NISTIR 7837

Measurement and Evaluation of Visibility Experiments for Powered Industrial Vehicles

Roger Bostelman
U.S DEPARTMENT OF COMMERCE
National Institute of Standards and Technology
Intelligent Systems Division
Gaithersburg, MD 20899-8230

Li Peng Liang
University of Maryland, College Park
College Park, MD 20742

National Institute of Standards and Technology
U.S. Department of Commerce

NISTIR 7837

Measurement and Evaluation of Visibility Experiments for Powered Industrial Vehicles

Roger Bostelman
U.S DEPARTMENT OF COMMERCE
National Institute of Standards and Technology
Intelligent Systems Division
Gaithersburg, MD 20899-8230

Li Peng Liang
University of Maryland, College Park
College Park, MD 20742

December 2011

U.S. DEPARTMENT OF COMMERCE
John Bryson, Secretary
NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
Patrick D. Gallagher, Under Secretary for Standards and Technology and Director

Abstract

Powered industrial vehicles, such as forklifts, are widely used in manufacturing and other industries. Potential safety issues exist due to limitations in the operator's ability to see all around the vehicle. Areas the operator cannot see are called non-visible vehicle regions. Non-visible regions for operators of powered industrial vehicles are mainly caused by vehicle obstructions The regions are required to meet certain criteria specified by standards. American National Standard Institute (ANSI)/Industrial Truck Standards Development Foundation (ITSDF) ANSI/ITSDF B56.5, ANSI/ITSDF B56.11.6, and International Organization for Standardization/Draft International Standard (ISO/DIS) 13564-1 standards require measurement and evaluation of visibility from powered industrial vehicles. The National Institute of Standards and Technology's (NIST) Intelligent System Division has been researching advanced 2D and 3D imaging sensors for improving both automated and manned forklift safety. Improvements are expected to provide 3D obstacle detection for both vehicle types. It is important to understand non-visible region locations initially, since that would then determine what type of 3D imagers would be required and where the sensors would be mounted. Visibility of a forklift was evaluated at NIST by following the above ANSI and ISO standards through 11 tests which set criteria based on the patterns of shadows cast when the forklift does not carry any load. Also, new test methods were created and tested. The new test methods were based on the forklift carrying loads and using standard sized test pieces and a mannequin. The NIST experiments, tests methods, and results are detailed in this report. This report will then serve as a basis for further advanced visibility and semi-automated powered industrial vehicle safety performance measurements and test methods development.

Keywords: ANSI/ITSDF B56 standards, visibility, powered industrial vehicles, forklift, safety, recommendations

Table of Contents

INTRODUCTION 4
BACKGROUND 6
EXPERIMENTAL SETUP 7
EXPERIMENTS 14
EXPERIMENTAL RESULTS 16
RESULTS OF ADDITIONAL EXPERIMENTS 19
RECOMMENDED IMPROVEMENTS TO CURRENT STANDARDS 23
ISO/DIS 13564-1 and ANSI/ITSDF B56.11.6 23
ISO 5353: 1995 29
SUMMARY AND CONCLUSIONS 30
ACKNOWLEDGEMENTS 31
REFERENCES 31
APPENDICES 33
Appendix 1 - Modified SIP Apparatus Design 33
Appendix 2 - Forklift Test Orientation and Patterns of Shadows 34
Appendix 3 - Recent and planned visibility efforts 36

List of Tables

Table 1. Forklift specifications 7
Table 2. Description of visibility tests 14
Table 3. Test results of travelling mode of forklift 18
Table 4. Test results for maneuvering mode of forklift 18
Table 5. Test results with forklift carrying a pallet of boxes 20
Table 6. Results when fork arms were raised to 117mm above floor 21

INTRODUCTION

Powered industrial vehicles are widely used in many industries. There are over 1 million forklifts and nearly 2000 automated guided vehicles (AGVs) in use in the United States. The number of forklift operators is estimated to be 2 million (6 million including part time operators) [1]. Forklifts are necessary vehicles for materials handling and delivering. However, forklifts can be a hazard to drivers and pedestrians if not operated properly or if non-visible regions due to forklift structure and loads they carry are not addressed. Training and forklift activity monitoring are being addressed through driver education, tracking technology, and supervision.

According to American National Standard Institute (ANSI)/Industrial Truck Standards Development Foundation (ITSDF) [2] B56.1, the manned industrial lift truck operator is responsible for vehicle control. Safe speeds, driver training, and other vehicle operator responsibilities must also be adhered to according to the standard. Visibility from within forklifts or other powered industrial vehicles is typically measured by the vehicle manufacturer according to visibility standards, such as International Organization for Standardization/Draft International Standard (ISO/DIS) [3] ISO/DIS 13564-1 [4] and ANSI/ITSDF B56.11.6 [5] which allow up to 20 % non-visible regions. Non-visibility is being addressed through commercial, off-the-shelf forklift tracking, cameras, barriers, etc. [6] However, even with these operational and visibility solutions and standards, forklift accidents frequently occur. Accidents statistics involving forklifts were presented at the 2010 “Towards Improved Forklift Safety” workshop and summarized in [6]. For example:

- OSHA estimates that there are 110 000 accidents each year.
- Almost 80% of forklift accidents involve a pedestrian.
- According to OSHA, approximately 70 % of all accidents reported could have been avoided with proper safety procedures.

In the next generation manufacturing facility, the Intelligent Systems Division (ISD) at the National Institute of Standards and Technology (NIST) envisions increased human-vehicle collaboration [7] Current forklift visibility standard criteria are likely insufficient in providing guidance for this kind of operation with respect to safety. Therefore, NIST ISD has been researching advanced 2D and 3D imaging sensors for viewing the local environment of AGVs and recently, to address the issue of forklift safety. Several safety technology implementation concepts for manufacturing vehicles were presented in [6] including use of 3D imagers mounted on a forklift and used as non-visible region detection devices to assist drivers. It may be feasible to integrate the 3D sensor information with driver alerts (e.g., audible, visual, etc.) and/or to provide semi-autonomous slow/stop functionality to prevent accidents when the driver doesn’t see the hazard.

The test methods in current visibility standards do not determine exactly where non-visible regions occur, only that they do or do not occur. These non-visible regions must be known for sensor manufacturers and integrators to determine what 2D and 3D imaging devices are useful for this safety application and where they are best mounted on industrial vehicles to provide the most cost effective solution. It is also unclear in the current visibility standards, how well the test method results determine the non-visible regions. Many lamps are used simultaneously for most standard tests to illuminate an area resulting in few shadows created by vehicle obstructions and therefore, visibility appears to meet visibility standard requirements. However, it is obvious to a viewer sitting in the vehicle driver's seat that vehicle obstructions exist.

In order to fully understand how visibility standard test methods determine non-visible regions and if necessary, how these methods can or should be improved, ISD researchers first implemented the visibility standards on a forklift. The results provided the basis for recommendations for improving current visibility standards. One key result is that the standard test method of turning on all the lights at the same time did not effectively simulate the positions of two eyes of an operator. A forklift (Figure 1) owned by the NIST ISD was used for visibility testing according to the ANSI/ITSDF B56.5 [8] and ANSI B56.11.6 [9] standards and the ISO/DIS 13564-1 and ISO 5353 [10] standards. Specifications of the forklift are presented in the Background section. The NIST ISD tests were not meant to evaluate whether the forklift used can pass the standard visibility tests. Instead, the forklift was used to evaluate visibility standards and determine the potential need, type, and location for 3D imagers.

The specific standards referenced for the visibility tests and forklift safety operation were:

- ANSI/ITSDF B56.11.6: 20xx - Evaluation of Visibility From Powered Industrial Trucks
- ANSI/ITSDF B56.5: 2010 - Safety Standard for Driverless, Automatic Guided Industrial Vehicles and Automated Functions of Manned Industrial Vehicles
- ISO/DIS 13564-1: 2007 - Powered Industrial trucks – Visibility - Test methods and verification-Part 1: Sit-on and stand-on operator trucks and variable reach trucks
- ISO 5353: 1995 - Earth-moving machinery, and tractors and machinery for agriculture and forestry-Seat Index Point

This paper describes the apparatuses needed for the visibility tests. The procedures of the visibility tests and experimental setup are also discussed. By following standard ISO 13564-1, eleven (11) visibility tests were conducted. Test results are discussed followed by recommended improvements to the standards and conclusions. Appendices provide additional information on apparatus design, shadows produced from tests, and other recent advanced visibility efforts.

Figure 1. Forklift[1] used for Visibility experiments.

BACKGROUND

Draft International Standard ISO/DIS 13564-1 is based on the current ANSI B56.11.6 standard for visibility tests of powered industrial vehicles. ISO/DIS 13564-1 is now being rewritten. Upon completion of the ISO standard, the ANSI 56.11.6 standard will again be addressed and updated according to the latest ISO 13564-1 standard.

Both ISO and ANSI standards state that the visibility of the operator sitting inside the forklift is required to meet certain criteria - generally to have 20 % visibility of specific sized targets placed at specified locations. ISO/DIS 13564-1 and ISO 5353 were followed and applied to the ISD forklift. A light source array is used to determine obstructed lines-of-sight from a position comparable to that of an operator's eyes. ISO/DIS 13564-1 specifies the exact locations of the light source array to simulate the positions of the operator's eyes. This point is critical since (a) the operator can move his/her head for better visibility and (b) the operator also has peripheral vision. For (a), the standard tests mandate the use of a 13 lamp array which simulates operator head movement. For (a) and (b), the standard tests mandate rotating the lamp array about a known point.

The location of the lamp array is based on a reference point called the Seat Index Point (SIP) located on an SIP apparatus. The SIP apparatus is specified in and was fabricated at ISD following ISO 5353. Once fabricated, the SIP apparatus was placed on the operator seat according to ISO/DIS 13564-1and the position was adjusted using the specified 400 N vertical and 100 N horizontal forces which simulate an average weight operator sitting on the seat.

[1] Commercial equipment and materials are identified in this paper in order to adequately specify certain procedures. Such identification does not imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the materials or equipment are necessarily the best available for the purpose.

Muslin cloth, as specified by 13564-1, was not used since both the seat and SIP apparatus were considered smooth surfaces with very low friction between them. The lamp array could then be mounted to the forklift with position referenced to the SIP. Once mounted, the array can then be rotated to specified angles to simulate the rotation of the operator's head. The shadows from the lamp array from within the forklift were displayed on a screen positioned and moved along test paths around the forklift. The shadow areas were summed and required to meet the standard specifying at least 80 % of the test screen be illuminated by a varied set of lamps. For example, eleven tests included illuminating four outside lights (two on either end), nine center lights, all thirteen lights or any two lamps separated by 75 mm. The test results are discussed in the Discussion of Results section. All eleven visibility tests simulate two major forklift operation modes: Travelling and Maneuvering. Three tests simulated the travelling mode and the remaining tests simulated maneuvering mode.

Forklift specifications are shown in Table 1 as directed in ISO/DIS 13564-1 Section 10.1 Truck Information. This table shows the test report's Truck information required for visibility reports.

Table 1. Forklift Specifications

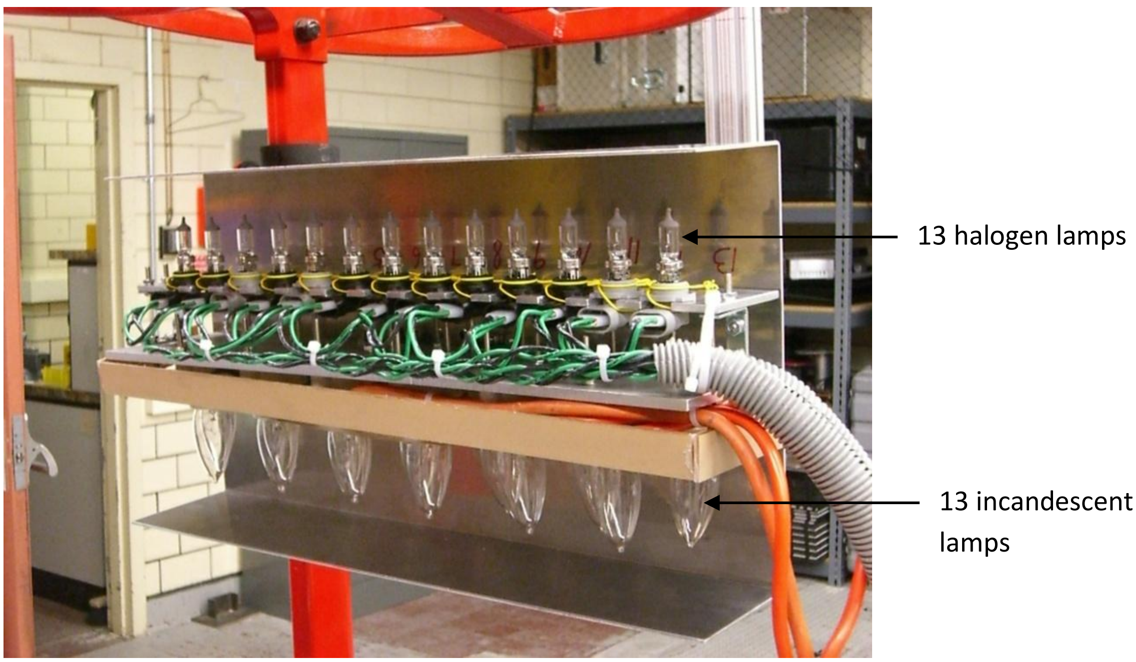
a	manufacturer	V.MARIOTTI
b	model	MYCROS 8C
c	serial number	62,5/3339
d	capacity and load centre	794 kg (1746 Lbs)
e	description of lifting mechanism	
	lift height	
	number of stages	2
	lowered height	floor
	reach	320 cm (126 in)
f	tire information	PM 267*127*65.1
g	location and dimensions of truck profile in 3.2	N/A
h	location of SIP and seat information, direction of the seat (see fig 9)	direction: Forward
i	stand-on truck info.	N/A
j	location an description of auxiliary equipment for indirect visibility	N/A

EXPERIMENTAL SETUP

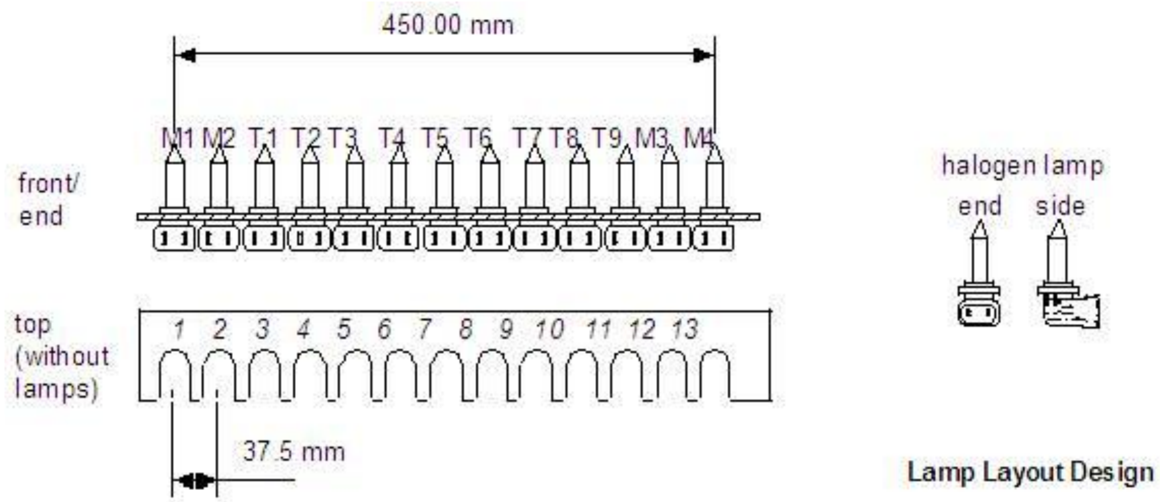
Apparatuses were designed and fabricated to use in the experiment according to visibility standards. These apparatuses included the: 1) 13 lamp array; 2) test body and test screen; 3) Seat Index Point (SIP) apparatus; 4) 100 N horizontal and 400 N vertical force application apparatuses that applied and forces to the SIP apparatus; and 5) lamp array electronics and a power supply. The test paths for eleven visibility tests, as specified in ISO/DIS 13564-1, were also marked on the floor. Each apparatus is explained in more detail and shown in Figures 2 through 6 with the entire experimental setup shown in Figure 7. Apparatuses designed and used are detailed here so that they can be mimicked by manufacturers, potentially saving time and effort. The Recommendations section includes possible improvements in apparatus design and development methods.

1. Light Source Array

Thirteen 55 W halogen lamps were used to generate light from within the forklift and were mounted at the specified location according to ISO/DIS 13564-1. Lamps were separated by 37.5 mm and numbered according to ISO/DIS 13564-1 as in Figure 2 (b) front/end view and position numbered as in Figure 2 (b) top view. Thirteen incandescent lamps were also initially tested and determined to provide unclear edges and therefore, not used for standard tests. Both sets of lights are shown in Figure 2 (a). A combination of incandescent and halogen was also tested with little improvement. Therefore, the standard was followed using only the top row of halogen lamps positioned as instructed in the standard. The lamp layout and numbering is shown in Figure 2 (b).



a



b

Figure 2. (a) Light source arrays, including: halogen (top row) and incandescent (bottom row); (b) Halogen lamp layout design.

2. Test Body and Test Screen

The 500 mm x 1200 mm test body and 500 mm x 1500 mm test screen (includes the test body), as shown in Figure 3, were drawn on a white board. The test body and test screen were drawn as specified in ISO/DIS 13564-1.

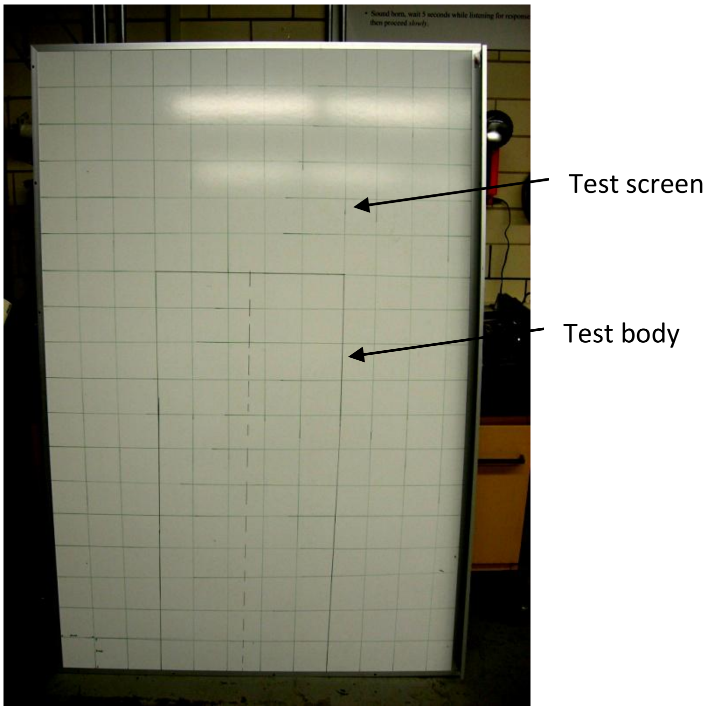
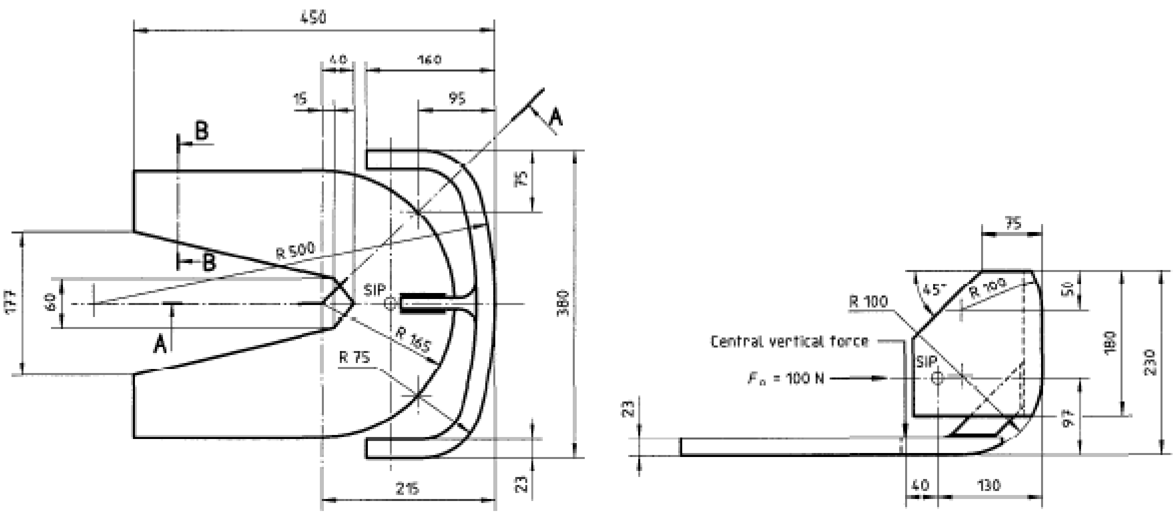


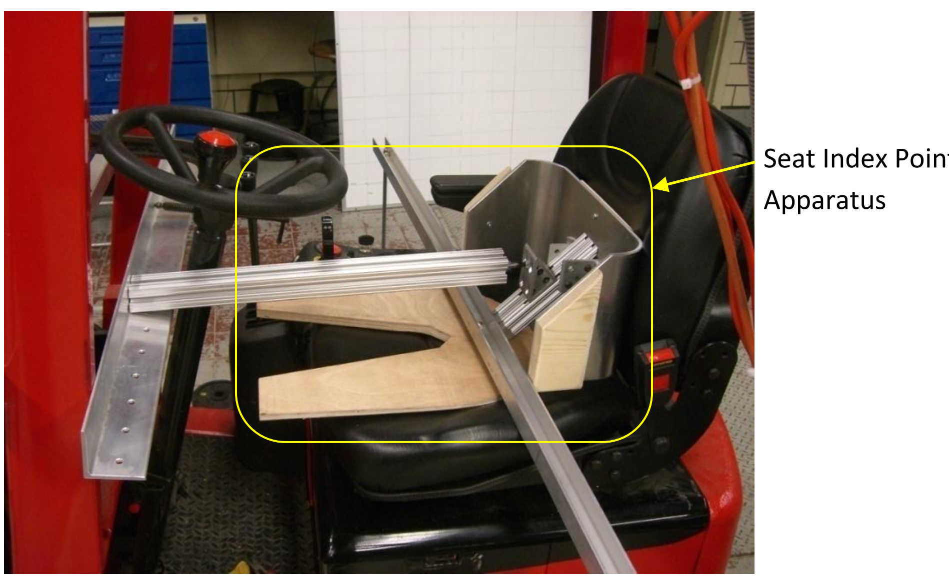
Figure 3. Test body and test screen

3. Seat Index Point Apparatus

ISO 5353 details the SIP apparatus as shown in Figure 4 (a). Since the back of the SIP apparatus was relatively complex to design and build, a modified design was used as shown in Figure 4 (b). Computer aided designs of the differences of specified standard and the as-built SIP apparatus used for ISD tests are shown in Appendix 1 – Modified SIP Apparatus Design. Similar contact points are applied to the seat as in the ISO 5353 specified design since wooden blocks combined with curved aluminum were used in the ISD design to fill the specified outside contact surface.



a



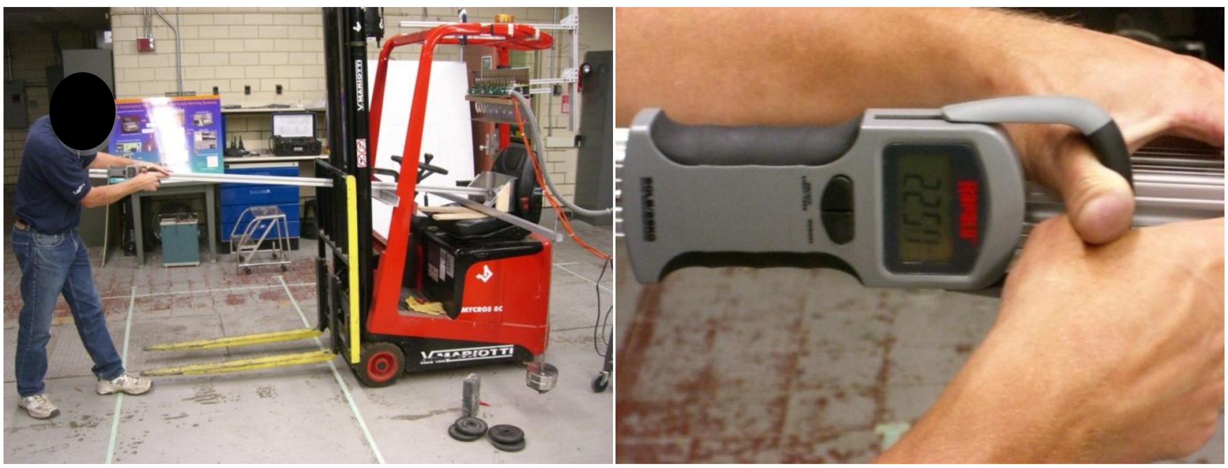
b

Figure 4. Seat Index Point Apparatus (a) as specified in ISO 5353 showing top (left drawing) and side (right drawing) views and (b) as-built by NIST ISD.

4. Horizontal and Vertical Force Application Apparatuses

The 100 N horizontal force was applied by a researcher (see Figure 5 (a)) through a piece of extruded aluminum bar and measured using a spring scale. A second researcher measured the distance between the point of applied force and an aluminum crossbar temporarily attached to the forklift. Following the measurement, a push bar was cut and inserted between the force application point and the cross bar (see Figure 5 (b)).

A 400 N vertical force was applied by adding weights to the SIP apparatus (see Figure 5 (b)). The weights were suspended on both ends of an aluminum bar using threaded rods. The bar also included a 10-32 bolt protruding from its center and was used to apply a point load to the SIP at the standard specified location.



a

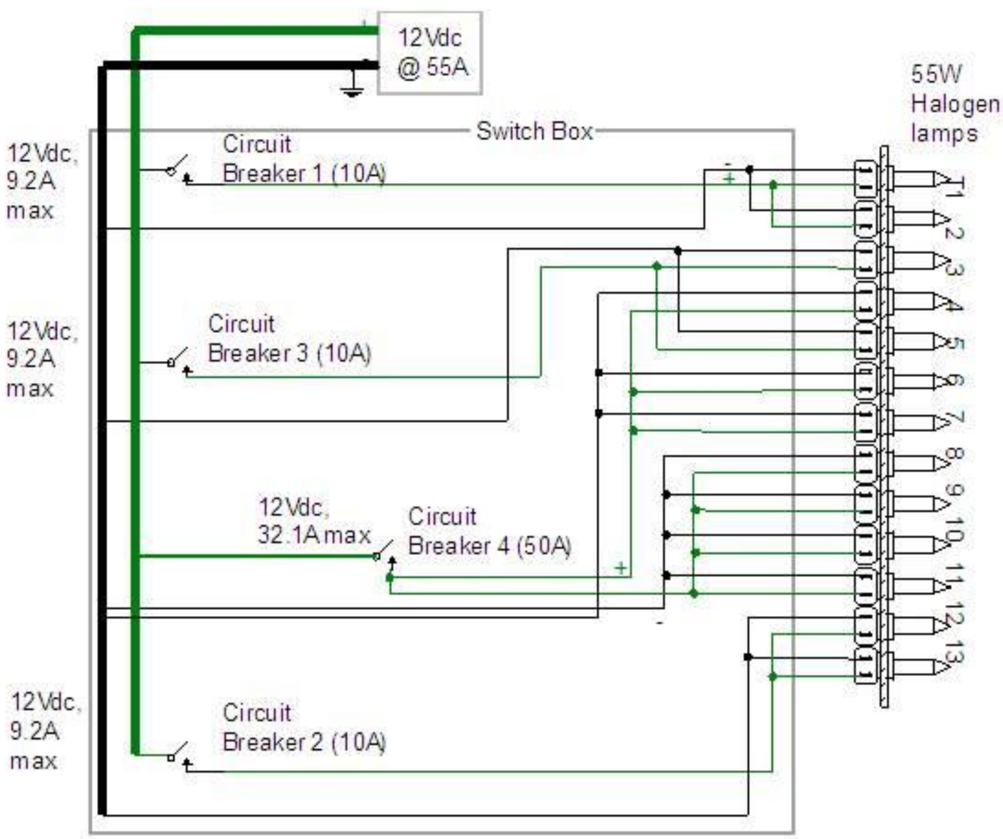
b

Figure 5. Applying (a) horizontal and (b) vertical forces. The spring scale shown in (a) indicates the applied force on the SIP device.

5. Electrical Circuits and Power Supply

A lamp switch box was designed and built and powered by a 55 Amp power supply as shown in Figure 6 (a). The lamp switch configuration was designed as in ISO/DIS 13564-1 to turn on only the specified lamps. Four circuit breakers were used as switches to power various combinations of lights as shown in the schematic in Figure 6 (b).

a



b

Figure 6. (a) Electrical setup: (left) power supply and (right) lamps switch box; (b) Lamps wiring diagram.

The entire experimental setup is shown in Figure 7. Note that the forklift locator line shown in Figure 7 (bottom) is not a test path. It was simply used as a marker in case the forklift was moved.

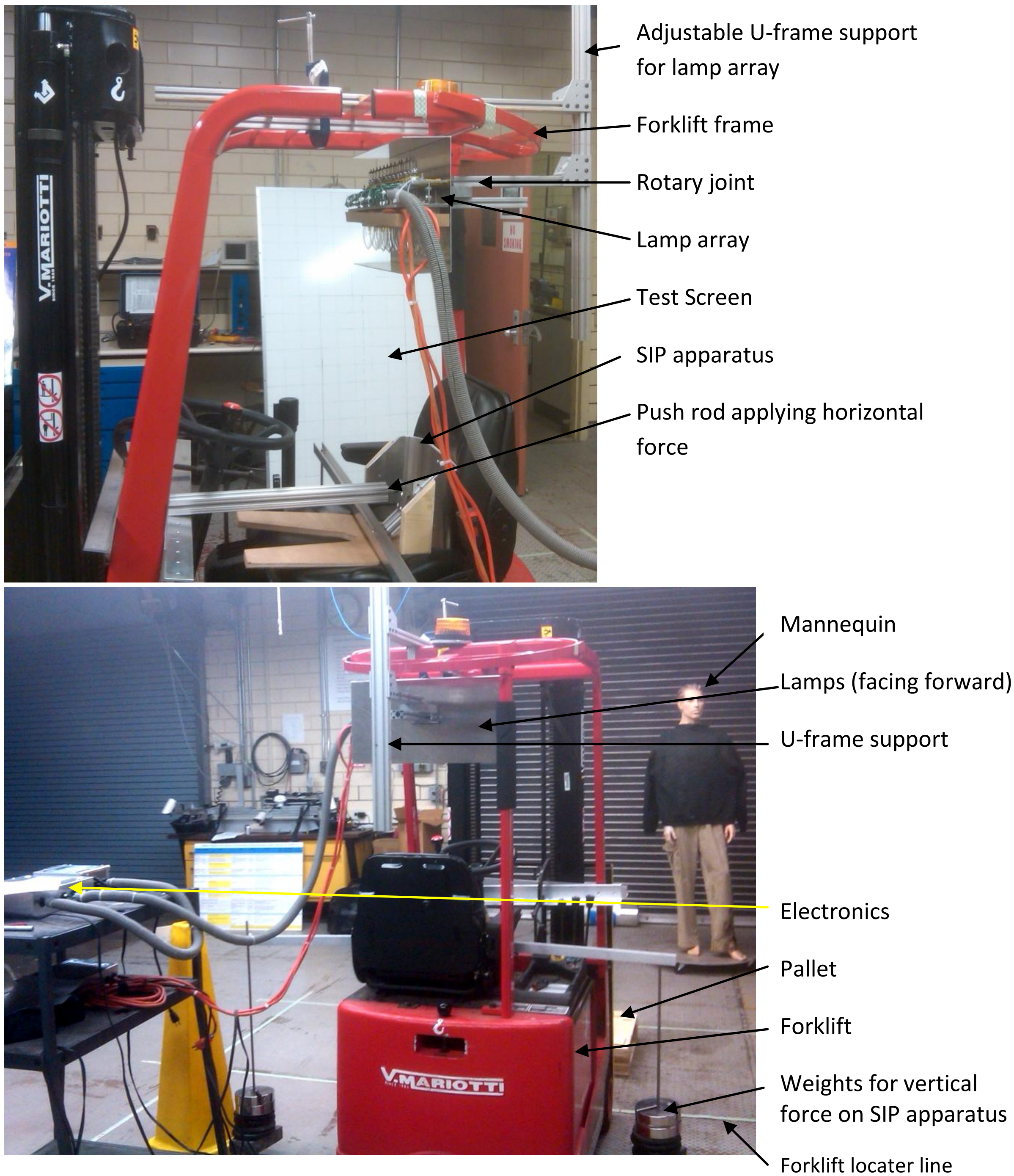


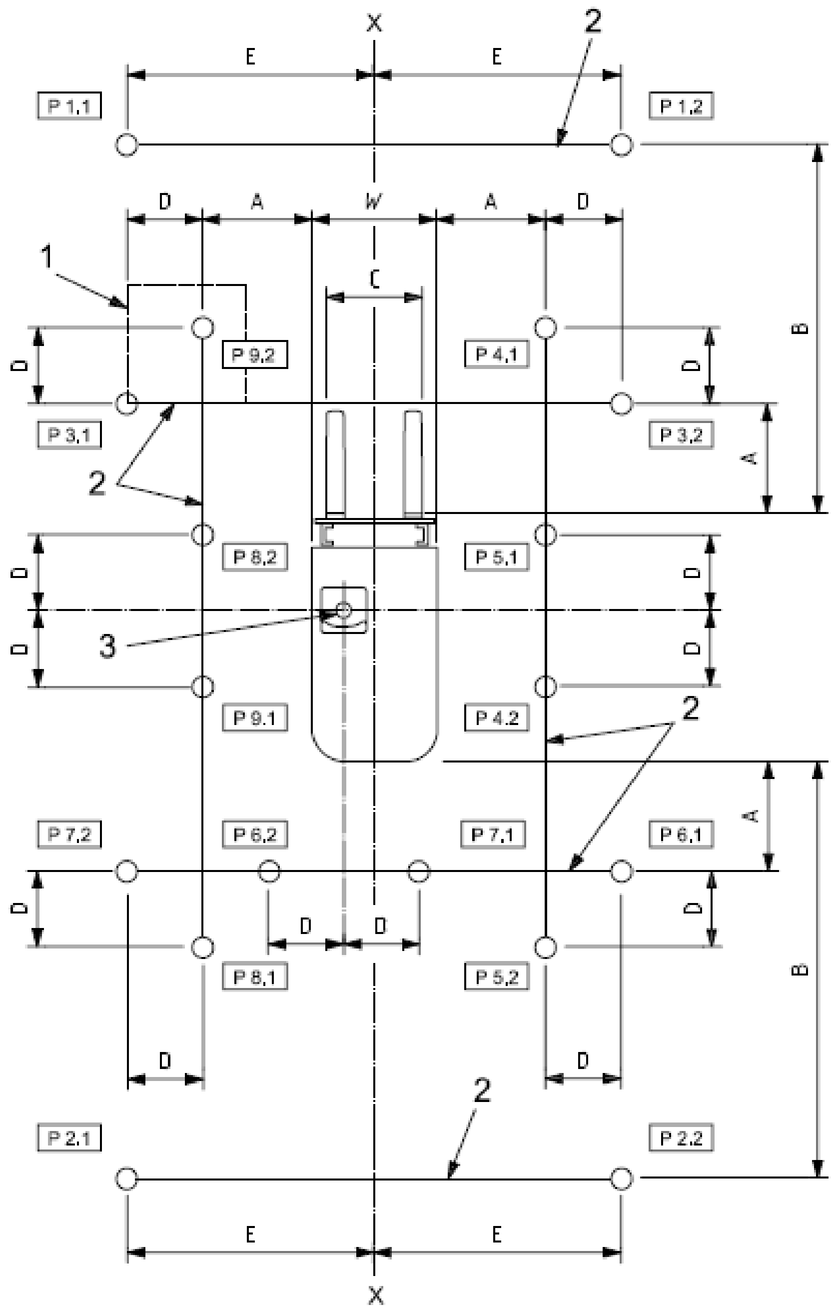
Figure 7 – Experimental setup showing all components.

EXPERIMENTS

Eleven tests were performed to evaluate the visibility from within the forklift when the lamp array was rotated to different directions. For each test, the test body or test screen was moved along the test paths specified by the standard. Percentage of shadows and illuminated areas associated with the specific location along the test path were then recorded. The visibility tests were conducted by following ISO 13564-1. Table 2 shows a description of the 11 visibility tests and Figure 8, included from the ISO/DIS 13564-1 standard, shows the test paths used. Test direction values are shown in Figure 18 (a) in Appendix 2 - Forklift Test Orientation and Patterns of Shadows. Forward is equivalent to 0°. Distance of lights to axis of rotation is shown in Figure 18 (b).

Table 2. Description of visibility tests

Test No.	Tests	Test Direction	Distance of lights to axis of rotation(cm)	Number of Lights	Test path	Test Object
1	Travelling	Forward	125	9	P1.1-P1.2	Test body
2	Travelling	-	125	9	P2.1-P2.2	Test body
3	Travelling	Forward	125	2	P1.1-P1.2	Test screen
4	Maneuvering	Forward	125	13	P3.1-P3.2	Test body
5	Maneuvering		125	13	P4.1-P4.2	Test body
6	Maneuvering		125	13	P5.1-P5.2	Test body
7	Maneuvering		125	13	P6.1-P6.2	Test body
8	Maneuvering		125	13	P7.1-P7.2	Test body
9	Maneuvering		125	13	P8.1-P8.2	Test body
10	Maneuvering		125	13	P9.1-P9.2	Test body
11	Fork arms	Direction of load center	275	13	N/A	Load carrying device



Key

A = 1 200 mm	*W*	maximum truck width
B = 4 000 mm	1	test body
C = 800 mm to 1 000 mm	2	test path
D = 250 mm	3	axis of rotation
E = *W*/2 + 500 mm	XX	longitudinal axis of the truck

Figure 8. Tests Path (excerpt from ISO/DIS 13564-1 FIG 7, P. 16).

NIST researchers performed additional experiments beyond the tests specified in ISO/DIS 13564-1, including:

1. Use of incandescent lamps instead of halogen lamps

   Reason: ISO/DIS 13564-1 states the use of 13 x 55W (12 V) lamps totaling 715W when all lamps are on. Because the lamps are 12 V powered, a power supply of nearly 60 A is required to meet this criteria. Incandescent lamps are 120 V (in the US) x 60 W (standard) each. They can use typical alternating current power at 0.5 A each or 7.5 A for all 13 lamps with no additional power supply required.

2. Use of 13 incandescent and 2 halogen lamps

   Reason: As in 1 above, power is the main issue. However, incandescent lamps do not produce clear shadow edges from vehicle obstructions as do halogen bulbs. The combination was therefore tested.

3. Use of loads carried by the forklift

   Reason: the forklift is frequently loaded. Forklift operators must be able to use the forklift during these times, too, and have appropriate visibility to control the vehicle safely. Therefore, tests were completed using underslung and palletized loads.

Added to this test was the use of more human-type test bodies instead of a screen.

> Reason: Since one main concern with operator visibility is to see pedestrians when carrying loads, standard test pieces specified in ANSI B56.5 and a mannequin were used. ANSI B56.5 test pieces simulate a person's lower leg when standing (70 mm diameter x 400 mm high) and a person's torso when they have fallen down (200 mm diameter x 600 mm long). The mannequin was 1.8 m high. For these tests, NIST researchers set questions to be addressed as: Can the test pieces be seen? For the mannequin, which body part(s) can or cannot be seen?

The results of the additional experiments are summarized in the Results of Additional Experiments section.

EXPERIMENTAL RESULTS

Most of the tests results for the forklift used met the criteria specified by the ISO/DIS 13564-1 standard which requires that the percentage of area illuminated by at least one light be at least 20 %. For those results that met the criteria, the percentage of illuminated area was very high, around 100 % as shown in Table 3. This was because 9 or all 13 lamps, depending on the test, were turned on simultaneously to simulate the range of positions of an operator's eyes from head movement. However, this simulation was not very accurate because although the two eyes of an operator could actually reach any position within the width of the lamp array, the operator’s eyes cannot reach all the positions at the same time.

For example, in test 1, nine lamps were turned on according to the standard. Illuminated areas were 100 % as shown in Figure 9 (a). However, with just two lamps (No. 9 and No. 11) turned on, the percentage of illuminated area dropped to 0 % as shown in Figure 9 (b). Therefore, there was a blind spot with the two eyes at locations of lamps 9 and 11. Since the percentage of illuminated area was almost 100 % for all the standard tests and the test results did not show the existence of blind spots, the simulation was not accurate, although the results meet the criteria of the existing standard.

a b

Figure 9. (a) Shadows of test1, (b) Shadow of test 1 with just two lamps separated by 75 mm turned on

Test results directed by ISO 13564-1 include these points:

1) There were no auxiliary equipment used in the tests
2) For test 3, the lamps used were No. 3 and No. 5
3) For test 11, distance between lamps axis and axis of lamps rotation was 275 mm.
4) Height of load carrying surface for test 11 was 200 mm; height of load carrying surface was 0 for all other tests.
5) Number of lamps that were not used in 5.13 was none.

Tables 3 and 4 include test results for traveling mode and maneuvering mode, respectively, and include the following rows:

a: test number

b: percentage of illuminated area for all dark shadows c: position of test body on the test path or location of dark shadow on the screen – test positions are with respect to Figure 8 - Tests Paths as excerpt from ISO/DIS 13564-1 FIG 7, P. 16.

The percentage shown in each column under each test is with respect to row c test body and test path position. For example, under Test 1, the percentage is 100 % illumination with the left edge of the test screen at position P1.1.

Table 3. Test results for traveling mode of forklift

a) test number	**b) percentage of illuminated area for all dark shadows**	**c) position of test body on the test path or location of dark shadow on the screen**
Test 1	100 %	left edge of screen at P1.1
	100 %	center of screen at longitudinal axis of forklift
	100 %	right edge of screen at P 1.2
Test 2	100 %	right edge of screen at P2.1
	100 %	center of screen at midpoint of P2.1 and P2.2
	100 %	left edge of screen at P2.2
Test 3	100 %	left edge of screen at P1.1
	100 %	center of screen at longitudinal axis of forklift
	100 %	right edge of screen at P 1.2
	100 %	right edge of screen at P3.1
	100 %	left edge of screen at 60 mm to the right of P3.1
	95 %	left edge of screen at P2.2

Table 4. Test results for maneuvering mode of forklift

a) test number	**b) percentage of illuminated area for all dark shadows**	**c) position of test body on the test path or location of dark shadow on the screen**
Test 4	100 %	right edge of screen at P3.1
	100 %	left edge of screen at 60 mm to the right of P3.1
	95 %	left edge of screen at P2.2
	90 %	left edge of screen at 120 mm to the right of P3.1
	91.5 %	center of screen at the longitudinal axis of forklift

	97 %	right edge of screen at 120 mm to the left of P3.2
	100 %	right edge of screen at P3.2
Test 5	100 %	left edge of screen at P4.1
	100 %	center of screen at 70 mm away from P4.1
	100 %	center of screen at 140mm away from P4.1
	100 %	center of screen at 210 mm away from P4.1
	100 %	right edge of screen at P4.2
Test 6	100 %	left end point of screen at P5.1
	100 %	midpoint of screen at midpoint of P5.1-P5.2
	100 %	right end point of screen at P5.2
Test 7	100 %	left end point of screen at P6.1
	100 %	midpoint of screen at midpoint of path P6.1-P6.2
	100 %	right end point of screen at P 6.2
Test 8	100 %	right end point of screen at P7.2
	100 %	midpoint of screen at midpoint of P7.1-P7.2
	100 %	left end point of screen at P7.1
Test 9	100 %	right end point of screen at P 8.2
	100 %	midpoint of screen at midpoint of P8.1-P8.2
	100 %	left end point of screen at P 8.1
Test 10	100 %	right end point of screen at P9.2
	100 %	midpoint of screen at 70mm away from P9.2
	100 %	midpoint of screen at 140mm away from P9.2
	100 %	midpoint of screen at 70mm away from P9.1
	100 %	left end point of screen at P9.1
Test 11	50 %	Forklift tines

RESULTS OF ADDITIONAL EXPERIMENTS

Additional tests beyond ISO/DIS 13564-1 tests were completed by NIST researchers. Each of the tests results are explained below.

1. Use of incandescent lamps instead of halogen lamps

Incandescent lamps resulted in unclear lines on the test body where percentage of shadows could not be determined. Therefore, no results are shown for this additional test.

2. Use of 13 incandescent and 2 halogen lamps

   The two halogen lamps provided additional clarity over the use of only incandescent lamps. However, there was no additional information that could be clearly determined without complex experimental data from the lights being use at all 13 locations. Therefore, no results are shown for this additional test.

3. Use of loads carried by the forklift – tested on human-type test bodies instead of a screen.

   Tests 1, 3, and 4 from ISO/DIS 13564-1 were completed for loads carried by a forklift. Table 5 shows the results.

Table 5. Test results with forklift carrying a pallet of boxes. Fork arms height 90 cm, tests with four boxes, each 31 cm^3. Tests 1, 3, 4 are in the forward direction. Tests in other directions were not affected by the pallet of boxes. See examples in Figure 10.

Test object	Mannequin 1.8 m high		
Standard Test Number	1	3	4
Test Results	Only head could be seen	Only head could be seen	Only head could be seen at midpoint of path

Test object	ANSI B56.5 Standard Test pieces (200 mm dia. x 600 mm long and 70 mm dia. x 400 mm high)		
Standard Test Number	1	3	4
Test Results	Could not be seen at locations 2 and 3	Could not be seen	Could be seen

Test object	Standard Test body		
Standard Test Number	1	3	4
Test Results comparied to standard tests.	Percentage of illuminated area dropped from 100 % to 21 %	Percentage of illuminated area dropped from 100% to 21 %	Illuminated area dropped to 5 % at midpoint of path and it dropped to 50 % at location 3 along path.

Figure 10: Photos of tests with pallet of boxes (left) using the test board and (right) using a mannequin.

Table 6. Results when fork arms were raised to 117 mm above floor. See examples in Figure 11.

Test object	Mannequin		
Test Number	1	3	4
Test Results	Only feet and head could be seen along test path	Only feet and head could be seen along test path	Head and legs could be seen at midpoint of path. Entire mannequin could be seen elsewhere

Test object	ANSI B56.5 Standard Test pieces (200 mm dia. x 600 mm long and 70 mm dia. x 400 mm high)		
Test Number	1	3	4
Test Results	Could be seen	Could be seen	Could be seen along path

Test object	Standard Test body		
Test Number	1	3	4
Test Results Compared to standard tests	Illuminated area dropped from 100% to 42% along path	Illuminated area dropped from 100% to 42% along path	Illuminated area dropped to 85% when test body was located at midpoint of path, at location 3, and at location 5, respectively.

Figure 11. Shadows on the test screen when fork arms were raised to 117 cm

RECOMMENDED IMPROVEMENTS TO CURRENT STANDARDS

ISO/DIS 13564-1 and ANSI/ITSDF B56.11.6

1. <u>Change to the simulation of operator eyes.</u>

Since turning on all the lights at the same time did not effectively simulate the positions of two eyes of an operator, a change to the current method can be introduced and tested. Two lamps separated by 75 mm could be used to approximate the operator’s eye spacing. The average human eye separation, as found in online web searches, is 65 mm. [6] Therefore, to simulate the two eyes of an operator, only two lamps (3 and 5) were turned on. To better simulate the movement of the head of an operator, the entire light source array was rotated from +45° to -45°. The two shadows at the same location P1.1 were compared when generated by the standard stationary method and the recommended rotated lamps method. The resulting illuminated area according to the standard method was 100 %. However, the illuminated area dropped to 0 % when the light source array was rotated to -30°. This meant that there was a blind spot that could not be detected by the standard method and therefore, by the operator. Figures 12 shows photos of shadows on the test screen when following the standard and also shadows on a mannequin. Figure 13 shows the same scene after rotating the lights -30°.

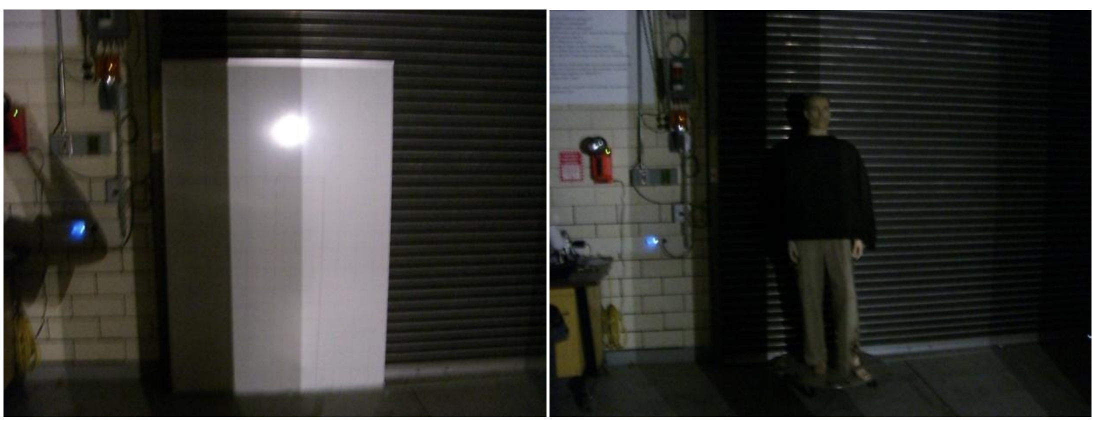


Figure 12 Shadows by following standard: (left) on a test board as specified in the standard, (right) using a mannequin instead of the test board.

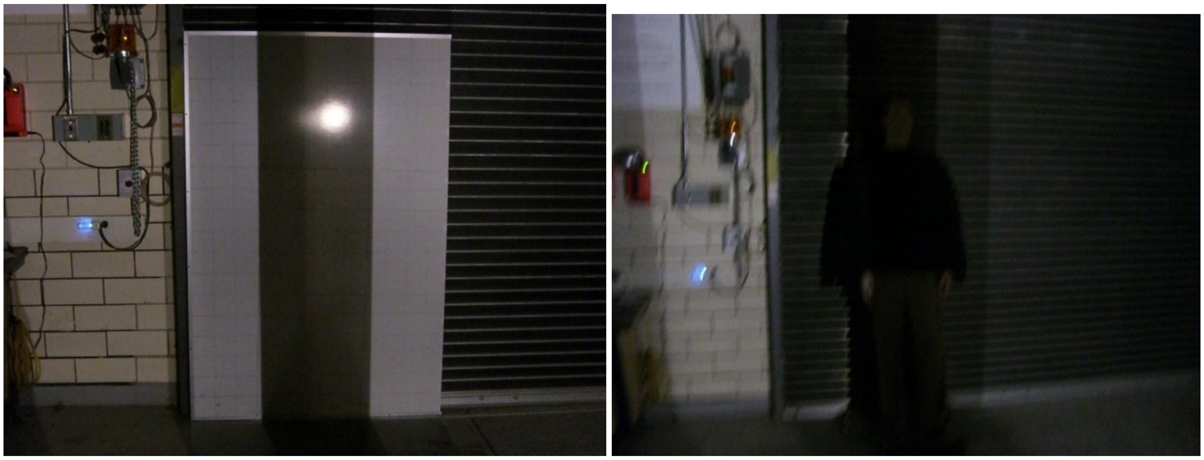


Figure 13. Shadows by rotating light source array -30°: (left) on the test board and (right) using a mannequin instead of the test board.

The first suggested change of the standard is, therefore, to rotate the lamp array with only two lamps turned on and separated 75 mm.

2. Change to test 3.

Test 3 requires turning on any two lamps separated by 75 mm. The chosen two lamps to illuminate for tests can dramatically affect the results where a certain combination of lamps may detect non-visible regions and the test may fail. A suggested change to the standard is that all combinations of the lamps separated by 75 mm should be tested. Individual switches for each light or a sliding mechanism could perhaps allow the two lamps separated by 75mm to move as if the operators head moves side to side.

3. Include tests with underslung loads.

ISO/DIS 13564-1 mandates that the forklift be 'unladen' (unloaded) during testing. However, forklifts are used to carry and deliver loads. Tests were conducted with the forklift as if carrying a battery charger as shown in Figure 14 (a). The fork arms were raised and the fork frame structure blocked the operator's visibility. Three test pieces were used in the test, including: test body, mannequin, ANSI/ITSDF B56.5 standard test pieces. When the fork arms were raised, the percentage of illuminated area decreased as expected due to additional forklift structure blocking lamps. When the fork arms were raised to 117 cm high, illuminated percentage of test body dropped from 100 % shown in Figure 14 (b) to 42% as shown in Figure 14 (c). Figure 14 (d) shows resulting shadows on a mannequin to interpret visibility results for pedestrians and Figure 14 (e) shows similar results as in Figure 14 (c) but on a closer test body path to the vehicle. A suggested change to the standard is that visibility tests should be tested with the forklift carrying underslung loads.

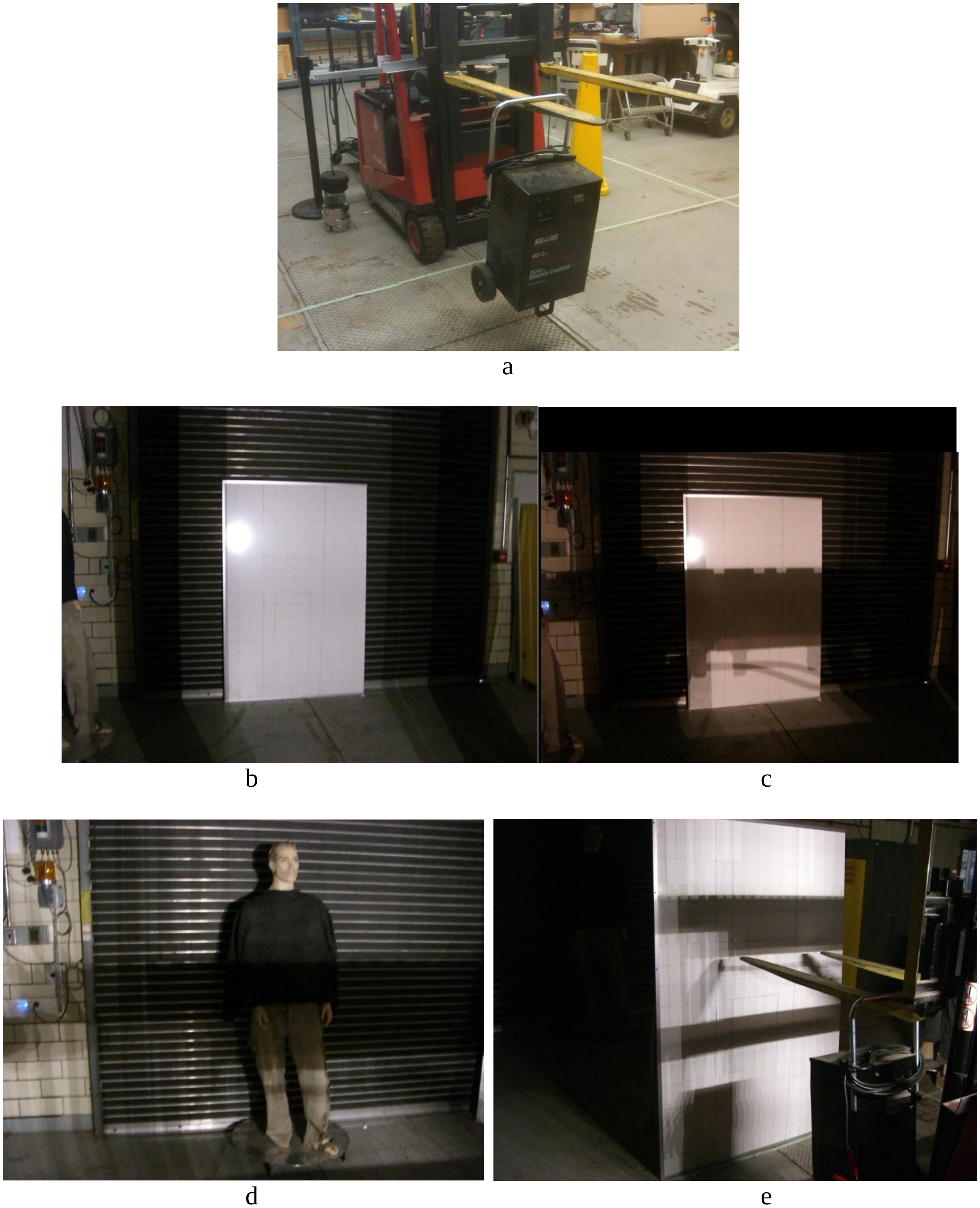


Figure 14 (a) Forklift with an underslung load used for visibility tests, (b) test body before the arms were raised, (c) test body when forklift tines were raised and resulting shadows: (d) on a mannequin and (e) on the test body at a closer path to the fork tines.

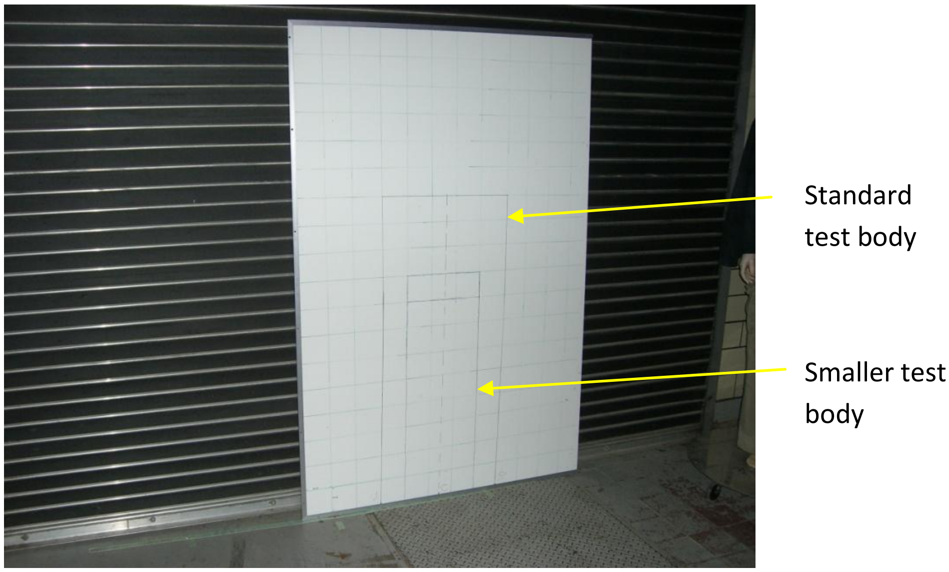
4. Include tests with palletized (on-fork tine) loads.

Similar to recommendation 3, recommendation 4 suggests visibility tests also be conducted while the forklift carries loads above the fork tines (see Figure 15 (a)), such as a pallet of chosen standard-size boxes. Specific load size should be specified. Illuminated area was 0 % with the test body at P1.2 as shown in Figure 15 (b). Other visibility test apparatuses were also used in NIST tests including a mannequin and ANSI/ITSDF B56.5 standard test pieces (see Figure 15 (c, d)). Illuminated area was 0 % with the mannequin and 0 % with the test pieces when they were located at the midpoint of P3.1 - P3.2.

Figure 15. (a) Forklift carrying a pallet of boxes for visibility tests with resulting shadows shown on: (b) the test body, (c) ANSI/ITSDF B56.5 standard test pieces, and (d) a mannequin.

5. Include tests with a smaller screen.

As in recommendation 4, ANSI/ITSDF B56.5 standard test pieces can go undetected in certain cases. These pieces can represent a person's lower leg and the midsection or thigh of a person lying in the vehicle path. Therefore, a suggested recommendation to visibility standards is to also use a smaller screen to represent small obstacles along with an appropriately safe visibility percentage. A smaller screen with 300 mm x 1000 mm was used in the test as shown in Figure 16 (a). With the midpoint of the screen at about 45 mm to the right of the midpoint of P1.2 - P1.2, the illuminated area of the original screen was 20 %, but the illuminated area of the smaller screen was 0 % where it failed the visibility test. Figure 16 (b) shows that the entire smaller screen is within the shadow thereby demonstrating 0 % visibility.



a

b

Figure 16. (a) Standard and smaller sized test screens marked on the board; (b) large screen passing the visibility test and the smaller screen failing the visibility test (i.e., fully within the shadow).

6. Specify exact locations of the test screen along test paths.
   Locations of the test screen and test body are not exactly presented in the standard and provide some ambiguity as to what the exact location should be. Tests proved that test screen locations can vary the test results. Therefore, we recommend that the exact locations of the test screen and test body be specified to avoid confusion and to compare exact test results to other similar forklifts. Should locations vary with respect to the forklift size and geometry, it is recommended that varying test screen locations with respect to the forklift be required.

7. Inform the reader of a typical type of lamps and their mounts.

   Lamps were relatively expensive ($11 each x 13), difficult to locate, and were eventually purchased from an automobile parts store. As a result, a custom slot-type mounting plate was designed (see Figure 2) to support the lamps due to their unique shape and spacing requirement. The slotted lamp plate also allowed lamps to be moved as in recommendation 2 to test two lamps, spaced 75 mm apart and mounted in various slots. Therefore, it is recommended that the standard provide information of the typical type of lamps, beyond stating "halogen or similar," and how to mount them in the specified array.

8. Specify the danger of using halogen lamps.

   Although halogen lamps provide the ideal sharp edged shadows required by the standard, they can be hazardous. Halogen lamps are extremely hot, extremely bright, and require relatively high power as compared to standard incandescent light bulbs. Two recommendations are therefore: a) to provide a safety discussion in the standard with regard to lamp heat, luminescence, and power; b) to list the lamp luminescence in lumens, not watts, so that potentially safe, lower power or heat lamps can be used for tests and advanced technology in light sources can be compared to the 55 W halogen lamps currently specified. We also suggest that further research is needed with the use of Light Emitting Diode (LED) or other low temperature and low power lamps.

9. Include advanced visibility measurement test methods.

   Minimal information is provided in visibility standards for an advanced measurement solution for powered industrial vehicles. A proposed plan is in place at NIST to collaborate with a university to develop test methods for the advanced visibility measurement of powered industrial vehicles. At least one university has studied construction vehicle visibility issues using advanced laser scanning techniques. [11] As these visibility measurement techniques evolve for powered industrial vehicles, the standard should reflect the usefulness of such systems and how they provide additional benefit. Benefits will include measurement time savings, safe test methods, and more accurate and detailed measurement and representation of non-visible regions.

Current efforts are being made towards ensuring complete powered industrial vehicle operator visibility (see Appendix 3 – Recent visibility efforts) and accurate knowledge of sensor type (e.g., 2-dimensional laser detection and ranging verses 3-dimensional light detection and ranging) that can ensure safe vehicle operation. Hence, the non-visible regions must be clearly represented to advanced technology providers of augmented visibility sensor systems on, or soon to be on, the market. Current test methods described in visibility standards provide allowable non-visibility percentages from shadows on a movable test body creating a piecemeal model of non-visible regions. The methods may be tedious, time-consuming, and less accurate for industrial vehicle manufacturers to design improvements and for augmenting visibility sensor providers to determine sensor type and mounting locations for safe 100 % operator visibility.

ISO 5353: 1995

1. Change the SIP apparatus drawings.

Separate SIP apparatus component dimensioned drawings into individual drawings and also provide an assembly drawing with appropriate tolerances. The SIP apparatus drawing layout specified by the standard required potentially unnecessary time and additional materials. Drawings that interpreted the standard were additionally required to produce parts. This is because X, Y coordinates, as used by machinists for dimension layout and computer numerical control input, are not shown in the standard on each piece to be fabricated. See the SIP apparatus base drawing on wood in Figure 17 (a). The outside rectangle is the overall dimension of the SIP apparatus where several base dimensions are referenced in the standard (see Figure 23 of Appendix 1 – Modified SIP Apparatus Design). To produce the drawing shown within the Figure 17 (a) rectangle, either the wood must be marked or an additional interpretation drawing is required. Other components needed for NIST to make the SIP apparatus are shown in Figure 17 (b) and the fully assembled apparatus is shown in Figure 17 (c). Ideally, a base drawing and each other component drawing required are individually shown in the standard with an additional assembly drawing showing mounting dimensions and locations. A photo of a completed system may also be very useful.

Also, tolerances are shown to 0.0 mm and may not be necessary for fabrication and as such, increase machining and assembly costs.

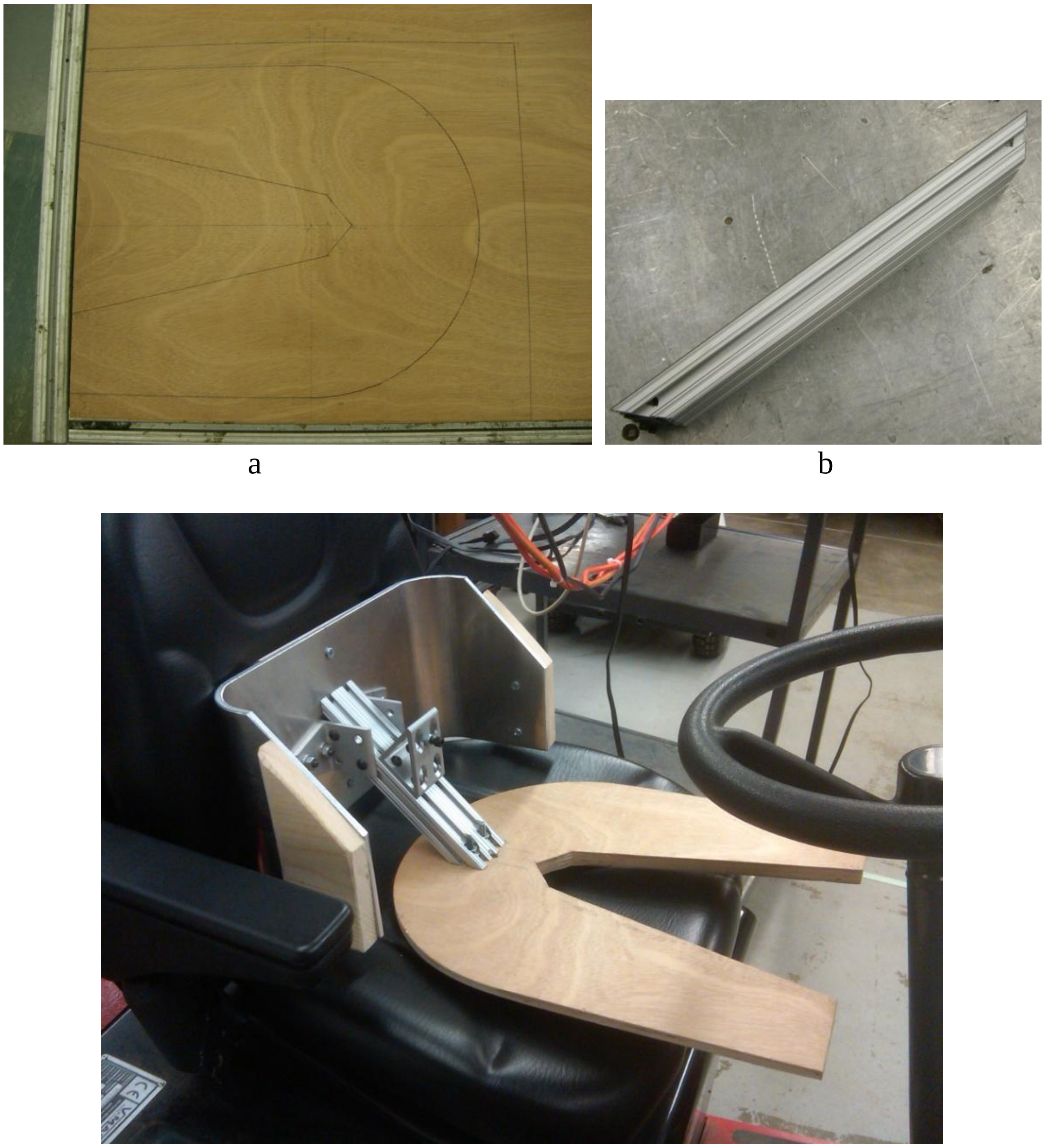


Figure 17. (a) SIP Apparatus: (a) base drawn on a piece of wood (b) joining bar for base to back, (c) fully assembled apparatus on a forklift seat.

SUMMARY AND CONCLUSIONS

Standard tests for operator visibility when driving forklifts allow for 20 % non-visible regions. Some safety technologies are on the market that can help to reduce pedestrian and forklift driver injuries. However, large numbers of accidents still occur. Standard tests were performed by NIST researchers to provide recommendations to the standard committees on better test methods and to provide basis for future NIST industrial vehicle programs. Standard tests provided few results that demonstrate the actual non-visible regions of forklifts. Based on the results of the testing, there are a number of recommendations to improve these standards including: the use of low power and temperature lamps; tests that allow lamp placement resembling an operators instantaneous eye position; and use of simpler test apparatuses and advanced test methods that use lasers that measure exact locations of non-visible regions for improving forklifts and their safety. These advanced methods can also allow sensor and vehicle manufacturers to develop on-board vehicle systems to improve operator alerts and semi-autonomous slow and stop controls. Advanced 2D and 3D imaging sensors are potentially useful for onboard safety measurement of non-visible regions. Future plans are to measure the performance of advanced laser systems used to measure non-visible regions of forklifts and to publish results as further recommendations to standards committees. Example measurement results of 3D imagers with operator alerts and a laser measurement system are shown in Appendix 3 – Recent and planned visibility efforts.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the ANSI/ITSDF B56.11.6 committee who provided standards information to perform the tests.

REFERENCES

[1] Roger Bostelman, Will Shackleford, "Advanced Sensing Towards Improved Forklift Safety", PerMIS 2010 Proceedings, Gaithersburg, MD.

[2] ANSI/ITSDF, http://www.itsdf.org/pB56.asp, 2011.

[3] International Organization for Standardization, http://www.iso.org, 2011.

[4] ISO/DIS 13564-1: 2007 - Powered Industrial trucks – Visibility - Test methods and verification-Part 1: Sit-on and stand-on operator trucks and variable reach trucks.

[5] ANSI/ITSDF B56.11.6: 20xx - Evaluation of Visibility from Powered Industrial Trucks.

[6] Bostelman, Roger, 2009. "White paper, Towards Improved Forklift Safety," PerMIS 2009 Proceedings, Gaithersburg, MD.

[7] Measurement Science for Intelligent Manufacturing Robotics and Automation Program website: http://www.nist.gov/el/isd/si/msimra.cfm, 2011.

[8] ANSI/ITSDF B56.5: 2010 - Safety Standard for Driverless, Automatic Guided Industrial Vehicles and Automated Functions of Manned Industrial Vehicles.

[9] ANSI/ITSDF B56.11.6: 20xx - Evaluation of Visibility From Powered Industrial Trucks

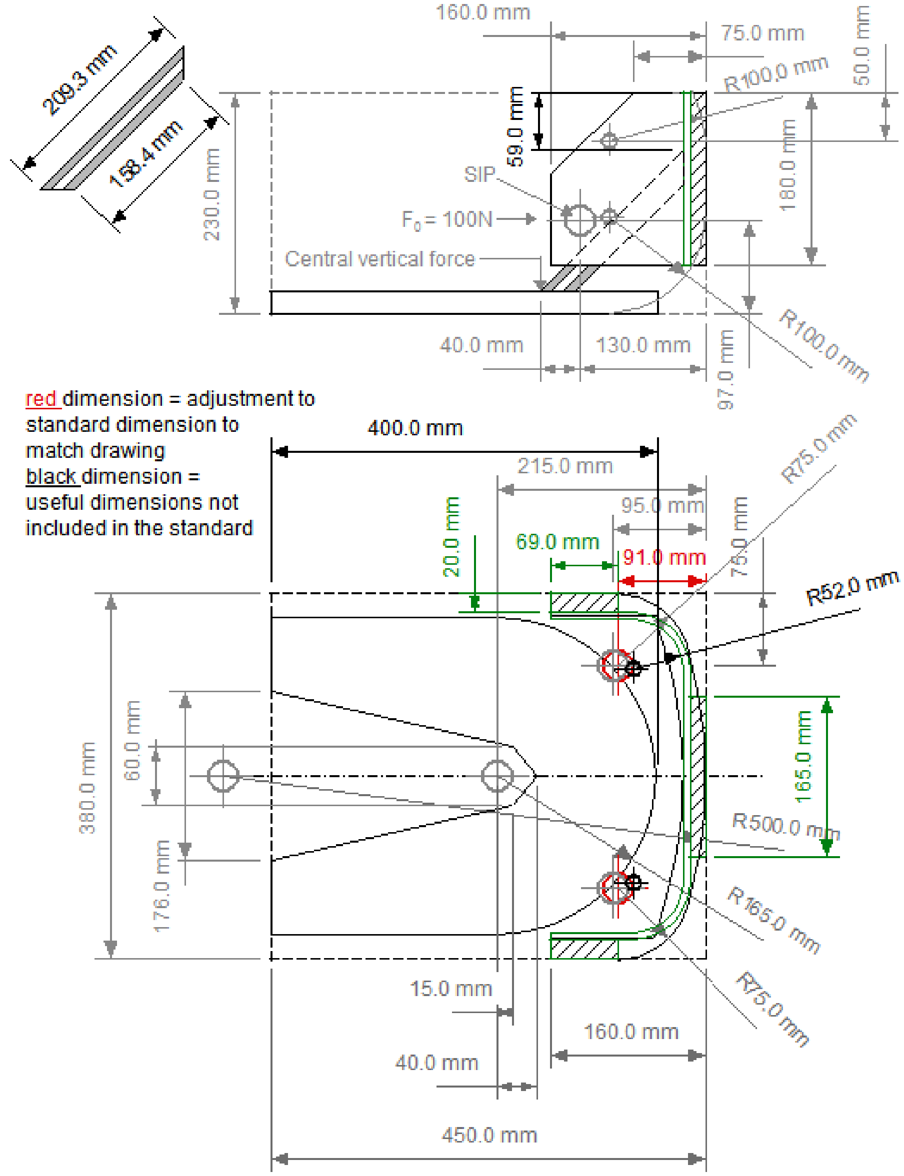
[10] ISO 5353: 1995 - Earth-moving machinery, and tractors and machinery for agriculture and forestry-Seat Index Point

[11] Wolfgang Wieser, “Creating stereoscopic left-right image pairs with POVRay,” http://www.triplespark.net/render/stereo/create.html, September 2, 2007.

[12] Jochen Teizer, Ben S. Allread, Uday Mantripragada, “Automating the blind spot measurement of construction equipment,” Automation in Construction Journal, Vol. 19 (2010), pp. 491–501.

APPENDICES

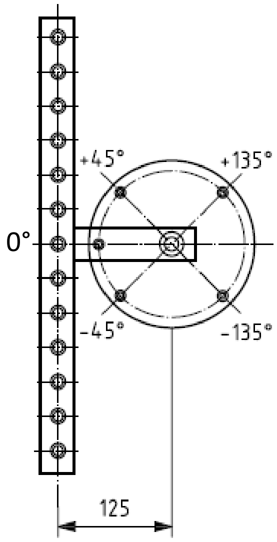
Appendix 1 - Modified SIP Apparatus Design



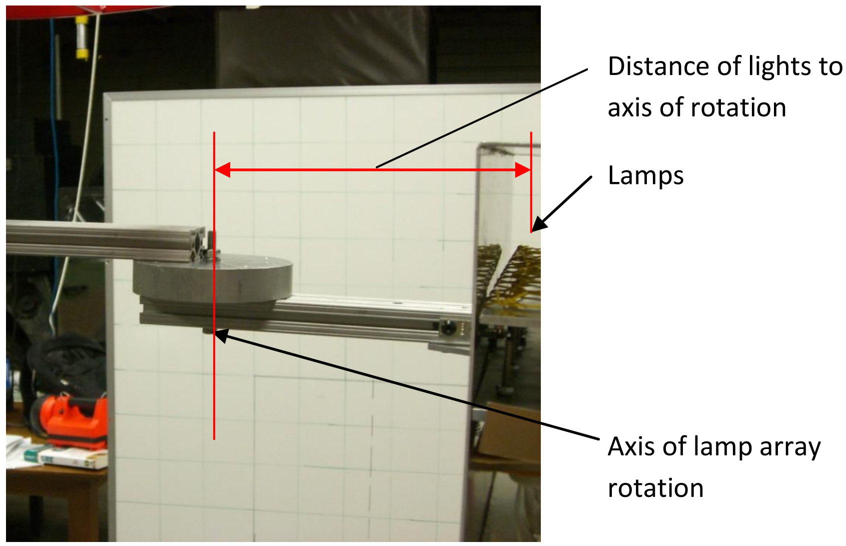
green outlined parts = NIST machined part adapted to ISO standard – green part is 6.4 mm (1/4 in) thick aluminum with wooden blocks added to match standard dimensions.

Figure 18. SIP Apparatus drawing showing standard drawing in gray and red, black and green modifications for NIST experiments.

Appendix 2 - Forklift Test Orientation and Patterns of Shadows



a



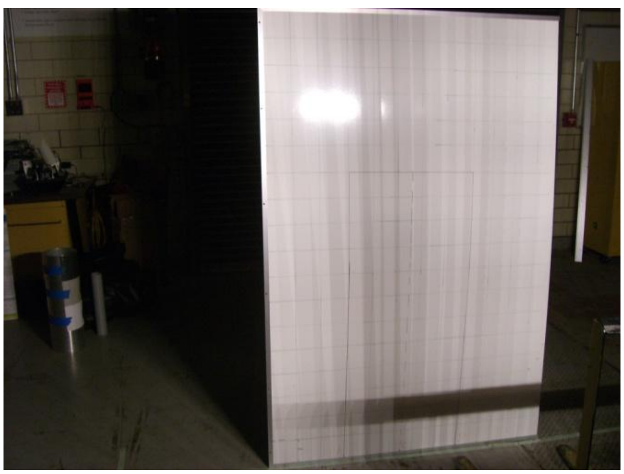
b

c

d

Figure 19. (a) Top view of lamps test angles as specified by ISO/DIS 13564-1, (b) Lamps rotary joint, (c) Lamps facing forward, (d) Lamps facing to the rear of the forklift.

a



b

c

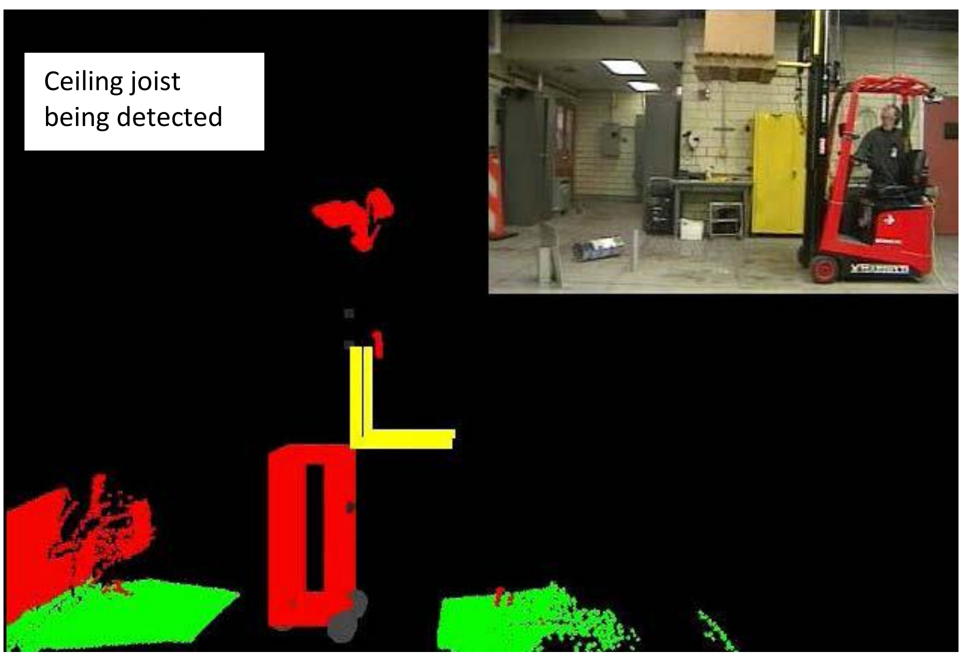
Figure 20. Examples of shadows of visibility tests, from: (a)Test 3, at location 3, (b) test 4, location 3, and (c) test 3, location is left edge of test screen at P1.1.

Appendix 3 - Recent and planned visibility efforts

- Performance testing of advanced 3D imagers on test pieces
- Performance measurement of advanced 3D imagers mounted to forklifts to detect obstacles, pedestrians in the NIST lab and in a real manufacturing facility
- Development of software to integrate 3D imaging with operator alerts (see Figure 20)
- Georgia Institute of Technology has focused advanced visibility measurements on construction vehicle visibility (see Figure 21) [11]. NIST is planning to work with a university on advanced visibility measurements for powered industrial vehicles.

a

b



c

Figure 21. 3D imagers mounted on a forklift and integrated with simple operator alerts – (a) obstacle is behind the forklift and (b) the alert indicates the obstacle, (c) high lift obstacle detect sensor mounted to forks frame (upper right photo) capturing data of ceiling joists (lower left).

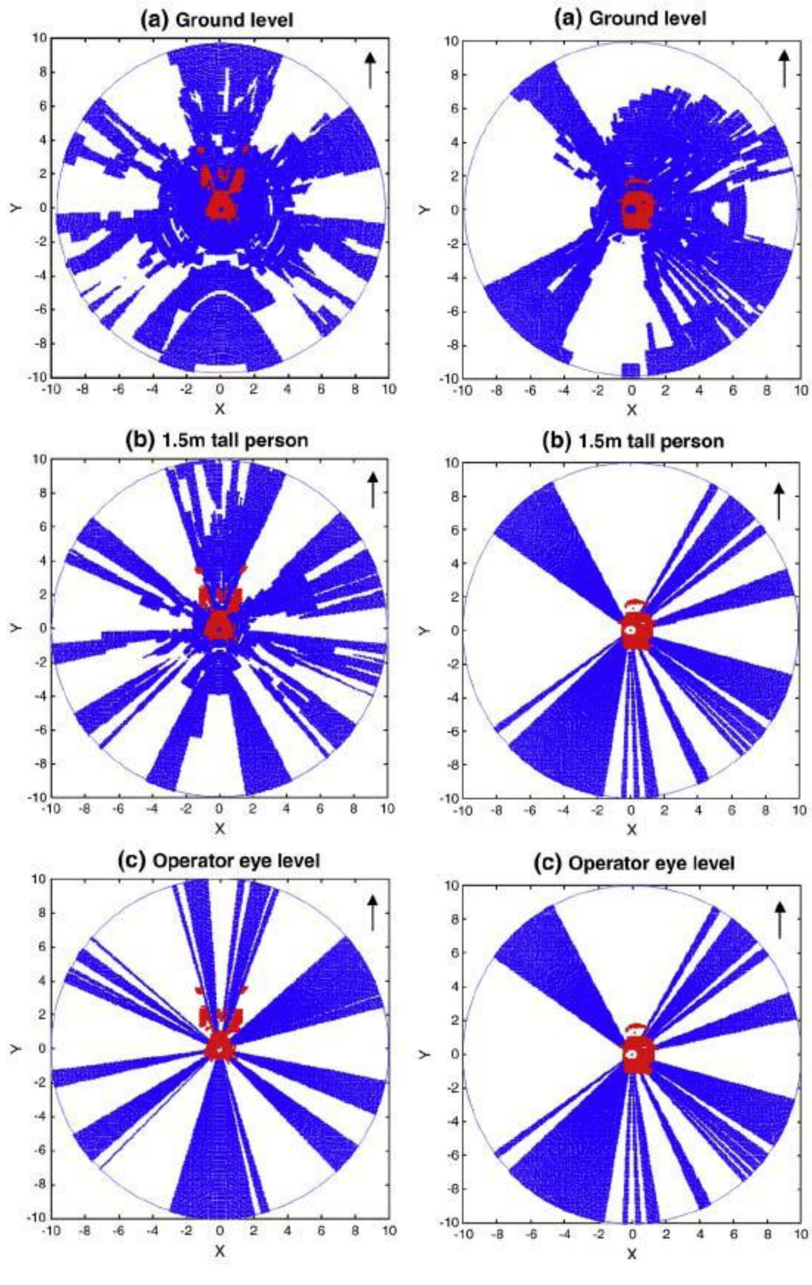


Figure 22. GaTech automatic detection of blind spots for construction dozer (left column) and pickup truck (right column) [12]