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

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

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

<table>
<thead>
<tr>
<th>Item</th>
<th>Specifications</th>
<th>Photo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>DK470</td>
<td></td>
</tr>
<tr>
<td>Power</td>
<td>35 kW</td>
<td></td>
</tr>
<tr>
<td>Traction</td>
<td>MFWD</td>
<td></td>
</tr>
<tr>
<td>Size (mm)</td>
<td>3430 (L) × 1920 (W) × 2434 (H)</td>
<td></td>
</tr>
<tr>
<td>Seat height</td>
<td>500 (L) × 450 (W) × 600 (H)</td>
<td></td>
</tr>
<tr>
<td>Front tire pressure</td>
<td>205 kPa</td>
<td></td>
</tr>
<tr>
<td>Rear tire pressure</td>
<td>196 kPa</td>
<td></td>
</tr>
</tbody>
</table>
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 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...
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):

$$X = \frac{b - 65}{a} \times l + 65$$

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.

The manual method recommended by the NIOSH was
Figure 5. Device setup for the light source support (a), and observer marking points on the polar grid for blind area determination (b).

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

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 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

<table>
<thead>
<tr>
<th>Position of light sources, mm</th>
<th>Number and width of maskings (mm) by sectors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
</tr>
<tr>
<td>FPCP</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>1-3700</td>
</tr>
<tr>
<td>50 left of FPCP</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>1-3300</td>
</tr>
<tr>
<td>50 right of FPCP</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>1-3200</td>
</tr>
<tr>
<td>100 left of FPCP</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>1-3900</td>
</tr>
<tr>
<td>100 right of FPCP</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>1-3100</td>
</tr>
<tr>
<td>170 left of FPCP</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>1-4100</td>
</tr>
<tr>
<td>170 right of FPCP</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>1-2900</td>
</tr>
</tbody>
</table>

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 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 deter-
mined 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.

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