of the subject vehicle. It should be noted that, for all tests, the test subject could locate the target vehicle in his direct field of view prior to no longer being able to locate it in his indirect field of view.

Table 29: Results of blind spot comparison test with target vehicle on driver side (Driver 1)

Test	Mirror-Based Indirect Vision System		Camera-Based Indirect Vision System	
	Lateral Clearance Distance Between Vehicles (m)	Bumper to Bumper Distance (m)	Lateral Clearance Distance Between Vehicles (m)	Bumper to Bumper Distance (m)
1	1.14	2.18	1.12	1.68
2	1.02	2.42	0.69	2.19
3	1.00	2.32	0.81	2.22
Average	**1.05**	**2.31**	**0.87**	**2.03**

Table 30: Results of blind spot comparison test with target vehicle on passenger side (Driver 1)

Test	Mirror-Based Indirect Vision System		Camera-Based Indirect Vision System	
	Lateral Clearance Distance Between Vehicles (m)	Bumper to Bumper Distance (m)	Lateral Clearance Distance Between Vehicles (m)	Bumper to Bumper Distance (m)
1	0.86	2.47	0.84	2.17
2	1.09	2.57	0.76	2.09
3	0.94	2.42	0.72	2.17
Average	**0.97**	**2.49**	**0.77**	**2.14**

5.2.2 Driver 2

The results of the blind spot comparison test for Driver 2 may be found in Table 31 and Table 32. Table 31 provides the results of the blind spot comparison test with the target vehicle on the driver side of the subject vehicle, Table 32 provides the results of the test with the target vehicle on the passenger side of the subject vehicle. It should be noted that, for all tests, the test subject could locate the target vehicle in his direct field of view prior to no longer being able to locate it in his indirect field of view.

Table 31: Results of blind spot comparison test with target vehicle on driver side (Driver 2)

Test	Mirror-Based Indirect Vision System		Camera-Based Indirect Vision System	
	Lateral Clearance Distance Between Vehicles (m)	Bumper to Bumper Distance (m)	Lateral Clearance Distance Between Vehicles (m)	Bumper to Bumper Distance (m)
1	0.86	2.74	0.89	1.91
2	0.91	2.66	0.89	1.91
3	0.97	2.61	0.81	2.00
Average	**0.91**	**2.67**	**0.86**	**1.94**

Table 32: Results of blind spot comparison test with target vehicle on passenger side (Driver 2)

Test	Mirror-Based Indirect Vision System		Camera-Based Indirect Vision System	
	Lateral Clearance Distance Between Vehicles (m)	Bumper to Bumper Distance (m)	Lateral Clearance Distance Between Vehicles (m)	Bumper to Bumper Distance (m)
1	0.76	2.51	1.00	1.88
2	0.81	2.52	0.99	1.90
3	0.86	2.46	1.02	1.89
Average	**0.81**	**2.50**	**1.00**	**1.89**

5.2.3 Driver 3

The results of the blind spot comparison test for Driver 3 may be found in Table 33 and Table 34. Table 33 provides the results of the blind spot comparison test with the target vehicle on the driver side of the subject vehicle, Table 34 provides the results of the test with the target vehicle on the passenger side of the subject vehicle. It should be noted that, for all tests, the test subject could locate the target vehicle in his direct field of view prior to no longer being able to locate it in his indirect field of view.

Table 33: Results of blind spot comparison test with target vehicle on driver side (Driver 3)

Test	Mirror-Based Indirect Vision System		Camera-Based Indirect Vision System	
	Lateral Clearance Distance Between Vehicles (m)	Bumper to Bumper Distance (m)	Lateral Clearance Distance Between Vehicles (m)	Bumper to Bumper Distance (m)
1	1.19	1.54	1.02	1.74
2	1.04	1.72	1.02	1.74
3	1.17	1.66	1.07	1.66
Average	**1.13**	**1.64**	**1.03**	**1.71**

Table 34: Results of blind spot comparison test with target vehicle on passenger side (Driver 3)

Test	Mirror-Based Indirect Vision System		Camera-Based Indirect Vision System	
	Lateral Clearance Distance Between Vehicles (m)	Bumper to Bumper Distance (m)	Lateral Clearance Distance Between Vehicles (m)	Bumper to Bumper Distance (m)
1	0.99	2.17	0.95	1.66
2	0.91	2.24	0.91	1.65
3	0.91	2.26	0.81	1.77
Average	**0.94**	**2.22**	**0.89**	**1.69**

5.2.4 **Driver 4**

The results of the blind spot comparison test for Driver 4 may be found in Table 35 and Table 36. Table 35 provides the results of the blind spot comparison test with the target vehicle on the driver side of the subject vehicle, Table 36 provides the results of the test with the target vehicle on the passenger side of the subject vehicle. It should be noted that, for all tests, the test subject could locate the target vehicle in his direct field of view prior to no longer being able to locate it in his indirect field of view.

Table 35: Results of blind spot comparison test with target vehicle on driver side (Driver 4)

Test	Mirror-Based Indirect Vision System		Camera-Based Indirect Vision System	
	Lateral Clearance Distance Between Vehicles (m)	Bumper to Bumper Distance (m)	Lateral Clearance Distance Between Vehicles (m)	Bumper to Bumper Distance (m)
1	0.84	2.24	0.91	2.07
2	0.84	2.22	0.91	2.05
3	0.91	2.29	0.86	1.99
Average	**0.86**	**2.25**	**0.90**	**2.04**

Table 36: Results of blind spot comparison test with target vehicle on passenger side (Driver 4)

Test	Mirror-Based Indirect Vision System		Camera-Based Indirect Vision System	
	Lateral Clearance Distance Between Vehicles (m)	Bumper to Bumper Distance (m)	Lateral Clearance Distance Between Vehicles (m)	Bumper to Bumper Distance (m)
1	0.99	2.22	0.95	2.05
2	1.07	2.15	0.85	2.17
3	0.97	2.19	0.91	2.07
Average	**1.01**	**2.19**	**0.91**	**2.10**

5.2.5 Results of Questionnaire

The results of the questionnaires provided to the test subjects after completion of the blind spot comparison test may be found in Table 37 and Table 38. The scale used for the quantitative evaluation may be found in Table 7 on page 30.

Table 37: Quantitative results of blind spot comparison test questionnaire

	Driver 1	Driver 2	Driver 3	Driver 4
Ease of locating target vehicle in blind spot with mirror-based indirect vision system	5	7	6	5
Ease of locating target vehicle in blind spot with camera-based indirect vision system	5	6.5	6	5

Table 38: Qualitative results of blind spot comparison test questionnaire

Test Subject	Comment
Driver 1	(no comments provided for this test)
Driver 2	• Test subject stated that it was difficult to determine the location of the rear edge of the trailer as well as the top edge of the trailer with the camera system (required for some docking manoeuvres).
Driver 3	• Test subject stated that he would like to see a zoom function for the cameras. • Test subject also stated that he would prefer to have higher definition monitors. • Test subject suggested that different locations for the monitors be tested (other than locating the monitors on the A-pillars).
Driver 4	(no comments provided for this test)

5.3 Coupling and Uncoupling

The list of test subjects who completed the coupling and uncoupling test along with the dates on which they completed the test may be found in Table 39.

Table 39: List of test subjects for coupling and uncoupling test

Test Subject	Tested System	Test Condition	Date Test Performed
Driver 2	Camera System	Daytime	November 15, 2013
		Nighttime	November 15, 2013
	Mirror System	Daytime	November 18, 2013
		Nighttime	November 18, 2013
Driver 3	Camera System	Daytime	November 22, 2013
		Nighttime	November 20, 2013
	Mirror System	Daytime	November 21, 2013
		Nighttime	November 21, 2013

5.3.1 Driver 2

The results of the coupling and uncoupling test for Driver 2 are provided in Table 40.

While performing the coupling and uncoupling tests with both the mirror-based indirect vision system and the camera-based indirect vision system, the test subject was able to place the trailer in a final position between the cones of the simulated loading dock, but struck cones while performing the manoeuvre with both systems.

While performing the coupling and uncoupling tests with the mirror-based indirect vision system, Driver 2 struck cones two cones (cones 3 and 7 from Figure 12) while performing test 5 in Table 40. Driver 2 contacting cone 7 may be seen in Figure 28. In addition, Driver 2 contacted cone 7 while performing test 13 in Table 40. While performing the coupling and uncoupling tests with the camera-based indirect vision system, the test subject struck two cones (cones 4 and 6 in Figure 12) while performing the test 6 in Table 40, but was otherwise able to perform the docking and undocking manoeuvres without striking the test cones using the camera-based indirect vision system.

While performing the required manoeuvres with the mirror-based indirect vision system, the test subject exhibited much greater head movements than would be expected while driving in the forward direction, providing the test subject with a larger visual field through which to collect indirect visual information.

Figure 28: Driver 2 contacting cones during coupling and uncoupling test with mirrors

Table 40: Results of coupling and uncoupling test for Driver 2

Test	Test Condition	Simulated Loading Dock Approached From	Trailer Pick Up or Drop Off	System Under Test	Total Time of Manoeuvre (s)
1	Daytime	Driver side	Drop Off	Mirror	109
2				Camera	254
3			Pick Up	Mirror	49
4				Camera	116
5		Passenger side	Drop Off	Mirror	431
6				Camera	784
7			Pick Up	Mirror	55
8				Camera	126
9	Nighttime	Driver side	Drop Off	Mirror	118
10				Camera	115
11			Pick Up	Mirror	55
12				Camera	97
13		Passenger side	Drop Off	Mirror	443
14				Camera	243
15			Pick Up	Mirror	56
16				Camera	77

5.3.2 **Driver 3**

The results of the coupling and uncoupling test for Driver 3 are provided in Table 41.

While performing the coupling and uncoupling tests with both the mirror-based indirect vision system and the camera-based indirect vision system, the test subject was able to place the trailer in a final position between the cones of the simulated loading dock, but struck cones while performing the manoeuvre with both systems.

While performing the coupling and uncoupling tests with the mirror-based indirect vision system, Driver 3 struck cone 8 from Figure 12 while performing test 9 in Table 41 and cones 7 and 4 while performing test 13 in Table 41.

While performing the coupling and uncoupling tests with the camera-based indirect vision system, the test subject struck cone 7 while performing test 10 in Table 41, and cones 7 and 8 while performing test 10 in Table 41.

As with Driver 2, Driver 3 also moved his head more with the mirror-based indirect vision system to increase his indirect visual field.

Table 41: Results of coupling and uncoupling test for Driver 3

Test	Test Condition	Simulated Loading Dock Approached From	Trailer Pick Up or Drop Off	System Under Test	Total Time of Manoeuvre (s)
1	Daytime	Driver side	Drop Off	Mirror	185
2				Camera	308
3			Pick Up	Mirror	52
4				Camera	204
5		Passenger side	Drop Off	Mirror	449
6				Camera	362
7			Pick Up	Mirror	75
8				Camera	89
9	Nighttime	Driver side	Drop Off	Mirror	1108
10				Camera	227
11			Pick Up	Mirror	111
12				Camera	69
13		Passenger side	Drop Off	Mirror	743
14				Camera	326
15			Pick Up	Mirror	109
16				Camera	64

5.3.3 **Results of Questionnaire**

The results of the questionnaires provided to the test subjects after completion of the coupling and uncoupling test may be found in Table 42 and Table 43. The scale used for the quantitative evaluation may be found in Table 7 on page 30.

Table 42: Quantitative results of coupling and uncoupling test questionnaire

		Driver 2	**Driver 3**
Mirror-Based Indirect Vision System	Ease of performing required manoeuvres during daytime conditions	5	6
	Ease of performing required manoeuvres during nighttime conditions	5	4.5
Camera-Based Indirect Vision System	Ease of performing required manoeuvres during daytime conditions	3.5	3.5
	Ease of performing required manoeuvres during nighttime conditions	3.5	3

Table 43: Qualitative results of coupling and uncoupling test questionnaire

Test Subject	**Comment**
Driver 2	• Test subject stated that the glare of bright objects in the monitors during nighttime tests reduced his overall visibility.
Driver 3	(no comments provided for this test)

5.4 Quasi-Static Lane Change

The list of test subjects who completed the quasi-static lane change test along with the dates on which they completed the test may be found in Table 44.

Table 44: List of test subjects for quasi-static lane change test

Test Subject	Test Condition	Tested System	Target Vehicle	Date Test Performed
Driver 1	Daytime	Camera System	Driver Side	November 14, 2013
			Passenger Side	
		Mirror System	Driver Side	November 13, 2013
			Passenger Side	
	Nighttime	Camera System	Driver Side	November 13, 2013
			Passenger Side	
		Mirror System	Driver Side	November 26, 2013
			Passenger Side	November 13, 2013
Driver 2	Daytime	Camera System	Driver Side	November 15, 2013
			Passenger Side	
		Mirror System	Driver Side	November 18, 2013
			Passenger Side	
	Nighttime	Camera System	Driver Side	November 15, 2013
			Passenger Side	
		Mirror System	Driver Side	November 18, 2013
			Passenger Side	
Driver 3	Daytime	Camera System	Driver Side	November 20, 2013
			Passenger Side	
		Mirror System	Driver Side	November 21, 2013
			Passenger Side	
	Nighttime	Camera System	Driver Side	November 20, 2013
			Passenger Side	
		Mirror System	Driver Side	November 21, 2013
			Passenger Side	

5.4.1 **Driver 1**

The results of the quasi-static lane change test for Driver 1 are summarized in Table 45 and Table 46.

The results of the quasi-static lane change test for Driver 1 may be seen in Figure 29 through Figure 36. The provided plots show the clearance distance between the target vehicle and the subject vehicle when the test subject activated the pendant switch while the target vehicle was moving in a forward direction (blue dots) and in the reverse direction (red dots). The plots also have Driver 1's mean clearance distance for all activations of the pendant switch, as well as dashed lines one standard deviation above the mean and one standard deviation below the mean.

Table 45: Driver 1 quasi-static lane change test results (day)

		Camera-Based Indirect Vision System		Mirror-Based Indirect Vision System	
		Target Vehicle on Driver Side	Target Vehicle on Passenger Side	Target Vehicle on Driver Side	Target Vehicle on Passenger Side
Number of Samples	Forward	30	29	34	33
	Reverse	31	32	33	32
	Total	**61**	**61**	**67**	**65**
Average Target Vehicle Speed (km/h)	Forward	4.1	4.5	4.3	3.9
	Reverse	4.1	4.2	4.2	3.7
	All Samples	**4.1**	**4.2**	**4.2**	**3.7**
Average Clearance Distance (m)	Forward	2.497	2.408	0.331	0.876
	Reverse	0.387	-0.340	0.262	0.533
	All Samples	**1.425**	**0.966**	**0.297**	**0.707**
Standard Deviation - All Samples (m)		1.316	1.741	0.174	0.267
Maximum (m)		4.309	7.933	0.714	1.394
Minimum (m)		-0.841	-1.131	-0.002	0.105

Table 46: Driver 1 quasi-static lane change test results (night)

		Camera-Based Indirect Vision System		Mirror-Based Indirect Vision System	
		Target Vehicle on Driver Side	Target Vehicle on Passenger Side	Target Vehicle on Driver Side	Target Vehicle on Passenger Side
Number of Samples	Forward	32	30	35	30
	Reverse	32	29	32	30
	Total	**64**	**59**	**67**	**60**
Average Target Vehicle Speed (km/h)	Forward	4.5	3.6	4.3	3.5
	Reverse	4.2	3.6	4.8	3.1
	All Samples	**4.2**	**3.6**	**4.8**	**3.2**
Average Clearance Distance (m)	Forward	2.242	-0.519	3.227	0.587
	Reverse	-0.524	-0.309	0.174	0.428
	All Samples	**0.859**	**-0.416**	**1.769**	**0.507**
Standard Deviation - All Samples (m)		1.723	1.562	1.736	0.997
Maximum (m)		5.404	5.060	4.570	2.894
Minimum (m)		-1.913	-3.980	-1.880	-1.554

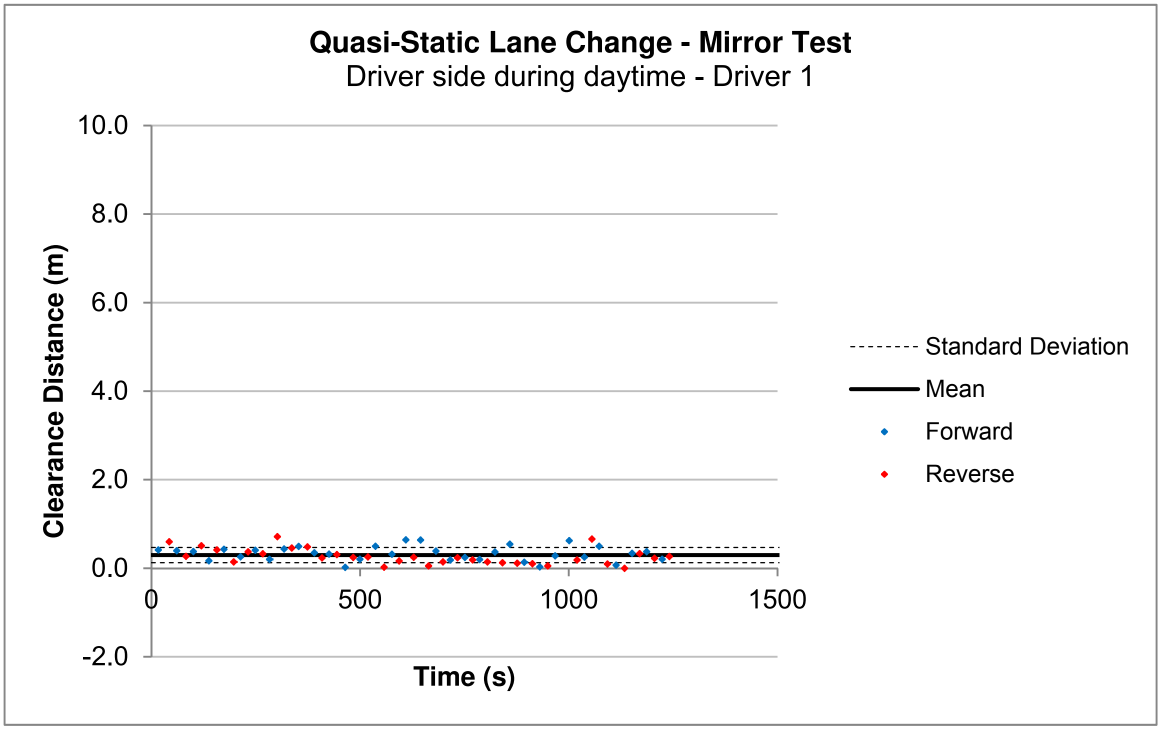

Figure 29: Driver 1 quasi-static lane change results for mirror test with target vehicle on driver side (day)

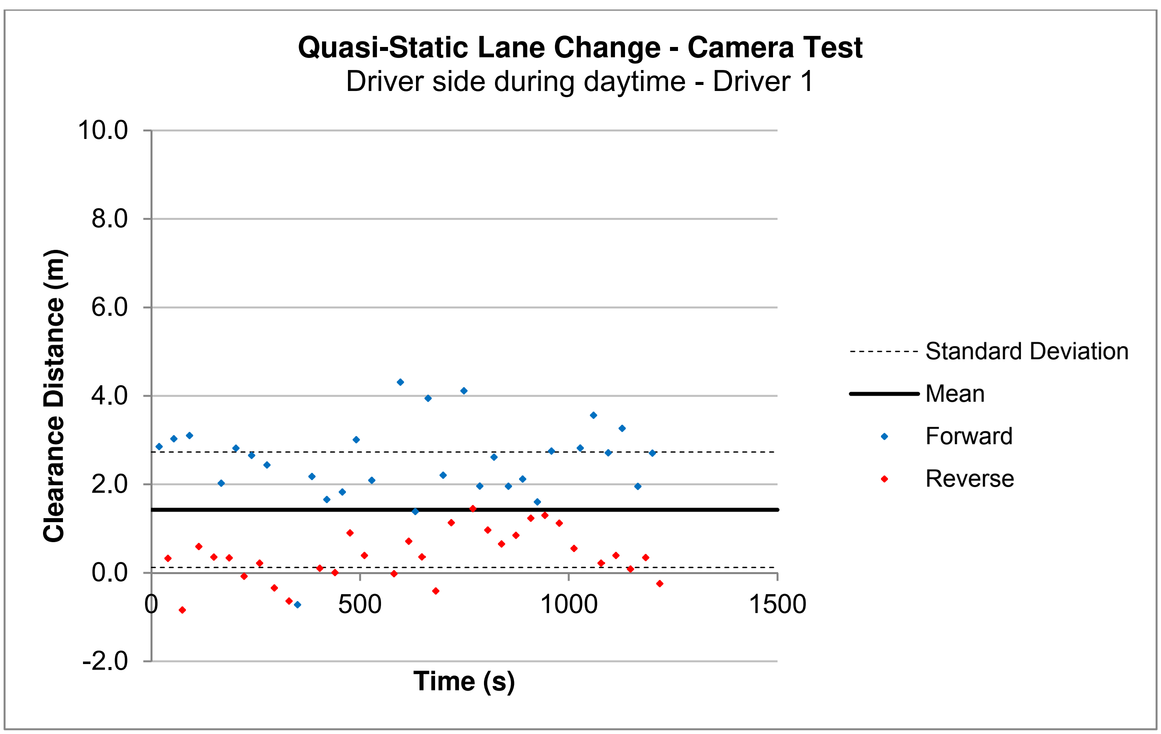

Figure 30: Driver 1 quasi-static lane change results for camera test with target vehicle on driver side (day)

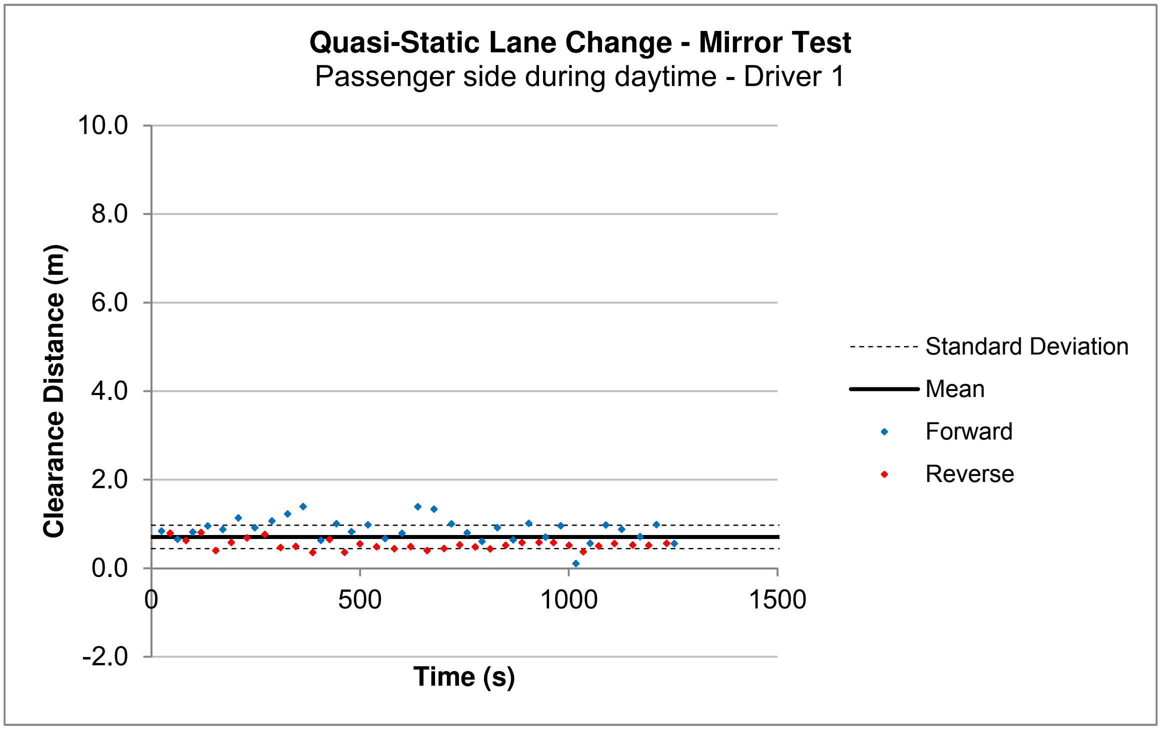

Figure 31: Driver 1 quasi-static lane change results for mirror test with target vehicle on passenger side (day)

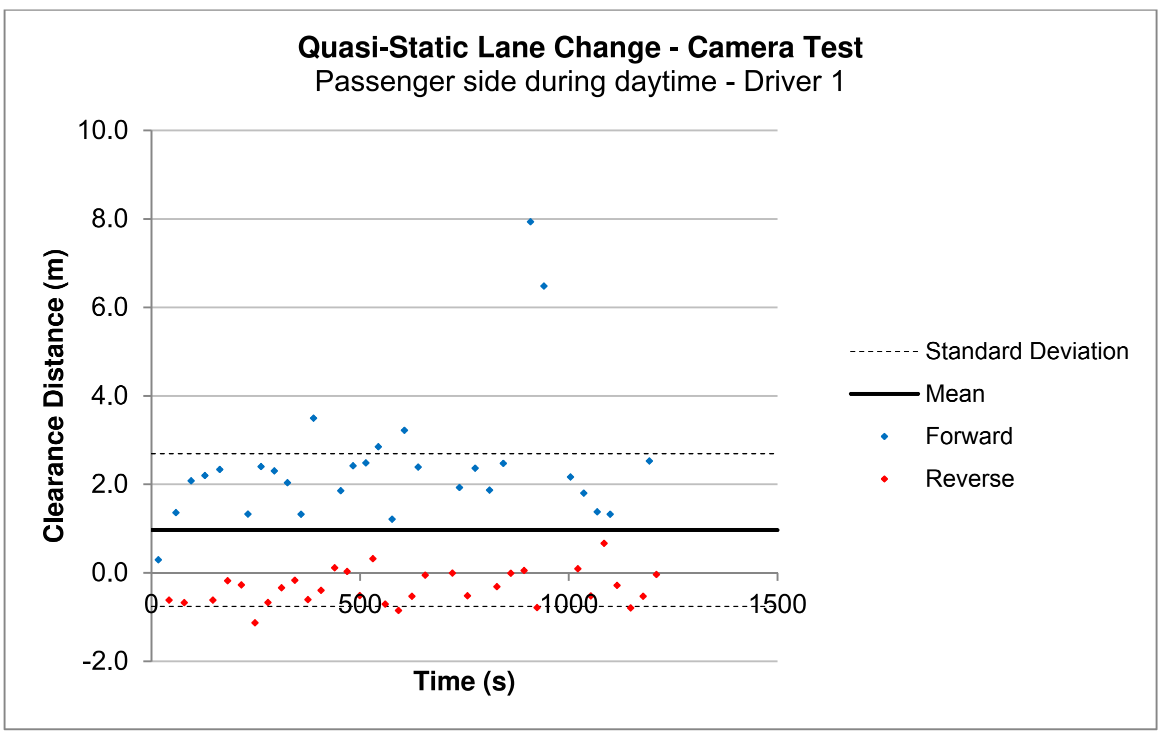

Figure 32: Driver 1 quasi-static lane change results for camera test with target vehicle on passenger side (day)

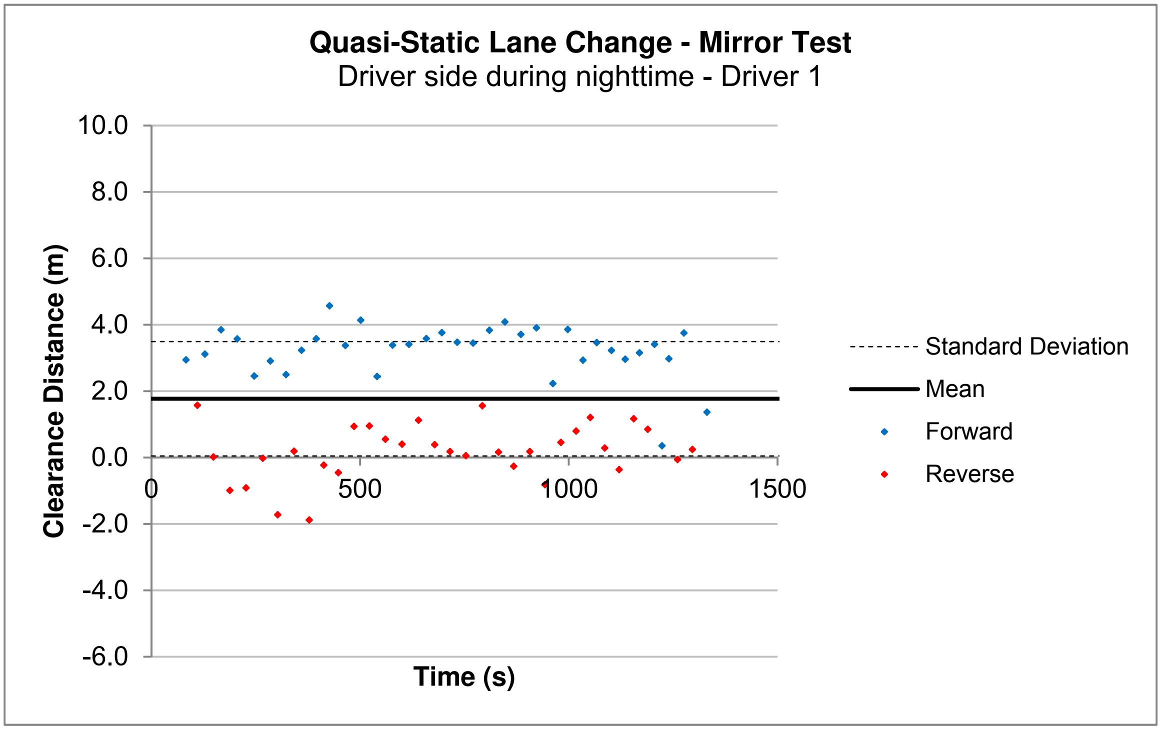

Figure 33: Driver 1 quasi-static lane change results for mirror test with target vehicle on driver side (night)

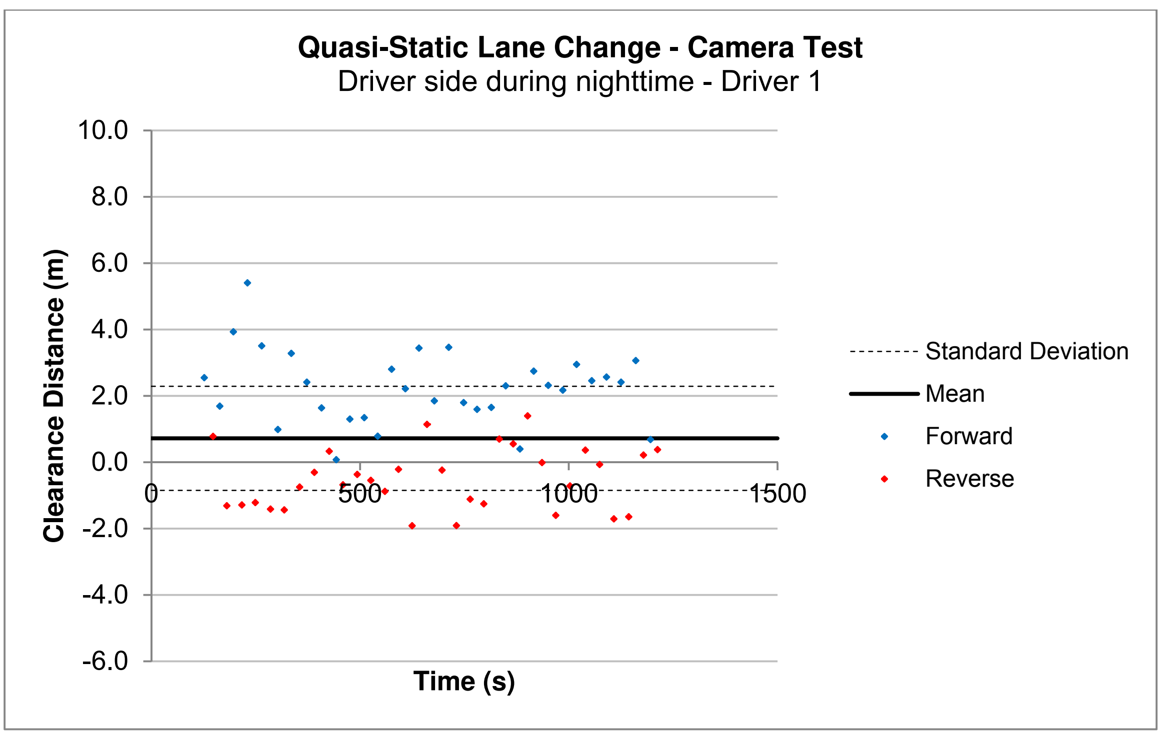

Figure 34: Driver 1 quasi-static lane change results for camera test with target vehicle on driver side (night)

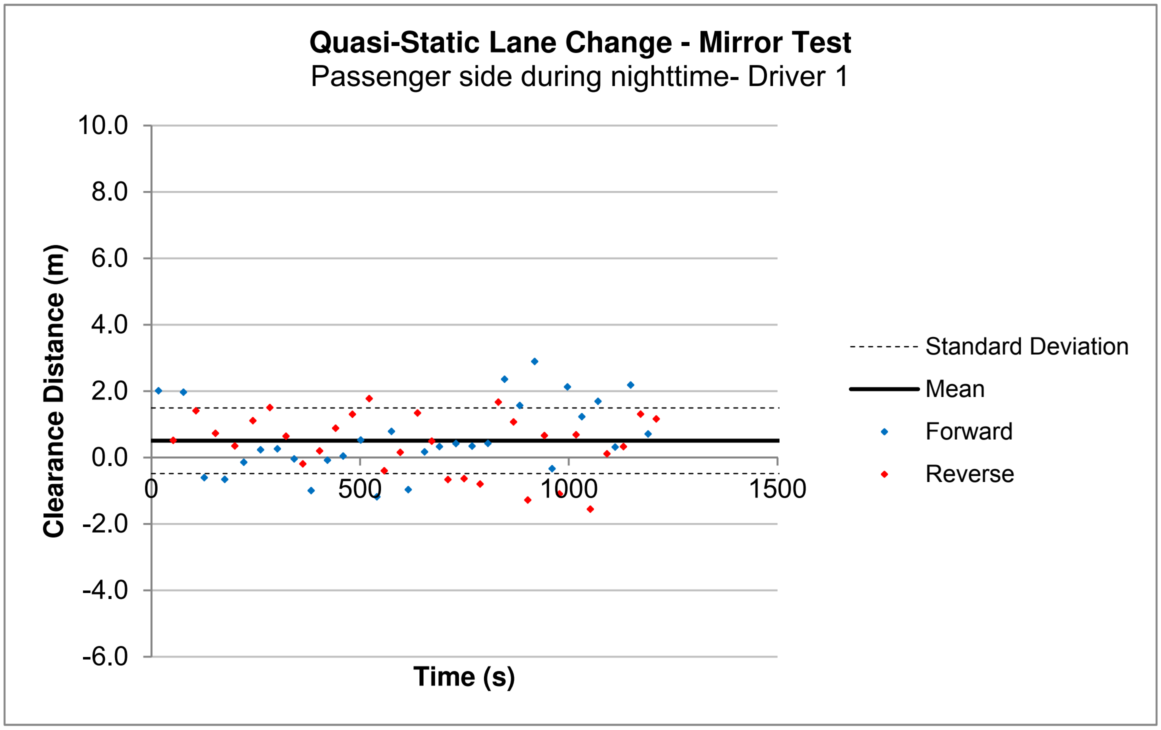

Figure 35: Driver 1 quasi-static lane change results for mirror test with target vehicle on passenger side (night)

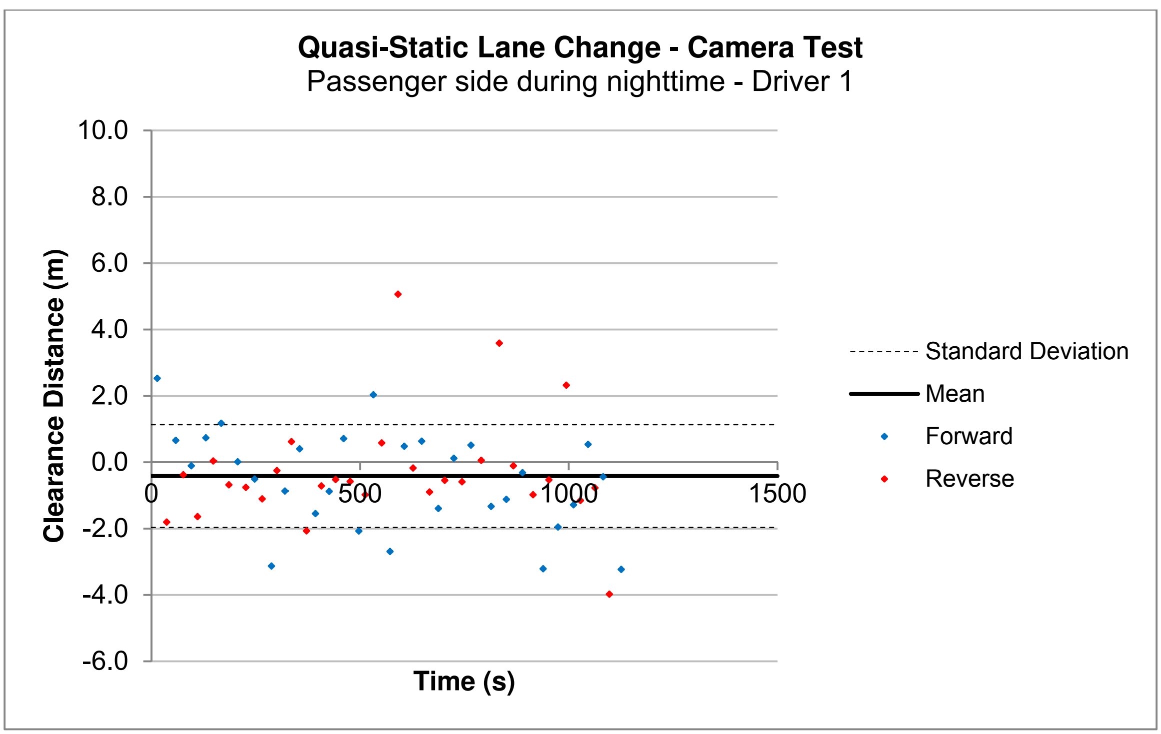

Figure 36: Driver 1 quasi-static lane change results for camera test with target vehicle on passenger side (night)

5.4.2 **Driver 2**

The results of the quasi-static lane change test for Driver 2 are summarized in Table 47 and Table 48.

The results of the quasi-static lane change test for Driver 2 may be seen in Figure 37 through Figure 44. The provided plots show the clearance distance between the target vehicle and the subject vehicle when the test subject activated the pendant switch while the target vehicle was moving in a forward direction (blue dots) and in the reverse direction (red dots). The plots also have Driver 2's mean clearance distance for all activations of the pendant switch, as well as dashed lines one standard deviation above the mean and one standard deviation below the mean.

Table 47: Driver 2 quasi-static lane change test results (day)

		Camera-Based Indirect Vision System		Mirror-Based Indirect Vision System	
		Target Vehicle on Driver Side	**Target Vehicle on Passenger Side**	**Target Vehicle on Driver Side**	**Target Vehicle on Passenger Side**
Number of Samples	**Forward**	34	34	33	33
	Reverse	34	36	33	33
	Total	**68**	**70**	**66**	**66**
Average Target Vehicle Speed (km/h)	**Forward**	4.3	4.1	4.1	3.9
	Reverse	4.0	3.3	3.9	3.9
	All Samples	**4.0**	**3.4**	**3.9**	**3.9**
Average Clearance Distance (m)	**Forward**	4.329	5.579	3.270	2.115
	Reverse	2.297	5.968	2.353	1.663
	All Samples	**3.313**	**5.779**	**2.811**	**1.889**
Standard Deviation - All Samples (m)		1.384	1.117	0.797	0.602
Maximum (m)		6.393	7.982	5.054	3.896
Minimum (m)		0.337	3.697	0.972	0.618

Table 48: Driver 2 quasi-static lane change test results (night)

		Camera-Based Indirect Vision System		Mirror-Based Indirect Vision System	
		Target Vehicle on Driver Side	Target Vehicle on Passenger Side	Target Vehicle on Driver Side	Target Vehicle on Passenger Side
Number of Samples	Forward	37	34	34	35
	Reverse	36	35	34	35
	Total	**73**	**69**	**68**	**70**
Average Target Vehicle Speed (km/h)	Forward	3.2	4.1	4.3	4.2
	Reverse	3.8	4.0	4.1	4.0
	All Samples	**3.7**	**4.0**	**4.1**	**4.0**
Average Clearance Distance (m)	Forward	7.081	4.934	1.338	1.471
	Reverse	6.532	3.383	1.256	0.903
	All Samples	**6.810**	**4.147**	**1.297**	**1.187**
Standard Deviation - All Samples (m)		0.943	1.900	0.928	1.109
Maximum (m)		7.983	7.780	3.037	3.678
Minimum (m)		3.760	-0.523	-0.884	-1.413

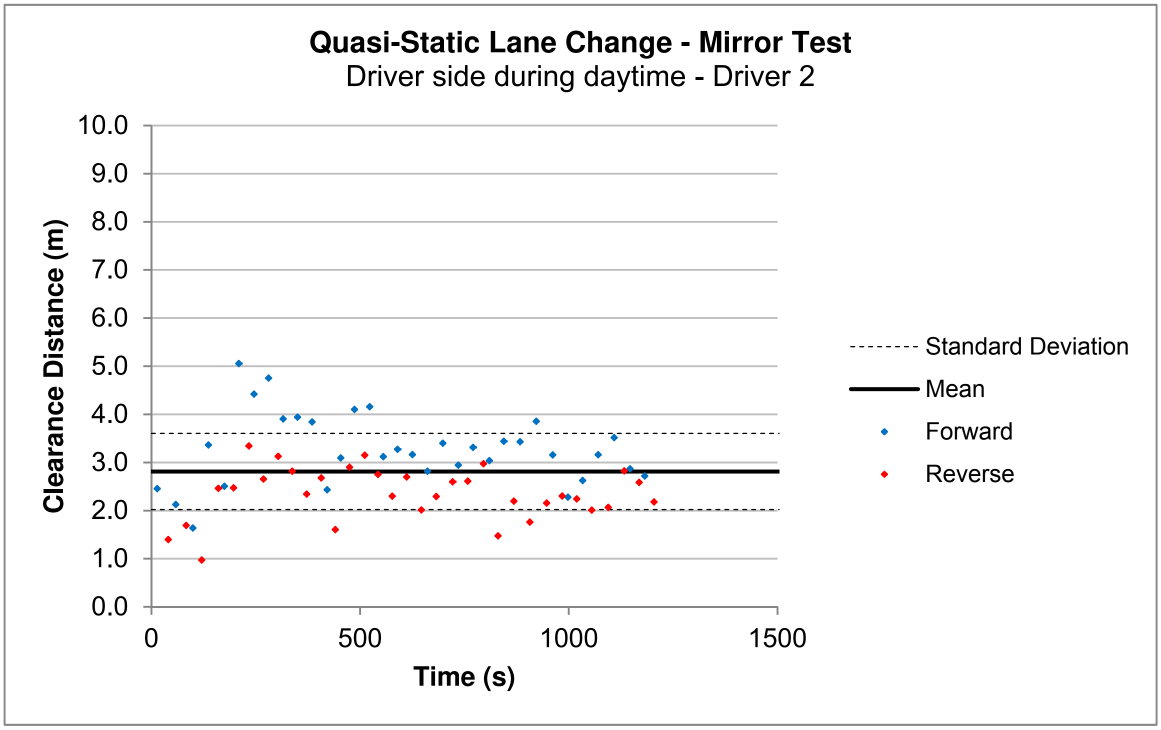

Figure 37: Driver 2 quasi-static lane change results for mirror test with target vehicle on driver side (day)

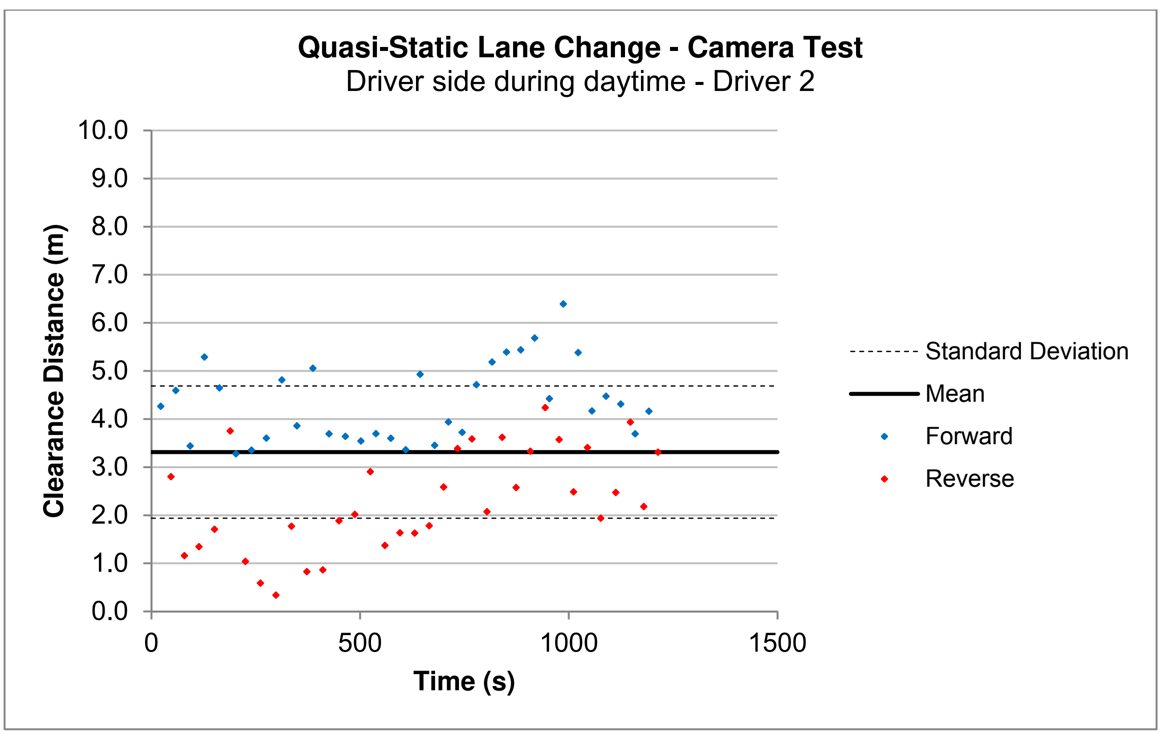

Figure 38: Driver 2 quasi-static lane change results for camera test with target vehicle on driver side (day)

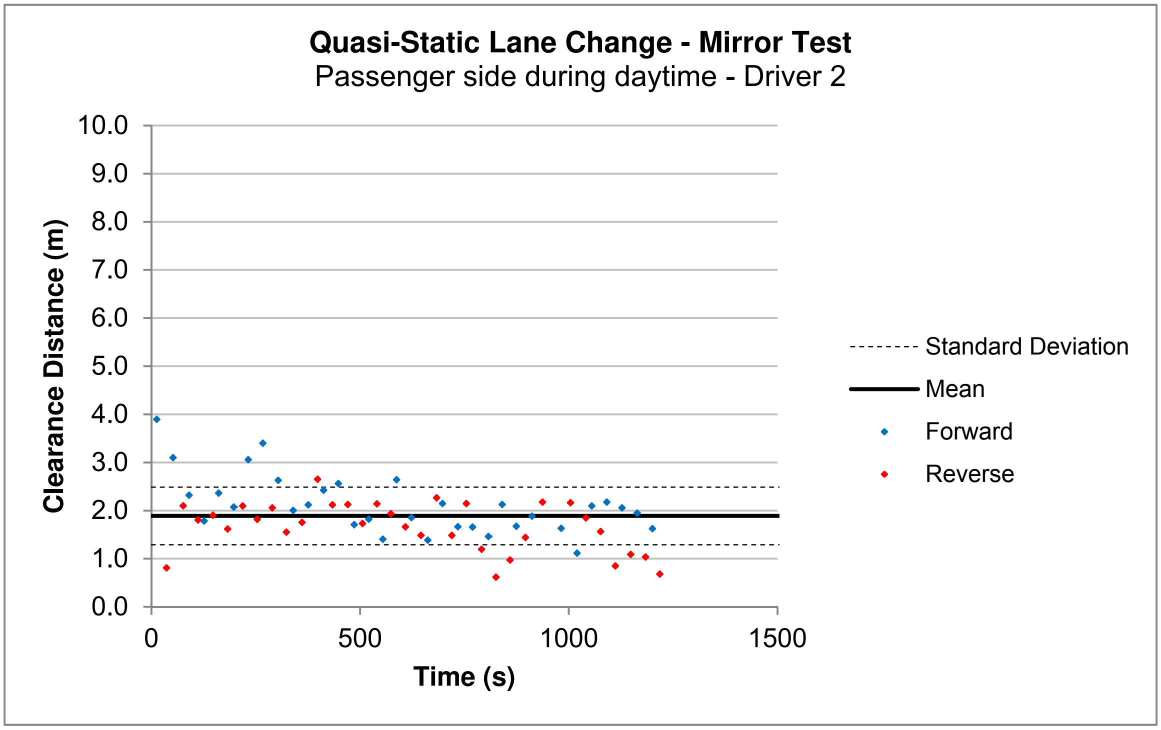

Figure 39: Driver 2 quasi-static lane change results for mirror test with target vehicle on passenger side (day)

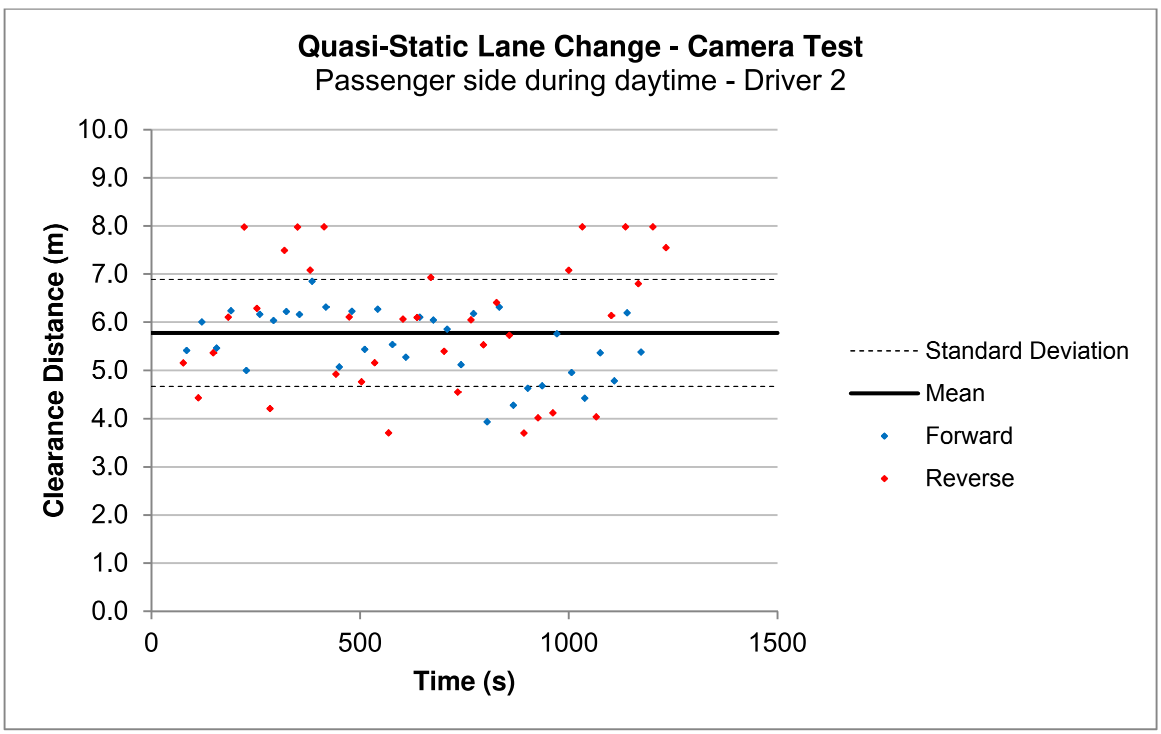

Figure 40: Driver 2 quasi-static lane change results for camera test with target vehicle on passenger side (day)

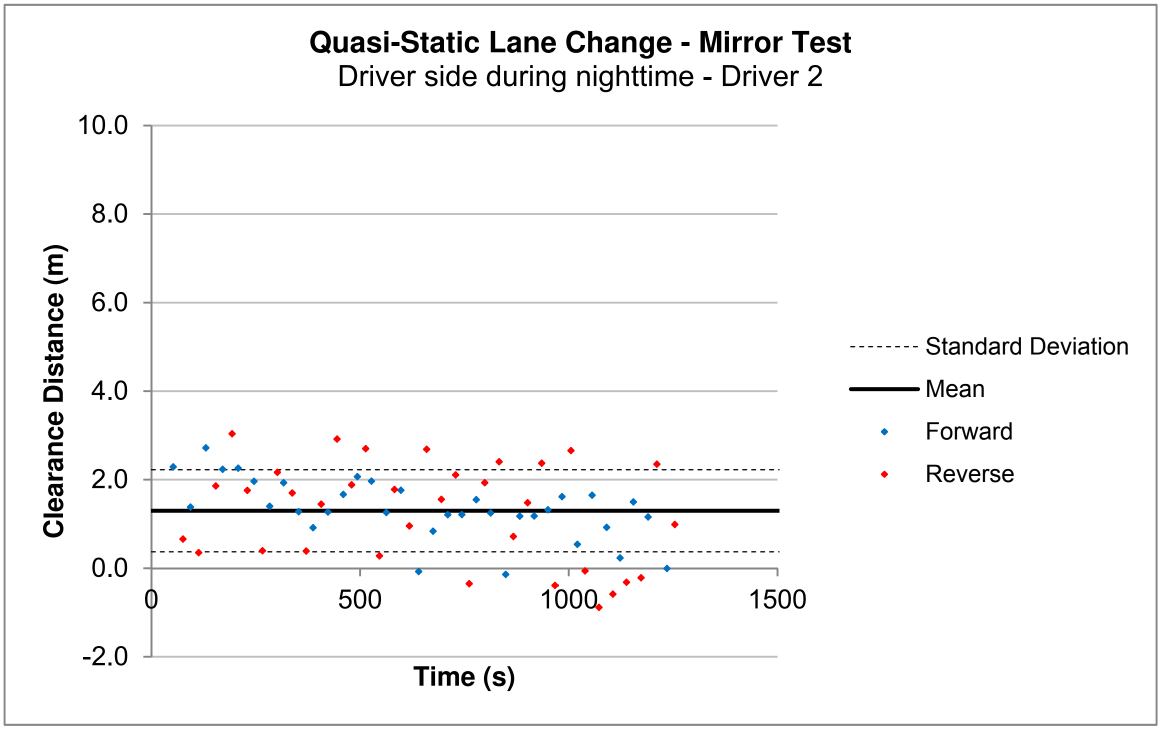

Figure 41: Driver 2 quasi-static lane change results for mirror test with target vehicle on driver side (night)

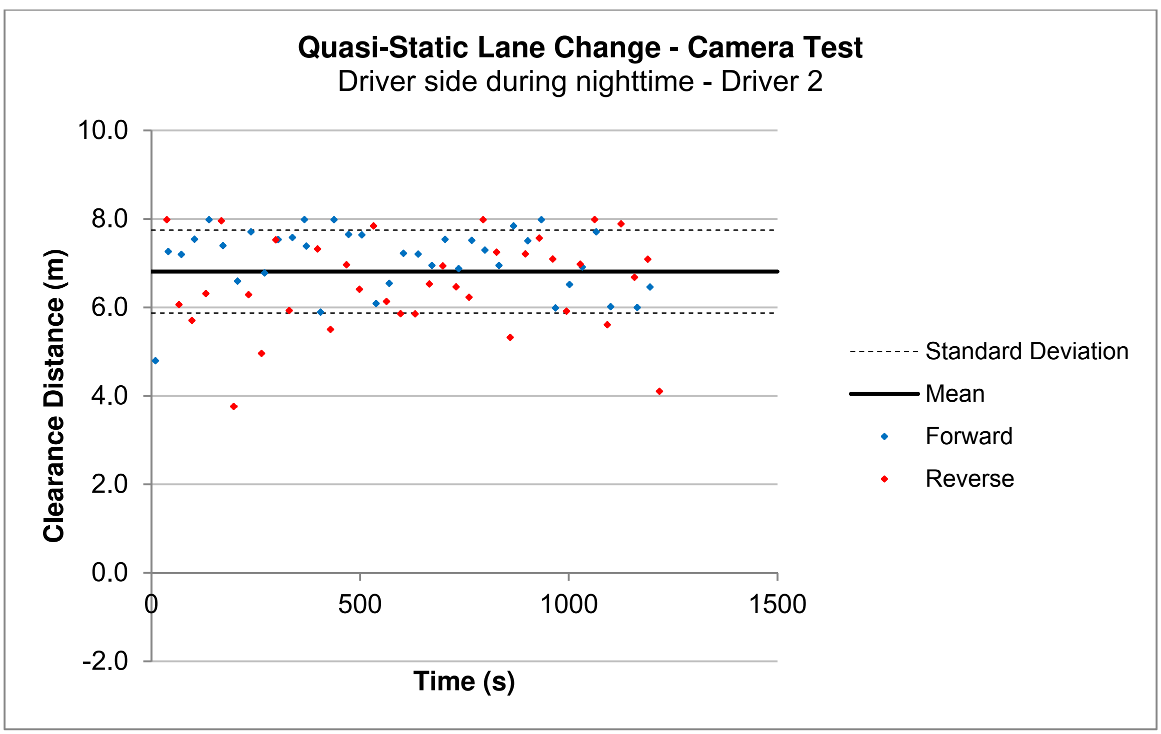

Figure 42: Driver 2 quasi-static lane change results for camera test with target vehicle on driver side (night)

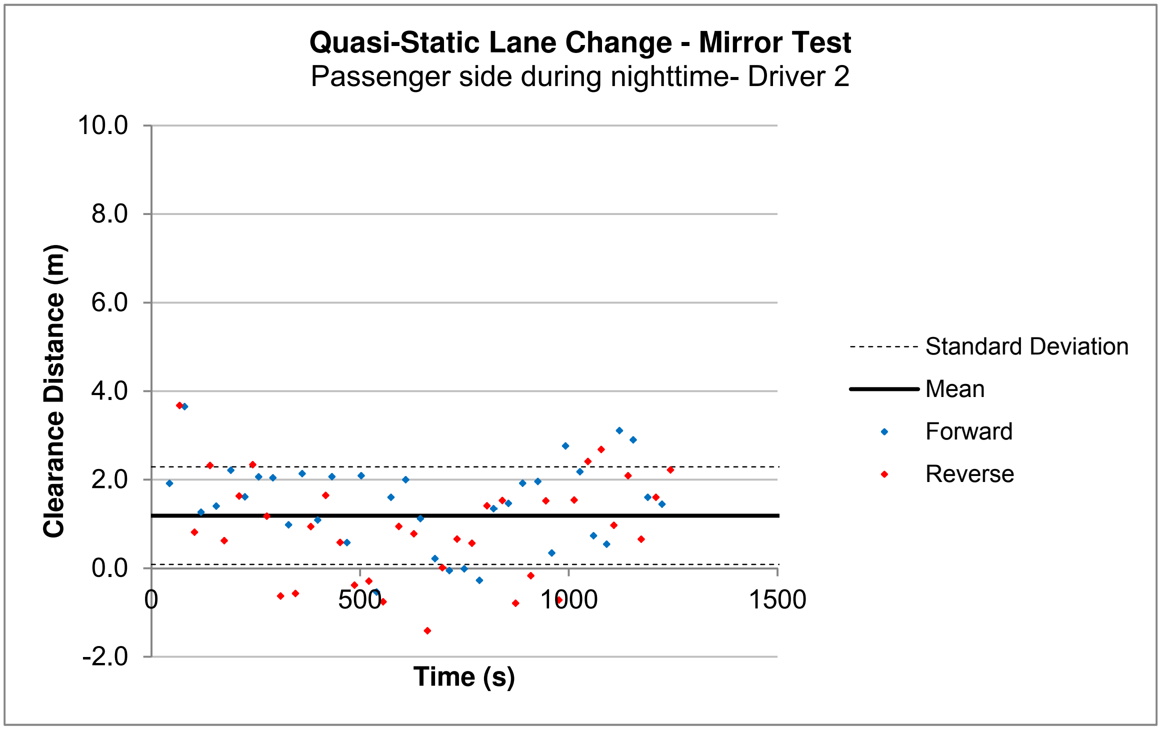

Figure 43: Driver 2 quasi-static lane change results for mirror test with target vehicle on passenger side (night)

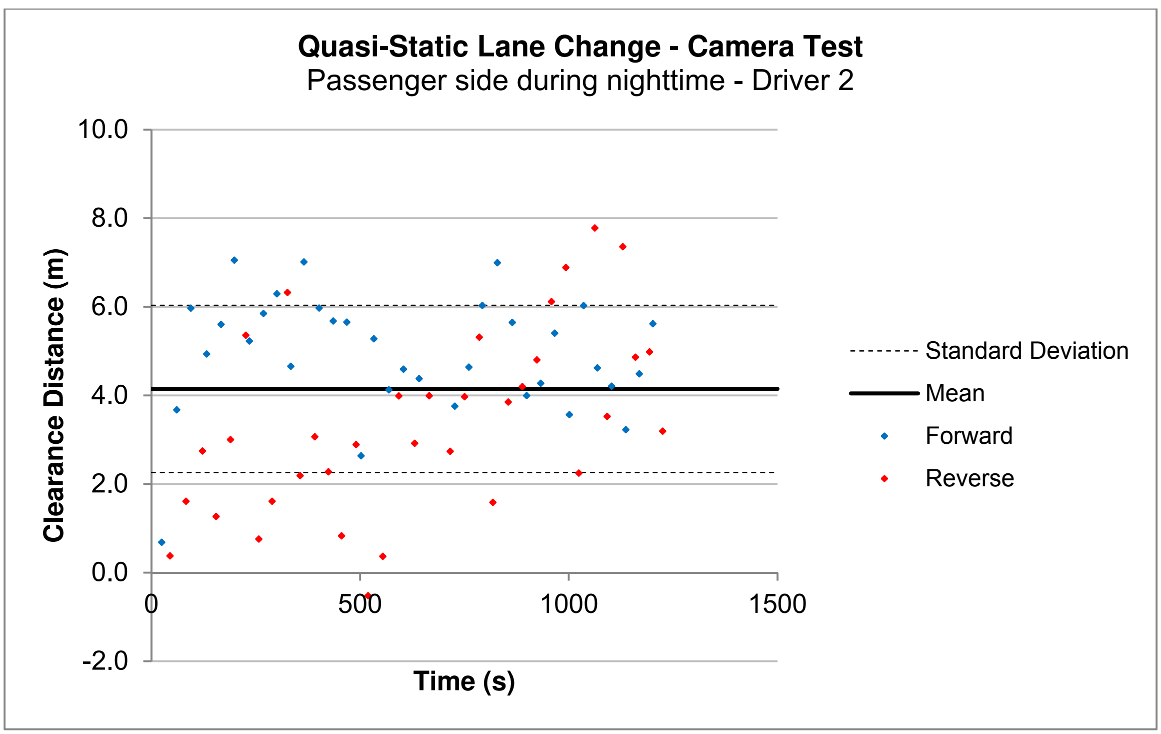

Figure 44: Driver 2 quasi-static lane change results for camera test with target vehicle on passenger side (night)

5.4.3 **Driver 3**

The results of the quasi-static lane change test for Driver 3 are summarized in Table 49 and Table 50.

The results of the quasi-static lane change test for Driver 3 may be seen in Figure 45 through Figure 52. The provided plots show the clearance distance between the target vehicle and the subject vehicle when the test subject activated the pendant switch while the target vehicle was moving in a forward direction (blue dots) and in the reverse direction (red dots). The plots also have Driver 3's mean clearance distance for all activations of the pendant switch, as well as dashed lines one standard deviation above the mean and one standard deviation below the mean.

Table 49: Driver 3 quasi-static lane change test results (day)

		Camera-Based Indirect Vision System		Mirror-Based Indirect Vision System	
		Target Vehicle on Driver Side	**Target Vehicle on Passenger Side**	**Target Vehicle on Driver Side**	**Target Vehicle on Passenger Side**
Number of Samples	**Forward**	34	37	40	41
	Reverse	35	37	37	40
	Total	**69**	**74**	**77**	**81**
Average Target Vehicle Speed (km/h)	**Forward**	4.0	4.5	4.5	4.8
	Reverse	3.9	4.2	4.6	4.7
	All Samples	**3.9**	**4.2**	**4.6**	**4.7**
Average Clearance Distance (m)	**Forward**	-1.650	-0.055	-1.069	0.187
	Reverse	1.151	3.268	4.235	5.114
	All Samples	**-0.229**	**1.606**	**1.480**	**2.620**
Standard Deviation - All Samples (m)		1.801	2.165	2.892	2.790
Maximum (m)		2.666	5.402	6.457	7.348
Minimum (m)		-6.224	-3.230	-3.643	-2.102

Table 50: Driver 3 quasi-static lane change test results (night)

		Camera-Based Indirect Vision System		Mirror-Based Indirect Vision System	
		Target Vehicle on Driver Side	Target Vehicle on Passenger Side	Target Vehicle on Driver Side	Target Vehicle on Passenger Side
Number of Samples	Forward	42	40	40	38
	Reverse	38	40	38	38
	Total	**80**	**80**	**78**	**76**
Average Target Vehicle Speed (km/h)	Forward	4.8	4.4	4.7	4.4
	Reverse	3.7	4.3	3.6	4.4
	All Samples	**3.7**	**4.3**	**3.7**	**4.4**
Average Clearance Distance (m)	Forward	-1.102	-1.161	1.615	0.037
	Reverse	6.580	4.372	6.710	4.047
	All Samples	**2.547**	**1.606**	**4.097**	**2.042**
Standard Deviation - All Samples (m)		4.345	4.018	2.932	2.860
Maximum (m)		7.978	7.974	7.980	7.951
Minimum (m)		-5.079	-6.161	-1.509	-3.796

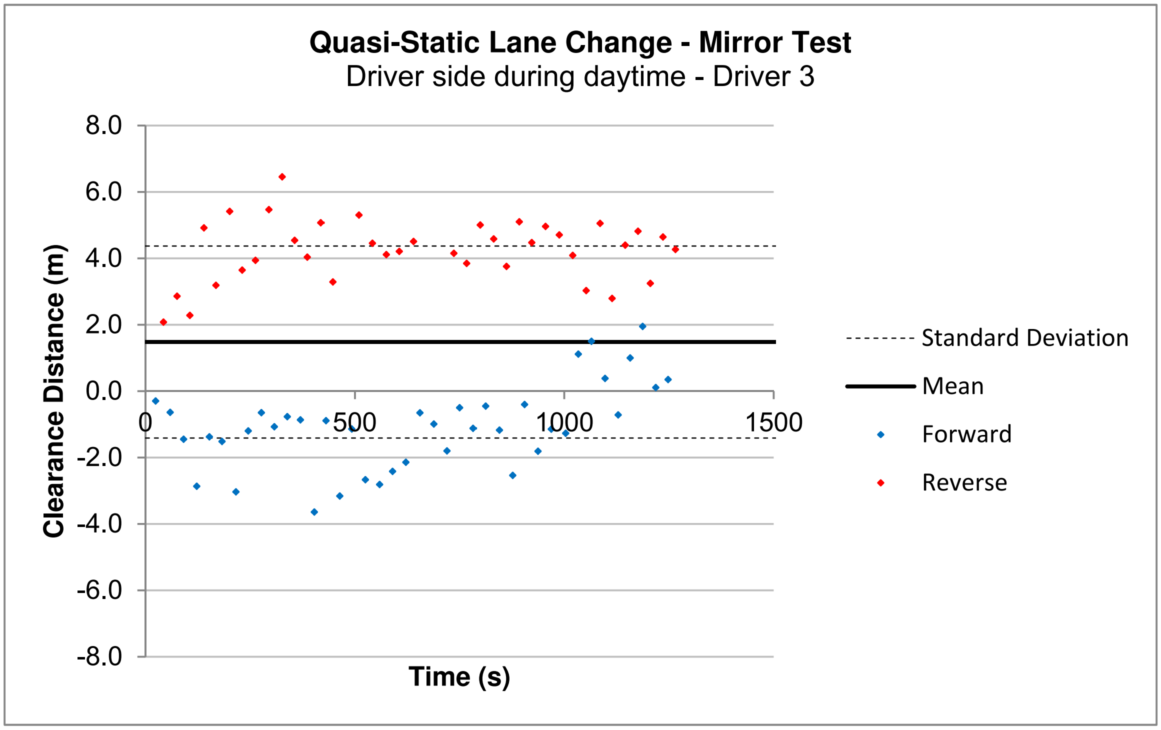

Figure 45: Driver 3 quasi-static lane change results for mirror test with target vehicle on driver side (day)

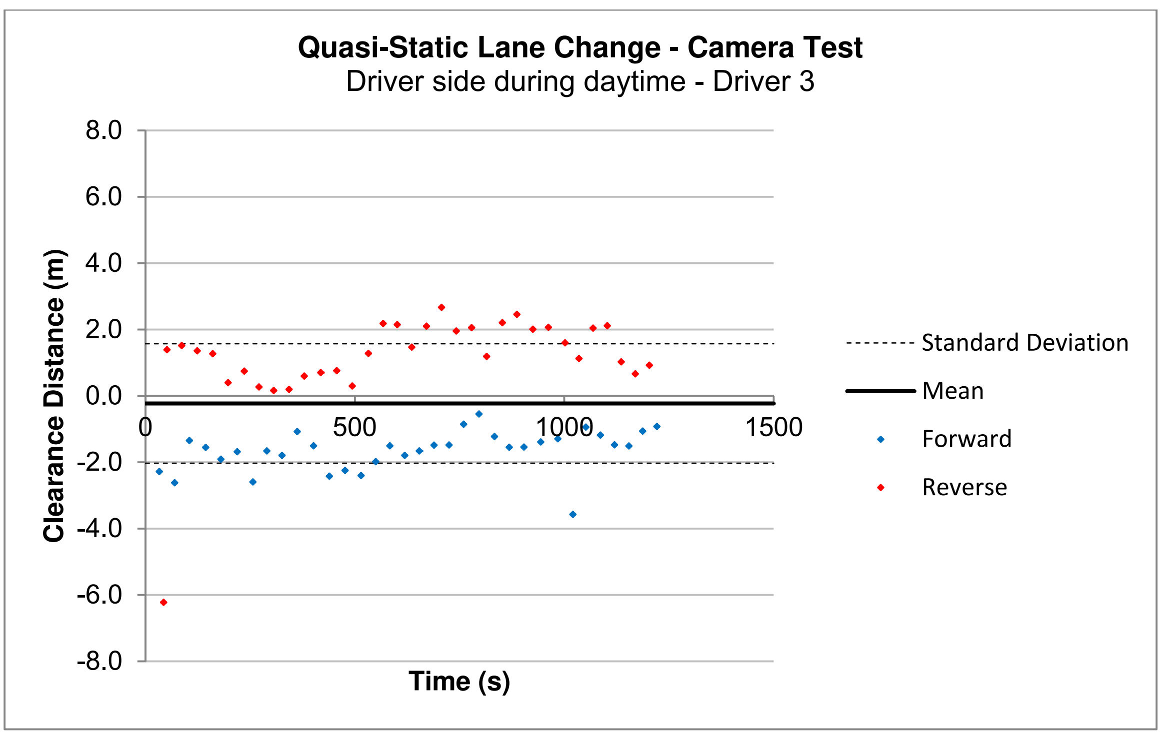

Figure 46: Driver 3 quasi-static lane change results for camera test with target vehicle on driver side (day)

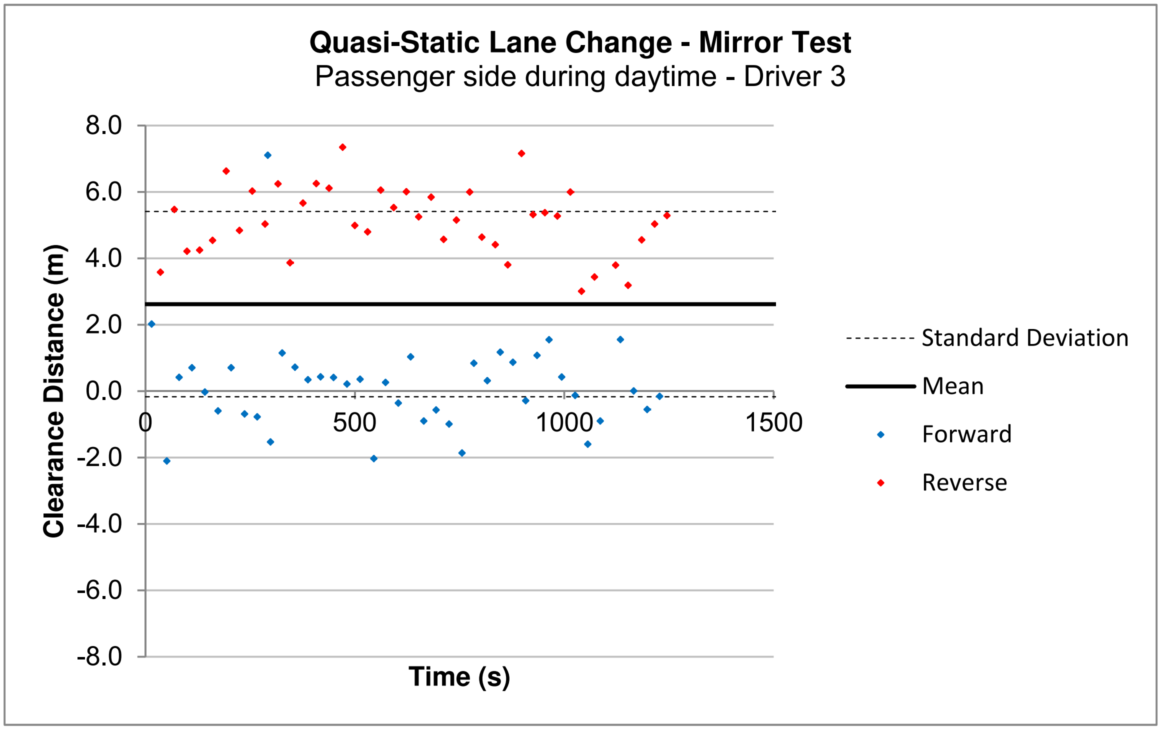

Figure 47: Driver 3 quasi-static lane change results for mirror test with target vehicle on passenger side (day)

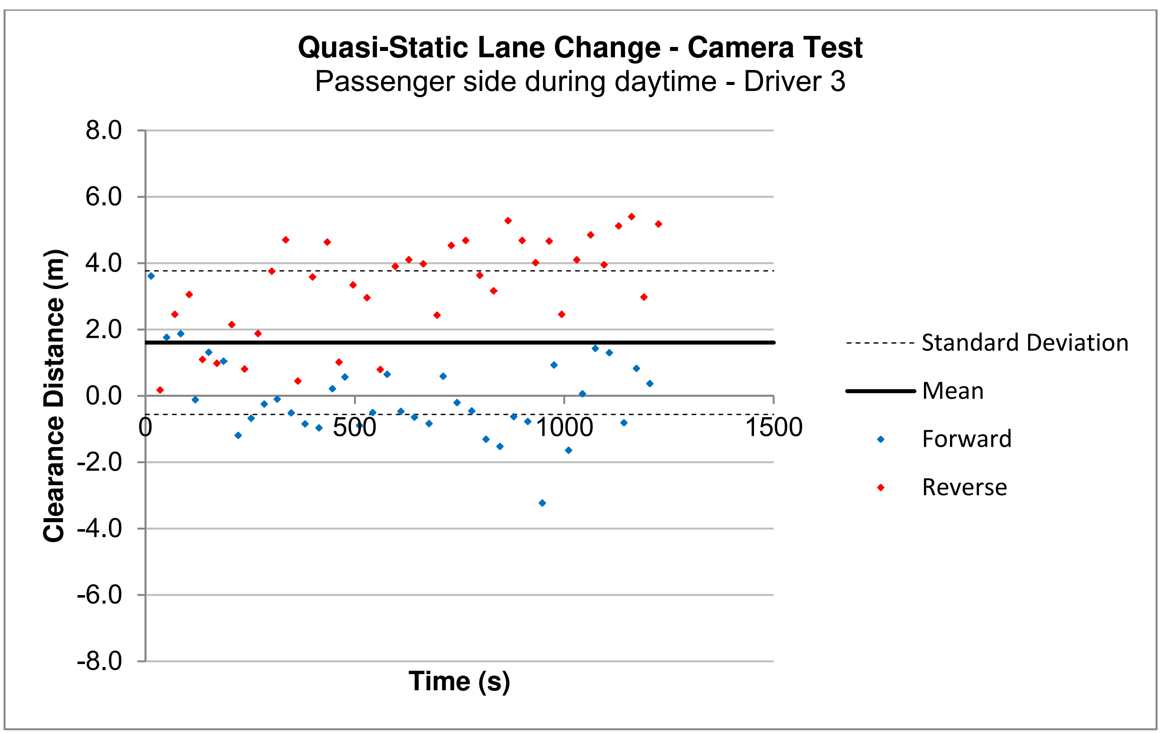

Figure 48: Driver 3 quasi-static lane change results for camera test with target vehicle on passenger side (day)

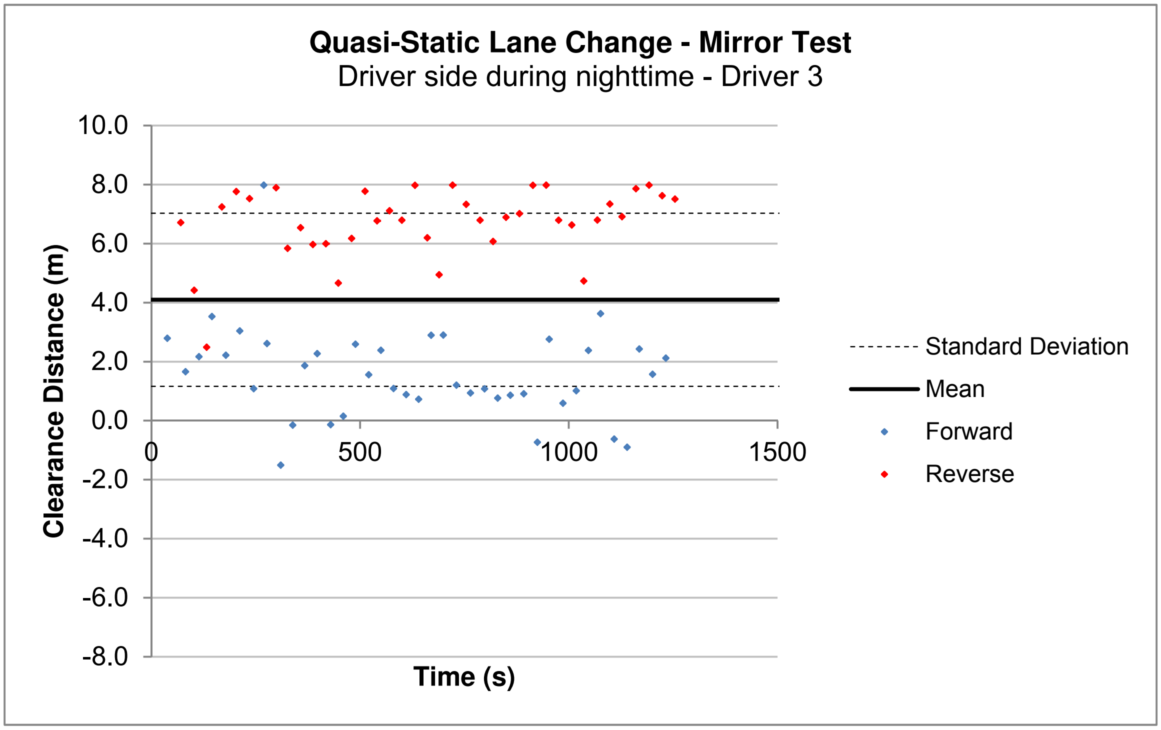

Figure 49: Driver 3 quasi-static lane change results for mirror test with target vehicle on driver side (night)

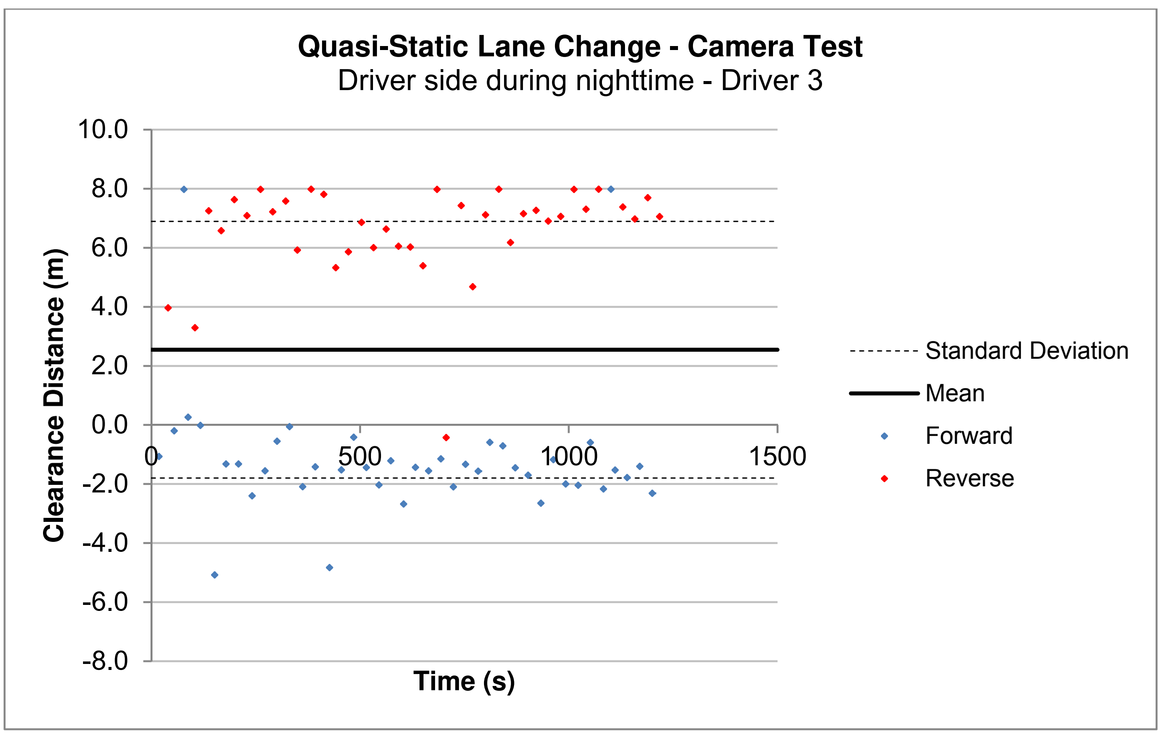

Figure 50: Driver 3 quasi-static lane change results for camera test with target vehicle on driver side (night)

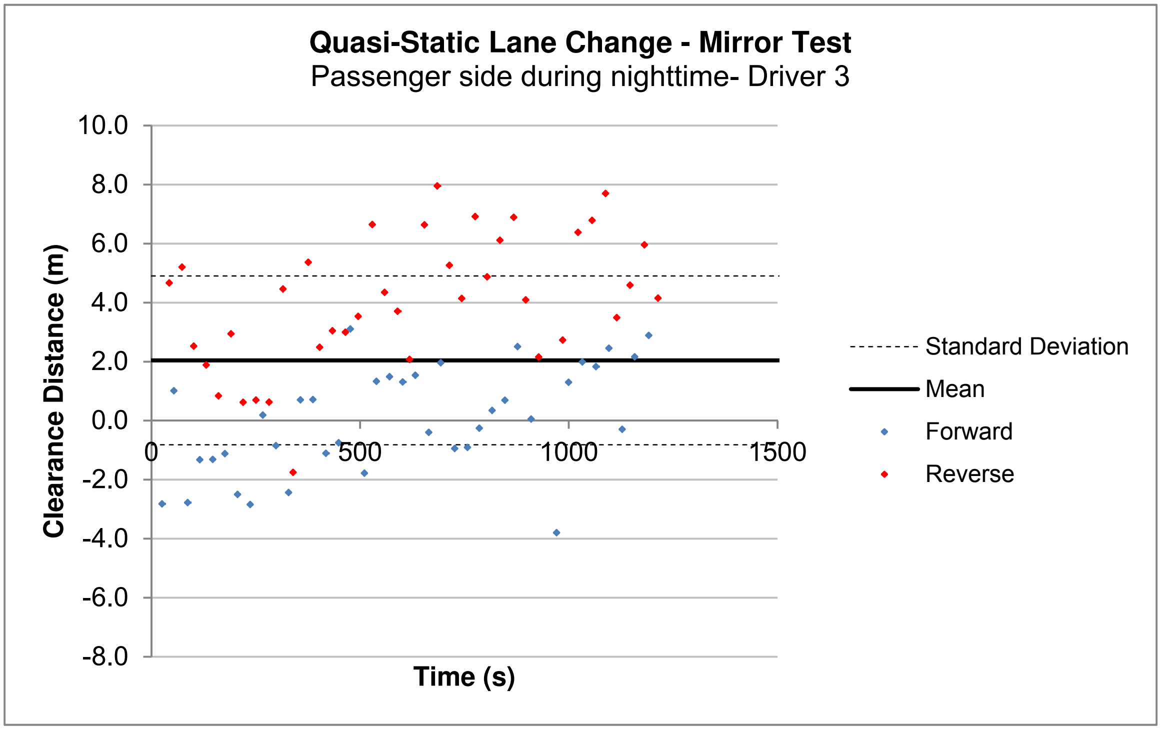

Figure 51: Driver 3 quasi-static lane change results for mirror test with target vehicle on passenger side (night)

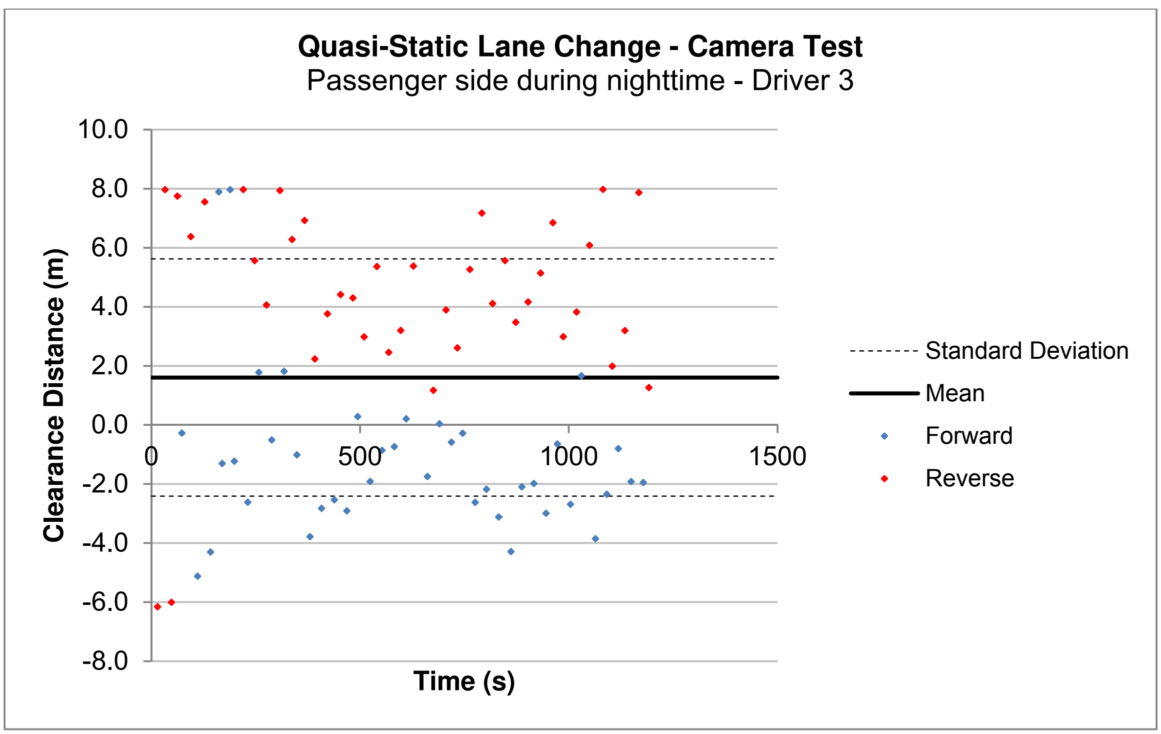

Figure 52: Driver 3 quasi-static lane change results for camera test with target vehicle on passenger side (night)

5.4.4 **Results of Questionnaire**

The results of the questionnaires provided to the test subjects after completion of the quasi-static lane change test may be found in Table 51 and Table 52. The scale used for the quantitative evaluation may be found in Table 7 on page 30.

Table 51: Quantitative results of quasi-static lane change questionnaire

		Driver 1	Driver 2	Driver 3
Mirror-Based Indirect Vision System	Ease of judging clearance distance during daytime conditions	6	7	6
	Ease of judging clearance distance during nighttime conditions	5	6	5
Camera-Based Indirect Vision System	Ease of judging clearance distance during daytime conditions	2	4	3.5
	Ease of judging clearance distance during nighttime conditions	1	2.5	2.5

Table 52: Qualitative results of quasi-static lane change questionnaire

Test Subject	Comment
Driver 1	• Test subject suggested moving the cameras to a higher position on the subject vehicle with the aim of reducing the glare from the target vehicle headlights.
Driver 2	• Test subject stated that he liked the smaller monitor on the left-hand A-pillar the best. This monitor has the highest pixel density of all the monitors.
Driver 3	(no comments provided for this test)

5.5 Dynamic Lane Change

The list of test subjects who completed the quasi-static lane change test along with the dates on which they completed the test may be found in Table 53.

Table 53: List of test subjects for dynamic lane change test

Test Subject	Test Condition	Tested System	Date Test Performed
Driver 2	Daytime	Camera System	November 15, 2013
		Mirror System	November 19, 2013
	Nighttime	Camera System	November 15, 2013
		Mirror System	November 18, 2013
Driver 3	Daytime	Camera System	November 20, 2013
		Mirror System	November 22, 2013
	Nighttime	Camera System	November 20, 2013
		Mirror System	November 21, 2013

5.5.1 **Driver 2**

The results of the dynamic lane change test for Driver 2 are provided in Table 54 through Table 61. The clearance distance listed in the tables is the distance measured between the rear of the subject vehicle and the front of the target vehicle at the point where the subject vehicle crossed the line separating the two lanes.

Table 54: Results of low speed dynamic lane change test with subject vehicle passing on the left during the day (Driver 2)

Trial	Mirror-Based Indirect Vision System			Camera-Based Indirect Vision System		
	Subject Vehicle Speed (km/h)	Target Vehicle Speed (km/h)	Clearance Distance (m)	Subject Vehicle Speed (km/h)	Target Vehicle Speed (km/h)	Clearance Distance (m)
1	51.3	40.4	10.7	53.9	40.3	34.5
2	51.9	40.4	9.5	51.1	40.2	23.0
3	53.9	40.3	14.5	51.5	40.3	14.6
Average	**52.3**	**40.3**	**11.5**	**52.2**	**40.3**	**24.0**

Table 55: Results of low speed dynamic lane change test with subject vehicle passing on the right during the day (Driver 2)

Trial	Mirror-Based Indirect Vision System			Camera-Based Indirect Vision System		
	Subject Vehicle Speed (km/h)	Target Vehicle Speed (km/h)	Clearance Distance (m)	Subject Vehicle Speed (km/h)	Target Vehicle Speed (km/h)	Clearance Distance (m)
1	52.1	40.4	11.4	53.4	40.2	21.3
2	52.8	40.6	7.2	54.2	40.3	17.9
3	54.8	40.0	17.0	52.2	40.1	32.5
Average	**53.2**	**40.3**	**11.8**	**53.3**	**40.2**	**23.9**

Table 56: Results of high speed dynamic lane change test with subject vehicle passing on the left during the day (Driver 2)

Trial	Mirror-Based Indirect Vision System			Camera-Based Indirect Vision System		
	Subject Vehicle Speed (km/h)	Target Vehicle Speed (km/h)	Clearance Distance (m)	Subject Vehicle Speed (km/h)	Target Vehicle Speed (km/h)	Clearance Distance (m)
1	82.9	74.4	8.5	79.5	74.4	26.0
2	85.2	74.5	10.7	80.3	74.3	14.8
3	84.5	74.3	12.1	82.7	75.0	28.9
Average	**84.2**	**74.4**	**10.5**	**80.8**	**74.6**	**23.2**

Table 57: Results of high speed dynamic lane change test with subject vehicle passing on the right during the day (Driver 2)

Trial	Mirror-Based Indirect Vision System			Camera-Based Indirect Vision System		
	Subject Vehicle Speed (km/h)	Target Vehicle Speed (km/h)	Clearance Distance (m)	Subject Vehicle Speed (km/h)	Target Vehicle Speed (km/h)	Clearance Distance (m)
1	83.5	74.3	7.3	82.3	74.5	12.9
2	82.6	74.5	11.8	82.1	74.7	28.7
3	86.2	74.4	10.4	84.5	74.7	14.6
Average	**84.1**	**74.4**	**9.8**	**83.0**	**74.6**	**18.7**

Table 58: Results of low speed dynamic lane change test with subject vehicle passing on the left during the night (Driver 2)

Trial	Mirror-Based Indirect Vision System			Camera-Based Indirect Vision System		
	Subject Vehicle Speed (km/h)	Target Vehicle Speed (km/h)	Clearance Distance (m)	Subject Vehicle Speed (km/h)	Target Vehicle Speed (km/h)	Clearance Distance (m)
1	51.8	40.0	24.1	51.9	40.3	31.5
2	52.6	40.2	19.6	51.9	40.3	29.8
3	54.3	40.1	21.2	53.2	40.3	37.2
Average	**52.9**	**40.1**	**21.6**	**52.3**	**40.3**	**32.8**

Table 59: Results of low speed dynamic lane change test with subject vehicle passing on the right during the night (Driver 2)

Trial	Mirror-Based Indirect Vision System			Camera-Based Indirect Vision System		
	Subject Vehicle Speed (km/h)	Target Vehicle Speed (km/h)	Clearance Distance (m)	Subject Vehicle Speed (km/h)	Target Vehicle Speed (km/h)	Clearance Distance (m)
1	53.5	40.4	16.4	51.2	40.2	45.0
2	53.3	40.6	13.8	51.2	40.2	37.8
3	54.5	40.3	18.7	53.0	40.2	33.9
Average	**53.8**	**40.4**	**16.3**	**51.8**	**40.2**	**38.9**

Table 60: Results of high speed dynamic lane change test with subject vehicle passing on the left during the night (Driver 2)

Trial	Mirror-Based Indirect Vision System			Camera-Based Indirect Vision System		
	Subject Vehicle Speed (km/h)	Target Vehicle Speed (km/h)	Clearance Distance (m)	Subject Vehicle Speed (km/h)	Target Vehicle Speed (km/h)	Clearance Distance (m)
1	82.9	74.2	12.6	79.1	74.8	13.9
2	84.9	74.4	13.6	83.6	75.6	24.0
3	83.7	74.5	20.2	83.4	74.9	27.8
Average	**83.9**	**74.4**	**15.5**	**82.0**	**75.1**	**21.9**

Table 61: Results of high speed dynamic lane change test with subject vehicle passing on the right during the night (Driver 2)

Trial	Mirror-Based Indirect Vision System			Camera-Based Indirect Vision System		
	Subject Vehicle Speed (km/h)	Target Vehicle Speed (km/h)	Clearance Distance (m)	Subject Vehicle Speed (km/h)	Target Vehicle Speed (km/h)	Clearance Distance (m)
1	81.7	74.6	14.2	81.8	74.1	32.8
2	83.5	74.4	18.0	87.3	74.9	35.5
3	84.2	74.4	14.9	82.8	74.5	28.1
Average	**83.2**	**74.5**	**15.7**	**84.0**	**74.5**	**32.2**

5.5.2 Driver 3

The results of the dynamic lane change test for Driver 3 are provided in Table 62 through Table 69. The clearance distance listed in the tables is the distance measured between the rear of the subject vehicle and the front of the target vehicle at the point where the subject vehicle crossed the line separating the two lanes.

Table 62: Results of low speed dynamic lane change test with subject vehicle passing on the left during the day (Driver 3)

Trial	Mirror-Based Indirect Vision System			Camera-Based Indirect Vision System		
	Subject Vehicle Speed (km/h)	Target Vehicle Speed (km/h)	Clearance Distance (m)	Subject Vehicle Speed (km/h)	Target Vehicle Speed (km/h)	Clearance Distance (m)
1	51.0	40.4	17.3	53.0	40.4	42.2
2	52.0	40.3	15.6	54.8	40.4	48.3
3	50.7	40.3	19.5	54.1	40.5	53.2
Average	**51.2**	**40.3**	**17.5**	**54.0**	**40.4**	**47.9**

Table 63: Results of low speed dynamic lane change test with subject vehicle passing on the right during the day (Driver 3)

Trial	Mirror-Based Indirect Vision System			Camera-Based Indirect Vision System		
	Subject Vehicle Speed (km/h)	Target Vehicle Speed (km/h)	Clearance Distance (m)	Subject Vehicle Speed (km/h)	Target Vehicle Speed (km/h)	Clearance Distance (m)
1	51.2	40.3	17.8	56.8	40.4	52.1
2	52.6	40.3	26.0	59.9	40.5	59.0
3	50.5	40.3	22.3	53.4	40.4	27.0
Average	**51.4**	**40.3**	**22.0**	**56.7**	**40.4**	**46.0**

Table 64: Results of high speed dynamic lane change test with subject vehicle passing on the left during the day (Driver 3)

Trial	Mirror-Based Indirect Vision System			Camera-Based Indirect Vision System		
	Subject Vehicle Speed (km/h)	Target Vehicle Speed (km/h)	Clearance Distance (m)	Subject Vehicle Speed (km/h)	Target Vehicle Speed (km/h)	Clearance Distance (m)
1	81.9	74.7	13.8	86.0	74.9	42.4
2	81.2	74.4	15.3	84.1	74.6	43.3
3	81.8	74.6	12.1	85.9	74.7	47.5
Average	**81.6**	**74.6**	**13.7**	**85.3**	**74.7**	**44.4**

Table 65: Results of high speed dynamic lane change test with subject vehicle passing on the right during the day (Driver 3)

Trial	Mirror-Based Indirect Vision System			Camera-Based Indirect Vision System		
	Subject Vehicle Speed (km/h)	Target Vehicle Speed (km/h)	Clearance Distance (m)	Subject Vehicle Speed (km/h)	Target Vehicle Speed (km/h)	Clearance Distance (m)
1	84.2	74.6	25.2	85.7	74.6	48.2
2	79.9	74.4	17.8	81.6	74.9	21.9
3	82.7	74.4	23.9	85.2	74.6	43.6
Average	**82.3**	**74.5**	**22.3**	**84.2**	**74.7**	**37.9**

Table 66: Results of low speed dynamic lane change test with subject vehicle passing on the left during the night (Driver 3)

Trial	Mirror-Based Indirect Vision System			Camera-Based Indirect Vision System		
	Subject Vehicle Speed (km/h)	Target Vehicle Speed (km/h)	Clearance Distance (m)	Subject Vehicle Speed (km/h)	Target Vehicle Speed (km/h)	Clearance Distance (m)
1	52.6	40.4	34.9	50.2	40.5	47.8
2	51.3	40.4	37.0	52.9	40.4	53.0
3	54.4	40.3	40.4	52.9	40.3	59.1
Average	**52.8**	**40.4**	**37.5**	**52.0**	**40.4**	**53.3**

Table 67: Results of low speed dynamic lane change test with subject vehicle passing on the right during the night (Driver 3)

Trial	Mirror-Based Indirect Vision System			Camera-Based Indirect Vision System		
	Subject Vehicle Speed (km/h)	Target Vehicle Speed (km/h)	Clearance Distance (m)	Subject Vehicle Speed (km/h)	Target Vehicle Speed (km/h)	Clearance Distance (m)
1	50.9	40.4	30.5	52.5	40.4	65.8
2	51.3	40.4	37.7	53.4	40.1	92.2
3	52.0	40.4	31.2	52.6	40.4	65.3
Average	**51.4**	**40.4**	**33.1**	**52.9**	**40.3**	**74.4**

Table 68: Results of high speed dynamic lane change test with subject vehicle passing on the left during the night (Driver 3)

Trial	Mirror-Based Indirect Vision System			Camera-Based Indirect Vision System		
	Subject Vehicle Speed (km/h)	Target Vehicle Speed (km/h)	Clearance Distance (m)	Subject Vehicle Speed (km/h)	Target Vehicle Speed (km/h)	Clearance Distance (m)
1	83.6	74.9	33.6	82.5	74.7	32.3
2	81.8	74.6	33.5	81.7	74.6	42.6
3	81.9	74.8	33.0	78.3	74.6	46.3
Average	**82.4**	**74.8**	**33.4**	**80.8**	**74.6**	**40.4**

Table 69: Results of high speed dynamic lane change test with subject vehicle passing on the right during the night (Driver 3)

Trial	Mirror-Based Indirect Vision System			Camera-Based Indirect Vision System		
	Subject Vehicle Speed (km/h)	Target Vehicle Speed (km/h)	Clearance Distance (m)	Subject Vehicle Speed (km/h)	Target Vehicle Speed (km/h)	Clearance Distance (m)
1	82.2	74.6	40.9	79.6	74.5	42.5
2	84.3	74.9	33.4	83.4	74.6	44.5
3	82.3	74.6	38.4	83.9	74.5	42.5
Average	**82.9**	**74.7**	**37.5**	**82.3**	**74.5**	**43.1**

5.5.3 **Results of Questionnaire**

The results of the questionnaires provided to the test subjects after completion of the dynamic lane change test may be found in Table 70. The scale used for the quantitative evaluation may be found in Table 7 on page 30.

No qualitative comments were provided by either test subject on the post-test questionnaires.

Table 70: Quantitative results of dynamic lane change questionnaire

		Driver 2	**Driver 3**
Mirror-Based Indirect Vision System	Ease of performing a passing manoeuvre at low speeds during daytime conditions	7	5
	Ease of performing a passing manoeuvre at high speeds during daytime conditions	7	5
	Ease of performing a passing manoeuvre at low speeds during nighttime conditions	6	4.5
	Ease of performing a passing manoeuvre at high speeds during nighttime conditions	6	4.5
Camera-Based Indirect Vision System	Ease of performing a passing manoeuvre at low speeds during daytime conditions	5	4
	Ease of performing a passing manoeuvre at high speeds during daytime conditions	5	4
	Ease of performing a passing manoeuvre at low speeds during nighttime conditions	3.5	3.5
	Ease of performing a passing manoeuvre at high speeds during nighttime conditions	3.5	3.5

5.6 Evasive Manoeuvre

The list of test subjects who completed the evasive manoeuvre test along with the dates on which they completed the test may be found in Table 71.

Table 71: List of test subjects for evasive manoeuvre test

Test Subject	Tested System	Test Condition	Date Test Performed
Driver 2	Camera System	Daytime	November 19, 2013
		Nighttime	November 19, 2013
	Mirror System	Daytime	November 19, 2013
		Nighttime	November 18, 2013
Driver 3	Camera System	Daytime	November 21, 2013
		Nighttime	November 20, 2013
	Mirror System	Daytime	November 22, 2013
		Nighttime	November 21, 2013

5.6.1 **Driver 2**

The results of the evasive manoeuvre test for Driver 2 are provided in Table 72 and Table 73. The average decision time presented in the tables is calculated using all available elapsed times for the test subject to make the decision to perform an evasive manoeuvre.

Table 72: Results of evasive manoeuvre test during daytime (Driver 1)

Test	Mirror-Based Indirect Vision System			Camera-Based Indirect Vision System		
	Test Position	Time for Decision to Move (s)	Correct Decision	Test Position	Time for Decision to Move (s)	Correct Decision
1	3	1.2	Yes	3	No Move	No
2	3	2.1	Yes	3	2.0	Yes
3	5	2.0	Yes	2	No Move	Yes
4	1	No Move	Yes	6	1.0	Yes
5	6	1.6	Yes	2	No Move	Yes
6	2	No Move	Yes	4	0.6	Yes
7	3	1.6	Yes	5	1.1	Yes
8	4	0.4	Yes	1	No Move	Yes
9	2	No Move	Yes	6	0.8	Yes
10	6	1.4	Yes	3	0.4	Yes
Average decision time:		**1.5**			**1.0**	
Percent correct decisions:			**100%**			**90%**

Table 73: Results of evasive manoeuvre test during nighttime (Driver 1)

Test	Mirror-Based Indirect Vision System			Camera-Based Indirect Vision System		
	Test Position	Time for Decision to Move (s)	Correct Decision	Test Position	Time for Decision to Move (s)	Correct Decision
1	4	1.9	Yes	3	No Move	No
2	3	0.8	Yes	5	No Move	No
3	4	3.0	Yes	4	No Move	No
4	5	0.7	Yes	5	No Move	No
5	1	No Move	Yes	4	No Move	No
6	1	No Move	Yes	6	2.6	Yes
7	5	1.0	Yes	4	No Move	No
8	4	0.3	Yes	2	No Move	Yes
9	6	2.6	Yes	1	No Move	Yes
10	2	No Move	Yes	1	No Move	Yes
Average decision time:		**1.5**			**2.6**	
Percent correct decisions:			**100%**			**40%**

5.6.2 **Driver 3**

The results of the evasive manoeuvre test for Driver 2 are provided in Table 74 and Table 75. The average decision time presented in the tables is calculated using all available elapsed times for the test subject to make the decision to perform an evasive manoeuvre.

Table 74: Results of evasive manoeuvre test during daytime (Driver 2)

Test	Mirror-Based Indirect Vision System			Camera-Based Indirect Vision System		
	Test Position	Time for Decision to Move (s)	Correct Decision	Test Position	Time for Decision to Move (s)	Correct Decision
1	3	No Move	No	3	No Move	No
2	3	1.2	Yes	3	2.6	Yes
3	5	1.6	Yes	2	No Move	Yes
4	1	No Move	Yes	6	No Move	No
5	6	1.1	Yes	2	No Move	Yes
6	2	No Move	Yes	4	No Move	No
7	3	2.2	Yes	5	1.4	Yes
8	4	1.1	Yes	1	No Move	Yes
9	2	No Move	Yes	6	No Move	No
10	6	0.7	Yes	3	1.7	Yes
Average decision time:		**1.3**			**1.9**	
Percent correct decisions:			**90%**			**60%**

Table 75: Results of evasive manoeuvre test during nighttime (Driver 2)

Test	Mirror-Based Indirect Vision System			Camera-Based Indirect Vision System		
	Test Position	Time for Decision to Move (s)	Correct Decision	Test Position	Time for Decision to Move (s)	Correct Decision
1	4	No Move	No	3	No Move	No
2	3	No Move	No	5	2.8	Yes
3	4	1.8	Yes	4	No Move	No
4	5	2.8	Yes	5	1.7	Yes
5	1	No Move	Yes	4	No Move	No
6	1	No Move	Yes	6	No Move	No
7	5	2.2	Yes	4	No Move	No
8	4	1.9	Yes	2	No Move	Yes
9	6	No Move	No	1	No Move	Yes
10	2	No Move	Yes	1	No Move	Yes
Average decision time:		**2.2**			**2.3**	
Percent correct decisions:			**70%**			**50%**

5.6.3 Results of Questionnaire

The results of the questionnaires provided to the test subjects after completion of the evasive manoeuvre test may be found in Table 76 and Table 77. The scale used for the quantitative evaluation may be found in Table 7 on page 30.

Table 76: Quantitative results of evasive manoeuvre test questionnaire

		Driver 2	Driver 3
Mirror-Based Indirect Vision System	Ease of performing evasive manoeuvre during daytime conditions	7	5
	Ease of performing evasive manoeuvre during nighttime conditions	6	4.5
Camera-Based Indirect Vision System	Ease of performing evasive manoeuvre during daytime conditions	5	3.5
	Ease of performing evasive manoeuvre during nighttime conditions	3	3

Table 77: Qualitative results of evasive manoeuvre test questionnaire

Test Subject	Comment
Driver 2	• Test subject stated that the light intensity of the headlights in the camera-based indirect vision system resulting in bloom on the monitors was of large concern.
Driver 3	• Test subject stated that depth perception in the camera-based indirect vision system is difficult. He found the differing fields of view confusing.

5.7 Additional Findings

5.7.1 Moving Cameras Outboard

As a result of the comments received from the test subjects after performing the blind spot comparison test (specifically, Driver 2), the cameras were moved outboard in an attempt to provide the test subjects with a better view of the rear edge of the subject vehicle's trailer. The cameras were moved outboard such that the centerlines of the camera lenses were roughly 27.5 cm away from the surface of the subject vehicle. This placed the cameras such that the distance between the driver side and passenger side cameras was the same as the distance between the outermost points of the driver side and passenger side west coast mirrors. This resulted in a camera to camera width of roughly 2.9 m, 0.3 m more than is allowable on Ontario highways. However, mirrors are exempt from the overall vehicle width restrictions, and it is possible that camera-based indirect vision systems could also be made exempt.

The driver side camera housing after having been moved outward from the subject vehicle's surface may be seen in Figure 53.

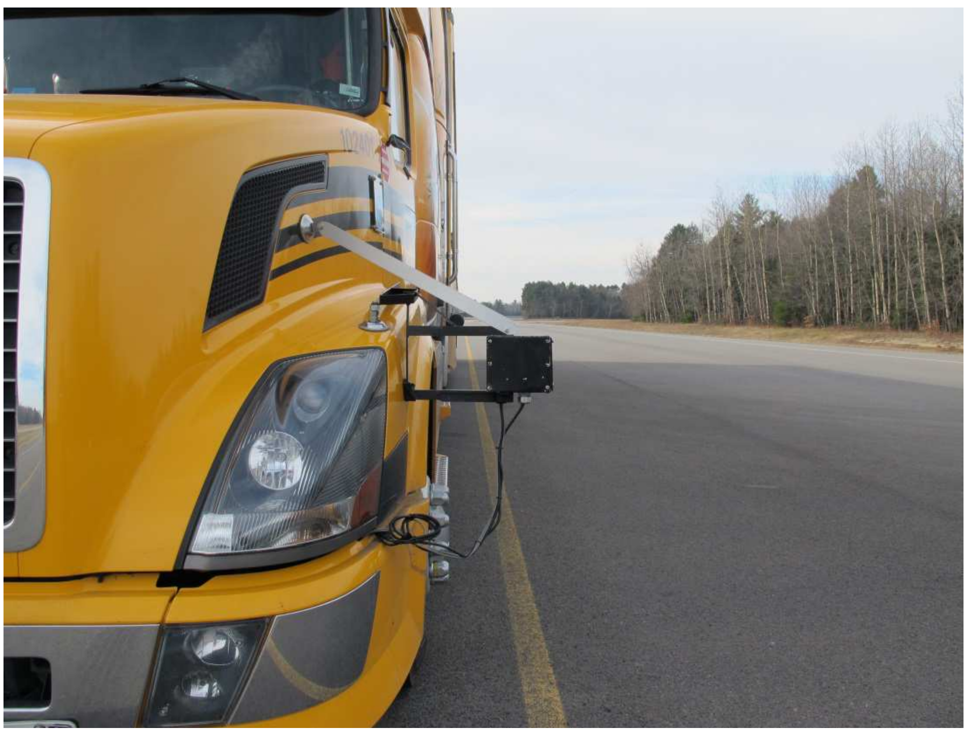

Figure 53: Driver side cameras moved away from subject vehicle surface

5.7.2 **Blooming**

Throughout testing, the test subjects complained about the bloom on the monitors caused by bright lights shining into the cameras during nighttime operations. This made determining clearance distance, as well as gathering other pertinent visual information difficult if not impossible. The blooming on the camera monitors may be seen in Figure 54. In Figure 54, the target vehicle is located in the zero clearance distance position on the driver side of the vehicle (the image shown on the monitors is reversed to simulate looking into a mirror).

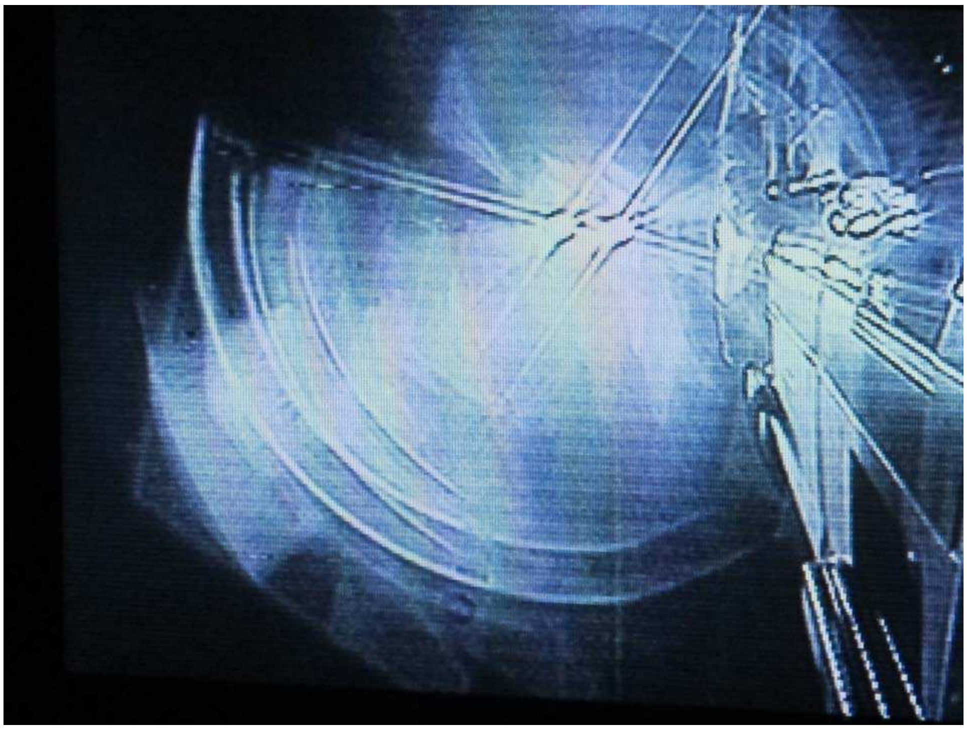

Figure 54: Blooming in monitors caused by target vehicle's headlights

5.7.2.1 Dew on Camera Housing

As shown in Figure 2 and Figure 3, the protective housing surrounding the cameras had a Plexiglas cover to protect the camera lenses. At one point during nighttime testing with Driver 1, the outdoor temperature and relative humidity levels created the necessary conditions for dew to form on the Plexiglas cover. This exacerbated the blooming shown in Figure 54 as a result of additional light refraction as it passed through the dew. The dew was cleaned from the surface of the camera housing manually and testing resumed.

6 ANALYSIS

6.1 Object Identification

The results of the object identification test may be analyzed in two ways. Firstly, they may be analyzed in terms of the proportion of test objects which were correctly identified by the test subject. Secondly, they may be analyzed in terms of the time it took for the test subject to locate the target.

Bar charts presenting the proportion of correctly identified test objects for Driver 1, Driver 2, Driver 3 and Driver 4 may be found in Figure 55, Figure 56, Figure 57 and Figure 58, respectively. As may be seen from the four figures, Driver 1 performed slightly better with the camera-based indirect vision system, Driver 2 performed equally well with both systems, and Driver 3 and Driver 4 performed slightly better with the mirror-based indirect vision system.

Of all object identification errors, 46% were made with the camera-based indirect vision system. Of these errors, 33% involved not being able to locate the test object and 67% involved not being able to correctly identify the test object.

Of all object identification errors, 54% were made with the mirror-based indirect vision system. Of these errors, 86% involved not being able to locate the test object and 14% involved not being able to correctly identify the test object.

To compare the time taken to locate a test object, a paired t-test was performed on the results to determine whether the difference of the sample means were statistically significant. The resultant p-values of the t-tests are summarized in Table 78. As may be seen in the table, the only two tests which showed a statistically significant difference between the means (p-value < 0.05) were the nighttime tests for Driver 2 and Driver 3. Here, the mean time to locate the test object was statistically significantly lower for the camera-based indirect vision system than for the mirror-based indirect vision system. It should be noted that pairs of data for which an object was not located in either the mirror or camera tests were omitted from the analysis. It should be taken into account that the sample size under analysis was small and that the results of the statistical analysis may not be applicable to the population from which the sample was taken.

The results of the tests may also be expressed graphically as shown in the boxplots of the time taken to locate the test objects for Driver 1, Driver 2, Driver 3 and Driver 4. These may be found in Figure 59, Figure 60, Figure 61 and Figure 62, respectively. These plots omit errors related to not being able to locate the test object but include errors related to incorrectly identifying the test object.

As may be seen in Figure 59 by comparing the four boxes, Driver 1 performed very similarly for both the camera-based and mirror-based systems.

Figure 60 shows that the spread of Driver 2's results were similar, but Driver 2 performed slightly better with the camera-based system than with the mirror-based system, especially while being tested in the low light conditions.

Figure 61 shows that the spread of Driver 3's reactions are similar for the camera and mirror-based systems in the daytime tests, but the spread for the mirrors in the nighttime tests was larger than for the cameras. From Figure 61, Driver 3 performed better with the camera-based system during the nighttime tests than with the mirror-based system.

Figure 62 shows that the spread of Driver 4's times to locate the test objects are slightly larger with the mirror-based system for both daytime and nighttime test conditions.

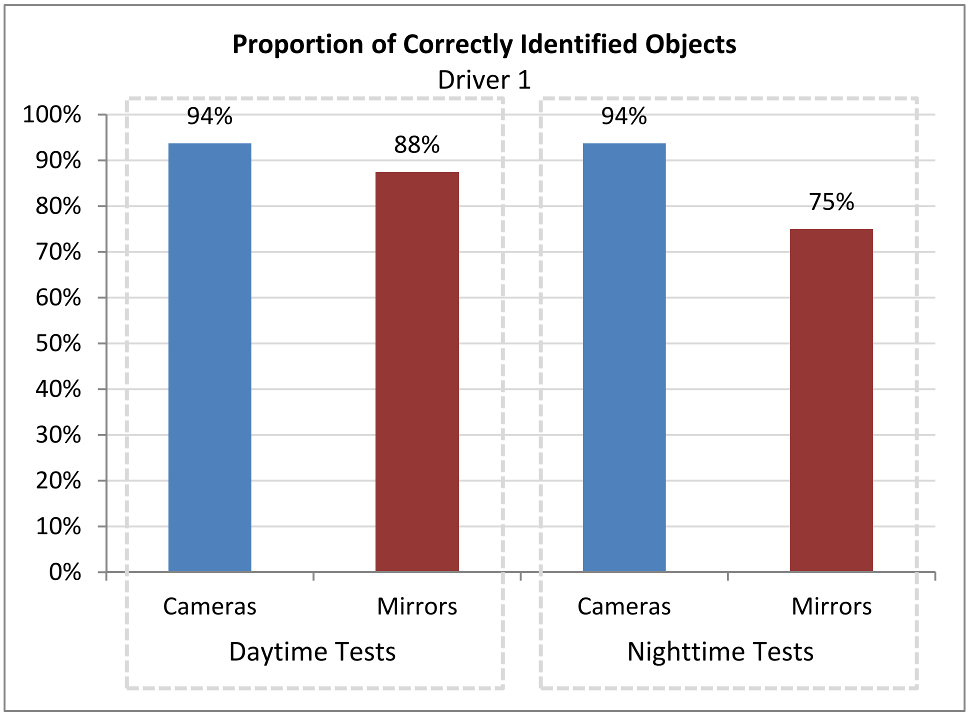

Figure 55: Proportion of correctly identified test objects for object identification test (Driver 1)

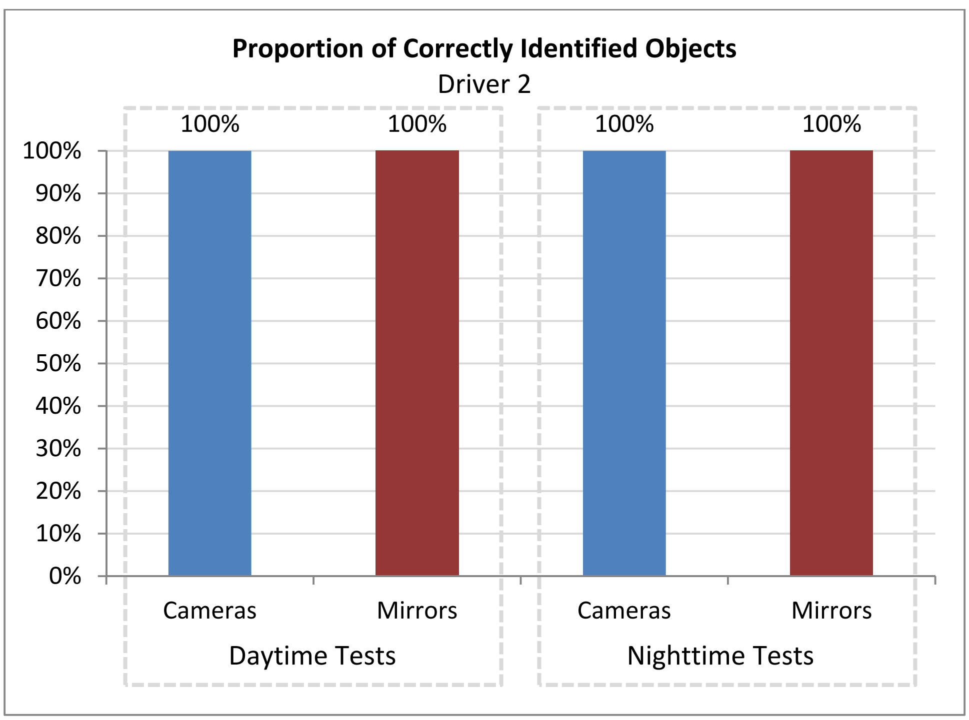

Figure 56: Proportion of correctly identified test objects for object identification test (Driver 2)

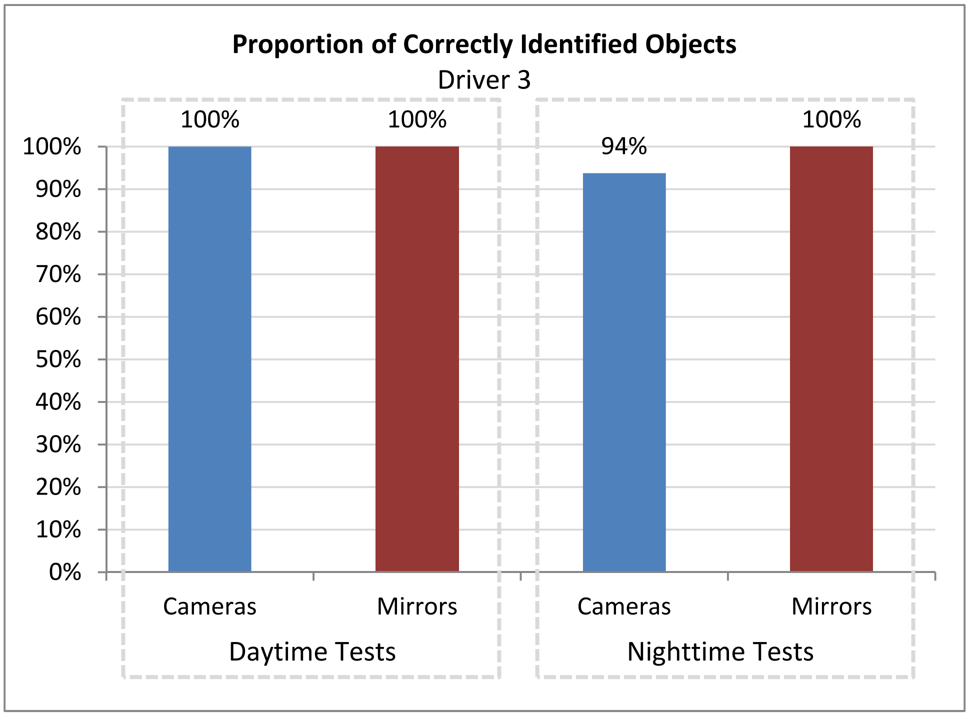

Figure 57: Proportion of correctly identified test objects for object identification test (Driver 3)

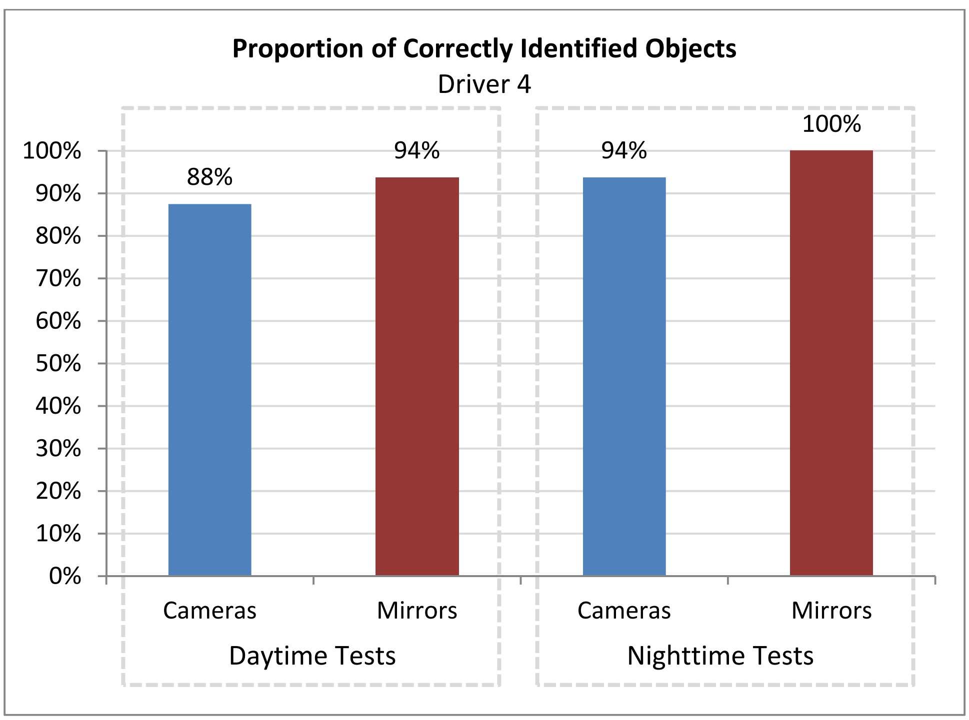

Figure 58: Proportion of correctly identified test objects for object identification test (Driver 4)

Table 78: Results of test for statistical significance for object identification test results (p-values)

Test Subject	Daytime Test (p-value)	Nighttime Test (p-value)
Driver 1	0.802	0.539
Driver 2	0.083	0.033
Driver 3	0.693	0.004
Driver 4	0.148	0.504

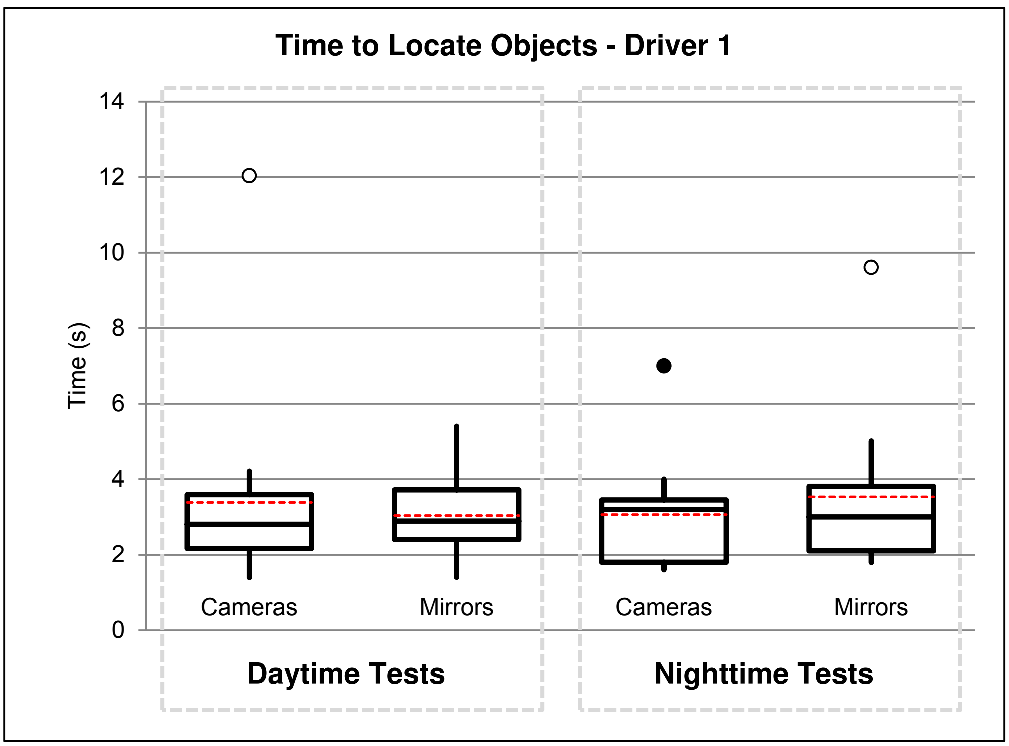

Figure 59: Time to locate test objects for object identification test (Driver 1)

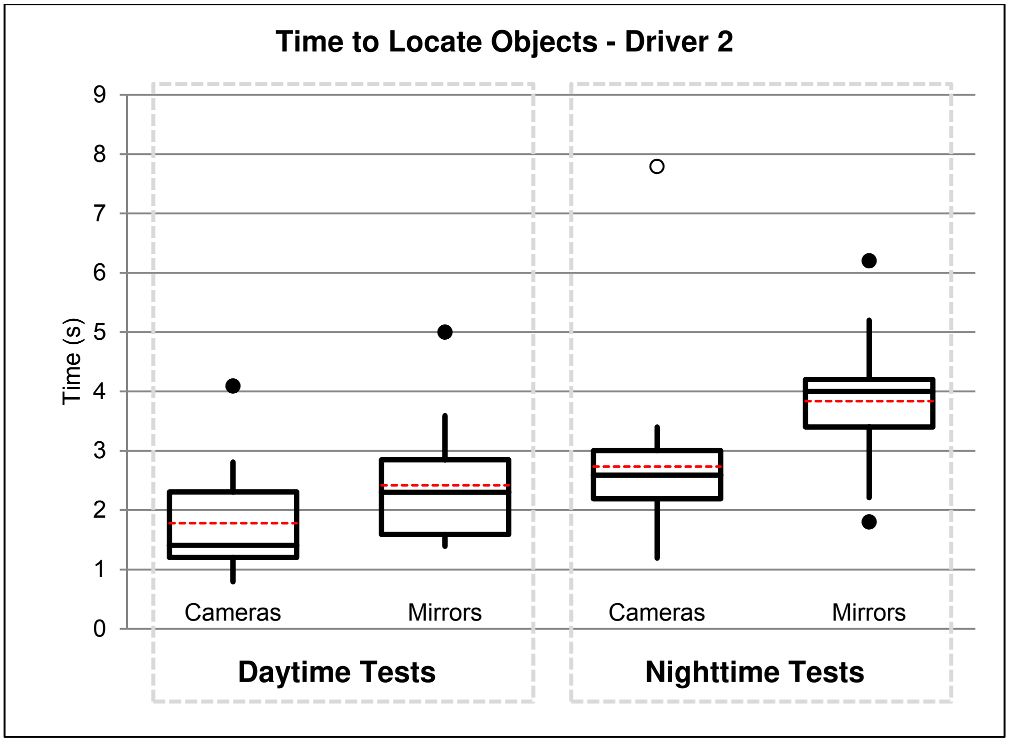

Figure 60: Time to locate test objects for object identification test (Driver 2)

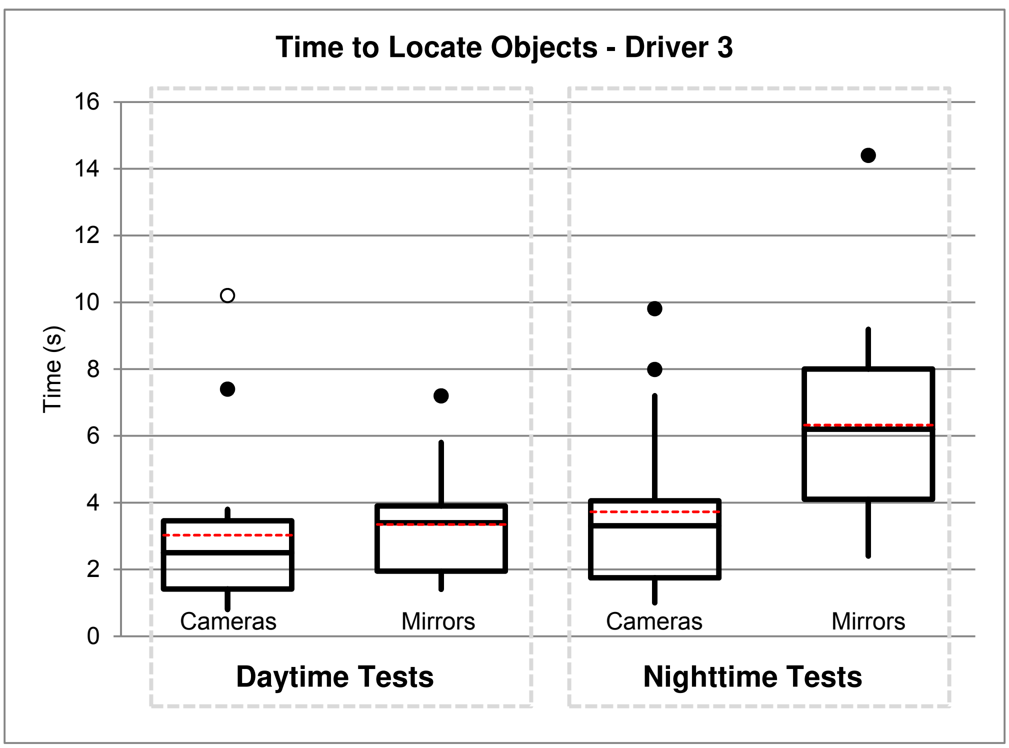

Figure 61: Time to locate test objects for object identification test (Driver 3)

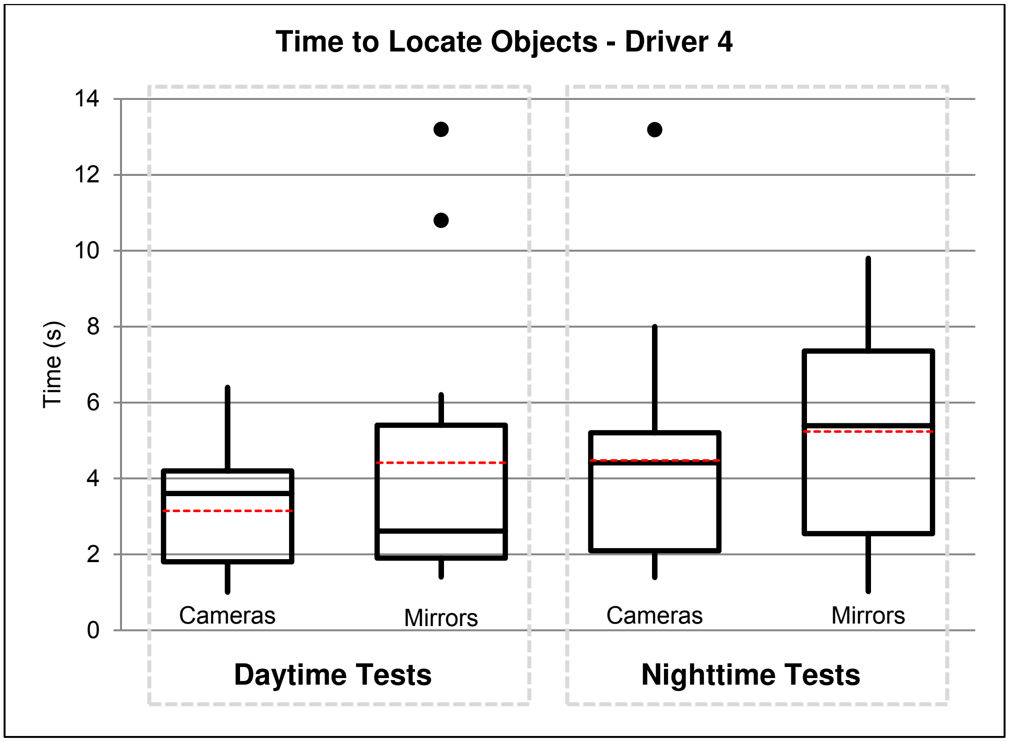

Figure 62: Time to locate test objects for object identification test (Driver 4)

6.2 Blind Spot Comparison

The results of the blind spot comparison tests for Driver 1 through Driver 4 are shown graphically in Figure 64 through Figure 67, respectively. The figures show two position vectors for each side of the subject vehicle. For the driver side tests, the position vector tail is located on the front left corner of the subject vehicle and the position vector head rests on the front right corner of the target vehicle. For the passenger side tests, the position vector tail is located on the front right corner of the subject vehicle and the position vector head rests on the front left corner of the target vehicle. An example of the position vector for the driver side tests is provided in Figure 63, shown in red. This vector was simply chosen to compare the results of each test subject while using both the camera-based indirect vision system and the mirror-based indirect vision system.

It is the angular difference between the two position vectors which shows the variation between the camera-based indirect vision system tests and the mirror-based indirect vision system tests. These angular differences are summarized in Table 79. However, the variation in the position vectors are a result of how the test subjects set up their indirect vision systems, camera or mirror. Although they were not able to change the field of views of the cameras, they were allowed, and requested to, change the direction in which the cameras pointed so that they had a visual field with which they were comfortable. They were also instructed to move their mirrors to provide them with the field of view they would have during normal operations of their vehicle.

Driver 1 and Driver 4, the most experienced test subjects, set up their cameras and mirrors in much the same way. This can be seen in Figure 64 and Figure 67 for Driver 1 and Driver 4 respectively, as well as in Table 79 where the angular differences are small for these drivers. Driver 3 had slightly larger angular differences due to system setup, but Driver 2 had the greatest difference between the two tested indirect vision systems. Driver 2 had set his fender mounted convex mirrors at more of an outward angle compared to the camera system than the other test subjects, as shown in Figure 65.

However, all of the test subjects were able to see the target vehicle within their direct line of sight prior to losing the vehicle in the indirect vision system under test; the target vehicle could always be seen by the test subjects regardless of the indirect vision system being used. The test results do not show superiority of one indirect vision system over another in terms of the size of the blind spots associated with each system.

Figure 68 shows all of the test results on one plot. This figure shows that there is not a large variation in the final location of the target vehicle for all tests.

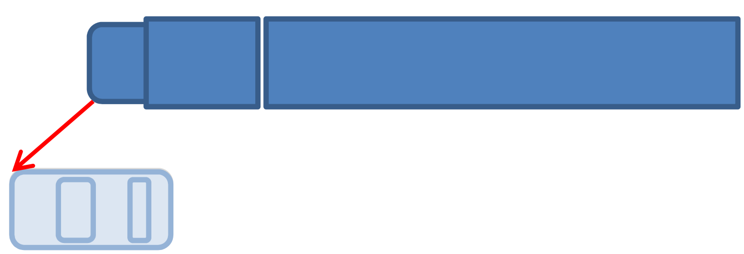

Figure 63: Position vectors for driver side blind spot comparison testing

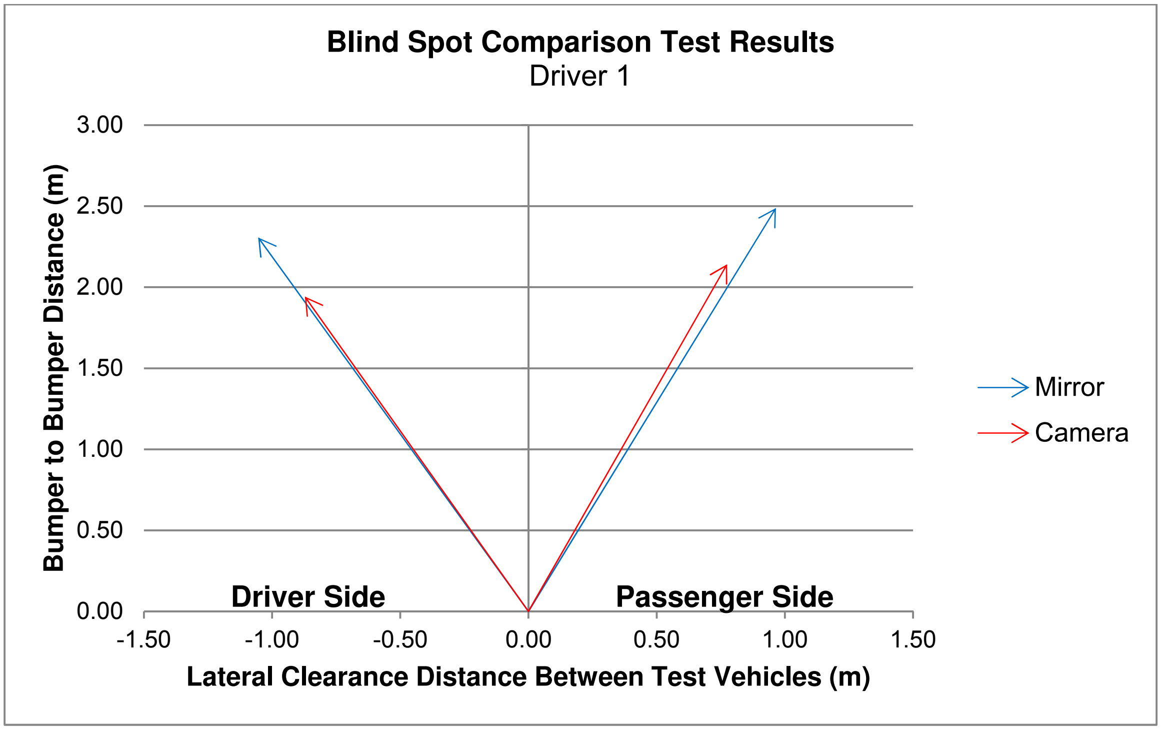

Figure 64: Blind spot comparison results for Driver 1

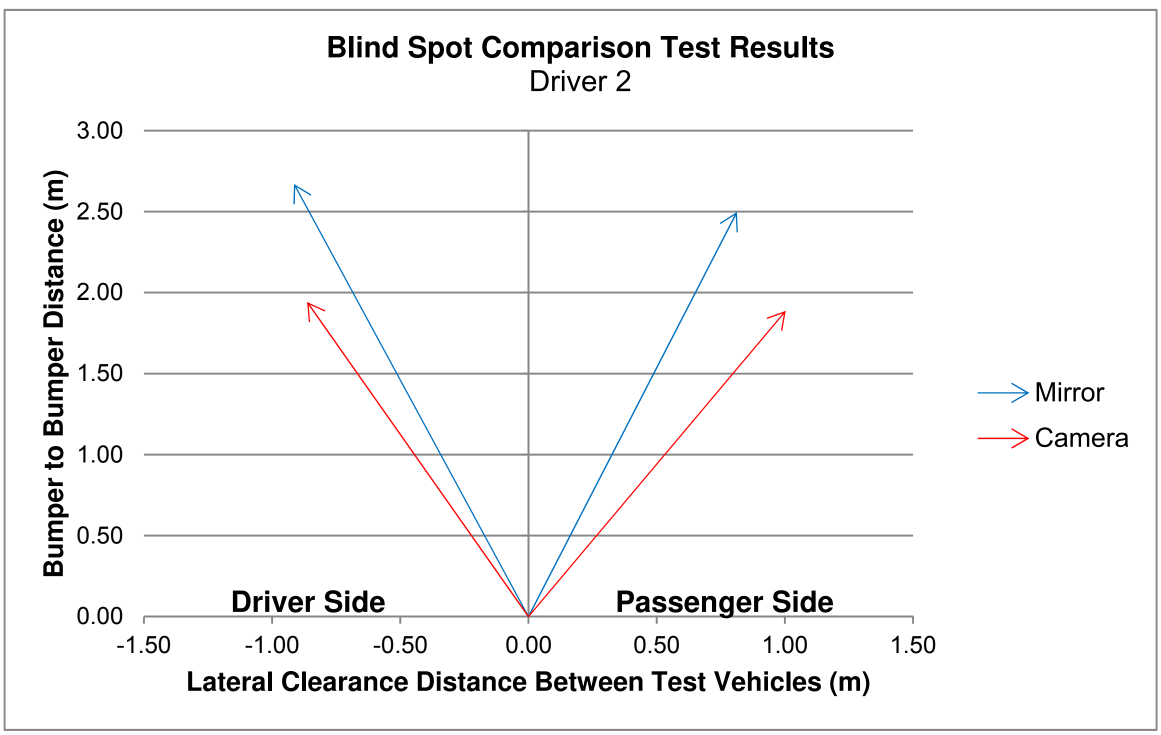

Figure 65: Blind spot comparison results for Driver 2

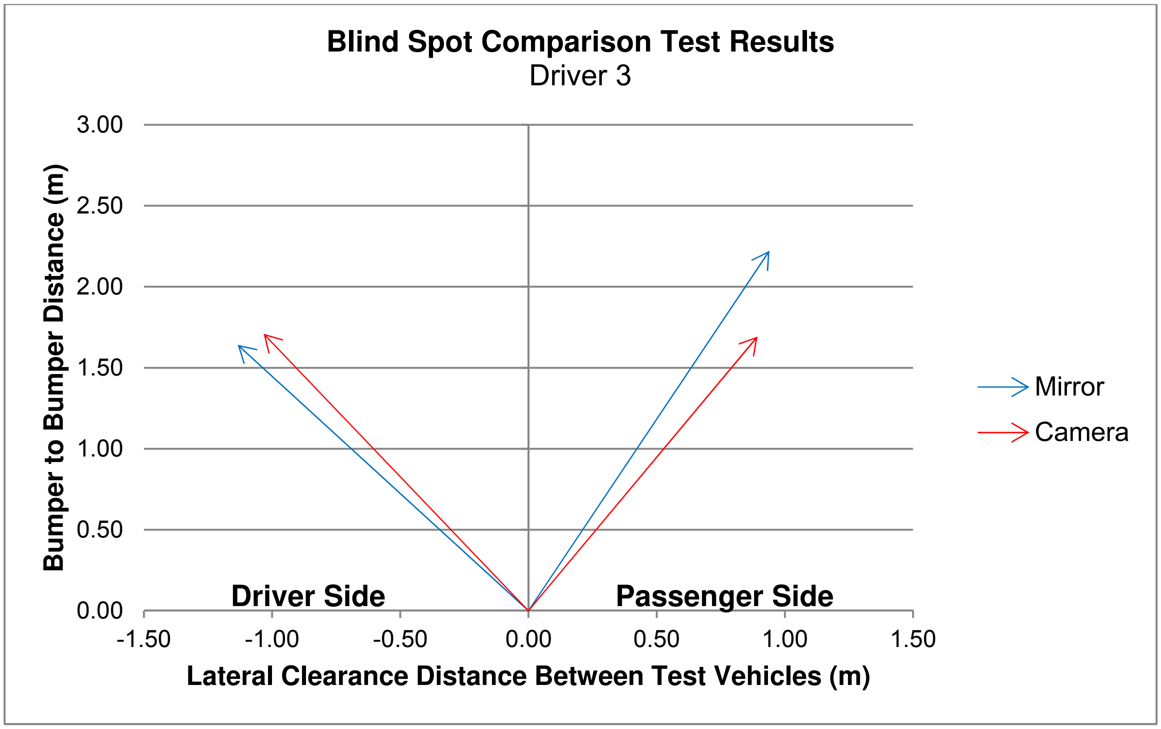

Figure 66: Blind spot comparison results for Driver 3

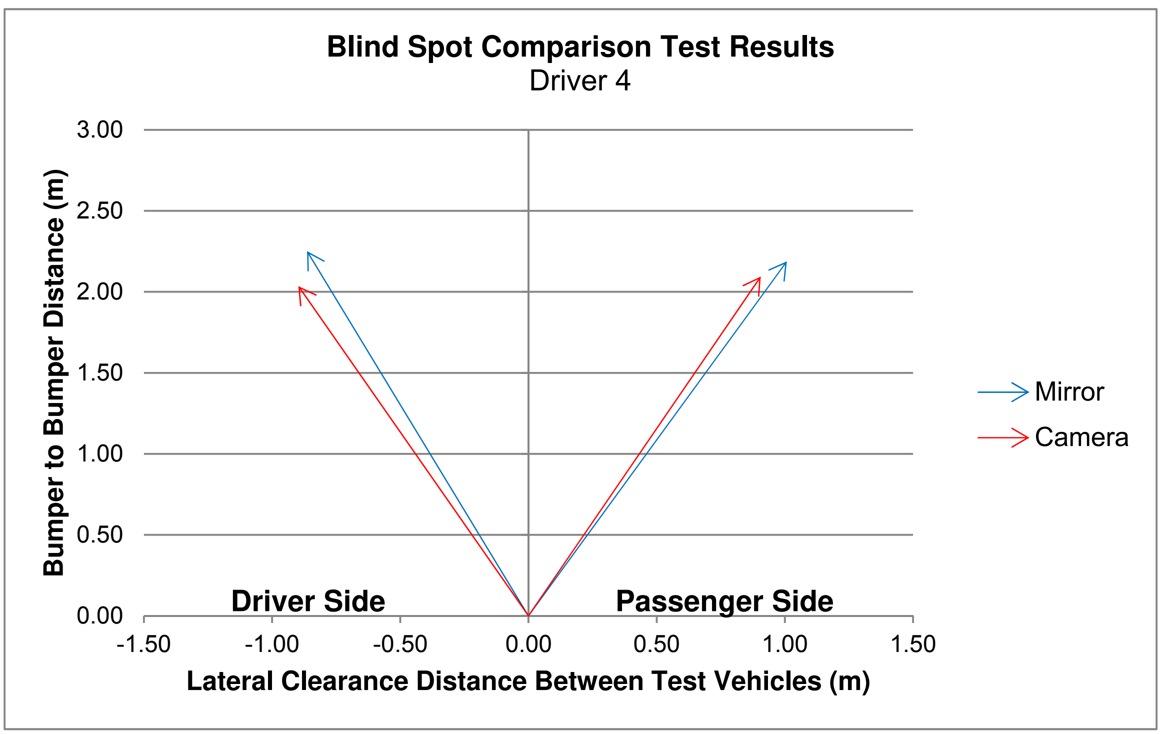

Figure 67: Blind spot comparison results for Driver 4

Table 79: Angular difference between position vectors for blind spot comparison test

Test Subject	Angular Difference (°)	
	Driver Side Test	Passenger Side Test
Driver 1	0.4	1.3
Driver 2	5.1	10.0
Driver 3	3.5	4.9
Driver 4	2.8	1.3

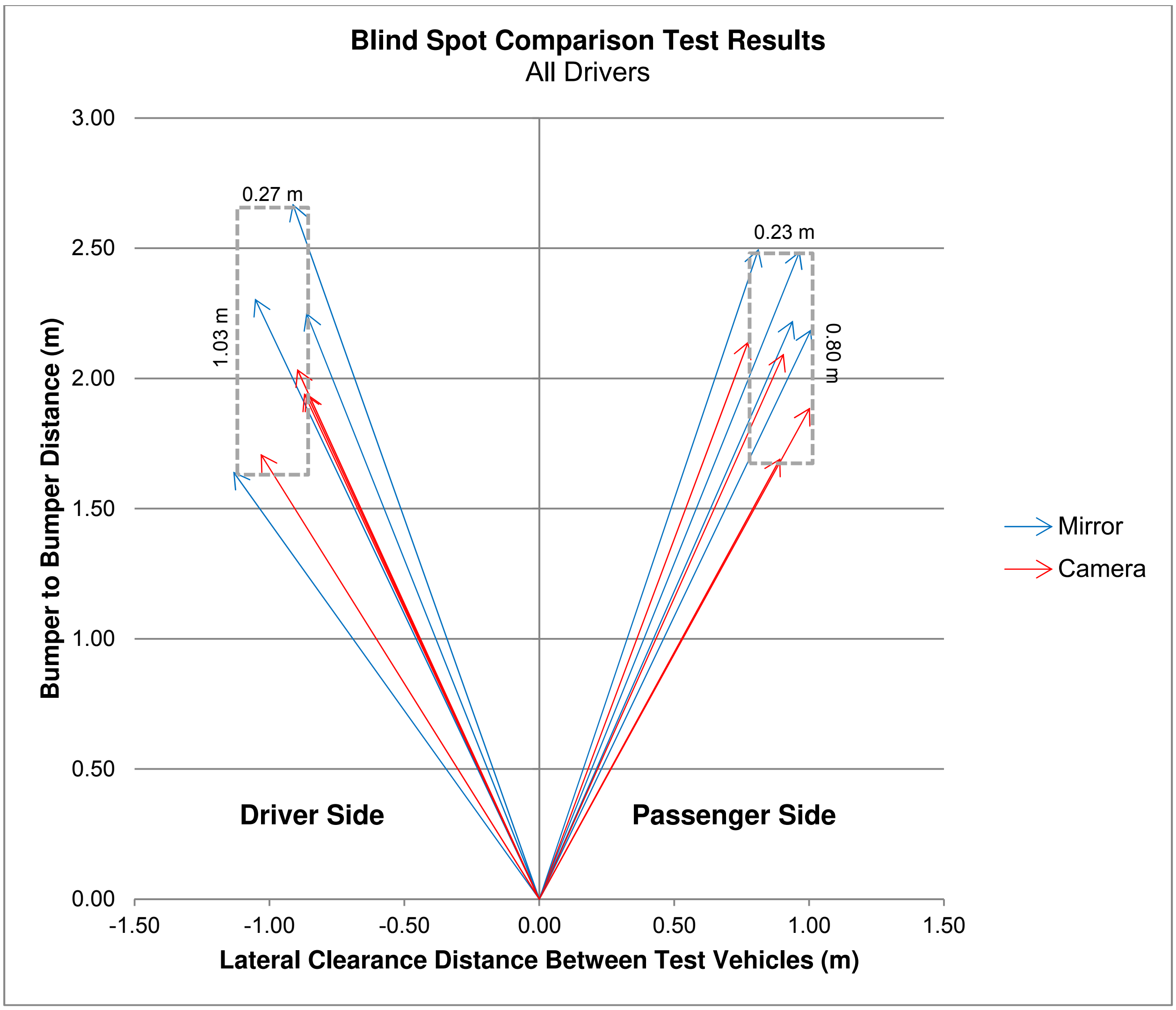

Figure 68: Blind spot comparison results for all drivers

6.3 Coupling and Uncoupling

The results of the coupling and uncoupling test for Driver 2 are shown graphically in Figure 69 and Figure 70. Although there was not a large difference in the number of cones struck by the test subject during testing (three cones struck while using the mirror-based indirect vision system and two cones struck when using the camera-based indirect vision system) it may be seen in the two figures that Driver 2 generally took more time to manoeuvre the subject vehicle with the camera-based indirect vision system than he did with the mirror-based indirect vision system. There were two exceptions where Driver 2 took less time manoeuvring the subject vehicle with the camera-based indirect vision system: trailer drop off manoeuvres during the nighttime tests for both driver side and passenger side approaches. When asked why he thought this was the case, Driver 2 stated that he found it easier to see the cones at night with the camera-based indirect vision system.

The average time it took Driver 2 to complete all coupling and uncoupling manoeuvers may be found in Table 80. It may be seen from the table that, on average, Driver 2 took less time to complete the manoeuvres with the mirror-based indirect vision system during daytime tests but less time with the camera-based indirect vision system tests during nighttime tests.

It should be noted that Driver 2 had the most difficulty with the passenger side approaches involving dropping off of the trailer into the simulated loading dock. His performance remained relatively constant across daytime and nighttime conditions while using the mirror-based indirect vision system, but improved considerably when using the camera-based indirect vision system. Again, this is most likely due to his improved ability to see the cones at night while using the camera-based indirect vision system. In general, Driver 2’s times to complete a particular manoeuvre with the mirror-based indirect vision system remained relatively constant between daytime and nighttime tests. However, Driver 2 showed considerable reductions in the times to complete the manoeuvres between daytime and nighttime tests while using the camera-based indirect vision system.

The results of the coupling and uncoupling test for Driver 3 are shown graphically in Figure 71 and Figure 72. The average time it took Driver 3 to complete all coupling and uncoupling manoeuvers may be found in Table 81. Again, on average, as with Driver 2, it took less time for Driver 3 to complete the coupling and uncoupling manoeuvres while using the mirror-based indirect vision system during daytime tests, but less time with camera-based indirect vision system during the nighttime tests.

It should be noted that the results for the average time for Driver 3 to complete the nighttime tests with the mirror-based indirect vision system are skewed due to the nearly 18.5 minutes it took the test subject to position the trailer when approaching the simulated loading dock from the driver side. Discussions with the driver after this test revealed no particular reason as to why this approach took as long as it did. Review of the video from this test also did not reveal any reason for the amount of time it took for the test subject to position the trailer. However, even after removing this test from the data set, the average time Driver 3 took to perform the coupling and uncoupling manoeuvres during nighttime tests was less while using the camera-based indirect vision system than it was using the mirror-based indirect vision system; 321 seconds on average for the mirror-based indirect vision system compared to 153 seconds for the camera-based indirect vision system.

In general, Driver 3’s times to complete a particular manoeuvre increased between daytime and nighttime conditions while using the mirror-based indirect vision system. However, the test subject’s times to complete a particular manoeuvre decreased between daytime and nighttime tests while using the camera-based indirect vision system.

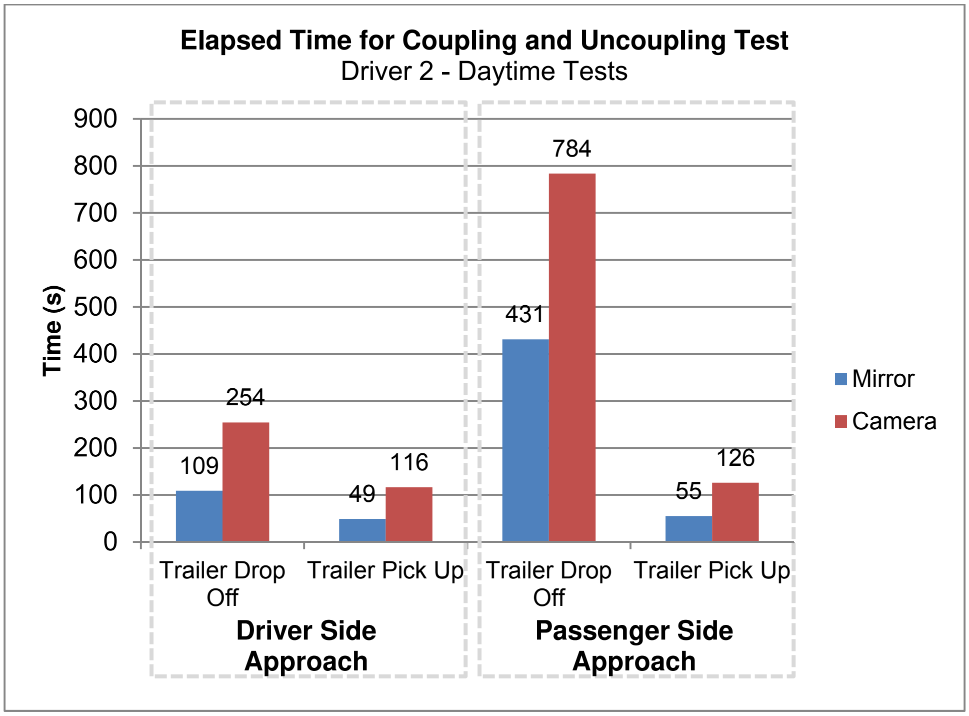

Figure 69: Elapsed time for daytime coupling and uncoupling tests (Driver 2)

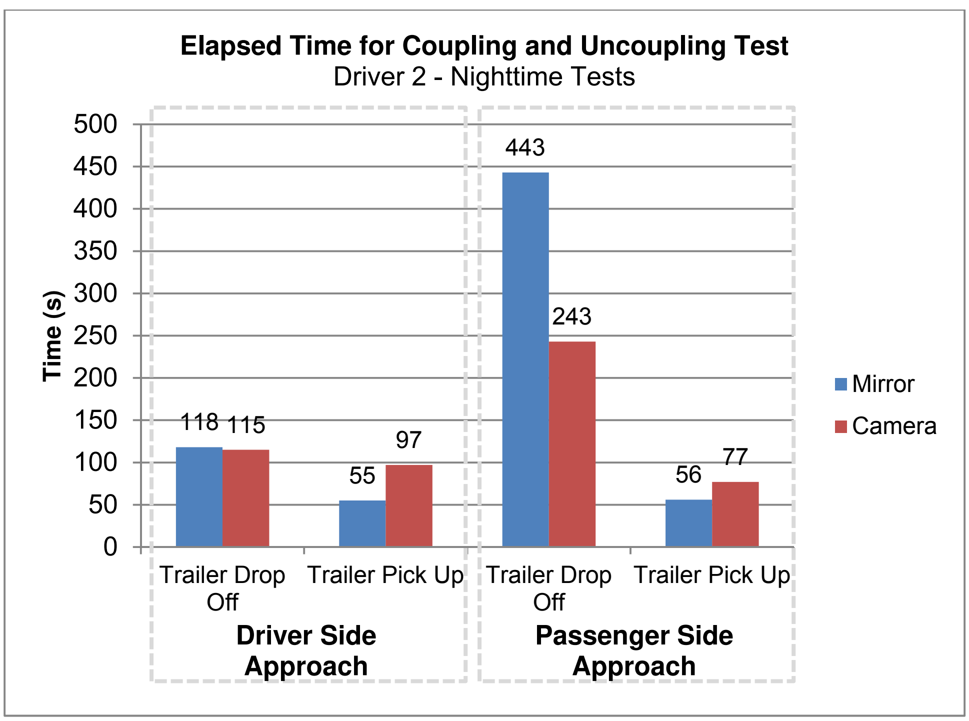

Figure 70: Elapsed time for nighttime coupling and uncoupling tests (Driver 2)

Table 80: Average times for completion of coupling and uncoupling test (Driver 2)

System Under Test	Average Time for Daytime Tests (s)	Average Time for Nighttime Tests (s)
Mirror-Based Indirect Vision System	161	168
Camera-Based Indirect Vision System	320	133

Table 81: Average times for completion of coupling and uncoupling test (Driver 3)

System Under Test	Average Time for Daytime Tests (s)	Average Time for Nighttime Tests (s)
Mirror-Based Indirect Vision System	190	518
Camera-Based Indirect Vision System	241	172

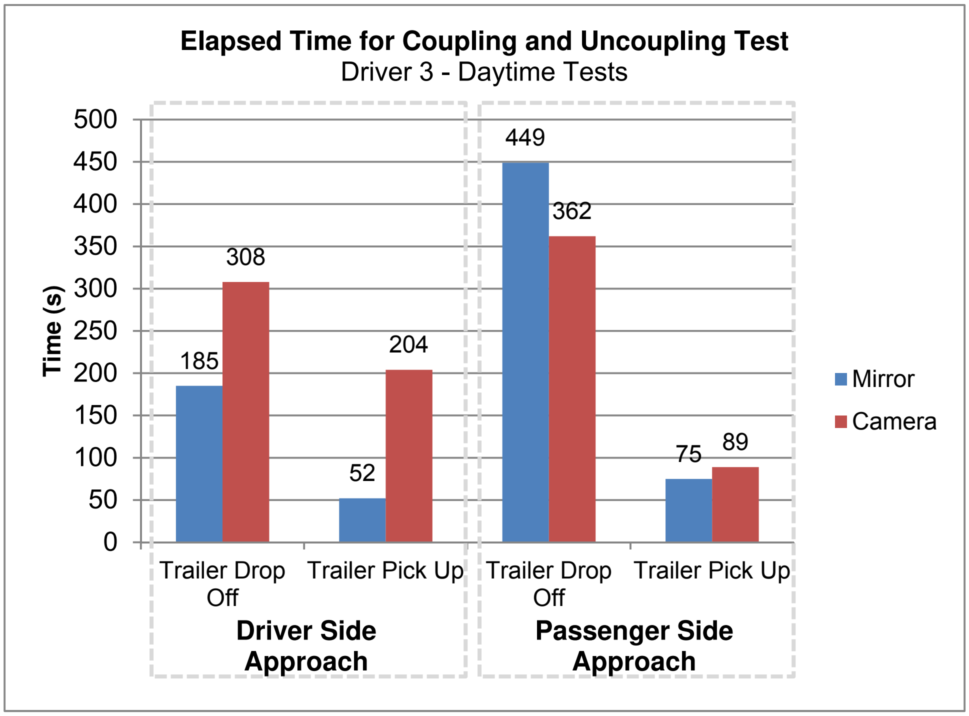

Figure 71: Elapsed time for daytime coupling and uncoupling tests (Driver 3)

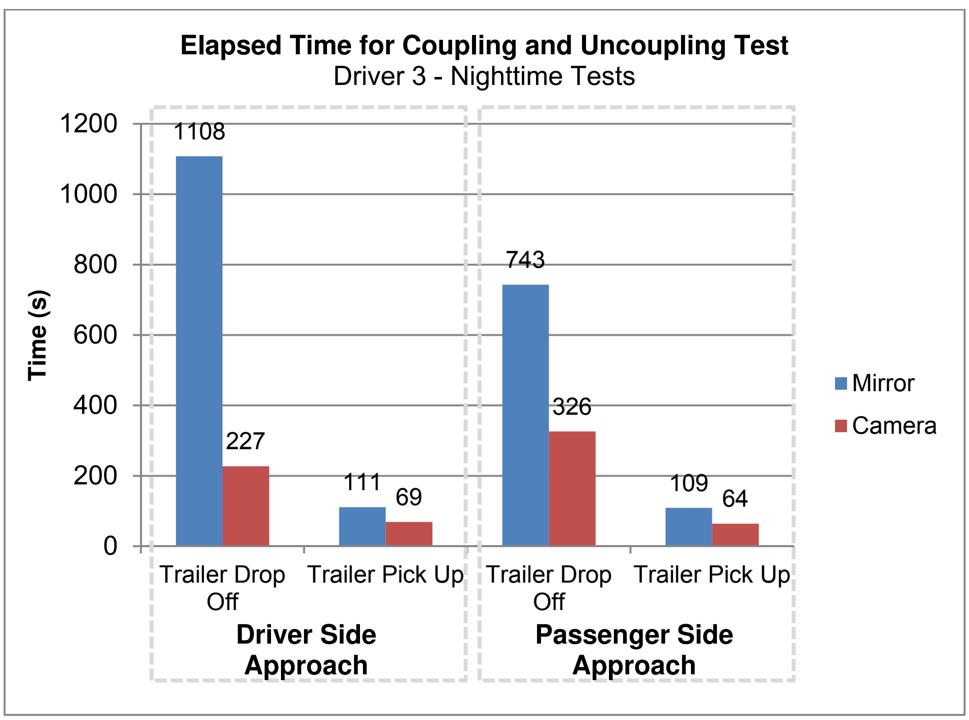

Figure 72: Elapsed time for nighttime coupling and uncoupling tests (Driver 3)

6.4 Quasi-Static Lane Change

A statistical analysis of the results of the quasi-static lane change test revealed that, for all but one of the tests, the mean perceived zero clearance distance position of the target vehicle was significantly different than the true zero clearance distance position. For neither the mirror-based indirect vision system nor the camera-based indirect vision system were the test subjects able to correctly perceive the position they were attempting to indicate.

The only test results which displayed insufficient evidence to infer that there was a mean of other than 0 m of perceived clearance distance was the daytime camera-based indirect vision system test with the target vehicle on the driver side of the subject vehicle performed by Driver 3, as shown in Figure 47 on page 79. However, it may be seen in this figure that there are two distinct sets of data: one when the target vehicle was moving in the forward direction (blue dots) and one when the target vehicle was moving in the reverse direction (red dots). The fact that the sample mean fell close to 0 m in this test is a result of the means of the two sets of data being roughly equidistant from the true zero clearance distance position of the target vehicle. This is not the only data set in which there appear to be two distinct sets of data.

As a result, the collected data will be analyzed as two distinct sets of data for each test: one while the target vehicle is moving in the forward direction and one while the target vehicle is moving in the reverse direction.

In addition to the segregated data being analyzed to determine whether it may be inferred that the population mean is other than 0 m, the data for mirror-based indirect vision system tests was compared to the data for the camera-based indirect vision system tests to determine whether it may be inferred that there exists a significant difference in the population means of these two data sets.

6.4.1 **Driver 1**

The results of the quasi-static lane change test with the target vehicle moving in the forward direction are summarized in Table 82 and Table 83. The results of the quasi-static lane change test with the target vehicle moving in the reverse direction are summarized in Table 84 and Table 85.

A statistical analysis of the results revealed that for only two of the sixteen data sets was there insufficient evidence to infer that the population mean of the perceived zero clearance distance position was other than 0 m. These two data sets occurred with the target vehicle moving in the reverse direction and were performed during nighttime conditions, one with the camera-based indirect vision system with the target vehicle positioned on the passenger side of the subject vehicle, the other performed with the mirror-based indirect vision system with the target vehicle positioned on the driver side of the subject vehicle. All other data sets provided statistically significant evidence that Driver 1 was not able to correctly perceive the true location of the zero clearance distance position of the target vehicle (p-values < 0.05).

A comparison of means t-test was performed on each set of data to determine whether there was any difference in population means between the tested indirect vision systems. The results of the tests (p-values) are provided in Table 86. From Table 86 it may be seen that only one of the eight sets of compared data showed insignificant evidence of statistical difference of population means. These sets of data were collected during the daytime tests with the target vehicle moving in reverse on the driver side of the subject vehicle. All other compared data sets provided sufficient evidence to infer that the population means of the two samples were significantly different.

However, despite there being insufficient evidence to infer a difference in the population means of the daytime tests with the target vehicle moving in reverse on the driver side of the subject vehicle, it may be seen in Table 84, as well as in Figure 73 and Figure 74 that the standard deviations and total spread of the collected data appear to differ. A comparison of variances F-test performed on this data confirms that the variances of these two data sets are indeed different (p-value < 0.00).

Table 82: Driver 1 quasi-static lane change test results with target vehicle moving forward (day)

	Camera-Based Indirect Vision System		Mirror-Based Indirect Vision System	
	Target Vehicle on Driver Side	Target Vehicle on Passenger Side	Target Vehicle on Driver Side	Target Vehicle on Passenger Side
Number of Samples	30	29	34	33
Average Clearance Distance (m)	2.497	2.408	0.331	0.876
Standard Deviation (m)	0.952	1.492	0.163	0.264
Maximum (m)	4.309	7.933	0.640	1.394
Minimum (m)	-0.721	0.293	0.019	0.105
Total Spread (m)	5.030	7.640	0.621	1.289

Table 83: Driver 1 quasi-static lane change test results with target vehicle moving forward (night)

	Camera-Based Indirect Vision System		Mirror-Based Indirect Vision System	
	Target Vehicle on Driver Side	Target Vehicle on Passenger Side	Target Vehicle on Driver Side	Target Vehicle on Passenger Side
Number of Samples	32	30	35	30
Average Clearance Distance (m)	2.242	-0.519	3.227	0.587
Standard Deviation (m)	1.110	1.482	0.792	1.085
Maximum (m)	5.404	2.526	4.570	2.894
Minimum (m)	0.076	-3.231	0.353	-1.181
Total Spread (m)	5.328	5.757	4.217	4.075

Table 84: Driver 1 quasi-static lane change test results with target vehicle moving in reverse (day)

	Camera-Based Indirect Vision System		Mirror-Based Indirect Vision System	
	Target Vehicle on Driver Side	Target Vehicle on Passenger Side	Target Vehicle on Driver Side	Target Vehicle on Passenger Side
Number of Samples	31	32	33	32
Average Clearance Distance (m)	0.387	-0.340	0.262	0.533
Standard Deviation (m)	0.569	0.386	0.181	0.116
Maximum (m)	1.448	0.664	0.714	0.806
Minimum (m)	-0.841	-1.131	-0.002	0.353
Total Spread (m)	2.289	1.795	0.716	0.453

Table 85: Driver 1 quasi-static lane change test results with target vehicle moving in reverse (night)

	Camera-Based Indirect Vision System		Mirror-Based Indirect Vision System	
	Target Vehicle on Driver Side	Target Vehicle on Passenger Side	Target Vehicle on Driver Side	Target Vehicle on Passenger Side
Number of Samples	32	29	32	30
Average Clearance Distance (m)	-0.524	-0.309	0.174	0.428
Standard Deviation (m)	0.925	1.660	0.837	0.911
Maximum (m)	1.394	5.060	1.576	1.777
Minimum (m)	-1.913	-3.980	-1.880	-1.554
Total Spread (m)	3.307	9.040	3.455	3.331

Table 86: Results of comparison of means test for quasi-static lane change test (Driver 1)

		Target Vehicle on Driver Side (p-value)	Target Vehicle on Passenger Side (p-value)
Daytime Tests	**Target Vehicle Moving Forward**	< 0.000	< 0.000
	Target Vehicle Moving in Reverse	0.249	< 0.000
Nighttime Tests	**Target Vehicle Moving Forward**	< 0.000	< 0.000
	Target Vehicle Moving in Reverse	< 0.002	0.041

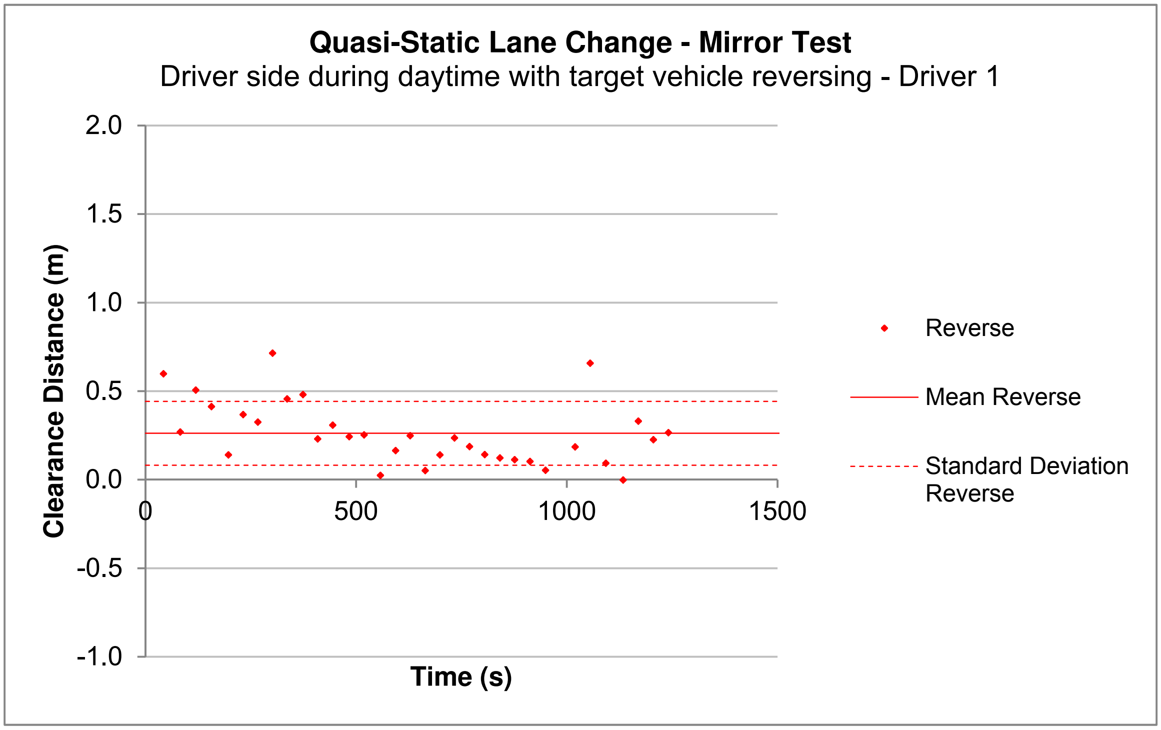

Figure 73: Driver 1 quasi-static lane change results for mirror test with target vehicle on driver side moving in reverse direction (day)

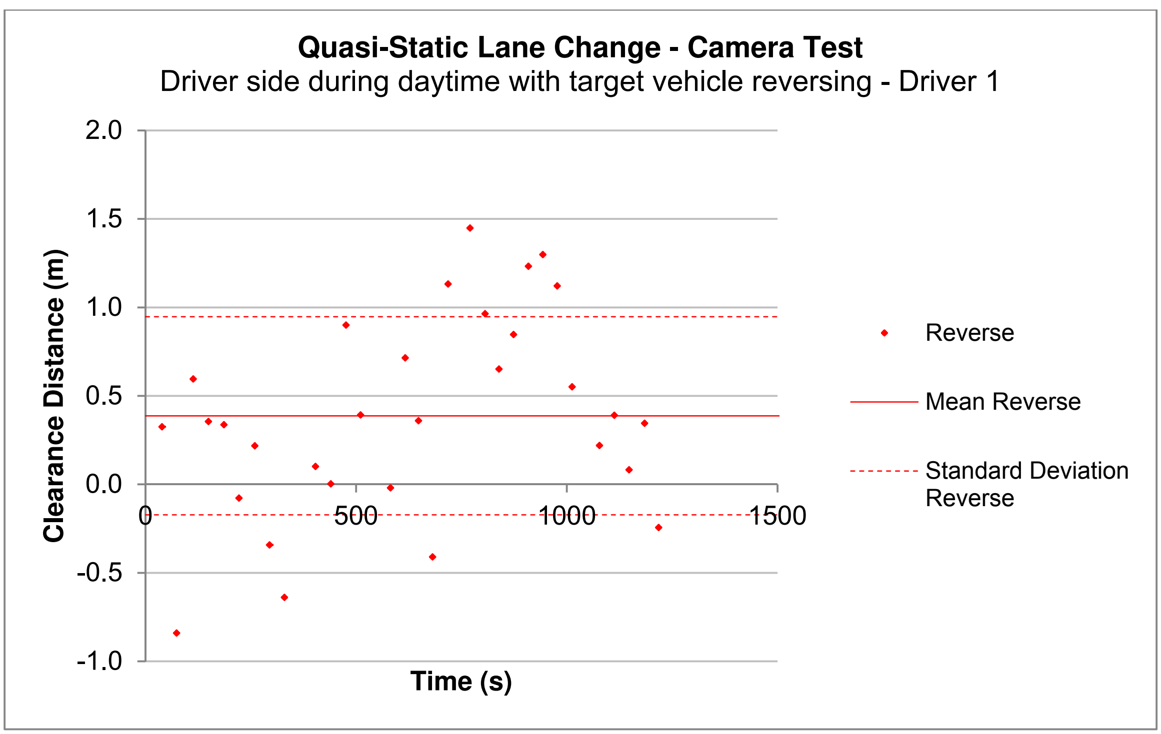

Figure 74: Driver 1 quasi-static lane change results for camera test with target vehicle on driver side moving in reverse direction (day)

6.4.2 Driver 2

The results of the quasi-static lane change test with the target vehicle moving in the forward direction are summarized in Table 87 and Table 88. The results of the quasi-static lane change test with the target vehicle moving in the reverse direction are summarized in Table 89 and Table 90.

A statistical analysis of the results revealed that all of the sixteen data sets provided statistically significant evidence that Driver 2 was not able to correctly perceive the true location of the zero clearance distance position of the target vehicle (p-values < 0.05).

A comparison of means t-test was performed on each set of data to determine whether there was any difference in population means between the tested indirect vision systems. The results of the tests (p-values) are provided in Table 91. From Table 91 it may be seen that only one of the eight sets of compared data showed insignificant evidence of statistical difference of population means. These sets of data were collected during the daytime tests with the target vehicle moving in reverse on the driver side of the subject vehicle. All other compared data sets provided sufficient evidence to infer that the population means of the two samples were significantly different.

However, despite there being insufficient evidence to infer a difference in the population means of the daytime tests with the target vehicle moving in reverse on the driver side of the subject vehicle, it may be seen in Table 89, as well as in Figure 75 and Figure 76 that the standard deviations and total spread of the collected data appear to differ. A comparison of variances F-test performed on this data confirms that the variances of these two data sets are indeed different (p-value < 0.00).

Table 87: Driver 2 quasi-static lane change test results with target vehicle moving forward (day)

	Camera-Based Indirect Vision System		Mirror-Based Indirect Vision System	
	Target Vehicle on Driver Side	Target Vehicle on Passenger Side	Target Vehicle on Driver Side	Target Vehicle on Passenger Side
Number of Samples	34	34	33	33
Average Clearance Distance (m)	4.329	5.579	3.270	2.115
Standard Deviation (m)	0.805	0.705	0.752	0.605
Maximum (m)	6.393	6.849	5.054	3.896
Minimum (m)	3.276	3.931	1.637	1.114
Total Spread (m)	3.117	2.918	3.417	2.781

Table 88: Driver 2 quasi-static lane change test results with target vehicle moving forward (night)

	Camera-Based Indirect Vision System		Mirror-Based Indirect Vision System	
	Target Vehicle on Driver Side	Target Vehicle on Passenger Side	Target Vehicle on Driver Side	Target Vehicle on Passenger Side
Number of Samples	37	34	34	35
Average Clearance Distance (m)	7.081	4.934	1.338	1.471
Standard Deviation (m)	0.734	1.322	0.680	0.974
Maximum (m)	7.983	7.053	2.718	3.650
Minimum (m)	4.792	0.684	-0.139	-0.537
Total Spread (m)	3.191	6.369	2.857	4.188

Table 89: Driver 2 quasi-static lane change test results with target vehicle moving in reverse (day)

	Camera-Based Indirect Vision System		Mirror-Based Indirect Vision System	
	Target Vehicle on Driver Side	Target Vehicle on Passenger Side	Target Vehicle on Driver Side	Target Vehicle on Passenger Side
Number of Samples	34	36	33	33
Average Clearance Distance (m)	2.297	5.968	2.353	1.663
Standard Deviation (m)	1.056	1.385	0.541	0.515
Maximum (m)	4.236	7.982	3.342	2.650
Minimum (m)	0.337	3.697	0.972	0.618
Total Spread (m)	3.899	4.285	2.370	2.033

Table 90: Driver 2 quasi-static lane change test results with target vehicle moving in reverse (night)

	Camera-Based Indirect Vision System		Mirror-Based Indirect Vision System	
	Target Vehicle on Driver Side	Target Vehicle on Passenger Side	Target Vehicle on Driver Side	Target Vehicle on Passenger Side
Number of Samples	36	35	34	35
Average Clearance Distance (m)	6.532	3.383	1.256	0.903
Standard Deviation (m)	1.057	2.074	1.144	1.177
Maximum (m)	7.983	7.780	3.037	3.678
Minimum (m)	3.760	-0.523	-0.884	-1.413
Total Spread (m)	4.223	8.303	3.922	5.091

Table 91: Results of comparison of means test for quasi-static lane change test (Driver 2)

		Target Vehicle on Driver Side (p-value)	Target Vehicle on Passenger Side (p-value)
Daytime Tests	**Target Vehicle Moving Forward**	0.000	0.000
	Target Vehicle Moving in Reverse	0.783	0.000
Nighttime Tests	**Target Vehicle Moving Forward**	0.000	0.000
	Target Vehicle Moving in Reverse	0.000	0.000

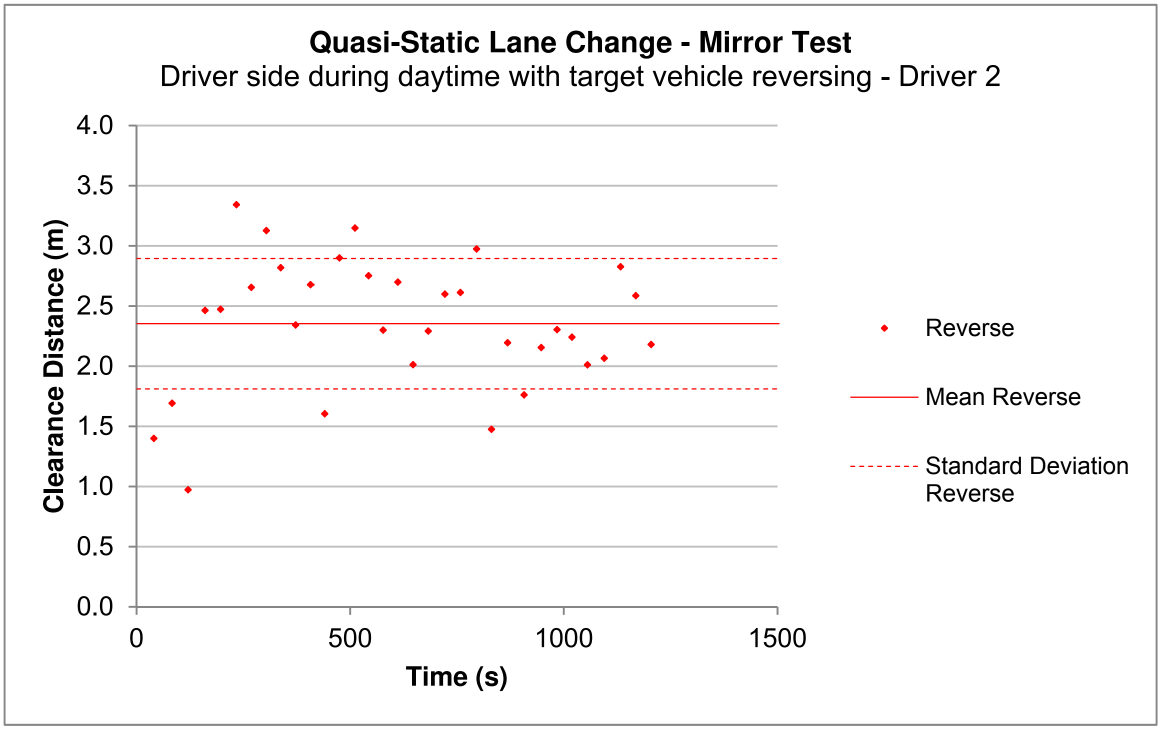

Figure 75: Driver 2 quasi-static lane change results for mirror test with target vehicle on driver side moving in reverse direction (day)

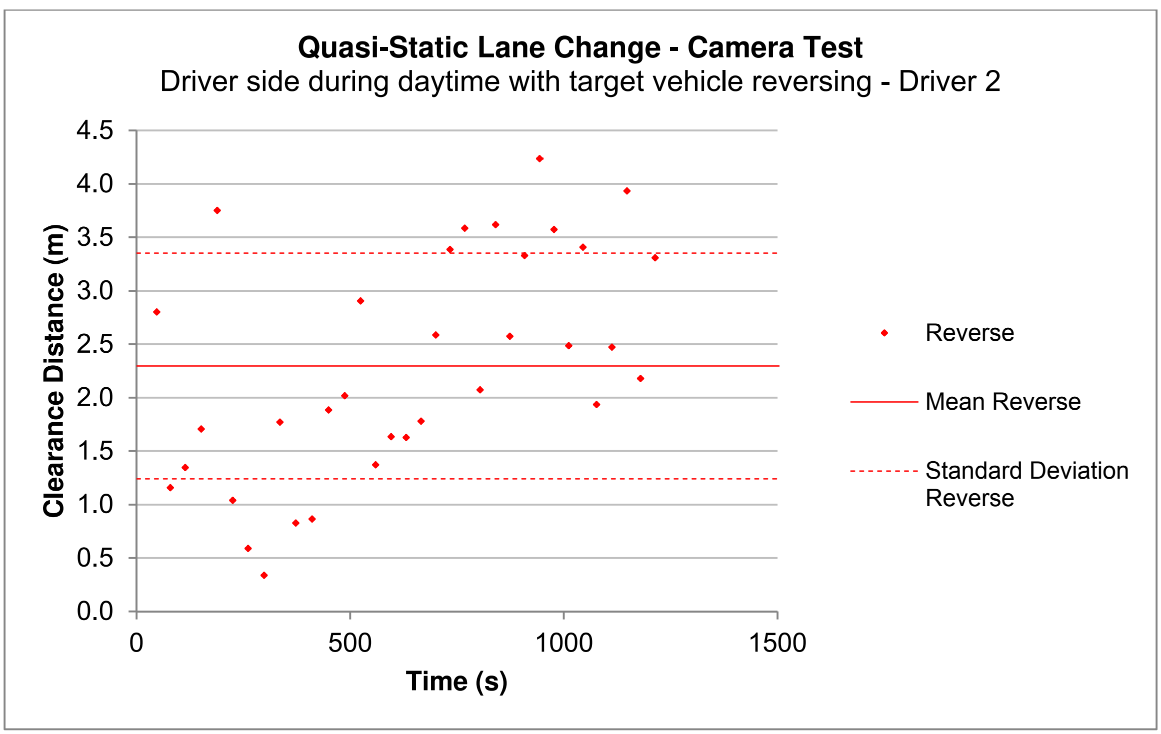

Figure 76: Driver 2 quasi-static lane change results for camera test with target vehicle on driver side moving in reverse direction (day)

6.4.3 **Driver 3**

The results of the quasi-static lane change test with the target vehicle moving in the forward direction are summarized in Table 92 and Table 93. The results of the quasi-static lane change test with the target vehicle moving in the reverse direction are summarized in Table 94 and Table 95.

A statistical analysis of the results revealed that for only three of the sixteen data sets was there insufficient evidence to infer that the population mean of the perceived zero clearance distance position was other than 0 m. All three of these data sets occurred with the target vehicle moving in the forward direction positioned on the passenger side of the subject vehicle. One of the tests was performed with the camera-based indirect vision system during the day. The other two tests were performed with the mirror-based indirect vision system; one during daytime tests the other during nighttime tests. All other data sets provided statistically significant evidence that Driver 3 was not able to correctly perceive the true location of the zero clearance distance position of the target vehicle (p-values < 0.05).

A comparison of means t-test was performed on each set of data to determine whether there was any difference in population means between each of the tested indirect vision systems. The results of the tests (p-values) are provided in Table 96. From Table 96 it may be seen that three of the eight sets of compared data showed insignificant evidence of statistical difference of population means. All other compared data sets provided sufficient evidence to infer that the population means of the two samples were significantly different.

The data set pairs which provided insufficient evidence to infer that their population means differ from one another were collected during the day with the target vehicle traveling in the forward direction positioned on the passenger side of the subject vehicle, and during the night with the target vehicle moving in the reverse direction, positioned on both driver and passenger sides of the subject vehicle.

The data collected during the day with the target vehicle traveling in the forward direction positioned on the passenger side of the subject vehicle is presented in Figure 77 and Figure 78. It may be observed by comparing these two figures that not only was Driver 3 successful in determining the location of the zero clearance distance position, but, based upon comparison of variations, there was also no significant difference between his performance between the camera-based and mirror-based indirect vision systems.

The data collected during the night with the target vehicle moving in the reverse direction is presented in Figure 79 and Figure 80 with the target vehicle positioned on the driver side of the subject vehicle, and in Figure 81 and Figure 82 with the target vehicle positioned on the passenger side of the subject vehicle. By comparing Figure 79 and Figure 80, it may be observed that Driver 3's performance between the camera-based and mirror-based indirect vision systems was not significantly different. Similar observations may be made by comparing Figure 81 and Figure 82.

Table 92: Driver 3 quasi-static lane change test results with target vehicle moving forward (day)

	Camera-Based Indirect Vision System		Mirror-Based Indirect Vision System	
	Target Vehicle on Driver Side	Target Vehicle on Passenger Side	Target Vehicle on Driver Side	Target Vehicle on Passenger Side
Number of Samples	34	37	40	41
Average Clearance Distance (m)	-1.650	-0.055	-1.069	0.187
Standard Deviation (m)	0.605	1.227	1.274	1.490
Maximum (m)	-0.547	3.613	1.950	7.106
Minimum (m)	-3.573	-3.230	-3.643	-2.102
Total Spread (m)	3.026	6.843	5.593	9.208

Table 93: Driver 3 quasi-static lane change test results with target vehicle moving forward (night)

	Camera-Based Indirect Vision System		Mirror-Based Indirect Vision System	
	Target Vehicle on Driver Side	Target Vehicle on Passenger Side	Target Vehicle on Driver Side	Target Vehicle on Passenger Side
Number of Samples	42	40	40	38
Average Clearance Distance (m)	-1.102	-1.161	1.615	0.037
Standard Deviation (m)	2.302	2.661	1.620	1.811
Maximum (m)	7.978	7.966	7.978	3.105
Minimum (m)	-5.079	-5.122	-1.509	-3.796
Total Spread (m)	13.057	13.088	9.487	6.901

Table 94: Driver 3 quasi-static lane change test results with target vehicle moving in reverse (day)

	Camera-Based Indirect Vision System		Mirror-Based Indirect Vision System	
	Target Vehicle on Driver Side	Target Vehicle on Passenger Side	Target Vehicle on Driver Side	Target Vehicle on Passenger Side
Number of Samples	35	37	37	40
Average Clearance Distance (m)	1.151	3.268	4.235	5.114
Standard Deviation (m)	1.466	1.524	0.937	1.039
Maximum (m)	2.666	5.402	6.457	7.348
Minimum (m)	-6.224	0.174	2.078	3.012
Total Spread (m)	8.890	5.228	4.380	4.336

Table 95: Driver 3 quasi-static lane change test results with target vehicle moving in reverse (night)

	Camera-Based Indirect Vision System		Mirror-Based Indirect Vision System	
	Target Vehicle on Driver Side	Target Vehicle on Passenger Side	Target Vehicle on Driver Side	Target Vehicle on Passenger Side
Number of Samples	38	40	38	38
Average Clearance Distance (m)	6.580	4.372	6.710	4.047
Standard Deviation (m)	1.618	3.149	1.205	2.246
Maximum (m)	7.978	7.974	7.980	7.951
Minimum (m)	-0.429	-6.161	2.486	-1.749
Total Spread (m)	8.408	14.135	5.494	9.700

Table 96: Results of comparison of means test for quasi-static lane change test (Driver 2)

		Target Vehicle on Driver Side (p-value)	Target Vehicle on Passenger Side (p-value)
Daytime Tests	**Target Vehicle Moving Forward**	0.013	0.438
	Target Vehicle Moving in Reverse	0.000	0.000
Nighttime Tests	**Target Vehicle Moving Forward**	0.000	0.023
	Target Vehicle Moving in Reverse	0.693	0.600

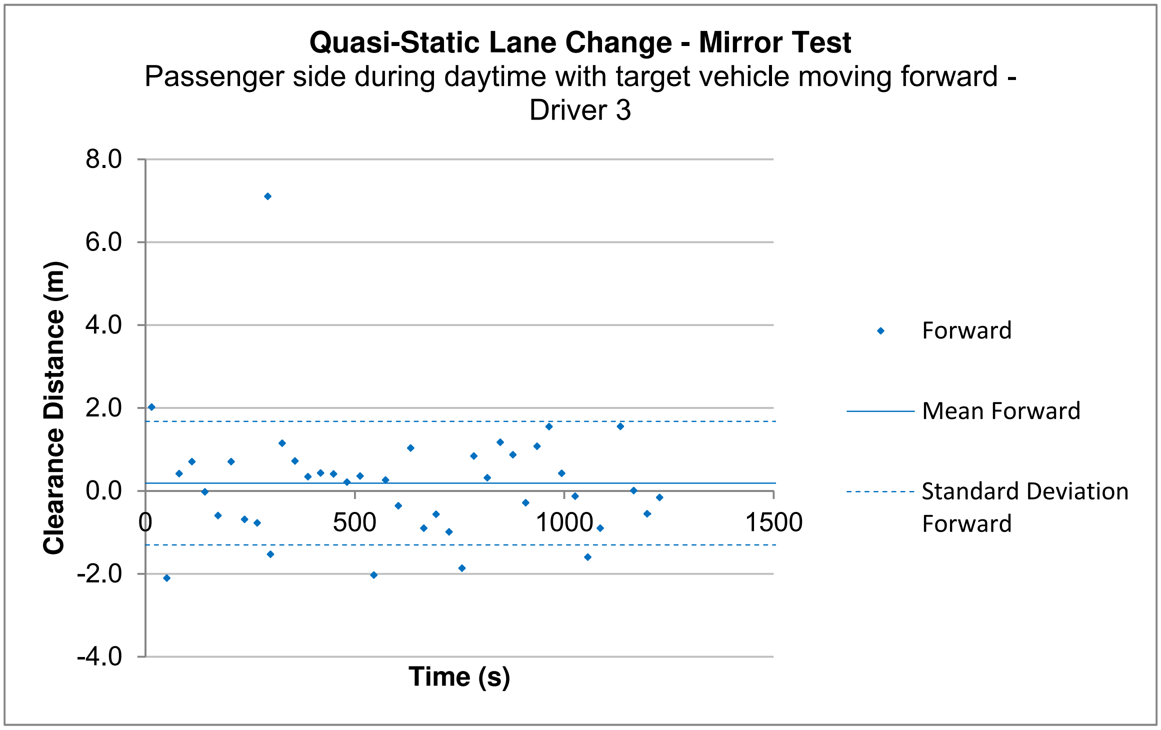

Figure 77: Driver 3 quasi-static lane change results for mirror test with target vehicle on driver side moving in forward direction (day)

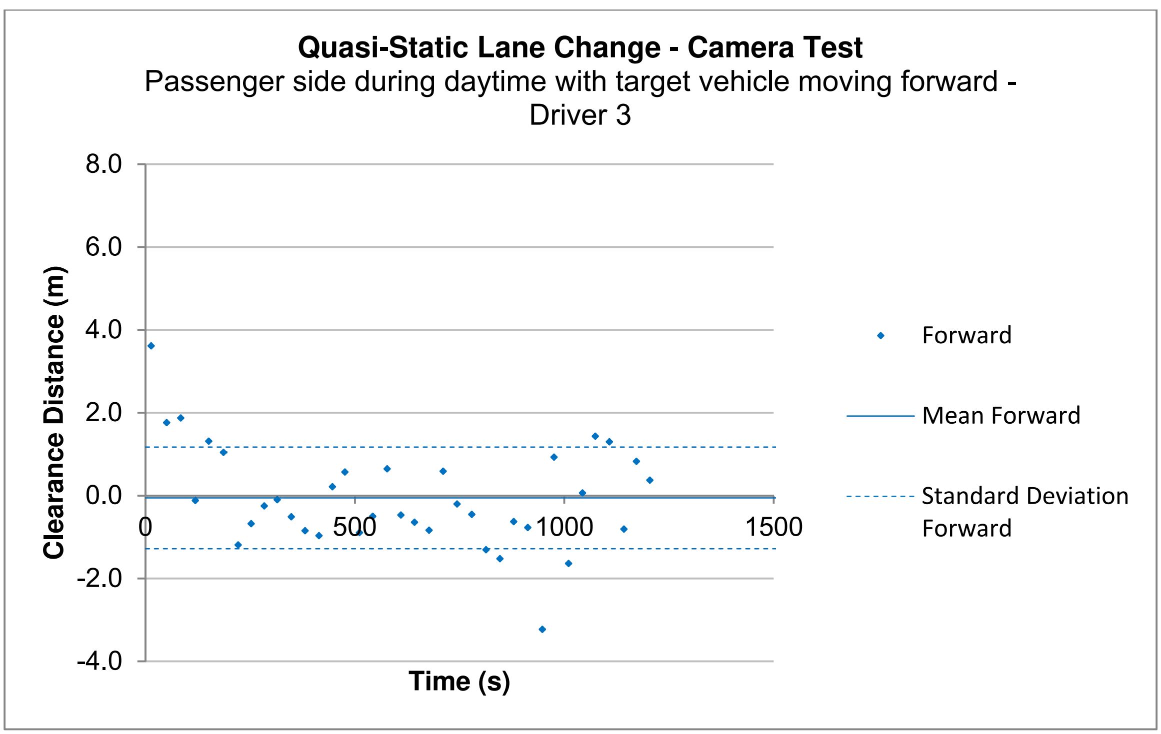

Figure 78: Driver 3 quasi-static lane change results for camera test with target vehicle on driver side moving in forward direction (day)

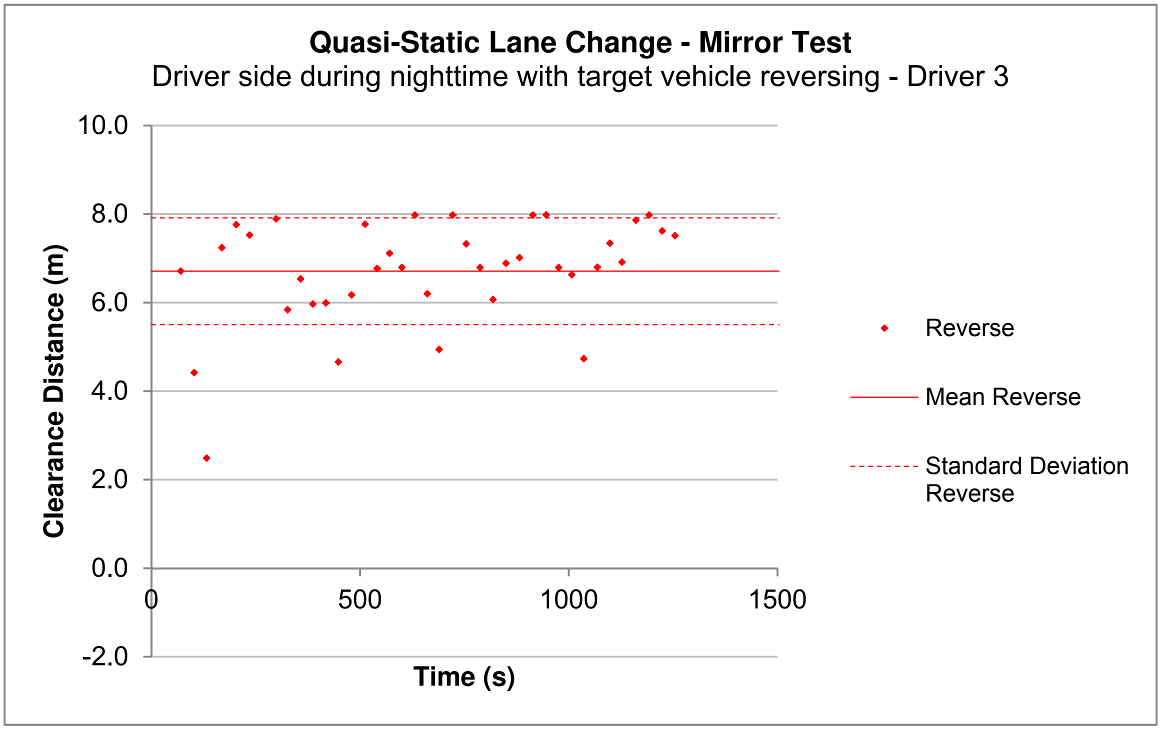

Figure 79: Driver 3 quasi-static lane change results for mirror test with target vehicle on driver side moving in reverse direction (night)

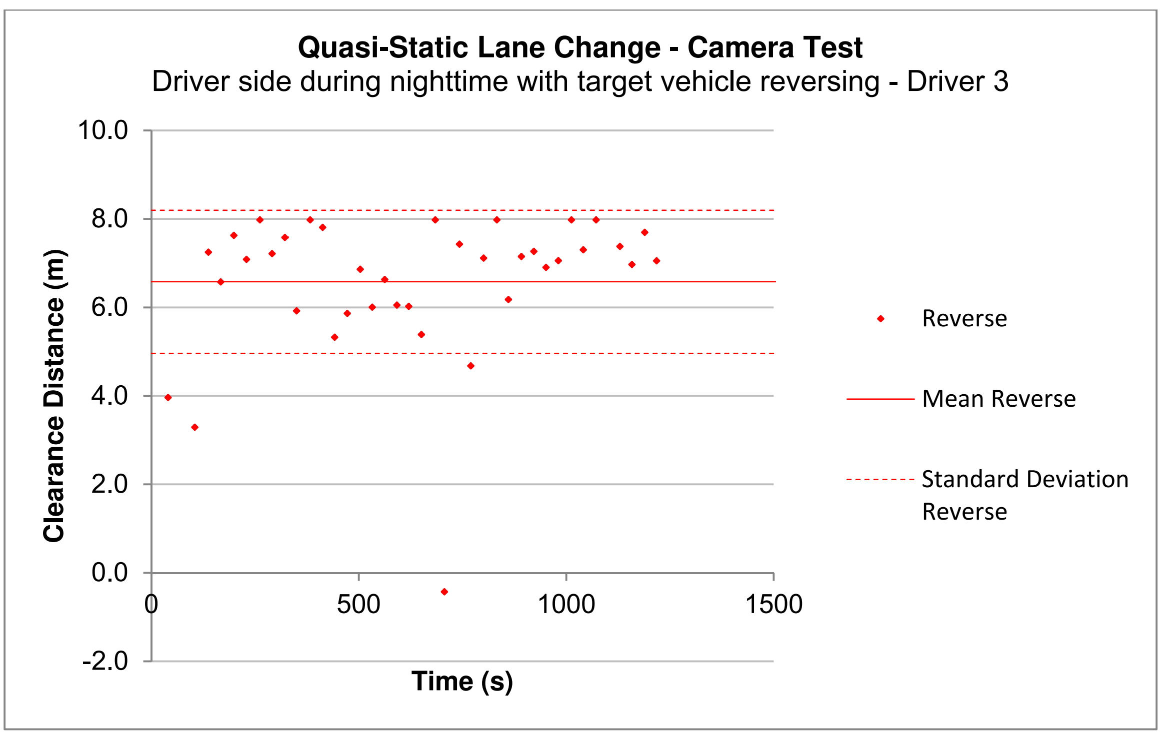

Figure 80: Driver 3 quasi-static lane change results for camera test with target vehicle on driver side moving in reverse direction (night)

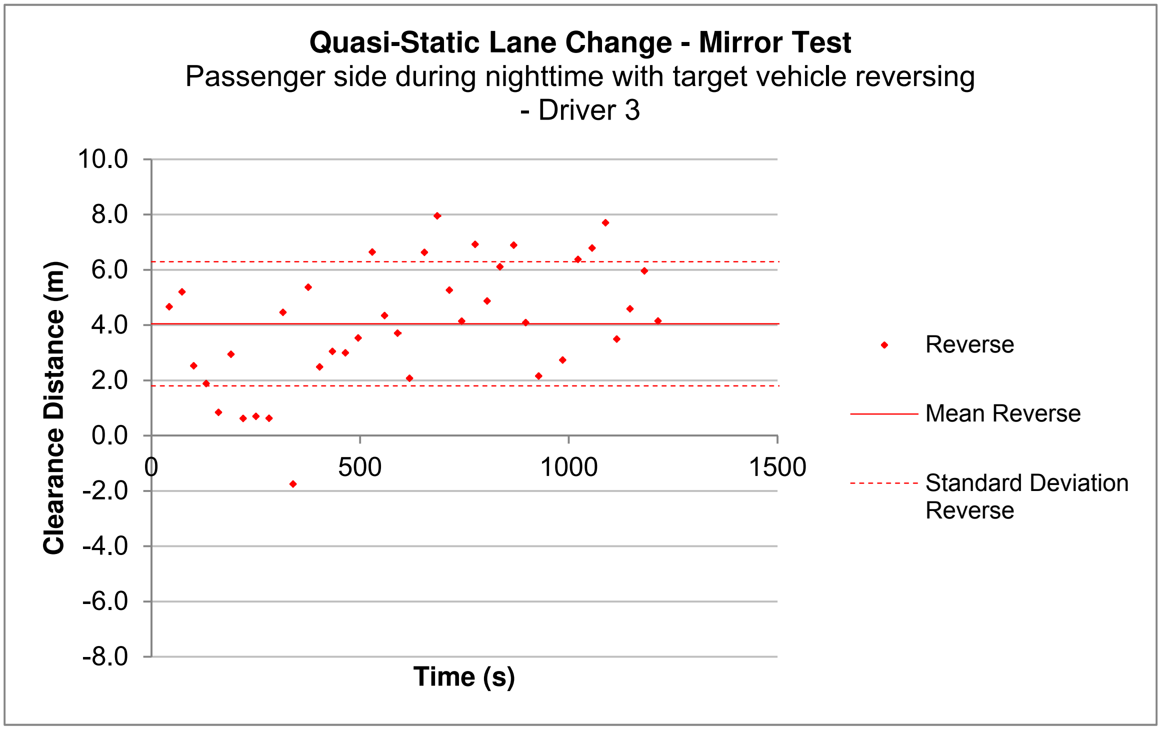

Figure 81: Driver 3 quasi-static lane change results for mirror test with target vehicle on passenger side moving in reverse direction (night)

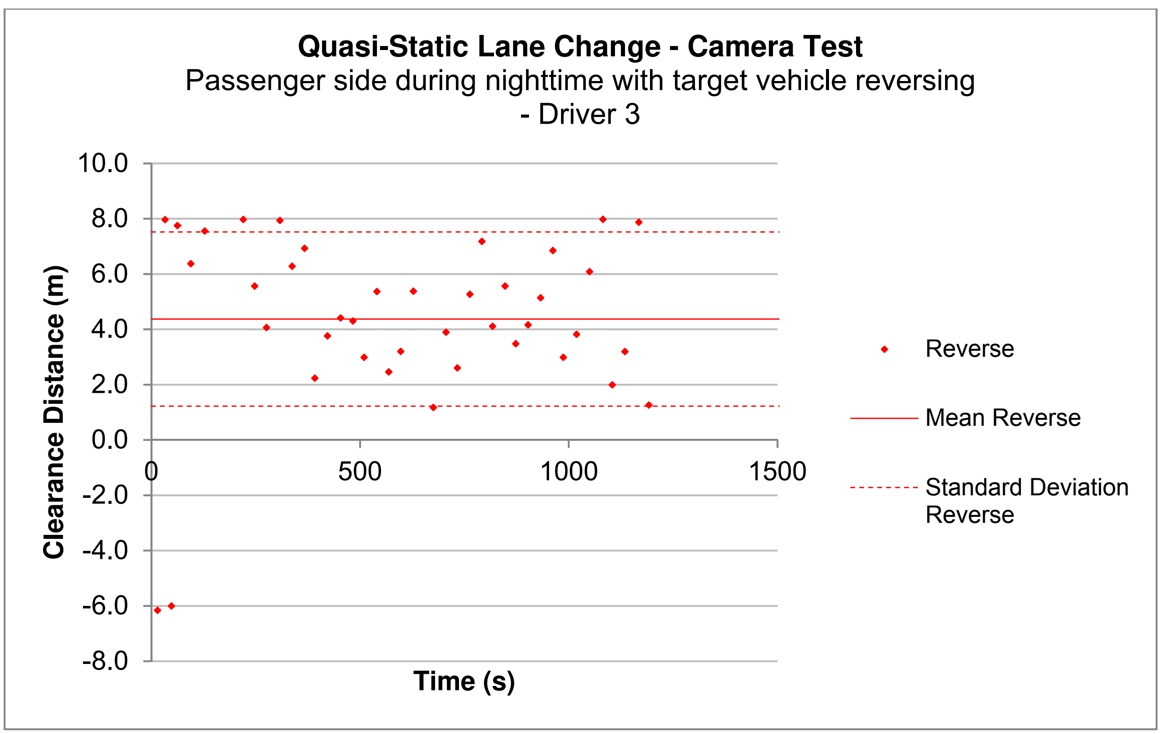

Figure 82: Driver 3 quasi-static lane change results for camera test with target vehicle on passenger side moving in reverse direction (night)

6.5 Dynamic Lane Change

The results of the dynamic lane change test for Driver 2 are presented graphically in Figure 83 and Figure 84. Both of these figures show that the test subject allowed for much more clearance distance while using the camera-based indirect vision system than he did while using the mirror-based indirect vision system. Figure 83 shows that Driver 2 allowed about twice as much clearance distance while changing lanes during daytime conditions. Although this ratio decreased slightly for nighttime tests, as shown in Figure 84, the test subject allowed for more clearance distance with both systems for these tests.

The results of the dynamic lane change test for Driver 3 are presented graphically in Figure 85 and Figure 86. The results for Driver 3 are similar to Driver 2 in that the average allowed clearance distances are larger for the camera-based indirect vision system than they are for the mirror-based indirect vision system.

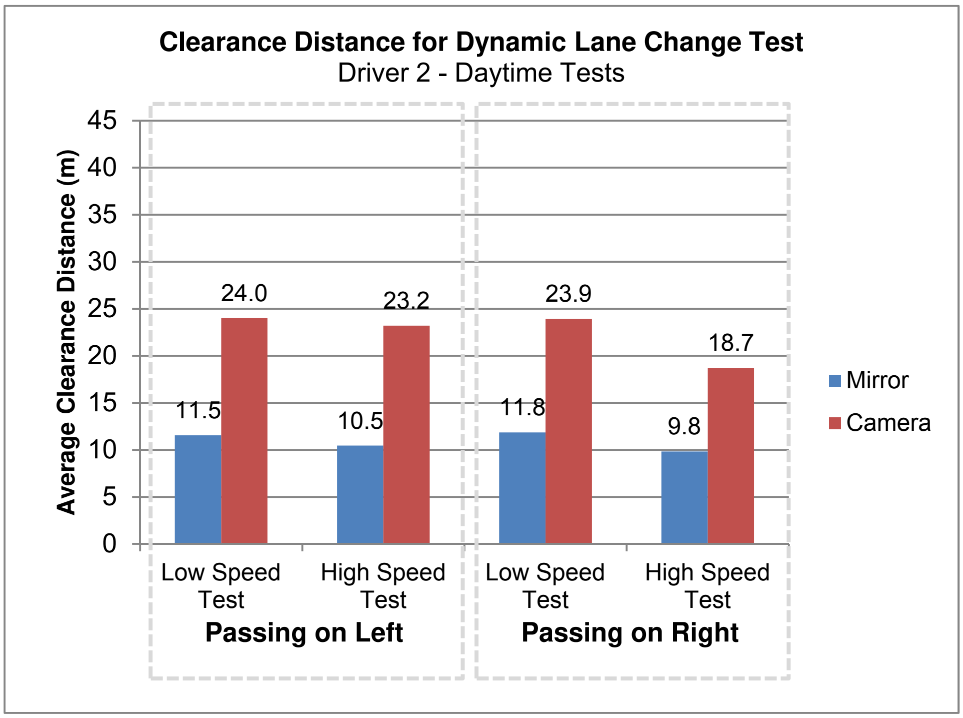

Figure 83: Average clearance distance during daytime dynamic lane change tests (Driver 2)

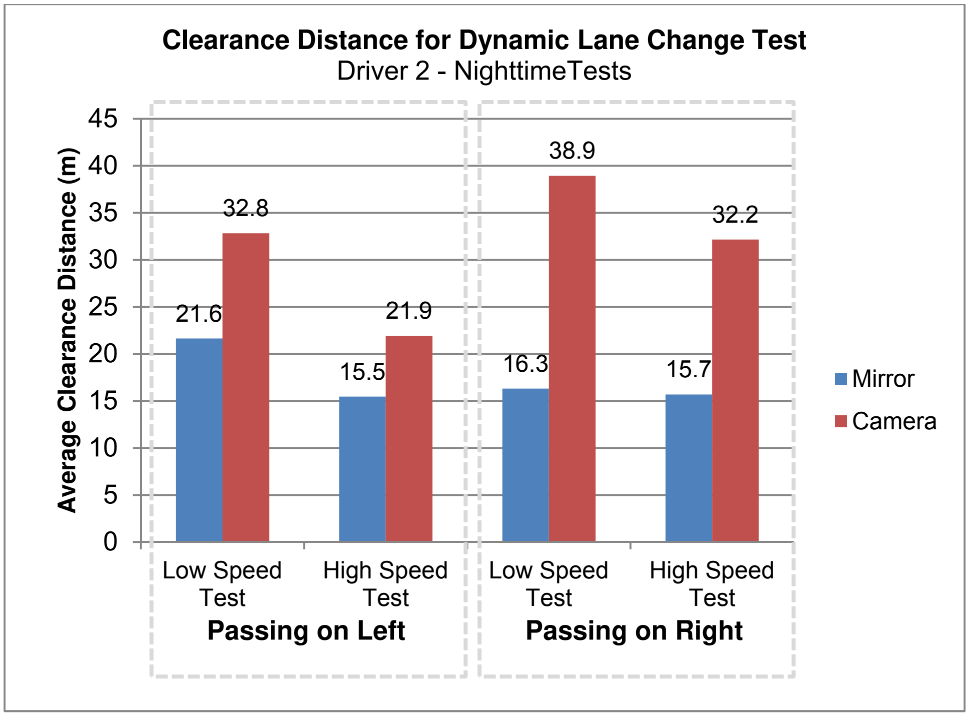

Figure 84: Average clearance distance during nighttime dynamic lane change tests (Driver 2)

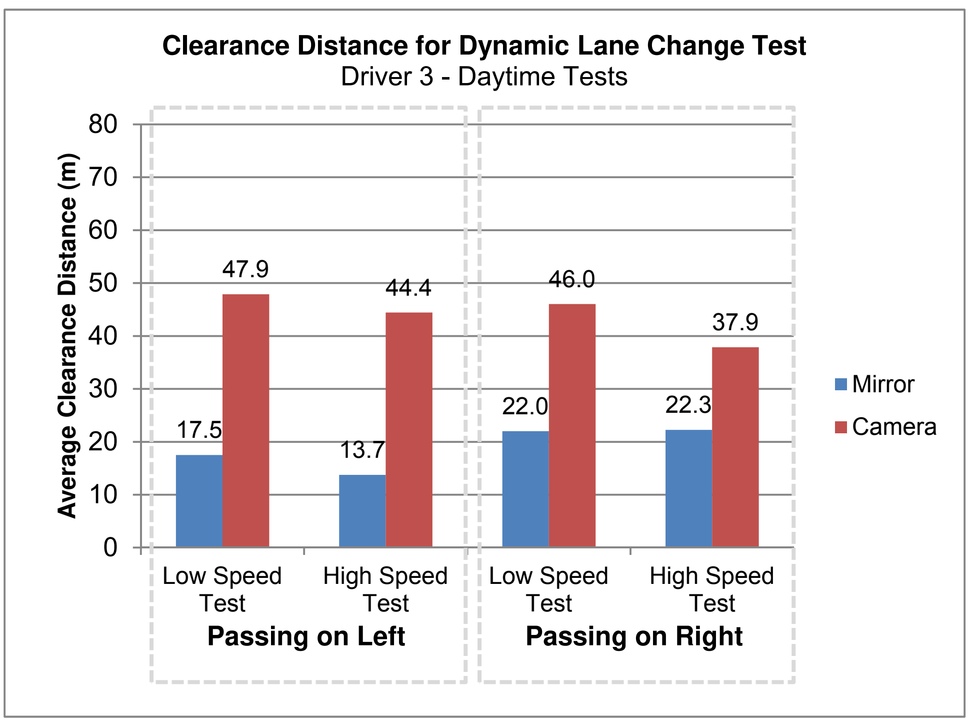

Figure 85: Average clearance distance during daytime dynamic lane change tests (Driver 3)

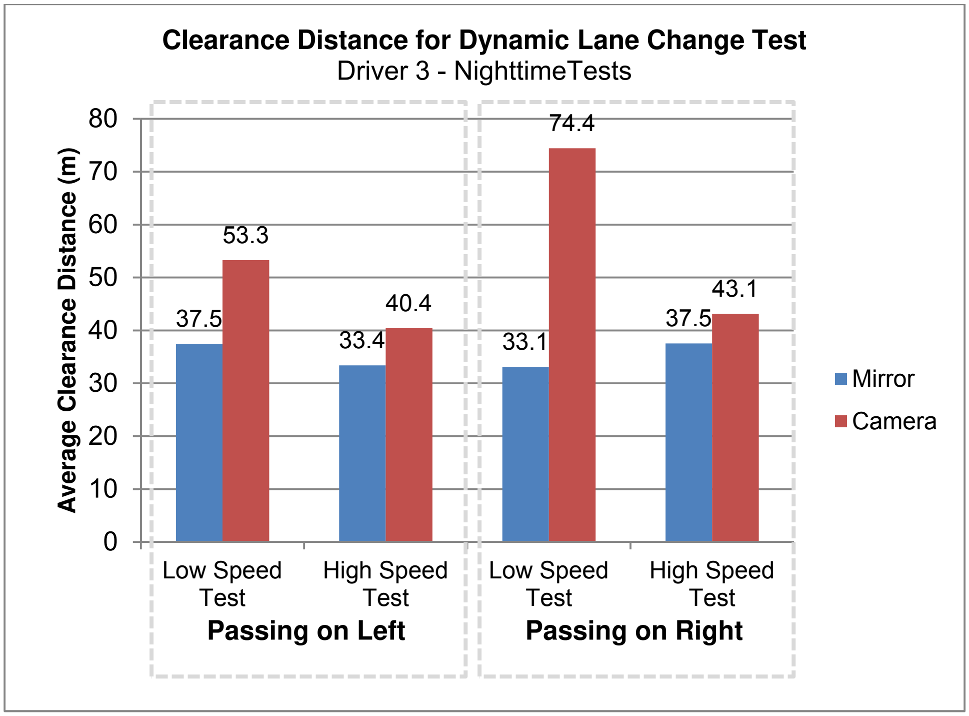

Figure 86: Average clearance distance during nighttime dynamic lane change tests (Driver 3)

6.6 Evasive Manoeuvre

The results of the evasive manoeuvres test may be analysed in two ways. Firstly, the results may be analyzed in terms of the elapsed time it took for the test subjects to decide if they were going to perform an evasive lane change manoeuvre. Only the time it took to make a decision to perform the lane change was recorded; the time it took to make the decision not to move was not recorded. The average elapsed times recorded for each of the two test subjects that partook in the evasive manoeuvers test is shown in Table 97. From Table 97, it may be seen that, in general, the test subjects took more time to decide to make a lane change manoeuvre with the camera-based indirect vision system than they did while using the mirror-based indirect vision system. However, Driver 2 did shorten his average decision making time when using the camera-based indirect vision system time during the daytime tests and Driver 3's average decision making time was only slightly greater for nighttime tests.

Table 97: Average elapsed decision times for evasive manoeuvres test

Test Subject	Daytime Test Average Time (s)		Nighttime Test Average Time (s)	
	Mirror-Based Indirect Vision System	Camera-Based Indirect Vision System	Mirror-Based Indirect Vision System	Camera-Based Indirect Vision System
Driver 2	1.5	1.0	1.5	2.6
Driver 3	1.3	1.9	2.2	2.3

The second manner in which the evasive manoeuvres test data may be analysed is in the number of correct decisions made by the test subjects. The results of these calculations are shown in Figure 87. It is here where it may be seen that the test subjects were not able to perform as effectively with a camera-based indirect vision system as they were with a mirror-based indirect vision system. For every test, the test subject's percentage of correct decisions lowered. However, neither of the test subjects made an incorrect decision that would have resulted in a collision between the two vehicles. Both test subjects were more apprehensive about performing a lane change manoeuvre when they did not absolutely know it was safe to do so while using the camera-based indirect vision system.

The lane change manoeuvre apprehension was a result of not being able to determine the location of the rear of the subject vehicle's trailer. The inability to determine the location of the rear of the subject vehicle's trailer was further exacerbated during nighttime test conditions due to the camera bloom resulting from the glare of the target vehicle's headlights.

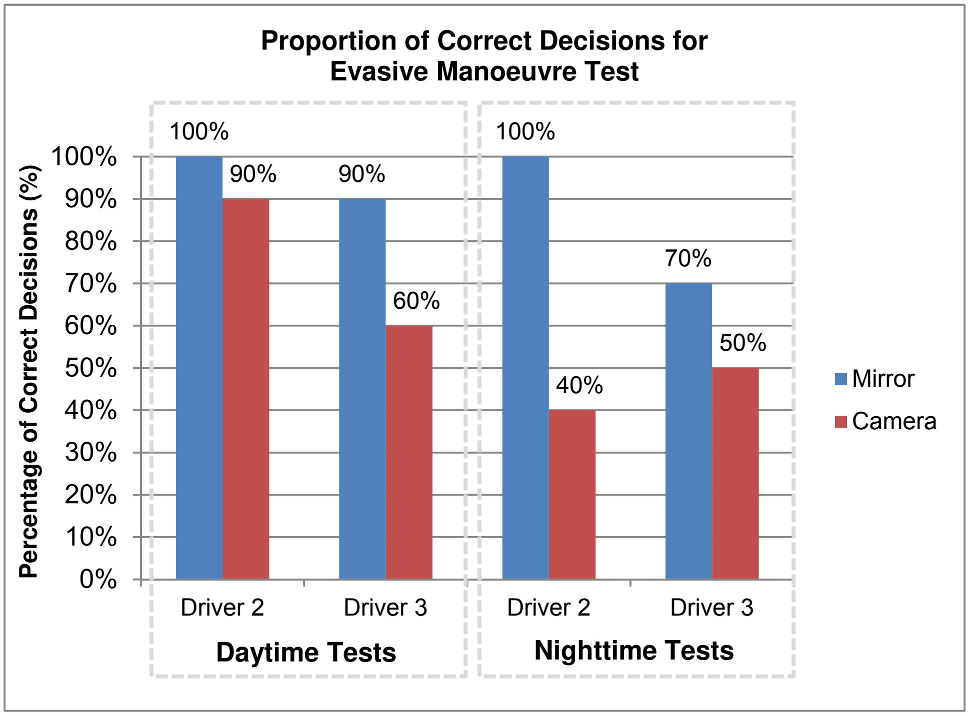

Figure 87: Proportion of correct decisions for evasive manoeuvre test

6.7 Questionnaires

On average, the test subjects rated the camera-based indirect vision system as more difficult to use than the mirror-based indirect vision system. Table 98 provides the averages of the ratings each test subject provided for the tested indirect vision systems. In Table 98, it may be seen that the test subjects rated the mirror-based indirect vision system in the easy to very easy to use range. The camera-based indirect vision system was rated in the neutral to easy to use range.

Table 98: Average test subject ratings of tested indirect vision systems

Test Subject	Mirror-Based Indirect Vision System	Mirror-Based Indirect Vision System
Driver 1	5.6	4.0
Driver 2	6.2	4.5
Driver 3	5.1	3.9
Driver 4	5.0	5.0

Only Driver 4 rated the mirror-based and camera-based indirect vision systems as being equal. This is likely due to the fact that the presented averages include only those tests in which the test subject participated, and Driver 4 only participated in the object identification and blind spot comparison tests. These were the two tests in which the test subjects were more likely to rate the two tested indirect vision systems as being equally as easy to use. Driver 2 rated the camera-based indirect vision system as easier to use for the object identification test both in daytime and in nighttime conditions. Driver 3 rated the camera-based indirect vision system as easier to use for the object identification test during nighttime conditions.

For tests other than the object identification test, the camera-based indirect vision system received lower scores for tests performed during nighttime conditions. This is most likely due to the issue of blooming which decreased the test subjects' ability to assess their surroundings through the indirect vision system. However, it is interesting to note that the magnitude of the ratings difference between the two tested indirect vision systems remained relatively constant. That is, the decrease in indirect vision system ease of use between daytime to nighttime was similar for both systems: if the camera-based indirect vision system rating was decreased by one point due to nighttime operations, so too was the mirror-based indirect vision system.

Of the qualitative comments received from the test subjects, the most noted concern was that of the blooming in the monitors caused by bright objects in the camera field of view during nighttime operations. Blooming in the monitors not only detracted from the available visual information, but also caused the monitors in the cab to become excessively bright, creating a further distraction.

The second most frequent comment concerned the resolution of the monitors: the test subjects would prefer to have a system with a higher resolution. This may simply be a result of a general expectation from the public that all newly developed systems have high definition monitors. However, as detailed in section 5.7.1, despite being located as far outboard as the outer edge of the mirrors, the test subjects could still not distinguish the rear edge of their trailer even though it was present in their field of view. This fact provides some validity to the comment.

The test subjects also provided some comments concerning what they liked about the camera-based indirect vision system. Test subjects enjoyed the larger forward field of view provided through the use of such a system. They also enjoyed the smaller visual scan area associated with monitors over the larger mirrors.

The remainder of the comments received from the test subjects may be organized into the following categories:

- Difficulty associated with depth perception;
- Desire for control over the field of views of the cameras;
- Desire for easier control over the brightness of the monitors;
- The inclusion of additional cameras for visual information not normally available through mirror-based indirect vision systems (i.e. the inclusion of augmented visual information); and
- Location and size of monitors (one test subject would prefer larger monitors, another would prefer smaller monitors).

7 CONCLUSIONS

7.1 Object Identification

The results of the object identification test do not show any statistically significant difference in test subject performance between the camera-based indirect vision system and the mirror-based indirect vision system for daytime tests. However, Driver 2 and Driver 3 were able to locate objects more quickly during nighttime tests with the camera-based indirect vision system with statistical significance.

The test results suggest that there is an increased ability to locate an object using the camera-based indirect vision system over the mirror-based indirect vision system. However, there is an increased ability to identify an object using a mirror-based indirect vision system over a camera-based indirect vision system. The decreased ability to identify an object with the camera-based indirect vision system could possibly be remedied by using a higher definition camera and monitor.

In terms of the time taken to locate an object, the test results suggest that there could be a slight advantage in the use of a camera-based indirect vision system over the use of a mirror-based indirect vision system. This could be due to the fact that there is less scan area to cover using a camera-based system rather than a mirror-based system; the mirrors are larger than the monitors. Although evidence supports placing the monitors on the vehicle A-pillars to match the driver's expectations of where the indirect vision information should be [1], the advantage of smaller scan area of a camera-based indirect vision system could be increased by moving the monitors closer to the driver's forward line of sight.

7.2 Blind Spot Comparison

The blind spot comparison tests did not reveal any significant differences between the size or location of the blind spots associated with either indirect vision system. Although the final position of the target vehicle varied with the test subject as well as between systems, the size of the variation was not large enough to make a vehicle not visible to the test subject while using either system.

The variation in the blind spot comparison tests for each test subject are a result of how each test subject set up their indirect vision systems. This highlights the personal preference of each driver while operating their vehicle. In future revisions of the camera-based indirect vision system, it will be necessary to include flexibility in the direction in which the cameras are pointed. This will allow the operator of the vehicle to customize his or her view, providing them with a more comfortable driving experience.

7.3 Coupling and Uncoupling

The results of the coupling and uncoupling test reveal that the test subjects were capable of positioning the subject vehicle's trailer within the cones of the simulated loading dock with the camera-based indirect vision system. In general, both test subjects took more time performing the required manoeuvres during daytime conditions with the camera-based indirect vision system compared to the mirror-based indirect vision system, but showed significant improvement during nighttime tests when using the camera-based indirect vision system compared to the mirror-based indirect vision system.

The improvement during nighttime tests is most likely attributable to the greater ease with which the test subjects could see their surroundings and the simulated loading dock as a result of the IR capabilities of the camera-based indirect vision system. However, as noted in section 5.3.3, Driver 2 found that the glare from bright objects (e.g. lights on the side of the subject vehicle's trailer) detracted from his overall visibility.

In order to ease the strain on the driver of a vehicle equipped with a camera-based indirect vision system, it will be important to manage the blooming effects on the system monitors as a result of bright objects located with the indirect visual field during nighttime conditions.

It will also be important to determine a method of improving the driver's ability to perform coupling and uncoupling manoeuvres with the camera-based indirect vision system during daytime conditions to, at the very least, have the performance with the camera-based system be comparable to that experienced with the use of a mirror-based indirect vision system. This could be accomplished by providing the driver better control over the camera fields of view during such manoeuvres, allowing them to increase their indirect visual field of view in a similar manner to that gained while moving one's head with the use of a mirror-based indirect vision system.

7.4 Quasi-Static Lane Change

The results of the quasi-static lane change test may be summarized by two findings. Firstly, the test subjects were not able to accurately locate the zero clearance distance position with either the mirror-based or camera-based indirect vision systems. Secondly, there were significant differences in the perceived location of the zero clearance distance position between the mirror-based and camera-based indirect vision systems.

The first finding, that test subjects were not able to accurately locate the zero clearance distance position with either the mirror-based or camera-based indirect vision systems, allows for the possibility of improved clearance distance perceptions with the camera-based indirect vision system. Of the 48 individual sets of data analyzed (24 with the mirror-based indirect vision system and 24 with the camera-based indirect vision system), only five resulted in the driver being able to correctly perceive the zero clearance distance position of the target vehicle (three with the mirror-based indirect vision system and two with the camera-based indirect vision system). This result leads to the conclusion that drivers are not able to correctly perceive the zero clearance distance position of another vehicle with a mirror-based indirect vision system. The possibility of providing an additional visual cue as to the location of this position with the camera-based indirect vision system (for example, a line on the system monitor) could provide enhanced driver performance through the use of such systems.

The second finding, that there were significant differences in the perceived location of the zero clearance distance position between the mirror-based and camera-based indirect vision systems shows that the test subjects were not able to perceive depth in a similar manner across the two tested indirect vision systems. Even though the camera-based indirect vision system was carefully designed and installed to maintain a similar sense of depth perception as is provided by the mirrors, the test subjects' performance differed between the two systems. Only three of the 24 pairs of analyzed data showed a similar performance between the tested indirect vision systems, and all of these were performed by Driver 3. This result suggests that the camera-based indirect vision system need not be placed in the front fender location of the vehicle to maintain a sense of depth similar to that available with the mirrors. This provides the option to move the camera-based indirect vision system elsewhere on the vehicle, perhaps in a location less susceptible to road debris and soiling. This also provides the option of driver adjustable camera fields of view, as this was one of the controlled variables in an attempt to maintain depth perception capabilities.

However, if the cameras are moved to a more rearward location, it will be important to take into account the size of the forward blind spots, especially on the passenger side of the vehicle equipped with the camera-based indirect vision system. Optimization will need to occur to minimize these blind spots while at the same time gaining the maximum possible benefits from improved aerodynamics, driver adjustable fields of view and improved resistance to debris and soiling.

7.5 Dynamic Lane Change

The greater allowance of clearance distance while changing lanes with the camera-based indirect vision system is likely a result of the test subject not knowing the location of the end of the subject vehicle's trailer. In practice, although this greater clearance distance allowance will provide an additional buffer between the two vehicles, there could be issues which arise when a vehicle equipped with a camera-based indirect vision system essentially gets stuck in the passing lane because the vehicle operator does not feel as though there is sufficient clearance distance, despite sufficient clearance being available.

The results of this test further emphasize the need for an assisted means of locating the end of the trailer. As in the quasi-static lane change tests, the test subjects were not as effective in determining where the end of their trailer was located, resulting in difficulty in determining when they could perform a passing manoeuvre, both during the day and the night.

7.6 Evasive Manoeuvre

The results of the evasive manoeuvres test revealed that the test subjects had difficulty in determining the location of the rear of the subject vehicle's trailer, similar to the results of the quasi-static lane change and dynamic lane change tests. Determining the location of the rear of the subject vehicle's trailer was made even more difficult at night as a result of the camera bloom emanating from the target vehicle's headlights. The test subjects were much more hesitant in their lane changing manoeuvres during nighttime operations with the camera-based indirect vision system compared to similar lane change manoeuvres with the mirror-based indirect vision system as a result of the blooming effect of the digital cameras. However, at no point during testing did the test subjects attempt to perform a lane change manoeuvre which would have caused a collision.

In order to ensure the effective operation of a vehicle with a camera-based indirect vision system, it will be important to provide an improved means showing the location of the rear of the trailer to the vehicle operator. It will also be important to ensure the effects of monitor blooming are minimized to improve the visual information provided to the vehicle operator.

7.7 Questionnaires

In general, the test subjects rated the camera-based indirect vision system as more difficult to use than the mirror-based indirect vision system. It should be noted that the results of the questionnaires represent initial reactions to the use of a camera-based indirect vision system. It is possible that the difference in ratings between camera-based indirect vision systems and mirror-based indirect vision systems would become smaller with time as driver acceptance increases and behaviours change as a result of increased usage and training. However, no data to support such a claim was collected throughout this test program. If camera-based indirect vision systems are to be introduced into regular service, it will be important that drivers are properly trained on the use of such systems to overcome any initial reluctance concerning their use.

In terms of the comments received from the test subjects, the most frequent concern was that of blooming in the monitors as a result of viewing bright lights during nighttime operations. It will be important to find a method of eliminating the blooming or, at the very least, minimizing it to acceptable levels. Test subjects were also concerned about the resolution of the system, difficulties in proper depth perception, and the lack of control over the cameras fields of view and monitor brightness. However, test subjects did enjoy the greater forward field of view associated with the use of a camera-based indirect vision system as result of the removal of the mirrors, as well as the smaller scan area associated with such a system.

7.8 Additional Findings

Despite moving the cameras outboard, the test subjects continued to remark that they could not determine the location of the rear edge of their trailer even though the edge of the trailer was visible in the monitor. The results of testing confirmed that this was the case. Although the cameras were moved as far outboard from the subject vehicle as the outermost reflective surface of the west coast mirrors, they did not provide the necessary visual information to determine the location of the rear of the trailer. This issue could possibly be resolved through the use of high definition cameras and monitors. The issue could also be resolved by providing an assisted means of locating the end of the trailer.

The blooming on the monitors as a result of bright lights shining into the cameras is of serious concern. The selected cameras were chosen for their anti-bloom characteristics [1]. Despite the careful selection of the cameras, the headlights of the target vehicle still caused significant bloom, preventing the test subjects from being able to correctly identify the zero clearance distance position. The formation of dew on the clear protective surface of the camera housing further exacerbated the issue.

8 DISCUSSION

The preliminary comparison of the camera-based indirect vision system with a conventional mirror-based indirect vision system reveals that the camera-based indirect vision system provides potential advantages in locating and identifying objects during nighttime operations. This was shown in the object identification test as well as the coupling and uncoupling test. However, it is during nighttime operations when the camera-based indirect vision system is at its most vulnerable due to image blooming as a result of bright objects within the camera fields of view. This was also the most frequent concern about the system listed by the test subjects on the questionnaires. It will be important to resolve the issue of image blooming in any subsequent revision of the camera-based indirect vision system.

The quasi-static lane change test, the dynamic lane change test and the evasive manoeuvre test all revealed that the test subject's inability to locate the end of their trailer resulted in hesitation to perform lane changes which could be deemed as safe to perform. However, the quasi-static lane change test revealed that the test subjects were not any better in locating the actual position of their trailer with a mirror-based indirect vision system. The hesitation in performing lane change manoeuvres, especially during daytime conditions, could be the result of unfamiliarity with the use of a camera-based indirect vision system. During nighttime conditions, it is likely a combination of this unfamiliarity and the aforementioned issue of image blooming.

Since the test subject's inability to locate the end of the trailer is common across indirect vision platforms, it is here where a camera-based indirect vision system may allow for improved operational efficiency over a mirror-based indirect vision system. The camera-based indirect vision system allows for additional data to be displayed on the monitor which will allow the vehicle operator to more accurately locate the end of their vehicle. This additional data could be as simple as superimposing a line on the monitor which indicates the location of the end of the trailer, or more complicated such as identifying the precise distance to an adjacent vehicle, identifying the closing speed of an adjacent vehicle, or automatic judgement by the system of whether sufficient clearance distance exists to perform a lane change manoeuvre. A truly integrated system could alert the vehicle operator if they were to activate a turn signal without sufficient clearance distance. A less integrated system could alert the driver if it determined that the two vehicles appeared to be on intersecting paths.

The development of any end of vehicle demarcation system would not be a trivial task. The blind spot comparison test and coupling and uncoupling test revealed that the test subjects require the ability to change the direction in which the cameras are pointing to meet each operator's personal preferences and to provide the necessary indirect vision information. If a line or other marker were to be superimposed on the camera-based indirect vision system monitors, the movement of the direction in which the cameras are pointing would require immediate recalculation of the location of the line on the monitor. The quasi-static lane change test revealed that the calibration of the camera fields of view to provide a sense of depth perception similar to that provided by the mirrors was not successful. This allows for the possibility of vehicle operators altering the camera fields of view to better suit their needs. An adjustment of these fields of view would also require immediate recalculation of the displayed location of the end of the trailer.

An end of vehicle demarcation system would also require a built in calibration sequence that occurred, if not on every vehicle start, at a regular interval. This could be accomplished by applying calibration points on the side of the tractor which the system could use to reorient itself. Such a system would also require that the length of the vehicle being operated is known. This could be accomplished via input from the vehicle operator, automatic determination by the system through image recognition, or by electronic communication between the tractor and the trailer. Each of these methods has specific advantages and disadvantages.

In addition, an end of trailer demarcation system would incur significant development cost as a result of its inherent complexity. Additional costs would be incurred for system maintenance or replacement in the event of a system failure. These costs must be taken into account when considering the payback period associated with a camera-based indirect vision system.

The finding that the careful calibration of the camera fields of view to provide a similar sense of depth as is available with the use of a mirror-based indirect vision system is not effective allows for the placement of the cameras in locations other than the front fender of the equipped vehicle. This will allow for cameras to be mounted in locations which are less susceptible to road debris and soiling. This will also allow for placement of the cameras in the location which results in the greatest reduction in aerodynamic drag, the potential for aerodynamic drag reduction and the resultant fuel savings being the main driver for the adoption of camera-based indirect vision systems.

The movement of the cameras to a location where the soiling of the lenses can be minimized will be important for continuous provision of the necessary visual information to the operator of a vehicle equipped with a camera-based indirect vision system. However, the formation of dew on the camera housing, as detailed in section 5.7.2.1 will not be resolved by moving the cameras to a location other than the front fender. It is for this reason that any additional revision to the camera-based indirect vision system will require an integrated lens cleaning system that the vehicle operator may activate when required. Such a system should also include provisions for lens defrosting.

The attempt at simulating depth perception through careful selection of camera fields of view was also an important consideration in choosing the size of the system monitors. The finding that this methodology is ineffective allows for greater flexibility in the sizing of the monitors. Although there is an upper practical limit on the size of the monitors, the larger the monitor, the more visual information may be provided to the vehicle operator. However, the amount of visual information that may be transmitted is limited to the resolution of the cameras and monitors used in the design of such a system. It was suggested through the results of the object identification and quasi-static lane change tests that the camera-based indirect vision system could benefit from the use of a higher definition system. When the original system was developed, high definition cameras were not able to transmit visual information without considerable lag. However, due to the rapidly advancing field of high definition camera and monitor development, it would be beneficial to revaluate the available technology.

9 ACRONYMS AND ABBREVIATIONS

AST	Automotive and Surface Transportation
GPS	Global Positioning System
eTV	ecoTechnology for Vehicles
Hz	Hertz
km/h	Kilometre per Hour
m	Metre
NRC	National Research Council
s	Second
TC	Transport Canada

10 REFERENCES

[1] T. McWha and F. DeSouza, "Camera-Based Indirect Vision Systems for Heavy Duty Vehicles - Phase I," National Research Council Canada, Ottawa, Ontario, 2013.

11 ACKNOWLEDGEMENTS

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- Jeff Patten, project engineering support and management
- David Poisson, project manager
- Guy Charbonneau, field testing and data acquisition
- Mark Croken, field testing and data acquisition

Appendix A OBJECT IDENTIFICATION QUESTIONNAIRE (MIRROR)

Please answer the following questions by writing a numerical response in the space provided using the scale associated with the question being asked. Half numbers are acceptable. For example:

Response: 2.5

1) How difficult or easy is it for you to identify objects **using the mirrors during the day**?

   Response: ____________

1	2	3	4	5	6	7
Extremely Difficult	Very Difficult	Difficult	Neutral	Easy	Very Easy	Extremely Easy

2) How difficult or easy is it for you to identify objects **using the mirrors during low light driving conditions**?

   Response: ____________

1	2	3	4	5	6	7
Extremely Difficult	Very Difficult	Difficult	Neutral	Easy	Very Easy	Extremely Easy

Thank you very much for your participation in our study.

Appendix B OBJECT IDENTIFICATION QUESTIONNAIRE (CAMERA)

Please answer the following questions by writing a numerical response in the space provided using the scale associated with the question being asked. Half numbers are acceptable. For example:

Response: 2.5

1) How difficult or easy is it for you to identify objects **using the camera system during the day**?

   Response: ____________

1	2	3	4	5	6	7
Extremely Difficult	Very Difficult	Difficult	Neutral	Easy	Very Easy	Extremely Easy

2) How difficult or easy is it for you to identify objects **using the camera system during low light driving conditions**?

   Response: ____________

1	2	3	4	5	6	7
Extremely Difficult	Very Difficult	Difficult	Neutral	Easy	Very Easy	Extremely Easy

3) Are there any changes or improvements you would make to the camera system based upon your experience performing the tasks associated with this test? If so, please write them in the box below. Any comments you may have would be greatly appreciated.

Thank you very much for your participation in our study.

Appendix C BLIND SPOT COMPARISON QUESTIONNAIRE (MIRROR)

Please answer the following questions by writing a numerical response in the space provided using the scale associated with the question being asked. Half numbers are acceptable. For example:

Response: 2.5

1) How difficult or easy is it for you to locate the target vehicle in your blind spot **using the mirrors**?

   Response: ____________

1	2	3	4	5	6	7
Extremely Difficult	Very Difficult	Difficult	Neutral	Easy	Very Easy	Extremely Easy

Appendix D BLIND SPOT COMPARISON QUESTIONNAIRE (CAMERA)

Please answer the following questions by writing a numerical response in the space provided using the scale associated with the question being asked. Half numbers are acceptable. For example:

Response: 2.5 ____________

1) How difficult or easy is it for you to locate the target vehicle in your blind spot **using the camera system**?

   Response: ____________

1	2	3	4	5	6	7
Extremely Difficult	Very Difficult	Difficult	Neutral	Easy	Very Easy	Extremely Easy

2) Are there any changes or improvements you would make to the camera system based upon your experience performing the tasks associated with this test? If so, please write them in the box below. Any comments you may have would be greatly appreciated.

Thank you very much for your participation in our study.

Appendix E COUPLING AND UNCOUPLING QUESTIONNAIRE (MIRROR)

Please answer the following questions by writing a numerical response in the space provided using the scale associated with the question being asked. Half numbers are acceptable. For example:

Response: 2.5

1) How difficult or easy is it for you to couple and uncouple the tractor and trailer **using the mirror system during the day**?

   Response: ____________

1	2	3	4	5	6	7
Extremely Difficult	Very Difficult	Difficult	Neutral	Easy	Very Easy	Extremely Easy

2) How difficult or easy is it for you to couple and uncouple the tractor and trailer **using the mirror system during low light driving conditions**?

   Response: ____________

1	2	3	4	5	6	7
Extremely Difficult	Very Difficult	Difficult	Neutral	Easy	Very Easy	Extremely Easy

Appendix F COUPLING AND UNCOUPLING QUESTIONNAIRE (CAMERA)

Please answer the following questions by writing a numerical response in the space provided using the scale associated with the question being asked. Half numbers are acceptable. For example:

Response: 2.5

3) How difficult or easy is it for you to couple and uncouple the tractor and trailer **using the camera system during the day**?

   Response: ____________

1	2	3	4	5	6	7
Extremely Difficult	Very Difficult	Difficult	Neutral	Easy	Very Easy	Extremely Easy

4) How difficult or easy is it for you to couple and uncouple the tractor and trailer **using the camera system during low light driving conditions**?

   Response: ____________

1	2	3	4	5	6	7
Extremely Difficult	Very Difficult	Difficult	Neutral	Easy	Very Easy	Extremely Easy

5) Are there any changes or improvements you would make to the camera system based upon your experience performing the tasks associated with this test? If so, please write them in the box below. Any comments you may have would be greatly appreciated.

Thank you very much for your participation in our study.

Appendix G QUASI-STATIC LANE CHANGE QUESTIONNAIRE (MIRROR)

Please answer the following questions by writing a numerical response in the space provided using the scale associated with the question being asked. Half numbers are acceptable. For example:

Response: 2.5

1) How difficult or easy is it for you to determine whether there is clearance between the back edge of the trailer and the front of the target vehicle **using the mirrors during the day**?

   Response: ____________

1	2	3	4	5	6	7
Extremely Difficult	Very Difficult	Difficult	Neutral	Easy	Very Easy	Extremely Easy

2) How difficult or easy is it for you to determine whether there is clearance between the back edge of the trailer and the front of the target vehicle **using the mirrors during low light driving conditions**?

   Response: ____________

1	2	3	4	5	6	7
Extremely Difficult	Very Difficult	Difficult	Neutral	Easy	Very Easy	Extremely Easy

Thank you very much for your participation in our study.

Appendix H QUASI-STATIC LANE CHANGE QUESTIONNAIRE (CAMERA)

Please answer the following questions by writing a numerical response in the space provided using the scale associated with the question being asked. Half numbers are acceptable. For example:

Response: 2.5

1) How difficult or easy is it for you to determine whether there is clearance between the back edge of the trailer and the front of the target vehicle **using the camera system during the day**?

   Response: ____________

1	2	3	4	5	6	7
Extremely Difficult	Very Difficult	Difficult	Neutral	Easy	Very Easy	Extremely Easy

2) How difficult or easy is it for you to determine whether there is clearance between the back edge of the trailer and the front of the target vehicle **using the camera system during low light driving conditions**?

   Response: ____________

1	2	3	4	5	6	7
Extremely Difficult	Very Difficult	Difficult	Neutral	Easy	Very Easy	Extremely Easy

3) Are there any changes or improvements you would make to the camera system based upon your experience performing the tasks associated with this test? If so, please write them in the box below. Any comments you may have would be greatly appreciated.

Thank you very much for your participation in our study.

Appendix I DYNAMIC LANE CHANGE QUESTIONNAIRE (MIRROR)

Please answer the following questions by writing a numerical response in the space provided using the scale associated with the question being asked. Half numbers are acceptable. For example:

Response: 2.5

1) How difficult or easy is it for you to perform a passing manoeuver **using the mirrors during the day at low speeds (40 km/h)**?

   Response: ____________

1	2	3	4	5	6	7
Extremely Difficult	Very Difficult	Difficult	Neutral	Easy	Very Easy	Extremely Easy

2) How difficult or easy is it for you to perform a passing manoeuver **using the mirrors during low light driving conditions at low speeds (40 km/h)**?

   Response: ____________

1	2	3	4	5	6	7
Extremely Difficult	Very Difficult	Difficult	Neutral	Easy	Very Easy	Extremely Easy

3) How difficult or easy is it for you to perform a passing manoeuver **using the mirrors during the day at high speeds (90 km/h)**?

   Response: ____________

1	2	3	4	5	6	7
Extremely Difficult	Very Difficult	Difficult	Neutral	Easy	Very Easy	Extremely Easy

4) How difficult or easy is it for you to perform a passing manoeuver **using the mirrors during low light driving conditions at high speeds (90 km/h)**?

Response: ____________

1	2	3	4	5	6	7
Extremely Difficult	Very Difficult	Difficult	Neutral	Easy	Very Easy	Extremely Easy

Thank you very much for your participation in our study.

Appendix J DYNAMIC LANE CHANGE QUESTIONNAIRE (CAMERA)

Please answer the following questions by writing a numerical response in the space provided using the scale associated with the question being asked. Half numbers are acceptable. For example:

Response: 2.5

1) How difficult or easy is it for you to perform a passing manoeuver **using the camera system during the day at low speeds (40 km/h)**?

   Response: ____________

1	2	3	4	5	6	7
Extremely Difficult	Very Difficult	Difficult	Neutral	Easy	Very Easy	Extremely Easy

2) How difficult or easy is it for you to perform a passing manoeuver **using the camera system during low light driving conditions at low speeds (40 km/h)**?

   Response: ____________

1	2	3	4	5	6	7
Extremely Difficult	Very Difficult	Difficult	Neutral	Easy	Very Easy	Extremely Easy

3) How difficult or easy is it for you to perform a passing manoeuver **using the camera system during the day at high speeds (90 km/h)**?

   Response: ____________

1	2	3	4	5	6	7
Extremely Difficult	Very Difficult	Difficult	Neutral	Easy	Very Easy	Extremely Easy

4) How difficult or easy is it for you to perform a passing manoeuver **using the camera system during low light driving conditions at high speeds (90 km/h)**?

Response: ____________

1	2	3	4	5	6	7
Extremely Difficult	Very Difficult	Difficult	Neutral	Easy	Very Easy	Extremely Easy

5) Are there any changes or improvements you would make to the camera system based upon your experience performing the tasks associated with this test? If so, please write them in the box below. Any comments you may have would be greatly appreciated.

Thank you very much for your participation in our study.

Appendix K EVASIVE MANEUVER QUESTIONNAIRE (MIRROR)

Please answer the following questions by writing a numerical response in the space provided using the scale associated with the question being asked. Half numbers are acceptable. For example:

Response: 2.5

1) How difficult or easy is it for you to determine whether a quick lane change could be performed **using the mirrors during the day**?

   Response: ____________

1	2	3	4	5	6	7
Extremely Difficult	Very Difficult	Difficult	Neutral	Easy	Very Easy	Extremely Easy

2) How difficult or easy is it for you to determine whether a quick lane change could be performed **using the mirrors during low light driving conditions**?

   Response: ____________

1	2	3	4	5	6	7
Extremely Difficult	Very Difficult	Difficult	Neutral	Easy	Very Easy	Extremely Easy

Thank you very much for your participation in our study.

Appendix L EVASIVE MANEUVER QUESTIONNAIRE (CAMERA)

Please answer the following questions by writing a numerical response in the space provided using the scale associated with the question being asked. Half numbers are acceptable. For example:

Response: 2.5

1) How difficult or easy is it for you to determine whether a quick lane change could be performed **using the camera system during the day**?

   Response: ____________

1	2	3	4	5	6	7
Extremely Difficult	Very Difficult	Difficult	Neutral	Easy	Very Easy	Extremely Easy

2) How difficult or easy is it for you to determine whether a quick lane change could be performed **using the camera system during low light driving conditions**?

   Response: ____________

1	2	3	4	5	6	7
Extremely Difficult	Very Difficult	Difficult	Neutral	Easy	Very Easy	Extremely Easy

3) Are there any changes or improvements you would make to the camera system based upon your experience performing the tasks associated with this test? If so, please write them in the box below. Any comments you may have would be greatly appreciated.

Thank you very much for your participation in our study.