Original Article
Journal of Biosystems Engineering

J. of Biosystems Eng. 40(1):19-27. (2015. 3)
http://dx.doi.org/10.5307/JBE.2015.40.1.019

eISSN : 2234-1862
pISSN : 1738-1266

# Visibility Evaluation for Agricultural Tractor Operators According to ISO 5006 and 5721-1 Standards

**Md. Shaha Nur Kabir[1], Mingzhang Song[1], Sun-Ok Chung[1]*, Yong-Joo Kim[1], Su-Chul Kim[2], Jong-Kyou Ha[3]**

[1]*Department of Biosystems Machinery Engineering, Chungnam National University, Daejeon, Korea*
[2]*LS Mtron R&D Center, Gunpo, Korea*
[3]*Research Institute, Kukje Machinery Co., Ltd., Okcheon, Korea*

Received: October 24th, 2014; Revised: November 27th, 2014; Accepted: December 3rd, 2014

## Abstract

**Purpose:** A system to measure the visibility of agricultural tractor operators was designed and evaluated according to ISO standards, and a blind area diagram around the tested tractor was created based on the manual method recommended by the National Institute for Occupational Safety and Health (NIOSH). **Methods:** A visibility measurement system was designed and evaluated based on the ISO 5006 and ISO 5721-1 standards. Two bulbs used to simulate the operator's eyes were mounted on a bar with a supporting frame. A wooden frame was used to determine the seat index point position. The 12-m visibility test circle was divided into six sectors of vision, and the test tractor was placed at the center of the circle. Artificial light was supplied in the darkened environment, and shadow or masking effects were measured manually around the 12-m circle. **Results:** When the bulbs were placed at the operator's eye level, front visibility was good; no masking was found in the "A" vision sector, but larger masking widths were found in the "B" and "C" vision sectors. Since the masking width exceeded 700 mm, additional tests, such as movement of the light sources to both sides of the operator's eye level, were performed. Less than six masking effects were found in the semi-circle of vision to the front, and more than one masking was found in the "B" and "C" visual fields. The minimum distance between the centers of two masking effects exceeded 2500 mm when measured as a chord on the semi-circle of vision. A blind area diagram was created to define the exact nature of the blind spots and mirror visibility. **Conclusions:** Visibility evaluation is an effective way to enable proper and safe operation for agricultural tractor operators. Inclusion of this visibility evaluation test in the general testing process might aid tractor manufacturers.

**Keywords:** Agricultural tractor, Field of view, Operator visibility, Safety, Test standard

## Introduction

Operation of agricultural tractors is one of the most hazardous activities that farmers and agricultural workers undertake (OHS, 2013), and the average accident rate of the agricultural sector has been reported to be greater than other industries in Korea (MOEL, 2008; Jung et al., 2011). In 2006, the number of farm accidents was 76.6 cases per 10,000 farm machineries. The average annual incidence of accidents per 10,000 farm machineries was 128.0 for tractors with 13% of these accidents due to unsafe working environments (RDA, 2007a; RDA, 2007b; Lee and Lim, 2008).

Visibility can be defined as the degree of clarity with which objects in the field of view may be perceived or the area viewed from the eye position of the seated operator (Lund and Butters, 2011). A blind spot, or zone of invisibility, however, is a distortion or absence of sight in a portion of the visual field. These blind spots on a vehicle will generally be to the left and right of the vehicle, where the internal or external mirrors do not cover or the peripheral vision ends (Whitelaw, 2012). The operator's field of view may be masked due to structural components

***Corresponding author:** Sun-Ok Chung
**Tel:** +82-42-821-6712; **Fax:** +82-42-823-6246
**E-mail:** sochung@cnu.ac.kr

such as roof-pillars, air intakes or exhaust stacks, frame of the windscreen, or cab protective grills. Poor field of view may increase the health risks to the operator and danger to a worker in the surrounding area of the machine operation (Barron et al., 2005a).

The "light bulb shadow test" is commonly used for assessment of task visibility (Hutter, 2000). Based on this method, several approaches have been developed for visibility evaluation of forest harvesting machinery, construction machinery, and powered industrial vehicles. Barron et al. (2005b) used a light source and a series of light sensors and derived a contour plot of the visibility index to quantify the masking effect of obstructions on the light source, as well as to map the blind areas caused by inherent obstructions in the operator's field of view. Choi et al. (2009) compared three different visibility measurement techniques, such as the light bulb shadow test, manikin vision assessment test, and an individual test for a fork lift truck, to identify design factors influencing visibility. Ray and Teizer (2011) demonstrated the feasibility of creating dynamic blind spot diagrams by integrating blind spot maps for static equipment with automated estimation of head pose of construction equipment operators. An automated blind spot measurement tool was developed by Teizer et al. (2010) to measure blind spots of static construction equipment by applying a ray tracing algorithm on a three-dimensional (3D) point cloud generated by a laser scanner. The primary reason for poor operator visibility of the space surrounding a vehicle is the vehicle blind spot, but not the dynamic field-of-view of the equipment operator. Therefore, the presence of workers in blind spots poses a threat to the safety and health of workers when the equipment is in operation (Hinze and Teizer, 2011).

In recent years, there has been an increased emphasis on the health and safety of agricultural tractor operators. Among the safety concerns, the operator's visibility is of primary importance for efficient and safe operation of a tractor. In this study, a measurement system was designed, and the test procedure was demonstrated according to the ISO 5006 and ISO 5721-1 standards for a tractor operator's visibility.

## Materials and Methods

ISO 5006: 2006 provides an outline of the "light bulb shadow test" procedure for earth-moving machinery (ISO, 2006). ISO 5721: 1989 provides the test procedures for determining the masking effects of obstructions, i.e., areas where shadows have been cast (non-visible areas) for the operator of agricultural tractors (ISO, 1989). ISO 5721: 1989 has been revised, specifically regarding the test procedures and acceptance criteria for the front view of the operator of agricultural tractors, in ISO 5721-1: 2013 (ISO, 2013). In this study, the visibility evaluation test procedure was demonstrated according to the revised ISO 5721-1 standard, which followed the principles of ISO 5006. Another visibility evaluation was also used based on the manual method recommended by the National Institute for Occupational Safety and Health (NIOSH, 2012) for creating the blind area diagrams around the tested tractor. A 35 kW tractor (model: DK470; Daedong Co. LTD., Republic of Korea) was used for visibility evaluation, and the test characteristics of the tested tractor are shown in Table 1.

### Determination of seat index point (SIP)

SIP is a fixed point located on the central vertical plane of the seat inside the cab, and is determined with the help of a special instrument (Figure 1) according to ISO 5353 (ISO, 1995). For determining the SIP, a wooden frame was fabricated in accordance with the dimensions of the standard ISO 5353. Since the back of this apparatus was

**Table 1.** Specifications of the tractor used for the visibility evaluation

| Item | Specifications | Photo |
|---|---|---|
| Model | DK470 |  |
| Power | 35 kW | |
| Traction | MFWD | |
| Size (mm) | 3430 (L) × 1920 (W) × 2434 (H) | |
| Seat height | 500 (L) × 450 (W) × 600 (H) | |
| Front tire pressure | 205 kPa | |
| Rear tire pressure | 196 kPa | |

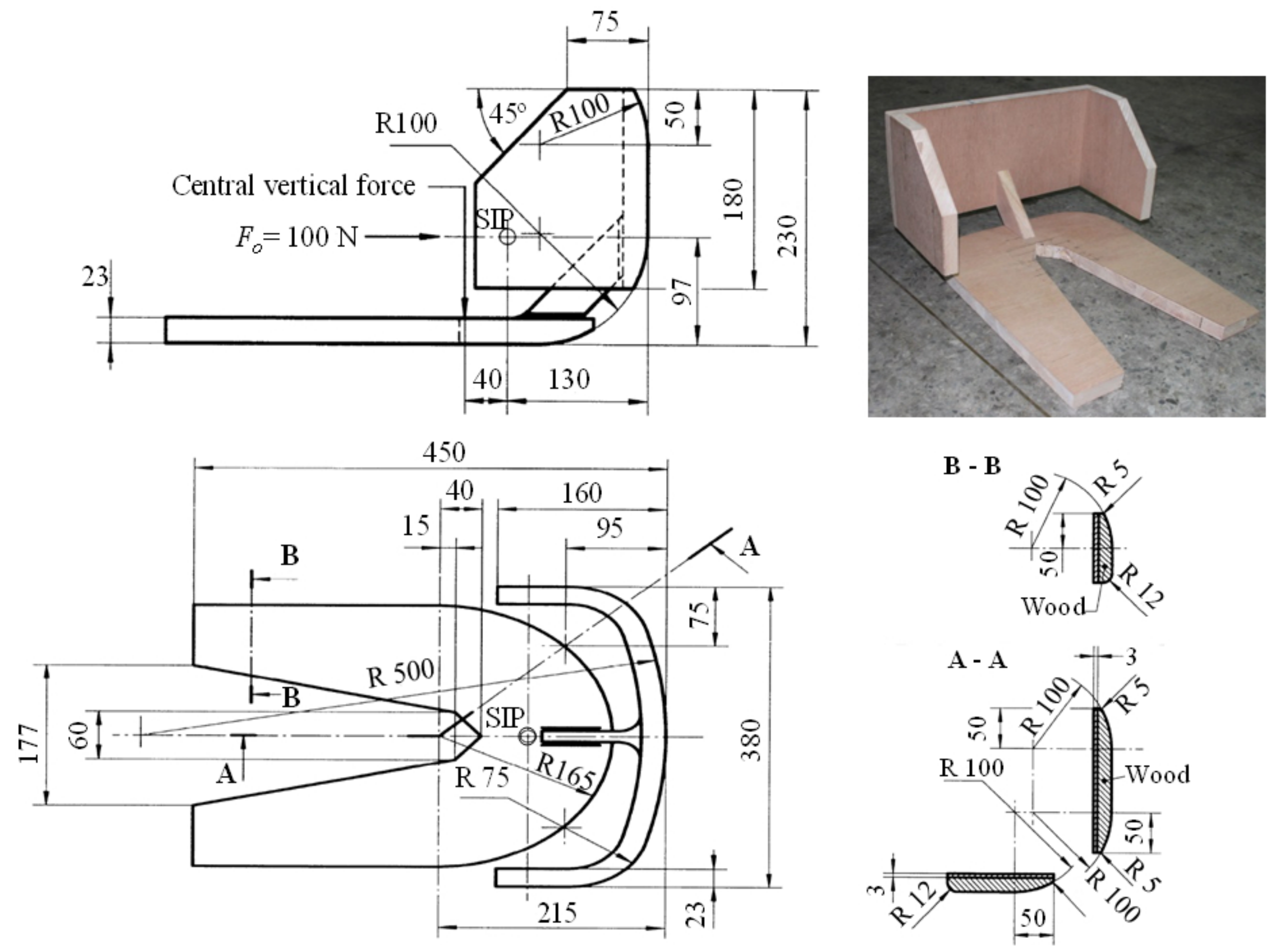


**Figure 1.** Device used to determine the seat index point according to ISO 5353:1995, dimensions are in mm (ISO, 1995).

relatively complex to design and build, a slightly modified design was prepared as shown in Figure 1 (top, right).

## Procedures for the visibility evaluation

Considering the ISO standards, the procedures for the visibility evaluation were developed as illustrated in Figure 2. The bulbs, or more specifically filaments, were used to simulate the operator's eyes, and a light bar with a supporting frame was prepared. A wooden frame was also made for determining the position of the SIP. A darkened environment was used for manual measurements of the shadow or the masking effects in a 12 m circle.

The "light bulb shadow" test equipment consisted of two point sources of light (150 W bulbs) spaced 65 mm apart on a bar representing the nominal binocular eye spacing of the 50th percentile of operators (ISO, 2006) and symmetrically located with respect to the reference point, i.e., the position on the ground vertically below the

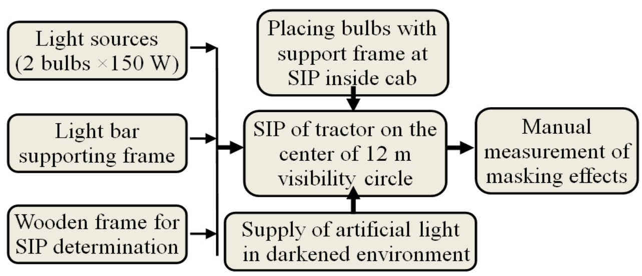


**Figure 2.** Procedures of evaluation of the operator's visibility.

eye position (Figure 3). The arrangement was made in such a way that the filament position center point (FPCP) (eye position) was placed 680 mm above and 20 mm in front of the SIP, representing the seated operator's eye height (ISO, 2007). For the purpose of measuring the masking effects, the support bar was aligned so that the line joining the two light sources was perpendicular to the line joining the masking component and the reference point (eye level). The light sources were horizontally

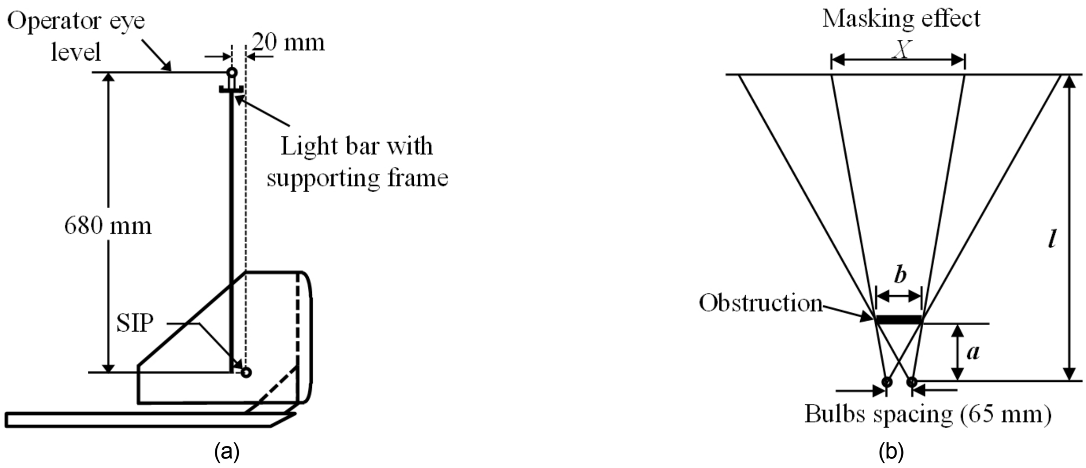


**Figure 3.** Arrangement of the light bulb shadow test equipment according to ISO 5353 and ISO 5721-1: 2013 (a), and determination of masking effects (b).

movable to both sides of the reference point above the supporting bar. From the reference point, the light sources were moved first to one side and then to the other within the limits of 170, 100, and 50 mm, representing the operator's head movements as given in ISO 5721-1 (ISO, 2013) until the area of each obstructing part not covered by the light sources in either of the two positions became as small as possible on the semi-circle of vision (deepest shadow, dimension '*X*', Figure 3). The areas determined in this way were considered masking effects and were calculated by Equation (1):

$$X = \frac{b-65}{a} \times l + 65 \quad (1)$$

where *a* is the distance between the component obstructing vision and the reference point (mm), *b* is the width of the component obstructing vision measured horizontally and perpendicular to the visual radius (mm), and *l* is the straight line distance from the center of the light source to the measurement point (mm).

A 12 m radius circle was drawn on a smooth asphalt parking lot, and six (6) divisions of major visual fields were marked, as shown in Figure 4. Polar grids, consisting of 12-m long lines radiating from the center of the grid at 10 degree intervals, and a series of concentric circles centered on the grid at 2 m intervals were also marked by chalk for determining the blind area diagram according to the manual method recommended by the NIOSH.

The test tractor was placed at the center of the visibility test circle. The bulbs were mounted on a bar so that the pair of bulbs was able to be moved horizontally from the center position up to 170 mm. After supplying artificial light, masking effects were measured when the light sources were located at the FPCP. Masking effects were also measured at 170, 100, and 50 mm distances on both sides of the FPCP. The filament spacing represented the range of eye movement that an operator would use to look around a blockage. Each filament casted a separate shadow due to the visibility blockage. If the two shadows overlapped, a dark shadow was created, called a masking or blind area; whereas, if the two shadows did not overlap, there was no blind area because at least one filament could see the area of interest. The actual light support device used for the tests is shown in Figure 5.

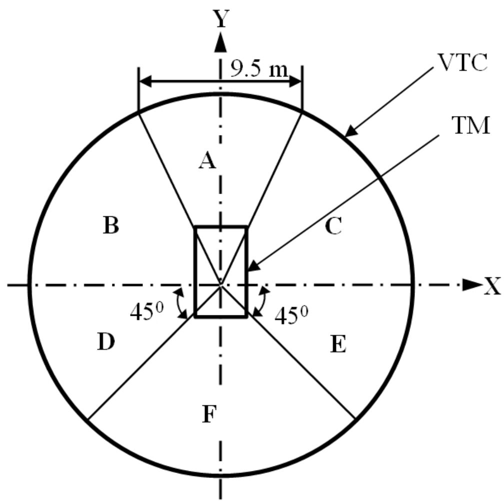


**Figure 4.** Designations of the test locations for the visibility evaluation (VTC: 12 m visibility test circle, TM: test machine (tractor), Y: forward direction of tractor, A-F: sectors of vision).

The manual method recommended by the NIOSH was


(a) (b)

**Figure 5.** Device setup for the light source support (a), and observer marking points on the polar grid for blind area determination (b).

also used in the daytime for determining the blind area diagram (Figure 5(b)). This blind area mapping was done by a tractor driver (height: 1,980 mm), an observer, and two assistant measurers. For convenience of drawing, the 12 m visibility circle was divided from 0° to 360°. During the tests, the driver was seated in the cab in a normal driving posture and remained as still as possible in the seat. The driver turned his head and torso no more than 30º to both side, and his head was not tilted more than 5º up and 25º down for sustained comfort (Gellerstedt et al., 1999). For determining the ground area where the driver was not able to see, the observer walked along the radial grid lines and marked those invisible areas as indicated by the driver. The observer started at the 0° line as close to the tractor as possible. While the observer walked along the line and away from the tractor, the driver signaled when the bottom of the observer's shoes became visible. The observer used a pointing device to find the exact location where the driver could see the ground. A mark was placed on the ground at each point that a transition occurred between visible and invisible areas (Figure 5(a)). The observer then continued to mark points along the lines where necessary. When the 12-m radius was reached, the recorder moved back to the tractor and walked to the next degree line. As the observer marked points on the ground, the analogous points were recorded on a polar plot.

## Results and Discussion

The distribution of the masking effects (dark shadows) found on the 12 m circle when the light sources were at the operator’s eye level is shown in Figure 6. The dark

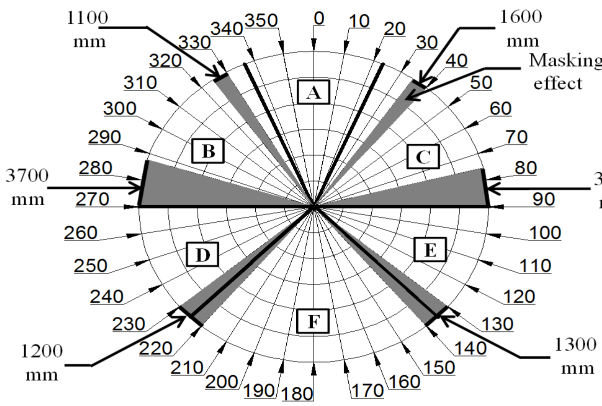


**Figure 6.** Masking effects for the 12 m diameter circle where bulbs were located at the FPCP.

lines show the boundary between the sectors of vision. At this condition, forward visibility was good and no maskings were found in the “A” sector of vision. Side visibility was not good because large maskings, such as 1100 mm and 3700 mm, were found in the “B” sector of vision, and those of 1600 mm and 3700 mm were found in the “C” sector of vision. In the case of rear visibility, maskings were found between the “D” and “F” sector of vision and between the “E” and “F” sector of vision.

The masking effects found at the 12 m circle under different horizontal movements of the light sources at the operator’s eye level are shown in Figure 7.

No maskings were found in the sector of vision “A” for the 50 mm left and right horizontal movements of the light sources from the FPCP; whereas, 3300 mm and 3150 mm large masking widths were found in the “B” and “C” sector of vision, respectively, for the 50 mm movement to the left. 3200 mm and 3700 mm maskings were found in the “B” and “C” sector of visions, respectively, for the 50 mm horizontal movement of the light sources to the right

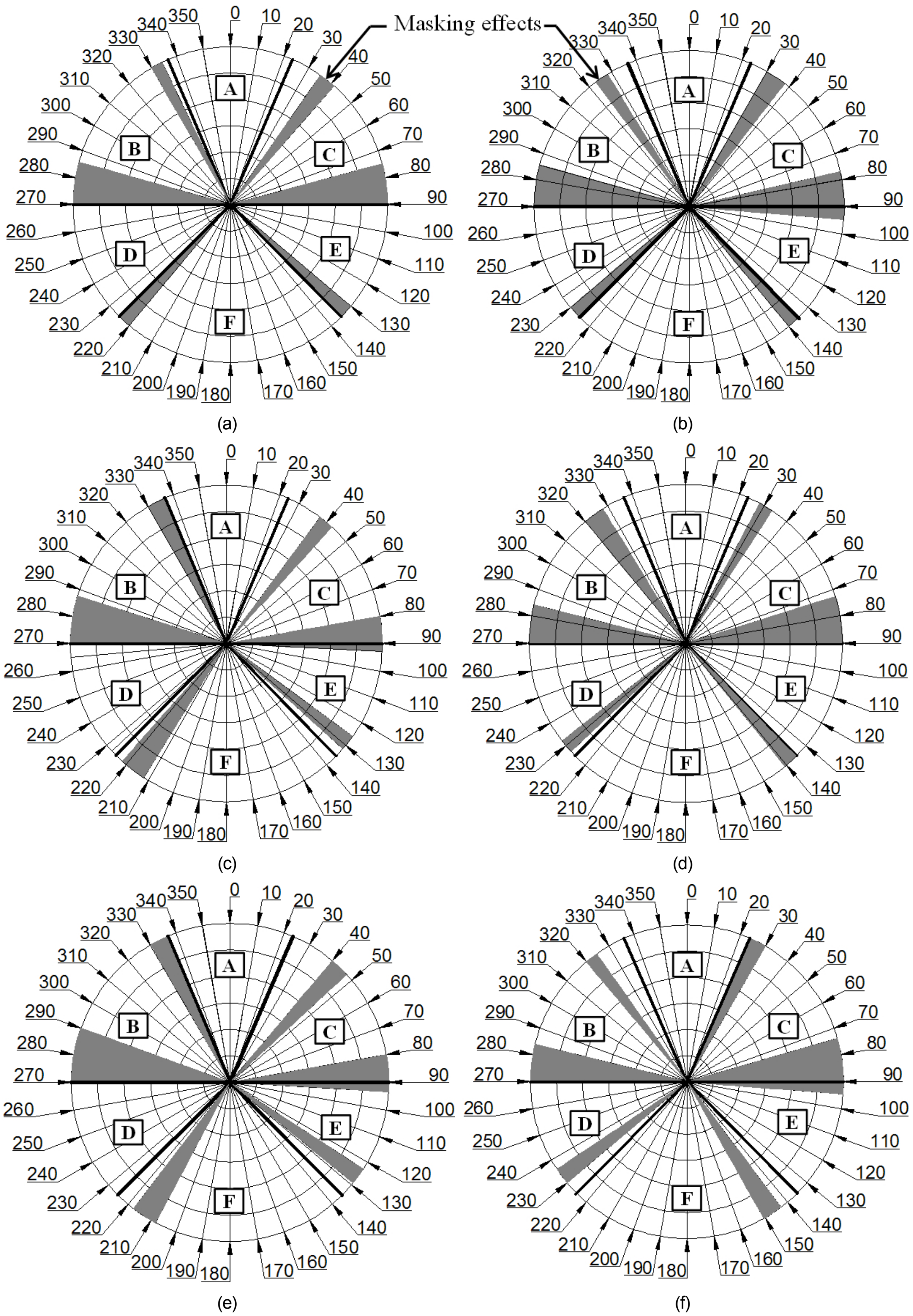


**Figure 7.** Masking effects for the 12 m diameter circle where bulbs were shifted from the FPCP horizontally by 50 mm to the left (a), 50 mm to the right (b), 100 mm to the left (c), 100 mm to the right (d), 170 mm to the left (e), and 170 mm to the right (f).

**Table 2.** Visibility performance on 12 m circular boundary

| Position of light sources, mm | Number and width of maskings (mm) by sectors | | | | | |
|---|---|---|---|---|---|---|
| | A | B | C | D | F | E |
| FPCP | - | 1-1100<br>1-3700 | 1-1600<br>1-3700 | 1-1200 | 1-1300 | |
| 50 left of FPCP | - | 1-900<br>1-3300 | 1-1300<br>1-3150 | - | 1-1500 | 1-2000 |
| 50 right of FPCP | - | 1-1100<br>1-3200 | 1-1700<br>1-3700 | 1-1600 | 1-2000 | 1-2000 |
| 100 left of FPCP | - | 1-1300<br>1-3900 | 1-1600<br>1-2700 | - | 1-1900 | 1-1200 |
| 100 right of FPCP | - | 1-1100<br>1-3100 | 1-1200<br>1-3600 | 1-1200 | 1-1210 | - |
| 170 left of FPCP | - | 1-1200<br>1-4100 | 1-1500<br>1-2800 | - | 1-2000 | 1-1300 |
| 170 right of FPCP | - | 1-1200<br>1-2900 | 1-1400<br>1-4300 | 1-1300 | 1-1600 | - |

of the FPCP. Similar trends were found when the light sources were at a distance of 100 mm and 170 mm to the left and right of the FPCP. 3900 mm and 2700 mm large masking widths were found in the "B" and "C" sector of vision, respectively, for the 100 mm movement to the left. 3100 mm and 3600 mm large maskings were found in the "B" and "C" sectors of vision, respectively, for the 100 mm horizontal movement of the light sources to the right of the FPCP. During the horizontal movement of the light sources 170 mm to the left and right of the FPCP, larger maskings, such as 4100 mm and 4300 mm, were found in the "B" and "C" sectors of vision, respectively. There was no masking in the "D" sector of vision during the movements of the light sources to the left side at the operator's eye level. Table 2 shows the widths and number of maskings found in the different visual fields around the 12 m visibility test circle.

According to ISO 5721-1, if the masking effects are more than 700 mm, additional tests (i.e., movements of the light sources to each side) need to be performed. In our evaluation, masking effects of more than 700 mm were found. Therefore, additional tests were performed to measure the masking effects caused by the movement of the light sources to both sides of the FPCP at the operator's eye level. Less than six masking effects were found in the semi-circle of vision to the front, also a prerequisite of ISO 5721-1. However, more than one masking was found in the "B" and "C" visual fields due to the adjacent structural components of the tractor cab. A minimum distance of 2500 mm was found between the

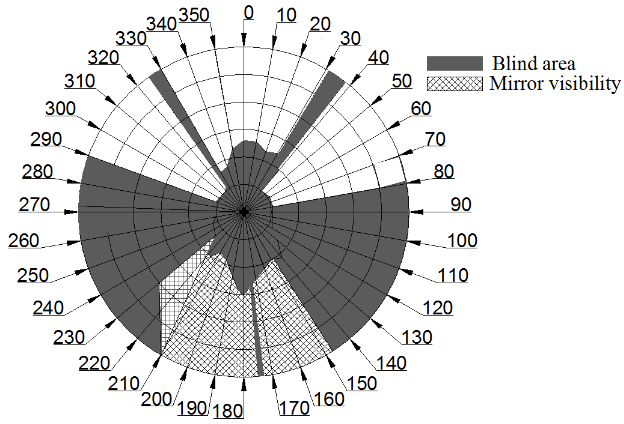


**Figure 8.** The manual method recommended by the NIOSH for blind area determination.

centers of the two masking effects when measured as a chord on the semi-circle of vision.

The blind area diagram created according to the manual method recommended by the NIOSH is shown in Figure 8. When the observer walked along each degree line, additional points were also marked, estimating intermediate degree lines or radius marks. The front and side visibilities were determined by methods similar to that of the ISO standards, shown in Figure 7; however, the rear visibility was determined by a different method. The manual method recommended by the NIOSH was helpful to define the exact nature of the blind or non-visible areas, and mirror visibility can also be determined by this method.

## Conclusions

In this study, a measurement system for tractor operator visibility was designed and evaluated according to the ISO test standards. Visibility evaluation was done by establishing a 12 m diameter VTC around the tractor. Based on the visibility tests, the front visibility was found to be good; whereas, the side visibility was found to be poor due to the adjacent structural component of the tractor cab. Blind areas were also determined according to the manual method recommended by the NIOSH.

Many tractor accidents are the result of the inability of the operator to clearly see other vehicles or hazards surrounding the operation area. Increasing the visibility of the wheels and attachments of the tractor would reduce contact collisions and other incidents caused by limited visibility. Therefore, it is important to make sure that the tractor operator has the best possible visibility in all directions. Visibility evaluation can be practiced by the designer to enable proper, effective, and safe operation for the tractor operator, and visibility can be improved by reducing the width of the structural components of the tractor.

Many factors influence the export demands of tractors. In the long term, the growth of the tractor industry is expected to be large in Korea. In the industrialized world, the spotlight on the sales of tractors will be largely determined by the higher performance of the tractor, along with the safety and comfort of the tractor operator. Therefore, operator visibility evaluation should be considered for implementation at the official tractor test station in Seoul, Korea, as this issue of visibility has not yet been solved and this evaluation method would aid the industry in the export of safer Korean tractors.

## Conflict of Interest

The authors have no conflicting financial or other interests.

## Acknowledgements

This research was supported by Technology Development Program for Agriculture and Forestry, Institute of Planning and Evaluation for Technology in Food, Agriculture, Forestry and Fisheries, Ministry of Agriculture, Food and Rural Affairs, Republic of Korea.

## References

Barron, P. J., K. P. McDonnell, S. M. Ward and P. M. O. Owende. 2005b. A light-meter method for assessment of blind areas in operator field of view. Journal of Agricultural Safety and Health 11(3):373-377.

Barron, P. J., P. M. O. Owende, K. P. McDonnell and S. M. Ward. 2005a. A method for assessment of degradation of task visibility from operator cabins of field machines. International Journal of Industrial Ergonomics 35(7): 665-673.

Choi, C. B., P. Park, Y. H. Kim, M. S. Hallbeck and M. C. Jung. 2009. Comparison of visibility measurement techniques for forklift truck design factors. Applied Ergonomics 40:280-285.

Gellerstedt, S., R. Almqvist, D. Myhrman, B. O. Wikstrom, M. Attebrandt and J. Winkel. 1999. Ergonomic Guideline for Forest Machines. Handbook. Skogforsk, Uppsala, Sweden.

Hinze, J. W and J. Teizer. 2011. Visibility-related fatalities related to construction equipment. Journal of Safety Science 49(5):709-718.

Hutter, G. M. 2000. Earthmoving equipment - An operator's field of view (SAE Standard J1091). Safety and Forensic Engineering Journal. Available at: www.meridianeng.com/EarthMovers.html.

ISO. 1989. ISO 5721: Tractors for agriculture - Operator's field of vision. Geneva, Switzerland: ISO.

ISO. 1995. ISO 5353: Earth-moving machinery, and tractors and machinery for agriculture and forestry - Seat index point. Geneva, Switzerland: ISO.

ISO. 2006. ISO 5006: Earth-moving machinery - Operator's field of view - Test method and performance criteria. Geneva, Switzerland: ISO.

ISO. 2007. ISO 3411: Earth-moving machinery - Physical dimensions of operators and minimum operator space envelope. Geneva, Switzerland: ISO.

ISO. 2013. ISO 5721-1: Agricultural tractors - Requirements, test procedures and acceptance criteria for the operator's field of vision - Part 1: Field of vision to the front. Geneva, Switzerland: ISO.

Jung, D. Y., H. C. Kim, J. H. Leem, S. G. Park, D. H. Lee, S. J. Lee and G. W. Kim. 2011. Estimated occupational injury rate and work related factors based on data from the fourth Korea National Health and Nutrition Examination Survey. Korean Journal of Occupational and Environmental Medicine 23(2):149-163.

Lee, K and H. S. Lim. 2008. Work-related injuries and diseases of farmers in Korea. Industrial Health 46:424-434.

Lund, M and L. Butters. 2011. An investigation and comparison into operator field of vision for modern tractor cabs. Scientific Papers, University of Agronomic Sciences and Veterinary Medicine, Bucharest, Series A, Agronomy, LIV (1):414-419.

MOEL. 2008. Statistics on occupational injuries and illnesses, Ministry of Employment and Labor (MOEL). Retrieved from http://www.kosha.or.kr/www/boardView.do?contentId=204893&menuId=554&boardType=A2.

NIOSH. 2012. Highway Work Zone Safety, Construction equipment visibility - Manual method: National Institute for Occupational Safety and Health (NIOSH). Retrieved from http://www.cdc.gov//niosh.

OHS. 2013. Agricultural tractor safety - Fact sheet. University of Minnesota, S.E., Minneapolis, MN: Occupational Health and Safety (OHS).

Ray, S. J and J. Teizer. 2011. Coarse head pose estimation of construction equipment operators to formulate dynamic blind spots. Advanced Engineering Informatics 26:117-130.

RDA. 2007a. A study on agriculture machinery accidents. 2006 annual report of NIAE, 36. National Institute of Agriculture Engineering (NIAE), Rural Development Administration (RDA), Republic of Korea.

RDA. 2007b. A study on patterns and characteristics of agriculture-related injury by analysis of safety aid system of farm workers. Final research report. Rural Development Administration (RDA), Ministry of Food, Agriculture, Forestry and Fisheries, Republic of Korea.

Teizer, J., B. S. Allread and U. Mantripragada. 2010. Automating the blind spot measurement of construction equipment. Automation in Construction 19(4):491-501.

Whitelaw, T. 2012. Safer motoring: Learning about the blind spot when driving, UK. Retrieved from http://www.safermotoring.co.uk/learning-about-blind-spot-when-driving.html.