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ASHCA/NIOSH CONFERENCE: PANEL PRESENTATION

Tractors and Rollover Protection in the United States

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ABSTRACT. There are approximately 4.2 million tractors on farms and ranches across the United States. The average age of tractors is over 25 years and some of the oldest models are the most popular. Older tractors are less safe than newer tractors, and many older tractors are operated by individuals with increased risk of being injured or killed on a tractor. A key tractor safety device, a rollover protective structure (ROPS), is missing from most tractors manufactured before 1985. Data from the US Department of Labor's Census of Fatal Occupational Injuries (CFOI) suggest that the production agriculture sector accounts for approximately 70.3% of the 3299 work deaths in the Agriculture, Forestry, and Fishing industry between 2003 and 2007. Nearly 900 of these incidents involve farm tractors and of these, approximately 43% were from tractor overturns. Efforts to reduce both the number of tractor overturn fatalities and injuries have been underway for years. These efforts primarily encompass worker education/training programs and activities, ROPS design and engineering applications, and research on more effective ways of encouraging tractor owners to retrofit their older tractors with ROPS. This paper reviews various approaches available to reduce the fatalities, serious injuries, and economic burden associated with tractor overturns. Past and current efforts to promote ROPS in the United States and in other countries, current safe tractor operations education and training programs, and ROPS-related safety engineering projects are discussed. Recommendations for advancing safe tractor operation and the number of tractors protected by ROPS are given. This review was prepared for the Agricultural Safety and Health Council of America/National Institute for Occupational Safety and Health conference, "Be Safe, Be Profitable: Protecting Workers in Agriculture," January 2010.

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INTRODUCTION

Production agriculture, or farming, has long been recognized as one of the most hazardous industries in the United States.¹⁻³ Between 1992 and 2005, 7571 farmers and farm workers died from injuries sustained while performing farm work. The average annual fatality rate for this time period was 26 deaths per 100,000 workers.³ During this same time period, the leading cause of occupational fatalities on US farms were farm tractors (37%), other machinery (18%), and trucks (10%). Of the 2795 tractor related deaths, 1411 were due to tractor overturns.

Agricultural tractor overturn deaths have been an identified problem since the 1920s⁴ and have been a public health concern for decades.⁵⁻⁷ Numerous studies on farm-related fatalities have continued to identify tractor overturns as a common cause of fatal occupational injury for farmers and farm workers.⁸⁻¹⁰ Factors associated with increased risk of overturn deaths include older farmers, crop farmers, farm owners/operators, geographic location, and older farm tractors.¹¹⁻¹⁴ Fatality statistics for the years 2003 through 2007 for all tractor-related deaths and some of the most common risk factors for these deaths are provided in Table 1. Fatality statistics

TABLE 1. Agricultural Production Work-Related Tractor Deaths by Type of Event, 2003–2007^a

Categorical variable	All tractor deaths		Tractor overturns		Tractor runovers		Other tractor events	
	Deaths ^b	Rate ^c	Deaths ^b	Rate ^c	Deaths ^b	Rate ^c	Deaths ^b	Rate ^c
Year								
2003	207	11.1	100	5.4	58	3.1	49	2.6
2004	168	9.2	81	4.5	53	2.9	34	1.9
2005	178	9.7	73	4.0	56	3.0	49	2.7
2006	151	8.3	65	3.6	46	2.5	40	2.2
2007	128	7.3	62	3.5	37	2.1	29	1.7
Type of farm								
Crop	673	15.1	319	7.2	198	4.5	156	3.5
Livestock	159	3.4	62	1.3	52	1.1	45	1.0
Age group								
<25 years	40	3.6	22	2.0	9	0.8	9	0.8
25–34 years	36	2.6	13	0.9	11	0.8	12	0.9
35–44 years	69	4.1	31	1.8	18	1.1	20	1.2
45–54 years	109	5.7	58	3.1	29	1.5	22	1.2
55–64 years	150	9.6	78	5.0	36	2.3	36	2.3
65–74 years	210	21.2	99	10.0	64	6.5	47	4.7
75 years and older	218	48.5	80	17.8	83	18.5	55	12.2
Relation to farm								
Family	716	14.8	341	7.1	213	4.4	162	3.4
Hired	114	2.7	40	0.9	37	0.9	37	0.9
Region								
Northeast	61	7.8	25	3.2	21	2.7	15	1.9
Midwest	469	16.1	222	7.6	136	4.7	111	3.8
South	227	7.7	101	3.4	74	2.5	52	1.8
West	75	3.1	33	1.3	19	0.8	23	0.9
Total	832	9.2	381	4.2	250	2.7	201	2.2

^aThis research was conducted with restricted access to BLS CFI data. Rates calculated by NIOSH may differ from those published by BLS. The views expressed here do not necessarily reflect the views of the BLS.

^bCategories may not add to the total because of cells not meeting BLS reporting requirements.

^cDeaths per 100,000 Workers.

were derived from the Bureau of Labor Statistics (BLS) Census of Fatal Occupational Injuries (CFOI).¹⁵ The denominator used to derive rates for these tractor-related deaths per 100,000 workers was the BLS Current Population Survey.¹⁶

A variety of approaches have the potential to impact these tractor overturn injuries, both fatal and nonfatal. These will be discussed in the following sections. The effectiveness of each as an injury/death intervention will be assessed. As will be seen, with the continuing trend toward greater prevalence of ROPS on farm tractors, it may be anticipated that significant impact on injury/death rates could occur in the next two decades. An “effective” intervention is one that might be anticipated to shorten this time period.

ROLLOVER PROTECTIVE STRUCTURES PREVALENCE

A widely accepted prevention strategy for overturn fatalities is the use of a rollover protective structure (ROPS). ROPS come in various designs, but essentially are roll bars or cabs developed to provide a protective zone for the tractor operator in the event of a tractor overturn. The tractor operator should use a seatbelt in conjunction with a ROPS in order to remain inside the protective zone during an overturn.¹⁷ The effectiveness of ROPS and seatbelts has been well documented.^{18–20} The National Institute for Occupational Safety and Health (NIOSH) has estimated that fatality rates due to tractor overturns could be reduced by a minimum of 71% if all tractors were equipped with ROPS in the United States.²¹

Outside the United States

ROPS on tractors are much more common in Europe and Australia. For example, Sweden used a combination of financial incentives and legislation to significantly reduce its rate of overturn fatalities. In a study conducted by Thelin from the period 1957 to 1986 these measures reduced fatalities from 17 to 0.3 deaths per 100,000 tractors.²² Using a similar combination

of incentives and legislation Denmark and Germany have reduced their overturn rates from 30 to 2 deaths per 100,000 tractors in Denmark and 6.7 to 1.3 deaths per 100,000 tractors in West Germany. In these countries the increased rates of tractor protection and decreased fatalities were accomplished primarily through phased-in legislative mandates.^{22,23} In Australia a more recent effort has succeeded in reducing the proportion of unprotected tractors from 24% to 7%.²⁴ A voluntary effort and less expensive ROPS designs are currently being explored in Canada.

United States

Recent studies have shown that the prevalence of ROPS on farm tractors has been steadily increasing since the 1990s, with the percentage of ROPS-equipped tractors used on US farms increasing from 38% in 1993 up to 59% in 2006.^{25–27} The steady increase in the prevalence of ROPS-equipped tractors has resulted in a modest but statistically significant decrease in tractor overturn-related fatality rates in the United States between 1992 and 2007.¹⁴ However, the decrease in overturn fatality rates was not uniform across the United States. The Northeastern and Southern regions of the United States show the most significant decreases in tractor overturn-related fatalities, whereas the Midwest region showed a statistically insignificant increasing overturn rate. Of note, the significant decreases in overturn fatality rates corresponded to the two regions that had the greatest increase in ROPS prevalence rates.²⁸

Although these increases in ROPS prevalence are encouraging, studies from Europe suggest that ROPS usage needs to exceed 75% for the number of overturn fatalities to approach zero.^{22,23} Currently, there are about 1.7 million tractors in use on US farms that are not equipped with ROPS.²⁶ Based on the number of overturn deaths in the United States (Table 1) and the number of non-ROPS tractors in use on US farms, the 2002–2007 tractor-based fatality rate in the United States was 4.5 deaths per 100,000 non-ROPS tractors. Of these unprotected tractors, an estimated 805,000 units were manufactured prior to 1965, with some tractors

having been manufactured as long ago as the 1930s.²⁷ As with the overturn fatality statistics, operator age has been identified as a strong risk factor for low ROPS prevalence rates. Older farmers are identified as the group most likely to operate tractors without ROPS.^{25,27,29} Other factors related to a low proportion of ROPS on farms are farms with low annual value of sales; farms that are operated on a part-time basis; farms with small acreages; farms located in the Northeast and Midwest sections of the United States; and farms without hired farm workers.^{25,27,29,30} Based upon these data, it is apparent that although ROPS represent an effective tractor overturn intervention, the impact of ROPS in the United States is limited by relatively low prevalence.

Over the years, there have been a variety of approaches or suggested strategies for increasing the number of ROPS on tractors. These include educational programs³¹; providing incentives to farm operators to retrofit older tractors^{19,32-34}; providing voluntary standards or other programs to encourage farm equipment dealers to retrofit tractors with ROPS before resale to farm operators³⁵; social marketing³³; purchasing and scrapping older farm tractors without ROPS from farm operators^{7,36}; reducing the cost of ROPS retrofit kits³⁷; publishing a guide to help a farmer find a ROPS to retrofit a tractor³⁸; and enacting some form of state or national regulation to require tractors used on farms to be equipped with ROPS after some designated time period.^{5,6,32,39} Several of these approaches are reviewed below.

ROPS SALES AND PROMOTION INTERVENTIONS IN THE UNITED STATES

For those tractors manufactured between 1966 to the late 1970s, ROPS were sold as options, which generally ensured that these tractors were ROPS compatible. From the late 1970s to 1985, manufacturers sold tractors with ROPS, unless the purchaser specifically requested that the tractor be provided without one.²⁹ In many cases, because the cost of the

ROPS was added on to the base price of the tractor, buyers elected not to purchase the protective structures. For tractors with cabs, this trend was slightly different. After 1975, tractor manufacturers began to build ROPS into the design of cabs.⁴⁰

In most cases, tractors manufactured prior to 1966 were neither provided with ROPS, nor necessarily designed to accommodate a ROPS. Many of these machines continue to be used on farms and their operators have no viable injury protection in the event of an overturn. Many pre-1966 tractors have axle housings (a frequent attachment location for ROPS), which were not designed for ROPS and would be too weak to withstand the force of an overturn without failing.⁴¹

Industry Initiative

In 1985, in response to changes made in the voluntary American Society of Agricultural Engineers (ASAE) standard, manufacturers began to include ROPS as standard equipment on all tractors. Soon after this change, the major tractor manufacturers (Deere, Ford, International Harvester, Case and Kubota) jointly sponsored a campaign aimed at encouraging owners of unprotected tractors to install ROPS. In conjunction with Farm and Industrial Equipment Institute (FIEI), the "One thing the entire industry can agree on" campaign sponsored ads in magazines and radio spots to promote ROPS retrofitting. To the disappointment of the industry, farmers' response to this retrofitting initiative was limited (D. Drollinger, personal communication, October 26, 2009).

Farm Bureau Initiative

For more than a decade, the Virginia Farm Bureau has been offering financial incentives to farmers for retrofitting their unprotected tractors with ROPS. Over the past 15 years this program has retrofitted roughly 400 tractors.⁴² Based on estimates from the NASS (National Agricultural Statistics Service) and the NASD (National Agricultural Safety Database), there are approximately 65,000 tractors without ROPS in the state, which indicates roughly .6% of the states unprotected tractors have been retrofitted

through the program.^{43,44} More recently, a few other state farm bureaus have begun to offer similar financial incentives. These incentive programs have generally offered \$150 to \$500 towards the purchase of a ROPS. These programs are important in demonstrating the acceptability of financial rebate as an incentive for retrofitting. These programs also demonstrate the limited impact of financial incentives that constitute a small percentage of overall cost. For rebates to serve as effective interventions they need to be more substantial.

University of Kentucky Southeast CAHIP

Investigators at the University of Kentucky's Southeast Center for Agricultural Health and Injury Prevention reported the impact of local stakeholder partnerships and community-level marketing in 2001. In two intervention counties, print and audio media and raffle incentive awards for those who retrofitted were aimed at stimulating ROPS retrofitting. These efforts led to the well-documented retrofitting of 81 tractors (likely more), a 20-fold increase in the number of retrofits during the year prior to the onset of the project. This study was somewhat confounded when a rollover death stimulated concentrated retrofitting efforts by one tractor dealer in one of the "control" counties, but did clearly demonstrate the power of marketing efforts and also serendipitously demonstrated the impact of one dedicated dealer.⁴⁵ Details on the total number of tractors in the intervention counties are not available. Although these 81 tractors likely represent a small percentage of the entire fleet, this work does demonstrate the importance of active community involvement in retrofitting programs. Addition of the community component to a more robust financial incentive would likely substantially accelerate the rate of ROPS retrofitting.

Social Marketing in New York

The most comprehensive ROPS promotion effort to date in the United States is in the state of New York. The New York approach uses social marketing. Social marketing involves "the application of commercial marketing technologies to the analysis, planning, execution

and evaluation of programs" designed to stimulate socially desirable individual behaviors.⁴⁶ The social marketer acknowledges that in many cases the audience is sufficiently educated, but insufficiently motivated or capable of acting. Social marketing requires a clear understanding of the target audience's perceptions regarding the feasibility and cost (time, money, effort, etc.) of the desired behavior. Social marketing interventions aim to rebalance the cost/benefit relationship perceived by the target audience, thus making the intended behavior more desirable than competing behaviors. Tailored messaging is but one component of this comprehensive intervention.

In New York, baseline stage of change data indicated that although readily acknowledging the importance of ROPS, three quarters of farmers were not considering ROPS retrofitting. Formative data identified small crop and livestock (SCL) producers as the highest risk segment of New York agriculture.⁴⁷ Extensive in-depth interviews of SCL farmers identified a complex of perceived barriers to retrofitting, which included high tolerance for risk, powerful denial of personal risk, financial concerns, and the organizational complexity of comparing, selecting, ordering, and shipping the optimal ROPS kit. These interviews also identified significant motivators to retrofitting such as a concern for the safety of family members and hired workers, a desire to be perceived as a responsible farmer and recognition of the financial implications of a serious injury.⁴⁸ Messages building upon these themes were designed, extensively tested among SCL farmers, and further refined. Media trusted and favored by SCL producers were identified by a survey of 1500 SCL farmers, and these channels were used to promote retrofitting in intervention communities.

The intervention included supports that would minimize the barriers of cost and complexity while maximizing attention to motivators through the tested marketing messages. Funds obtained from the New York State legislature enabled rebates of 70% of the total cost up to an initial maximum of \$600. A hotline minimized the number of phone calls for farmers while providing each with detailed information on

price, availability, and shipping/installation costs for the tractor's appropriate ROPS kit. Rebates were distributed in a timely fashion through the hotline, which maintained an extensive database on each interaction.⁴⁹ This combined intervention was proven to be effective in a quasirandomized controlled trial and was subsequently undertaken across the state.

At the end of the initial 12 months of this program, more than 1000 farmers had contacted the hotline, with 356 committing to order a ROPS kit. Documentation of installation and subsequent rebates were completed on 268. Despite considerable financial hardship among New York farmers, interest in the ROPS program remains high and after 34 months over 700 tractors have been retrofitted with ROPS. These tractors represent approximately .9% of the state's unprotected tractors.⁴⁷ Two thirds of these have been self-installed. Systematic engineer inspections of 53 randomly selected self-installed ROPS revealed no problems in 34% and minor issues (mostly seatbelt and bolt torque problems) in 57%. Nine percent were referred immediately to a dealer with fundamental and potentially life threatening problems—nearly all relating to inappropriate anchoring bolts. Because of this, information sheets developed for self-installers have been mailed to each farmer who enters the program to caution them on common problems associated with self-installation.⁵⁰ The New York experience demonstrates that the rate of retrofitting can be accelerated with a combination of rebate and organizational support aimed at simplifying the task. Preliminary evidence also suggests that the promotional activities resulted in a shift of intention to retrofit within the larger agricultural community. Shifts in community stage of change were also demonstrated. These observations suggest that on a larger scale and with more time, this social marketing approach might be expected to measurably increase the rate of ROPS retrofitting.

The average total cost of ROPS retrofitting is currently \$935 per installation. Approximately 23% of hotline callers are seeking ROPS for tractors that cannot be retrofitted due to absence of any suitable kit or due to insufficient strength of the tractor rear axle. At 2 years, a survey of

participants identified 14 potential serious injury events that had been prevented by the new ROPS. A cost-benefit analysis indicates that the intervention will begin to show a net cost savings in year 3 of the program.⁵¹ A National Institute for Occupational Safety and Health (NIOSH)-funded trial to replicate the social marketing approach in neighboring Vermont and Pennsylvania has recently begun.

ROPS ENGINEERING INTERVENTIONS IN THE UNITED STATES

Although social marketing approaches are likely to remain prevalent in US tractor ROPS-retrofitting efforts, advances in ROPS engineering and related technology may also significantly contribute to this effort. The primary engineering approach has been the use of a roll bar or cab and seatbelt to protect operators during a rollover. Engineering techniques are also being used to make ROPS more useable and affordable. The following sections review current major engineering approaches to prevent or reduce operator injury involving tractor overturn.

Three types of ROPS frames are available: a two-post frame (with solid or fold down versions), a four-post frame, and a ROPS with enclosed cab. They all serve the same function: protecting the operator in case of a tractor rollover. In the United States the main ROPS performance safety standard is Society of Automotive Engineers (SAE) J2194 *Roll-Over Protective Structures (ROPS) for Wheeled Agricultural Tractors*.⁵² This standard is managed by the American Society of Agricultural and Biological Engineers (ASABE). The slowness with which all tractors become ROPS-equipped has led researchers to explore alternate ways, through applied engineering, to increase this percentage.

AutoROPS

One impediment to ROPS use is low-clearance situations, such as orchards and animal confinement buildings.⁵³ Foldable ROPS were created to address this problem but protection is not

afforded if the operator does not raise and lock the foldable ROPS after use in a low-clearance situation. To address the need for ROPS that are easily adaptable for low-clearance situations, NIOSH developed the concept of AutoROPS (Automatically Deployable Rollover Protective Structure). Liu and Ayers have also worked on the AutoROPS concept through development of a stability index model in developing control strategies for automatically deploying ROPS.⁵⁴

AutoROPS was to be a passive device that could be constantly in the retracted (or armed) position until a rollover was detected and then would be deployed into the protective position. At the time of initial concept in 1995 no other agricultural device as described existed, but some automakers had similar devices. AutoROPS is an electronically controlled deployable ROPS system consisting of the base (stationary) section containing the latching system, the crossbar (deployable) section, and the electronic control section.⁵³ The system is normally operated in its retracted position, where it remains until the electronic rollover sensor initiates deployment of the AutoROPS. The height of the AutoROPS in the retracted position was established based upon the sitting mid-shoulder height for a 5th percentile female.⁵⁵ This ensures that the AutoROPS operators can see over the crossbar. The deployed height of the structure is approximately equal to the height of a commercial fixed ROPS. Figure 1 is a picture of the initial AutoROPS on a tractor.

Limitations with the initial AutoROPS included reliability of sensors and latching mechanisms, material costs, and ease of resetting the AutoROPS in case of false deployment.⁵³ These limitations were addressed in the second through fourth generations of AutoROPS. The major emphasis of the current AutoROPS design (fourth generation) was to produce an AutoROPS that represented a finished product in lieu of a prototype design. This was accomplished by eliminating the hydraulic cylinders, reducing the weight, using square tubing, switching the deployable crossbar tube (outside tube) and the stationary base (inside tube), and allowing the latch and release mechanism to be

FIGURE 1. Ford 4600 after remote control with first-generation AutoROPS—1999.



FIGURE 2. Current AutoROPS on a scag commercial zero-turn mower.



on the deployed section rather than the fixed section. This current design, shown in Figure 2 on a zero-turn mower, is dramatically different in looks, material, and fabrication from its proof-of-concept predecessor.⁵⁶

Efforts are currently focused on creating an industry standard for the performance of an automatically deployed ROPS (AD-ROPS). The sponsoring organization for agricultural standards is the ASABE. In 2006, a proposal was filed with the ASABE to evaluate the need and relevance of a proposed AutoROPS standard. It was decided that a working group would look into the need and draft a standard if necessary. The working group voted in favor of the standard and it was assigned to the PM-52 (Power Machinery) committee for lawn and turf. This resulted in the development of a proposed standard X-599, "Standardized Deployment Performance of an Automatic Deployable ROPS for Agricultural and Turf & Landscape Equipment." The standard has been through several revisions and is under consideration by the ASABE Standards Development Committee (SDC).

CROPS

A barrier to the retrofitting of ROPS on older farm tractors is cost.⁵⁷ A cost estimate of ROPS retrofitting, including shipping and installation, is approximately \$900.⁵¹ If the cost were reduced, then the adoption rate of ROPS may increase substantially.

Research efforts by NIOSH to produce less costly rollover protection have resulted in a Cost-effective Rollover Protective Structure, or CROPS.⁵⁸ The cost savings is achieved by using a weld-free design with common structural elements and fasteners. CROPS designs are tailored to provide a cost-effective alternative for hard-to-find ROPS or an option for non-existent ROPS for older wheeled agricultural tractors. Based upon previous NIOSH research, six tractor models were identified for the program. The six models were (1) Ford 3000, (2) Ford 4000, (3) Ford 8N, (4) Farmall M, (5) Farmall H, and (6) Massey Ferguson 135. CROPS designs for each of the tractor models listed were successfully tested in accordance with SAE J2194. The estimated cost to commercially produce these CROPS was \$290 in 2003 (no shipping or installation cost included). Additionally, designs developed to date can be installed by one person.⁵⁸

NIOSH is currently developing a Web site with all CROPS designs and installation instructions. CROPS designs permit individuals to build CROPS for their privately owned tractor, or companies to build and sell CROPS. Some parts must be manufactured by a facility that can bend 0.5 inch thick plate steel, whereas other parts can be manufactured with a band saw and a drill press. One part must be welded by a professional welder for use in cold weather (-40°F). Any deviation from the published designs or the installation of CROPS on a tractor for which it was not intended will invalidate the performance of the CROPS and will leave the operator without adequate protection in the event of a rollover. Currently, CROPS are being distributed through a NIOSH demonstration project in New York and Virginia.

TRACTOR SAFETY EDUCATION AND TRAINING INTERVENTIONS IN THE UNITED STATES

As long as retrofitting tractors with ROPS remains optional for most farm operations, more commonly available tractor safety education and training programs also remain important. Although experimental evaluation of these education and training programs is important, there is little evidence in the literature that this has occurred with any regularity. Reasons for this can be found by reviewing DeRoo and Rautiainen⁵⁹ and Hagel et al.⁶⁰

Tractor safety education and training has always been a part of organized farm safety efforts because tractors and tractor overturns have always been a major source of farm work injury. Preventing tractor overturns through safe operation and the use of ROPS and a seat belt is most commonly included in broader, more general tractor safety education and training programs. Tractor safety education and training is most often directed at (a) farm/ranch owners/operators and their families, (b) hired adult labor, and (c) hired adolescent labor. Each of these groups has different legal and practical needs and requirements. Even so, the educational materials and programs often overlap and are

commonly used among all three target audiences. The following sections briefly review current major educational approaches and programs that serve these audiences.

Farm/Ranch Owners and Families

There are numerous educational resources for tractor safety directed at farm and ranch operators and families. Since 2000, several organizations have developed new and up-to-date materials to aid in tractor safety education. Electronic media allows for interactive computer training, whereas the Internet permits information to be delivered across a wide area with minimum personnel, and video (both real and animated) provides the opportunity to illustrate concepts. Recent special initiatives that have resulted in educational materials include the North American Guidelines for Children's Agricultural Task⁶¹ and the NIOSH National Agricultural Tractor Safety Initiative.⁶²

The largest depository of educational resources is the National Agricultural Safety Database,⁶³ a clearinghouse of agricultural safety information in English and Spanish, which includes pamphlets, brochures, fact sheets, interactive training materials, and videos. Similar materials exist at universities with agricultural safety and health research and outreach programs, with state Farm Bureau safety committees, and with tractor and machinery manufacturers. Although educational materials and programs are increasingly available through the Internet, the following provide on-site safety education and training programs that include tractor safety: cooperative extension farm safety specialists; state Farm Bureau safety committees; NIOSH Centers for Agricultural Disease and Injury Research, Education, and Prevention; and specialty organizations such as Farm Safety 4 Just Kids⁶⁴ and Progressive Agriculture Safety Day.⁶⁵

Hired Youth Labor

Through the Fair Labor Standards Act, established in 1938, the US Department of Labor Employment Standards Administration, Wage and Hour Division, published the Child Labor Bulletin 102⁶⁶ detailing the limits of

youth employment. Child labor restrictions on farms are outlined by a specific set of Agricultural Hazardous Orders (AgHOs). To assist in meeting these child labor requirements, a group of collaborators from Purdue University developed *Gearing Up for Safety: Production Agricultural Safety for Youth*.⁶⁷ This program consists of both interactive CD-ROM and Web-based educational training components.⁶⁸ A feature of the Purdue curriculum is the establishment of performance standards (i.e., passing scores), using established psychometric methods, for the AgHOs certification test used with the *Gearing Up for Safety* curriculum. An evaluation of the curriculum found no significant difference in attitudes or behaviors between a control group using the traditional workbook and classroom delivery method and the interactive curriculum and the *Gearing Up for Safety* interactive curriculum.⁶⁹

A separate effort to develop up-to-date training materials was undertaken jointly by educators from Penn State University, The Ohio State University, and the National Safety Council under the direction of the US Department of Agriculture. The result is the National Safe Tractor and Machinery Operation Program (NSTMOP).⁷⁰ A student and instructor manual were developed that consists of 77 task sheets, a written test that covers the minimum core content areas, and a skills and driving test. To facilitate the use of these materials, individuals from all 50 states were invited to a 2-day training workshop to become familiar with the materials. The understanding was that these individuals would return to their respective states and serve as master trainers, promoting the program locally.⁷⁰ To date, 38 states have master trainers and 13 states have a sizable list of local instructors. The diversity of these 13 states would indicate that local conditions (i.e., available resources, efforts by master trainers to recruit other trainers, interest in receiving training by youth, demand for trained youth by employers, etc.) play a major role in the acceptance of this program across the country.

A review of youth safety programs in specific states shows that the core material being used is either the manual *Safe Operations of Agricultural Equipment* published by Hobar,⁷¹ the interactive CD-ROM *Gearing Up for Safety: Production*

Agricultural Safety for Youth published by Purdue University,⁶⁷ or the NSTMOP materials.⁷⁰ These materials and programs are available through Hobar Publications (<http://www.finney-hobar.com/safety.html>) or from the NSTMOP Web site (<http://www.nstmop.psu.edu>).

Hired Adult Labor

Tractor safety programs for hired farm labor often utilize the same materials as programs for farm and ranch families and hired youth labor. However, in locales with high numbers of adult hired workers, educational efforts may focus more heavily on train-the-trainer education. Train-the-trainer programs extend impacts of educational programs by developing more instructors. When farm operators and supervisors become trained instructors, a knowledgeable person about tractor safety remains on site and can continue to teach and reinforce safe tractor operations. Industry groups in particular are interested in train-the-trainer programs. For example, AgSafe (see <http://www.agsafe.org>), based in Modesto, California, is an industry group that has organized to promote agricultural safety for hired labor. Their members are primarily employers and personnel from businesses that operate farms and ranches in a more corporate environment.

One example of a successful train-the-trainer model was developed by the Agricultural Safety Institute of Cal Poly State University, and delivered at the annual AgSafe conference. It is a 4-hour, stand-alone course that combines tractor safety topics with instruction on how to train others. The course materials consist of a notebook, available in English and Spanish, that includes an instructor's guide, tractor safety manual, tractor safety training topics, safety awareness checklist, training strategies, training evaluation tools, and resource list. The class format is a combination of lecture, discussion, and hands-on activities. Approximately two thirds of the time is spent on safety topics with the remaining time spent on how to effectively train others. In addition to other materials, a key component of tractor safety education for hired adult workers is the coverage of the nine basic rules outlined in the Occupational Safety and

TABLE 2. Tractor Operational Rules Required by OSHA

-
1. Securely fasten your seat belt if the tractor has a ROPS.
 2. Where possible, avoid operating the tractor near ditches, embankments, and holes.
 3. Reduce speed when turning, crossing slopes, and on rough, slick, or muddy surfaces.
 4. Stay off slopes too steep for safe operation.
 5. Watch where you are going, especially at row ends, on roads, and around trees.
 6. Do not permit others to ride.
 7. Operate the tractor smoothly—no jerky turns, starts, or stops.
 8. Hitch only to the drawbar and hitch points recommended by tractor manufacturers.
 9. When tractor is stopped, set brakes securely and use park lock if available.
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Health Administration 1928 regulation on operational instruction.¹⁷ These rules must be taught to employees that operate tractors upon initial employment and at least annually thereafter. The nine rules are presented in Table 2.

HUMAN FACTORS ENGINEERING TO REDUCE TRACTOR OVERTURNS

ROPS, AutoROPS, and CROPS all attempt to protect the operator during the rollover event. Tractor safety education and training programs attempt to protect the operator from rollover by increasing operator knowledge and skill to prevent the rollover. Human factors engineering can be used to enhance operator knowledge and skill.⁷² Researchers at Penn State University are examining a human factors engineering approach by conducting research to develop a real-time, stability feedback monitor. Although the effectiveness of ROPS and a buckled seat belt is a proven method of protecting tractor operators from tractor rollover, many tractors do not have ROPS, few operators buckle their seat belt, and any tractor rollover can result in serious but nonfatal injury, damage to the tractor and trailing or attached equipment, and considerable down time. For these reasons, efforts to prevent tractor overturns from occurring are justified, not as a substitute for ROPS and seat belt but in addition to ROPS and a seat belt.

Tractor Stability Visual Feedback Monitor

Operators are not adept at predicting an overturn because of the number of factors and variables that exist that the operator must track and analyze. This problem does not necessarily arise from poor judgment, but more from the inability to reliably interpret all the information present during operation coupled with the inability of the operator to react quickly enough to prevent an overturn.⁷³ A tractor operator neither controls nor notices every important aspect of the environment the tractor is operated in (e.g., hidden obstacles or holes, a collapsing ditch bank, wet grass that makes a slope slippery), but the operator does control some important aspects of the tractor such as ground speed, steering, turning speed and direction, and the operation of field implements and attachments. In the absence of unexpected environmental hazard-induced factors, one way to help prevent tractor overturns is to better inform the operator, in real-time, of their immediate potential for overturn.⁷⁴ A better-informed operator would be able to make appropriate decisions and take action to safely operate a tractor. With relevant tractor stability information, and in many day-to-day operating situations, an operator would have the opportunity to develop an awareness of tractor stability limits and better acquire the ability to distinguish between safe and hazardous situations and operations.

A low-cost microprocessor sensor system was developed to help prevent overturn of agricultural tractors.⁷⁵ A second-generation color LCD display was built to show current roll angle for side overturn as well as recent time history. Large numerals show current roll angle in degrees and a moving bar graph uses color-coded bars to graphically show safe, marginal, or dangerous roll angle over the past 15 seconds so that the operator need not watch the display continuously. The display was specifically designed as a learning tool to help tractor operators recognize that recent operating conditions may lead to a future potential side overturn. A simple dynamic model of overturn was developed to use pitch angle and rate measurements to control clutch release and prevent rear overturn. The sensor system and dynamic model were

successfully validated on a full size umbilical controlled tractor. The system stopped rear overturn for improperly high chain hitching over a wide range of pitch rates and did not produce false-positive interventions.⁷⁵

The current focus for this work is on human factors—ergonomics, cognition, and psychology—for the display unit to help operators avoid potentially dangerous operation. The initial work in this focus was a study of operators' understanding of tractor roll angles and testing a visual slope indicator to effectively deliver stability information to a tractor operator.⁷⁶ A simplified full-scale tractor cab roll simulator was used to identify roll angles at which volunteer participants felt uncomfortable, as well as roll angles at which they would no longer operate a tractor. In addition, the participants performed a series of tasks to test the functionality of a visual slope indicator that was designed to help them estimate slope angles. The project tested 236 tractor operators' perceptions of safe operation on side slopes, and 130 participants' interactions with the visual slope indicator.

Testing showed that (a) the difference between the feeling of moderate risk and the feeling of extreme risk was approximately 6.1 degrees; (b) both older operators and more experienced operators were willing to operate tractors on slightly steeper slopes; (c) participants were less accurate when estimating higher slopes than lower slopes, and their ability to estimate angles decreased as the slope became steeper; (d) novice operators were 6.1 times (610%) more likely to accurately estimate roll angles, and 96% more likely to properly rank these angles, when compared to the experienced operator group; (e) younger operators were 49% more likely to accurately estimate the angles than older operators but the older operators were 17% more likely to properly rank the angles; and (f) novice operators were 215% more likely to accurately estimate angles when the indicator was turned on than when it was turned off.⁷⁶

Future work will focus on using a more sophisticated six-axis cab roll simulator, high-definition video clips of agricultural field operation scenes, tractor operator eye movements, and more sophisticated monitoring device designs. This approach to reducing tractor

overturns has the potential to prevent rear tractor overturns almost completely⁷⁵ and to reduce side tractor overturns, within certain conditions, by better informing operators of how near they may be to an actual overturn so that appropriate preventive decisions can be made.

RESEARCH TO PRACTICE RECOMMENDATIONS

Reducing the number of fatalities due to tractor overturns by 50% by 2018 is a goal of the National Occupational Research Agenda (NORA) Agriculture, Forestry, and Fishing (AgFF) Sector Council.⁷⁷ Based on the data and evidence presented in this article, the authors suggest that in order for the agricultural safety and health community (both public and private) to reach this goal, we continue to support and conduct research that

- identifies at-risk populations for injury from tractor operations;
- develops viable options for retrofitting older tractors with low-cost rops options; and
- makes newer technologies such as AutoROPS, CROPS, and stability indicator sensors more widely available.

The authors also suggest that the agricultural safety and health community support the development and implementation of

- a social marketing toolkit that researchers and educators in at-risk regions can use to conduct local ROPS rebate campaigns (e.g., the New York State approach); and
- educational strategies that increase safe tractor operation.

Marketing research suggests that there is important variability in motivators/barriers across the country,⁷⁸ so these efforts will need calibration at the local level. Increasing the prevalence of ROPS on tractors in the United States is a complex and refractory problem without one simple solution. The most effective effort will require

identifying solutions for operators with older tractors, implementing technologies that offer alternative solutions for owners who have specific ROPS issues such as clearance, and developing affordable ROPS while focusing upon high-risk populations. Combining effective intervention strategies with new technology and education that enhance operators' abilities to identify risk is likely to have the greatest impact.

SUMMARY

Farming and ranching has long been recognized as one of the most hazardous industries in the United States. Numerous studies have documented tractor overturns as the most common cause of fatal agricultural occupational injury. A ROPS with seatbelt is a proven intervention but having all tractors in the United States equipped with a ROPS through voluntary means has proven difficult. Other countries have solved this dilemma through a combination of incentives and legislation. Currently, no nationally organized program is in place to increase the number of ROPS-equipped tractors on US farms. In place of a nationally organized program, a variety of educational, social marketing, and engineering and technology solutions continue to be explored.

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