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International Journal of Industrial Ergonomics 34 (2004) 155–165
International Journal of Industrial Ergonomics
www.elsevier.com/locate/ergon

An initial farmer evaluation of a NIOSH AutoROPS prototype

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Received 19 February 2002; received in revised form 23 February 2004; accepted 30 March 2004

Abstract

This evaluation study is a part of the NIOSH safety engineering research program on developing new types of rollover protective structures (ROPS) for farm tractors. Each year hundreds of people die as a result of agricultural tractor rollovers. The use of rollover protective structures (ROPS), along with seat belts, is the best-known method for reducing the frequency of these fatalities. One impediment to ROPS use, however, is low clearance situations, such as orchards and animal confinement buildings. Adjustable ROPS have been developed by the agricultural equipment industry to address the issue of low clearance situations. If these adjustable ROPS are used properly, they are quite effective systems. The problem is that they require the operator to take an active role in making sure the ROPS is properly adjusted when not in a low clearance situation—a task some operators may not consistently perform. To address the need for ROPS that are easily adapted to low clearance situations, NIOSH researchers have developed an automatically deploying, telescoping ROPS (AutoROPS). The objective of this study was to get an initial measurement of the usability of the NIOSH AutoROPS among tractor operators who would be probable users of this new technology. The study was not intended to evaluate all of the factors in the use of the AutoROPS. This study only examines whether farmers had an initial positive interest in this new concept for preventing tractor rollover-related fatalities. The procedure for comparing the AutoROPS prototype with a foldable ROPS was of a general nature. What was being sought were general opinions about the concept. A cost comparison was not a factor in this study. However, cost-effectiveness is an important criterion in the NIOSH design.

The farmer group was of the opinion that the AutoROPS deployment is more effective than the manual ROPS alternative ($p<0.0001$) and that the protection effectiveness provided by AutoROPS will be superior to the protection provided by manual ROPS ($p<0.01$). Of great prevention importance was the increase in interest in purchasing a tractor with an AutoROPS compared to purchasing a tractor with manual ROPS ($p<0.0001$). This result indicates that this new technology may successfully achieve wide use on the farm. Farmer opinions indicate the need for further design work to improve seating restraint and the method for lowering the structure. Based on the results of this study, NIOSH will be able to make recommendations to companies interested in developing and manufacturing an AutoROPS for the farm workplace.

Keywords: ROPS; Passive protection; Evaluation; Design; Usability

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doi:10.1016/j.ergon.2004.03.007

1. Introduction

Tractor overturns are by far the leading cause of fatal injuries in the agricultural industry (Myers and Snyder, 1993). Rollover protective structure (ROPS) use is increasing (Zwerling et al., 1997), but the number of overturn-related fatalities per year has not been declining significantly (NSC, 1997). There are still some tasks, such as orchard work and barn cleaning, that cannot be performed with a rigid ROPS mounted to the tractor. Innovation is needed to increase the use of lifesaving ROPS within this portion of the tractor population. Manually adjustable ROPS are available, but passive protection, with ROPS that can automatically move from a lowered to a raised configuration, would improve the safety of tractor work that includes low-clearance operation.

Adjustable ROPS have been developed by the agricultural equipment industry to address the issue of low clearance situations (Figs. 1 and 2). If these adjustable ROPS are used properly, they are quite effective systems. The problem is that they require the operator to take an active role in making sure the ROPS is properly adjusted when not in a low clearance situation—a task some operators may not consistently perform.

Fig. 1. Manually adjusted ROPS down.

Fig. 2. Manually adjusted ROPS up.

To address the need for ROPS that are easily adapted to low clearance situations, NIOSH researchers have developed an automatically deploying, telescoping ROPS (AutoROPS) (Figs. 3–6). The newly conceived NIOSH AutoROPS (Powers, et al., 2001) is signaled to automatically raise to its protective position before the overturning tractor contacts the ground.

A unique aspect of the NIOSH AutoROPS is that it is a passive device, which has the potential to be more protective for the tractor operator because it does not require any action on their part for the ROPS to be effective. The passive nature of the AutoROPS should make it more appealing to farmers. The AutoROPS is normally latched in its lowered position for day-to-day use. If a rollover condition is detected by the sensor, the retracted ROPS will automatically deploy and lock in the full upright position before ground contact. Static load testing and field upset tests of the AutoROPS have been conducted in accordance with SAE Standard J2194, 1997. Additionally, timed trials of the AutoROPS deployment mechanism have been completed. The results of these tests show that the

Fig. 3. AutoROPS down.

Fig. 4. AutoROPS deployed.

AutoROPS is a viable device that could be used to help further reduce deaths due to tractor rollovers.

2. Objective

The objective of this study was to obtain an initial assessment of the acceptability of an AutoROPS prototype relative to a manually adjustable ROPS among a sample of typical potential users of the new technology. The objective was to be achieved by obtaining potential user responses to rating questions about how the AutoROPS functions, how an AutoROPS-equipped tractor operates in simple tasks, and preferences in how the AutoROPS should be designed. The overall research question was: will

Fig. 5. Tractor approaching rollover pit with AutoROPS in low-profile position.

potential users of the AutoROPS technology, observing specific AutoROPS functions and operating an AutoROPS-equipped tractor, respond in

Fig. 6. As the tractor rolls over the AutoROPS deploys (raises).

a more strongly agreeable way to the AutoROPS than to manually adjustable ROPS? And, more to the point of getting this intervention into the workplace, would potential users of AutoROPS-equipped tractors be more inclined to procure an AutoROPS-equipped tractor and use it correctly than a tractor equipped with manually adjustable ROPS?

3. Study design

To answer the main research question, the following questions were addressed:

- After having observed AutoROPS deployments, does the device appear to provide a more effective way than manually adjusted ROPS to prevent fatalities in tractor rollover events?
- After having performed the reset (relatching) of the AutoROPS, is this task perceived as one that is more acceptable than manually adjusted ROPS in normal use of the device?
- After having initiated a deployment manually, is this task perceived as one that is more acceptable than manually adjusted ROPS in normal use of the device?
- Is required use of a seatbelt perceived as more acceptable in normal use of the AutoROPS than manually adjusted ROPS?
- After having operated the AutoROPS-equipped tractor on level ground, is vision not restricted behind and therefore perceived as more acceptable than manually adjusted ROPS?
- Is there a perception that operating an AutoROPS-equipped tractor would be safer than operating the manually adjustable ROPS-equipped tractor?
- If a new tractor were being purchased, would an AutoROPS-equipped tractor be of more positive interest than a manually adjusted ROPS-equipped tractor?

Numerous studies have used rating scales to evaluate the preferences of potential users for a variety of consumer and occupational safety devices (O'Borne and Clarke, 1975). Since categorical rating data is nonparametric in nature, the criteria upon which sample size is determined is desired power and expected rating distributions change between treatments. The desired power for this study is 0.80. Previous research studied preference ratings for various features in the design of manually adjustable ROPS (Etherton, 1995). In that study, there was a strong tendency toward neutral ratings (60%) with the other four rating levels being about equal (10% each).

Since this study was intended to see if there is a clear preference for the AutoROPS features over those for manually adjustable ROPS, the difference to be detected was large and the sample size was relatively small. The categorical responses on each of the seven design features were:

[strongly disagree; disagree; neutral; agree; strongly agree].

The preference responses for the features on the manually adjustable ROPS in this study were expected to follow the distribution seen in the previous study:

$$[0.1, 0.1, 0.6, 0.1, 0.1].$$

The preference criteria that were being tested against were whether there is a strong preference (50%) of the sample strongly agreeing that they like the design features of the AutoROPS and few (5%) strongly disliking them:

$$[0.05, 0.1, 0.1, 0.25, 0.5].$$

An SAS procedure for computing sample size for one-sided Wilcoxon tests (O'Brien, 1998) was applied for a statistical power equal to 0.8 and significance level equal to 0.05. The result was that 32 participants needed to be sampled for this study.

4. Apparatus and test instruments

4.1. Ford 4600 tractor equipped with an AutoROPS

The tractor was manufactured in 1976 and used in agriculture until it was purchased in used condition in 1999 by NIOSH for this project. The regular tractor seat was removed by NIOSH researchers and a special seat was installed that has a high back (above head level) and a 4-point seatbelt. This seat arrangement prevents the participant from getting any part of their body in the path of an unexpected AutoROPS deployment. In all other respects, the tractor was in normal-operating condition for farm work.

The NIOSH AutoROPS consists of two subsystems. The first is a retractable ROPS that is normally mounted to the tractor axle and latched in its lowered position for day-to-day use. The mechanisms are described in a paper by McKenzie and Etherton (2002). The second subsystem is a sensor that monitors the operating angle and rate of roll on two axes of the tractor (Powers, et al., 2001). If an overturn condition is detected by the sensor, the retracted ROPS will deploy and lock in the full upright position before ground contact. The AutoROPS has a 14° layback angle.

A manual winch was used to pull the upper structure into its lowered and latched position. The manual winch had a flat fiber strap that passed up and over the structure. A push button remote control was configured that could be used to deploy the AutoROPS from a safe distance. This remote control was used to show participants what a deployment looked and sounded like and to let them actually trigger a deployment themselves. Before the participant drove the tractor, the remote control was disconnected and the rollover sensor was reconnected.

4.1.1. Safety features that were on the tractor and AutoROPS for this study

Special measures were taken to ensure that participants were protected from inadvertent deployment of this AutoROPS prototype. This potential hazard is recognized for this prototype. Work is in progress to control this potential hazard.

Four-point seat restraint: In operating the AutoROPS-equipped tractor, a struck-by hazard area can exist in the path of the upper structure if it inadvertently deploys. The AutoROPS is designed to not deploy during tractor operation on level ground and the test procedure did not call for deployment during the tractor operation phase of the test. An injury could occur if the participant reached behind the top of the seat and was struck by the inadvertently deploying AutoROPS. The risk of such a hazard was reduced to a negligible level by constraining the participant in a 4-point seat belt that restrained them from reaching the potential hazard at any time during the test. It was understood that this seat and seatbelt design might not be acceptable for all kinds of low-clearance tractor operations. Making sure that this inadvertent deployment hazard is effectively controlled for all tasks performed by tractor operators will be the subject of future research. Only very simple tasks of driving forward and backing up on level ground were performed in this study.

Remote-control engine kill switch: While operating the AutoROPS-equipped tractor, a collision hazard existed if the operator, for some unknown reason, decided to drive the tractor in a direction and at a speed other than the planned course at a slow speed. This hazard was reduced to a negligible level by installing a remote-control engine kill switch on the tractor and providing the researcher with a control button that could be used to stop the tractor immediately if such an incident was observed by the researcher.

4.2. Low-profile tractor equipped with a foldable ROPS

Two low profile farm tractors (one for each test site) were rented from local farmers. These tractors were selected for the study because they had a

manually adjustable (foldable) ROPS as original equipment. Participants only raised and lowered the hinged ROPS on this tractor and did not operate it. The two tractors were not identical because two identical tractors were not available. They were similar in that they both had a foldable ROPS that required manual exertion to raise and lower.

4.3. Data collection instruments

The study data were collected on short rating instruments (paper forms) for documenting the perceptions of the participants as well as qualitative comments about their perceptions. For each of the questions the participants were asked to make a numerical rating (judgment) from a uniform 5-point Likert scale (1 = strongly disagree; 5 = strongly agree). The study design also provided for collecting reference data on manually adjustable ROPS using a questionnaire that had been validated for variance calculations in the statistical design (Etherton, 1995).

5. Participants

Thirty-two healthy participants with experience operating farm tractors in low-clearance tasks were recruited for this study. Participants were recruited by the Farm Bureau organizations from among the agriculture community in Grant and Berkely Counties, West Virginia.

The farmers ranged in age from 25 to 77 with most (81.3%) being less than 55 years old. Most (75%) were full time farmers. A few (12.5%) had actually survived a tractor rollover. Access to low buildings was the most prominent low-clearance problem (87.6%). Most (56.3%) needed such access on a monthly basis. Seatbelt use was fairly good (62.5%). Because of experience and various farm safety programs, 84.4% of the group knew that staying on a ROPS-equipped tractor is safer than trying to jump clear of an overturning tractor. This group seemed inclined to give new technology a try, with 56.3% responding that they were not inclined to wait long to get technology that would improve their farming operations. The types of farming conducted by these participants is shown in Table 1, with poultry operations (40.6%) being most prominent. Although a strong effort was made to recruit orchardists, the timing for the study unfortunately coincided with a time when many were busy pruning trees. Most of the farmers in this study are now using tractors without ROPS (90.6%). Table 2 indicates that they have numerous such tractors. About one-fifth of this group (21.9%) had removed ROPS from their tractors. All of those interviewed had over 10 years experience operating tractors.

Table 1
Participants' type of farming

Type of farm	Percent
Poultry	40.6
Beef	25.0
Dairy	21.9
Orchard	9.4
Crop	3.1

Table 2
Number of tractors without ROPS on participants' farms

Tractors without ROPS	Percent
0	9.4
1	25.0
2	28.1
3	25.0
4	12.5

The potential audience for the study is the agricultural community and more specifically manufacturers, purchasers and users of tractors that are used for low-clearance tasks, such as in orchards and animal confinement operations. The participation of tractor operators is considered vital to the future introduction of AutoROPS into the farm tractor market.

6. Method

A uniform procedure was followed for the evaluation made by each participating tractor operator. The researchers introduced themselves

and gave a verbal explanation of the purpose of the study. Then, participants read and signed the informed consent document. They were then shown 2 videoclips; a rearward and a sideways tractor rollover test with the AutoROPS deploying in each test. With these preliminary steps completed, the participants performed a set of tasks. Each task was explained to them before they performed it.

(1) *Operate and rate the manually adjustable ROPS*. The participant raised and lowered a manually adjustable ROPS. They were then read a list of seven questions about the design and use of manually adjustable ROPS. They were instructed that answers were to be how they would rate each of the seven design features. The rating choices were "strongly disagree", "disagree", "neutral", "agree", "strongly agree".
(2) *Walk-around observation of the AutoROPS-equipped tractor*. The researcher walked with the participant around the AutoROPS-equipped tractor pointing out AutoROPS features and answering questions.
(3) *Deployment demonstration*. The researcher then demonstrated an actual deployment of the AutoROPS using a push button several feet from the tractor. Then, the participant observed as the researchers reset the AutoROPS using the manual winch.
(4) *Participant initiated deployment*. The participant stood several feet from the tractor and pushed a button that deployed the AutoROPS. They then reset the AutoROPS using the manual winch.
(5) *Driving the tractor*. Next, the participant experienced what it was like to operate a tractor equipped with an AutoROPS. They were seatbelted into the tractor seat and instructed in the safe operation of the tractor. Then, the participant drove the AutoROPS-equipped tractor at low speed around a course about 400 yards in length. The course was marked by bright orange traffic cones. They were securely seatbelted at all times while driving. The participant backed the tractor up a few feet to put the hitch in-line with a target cone that the researcher placed behind the tractor; a simulated hitching task (Fig. 7).
(6) *Rate the AutoROPS*. Finally, they were read a list of seven questions about the design and use of the AutoROPS. They were instructed to rate each of the seven design features. The rating choices were "strongly disagree", "disagree", "neutral", "agree", "strongly agree" They were also encouraged to comment on things they liked or did not like about the design of the AutoROPS.

Fig. 7. Driving the AutoROPS-equipped tractor.

It was deemed unlikely that medical emergencies would result from the tasks specified in the study protocol, especially since the participants were healthy participants. However, an emergency plan was developed to address emergency situations. This included the addresses and phone numbers of hospitals in the Berkeley County and Grant County, WV area. Appropriate first-aid medical supplies were also taken to the test site.

7. Results

The marginal homogeneity test for ordered table (exact test) was applied to data from the two sets (manually adjustable ROPS and AutoROPS) for the seven categorical-response questions (Table 3). Bar charts (Figs. 8–14) show the distribution of responses on the seven questions.

Table 3
Testing hypothesis and p-value of rating comparisons between manual and AutoROPS

Rating comparison manual vs. AutoROPS	p-Value (one-sided) marginal homogeneity test[a]
Deployment effectiveness	<0.0001
Resetting effectiveness	0.1417
Raising the ROPS	<0.0001
Seatbelt usage	0.0110
Vision not restricted	0.1130
Protection effectiveness	0.0029
Purchasing decision	<0.0001

[a] Marginal homogeneity test for ordered table (Exact test): H_0: Probability that the ratings are the same for manual and AutoROPS vs. H_a: Probability that the ratings for manual ROPS are lower than for AutoROPS.

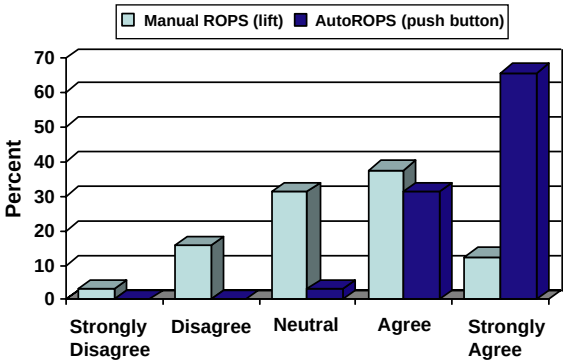

Fig. 10. Responses to "The method of raising when wanted is acceptable."

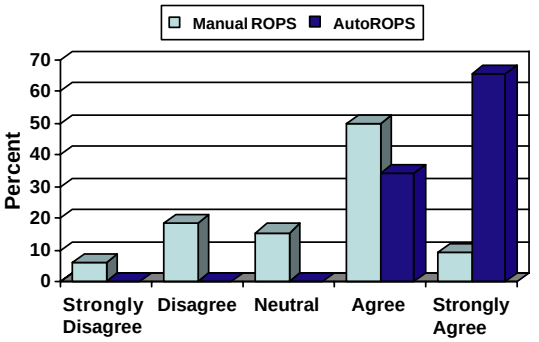

Fig. 8. Responses to "The deployment procedure looks effective."

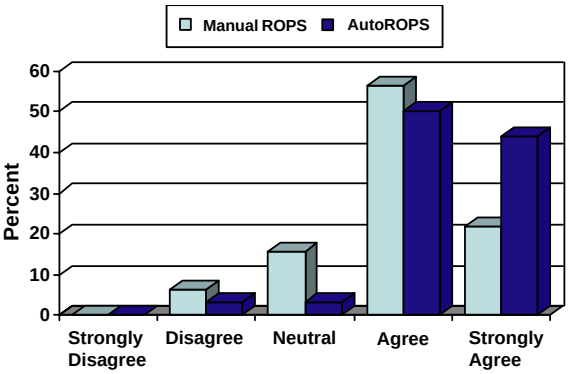

Fig. 11. Responses to "Can do normal tractor tasks while seatbelted."

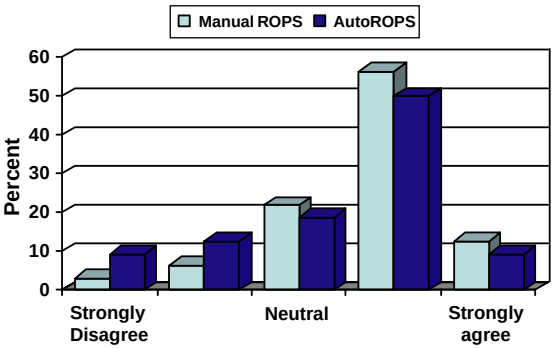

Fig. 9. Responses to "The method of lowering is acceptable."

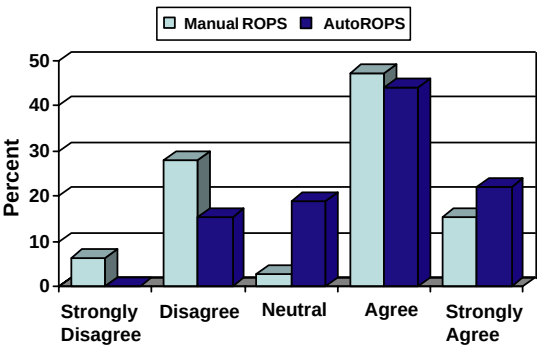

Fig. 12. Responses to "Does not restrict vision behind."

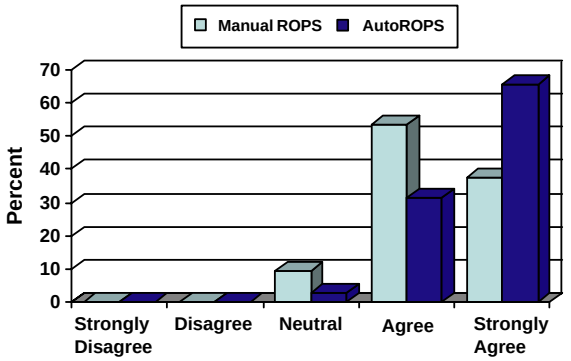

Fig. 13. Responses to "Protection in case of a rollover appears to be effective."

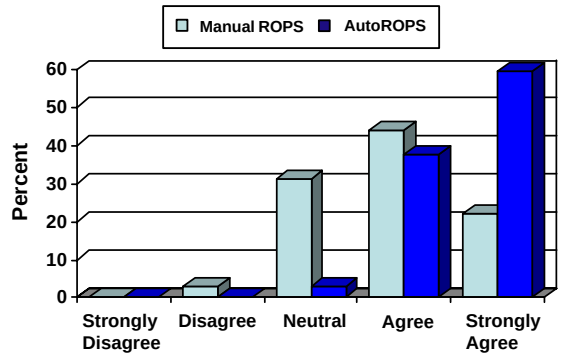

Fig. 14. Responses to "A new tractor so-equipped would be of positive interest."

7.1. Rating of deployment effectiveness

The farmer group was strongly of the opinion that the AutoROPS deployment is more effective than the manual ROPS alternative ($p<0.0001$). Fig. 8 shows participants' perceptions of manually adjustable ROPS compared with the AutoROPS with respect to how the devices are designed to move or be moved from its lowered position to its deployed position as a direct precursor to a rollover incident.

7.2. Rating of resetting effectiveness

Fig. 9 shows participants' perceptions of manually adjustable ROPS compared with the AutoROPS with respect to how the devices are designed to be lowered and relatched into their down position. The use of the manual winch to reset the AutoROPS was not seen as a significant improvement over the method for resetting the manual ROPS ($p = 0.1417$).

7.3. Rating of raising the ROPS by manual action

Fig. 10 shows participants' perceptions of manually adjustable ROPS compared with the AutoROPS with respect to how the devices are designed to be raised at a time that the operator feels is convenient (for conducting normal operations with the ROPS up). The pushbutton method for raising the AutoROPS whenever desired was seen as significantly better than the manual method of raising the current ROPS design ($p<0.0001$).

7.4. Rating of using a seatbelt

Opinions about wearing a seatbelt were somewhat more accepting ($p = 0.011$) with the AutoROPS than with the manual ROPS. Fig. 11 shows participants' perceptions of manually adjustable ROPS compared with the AutoROPS with respect to how the devices are designed given that a seatbelt must be worn, when the ROPS is up, for the ROPS to be effective. The 4-point harness was not being rated; only the need to wear a seatbelt for either ROPS to be fully effective.

7.5. Rating of restricted vision behind tractor

Fig. 12 shows participants' perceptions of manually adjustable ROPS compared with the AutoROPS with respect to how the devices are designed and their effect on not restricting vision behind while operating the tractor. The sample of regular tractor operators felt that the AutoROPS would not be significantly less restrictive for vision behind than the manual ROPS ($p = 0.113$).

7.6. Rating of overall protection effectiveness

The group felt that the protection effectiveness provided by AutoROPS will be superior to the protection provided by manual ROPS ($p<0.01$). Fig. 13 shows participants' perceptions of

manually adjustable ROPS compared with the AutoROPS with respect to how the devices are designed to achieve their overall purpose of reducing the likelihood of a rollover-related fatality.

7.7. Rating of purchasing decision effectiveness

A significant increase was observed in interest in purchasing a tractor with an AutoROPS compared to purchasing a tractor with manual ROPS ($p<0.0001$). Fig. 14 shows participants' current perceptions of manually adjustable ROPS compared with the AutoROPS with respect to how the devices' designs impact willingness to purchase a tractor equipped with that type of ROPS. The question was asked in such a way that the cost of the ROPS itself was not a factor.

General comments on the AutoROPS included recommendations that the final design be well sealed against the dust and corrosive materials that are common factors in the use of tractors for cleaning animal confinement areas. Safeguarding against inadvertent contact with an unexpectedly released AutoROPS was an additional consideration. This would include a design for seating restraints that is not as restrictive as the 4-point harness used in this evaluation.

8. Discussion and conclusions

The results of this evaluation provide an indication that the AutoROPS may be successfully introduced into the agricultural equipment marketplace. Although some features remain to be improved, the overall reaction of farmers to this technology was positive. The farmer group was of the opinion that the AutoROPS deployment is more effective than the manual ROPS alternative and that the protection effectiveness provided by AutoROPS will be superior to the protection provided by manual ROPS. Of great prevention importance was the clear increase in interest in purchasing a tractor with an AutoROPS compared to purchasing a tractor with manual ROPS.

Concerning particular parts of the AutoROPS, alternatives to the manual winch to reset the AutoROPS should be considered. A lighter structure that could be manually reset or hydraulic power for resetting are possibilities. The pushbutton method for raising the AutoROPS whenever desired was seen as significantly better than the manual method of raising the current ROPS design. A system that includes a keyed selection switch to guard against inadvertent contact with the deployment button will be considered. Although this sample of regular tractor operators felt that the AutoROPS would not be significantly less restrictive for vision behind than the manual ROPS, further design work could be performed to improve lines-of-sight behind the tractor.

A priority in getting this device ready for general use is to ensure that the final design is well-sealed against the dust and corrosive materials that are common factors in the use of tractors for cleaning animal confinement areas. Safeguarding against inadvertent contact with an unexpectedly released AutoROPS is also a design priority. Design improvements are needed to keep hands and arms away from the top of the lowered AutoROPS. These improvements could be presence sensing devices or surfaces that do not permit holding onto the crossbar. Designing seating restraints that make reaching over or leaning over the crossbar difficult need to be considered as alternatives to the 4-point harness used in this evaluation. Cost-effective design will obviously be important.

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