Evaluation of operator visibility in three different cabins type Far-East combine harvesters

Dae H. Lee[1], Yong J. Kim[1*], Chang H. Choi[2], Sun O. Chung[1], Yo S. Nam[3], Jin H. So[3]

(1. *Department of Biosystems Machinery Engineering, Chungnam National University, Daejeon 305-764, Republic of Korea*;
2. *Department of Bio-mechatronic Engineering, Sungkyunkwan University, Suwon 440-746, Republic of Korea*;
3. *TYM R&D Center, Tong Yang Moolsan Co.,Ltd.,Gongju 314-862, Republic of Korea*)

Abstract: The purpose of this study was to develop and evaluate a visibility evaluation system for the cabin type Far-East combine harvester. The human field of view has been classified into five levels (perceptive, effective, stable gaze, induced, and auxiliary) depending on the rotation of the human head and eye. The divider, reaper lever, gearshift, dashboard, and conveying component were considered as major viewpoints of the cabin type Far-East combine harvester. The visibility of the cabin type Far-East combine harvester was evaluated quantitatively using viewpoints and human field of view levels. The visibility evaluation system for the cabin type Far-East combine harvester consisted of a laser pointer, stepping motors to control the directions of the view, gyro sensors to measure horizontal and vertical angles, and I/O interface to acquire the signals. The visibility evaluation tests were conducted at different postures ('sitting straight', 'sitting with a 15° tilt', 'standing straight', and 'standing with a 15° tilt') for three cabin type Far-East combine harvesters. The LSD (least significant difference) multiple comparison tests showed that the visibilities of viewpoints differed significantly as the operator's posture changed. The results showed that the posture while standing with a 15° tilt provided the best visibility. The average visibility scores at sitting postures were 22.3 (straight) and 24.4 (15° tilt), and the scores at standing postures were 18.7 (straight) and 29.5 (15° tilt). Also, the average visibility scores were observed in order from highest to lowest as reaper lever (44.6), divider (28.7), dashboard (23.1), conveying part (12.2), and gearshift lever (10.1). Most viewpoints of the cabin type Far-East combine harvester were out of the stable gaze field of the view level. Modifications of the cabin type Far-East combine harvester design will be required to enhance the visibility during harvesting operation and to improve safety and convenience of farmers.

Keywords: combine harvester, cabin, operator visibility, field of view, evaluation system, ergonomics, safety and comfort
DOI: 10.3965/j.ijabe.20160904.1850

Citation: Lee D H, Kim Y J, Choi C H, Chung S O, Nam Y S, So J H. Evaluation of operator visibility in three different cabins type Far-East combine harvesters. Int J Agric & Biol Eng, 2016; 9(4): 33－44.

1 Introduction

An ergonomic design is about developing products reflecting the structure of the human body and psychological characteristics, and there have been improvements in the development of safe and convenient products focusing on ergonomics. This is especially true for the development of agricultural machines where the comport and safety of operators were most important since the working environments in the agricultural industry are poor[1].

A combine harvester is an example of agricultural machines that barely keep out dust, noise, vibration, etc. during harvesting[2]; therefore, there has been an increase in demand for cabin type combine harvesters that provide a comfortable and convenient working environment. However, for cabin type combine harvesters in Korea, each body part and cabin are constructed separately and assembled later; for this reason, most of the cabins lack

Received date: 2015-04-13 **Accepted date:** 2016-06-14
Biographies: Dae H. Lee, Postdoctoral researcher, research interest: agricultural engineering, Email: leedh18m@naver.com; **Chang H. Choi**, PhD, Professor, research interest: agricultural engineering, Email: choiauto@skku.edu; **Sun O. Chung**, PhD, Professor, research interest: agricultural engineering, Email: sochung@cnu.ac.kr; **Yo S. Nam**, PhD, Senior research engineer, research interest: Agricultural engineering, Email: ysnam@tym.co.kr; **Jin H. So**, Assistant Director, research interest: agricultural engineering, Email: so@tym.co.kr.
***Corresponding author: Yong J. Kim**, PhD, Associate Professor, research interest: agricultural engineering, Dept. of Biosystems Machinery Engineering, Chungnam National University, Daejeon, Republic of Korea, Email: babina@cnu.ac.kr.

ergonomic factors such as visibility, boarding, extensity, and controllability for their operators. Clarity of the field of view is of primary importance for the efficient and safe operation of field machines, since 90% of the operator's perception is visual[3]. Especially, visibility is more important in the head-feeding type combine harvesters that cut the ears of crop and are used in the Far-East regions than in the straight-through feeding type standard combine harvesters that cut the entire crop. The consequences of a poor field of view include poor utilization of Far-East combine harvester functions and capacity, increased health risks to the operator due to poor postural positions that may be assumed by the operator in an attempt to avoid the inherent obstructions to visibility of the task from the cabin, and increased danger to the operator and crew working in the surrounding area where the machine is being operated[4]. Good visibility is of primary importance for the safety of forklift truck operation. Collins et al.[5,6] found that visibility problems accounted for more than 80% of forklift truck-related accidents such as striking pedestrians or other vehicles, falling-off a ramp or loading dock, and rolling over as a result of hitting obstacles. However, improved visibility and posture during harvesting with a cabin type Far-East combine harvester are difficult to achieve because the operator's field of view may be masked by features such as discharge augers, cab protective grills and A-pillar of cabin structures, which are standard for field machines. Therefore, there is an urgent need to develop the cabin type Far-East combine harvesters that results in improved visibility and posture, since most Korean farmers must continuously lean their body or stand during harvesting[7].

Because visibility is important to the safe and economic operation of the combine harvester, techniques to assess visibility have become increasingly important. A common method used for the assessment of visibility is the 'light bulb shadow test'[8]. NOISH[9] showed blind-area diagrams developed as an additional method for visibility evaluation. It depicted non-visible areas around construction equipment for three different planes: ground level, 900 mm above the ground, and 1500 mm above the ground. ISO 5006: 2006 provides an outline of the procedure to be undertaken when conducting a light bulb shadow test for earth-moving machinery[10], and ISO 5721-1: 2013 provides the test procedures for determining the masking effects of obstructions and acceptance criteria for the operator's field of vision of agricultural tractors[11]. It also has test method for determining the masking effects by lateral movement of operator's position. Recently, the light bulb shadow method was used for evaluating visibility of agricultural tractors based on ISO standards and NIOSH manual method[12]. However, it was focused on masking effects of obstructions with qualitative method and considering horizontal evaluation aspect with limited vertical range. In addition, the light shadow visibility test requires a darkened environment, and visibility is assessed on the basis of masked, i.e., areas where shadows have been cast, or where light can be seen. The fact that regions can only fall into either dark or bright areas presents a problem, since the area of partial visibility where faded light exists cannot be evaluated. Another disadvantage of this method is that the accuracy of the assessment may be subjective and therefore lacks repeatability[4]. Subsequently, to address these limitations, a few new techniques to measure visibility have been developed. By measuring visibility on hydraulic excavators, Hella et al.[13] compared the light bulb shadow test of the International Standard Organization (ISO) standard to a photographic recording technique developed with a special camera that did not distort the circular field of view. Esteve et al.[14] developed three different techniques, the Cartesian reference frame, light beam capture, and light ray emission, all of which could be used in automobile design. Barron et al.[4] suggested a technique of quantifying visibility in a three-dimensional field of view using a light intensity-measuring sensor for general field machines to mitigate the weaknesses of the light bulb shadow test. Choi et al.[15] applied three different techniques to a forklift truck to measure visibility in order to compare differences among the techniques and to identify design factors influencing forklift truck visibility. The three tests were the light bulb shadow test, a manikin vision assessment test using CATIA V5R13 human modeling solutions[16], and an individual test in which participants actually sat on a forklift truck and pointed a head-mounted laser toward a grid. The KATS[17] evaluated visibility substituting a laser pointer at the center of the human eye, and took into consideration the collimation of the human field of view as in the ISO method. The visibility of viewpoints was mainly selected as the evaluation factor for the standards. Viewpoints are points that a driver views in a car; therefore, a controller, a driving mirror, and an instrument panel that a driver looks at frequently while driving could be important viewpoints in regards to the driver's safety and convenience. Studies on visibility have been actively conducted in the automobile industry and provide standards for the field of view, blockage, and other factors related to visibility. There are some evaluation methods for agricultural tractors[11,18], however it is hard to evaluate quantitatively because they were focused on masking effects of obstructions. And very little research on the visibility in agricultural vehicles such as investigating the tractor workspace interior[19] has been conducted compared to automobiles. In addition, the techniques described above have never been utilized to assess visibility in a cabin type Far-East combine harvester.

The aims of this study were to develop a visibility evaluation system of the cabin type Far-East combine harvester and to provide design guidelines for improving the visibility. Therefore, this study developed a visibility evaluation system for cabin type Far-East combine harvester and evaluated the visibility of three different cabin type Far-East combine harvesters manufactured in Korea. Visibility evaluation was conducted and analyzed at various major viewpoints considering the operator's working postures.

2 Materials and methods

2.1 Criteria of the visibility evaluation

The human field of view can secure the best visibility when the direction of the human eye is fully focused on an object. The more distant an object is from the center of the eye, the more qualitatively the function of eyesight declines. Thus, an operator rotates his eyes and head to obtain information on the object in a wide visual field. The visibility of viewpoints can be evaluated quantitatively by dividing the field of visibility based on the rotation range of the human eye and head[20]. The regions of the human field of view can be classified as the 'perceptive field of view', the 'effective field of view', the 'stable gaze field of view', the 'induced field of view', and the 'auxiliary field of view', considering the rotation of the human head and eye as shown in Table 1[21,22]. The perceptive field of view relates to the focus of the view field as an object is identified, with the consequence that the capacity range is at the highest degree of precision for the information of an object. The effective field of view is the capacity range of reasonable information for an object with only eye movement, and the stable gaze field of view is the capacity range of view security through head and eye movement. The induced field of view is the capacity range of perceiving only the presence of an object, and the auxiliary field of view is the range that vision security can be capable of using the whole motion of the human body due to the lack of the object's nature.

Table 1 Classification of human's field of view

Field of view	Horizontal angle/(°)	Vertical angle/(°)
Perceptive	0	0
Effective	−15 to 15	−12 to 8
Stable gaze	−15 to −45 15 to 45	−12 to −40 8 to 30
Induced	−45 to −50 45 to 50	−40 to −50 30 to 35
Auxiliary	−50 to −100 50 to 100	−50 to −75 35 to 50

To quantitatively assess the visibility of viewpoints for cabin type Far-East combine harvesters, evaluation scores were assigned based on the human field of view regions. The field of view marked with the range of vertical and horizontal angles was displayed using an ellipse as shown in Figure 1, and it was determined that the greater the distance from the center of the human field of view was, the lower the evaluation scores.

The perceptive field of view was assigned 100 points and the outside of the auxiliary field of view was assigned 0 point. And the ratio that each calculated area of the ellipse shapes of view regions was divided by the total area of the boundary to the auxiliary field of the given view, which was used to determine the evaluation scores. The distances from the operator's eye position to each viewpoint made the areas of the ellipses different. Thus, the evaluation scores for each viewpoint were calculated from the areas of ellipses covering the viewpoints using the vertical and horizontal angles measured by at each viewpoint as Equation (1). For example, in the case of effective field of view, E_a and T_a are area sums of upper and lower ellipses having horizontal and vertical boundaries of the effective field of view and the auxiliary field of view, respectively.

$$E_s = (1 - \frac{E_a}{T_a}) \quad (1)$$

where, E_s represents the evaluation score of the viewpoint; E_a is the elliptic area of the measured viewpoint; T_a is total area of the auxiliary field of view.

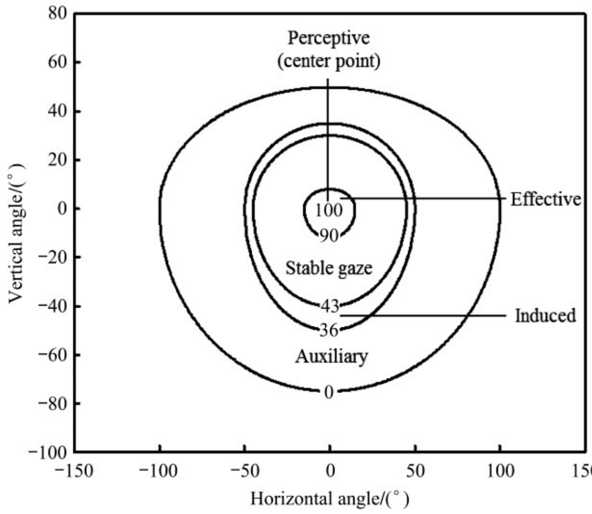


Figure 1 Quantitative score of visibility evaluation through the human's field of view

2.2 Determination of the eye position of farmers

The operator's eye position is dependent on the farmer's physical characteristics and was needed to assess the visibility for cabin type Far-East combine harvesters. In this study, the physical characteristics of farmers between the ages of 45 and 69 were determined, which covered more than 50 percent of the rural population by age as shown in Table 2[23]. The data from the Korean dimension survey[24] were used in view of the fact that there was no difference in stature between farmers and the average Korean male. As shown in Table 3, the operator's eye position was determined based on the dimensions of between the ages of 45 and 69, and the average eye level was 780 mm at a sitting posture and 1540 mm at a standing posture. And the average head length was 170 mm.

Table 2 Distribution of rural population by age in Korea

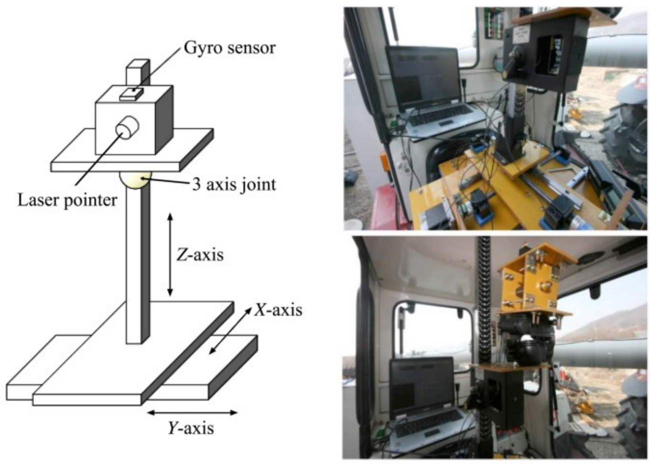
Age/yr	Population	Ratio/%	Age/yr	Population	Ratio/%
20-24	128	0.02	55-59	79 819	12.31
25-29	939	0.14	60-64	100 291	15.47
30-34	4 774	0.74	65-69	132 137	20.38
35-39	12 809	1.98	70-74	106 789	16.47
40-44	29 564	4.56	75-79	50 362	7.77
45-49	51 929	8.01	> 80	17 674	2.73
50-54	61 084	9.42			

Table 3 Head lengths and eye positions of farmers in Korea

Item		No. of subject	Avg/mm	S.D/mm	Min/mm	Max/mm
Head length		541	170	2.250	140	220
Eye height	Standing	916	1540	5.450	1360	1710
	Sitting	916	780	3.150	670	870

2.3 Visibility evaluation system

The visibility evaluation system, as shown in Figure 2, was developed by replacing the operator's eye position with a laser pointer. Three stepping motors were used to control the direction of the *XYZ* axes[25] considering the operator's view position, and a 3-axis joint replaced the rotation of the operator's eyes and head. In addition, 3-axis gyro sensors were used to measure the angles of rotation for altered viewpoints, and an I/O interface was used to acquire the signals.



a. Shematic diagram b. Actual system

Figure 2 Visibility evaluation system for cabin type Far-East combine harvester

The movement of the visibility evaluation system tracking linear guide could be possible using a stepping motor (AK-24, Autonics, Korea). Since the position of the human field of view varies depending on the position of the driver's seat in the cabin type Far-East combine harvesters, the distance covered by the stepping motors was set at 300 mm each toward the *X* and *Y* axes. The distance covered toward the *Z* axis was set at 1000 mm so as to be able to move the field of view to the highest point in the cabin at a sitting posture since the operator drove it in a standing position during harvesting in some cases. The rotation of the human head and eye was controlled with a 3-axis joint. To measure the changes of the human field of view, gyro sensors (ENV-05G, Murata, Japan) which measured the angles of rotation to three-axis in ±180° were used. The angles of rotation of the upper and lower sides (pitch) and the left and the right sides (yaw) for the gyro sensors were measured, as the human field of view was changed in a vertical and horizontal way by the motion of the human head and eye in particular positions. An analog input module (NI-9205, National Instrument, USA) with an I/O interface was used with gyro sensors to measure the angles of the rotation of the field of view, and LabVIEW software (Version 8.5, National Instrument, USA) was used to collect and correct signals.

2.4 Viewpoints for cabin type Far-East combine harvester

To evaluate the visibility of cabin type Far-East combine harvesters, the scope of the operator's secure view during harvesting should be selected as viewpoints. The viewpoints were largely divided into two parts, direct field of view which the driver could perceive without a mirror, and the mirror field of view[26]. The visibility was evaluated with only a direct field of view, considering the fact that it might be very rare to use a mirror similar to an automobile driving mirror during harvesting with a combine harvester.

Major viewpoints of the cabin type Far-East combine harvester were determined at the spots where the visibility should be secured during harvesting through the interviews with the operator[17]. The divider decided the driving direction, the reaper lever controlled the cutting height, the gearshift lever determined the operation speed, and the operator checked the harvesting process using the conveying component and the dashboard. Therefore, as shown in Figure 3, the visibilities of five viewpoints of the cabin type Far-East combine harvester were evaluated: the divider, the reaper lever, the gearshift lever, the dashboard, and the conveying part.

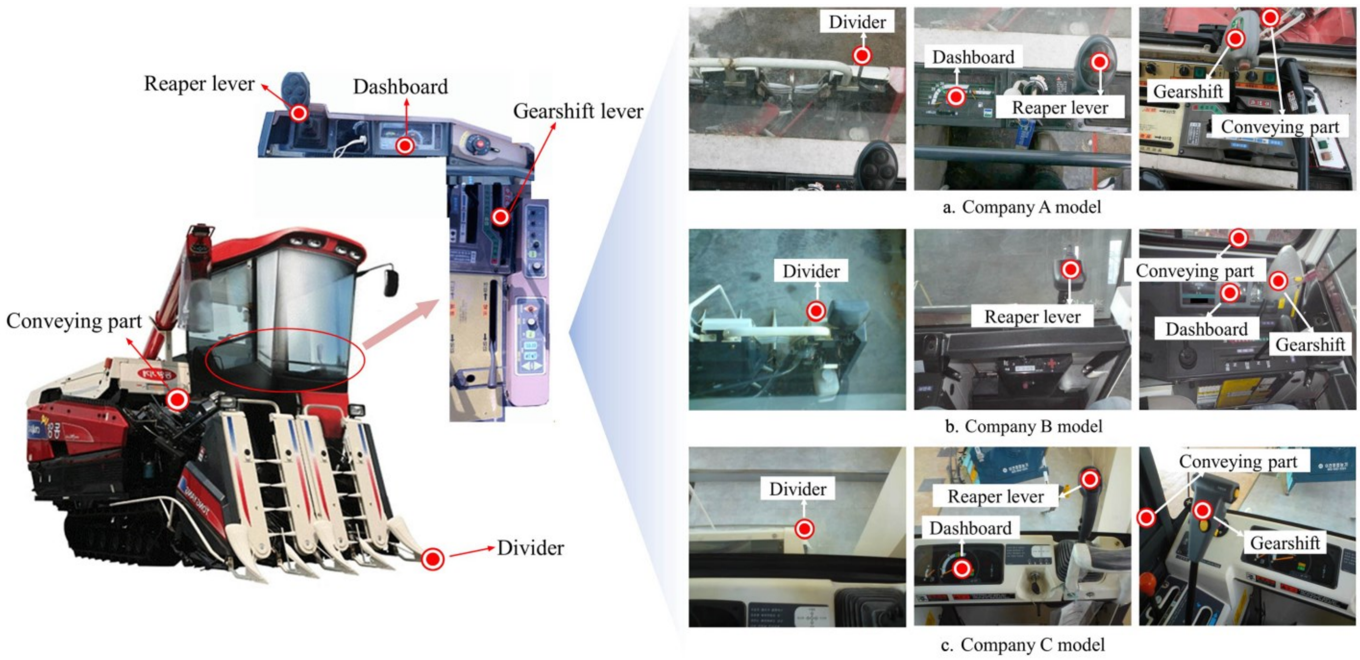


Figure 3 Major viewpoints of cabin type Far-East combine harvester

Three major agricultural manufactures produce the cabin type Far-East combine harvesters in Korea, and this study evaluated the visibility of three harvesters from different manufactures. Best-selling harvesters from each manufacture were used for the study, and major specifications of them are shown in Table 4. The visibility was evaluated by four working postures (sitting straight, sitting with a 15° tilt, standing straight, and standing with a 15° tilt) because the operator works standing or leaning his head for the visibility of the major viewpoints.

Table 4 Specifications of the cabin type Far-East combine harvesters used in this study

Specification	Company A	Company B	Company C
Length × Width × Height/mm	4880×2110×2400	4430×1900×2820	4950×2225×2700
Mass/kg	3 490	3 120	4 268
Engine rated power /kW	60	51	72
Wheel type	track	track	track

The visibility was marked at the center of viewpoints, and 100 points (perceptive field of view) was achieved when the human field of view was in the marks of each viewpoint. Major viewpoints of three combine harvesters such as levers and dashboards were placed in different positions, height, and sizes. Especially company A model had a control box for dashboard between dashboard and divider, and company B model had the dashboard on the side of the harvester.

2.5 Verification of the visibility evaluation system

To verify the accuracy of the visibility evaluation system, the horizontal and vertical angles from the operator's eye position to the cabin type Far-East combine harvester viewpoints were measured with a laser pointer, and then they were compared and analyzed with the original 3-D drawing of the cabin type Far-East combine harvester as shown in Figure 4. The verification test was conducted using only company A model since 3-D drawing of other models could not obtained due to security regulations. The operator's eye was positioned 780 mm upwards and 170 mm forwards based on the standard SIP (seat index point). These values were selected based on the average body type of male Korean population between the ages of 45 and 69. The horizontal and vertical angles were measured using the visibility evaluation system for five viewpoints such as the divider, the reaper lever, the gearshift lever, the dashboard, and the conveying part, and then they were compared with the horizontal and vertical angles measured in the drawing. The verification tests were repeated five times at each viewpoint for the analysis of the data. A t-test was conducted at the 5 percent level of significance with SAS (version 9.1, SAS Institute, Cary, USA), a statistical analysis program.

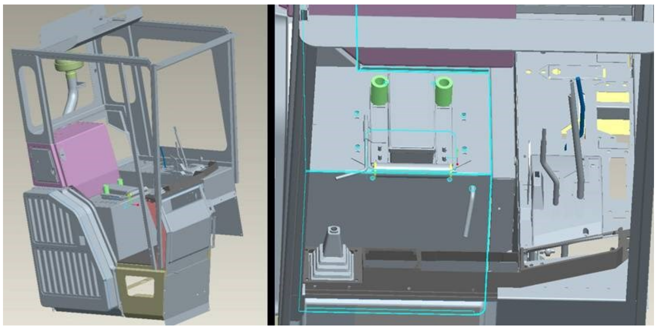


Figure 4 3D model of cabin type Far-East combine harvester (company A model) for verification of the visibility evaluation system

2.6 Visibility evaluation

In the visibility evaluation of the cabin type Far-East combine harvester, the major five viewpoints at different operation postures were evaluated. The most desirable posture during combine harvester operation was a sitting posture; however, standing or leaning postures were also needed to check the operation condition during harvesting. For this analysis, it was assumed that the human eye was located in the very front part of the human head and the axis of rotation of the leaning posture in a sitting or standing position on the driver's seat was identical with the hip, as shown in Figure 5.

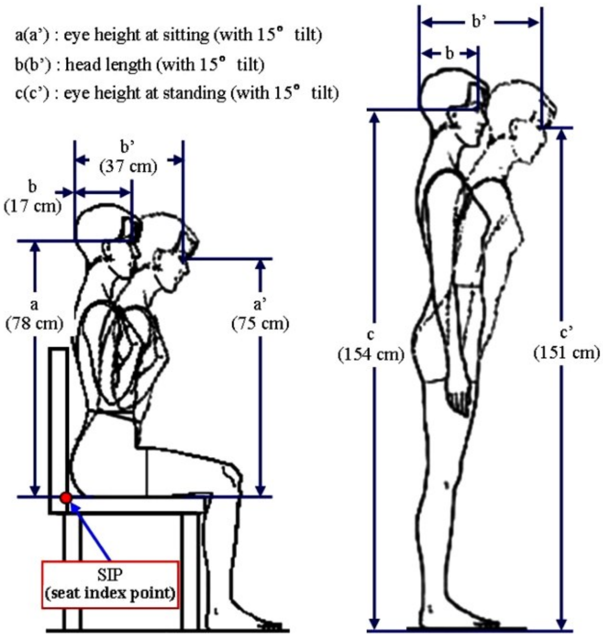


Figure 5 Operator's eye position with different postures

Four postures such as sitting up straight, sitting with a 15° tilt, standing straight, and standing with a 15° tilt were used for these tests[27]. The visibility was evaluated five times at each operation posture, and the 3-axis direction link of the visibility evaluation system was rotated to match the laser pointer and viewpoints, then the changes in the checked vertical and horizontal angles of the laser pointer were checked with the gyro sensors to determine the evaluation scores of the human field of view. To analyze the visibility, One-Way ANOVA and the least significant difference test (LSD test), whose factor were the operation posture, viewpoints were conducted with the SAS (version 9.1, SAS Institute, Cary, USA).

3 Results and discussion

3.1 Verification of visibility evaluation system

Table 5 shows results of the verification of the visibility evaluation system. The divider could not be measured due to blockage, and it was excluded from comparison since it was equal to the drawing. The calculated angles using the 3D drawing and the measured angles using the visibility evaluation system were within the same range for each viewpoint at the 5% level of significance. These results demonstrated that the visibility evaluation for the cabin type Far-East combine harvester was relatively accurate.

Table 5 Results of measured angles for verification of visibility evaluation system using company A model

	Horizontal angle			Vertical angle		
	Actual value/(°)	Measured value/(°)	t-value	Actual value/(°)	Measured value/(°)	t-value
Divider	(0.0)	(0.0±0.00)	Exclude	(0.0)	(0.0±0.00)	exclude
Reaper lever	9.8	10.3±0.76	2.21*	−39.2	−39.0±0.50	1.48*
Gearshift lever	−46.8	−47.1±0.48	−1.49*	−45.1	−45.2±0.57	−0.32*
Dashboard	−9.8	−10.3±0.57	−1.80*	−53.7	−54.2±0.46	−2.62*
Conveying part	−63.4	−63.0±0.65	2.18*	−39.9	−39.4±0.59	0.68*

Note: * $p<0.05$.

3.2 Visibility of major viewpoints by operating postures

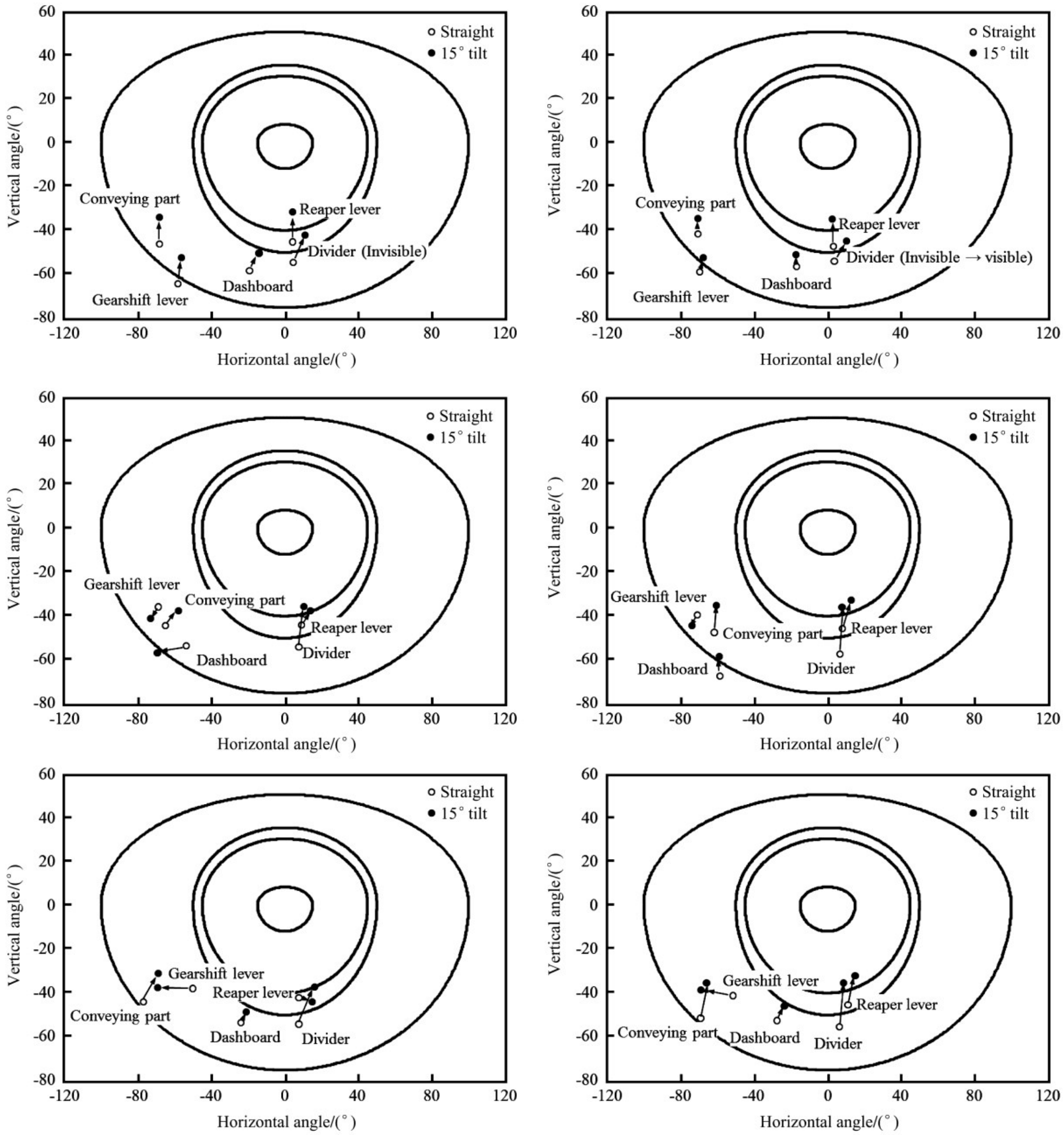
Figure 6a shows the field of view of the cabin type Far-East combine harvester viewpoints at a sitting posture including the vertical posture and sitting at a 15° tilt. The reaper lever was in the induced field of view at the sitting posture where the straight, vertical position resulted in the best visibility. Most of gearshift lever, dashboard, and conveying component were in the auxiliary field of view. However, the gearshift lever of company A model was out of the auxiliary field of view, therefore, the whole motion of the body would be required to visibly see the gearshift lever. Determining a sight line for the divider was not easy at a sitting, vertical posture during harvesting since the divider was within the auxiliary field of view. Especially, the divider of company A model was invisible since the control box blocked this field of view, although the divider was within the auxiliary field of view.

The most of visibility for conveying component, reaper lever, and divider at a sitting position with a 15° tilt was generally closer to the perceptive field of view, and it showed better visibility than the straight, vertical sitting position. The reaper lever was in the stable gaze field of view, and the lever was visible when sitting with a 15° tilt through only head and eye movement except company C model. Also, the divider was in the stable gaze field of view at a sitting position with a 15° tilt except company A model. Nevertheless, the divider of company A model was in the induced field of view, so its visibility would be possible by removing the control box or modifying the frame. The gearshift lever visibility of company A model was enhanced and moved into the auxiliary field of view. The conveying part visibility was changed within the auxiliary field of view. However, the dashboard visibility of company B model was reduced and moved out of the auxiliary field of view.

Figure 6b shows the field of visibility for viewpoints while standing straight and at a standing angle 15° tilt. Under these conditions, a vertical standing posture generally showed similar visibility to a straight sitting posture. In case of the reaper lever and divider, a standing posture with a 15° tilt was much closer to the perceptive field of view showing a better visibility than in the straight standing posture. Especially, the visibility for the dash board of company B model moved into the auxiliary field of view showing better visibility than a sitting posture with a 15° tilt.

3.3 Visibility score

Tables 6 and 7 show the evaluation scores at different company models by viewpoints and operating postures on the cabin type Far-East combine harvesters. As can be seen in Table 6, company A model showed the best visibility at the posture of standing with a 15° tilt, and the reaper lever (55.3) showed the highest score at a significance level of 5%. Reaper lever showed the highest scores at every posture, therefore cutting work can be performed smoothly with any postures. Dashboard and conveying part secured visibility at every posture. However, gearshift lever secured visibility at the posture of sitting with a 15° tilt or standing with a 15° tilt. Divider secured visibility only at the posture of standing with a 15° tilt because the control box for dashboard wiring blocked the field of view.



a. Sitting posture b. Standing posture

Note: top: at company A, middle : at company B, bottom : at company C.

Figure 6 Results of the visibility of major viewpoints by operating postures

Table 6 Results of visibility evaluation score for viewpoints at company A model by posture

View point	Sitting		Standing		Average
	Straight	15° tilt	Straight	15° tilt	
Divider	0.0 ± 0.00^{Bd}	0.0 ± 0.00^{Be}	0.0 ± 0.00^{Bd}	37.6 ± 0.51^{Ab}	9.4
Reaper lever	41.4 ± 0.34^{Ca}	52.2 ± 0.39^{Ba}	39.1 ± 0.27^{Da}	55.3 ± 0.42^{Aa}	47.0
Gearshift lever	0.0 ± 0.00^{Cd}	9.1 ± 0.37^{Ad}	0.0 ± 0.00^{Cd}	4.7 ± 0.28^{Be}	3.45
Dashboard	19.1 ± 0.41^{Db}	35.1 ± 0.29^{Ab}	24.5 ± 0.31^{Cb}	31.1 ± 0.42^{Bc}	27.2
Conveying part	11.7 ± 0.32^{Bc}	15.2 ± 0.31^{Ac}	12.2 ± 0.45^{Bc}	14.9 ± 0.43^{Ad}	13.5
Average	14.4	22.1	15.2	28.7	20.1

Note: 1) Average ± standard deviation; 2) Means with different superscript (A, B, C, D) in each row are significantly different at p<0.05 by LSD's multiple range tests; 3) Means with different superscript (a, b, c, d, e) in each column are significantly different at p<0.05 by LSD's multiple range tests.

Company B model showed the best visibility at standing with a 15° tilt, and the reaper lever (52.2) showed the highest scores like the company A model as provided in Table 7. The average score of standing straight was lowest because the visibility of dashboard was not good. Reaper lever showed the highest scores at every posture like the company A model. Different from the company A model, the company B model had no control box for dashboard wiring. Therefore, it secured visibility at the divider, which ensured the work path during combine harvesting. Dashboard in the company B model was moved to the side of the combine harvester, and this resulted in bad visibility at sitting with a 15° tilt or standing straight. The visibilities of the gearshift lever and conveying part were better than ones of the company A model.

Table 7 Results of visibility evaluation score for viewpoints at company B model by posture

View point	Sitting		Standing		Average
	Straight	15° tilt	Straight	15° tilt	
Divider	$31.1±0.31^{Cc}$	$45.2±0.30^{Ba}$	$26.7±0.21^{Db}$	$48.6±0.30^{Bb}$	37.9
Reaper lever	$41.0±0.43^{Ba}$	$43.1±0.32^{Bb}$	$38.4±0.32^{Ca}$	$52.2±0.27^{Aa}$	43.7
Gearshift lever	$12.2±0.11^{Ad}$	$6.4±0.27^{Cd}$	$9.5±0.19^{Bd}$	$5.6±0.15^{Dd}$	8.4
Dashboard	$34.1±0.28^{Ab}$	$0.0±0.00^{Ce}$	$0±0.00^{Ce}$	$3.2±0.20^{Be}$	9.3
Conveying part	$9.4±0.41^{De}$	$18.3±0.24^{Bc}$	$10.9±0.33^{Cc}$	$19.8±0.28^{Ac}$	14.6
Average	25.6	22.6	17.1	25.9	22.8

Note: 1) Average ± standard deviation;

2) Means with different superscript (A, B, C, D) in each row are significantly different at p<0.05 by LSD's multiple range tests;

3) Means with different superscript (a, b, c, d, e) in each column are significantly different at p<0.05 by LSD's multiple range tests.

The company C model showed the best visibility at standing with a 15° tilt like other models as provided in table 8, and standing with a 15° tilt showed the highest score at the reaper lever (53.8). The company C model secured visibility at every posture. Especially, reaper lever had the best scores at any postures like other models. Although dashboard was placed on the front like the company model A, the visibility was ensured at the divider. This was because the position of the control box for dashboard was moved to different position. The visibility at the gearshift lever was best among other models, and it was due to the close distance between gearshift lever and driving seat. Conveying part also secured visibility at any postures like other models.

Table 8 Results of visibility evaluation score for viewpoints at company C model by posture

View point	Sitting		Standing		Average
	Straight	15° tilt	Straight	15° tilt	
Divider	$31.1±0.34^{Cb}$	$43.0±0.33^{Ba}$	$29.7±0.19^{Db}$	$51.7±0.33^{Ab}$	38.9
Reaper lever	$41.1±0.34^{Ba}$	$38.1±0.35^{Cb}$	$38.9±0.30^{Ca}$	$53.8±0.40^{Aa}$	43.0
Gearshift lever	$25.3±0.34^{Ac}$	$12.7±0.34^{De}$	$21.2±0.22^{Bd}$	$14.7±0.19^{Cd}$	18.5
Dashboard	$35.1±0.34^{Cb}$	$34.1±0.45^{Bc}$	$26.2±0.25^{Dc}$	$35.4±0.31^{Ac}$	32.7
Conveying part	$2.3±0.34^{Cd}$	$15.2±0.28^{Ad}$	$2.7±0.16^{Ce}$	$13.5±0.29^{Be}$	8.4
Average	27.0	28.6	23.7	33.8	28.0

Note: 1) Average ± standard deviation;

2) Means with different superscript (A, B, C, D) in each row are significantly different at p<0.05 by LSD's multiple range tests;

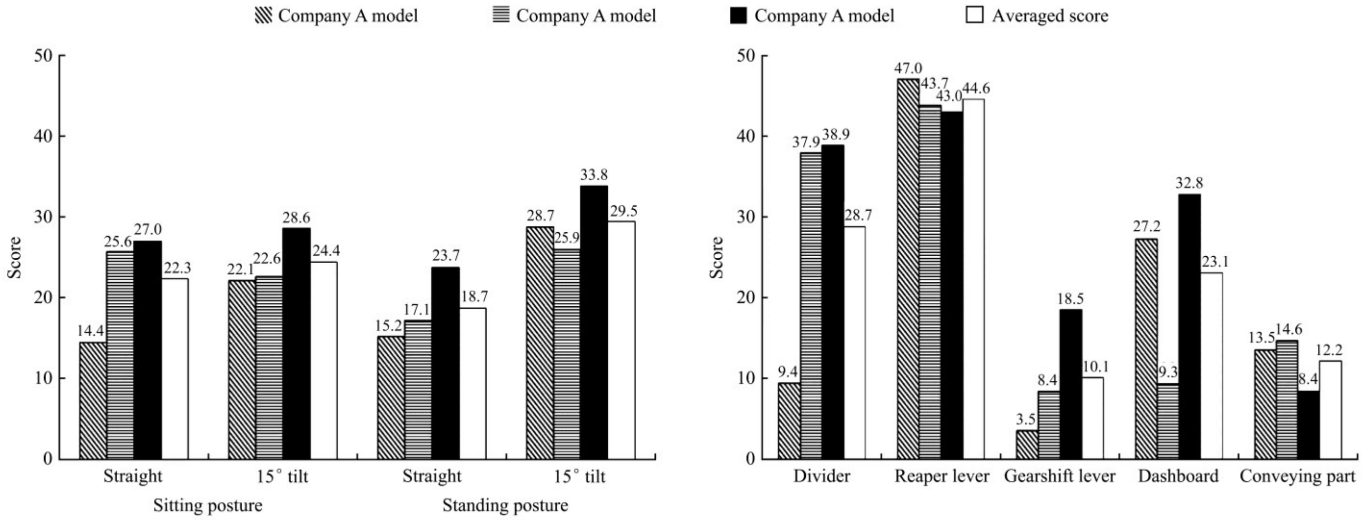
3) Means with different superscript (a, b, c, d, e) in each column are significantly different at p<0.05 by LSD's multiple range tests.

3.4 Visibility evaluation

Figure 7 shows the average visibility evaluation scores of each company model. In terms of postures (Figure 7a), the average visibility scores at sitting postures were 22.3 (sitting straight) and 24.4 (sitting with a 15° tilt), and the scores at standing postures were 18.7 (standing straight) and 29.5 (standing with a 15° tilt).

The visibility of both tilting posture were improved by 109% (sitting) and 158 % (standing) comparing to straight posture, and standing with a 15° tilt postures showed greater visibility improvement. The company C model showed the highest scores at every posture, while the company A model showed lower scores at most postures except standing with a 15° tilt. Overall visibility of the company A model was improved at sitting with a 15° tilt (153%) and at standing with a 15° tilt (189%) comparing to straight posture. On the other hand, overall visibility of the company B model was improved at standing with a 15° tilt (151%) but reduced at sitting with a 15° tilt (88%) comparing to straight posture. This infers that leaning the body or head for the visibility is not needed while working at sitting with the company B model. Overall visibility of the company C model was improved at sitting with a 15° tilt (110%) and at standing with a 15° tilt (143%) comparing to straight posture. The company A model provided the most improved visibility both at sitting and standing with a 15° tilt, which means that changing postures is required for the visibility while working with the company A model.

In terms of viewpoints (Figure 7b), the average visibility scores were observed in order from highest to lowest as reaper lever (44.6), divider (28.7), dashboard (23.1), conveying part (12.2), and gearshift lever (10.1). The gearshift lever showed the lowest visibility among the viewpoints for all company models, and visibility rates compared to the gearshift lever were 284% at divider, 440% at reaper lever, 228% at dashboard, and 120% at conveying part. It was known that the visibility at reaper lever was four times greater than at the gearshift lever. Visibility for company models was evaluated by comparing to the lowest visibility model according to each viewpoint. The lowest visibility models were the company A at the divider and gearshift lever, the company B at the dashboard, and the company C at the conveying part.



a. By posture

b. By view point

Figure 7 Results of average visibility evaluation score for viewpoints

The company C model showed the best visibility at the divider, and it was 414% greater than the company A model. The visibility at the reaper lever was best with the company A model, however, other companies' models showed similar visibility about 109% compared to the company C model. The company C model provided best visibility at the gearshift lever and dashboard, which reached 529% and 339% compared to the company A model and the company B model. The visibility at the conveying part of the company B model was best which reached 174% of the company C.

As results of this study, standing with a 15° tilt showed the best visibility, which was 132% higher than sitting straight. This is caused that most Korean operators worked leaning their body during harvesting, which resulted in diseases of musculoskeletal system or accidents. Therefore, to improve the visibility at sitting posture, following guidelines should be considered:

1) The visibility at the divider was blocked by the control box as in the company A model, therefore, placing the control box at front side of the operator should be avoided.

2) The visibility at the reaper lever was good at all models, and if moving the reaper lever to the center of the field of view is expected to improve the visibility.

3) The visibility at the gearshift lever was influenced by the distance between lever and operator's field of view, and the closest one, company C model (480 mm) showed the best visibility compared to the company A model (550 mm) and company B model (510 mm). Thus, the distance between lever and driving seat should be minimized when designing the gearshift lever.

4) Placing the dashboard on the side of the combine harvester might be improved the front visibility, however, it will be familiar to the operator to place it on the front as long as it does not block the field of view such as company A model.

5) The visibility of the conveying part is needed to check the conveying condition of grains. However, most of gearshift lever was between the middle of the operator's field of view and conveying part; therefore, considering the visibility at the conveying part is needed

for positioning the gearshift lever.

4 Conclusions

This study developed a visibility evaluation system for cabin type Far-East combine harvester and evaluated the visibility of three different cabin type Far-East combine harvesters manufactured in Korea. Four postures such as sitting up straight, sitting with a 15° tilt, standing straight, and standing with a 15° tilt were used for the evaluation. Main viewpoints from the divider, reaper lever, gearshift lever, dashboard, and conveying component were evaluated for the visibility. The main results of this study can be summarized as follows:

1) A visibility evaluation system for the cabin type Far-East combine harvester was developed to quantitatively assess the visibility level of cabin type Far-East combine harvesters. The visibility evaluation system consisted of a laser pointer that was used in the eye position, movable stepping motors to reproduce the operator's viewing position, gyro sensors to measure the angle of rotation, and an I/O interface to acquire the signals. This system measured horizontal and vertical angles from the eye position to the viewpoints, which were then used to calculate an evaluation score of the human field of view.

2) Each field of visibility for viewpoints in a sitting and standing posture on the cabin type Far-East combine harvester were in general similar. In addition, the divider was found to be invisible at the sitting and standing posture as well during harvesting with a combine harvester. The fields of visibility for viewpoints while sitting with a 15° tilt and at standing posture with a 15° tilt showed similar visibility in general. However, the visibility when the posture was standing with a 15° tilt was improved since the divider was visible at this posture.

3) The average visibility scores were observed in order from highest to lowest as reaper lever (44.6), divider (28.7), dashboard (23.1), conveying part (12.2), and gearshift lever (10.1). The gearshift lever showed the lowest visibility among the viewpoints for all company models, and visibility rates compared to the gearshift lever were 284% at divider, 440% at reaper lever, 228% at dashboard, and 120% at conveying part. It was known that the visibility at reaper lever was four times greater than at the gearshift lever. In all of the tests, the visibility for the most main viewpoints were at a lower level than the stable gaze field of view, and an overall improvement in visibility was required to improve convenience and safety during harvesting.

4) The developed visibility evaluation system could reliably and accurately assess the visibility of cabin type Far-East combine harvester. However, in this study similar specifications of cabin type Far-East combine harvesters were used to evaluate visibility, and it is hard to apply into the other combine harvesters. Therefore, to extend the result of the study carried out with compact combine used in Far-East countries to the more common and world-wide spread standard combines, more studies on the weighted importance of different viewpoints based on the frequency of checks during harvesting as well as additional tests on various types of combine harvester will be needed. In addition, applying electronically controlled complex lever and a camera-display system will be needed to improve the visibility.

Acknowledgement

This research was supported by Advanced Production Technology Development Program, Ministry of Agriculture, Food and Rural Affairs.

[References]

[1] Cavalllo E, Ferrari E. Likely technological trajectories in agricultural tractors by analyzing innovative attitudes of farmers. Int. J. Technology, Policy and Management, 2015; 15(2): 158–177.

[2] Kim C H, Jung H J, Jo J S, Kim M I , Lee B H, Park T J, Seo K W, Kim H T. Impact of sound insulation in a combine cabin. J. of Biosystems Eng., 2015; 40(3): 159–164.

[3] Drury C G, Clement M R. The effect of area, density, and number of background characters on visual search. Human Factors, 1978; 20(5): 597–602.

[4] Barron P J, Owende P M O, McDonnell K P, Ward S M. A method for assessment of degradation of task visibility from operator cabins of field machines. Ind. Ergonomics, 2005; 35: 665–673.

[5] Collins J W, Landen D D, Kisner S M, Johnston J J, Chin S F, Kennedy R D. Fatal occupational injuries associated with

forklift, United States, 1980–1994, American J. Ind. Med., 1999; 36: 504–512.

[6] Collins J W, Smith G S, Baker S P, Warner M. Injuries related to forklifts and other powered industrial vehicles in automobile manufacturing. American J. Ind. Med., 1999; 36: 513–521.

[7] Kim Y J, Lim D S, Lee S S, Mun J H. Ergonomic analysis of combine task. In Proc. KSAM 2008 Winter Conf., 2008; 13(1): 60–64.

[8] Hutter G M. Earthmoving equipment-an operator's field of view (SAE Standard J1091), Safety and Forensic Eng. J., 2000; 2.

[9] NIOSH. Highway work zone safety, construction equipment visibility – manual method. Atlanta, USA: National Institute for Occupational Safety and Health. 2012.

[10] ISO. ISO standard 5006: Earth-moving machinery – Operator's field of view – Test method and performance criteria. Geneva, Switzerland: International Organization for Standardization. 2006.

[11] ISO. ISO standard 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: International Organization for Standardization. 2013.

[12] Kabir M S N, Song M, Chung S O, Kim Y J, Kim S C, Ha J K. Visibility evaluation for agricultural tractor operators according to ISO 5006 and 5721-1 standards. J. of Biosystems Engineering, 2015; 40(1): 19–27.

[13] Hella F, Tisserand M, Schouller J F, Englert M. A new technique for checking the driving visibility on hydraulic excavators. Intl. J. Ind. Ergonomics, 1991; 8: 135–145.

[14] Esteve B, Aoussat A, Berger H. Various systems for measuring a car's visibility field. Intl. J. Vehicle Design, 2000; 25: 70–78.

[15] Choi C B, Park P, Kim Y H, Hallbeck M S, Jung M C. Comparison of visibility measurement techniques for forklift truck design factors. Appl. Ergonomics, 2009; 40: 280–285.

[16] Dassault Systems. CATIA Version 5 Release 13 Human Builder. France: Dassult Systems, 2004.

[17] KATS. KS R ISO 7397: Passenger cars-verification of driver's direct field of view. Gwacheon, Korea: Korean Agency for Technology and Standards, 2002.

[18] European Parliament. Directive 2008/2/EC of the European Parliament and of the Council of 15 January 2008 on the field of vision and windscreen wipers for wheeled agricultural or forestry tractors. Official Journal of the European Union, 2008; OJ L 24, 29.1: 30–38.

[19] Ferrari E, Cavalllo E. Operators' Perception of Comfort in Two Tractor Cabs. Int. J. Technology, Policy and Management, 2013; 19(1): 3–18.

[20] Ryu T B, Shin S W, Yoo H C. Development of a quantitative visibility evaluation system for the design of an occupant packaging layout. In Proc. KIIE 2004 Spring Conf., 2004; pp.659–662.

[21] Jang S R. Human engineering, Seoul, Korea: Dasom. 2001.

[22] Nakaji Y, Kitazaki S, Kato K, Hijikata S, Hirao A. Display apparatus and method for automotive vehicle. US patent No. 6556134.

[23] KOSTAT. Agricultural population by age. Daejeon, Korea: Statistics Korea. 2008.

[24] KATS. The 5th Korean critical anthropometric measurement report. Gwacheon, Korea: Korean Agency for Technology and Standards. Size Korea, 2005.

[25] ISO. ISO 2631-1: Mechanical vibration and shock -evaluation of human exposure to whole-body vibration - Part 1: General requirements. Geneva, Switzerland: ISO. 1997.

[26] Choi J H. A study on the visibility factors for seating packaging. J. of the Res. Inst. of Prod. Tech. 1999; 2: 19–29.

[27] Choi C H, Kim J D, Kim T H, Mun J H, Kim Y J. A study on visibility evaluation for cabin type combine. J. of Biosystems Eng., 2009; 34(2): 120–126.