

---

# Understanding the requirements for a blind-spot monitoring system on tractors from the operator's perspective

Xin Chen and Danny D. Mann

*Department of Biosystems Engineering, University of Manitoba, Winnipeg, MB R3T 5V6, Canada*

*Corresponding Author: Danny Mann (Danny.Mann@umanitoba.ca)*

*Submitted: 2018 April 19*

*Revision received: 2018 October 2*

*Accepted: 2018 October 10*

*Published online: 2019 April 11*

---

## ABSTRACT

Unintentional run-overs occur because the operator of a tractor is unable to physically see all around the machine. Therefore, there is a need to devise an effective blind-spot monitoring system for tractors to prevent unintentional run-overs. The purpose of the study was to identify the locations of blind spots around two types of tractors (i.e., with and without a front-end loader), with the ultimate goal of conceptualizing a blind-spot monitoring system capable of eliminating all existing blind spots. Grids were constructed around all four sides of the tractors to determine the presence of blind spots for drivers of varying sitting height (i.e., 5th, 50th and 95th percentile male for erect and slumped postures) at four horizontal planes representing people of varying stature who might be in the vicinity of the tractor (i.e., standing male, standing female, standing child, kneeling adult). Generally, the proportion of markers not visible decreased as the sitting height increased. Differences between erect and slumped sitting postures were not statistically different suggesting this variable could be ignored in the assessment of blind spots around tractors. The proportion of the markers not visible to the operator varied from 0 to 34%, with higher values observed for the tractor with the front-end loader installed. Values were as high as 42% of the markers not visible for the condition where a passenger was present in the passenger/trainer seat. Use of the existing rear-view mirrors eliminated only a small fraction of the blind spot area around the tractors. Through trial and error, it was determined that five and eight cameras would be required to fully detect the entire blind spot area around the two tractors selected for this study. A blind-spot monitoring system composed of five or eight cameras would create substantial additional monitoring burden for the tractor operator and, therefore, is not a feasible solution. A hybrid blind-spot monitoring system consisting of cameras and proximity sensors warrants further investigation.

## KEYWORDS

Blind spot, Run-overs, Tractor, Testing, Diagrams, Camera, Detection, Agricultural machine, Mirrors, Sensors, HAAT model

## RÉSUMÉ

Les écrasements accidentels de personnes par des tracteurs agricoles surviennent en raison de la présence d'angles morts qui empêchent le conducteur de bien voir autour de sa machine. Par conséquent, il existe un besoin pour un système efficace de surveillance de l'angle mort pour les tracteurs qui prévienne les accidents par écrasement. Le but de cette étude était d'identifier où se situent les angles morts autour de deux types de tracteurs (c.-à-d. sans et avec chargeur frontal), avec comme objectif ultime de conceptualiser un système de surveillance des angles morts capable d'éliminer tous les angles morts existants. Des grillages ont été construits autour des quatre côtés des tracteurs pour déterminer la présence d'angles morts pour les conducteurs de différentes tailles en position assise (c.-à-d. 5e, 50e et 95e centile chez les hommes en posture droite ou affaissée) à quatre plans horizontaux représentant des personnes de différentes statures qui pourraient être autour du tracteur (c.-à-d. un homme debout, une femme debout, un enfant debout, un adulte à genou). Généralement, la proportion des marqueurs qui n'étaient pas visibles diminuait avec une augmentation de la taille assise. Les différences entre la posture assise, droite ou affaissée, n'étaient pas statistiquement significatives suggérant que cette variable pouvait être ignorée dans l'évaluation des angles morts autour des tracteurs. La proportion des marqueurs qui n'étaient pas visibles pour le conducteur variait de 0 à 34 % avec les valeurs les plus importantes observées avec le tracteur muni d'un chargeur frontal. Les valeurs atteignaient 42 % des marqueurs non visibles lorsqu'un passager était présent dans le siège du passager/formateur. L'usage des rétroviseurs existants n'éliminait qu'une petite fraction de la zone d'angles morts autour des tracteurs. Par tâtonnements, il a été déterminé que cinq et huit caméras seraient nécessaires pour détecter complètement la zone entière d'angles morts autour des deux tracteurs sélectionnés pour cette étude. Un système de surveillance des angles morts composé de cinq ou huit caméras créerait un fardeau de surveillance additionnel et important pour le conducteur d'un tracteur et, par conséquent, n'est pas une solution viable. Un système hybride de surveillance des angles morts constitué de caméras et de senseurs de proximité devrait faire l'objet de recherches additionnelles.

## MOTS CLÉS

Angle mort, écrasement accidentel, tracteur, évaluation, diagramme, caméra, détection, machine agricole, miroir, senseur, modèle HAAT [technologie d'aide aux activités humaines]

---

## CITATION

Chen, X., and D.D. Mann. 2018. **Understanding the requirements for a blind-spot monitoring system on tractors from the operator's perspective.** *Canadian Biosystems Engineering/Le génie des biosystèmes au Canada* 60: 2.33-2.42. <https://doi.org/10.7451/CBE.2018.60.2.33>

## INTRODUCTION

The existence of blind-spots around tractors is a critical safety issue. The Canadian Agricultural Injury Reporting (CAIR) reported that, in Canada, run-overs accounted for the highest percentage of agriculture-related fatalities from 2003 to 2012 (i.e., 18%). Of the run-over fatalities reported, 21% were bystanders. Because only fatalities were recorded in the report, the exact number of run-overs could be higher. Unintentional run-overs may occur because the operator cannot detect nearby objects and bystanders when operating a tractor with an enclosed cab. A potential solution to overcome the problem of blind spots is to devise a blind-spot monitoring system. Before a blind-spot monitoring system can be conceptualized, it is necessary to first understand where blind spots exist. Therefore, the first objective of this study was to determine the locations of blind spots around a tractor. After knowing the locations of blind spots, the next step is to choose an appropriate technology to eliminate the identified blind spots. The second objective of this study, therefore, was to propose a conceptual design for a blind-spot monitoring system.

### **Methodologies for assessing blind-spots around machines or vehicles**

Despite the occurrence of unintentional run-overs associated with tractors, we were not able to identify any regulations on the subject of agriculture-related blind-spot protection or increasing the operator's visibility. However, four methodologies to assess visibility around machines or vehicles were found in the literature.

The first methodology is available from the Occupational Safety and Health Administration (OSHA) website. This methodology measures driver field of view by identification of visible targets outside of the vehicle. The steps include i) positioning a worker near the equipment, ii) moving the worker to different locations, and iii) changing the distance from the equipment until the other worker who sits in the cab cannot observe the worker standing nearby the equipment. With this technique, the length and width of blind spots can be approximated. The International Organization for Standards (ISO 2017) developed a standard to evaluate the operator's visibility which is referred to as the Earth-moving machinery-operator's field of view (ISO 5006:2017). Lights, which are rotatable through 360°, are located at the seated index point (SIP) which can be thought of as the position of the operator's eyes. A circle with 12 m radius, called the visibility circle, is marked on the ground. The equipment is located in the center of the circle and blind spots are identified as the regions where the structure of the machine prevents the light from shining. The third methodology is a volumetric projection technique (Marshall et al. 2013). It is a software-based technique that allows the operator's field of view to be modeled in three dimensions. If a CAD model of the machine can be generated, it should be possible to predict the location of blind spots, however, it can be time-consuming to develop a CAD model for every machine to be evaluated. The fourth method identified in the literature was recently developed for agricultural machines by Ehlers and Field (2016). This method employs a grid of cells,

containing poles at the center of each cell, adjacent to the machine. Visibility of the poles from the operator's seated position is assessed. Because vertical poles are used, this method is capable of assessing the visibility at various horizontal planes representing bystanders of various heights.

It is likely that any of the four methods could be used to determine the extent of blind spots around agricultural tractors, however, the Ehlers and Field (2016) method was selected for this research. An indoor facility was not available to allow the use of the ISO method (ISO 5006:2017), and it would have been time-consuming to develop CAD models to employ the method proposed by Marshall et al. (2013). The OSHA method shares some similarity with the Ehlers and Field (2016) method, however, the use of a defined grid was seen to be an advantage of the Ehlers and Field (2016) method. In summary, the methodology previously used by Ehlers and Field (2016) was chosen because it can:

- identify blind spots on all four sides of a tractor,
- identify blind spots on multiple elevations (representing bystanders of various heights) considering the fact that different people are likely to be present in the agricultural field, and
- enable the performance of existing rear-view mirrors in detecting blind spots to be assessed.

### **Characteristics of an effective blind-spot monitoring system**

The second objective of this study was to propose a conceptual design for a blind-spot monitoring system. In this section, a model called the Human Activity Assistive Technology (HAAT) model (Cook and Polgar, 2015) was borrowed from the discipline of occupational therapy in an attempt to identify the requirements for a blind-spot monitoring system from the operator's perspective. The HAAT model includes four elements: a human using an assistive device or technology to complete a specific activity within a unique context and it is typically applied as a means of identifying the most appropriate technology to enable a person with a disability to complete a desired task. Within the context of the HAAT model, a blind spot surrounding a tractor may be considered to be a form of disability (i.e., blindness) experienced by the operator. The HAAT model considers the abilities of the human (i.e., the machine operator), the activity to be completed (i.e., to eliminate unintentional run-overs while driving the machine), and the context in which the task occurs with the objective of identifying an appropriate technology solution (or assistive device) that should enable the human to complete the desired task in a satisfactory manner. The following paragraphs discuss three potential technologies (i.e., mirrors, cameras, and proximity sensors) using the framework of the HAAT model.

#### **HAAT Model: Activity**

The activity that the operator wants to achieve is to be warned of the presence of an object in a blind spot around the tractor during operation of the tractor. However, it is also important to consider the other tasks that the operators

are supposed to do because operating a tractor is a multi-task activity. It is essential to remember that the operator is usually focused on monitoring the operation of the tractor and a towed or mounted machine to maximize its efficiency. Scanning the environment for individuals who may be present near the machine is not the operator's priority. As a consequence, an ideal blind-spot monitoring system should allow the operator to monitor all blind spots without causing too much additional mental workload.

#### **HAAT Model: Human**

In this context, the "human" is the operator who is unable to see all the spots around the tractor. Many human factors should be considered for assisting with the detection and monitoring of blind spots. For example, the stature of the human (i.e., sitting height) defines the location of the driver's eyes when viewing the surroundings (Ehlers and Field 2014). Characteristics of the individual, such as fatigue, were noticed to be critical factors in many industrial accidents (Griffith and Mahadevan 2011). In most cases, operators need to monitor the situation behind the tractor, requiring a significant amount of time looking backward (Sjoflot 1980). A blind-spot monitoring system should consider the posture required of the operator because comfort is an important component of work (Sjoflot 1980).

#### **HAAT Model: Context**

Agricultural operations occur in the field. The characteristics of the field environment (i.e., darkness, dust) that can negatively influence visibility and use of assistive technologies (i.e., night vision cameras used in the dark environment) must be considered. Secondly, farms and other agricultural sites are not just workplaces, but also places where people of all ages live and participate in recreational activities. Family members, including children may be present near large tractors. In fact, compared to other industries, where victims of workplace injuries are usually workers, agriculture is unique in that children account for a significant number of work-related injuries (Canadian Agricultural Injury Reporting 2016). This also contributes to the context in which the blind-spot monitoring system must function.

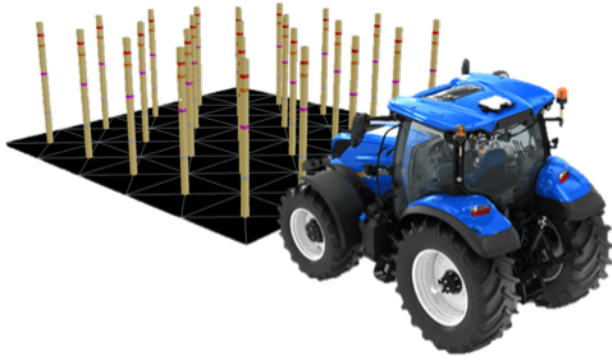
#### **HAAT Model: Assistive technology**

There are three assistive technologies (i.e., rear-view mirrors, cameras, and sensors) that could be used to create a blind-spot monitoring system for a tractor. The assistive technology that is already present on most tractors is the rear-view mirror. Mirrors are easy to install and are inexpensive. They allow the operator to detect objects and bystanders while maintaining their attention forward of the tractor (Ehlers and Field 2016). The operator can see behind or to the sides of the tractor without frequently turning or excessively straining their neck muscles. Large rear-view mirrors can improve the quality and capacity of work because they allow the operator to adopt a good working posture while operating most equipment (Sjoflot 1980). However, monitoring through rear-view mirrors still requires motion of the head and neck and this increases the neck muscle temperatures (Rakhra and Mann 2013), possibly leading to muscle fatigue. Sjoflot (1980) observed

that interior mirrors need a lot of space within the cab; the ideal size of mirror was 600 cm<sup>2</sup>. Convex or aspheric mirrors, rather than conventional spherical or flat mirrors, are often used by manufacturers because they can achieve a wider angle (Lee et al. 2013), however, distorted images in convex mirrors are difficult for the operator to interpret (Ehlers and Field 2016). Mirrors must be actively monitored by the operator; they do not passively alert the operator to the presence of bystanders. Dust or dirt, conditions of bad weather, and other special circumstances will impair visibility when using mirrors (Ehlers and Field 2014). Mirrors have relatively limited viewing angles. Ehlers and Field (2016) suggested that the mirrors provided by a manufacturer have limited detection capability. It would be ideal if the existing rear-view mirrors would be capable of making all blind spots visible to the tractor operator, however, it is not known whether rear-view mirrors alone are adequate.

A second technology that could be used for a blind-spot monitoring system is a proximity sensor. Sensor-based systems could detect objects and bystanders when they are in the dangerous vicinity of tractors. The greatest advantage of a sensor-based detection system is that it can be programmed to automatically alarm the operator when there might be a danger and this saves some of the operator's attention. Potential disadvantages of sensor-based systems were found in the literature. For example, the exact location of nearby objects is hard to verify when solely using a sensor-based monitor (Ruff 2001). False alarms from sensor-based monitoring systems are difficult for the operator to check (Steele 2006). Errors can be caused by wind on ultrasonic transition sensors (Song et al. 2004). Ultrasonic- and radar-based sensors are not impacted by dust or dirt conditions, therefore they could be used in the field environment (Wise 2011). In recent years, radar-based systems have become common on automobiles. A number of collision avoidance systems are able to interpret the data from sensors and automatically take an action (by braking or steering). For instance, when the vehicle is in a critical situation, Autonomous Emergency Braking (AEB) will intervene and avoid the accident by applying the brake. The National Highway Traffic Safety Administration (2016) announced 99% of automotive manufacturers agreed to include automatic emergency braking systems as standard equipment on vehicles. However, the use of these systems in tractors is rare. A lack of field trials that prove the reliability of these systems can be the reason of the limited applications; further evaluation needs to be done before recommending these systems for tractors.

The third technology to be considered for a blind-spot monitoring system is the camera. Camera-based monitoring systems usually include cameras detecting spots around the machine and a monitor mounted in the cab to display the view of the cameras. There are several advantages to camera-based monitoring systems. First, a camera-based system imposes the least physical workload on the operator compared with using rear-view mirrors and physically turning (Rakhra and Mann 2013). Also, camera-based



**Fig. 1. Evaluation grid in front of the tractor.**

monitoring systems can provide a wider view than the other detection systems (Mazzae and Garrott 2006). However, camera-based monitoring systems will be impaired with poor lighting or dirty conditions. The lenses of these cameras must be cleaned regularly. Vibration is also a factor for camera-based monitoring systems in tractors. Unless sophisticated object recognition algorithms are employed, cameras cannot automatically warn the operator; the operator has to look at the monitor and detect objects or bystanders in the screen. When the operator detects potential danger, he or she needs to respond quickly and with sufficient force applied to the brake pedal to bring the vehicle to a stop (Mazzae and Garrott 2006). Therefore, the true efficacy of camera-based systems is determined by many human factors.

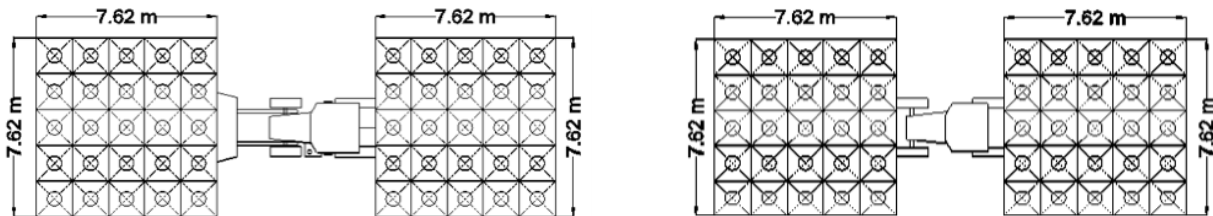
The rear-view mirror is the technology that is currently being used on tractors to assist with viewing the vicinity of the tractor, however, it is not known whether rear-view mirrors eliminate all blind spots. Cameras and sensors each

have advantages and disadvantages that must be considered. Camera-based systems are already being used for various monitoring tasks on agricultural machines so there is some familiarity with tractor operators, however, a camera-based blind-spot monitoring system would be properly classified as a passive system because it requires the operator to actively monitor the camera output for the presence of bystanders. Sensor-based technology is less common on agricultural machines, however, a blind-spot monitoring system composed of appropriate sensors could actively check the blind spots for the presence of bystanders.

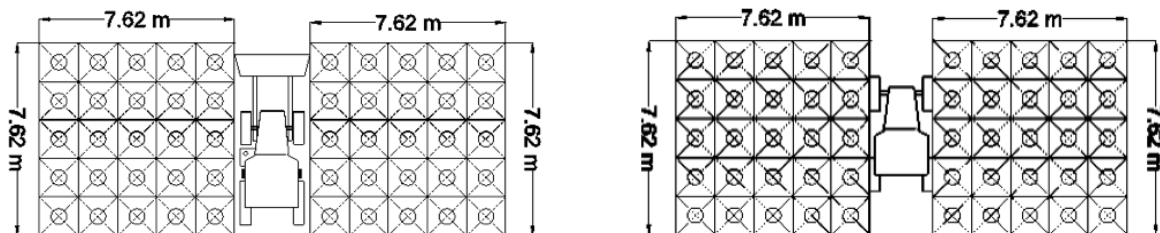
## MATERIALS AND METHODS FOR IDENTIFICATION OF BLIND SPOTS

### Overview of Methodology

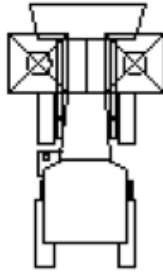
The methodology previously used by Ehlers and Field (2016) was modified for this research to enable blind spots to be identified on all four sides of the tractors available for this study. A large, level field site was selected at the University of Manitoba's research farm. A grid composed of 25 cells was established (Fig. 1). The grid was 7.62 m (25 feet) wide by 7.62 m (25 feet) long. Based on the orientation in which the tractor was parked, blind spots could be assessed on all four sides of the tractor (Figs. 2 and 3). At the center of each cell was a pole containing colored markers at different heights. The colored markers indicated the average height of a man (red tape), woman (orange tape), child (pink tape), and kneeling worker (grey tape). A camera situated on the tractor seat represented the position of the operator's eyes. From the digital pictures taken by the camera, the researchers were able to determine which colored markers were visible thereby quantifying blind spots around the tractor at four distinct horizontal planes. All the experiments in this study were conducted outdoors in a field during May and June, 2017.



**Fig. 2. Grids in the front side and rear side for T1 (left) and for T2 (right).**



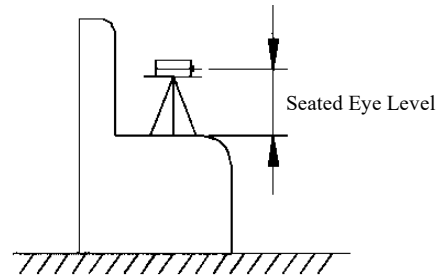
**Fig. 3. Grid on the two sides in T1 (left) and T2 (right).**



**Fig. 4. Additional cells added to grid for T1 to cover area directly behind bucket of front-end loader.**

**Test cases**

Two different tractors were selected as test cases for this research. One was a New Holland T6.175 tractor with a front-end loader (identified as T1) which included a passenger or trainer seat to the right of the operator’s seat. A research assistant was asked to sit in the passenger seat to simulate the situation where a passenger would be seated inside the cab. Accordingly, the visibility of the operator both with and without a seated passenger was assessed to compare these two conditions. The second tractor was a New Holland TV6070 bi-directional tractor without any implement attached during the experiments (identified as T2). Additional details about the tractors are listed in Table 1. Before the experiments, the two tractors were cleaned with a pressure washer to ensure windows were clean. There were some areas around T1 that the standard square grids did not cover. Therefore, additional cells were set up for T1 to determine those blind spots (Fig. 4).



**Fig. 5 Camera set-up.**

**Bystander heights**

Four different bystander heights were evaluated to document the blind spots at different horizontal planes: i) height of kneeling worker, ii) height of standing child, iii) height of standing woman, and iv) height of standing man. These four testing heights represented the average height of certain groups of people in order to evaluate the visibility at different heights. The average height of a kneeling worker is 61 cm (CDC 2012). The average heights for the other three groups of people, taken from the Canadian health measures survey (2009-2011), are shown in Table 2.

**Operator’s eye level**

An iPhone Model A1778 (12 megapixel camera, with up to 5X digital zoom) was positioned inside the cab at the level of the operator’s eyes. The positions selected were intended to represent the level of 5th, 50th and 95th percentile male driver’s eyes (Behara and Das 2012). Two seated postures

**Table 1. Detailed information of tractors used as test cases in this study.**

Tractor	Tractor 1 (T1)	Tractor 2 (T2)
Type	Front-wheel assist	Bi-directional tractor
Manufacturer & Model	New Holland T6.175	New Holland TV6070
Dimensions (mm)	Length	6000
	Width	2300
	Height	3000
Implement	A Loader in the front	None
Other Information	Two extended arm mirrors on two sides; one mirror inside the cab (right front corner)	Two mirrors inside the cab (one is located in the front right corner, the other located in the rear left corner.)

**Table 2. Heights chosen for each testing height (Canadian health measures survey).**

Categories	Mean Height (cm)	Height Value Selected
Child (both sexes, age 6 to 11)	134.84	135
Female (age 20 to 39)	162.98	163
Male (age 20 to 39)	177.70	178

**Table 3. Canadian adult male structural anthropometric measurements (Behara & Das, 2012).**

Seating Posture	Seated Eye Level (mm)		
	5 <sup>th</sup> Percentile Male	50 <sup>th</sup> Percentile Male	95 <sup>th</sup> Percentile Male
Straight sitting position	668	730	811
Slumped sitting position	614	706	781

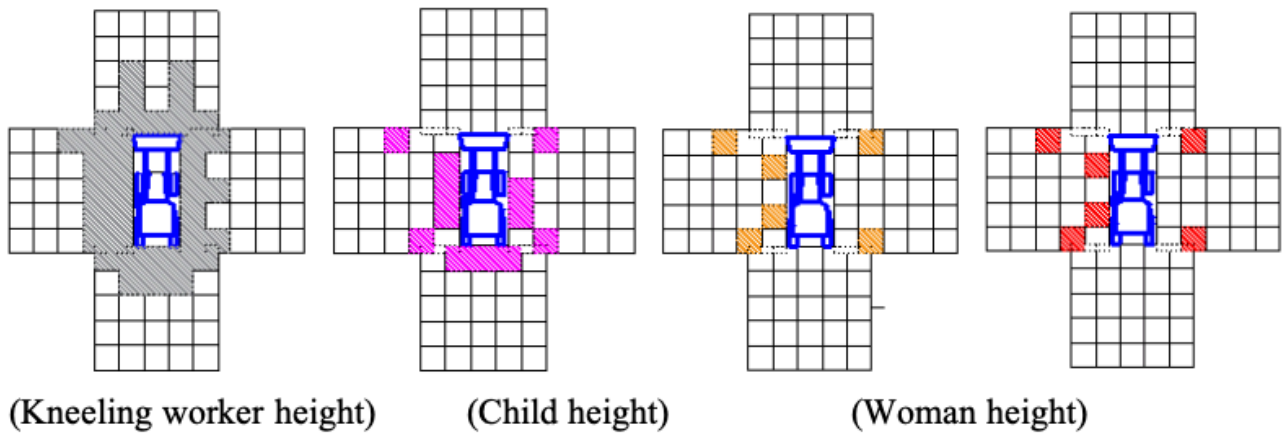


Fig. 6 Visibility of four testing heights around the T1 for an operator of 5th percentile slumped sitting level, without the passenger seated beside the operator.

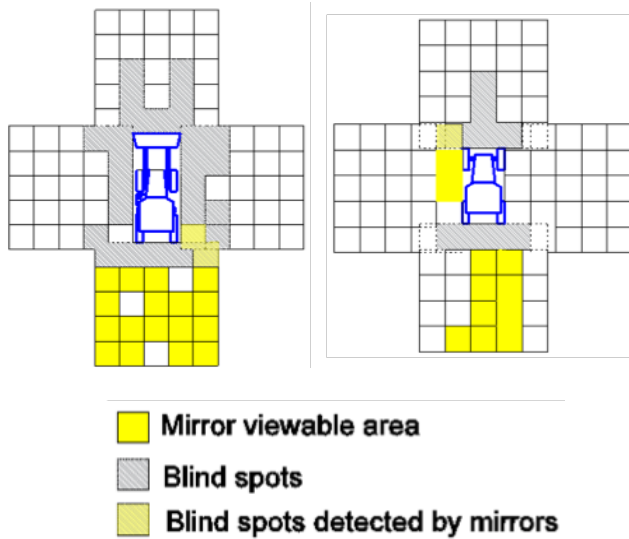


Fig. 7. Area detected by rear-view for T1(left) and for T2 (right).



Fig. 8 Locations of recommended cameras for T1.



Fig. 9. Locations of recommended cameras for T2.

(i.e., erect and slumped) were considered (Table 3). The slumped-posture eye level was determined as the vertical distance from the seat pan to the corner of the subject's eyes (Behara and Das 2012), with the subject sitting slumped on the seat.

Tools used to determine eye level included a camera tripod, a measuring tape and a level (Fig. 5). Setting up the camera at the appropriate eye level consisted of the following steps: 1) choosing a reference point in the center of the operator's seat, with the center pole of the tripod at the reference point, 2) using the measuring tape to adjust the legs to the desired eye level, 3) leveling the tripod to ensure the center pole of the tripod was perpendicular to the ground, and 4) placing the camera on the tripod, and rotating the tripod head allowing the camera to rotate 360° horizontally. In the experiment, the camera was rotated through 360° to simulate the operator's physically turning to view all sectors around the tractor. Images were taken at every 45° of rotation. Images were manually observed to identify the colored markers visible on each pole, enabling the blind spots around the tractors to be identified. In order to determine whether the existing rear-view mirrors were effective in detecting blind spots, the camera was pointed at the rear-view mirror and an image was captured. After the field experiments, all data were input into MS Excel and blind-spot zone plots were drawn using AutoCAD.

**Table 4. Proportion of markers not visible at each marker height tested.**

Tractor	Passenger Present	Marker height	Proportion of Markers Not Visible (%)					
			Sitting Position: Slumped			Sitting Position: Straight		
			5 <sup>th</sup>	50 <sup>th</sup>	95 <sup>th</sup>	5 <sup>th</sup>	50 <sup>th</sup>	95 <sup>th</sup>
T1	No	Kneeling worker	30.1	26.0	25.7	33.6	26.4	23.2
		Child	11.4	12.4	8.3	12.4	11.0	12.4
		Woman	5.2	6.0	4.1	6.2	6.2	6.2
		Man	5.2	6.0	4.1	6.2	6.2	6.2
	Yes	Kneeling worker	36.3	32.1	33.0	41.9	32.6	31.5
		Child	19.7	17.6	11.4	17.6	13.1	16.6
		Woman	9.3	10.4	8.3	11.4	8.3	10.4
		Man	9.3	9.3	7.3	7.3	8.3	10.4
T2	No	Kneeling worker	14.0	10.4	9.6	14.0	10.4	9.6
		Child	1.1	1.1	1.1	1.1	1.1	1.1
		Woman	0	0	0	0	0	0
		Man	0	0	0	0	0	0

## RESULTS AND DISCUSSION

### Blind-spot diagrams

The first objective of this study was achieved by assessing blind spots around the two tractors. The locations of blind spots under different experimental conditions are presented in grid diagrams. These blind-spot diagrams show a top view of the test grids with the tractor at the center of the grids. To simplify the presentation of the operator's visibility, four images were generated separately to describe the locations of blind spots. Different colors were used to indicate blind spots at different bystander heights. The colors are consistent with the tape colors used on the poles at the centre of each cell of the grid. Sample blind spot diagrams for an operator of 5th percentile slumped sitting posture for T1, without a passenger seated in the passenger seat, are provided in Fig. 6. The cells colored grey, pink, orange and red indicate cells that were not visible at the kneeling worker height, standing child height, standing woman height, and standing man height, respectively.

As Fig. 6 depicts, the number of cells that were not visible tended to increase as the marker height decreased. The proportion of markers not visible at each marker height is presented in Table 4 for all experimental conditions. These values can be used to estimate the total blind spot area. The total area covered by the grid around T1 and T2 is 223.97 m<sup>2</sup> and 216.34 m<sup>2</sup>, respectively, after adjusting the area according to the slight overlap that occurred around each tractor. The "blind spot area" for each tractor at any marker height can be calculated as a proportion of the total grid area around that tractor. For example, the area of blind spots, at kneeling worker height around T1 for an operator of 5th percentile slumped sitting posture, without the passenger seated beside the operator, is 67.41 m<sup>2</sup> (223.97 m<sup>2</sup> \* 30.1%).

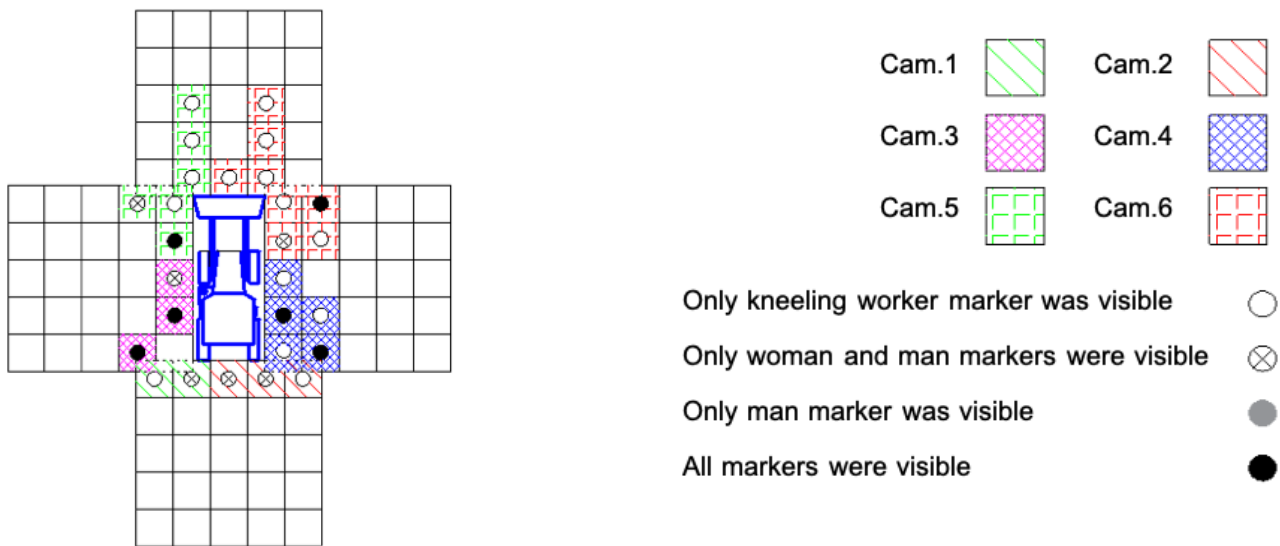
The blind spot area for T1 is greater than the blind spot area around T2. There are several factors that could have contributed to this observation. First, T2 was smaller than T1 and it is typically easier to see around small machines compared to large machines. Features of the cab design are

also important. For example, on the right side there was a blind spot near the front tire because there was a portion of the control panel on the right-hand side which blocked the right-side view. Templeton and Strong (1998) stated that controls should be placed logically and ergonomically in the cab of tractors because sufficient visibility of the surrounding area is critical for operator and bystander safety. Finally, T1 had a front-end loader which created additional obstacles to see around. The passenger seat itself did not cause blind spots, however, when occupied by a passenger, the proportion of markers not visible did increase (Table 4).

Including two distinct sitting postures (i.e., slumped and erect) enabled blind-spot area to be calculated for a greater number of seated eye levels (Table 3). There is insufficient evidence to suggest that the results for slumped posture are different from erect posture based on statistical analysis using a paired t-test (alpha = 0.05). In future studies, there is no need to consider slumped posture.

### Performance of mirrors

T1 had two extended arm mirrors outside of the cab (one on each side of the tractor) and one mirror inside the cab. T2 had only two mirrors inside the cab. One was located in the front right corner and the other in the rear left corner. During the experiments, the mirrors remained in the position selected by the tractor owner (i.e., they were not adjusted by the researchers). The purpose of this phase of the research was to determine whether the identified blind spots would be visible with the use of the rear-view mirrors present on the tractors. Although images were taken for six eye level positions (i.e., 5th, 50th and 95th percentile sitting height; erect and slumped posture), there was virtually no variation in observed results. The results for each tractor under 50th percentile (slumped posture eye level) are illustrated below (Fig. 7). The diagrams show that the mirrors cover only a small number of the blind spots. There were still a substantial number of blind spots that could not be eliminated solely with the assistance of mirrors. Therefore, a blind-spot monitoring system composed solely of the existing rear-view mirrors is inadequate.



**Fig. 10. Detection zone for each camera for T1.**

### Summary

The experiments identified the blind spots around two tractors. Several highlights from the results are:

- A number of aspects of the tractor’s design (i.e., size, design of control panel, mounted implements) affected visibility around the tractor. T1 had more blind spots than the smaller T2. Positioning of controls on the right side of the cab blocked some regions of the grid.
- The operator’s eye level affected the visibility of the operator. In general, higher eye levels had higher levels of visibility. The differences between straight sitting positions and slumped sitting positions were not found to be significantly different. In future studies, it would not be necessary to consider the slumped sitting posture.
- The seated passenger blocked the view of the operator and caused the number of blind spots to increase.
- The mirrors provided by the manufacturer were not adequate to monitor blind spots around the tractors; better technologies are required to fully monitor all of the blind spots that exist around tractors.

### BLIND-SPOT MONITORING SYSTEM DESIGN

#### Proposed design

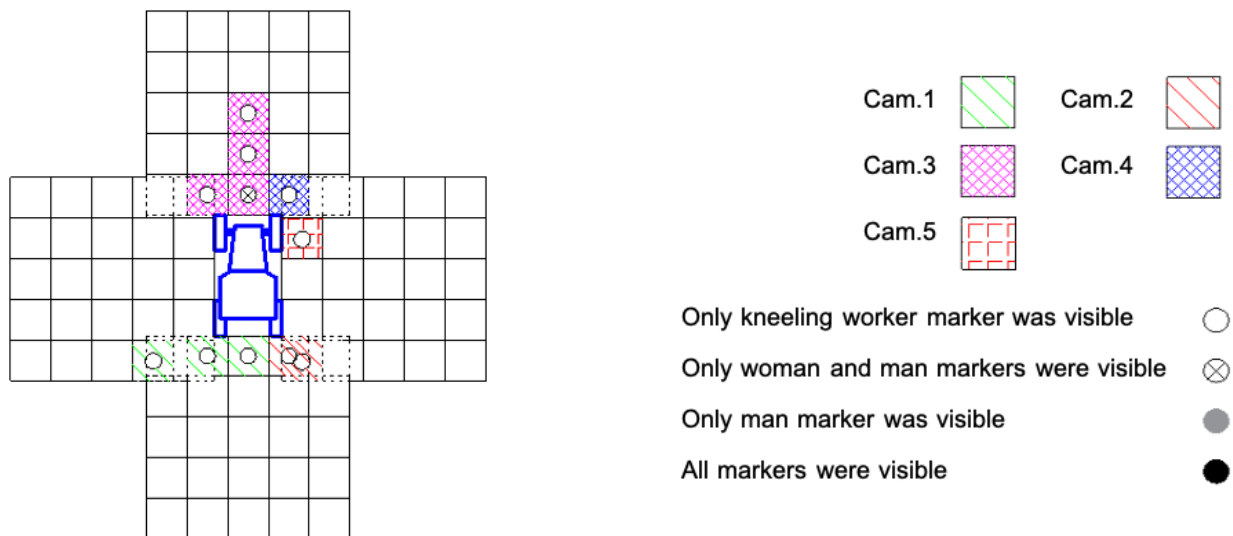
Our experimental results confirmed that the existing rear-view mirrors are inadequate as a blind-spot monitoring system. Camera-based systems are already being used by farmers to monitor difficult-to-see machine components, therefore, it was hypothesized that acceptance of a camera-based blind-spot monitoring system would be high. Furthermore, camera-based systems are proven to be an effective assistive technology for monitoring blind spots (Ruff 2001). Finally, cameras can be mounted in any imaginable location (Ehlers and Field 2014). For these reasons, the camera was the technology selected for development of a blind-spot monitoring system for tractors.

According to blind spot locations identified for the tractors, cameras were placed to eliminate all the blind spots. Field experiments were conducted to test the effectiveness of the cameras. Different mounting positions were tried. The camera positions identified in Fig. 8 and Fig. 9 yielded the best results according to the trials.

For T1, eight cameras were needed to eliminate all blind spots. The camera locations are indicated in Fig. 8. Cameras 7 and 8 are used to detect blind spots between the bucket and the arm of the front-end loader. The performance of the other cameras is shown in Fig. 10. Different colors in the test grids indicate the detection zone of each camera. For T2, five cameras were needed to eliminate all blind spots (Fig. 9). The blind-spot detection performance of each camera is indicated in Fig. 11.

#### Evaluation of the proposed design

The proposed design could be evaluated based on the four components of the HAAT model. First, the proposed design helped the operator eliminate all the blind spots by placing cameras to detect the blind spots. It achieved the goal of enabling the operator to see the blind spots. However, this system only works well when the operator continuously watches the monitor. Too many cameras providing information may distract the operator, especially when the operator’s primary task is to monitor the operation of the machine to maximize its efficiency. Scanning the environment for individuals who may be present near the machine is not supposed to draw much attention of the operator. Furthermore, based on the location of identified blind spots, some of the cameras needed to be placed near the tires where dust and mud might interfere with the performance of the camera-based system. It may be useful to consider a hybrid blind-spot monitoring system that employs both cameras and proximity sensors. Further investigation of such a system is warranted.



**Fig. 11. Detection zone for each camera for T2.**

In conclusion, it turned out this preliminary design can be improved. The combination of cameras and sensors is recommended for further study. This was also an approach that previous researchers recommended (Mazzae and Garrott 2006; Ruff 2001). The effectiveness and reliability of a hybrid blind-spot monitoring system consisting of both cameras and proximity sensors should be evaluated using field experiments.

### CONTRIBUTIONS

In this study, blind spots were successfully identified around two tractors (one with a front-end loader and one without any attached implement). Blind spot diagrams were produced. These diagrams clearly depicted the locations of the blind spots at different marker heights representing the various groups of people who might be in the proximity of tractors. Knowledge of the locations of the blind spots can be helpful for at least two reasons. Firstly, it provides information on high-risk spots to the operator in order to improve the operator's situation awareness during operation of the machine. Secondly, researchers and manufacturers can use this information to take steps to either develop effective blind-spot monitoring systems or eliminate blind spots through re-design of the machines. This method can be applied to identify blind spots around other types of agricultural machines.

A blind-spot monitoring system composed solely of the existing rear-view mirrors was shown to be inadequate. A blind-spot monitoring system composed solely of cameras might be considered adequate because it is possible to install cameras to provide visual information from all blind spots. However, there would be too many video sources for the operator to watch making a camera-based blind-spot monitoring system unrealistic. We did not investigate the use of a sensor-based blind-spot monitoring system, however, future work should be directed to examination of this technology, either alone or in combination with cameras, as a means of developing a feasible blind-spot monitoring system for agricultural tractors.

### ACKNOWLEDGEMENT

This research was funded by the Natural Sciences and Engineering Research Council of Canada (NSERC).

### REFERENCES

- Behara, D.N. and B. Das. 2012. Structural anthropometric measurements of the Canadian adult population: The fallacy of the “average person” concept. *Theoretical Issues in Ergonomics Science* 13(3): 380–392. <https://doi.org/10.1080/1463922X.2010.505271>
- Canadian Agricultural Injury Reporting. 2016. Agriculture-related fatalities in Canada. Edmonton, Alberta: Injury Prevention Centre, University of Alberta.
- Ehlers, S.G. and W.E. Field. 2014. Assistive viewing technology to improve agricultural safety. ASABE Paper No. 141952332. Montreal, QB: ASABE.
- Ehlers, S.G. and W.E. Field. 2016. Rearward visibility issues related to agricultural tractors and self-propelled machinery: contributing factors, potential solutions. *Journal of Agricultural Safety and Health* 22(1): 47–59. <https://doi.org/10.13031/jash.22.11127>
- Griffith, C.D. and S. Mahadevan. 2011. Inclusion of fatigue effects in human reliability analysis. *Reliability Engineering and System Safety* 96(11): 1437–1447. <https://doi.org/10.13031/jash.22.11127>
- Lee, H., D. Kim and S. Yi. 2013. Horizontally progressive mirror for blind spot detection in automobiles. *Optics Letters* 38(3): 317–319. <https://doi.org/10.1364/OL.38.000317>
- Marshall, R., S. Summerskill, and S. Cook. 2013. Development of a volumetric projection technique for the digital evaluation of field of view. *Ergonomics* 56(9): 1437–1450. <https://doi.org/10.1080/00140139.2013.815805>
- Mazzae, E.N. and W.R. Garrott. 2006. Evaluation of the performance of available backover prevention. United States, National Highway Traffic Safety Administration.

- Rakhra, A.K. and D.D. Mann. 2013. Evaluation of implement monitoring systems. *Journal of Agricultural Safety and Health* 19(1): 51–67. <https://doi.org/10.13031/2013.42542>
- Ruff, T.M. 2001. Monitoring blind spots: a major concern for haul trucks. *Engineering and Mining Journal* 2002(12):17-26.
- Sjoflot, L. 1980. Big mirrors to improve quality tractor driver ' s posture and of work. *Field Studies* (June 1979): 47–55.
- Song, K.T., C.H. Chen, and C.H.C Huang. 2004. Design and experimental study of an ultrasonic sensor system for lateral collision avoidance at low speeds. *IEEE Intelligent Vehicles Symposium* 2004(3): 647–652.
- Steele, J. 2006. Final report blind area study large mining equipment blind area diagrams for selected mining vehicles. Denver, Colorado:United States Department of Labor, Occupational Safety And Health Administration.
- Templeton, D.J. and R.W. Strong. 1998. Essential design considerations for today's tractor cab and a challenge for the future. *American Society of Agricultural Engineers* (22): 1–14.
- Wise, A. 2011. Tracking transit through the use of fmcw radar sensors. *Mass Transit* 37(4): 30–31.