

Prevention Effectiveness of Rollover Protective Structures—Part II: Decision Analysis

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Abstract

This is the second of three articles that evaluate the consequences of using rollover protective structures (ROPS) on agricultural tractors. It presents the results of a decision analysis that compares three strategies for preventing injuries when agricultural tractors without ROPS overturn. The three strategies examined are “do nothing”, “install ROPS”, and “replace tractor”. The strategies are implemented over a five-year period and health outcomes expressed as fatal and nonfatal injuries are calculated over a 23-year period. The “do nothing” strategy would result in 1,450 fatalities and 1,806 nonfatal injuries, while the “install ROPS” strategy would prevent 1,176 fatalities and 957 nonfatal injuries, and the “replace tractor” strategy would prevent 1,188 fatalities and 967 nonfatal injuries. The latter two strategies reflect more than an 80% reduction in fatalities and about 53% reduction in nonfatal injuries. The study does not consider overturn injuries that result from tractors lacking ROPS and for which ROPS are unavailable.

Keywords: ROPS, Tractor, Overturn, Prevention, Decision tree.

The purpose of this study is to examine the effectiveness of rollover protective structures (ROPS) to prevent fatal and nonfatal occupational injuries associated with agricultural tractor overturns. This article is the second of three parts. Part I presented the history of the safety problem of tractor overturns and a review of evolving solutions from a prevention effectiveness perspective. It established the intervention strategies that are known to work, which is a necessary precondition for conducting a decision analysis. This article compares alternative strategies for preventing injuries and deaths from tractor overturns. Part III, to follow this article, will assess the cost-effectiveness of ROPS relative to other intervention strategies by incorporating costs associated with the health outcomes examined in Part II.

The National Safety Council (NSC) estimates that 2,191 deaths resulted from agricultural tractor overturns for the 11-year period 1985 to 1995 (NSC, 1997). These deaths account for more than one-third of all production agriculture-related fatalities in the United States (Murphy and Yoder, 1998).

As shown in Part I of this series of articles, ROPS is a proven technology for preventing fatalities from tractor overturns. Recognizing this technology as an intervention strategy that works, the Centers for Disease Control and Prevention

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(CDC) published an analysis in 1993 of the effectiveness of ROPS to prevent injuries associated with agricultural tractor overturns. ROPS are frames attached to tractors or built into tractor cabs that are designed to protect the operator if the tractor overturns. Safety restraints (seatbelts) are used in combination with this structure to keep the operator within a protective "zone". In the absence of a ROPS, tractor manufacturers recommend not wearing a seatbelt on tractors (Deere, 1994).

The Occupational Safety and Health Administration (OSHA) established a standard that became effective in 1976 requiring ROPS on all tractors used by farm employees (OSHA, 1975). However, this standard covered neither self-employed farmers nor their family members. Furthermore, farm enterprises employing 10 or fewer workers were exempt from the enforcement of the standard. These limitations rendered the standard nearly ineffective (Karlson and Noren, 1979). U.S. manufacturers decided to voluntarily install ROPS on tractors as standard equipment since 1985, based on an ASAE standard (1985).

Another intervention strategy that prevents injuries from tractor overturns involves replacing non-ROPS tractors with newer, ROPS-equipped ones. This replacement will naturally occur as older tractors are replaced with newer ones, but since tractors are very durable, it may take several decades before the replacement occurs.

The decision analysis that will be presented compares the health outcomes of the two alternative intervention strategies discussed, relative to not intervening. Following this article, Part III of the study will further examine the decision analysis results using economic analysis.

Methods

Incorporating expected utility theory into economic theory provided the theoretical foundation of decision analysis (von Neumann and Morgenstern, 1947). The definition, uses, and methodology of decision analysis and economic evaluation for public health interventions are discussed in a recent CDC publication (Haddix et al., 1996). Accordingly, decision analysis is defined as the explicit, quantitative, and systematic approach for assessing the relative value of different decision options under uncertainty. It complements professional judgement or expertise and is used for complex decisions and unclear choices, and when choices are known to be efficacious, competitive options exist, and the consequences are significant. The fundamental tool used in decision analysis is the decision tree.

Efforts to apply decision analysis to medical and public health issues began 40 years ago, but the method has been widely applied since the 1980s (Snider et al., 1996). Applications of decision analysis to public health issues include, among others, studies on alternative strategies for folic acid intake for women of child-bearing age to prevent neural tube defects (Kelly et al., 1996), vaccinating infants against hepatitis B (Krahn and Detsky, 1993), screening for diabetic retinopathy (Dasbach et al., 1991), partner notification to prevent pelvic inflammatory disease in women (Howell et al., 1997), and preventing cumulative trauma disorders (Mitchell, 1995).

Model

Decision analysis is used to assess fatal and nonfatal injuries associated with the alternative intervention strategies. A decision tree is developed (Haddix et al., 1996) and shown in figure 1 that includes three major strategies: (1) do nothing, (2) install

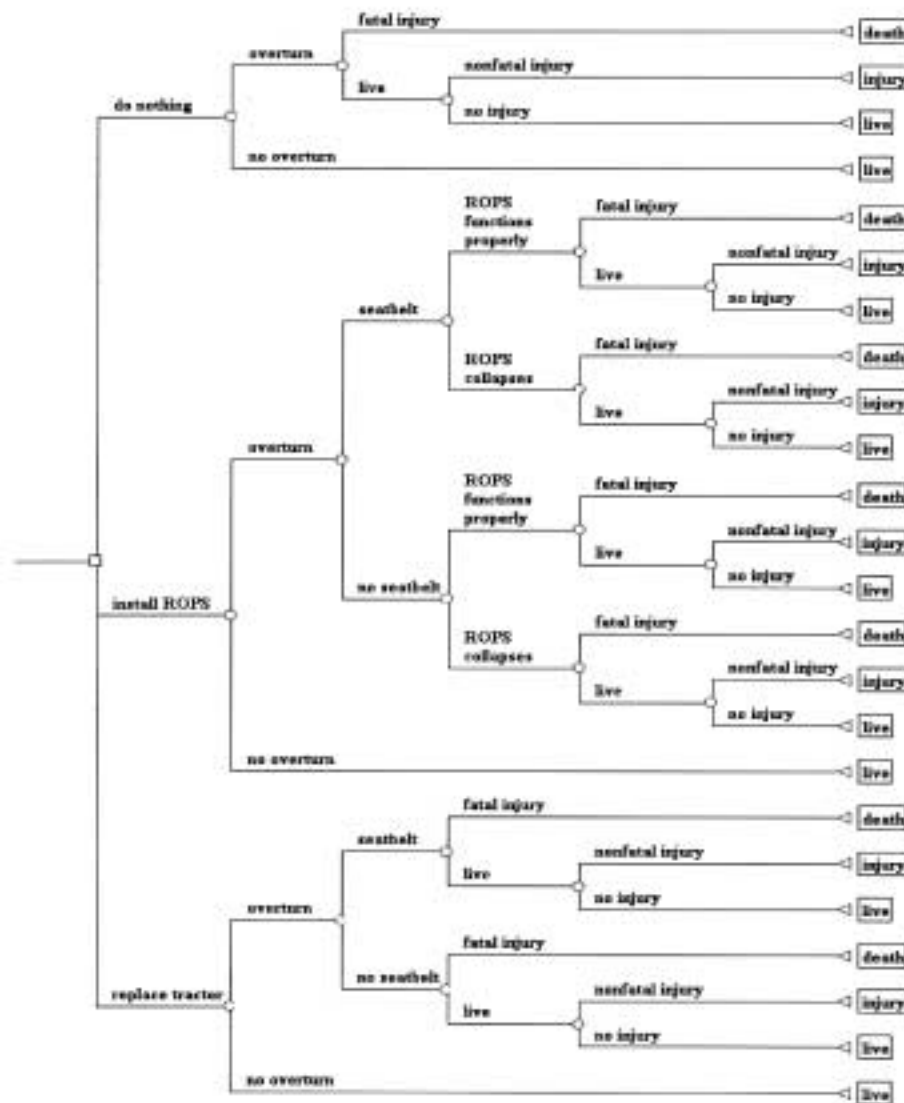


Figure 1—A decision tree showing three alternative strategies and health outcomes associated with tractor overturns.

ROPS, and (3) replace tractor. The following probabilities are used in the decision tree:

- The annual probability of an overturn per 2,000 h of tractor operation.
- The probability of death resulting from an overturn.
- The probability of a nonfatal injury resulting from an overturn, given survival.
- The probability of using a seatbelt.
- The probability of a ROPS functioning without failure.

Under the “do nothing” strategy, a full-time tractor operator has a given annual probability of having an overturn. If there is no overturn, neither benefits nor costs

are incurred. In the event of an overturn, the consequences can be either a fatal injury or no fatal injury. If the operator survives the overturn, he or she may incur a nonfatal injury.

Under the “install ROPS” strategy, the probability of an overturn is the same as in the “do nothing” strategy. A ROPS is more effective when used with a seatbelt. In a few cases, ROPS have failed because of breakage or deformation, usually in rear overturns (Springfeldt, 1998; Arndt, 1971). The combined integrity of the protective frame, its connection points to the chassis, and the strength of the chassis in withstanding overturn forces is an issue. Following an overturn, the operator may incur either a fatal injury, a nonfatal injury, or no injury with different probabilities depending upon whether he or she wore a seatbelt and the ROPS functioned properly.

Outcomes can vary depending upon the effectiveness of seatbelts to prevent fatal and nonfatal injuries from tractor overturns. There are four combined seatbelt and ROPS effectiveness variables, described below:

- Effectiveness of a properly functioning ROPS with no seatbelt use to reduce the probability of fatal injury after an overturn.
- Effectiveness of a properly functioning ROPS and seatbelt use to reduce the probability of fatal injury after an overturn.
- Effectiveness of a properly functioning ROPS with no seatbelt use to reduce the probability of nonfatal injury, given that the tractor operator did not die after an overturn.
- Effectiveness of a properly functioning ROPS and seatbelt use to reduce the probability of nonfatal injury, given that the tractor operator did not die after an overturn.

Under the “replace tractor” strategy, there is no risk from unprotected tractor use because a newer ROPS-equipped tractor would replace the one that lacked a ROPS. The events following an overturn are the same as under the “install ROPS” strategy, except for the possibility of the ROPS failing, which is unlikely on newer tractors.

For each strategy, the annual expected fatal and nonfatal injuries are estimated for a full-time tractor operator and multiplied by the total expected number of hours of operation by full-time tractor operators throughout the analytic horizon of the study. As a result, the total number of fatal and nonfatal injuries for each strategy is estimated.

Data and Assumptions

Data used in the decision analysis were derived from (1) published studies; (2) unpublished data from local, state, and national sources; and (3) consultation with national ROPS experts to provide estimates whenever empirical data were sparse or lacking. The sensitivity of the model to its variables was analyzed by varying their values within a range based on existing literature and expert opinion. Where data were lacking, extreme values were used to examine their effect upon the outcomes. The software DATA was used to create the decision tree and to derive the annual expected fatal and nonfatal injuries, and the software Microsoft EXCEL was used to derive the total number of fatal and nonfatal injuries throughout the analytic horizon of the study.

The perspective for this analysis is social in which all benefits and costs to society are considered. It is recommended that public health studies take the societal perspective in order to capture what society gains and gives up now and in the future to implement the intervention in question (Farnham et al., 1996).

A five-year time frame was used for either installing ROPS or replacing tractors at a rate of 20% per year. An analytic horizon of 23 years was used. Following the same reasoning with Myers and Snyder (1995), we estimated that if all retrofittable tractors had a ROPS installed at the beginning of the study's time frame, the level of protected hours of tractor operation would be 76% of total hours of tractor operation. The same level of protected versus total hours of tractor operation would be achieved in 23 years without the intervention.

The population of tractors in the United States can be divided into three categories from an engineering perspective. The first category of (pre-ROPS) tractors was manufactured prior to 1970, and they typically neither have nor were designed for ROPS. However, several ROPS retrofit designs have since emerged for many of the tractors from this period. The second category includes tractors manufactured during 1970 to 1985, that were designed for ROPS, but typically did not have them mounted unless cabs were installed that integrated ROPS into the design (Baker, 1992). The third category includes nearly all the tractors manufactured in the United States since 1985 that have ROPS installed. Sometimes farmers remove the ROPS because they may interfere with driving through agricultural structures' doors or under tree limbs (Myers, 1998), but foldable or telescoping ROPS are available for these circumstances. The percentage of ROPS-equipped tractors that have their ROPS removed is estimated to be 5% (NIOSH, 1996).

It was assumed that the strategies examined would apply to the number of tractors that lack a ROPS and for which a ROPS is available. This excludes those tractors for which no ROPS has been designed. It was further assumed that non-ROPS tractors are used on average 238 h per year during the analytic horizon of this study; this is lower than the annual average use of ROPS-equipped tractors, which is estimated at more than 400 h (Myers and Snyder, 1995).

The annual number of retrofittable tractors is presented in table 1 and was calculated according to the method described in Myers and Snyder (1995). Utilizing data collected through the Traumatic Injury Surveillance of Farmers study, they estimated the national number of tractors with and without ROPS by tractor age. Then they estimated the population of retrofittable tractors in 1993 and projected the number of such tractors after 10 and 20 years by assuming different retirement rates depending on tractor age. Finally, by allocating the respective annual average hours of operation to tractors with and without ROPS, they projected protected versus unprotected hours of tractor operation for the length of their analytic horizon.

Ideally, the unit of intervention used in our study would have been farm household, but the national data available and previous analyses found in the literature use 2,000 h of annual tractor operation instead (Myers, 1997; Myers and Snyder, 1995). In our study we also express national estimates on fatal and nonfatal injuries associated with overturns as injuries per 2,000 h of annual tractor operation, which is the amount of time a full-time worker would spend operating a tractor according to the Bureau of Labor Statistics definition of a full-time worker.

Outcomes are expressed as fatal and nonfatal injuries. Given that a nonfatal injury has very different health consequences from a fatality and that nonfatal injuries range from mild to severe, a common outcome measure such as quality-adjusted-life-years (QALYs), would capture these disparities by incorporating the quality or desirability of a health state to the duration of survival (Haddix et al., pg 150). However to calculate QALYs, one needs a detailed account of the kinds of injuries due to an overturn, the age and number of tractor operators incurring each type of injury, life expectancy for farmers at different age groups with and without

Table 1. Number of tractors without ROPS, number of retrofittable tractors, and hours of use of retrofittable tractors, 1997-2019

Year Count	Calendar Year	Tractors Without ROPS	Retrofittable Tractors	Hours of Use of Retrofittable Tractors
0	1997	2,708,126	1,215,949	289,395,767
1	1998	2,660,151	1,194,408	284,269,104
2	1999	2,612,177	1,172,867	279,142,441
3	2000	2,564,202	1,151,327	274,015,778
4	2001	2,516,228	1,129,786	268,889,116
5	2002	2,468,253	1,108,246	263,762,453
6	2003	2,420,278	1,086,705	258,635,790
7	2004	2,372,304	1,065,164	253,509,127
8	2005	2,324,329	1,043,624	248,382,464
9	2006	2,276,355	1,022,083	243,255,802
10	2007	2,228,380	1,000,543	238,129,139
11	2008	2,180,405	979,002	233,002,476
12	2009	2,132,431	957,461	227,875,813
13	2010	2,084,456	935,921	222,749,150
14	2011	2,036,482	914,380	217,622,488
15	2012	1,988,507	892,840	212,495,825
16	2013	1,940,532	871,299	207,369,162
17	2014	1,892,558	849,758	202,242,499
18	2015	1,844,583	828,218	197,115,836
19	2016	1,796,608	806,677	191,989,174
20	2017	1,748,634	785,137	186,862,511
21	2018	1,700,659	763,596	181,735,848
22	2019	1,652,685	742,055	176,609,185

Source: Myers and Snyder, 1995 (differences from the original tables are due to rounding).

the specific injuries examined, and “utility” values assigned to years of life lived with a certain injury. While we appreciate the usefulness of such an outcome measure that would allow for comparison among different kinds of interventions, we did not have the necessary information to calculate QALYs from overturn injuries. Therefore we estimate expected fatal and nonfatal injuries separately, and in Part III, we also calculate cost-effectiveness ratios per (fatal or nonfatal) injury prevented.

Outcomes can vary depending upon the effect of the combinations of seatbelt use and proper functioning of retrofitted ROPS. The events following the failure of a retrofitted ROPS after an overturn were assumed to be the same as those following an overturn without a ROPS.

The base-case probability values used in this analysis, alternative probability values, and sources of data are summarized in table 2. Details on how we calculated probability and effectiveness values for which no direct sources were available are presented in the Appendix.

Results

The total expected fatal and nonfatal injuries for the base-case values and sensitivity analyses according to different scenarios are presented in table 3.

Table 2. Base-case and alternative values for probabilities used to evaluate the effectiveness of ROPS

Variables	Base-case	References	Alternative Values	References
Overturn per 2,000 hours of annual use.	0.00145	Calculated using table 1; NSC, 1998; and CDC, 1993.	---	---
Fatal injury after overturn of tractor without ROPS.	0.4	CDC, 1993.	0.00, 1.00	Assumed
Nonfatal injury given survival after overturn of tractor without ROPS.	0.83	Calculated using NIOSH, 1996, and CDC, 1993.	0.00, 1.00	Assumed
Seatbelt use on tractors with ROPS.	0.08	Kelsey et al., 1996.	0.00, 1.00	Assumed
Retrofitted ROPS functions properly after overturn.	0.99	Expert opinion: NIOSH, Univ. of Kentucky; Woodward and Swan, 1980.	0.50	Assumed
Effectiveness of ROPS without seatbelts to reduce fatal injury after an overturn.	0.95	Calculated using CDC, 1993.	0.00, 0.50, 1.00	Assumed
Effectiveness of ROPS with seatbelts to reduce fatal injury after an overturn.	1.00	Assumed.	0.50, 0.95	Assumed
Effectiveness of ROPS without seatbelts to reduce non-fatal injury given survival after an overturn.	0.76	Calculated using CDC, 1993, and NIOSH, 1996.	0.39, 0.88, 1.00	Assumed
Effectiveness of ROPS with seatbelts to prevent nonfatal injury given survival after an overturn.	0.88	Assumed.	0.39, 0.76, 1.00	Assumed

“Do nothing” Strategy

About 1,450 full-time tractor operators would be expected to die from tractor overturns with no intervention over a 23-year period. An additional 1,806 operators who survive an overturn during this period of time would be expected to incur nonfatal injuries.

“Install ROPS” Strategy

Installing ROPS would reduce the number of fatal injuries to 274, preventing 1,176 fatalities over the 23 years following initiation of a program to install ROPS on 100% of the tractors for which a ROPS has been designed. The number of nonfatal injuries would be reduced to 849, preventing 957 injuries over the 23-year period.

Table 3. Results of the decision and sensitivity analyses of three strategies for preventing injuries from tractor overturns

Scenario	Out- come	Number of Injuries			Injuries Prevented	
		Do Nothing	Install ROPS	Replace Tractor	Install ROPS	Replace Tractor
Base-case.	Fatal	1,450	274	262	1,176	1,188
	Nonfatal	1,806	849	839	957	967
Interventions take place during the first year.	Fatal	1,450	81	67	1,369	1,383
	Nonfatal	1,806	691	680	1,115	1,126
Overturns result in fatal injuries only.	Fatal	3,626	685	655	2,941	2,971
Overturns result in nonfatal injuries only.	Nonfatal	3,626	1,253	1,229	2,373	2,397
Retrofitted ROPS function properly 50% of the time after an overturn.	Fatal	1,450	856	262	594	1,188
	Nonfatal	1,806	1,322	839	484	967
Tractor operators never wear their seatbelts on tractors with ROPS.	Fatal	1,450	279	267	1,171	1,183
	Nonfatal	1,806	872	863	934	943
Tractor operators always wear their seatbelts on tractors with ROPS.	Fatal	1,450	217	205	1,233	1,245
	Nonfatal	1,806	578	565	1,228	1,241
ROPS without seatbelts are not effective to reduce fatal injury after an overturn.	Fatal*	1,450	1,352	1,351	98	99
ROPS without seatbelts are 100% effective to reduce fatal injury after an overturn.	Fatal	1,450	217	205	1,233	1,245
ROPS with seatbelts are 95% effective to reduce fatal injury after an overturn.	Fatal	1,450	279	267	1,171	1,183
ROPS with and without seatbelts are 50% effective to reduce fatal injury after an overturn.	Fatal	1,450	834	828	616	622
ROPS with seatbelts are 76% effective to reduce nonfatal injury given survival after an overturn.	Nonfatal†	1,806	873	864	933	942
ROPS with seatbelts are 100% effective to reduce nonfatal injury given survival after an overturn.	Nonfatal	1,806	824	814	982	992
ROPS without seatbelts are 39% effective to reduce nonfatal injury given survival after an overturn.	Nonfatal	1,806	1,702	1,701	104	105
ROPS without seatbelts are 88% effective to reduce nonfatal injury given survival after an overturn.	Nonfatal	1,806	572	559	1,234	1,247
ROPS with and without seatbelts are 39% effective to reduce nonfatal injury given survival after an overturn.	Nonfatal	1,806	1,806	1,806	0	0
ROPS with and without seatbelts are 100% effective to reduce nonfatal injury given survival after an overturn.	Nonfatal	1,806	271	255	1,535	1,551

* The nonfatal outcomes are equal to the base-case ones for all analyses in this section.

† The fatal outcomes are equal to the base-case ones for all analyses in this section.

“Replace tractor” Strategy

Retiring and replacing the population of tractors examined under the “install ROPS” strategy would reduce the number of fatal injuries to 262, preventing 1,188 fatalities, and the number of nonfatal injuries to 839, preventing 967 nonfatal injuries over the 23-year period following initiation of the strategy.

Interventions Take Place During the First Year

If the interventions were completed in the first year rather than over a five-year period, the “install ROPS” and “replace tractor” strategies would save an additional

193 and 195 lives, respectively, and prevent 158 and 159 nonfatal injuries, respectively.

Proper Functioning of the ROPS

In the base-case scenario, it was assumed that ROPS would be 99% effective in the event of an overturn and performing without failure in the “install ROPS” strategy. When ROPS function properly 50% of the time after an overturn, the additional fatal and nonfatal injuries are 582 and 473, respectively.

Seatbelt Use and Effectiveness

The use of a seatbelt in the base-case scenario contributes five lives saved and 23 nonfatal injuries prevented in the “install ROPS” strategy. In the “replace tractor” strategy, five lives are saved and 24 nonfatal injuries are prevented by using a seatbelt 8% of the time relative to never using one. If a seatbelt is always used on a ROPS-equipped tractor, 57 additional deaths would be prevented under either the “install ROPS” strategy or the “replace tractor” strategy. An additional 271 or 274 nonfatal injuries can be prevented under the “install ROPS” or “replace tractor” strategies, respectively.

When the ROPS are 100% effective to prevent death, given the base-case rate of seatbelt use, there are 57 additional deaths prevented by either installing a ROPS or replacing the tractor. When ROPS are 100% effective to prevent nonfatal injuries, given the base-case rate of seatbelt use, there are 359 additional nonfatal injuries prevented by installing ROPS and 363 additional nonfatal injuries prevented by replacing the tractors.

Discussion

The analysis presented shows that in the base-case scenario, the “install ROPS” and “replace tractor” strategies resulted in an 81% to 82% respective reductions in fatal injuries as compared to the “do nothing” strategy. In addition, both strategies resulted in a 53% reduction in nonfatal injuries as compared to the “do nothing” strategy. From the public health perspective, either strategy is desirable as compared to the “do nothing” strategy. In Part III of this study, the results will be analyzed in terms of cost-effectiveness, which will improve the insight into the most cost-effective strategy.

Allowing tractors without ROPS results in 1,450 deaths and an additional 1,806 nonfatal but potentially serious injuries over the next 23 years. Despite strong opposition, some countries have mandated that all tractors be retrofitted with ROPS (Springfeldt, 1998). If such a policy were mounted in the United States, opposition could be also expected. Government can act against a spectrum of coerciveness, starting with information, then service, and onto endorsement, incentives, and enforcement (Millar and Myers, 1983). The first three approaches have been used in the United States, and unsuccessful attempts have been made to enforce the use of ROPS (Karlson and Noren, 1979). In combination with the other approaches, the incentive approach needs to be explored as a viable way to gain broad compliance with retrofitting ROPS on non-ROPS tractors.

Using the data available we managed to estimate an annual overturn probability per 2,000 h of tractors operation. However, surveys that provide overturn data would be helpful in further validating our base-case estimate. In addition, such surveys might provide data on alternative overturn probabilities by identifying variables that

increase or decrease the probability of an overturn, such as regional or task-specific differences in tractor usage.

No one contacted in the United States knew of a ROPS not maintaining its integrity during an overturn, but the literature refers to either pre-1970 problems in the United States (Arndt, 1971) or sparse problems in other countries (Springfeldt, 1998). The authors believe it is important to keep the possibility of a ROPS failing in the model, because an ineffective ROPS leads to significant increases in deaths and injuries. The probability we used of a retrofitted ROPS failing is consistent with the findings by Woodward and Swan (1980) for construction and mining equipment. The sensitivity analysis for the probability of retrofitted ROPS functioning properly indicated that a ROPS-equipped tractor that lacks structural integrity is no better than a non-ROPS tractor. In fact, it may be worse because it gives the operator a false sense of security.

The most serious limitation of this study is that it does not consider a significant number of tractors for which there is no ROPS design. Table 1 shows that nearly 1.5 million tractors lacked a ROPS retrofit design in 1997. If retrofits existed for these tractors, installing ROPS on them would prevent 1,444 additional fatal and 1,174 additional nonfatal injuries and replacing them would prevent 1,458 additional fatal and 1,185 additional nonfatal injuries, relative to doing nothing. In terms of effectiveness, the potential benefit of an investment in further retrofit designs for these tractors is significant.

Tractors are durable machines and are operated for decades. Unlike the automobile population, the population of older, non-ROPS tractors is retained typically beyond 25 or 30 years. They become inexpensive but are valuable as the only tractors on small farms or extra tractors on larger farms. As can be seen in table 1, the retention of these tractors contributes to the serious problem of non-ROPS tractors. Replacing these tractors with a more expensive tractor or installing a ROPS that may cost as much as the worth of the old tractor are difficult strategies to implement. Some type of incentive may be required.

About 5% of the tractors manufactured since 1985 lack ROPS because the farmer has removed them. The reasons for removal vary and include interference of ROPS with either tree limbs in orchards or barn doors. Foldable or telescoping ROPS are available, which can be deployed when driving beyond the obstruction (Deere, 1994). Nevertheless, how to assure that the ROPS are deployed in the absence of an obstruction requires investigation. Research is being conducted on ROPS that would automatically deploy in the event of an overturn, which may solve this problem of removal of ROPS from tractors (Snyder, 1993).

Current policy in the United States is to recommend that ROPS on tractors be accompanied with seatbelts. Although this decision analysis has shown that using seatbelts will save additional lives, it is much more important to emphasize installing a ROPS under the authority of the manufacturer. In the "install ROPS" strategy, five of the 1,176 fatal injuries prevented (0.004%) resulted from using a seatbelt 8% of the time. If a seatbelt was used all the time, 57 lives would be saved. Clearly, the priority should be on installing the ROPS, and secondarily, assuring compliance in seatbelt use. Baker (1998) recently made the same point.

Moreover, while both seatbelt use and the effectiveness of seatbelts is shown to save lives and prevent injuries, more than 90% of farmers do not currently use seatbelts and will probably continue not using them. The Swedish government mandated ROPS on all new farm tractors since 1959. Policy makers there opted not to require the "active" intervention of seatbelts but did require the more "passive" intervention of enclosed cabs to prevent the operator from being thrown outside of

the protective zone of the ROPS. In Sweden, a seatbelt is not required, but a cab is required wherein the operator is restrained in the event of an overturn (Springfeldt, 1998). The authors are planning to study the implications of adopting an active versus a passive restraint in a future study.

Conclusion

Both the "install ROPS" and "replace tractor" strategies are effective at preventing fatal and nonfatal injuries as compared to the "do nothing" strategy based upon a decision analysis. Part III of this study will address the cost-effectiveness of the three strategies and will further differentiate the most desirable social strategy for injury prevention related to tractor overturns. Several suggested actions are recommended to address the problems identified in this article:

- Conduct studies to better define the probability of a tractor overturn.
- Continue vigilance of maintaining the integrity of a ROPS during an overturn.
- Conduct studies for alternative strategies for operator restraint during an overturn.
- Address the need for a ROPS-design or tractor removal program for non-ROPS tractors for which a design is lacking.
- Investigate incentives to encourage retrofitting ROPS on non-ROPS tractors.
- Investigate solutions to the problem of farmers removing ROPS from their tractors so as to avoid interference with overhead obstructions.

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Appendix

Probability of an Overturn per 2,000 h of Annual Tractor Use

To derive an estimate for the probability of an overturn per 2,000 h of annual tractor use, the fatality rate associated with an overturn was divided by the weighted probability of fatal injury after an overturn as shown in the following formula:

$$\text{Fatality rate/weighted probability of death after an overturn} = 0.00145 \quad (1)$$

The fatality rate from overturns was calculated as 0.000266 per 2,000 h of operation using tractor operation hours for 1997. The average annual number of deaths from tractor overturns is estimated to be 200, based upon data from the NSC for the 11-year period 1985 to 1995, in which 2,191 deaths from overturns were reported (NSC, 1997). To derive the fatality rate, 200 deaths per year were multiplied by 2,000 full-time tractor operator hours per year and divided by the total annual hours of tractor operation. The total annual hours of tractor operation was calculated as 1,505 million hours by adding 645 million total unprotected hours of operation of 2.7 million non-ROPS tractors (see table 1) to 860 million total protected hours of operation of 2 million tractors with ROPS. The number of non-ROPS tractors refers to all tractors without ROPS and not only retrofittable tractors without ROPS. The number of ROPS-equipped tractors refers to tractors with either cabs or frames that are operated an average 442 and 402 h annually, respectively, as discussed in Myers and Snyder (1995).

The weighted probability of death after an overturn was calculated by adding two products as shown in the following formula:

$$U \times \text{Prd} + (1 - U) \times \text{Prd}_r = 0.425 \times 0.4 + 0.575 \times 0.22216 = 0.1828 \quad (2)$$

where U is the percentage of unprotected and (1 - U) is the percentage of protected tractors in 1997, Prd is the probability of fatal injury after an overturn of a non-ROPS tractor, and Prd_r is the probability of death following an overturn of a ROPS-equipped tractor (equal to the expected value of chance node "overturn" under the "install ROPS" strategy, assuming the base-case seatbelt use and that the ROPS collapses; see fig. 1), assuming that all tractors that had ROPS in 1997, had them retrofitted. Since we could not differentiate between ROPS-equipped tractors that had the ROPS retrofitted versus those that came as standard equipment from the manufacturer, the former was chosen in order to bias the results with the less safe strategy, e.g., higher propensity for structural failure.

Probability of Nonfatal Injury Given Survival after Overturn of a Tractor without ROPS

The probability of being injured after an overturn of a non-ROPS tractor is estimated at 50% (NIOSH, 1996). Taking the probability of survival after an overturn into account, the probability associated with nonfatal injuries was calculated using the following formula:

$$\begin{aligned} \text{Probability of injury after an overturn of a non-ROPS tractor}/(1 - \text{Prd}) = \\ 0.50/0.60 = 0.83 \end{aligned} \quad (3)$$

Probability of Retrofitted ROPS Functioning Properly after an Overturn

An empirical estimate of the probability of retrofitted ROPS functioning without failing during an overturn could not be found. However, based upon conversations with experts on the topic at NIOSH and at the University of Kentucky, it seemed reasonable to include a very small probability for ROPS failure. Based upon expert opinion, the probability of retrofitted ROPS functioning properly was assumed to be 0.99, which is consistent with experience with ROPS proper functioning in the mining and construction industries (Woodward and Swan, 1980).

Effectiveness of ROPS without Seatbelts to Reduce Fatal Injury after an Overturn

The effectiveness of a properly functioning ROPS, but no seatbelt use, to reduce the probability of death after an overturn was calculated by assuming that these deaths occur because a seatbelt is not used with the ROPS. According to CDC (1993), the probability of death after an overturn of a tractor with a ROPS that functions properly is 0.02. Then the effectiveness of ROPS to reduce fatal injury after an overturn is:

$$1 - 0.02/\text{Prd} = 0.95 \quad (4)$$

It was assumed that when the values for effectiveness variables that affect fatal injuries change, the nonfatal injury outcomes do not change. Likewise, when the values for the effectiveness variables that affect nonfatal injuries change, the fatal injury outcomes do not change.

Effectiveness of ROPS without Seatbelts to Reduce Nonfatal Injury after an Overturn

The effectiveness of a ROPS-equipped tractor to reduce nonfatal injury with a properly functioning ROPS, but with no seatbelt use, was calculated to be 0.76 when the tractor operator survived an overturn, given that the probability of nonfatal injury after an overturn with ROPS is 0.20 (NIOSH, 1996). The alternative value of 0.39 is the least value the effectiveness of a ROPS-equipped tractor to reduce nonfatal injury can take when it is the only variable that changes, because it satisfies the condition that the expected nonfatal injury with "replace tractor" after the chance node "no seatbelt" does not exceed the expected nonfatal injury with "install ROPS" after the respective chance node (see fig. 1).

Effectiveness of ROPS with Seatbelts to Reduce Fatal Injury after an Overturn

For lack of better data the assumption was made that not using a seatbelt will be half as effective as using a seatbelt in reducing the probability of nonfatal injuries

after an overturn of a ROPS-equipped tractor. Then the effectiveness of the combination of a ROPS-equipped tractor on which the ROPS functions without failure and on which an operator uses a seatbelt, given that the tractor operator did not die after an overturn, was assumed to be 0.88. The lowest value the effectiveness of a ROPS-equipped tractor with seatbelt use to reduce nonfatal injuries can take is the expected probability of nonfatal injury with the alternative interventions, which will be no larger than the expected probability of nonfatal injury without any intervention. Since "do nothing" results in an annual expected probability of nonfatal injury equal to 0.000722, the lowest value the effectiveness of using a seatbelt on a ROPS-equipped tractor to reduce nonfatal injuries can take is 0.39. When the effectiveness of a ROPS-equipped tractor without seatbelt use to reduce nonfatal injuries is equal to 0.39 as well, it will result in an annual expected probability of nonfatal injury with any intervention being equal to 0.000722.

