Effectiveness of Roll-Over Protective Structures in Reducing Farm Tractor Fatalities

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Objective: The purpose of this systematic review was to evaluate the effectiveness of roll-over protection structures (ROPS) as an engineering control for prevention of fatalities from farm tractor roll-overs.

Methods: Using a systematic approach to literature searching, relevant studies from peer-reviewed journals, technical and government reports, and unpublished reports were retrieved. Studies meeting initial criteria for possible inclusion were screened to determine whether they addressed the review topic (ROPS), included comparison data and included outcomes data such as injury or fatality. Articles that evaluated the use and impact of ROPS on operators of agricultural tractors were reviewed. Outcomes included two primary categories: implementation of ROPS and fatalities.

Main Results: Of a total 207 citations reviewed, 53 met initial screening criteria and 21 studies were included in this review. Farm tractor roll-overs result in approximately 200 fatalities per year in the United States. ROPS or crush-proof cabs, which are designed to protect the farmer during a roll-over incident, are currently used on only about 50% of the estimated 4.8 million tractors in the United States. A significant proportion of tractors built after 1985 (when manufacturers began implementing a voluntary ROPS standard) have had ROPS removed. Evidence from Sweden and other Northern European countries clearly demonstrates that ROPS can essentially eliminate roll-over fatalities. In the United States, the only fatalities associated with roll-overs of ROPS-equipped tractors occurred when farmers did not use a seatbelt to hold them within the protective envelope of the ROPS. Estimates of costs of programs to retrofit older tractors with ROPS range from approximately $500,000 to $900,000 per life saved, which is comparable to other accepted life-saving interventions.

Conclusions: Future research efforts should include the development of collapsible and telescoping ROPS that can be used in low clearance areas such as dairy barns and fruit orchards. ROPS retrofits also need to be developed for many older tractor models. Effective educational and incentive programs need to be developed to increase the acceptance and use of ROPS among U.S. farmers. A national policy should be implemented to ensure that all tractors operated in the United States are equipped with ROPS or crush-proof cabs.

Medical Subject Headings (MeSH): agriculture, disorders of environmental origin, intervention studies, man-machine systems, mortality review literature (Am J Prev Med 2000; 18(4S):63–69)

Farm tractors are the major cause of occupational fatalities in agriculture in the United States. Fatalities result from being run over or crushed by the tractor, entanglement in moving parts of the tractor, accidents on roadways, and tractor roll-overs, which involve tipping the tractor sideways or backwards and crushing the operator. Factors contributing to tractor roll-overs include older designs with high centers of gravity, rear-wheel drive, narrow or "tricycle" front ends, improper hitching of tow chain to points above the drawbar, and operation on uneven terrain.[1–4] A tipping tractor can reach a point of no recovery in less than 0.75 seconds, allowing very little time for the operator to react.[3] Tractor roll-overs account for up to 76% of all tractor-related fatalities, and in the United States, tractor roll-overs kill close to 200 farmers every year.[2,5–11]

Northern European countries have virtually eliminated fatalities from tractor roll-overs through implementation of engineering controls including roll-over protection structures (ROPS) or equivalent crush-proof cabs, and seatbelts.[4,11–14] ROPS are structural frames that provide a protective envelope around the tractor

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operator. Seatbelts are necessary to ensure that the operator remains within the ROPS environment. ROPS must meet specifications for plastic and elastic deflection on impact and energy loading requirements, and prevent intrusion and exposure of the occupant.[15–18] Equipment manufacturers in the United States have developed voluntary standards (e.g., ASAE S336.1 and ASAE S519), and since 1985 almost all new tractors sold in the United States are equipped with ROPS or crush-proof cabs.[15–18] The Occupational Health and Safety Administration (OSHA) also requires ROPS on almost all tractors built after 1976 operated on farms with nonfamily employees (29 CFR 1928.51).[19] Tractors used in "low profile" situations, such as orchards or inside farm buildings, are exempt. However, 90% of U.S. farms do not fall under OSHA jurisdiction. Even with these measures, less than one-half of the approximately 4.8 million tractors in the United States are currently equipped with ROPS.[1,9,20,21] Fatalities from tractor roll-overs that could be prevented by ROPS remain an important occupational health problem in the United States.

The purpose of this systematic review was to evaluate the effectiveness of ROPS as an engineering control for prevention of fatalities from farm tractor roll-overs. The prevalence of ROPS use, economic cost-benefit of the intervention and perceptions concerning effectiveness were also included. Critical evaluation of this literature can assist with efforts to plan and implement interventions including improved design of ROPS, education, and policy initiatives.

Methods

Search Strategy

Using a systematic approach to literature searching, relevant studies from peer-reviewed journals, technical and government reports, and unpublished reports were retrieved. Due to the multidisciplinary nature of the research question, the search was conducted across disciplines, and included diverse databases and collections of literature. A total of five databases were included in the search[22]: biomedical—MEDLINE, EMBASE; occupational health—NIOSHTIC; general—Expanded Academic Index; and social science—PsycINFO. (A full description of the databases is included in Beahler et al.[22]) In addition to database searching, other relevant information sources were identified by checking references and consulting with experts in the field.

Inclusion Criteria

Studies were evaluated using a two-phase approach. Studies meeting initial criteria for possible inclusion were screened to determine whether they addressed the review topic (ROPS), included comparison data, and included outcomes data such as injury or fatality. Studies were excluded if they did not objectively measure outcomes or if they did not contain interpretable data.

Study Population

We reviewed articles that evaluated the use and impact of ROPS on operators of agricultural tractors, regardless of age, gender, or race/ethnicity. We sought articles from the United States and from other countries. Most of the studies included can be categorized as surveys.

Types of Interventions

The primary intervention of interest was the use of ROPS on agricultural tractors. Interventions such as legislation and education that influenced the implementation of ROPS were also included.

Types of Outcome Measures

Outcomes included two primary categories: implementation of ROPS, and fatalities. Nonfatal injury and occurrence of a roll-over incident were also included for some studies.

Results

Of a total 207 citations reviewed, 53 met initial screening criteria, and 21 were included in this review. A summary of studies exclusively evaluating implementation and use of ROPS is presented in Table 1. Table 2 summarizes results of studies evaluating the effectiveness of ROPS as an intervention to prevent fatalities.

Implementation of ROPS

Eight studies reported on the use of ROPS in the United States. All were surveys of ROPS use. Implementation of ROPS varied by region, type of farming, and age of tractor. The largest study involved data from 21 states collected as part of NIOSH's Traumatic Injury Surveillance of Farmers.[21] Sixty-two percent of the 28,542 tractors used by the 12,913 respondents did not have ROPS or crush-proof cabs. ROPS were present most often on cash grain farms (48%) with the lowest use rate on vegetable/fruit farms (32%).[21] In Virginia, only 18% of all tractors had ROPS, and in New England, 78% of tractors used in dairy barns did not have ROPS.[1,23] The low use of ROPS in orchards and on dairy farms is reportedly due to low clearances and to OSHA's exemption of these environments. In Iowa, Kentucky, and Ohio, 40% of tractors had ROPS or crush-proof cabs.[20,24]

Older tractors built before 1985 were less commonly equipped with ROPS, and in some parts of the United States these older tractors make up more than 80% of tractors in use.[1,20,24] A large proportion of tractors built after 1985 have also been found to lack ROPS. Between 38% and 45% of newer tractors either were not sold with ROPS or had ROPS removed.[1,25,26]

The effectiveness of ROPS is limited if the farmer does not use a seatbelt to prevent ejection from the protective environment of the ROPS during a roll-over.

Table 1. Characteristics and results of survey studies evaluating implementation of ROPS

Study	Location	Results/Comments
Huizinga et al. (1989)[25]	Pennsylvania	38% of tractors in Pennsylvania manufactured with ROPS had ROPS removed.
Etherton et al. (1990)[1]	W. Virginia	Surveyed 689 farms. Overall, only 18% had ROPS or cab. For tractors 0–4 years old, 55% had ROPS or cab.
Kelsey et al. (1994)[26]	New England	1379 farmers responded to mailed survey. 34% of farmers used tractors inside dairy barns, and 78% of these did not have ROPS. 60% said they could not use ROPS in barns. 46% of tractors built after 1984 did not have ROPS (presumably removed). Deere and Case developed foldable ROPS in 1991.
Myers et al. (1995)[21]	U.S., 21 states	1994 NIOSH traumatic injury surveillance of farmers, 12,913 respondents. 28,542 tractors in use, estimate 4.8 million in U.S. 62% did not have ROPS or crush-proof cabs. Greatest use of ROPS on cash grain farms (48%); lowest use on vegetable/fruit farms (32%). More use of new tractors with ROPS; of estimated 1.474 billion hours of use, 53.2% are protected by ROPS. Of the 71 makes and models of tractors with more than 10,000 units in use, 77% had ROPS retrofits available. The average cost of a retrofit was $937, or $1.22 billion total. Retrofits would prevent 1478 fatalities given current trends. Cost per life saved in $824,500, including shipping, installation, and enforcement.
Kelsey et al. (1996)[23]	New York	Of 677 tractors on 170 farms, 33% had ROPS. 11.7% had rollbar, 17.1% had crush-proof cab, and 43% had rollbar and cab. The average age of the tractors was 23.3 years. Tractors used more hours per year were more likely to have ROPS. 68% of tractors with ROPS had seatbelts. Effective ROPS and seatbelt protection estimated to range from 8% to 34%.
MMWR (1997)[20]	Iowa, Kentucky, Ohio	FFHHS 1992–1997. 80–90% of tractors were built before 1985, the year ROPS were voluntarily installed by manufacturers on all new tractors. Less than 40% had ROPS. 70% of tractors without ROPS used more than 100 hours per year. Estimated 3 million tractors without ROPS in U.S
Zwerling et al. (1998)[24]	Iowa	Iowa Farm Family Health Hazard Survey of 989 farm operators; 390 responded. Average age of tractors 24 years; less than 40% had ROPS. 70% of tractors without ROPS used more than 100 hours per year. Only 10% of tractors are less than 7 years old, and 90% of these have ROPS.

In New York, 68% of tractors with ROPS also had seatbelts.[23] It is estimated that 54% of all tractor use time in the United States is not protected by ROPS and seatbelts.[6,21] For older tractors, the estimate for protected use time drops to below 10%.[23]

Prevention of Fatalities

Fourteen studies specifically evaluated the effectiveness of ROPS for preventing fatalities or injuries from tractor roll-overs. Studies from the United States were either specific case investigations of fatalities, or were ecologic studies relating patterns of ROPS use to patterns of fatalities. The overwhelming majority of fatalities occurred from roll-overs of tractors without ROPS.[2,3,5–7,9,10,27] In the very few cases where a fatality did occur during use of a tractor with ROPS, the farmer did not use a seatbelt and was thrown from the tractor.[3,6,27] In Nebraska, 60 roll-overs involving tractors with ROPS were reported from 1967 to 1993. Only one person died, and this person was not using a seatbelt at the time of the incident.[6] A similar pattern was reported for 15 fatalities in New York; again, only one of the fatalities involved a tractor with ROPS and again the occupant did not use a seatbelt.[3] In the other studies of U.S. farmers, all fatalities involved tractors without ROPS.[2,5,7]

The best evidence concerning the effectiveness of ROPS comes from Northern Europe, where design and implementation of ROPS began in the 1950s, and where surveillance systems allow more accurate measurement. Figure 1 shows fatality rates for the United States and Scandinavian countries. In Sweden, ROPS were required on all new tractors beginning in 1959, and they have been required on all tractors used by employees since 1965.[11–14] Currently, 98% to 99% of all tractors in Sweden, Britain, and West Germany are equipped with ROPS or crush-proof cabs.[11] Fatalities in Sweden and West Germany have dropped to essentially zero, almost 25 times lower than the U.S. fatality rate.[4,11–14] The temporal trend for decreasing fatalities corresponds strikingly to the trend for increased implementation of ROPS in Sweden.[12] Figure 2 illustrates the

Table 2. Characteristics and results of studies evaluating ROPS interventions

Study	Location	Intervention	Outcome	Results/Comments
Karlson et al. (1979)[9]	Wisconsin	ROPS	Fatality	1961–1975. 415 males were killed, more than 50% due to roll-overs. In 1971 to 1975 the fatality rate was 14 deaths per 100,000 tractors per year. Only 9% of tractors in SW Wisconsin had ROPS in 1977.
MMWR (1983)[5]	Georgia	ROPS	Fatality	202 tractor-related fatalities in 1971 to 1981. 76% involved roll-overs. 98% were males, occurring in late afternoon. The mortality rate was 54.1/100,000. Of the 16 fatal roll-overs in 1982, none had ROPS.
Springfeldt et al. (1987)[13]	Sweden	ROPS legislation	Fatality	Implementation of ROPS reduced risk of fatality 90% and injury 65% between 1961 and 1981. Number of tractors increased from 130,000 in 1959 to 195,000 in 1980s, but number of unprotected tractors decreased from 125,000 to 35,000.
Thelin (1990)[14]	Sweden	ROPS	Fatality Legislation	In 1959 ROPS required on all new tractors; in 1978 ROPS required on all tractors. 34 roll-over fatalities in 1959, 1 in 1984.
MMWR (1993)[6]	U.S.	ROPS	Fatality	4.6 million tractors in U.S.; 50% lack ROPS, 61% older than 1971. Nebraska 1967–1993: 40% of people involved in 250 roll-overs without ROPS died; one person of 60 rollovers with ROPS died. The latter did not use a seatbelt. Estimated 54% of use time is unprotected by ROPS.
MMWR (1995)[27]	Kentucky	ROPS	Fatality	FACE investigations of 28 fatalities in 1994, representing 16% of all occupational fatalities in Kentucky. 82% were due to tractor roll-overs, 32% during mowing, 82% on farms, 18% on roads. Only one had ROPS and did not have seatbelt.
Lehtola (1995)[2]	Iowa	ROPS	Fatality	173 agricultural tractor accidents in 1988–1990. 87 fatalities. 59% were roll-overs, and 82% of these sideways. 58% in field, 42% on roadways. None of these tractors had ROPS; no fatalities reported for tractors with ROPS.
Lee et al. (1996)[32]	Minnesota, Wisconsin, N Dakota, S Dakota, Nebraska	ROPS	Injury Roll-over	RRIS telephone survey of 3939 farm households, 13,144 persons, 1990. Of 764 injury events, 8.4% related to tractors—42% mounting/dismount, 12% field work, 40% travel. 12 roll-overs, no fatalities. 31% of tractors had ROPS, no specific data on whether rolled tractors had ROPS. Relative risk of roll-over event did not differ by tractor age.
Roerig et al. (1996)[3]	New York	ROPS	Fatality	NY State Dept. of Health OHNAC investigations of fatalities. 27 incidents of real roll-overs with 15 fatalities. Primary cause was improper hitching of tow chain to point above drawbar. Only one had ROPS on tractor, and did not use seatbelt.
Springfeldt (1996)[11]	International comparison	ROPS Legislation	Fatality	Sweden and New Zealand develop and test ROPS in 1950s. Sweden, Britain, West Germany have ROPS on 98–99% of tractors and fatality rates of 0.3 (Sweden) to 1.8 (Britain) per 100,000 tractors. The U.S. (34% ROPS on tractors) and Spain (20% ROPS) have fatality rates of 5 per 100,000 tractors.
Brown et al. (1997)[7]	Minnesota	ROPS	Fatality	FACE surveillance from 1994–1996. 46 farm work-related fatalities. 41% involved tractors, and 66% of these were roll-overs. None had ROPS. 7 of the 18 tractors could have been retrofit with ROPS; 2 did not have retrofits available.
Richardson et al. (1997)[10]	North Carolina	ROPS	Fatality	Medical examiner records for all fatalities, 1977–1991. 228 total agricultural fatalities. Tractors involved in 53% overall, 37% for farm laborers. Crude fatality rate among African American farmers was 1.5 x Caucasians, and among farm laborers, 2.5 x Caucasians. African Americans usually poorer, with older tractors without ROPS.

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Table 2. Characteristics and results of studies evaluating ROPS interventions

Study	Location	Intervention	Outcome	Results/Comments
Springfeldt (1998)[12]	Sweden	ROPS Legislation	Fatality Injury	Fatalities declined 93% over 30 years, and nonfatal injuries declined 90%. ROPS use increased from 3% of tractors in 1951 to 93% in 1990.
Thelin (1998)[4]	Denmark, Finland, Norway, Sweden	ROPS Legislation Education	Fatality	Sweden in 1957 had ROPS on 0% of tractors and 15 fatalities; in 1990 with ROPS on 100% of tractors had 1 fatality. Relative rates of lives lost 24 times higher in U.S. and Finland where less effective interventions are employed.

temporal relationship between increased ROPS use and decreased fatalities.

Cost Effectiveness

Based on current trends it is projected that almost 1480 U.S. farmers will be killed in tractor roll-overs between 1998 and 2015 if no changes in intervention occur.[28] ROPS retrofits are available for approximately one half of the 3 million U.S. tractors currently lacking ROPS.[7,16,20,21] Costs of purchase and installation of ROPS retrofits have been estimated to range from $400 to $2000 per tractor.[1,6,21,29,30] The total cost for retrofitting all older U.S. tractors would be in the range of $1.2 billion and could save 1478 lives over 24 years—the same time period it would take to achieve an equivalent protection rate of 74% of tractor use time.[21] The cost per life saved is estimated to range from about $500,000 to $900,000, depending on assumptions concerning the effectiveness of ROPS (75% or 100%), costs for enforcement, and discounting.[6,21,29]

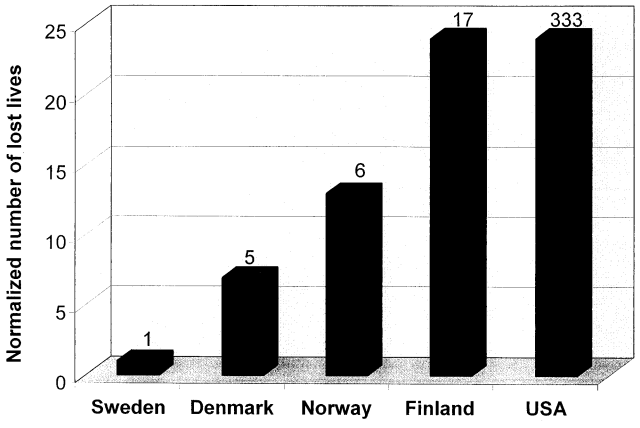

Figure 1. Fatalities in 1990 due to tractor roll-over accidents in United States and Scandinavian countries relative to Sweden. Actual fatality numbers are shown above bars. Bar height, corresponding to the vertical axis, indicates the normalized number of fatalities by country (number of fatalities / [number of tractors ÷ number of tractors in Sweden]) (from Thelin[4]).

Discussion

Farm tractor roll-overs in the United States result in approximately 200 fatalities every year. Evidence from Sweden and other Northern European countries clearly demonstrates that ROPS can essentially eliminate roll-over fatalities. In the United States, the only fatalities associated with roll-overs of tractors that did have ROPS occurred when farmers did not use a seatbelt to hold them within the protective envelope of the ROPS. It is important to note that a significant proportion of the reduction in fatalities in Europe may be due to the requirement for crush-proof ROPS cabs, which do not require the operator to use a seatbelt. A ROPS cab also greatly reduces the opportunity for contact with objects that may penetrate a ROPS frame during a roll-over event.

Unfortunately, ROPS or crush-proof cabs, which are designed to protect the farmer during a roll-over incident, are currently used on only about 50% of the estimated 4.8 million tractors in the United States. Cost estimates of programs to retrofit older tractors with ROPS range from approximately $500,000 to $900,000 per life saved, within the range of other accepted life-saving interventions.[31] Poverty is an obvious barrier for some farmers, and the risk of fatality from tractor roll-overs is disproportionately high among poor and minority farmers since they do not have the resources to invest in newer equipment.[10] Unfortunately, acceptance of ROPS by farmers remains a significant barrier regardless of cost. Only 12% of New York farmers were willing to pay for the costs of rollbar retrofits ($400) or cabs ($2000).[30] Even more disconcerting is that only an additional 10% were willing to accept free retrofits, and 40% stated they would not accept retrofits even if provided at no cost.[30]

Given current trends in replacing older tractors with newer models incorporating ROPS, close to 1500 U.S. farmers will die from tractor roll-overs in the next 24 years.[21] These deaths are preventable, as demonstrated by evidence from Scandinavia. In 1997, stakeholders representing tractor manufacturers/dealers, farmers, academics, government, and the insurance industry met in Iowa at the Tractor Risk Abatement and Control Policy Conference to develop a consensus document

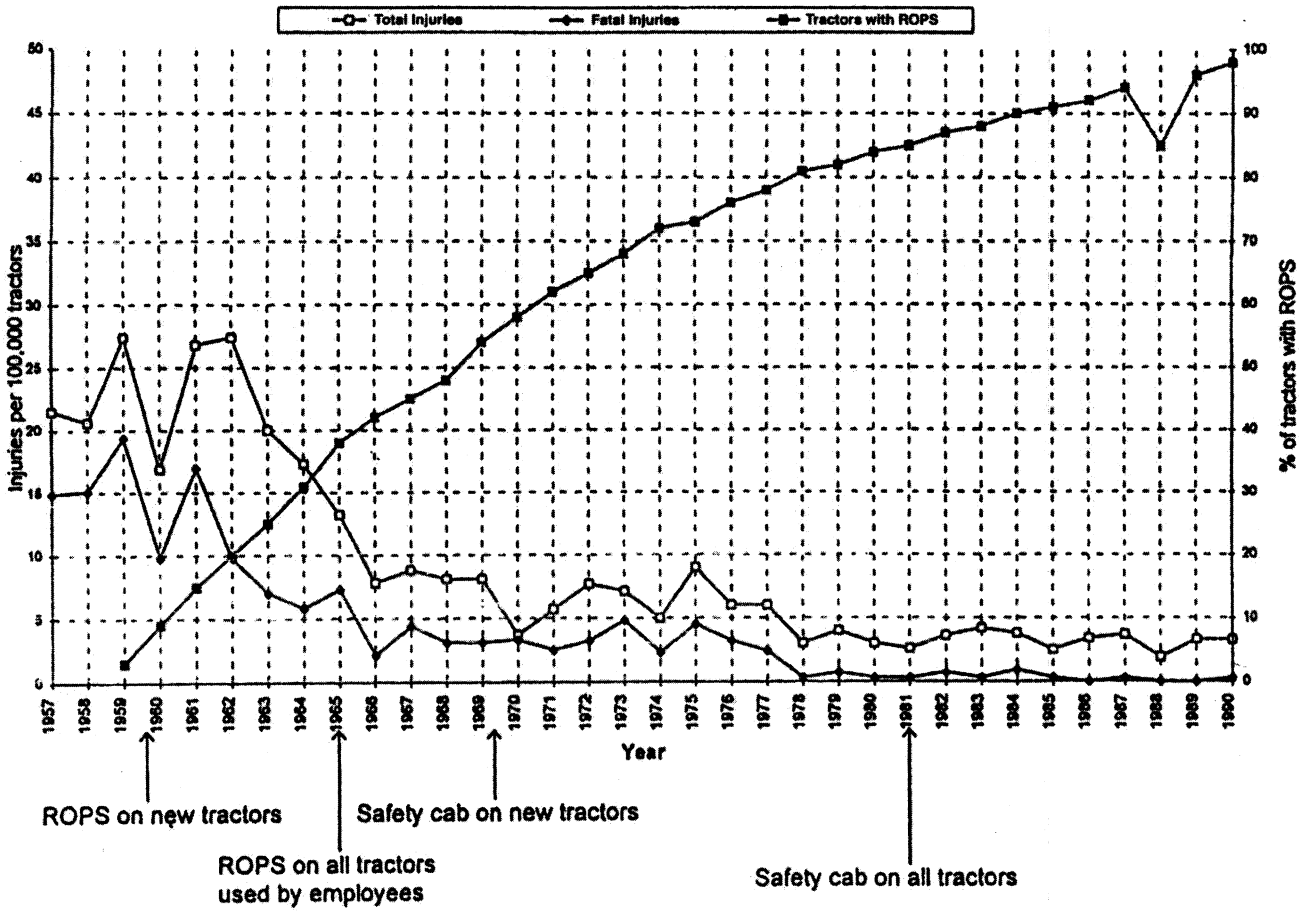

Figure 2. Roll-over injuries per 100,000 tractors in Sweden, 1957–1990. Years in which new regulations were introduced are marked (from Springfeldt et al.[12]).

providing guidance for improved intervention.[28] In addition to specific recommendations for the private sector, model state and federal legislation was developed addressing research needs, liability issues, and insurance incentives. This model also included regulations requiring tractor operators under the age of 18 to have a valid driver's license, and specifying that all tractors sold after 2005 (whether new or used) must be equipped with ROPS. Important research on ROPS intervention effectiveness is also currently underway at the University of Kentucky's Southeast Center for Agricultural Health and Injury Prevention.

Future research efforts should include the development of collapsible and telescoping ROPS that are useable in low-clearance areas such as dairy barns and fruit orchards. ROPS retrofits also need to be developed for many older tractor models. The relative effectiveness of ROPS frames compared to crush-proof cabs also needs to be further evaluated. It is apparent that engineering controls alone are not sufficient, and effort should also be directed toward development of educational and incentive programs to increase the acceptance and use of ROPS among U.S. farmers. Economic strategies are also needed to ensure that farmers with the oldest tractors and fewest resources are addressed. Implementation of national and state legislation would be most helpful in ensuring that all tractors operated in the United States are equipped with ROPS or crush-proof cabs.

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