Prevention Effectiveness of Rollover Protective Structures—Part III: Economic Analysis

R. Pana-Cryan, M. L. Myers

Abstract

The purpose of this part of the study is to assess the costs and benefits of either installing rollover protective structures (ROPS) on tractors lacking ROPS and for which ROPS are available or replacing the tractors with newer ROPS-equipped ones, relative to doing nothing. The methods used are cost-effectiveness and cost-benefit analyses. The cost-effectiveness analysis shows that compared to the "do nothing" strategy, the "install ROPS" strategy would cost $489,373 per injury averted and the "replace tractor" strategy would cost $14.3 million per injury averted over a 23-year period. The cost-benefit analysis shows that compared to the "do nothing" strategy, the "install ROPS" strategy would save society $1.5 billion while the "replace tractor" strategy would cost society $18.7 billion. While both the "install ROPS" and the "replace tractor" strategies are effective at saving lives and preventing injuries, this study has concluded that the preferred strategy in terms of cost-effectiveness is to "install ROPS" on tractors lacking them and for which ROPS are available.

Keywords. ROPS, Tractors, Cost-effectiveness, Cost-benefit, Injuries, Fatalities.

This is the third part of a prevention effectiveness analysis of rollover protective structures (ROPS) to prevent fatal and nonfatal injuries associated with agricultural tractor overturns. This part of the analysis incorporates a cost component to the decision analysis used in part II to estimate health outcomes for two intervention strategies to prevent injuries from tractor overturns as compared to doing nothing. Readers should refer to part II for a detailed discussion of the assumptions used in the decision analysis and the results derived from that analysis. Only additional assumptions, variables used, and results derived from the combination of costs and health outcomes are discussed in the sections that follow.

Previous cost-effectiveness studies of ROPS did not include productivity losses associated with fatal injuries from overturns (Myers and Snyder, 1995) or the number and cost of nonfatal injuries resulting from overturns (Kelsey and Jenkins, 1991; Myers and Snyder, 1995). As a result, these studies overestimated the net costs incurred using ROPS as an intervention strategy for reducing the fatal and nonfatal injuries associated with tractor overturns.

The purpose of this part of the study is to assess the cost-effectiveness of either installing ROPS on tractors lacking ROPS and for which ROPS are available or replacing these tractors with newer ones with ROPS, relative to doing nothing. In

The authors are Regina Pana-Cryan, PhD, Visiting Associate, NIOSH/CDC, Atlanta, Ga., and Melvin L. Myers, *ASAE Member Engineer,* MPA, NIOSH/CDC (retired), Avondale Estates, Ga. Corresponding author: Regina Pana-Cryan, NIOSH/CDC, 1600 Clifton Rd., NE, MS D-40, Atlanta, GA 30333, phone: 404.639.4352, fax: 404. 639.2196. e-mail: <rfp2@cdc.gov>.

addition, cost-benefit results are presented comparing doing nothing with each alternative intervention. The audience for this evaluation is policymakers at the Federal, state, and corporate levels who can influence decisions regarding the protective measures used to prevent tractor overturn injuries.

Methods

Model

Part II discussed the perspective, alternative strategies, time frame, analytic horizon, and unit of intervention used in the study. The perspective used is social, which means that all costs and benefits are considered regardless of who incurs costs or benefits from the interventions. The three strategies analyzed are "do nothing" compared to the alternatives "install ROPS" or "replace tractor". The time frame and analytic horizon considered are five and 23 years, respectively. The unit of intervention used is hours of annual tractor use per full-time operator. While the study focuses mostly on the results of a cost-effectiveness analysis, results from a cost-benefit analysis are presented as well. In addition, summary results are expressed as break-even costs per tractor retrofitted or replaced, calculated by dividing the net cost of the interventions by the number of tractors retrofitted or replaced. For example, the break-even cost per tractor retrofitted shows how much a ROPS would have to cost on average, in order for the costs of the intervention to equal the savings from the injuries prevented due to the intervention. While interventions do not inherently aim at breaking even, the authors believe that this additional summary outcome provides useful intuitive information to policymakers.

To estimate cost-effectiveness and cost-benefit results, the health outcomes derived in part II of the study are combined with the cost of fatal and nonfatal injuries estimated using the cost of illness and willingness to pay approaches, respectively. All future costs and health outcomes are discounted. Sensitivity analyses are performed in which the base-case values of variables are varied in order to assess how much the results change when the value of each variable alone changes or the values for a combination of variables change simultaneously.

Cost-effectiveness Analysis. Cost-effectiveness analysis is recommended for comparing alternative strategies with identical goals, providing empirical support for programs with low cost-effectiveness ratios, and identifying programs that are not worth their cost (Haddix and Shaffer, 1996). Examples of published cost-effectiveness analyses include, among others, studies on bicycle helmet use interventions (Hatziandreou et al., 1995), a comparison of the costs and benefits of 57 life-saving programs that included the implementation of mandatory air bags and speed limits (Graham and Vaupel, 1981), and a compilation of cost-effectiveness ratios for 587 life-saving interventions, 131 of which were on fatal injury reduction interventions, such as airplane, automobile safety, traffic safety, construction safety, and fire prevention (Tengs et al., 1995). This type of analysis is appropriate for the problem at hand, because both of the alternative interventions that are compared to doing nothing aim at reducing fatal and nonfatal injuries from tractor overturns. In addition, the study's results identify the alternative strategy with the lowest cost-effectiveness ratio and provide empirical support in favor of that alternative strategy and against the other.

The outcomes of a cost-effectiveness analysis include costs and health outcomes associated with the implementation of the intervention. The most informative summary result of such an analysis is an average cost-effectiveness ratio that is

calculated for each intervention by dividing the net cost of the intervention by the adverse health outcomes averted. In this study, the adverse health outcomes averted are total injuries prevented by implementing each of the alternative interventions compared to doing nothing. The net cost of each alternative intervention is calculated by subtracting the cost of injuries prevented from the implementation cost of each intervention. The cost-effectiveness ratio of net costs divided by total injuries prevented is referred to as "cost per injury prevented".

It is recommended that the "cost of illness" approach is used to assess the costs of illness or injury to be used in cost-effectiveness analyses (Haddix and Shaffer, 1996). According to the cost of illness approach, direct medical and non-medical costs are considered. Direct medical costs measure resources for medical treatment, for example, the cost of a physician visit, while non-medical costs are incurred in connection with the injury but not expended for medical care itself, for example, transportation costs associated with a physician visit (Haddix and Shaffer, 1996). In addition, the cost of illness approach considers indirect costs associated with lost productivity due to morbidity or premature mortality, but excludes the cost of pain and suffering experienced by the ill or injured individuals. Because it does not capture all the costs associated with morbidity or mortality, the cost of illness approach underestimates the consequences of illness or injury. While they are not comprehensive, morbidity and mortality costs estimated according to the cost of illness approach are more intuitive and tractable than morbidity and mortality costs estimated according to the willingness approach, which is briefly discussed in the following section.

Since published cost-effectiveness analyses lack comparability, results are presented in a number of alternative ways to allow for comparison among this and other studies. The results presented include all the health and cost outcomes for the base-case assumptions and summary results expressed as cost per injury prevented for the base-case and sensitivity analyses.

Cost-benefit Analysis. A cost-benefit analysis is also presented, because such an analysis is most useful before a program is implemented, to evaluate whether the program produces net savings, and when an intervention produces multiple health outcomes (Clemmer and Haddix, 1996). Cost-benefit analyses are routinely used by the Federal government in order to evaluate the impact of proposed regulations by agencies such as the U.S. Environmental Protection Agency, the U.S. National Highway Traffic Safety Administration, The U.S. Department of Agriculture, and the U.S. Department of Health and Human services (U.S. Office of Management and Budget, 1999). The outcomes of a cost-benefit analysis are costs only, because adverse health outcomes are "translated" into dollars. The summary result of such an analysis is net savings or net cost for each alternative intervention calculated by subtracting the cost of adverse health outcomes averted from the implementation cost of each intervention.

It is recommended that the costs of illness or injury used in cost-benefit analyses are assessed according to society's "willingness to pay" to reduce the risk of injury or illness (Haddix and Shaffer, 1996). The willingness to pay approach "attempts to measure the value an individual places on reducing the risk of injury or illness by estimating the maximum amount an individual would pay in a given risk-reducing situation" (Clemmer and Haddix, 1996, pg 92) and is extensively discussed in Viscusi (1993) and Leigh et al. (1996). Willingness to pay estimates do not distinguish between direct and indirect costs and include costs for pain and suffering. Typically, willingness to pay costs overestimate the consequences of injury

or illness, because given society's limited resources, there exists an upper bound of how much can be spent for improved safety and health.

Discount Rate

According to recent recommendations discussed in Shaffer and Haddix (1996) and Lipscomb et al. (1996), cost-effectiveness analyses that take the societal perspective must use a social real discount rate of 3% to 5% for discounting both health and cost outcomes. This study relies on the cost of illness estimates derived by Leigh et al. (1996) using a 4% discount rate. For consistency, a 4% rate is also chosen for discounting health outcomes and costs of implementing the alternative interventions. The discount rate used is within the recommended range, and sensitivity analyses are performed for the recommended low and high rates of 0% and 8%, respectively (Shaffer and Haddix, 1996; Lipscomb et al., 1996).

Health Outcomes

In part II of the study only health outcomes were estimated and their undiscounted values were presented. While this is appropriate when health outcomes are the only outcomes of a study, in cost-effectiveness analyses the discounted future values of health outcomes should be considered for the calculation of cost-effectiveness ratios (Shaffer and Haddix, 1996; Lipscomb et al., 1996). If costs are discounted and health outcomes are not discounted at the same rate, the cost per health outcome prevented would decrease over time (Shaffer and Haddix, 1996). Table 1 presents undiscounted and discounted health outcomes for the three interventions examined.

Cost of Injuries

Since both cost-effectiveness and cost-benefit methods are used, the costs of fatal and nonfatal injuries are expressed according to both the cost of illness approach (to be used in the cost-effectiveness analysis) and the willingness to pay approach (to be used in the cost-benefit analysis).

Cost of Illness. To estimate costs for injuries from agricultural tractor overturns, detailed information is needed on the nature and severity of the injuries, and direct and indirect costs associated with injuries of different severity, including whether they involved time away from work. While there exists partial information on these variables in several studies, differences in definitions and calculation methods among studies do not allow for a meaningful compilation of the existing data in order to derive cost estimates for fatal and nonfatal injuries from tractor overturns.

Because there is very limited information on the costs of injuries from tractor overturns, we used the estimates derived by Leigh et al. (1996) for direct (lifetime medical, insurance administrative, property damage, police and fire services, and injuries to third parties) and indirect (lost earnings, household production, fringe benefits, and time-loss) costs of fatal and nonfatal occupational injuries. For a detailed discussion of the assumptions they used, the reader is referred to their

Table 1. Undiscounted and discounted health outcomes of the interventions, 1997-2019

	Do Nothing		Install ROPS		Replace Tractor	
Injuries	Undisc.	Disc.	Undisc.	Disc.	Undisc.	Disc.
Fatal	1,450	1,038	274	242	262	234
Nonfatal	1,806	1,293	849	645	839	638
Total	3,256	2,331	1,123	887	1,101	872

Table 2. Average costs for fatal and nonfatal injuries according to cost of illness and willingness to pay

	Costs (in 1997 dollars)		
Approach and Outcomes	Direct	Indirect	Total
Cost of illness*			
Fatal injury	$46,012	$619,349	$665,361
Nonfatal injury	$4,305	$8,174	$12,479
Total	$50,317	$627,523	$677,840
Willingness to pay†			
Fatal injury			$4,575,908
Nonfatal injury			$45,759
Total			$4,621,667

* Source: Leigh et al., 1996.
† Source: Viscusi, 1993.

original work, which provides aggregate cost estimates for all occupational injuries in 1992. To derive an estimate for the cost per fatal occupational injury, we divided the aggregate cost of all fatal occupational injuries by the number of all fatal occupational injuries in 1992, as reported by Leigh et al. (1996). We divided the aggregate cost of all nonfatal occupational injuries by the number of all nonfatal occupational injuries in 1992 reported in the same study, to derive an estimate for the cost per nonfatal occupational injury. The costs adjusted for inflation are presented in table 2.

While we used the estimates for all occupational injuries, we recognize there are differences in both the rates and the costs of all occupational versus agricultural injuries. For example, comparing the study by Leigh et al. (1996) to the Traumatic Injury Surveillance of Farmers study, the most recent and comprehensive source for lost-time work injury estimates for production agriculture in 1993 (Myers, 1997), and given the differences in definitions between the two studies, it seems that the agricultural injuries fatality rate is approximately six times the respective average occupational rate, while the permanent agricultural injuries rate is approximately one-third of the respective average occupational rate.

In addition to definition-related difficulties and the differences in the rates of injuries by severity among all occupations and agriculture, estimates for costs of agricultural injuries and specifically injuries from tractor overturns are scarce. While the rate of fatalities among agricultural injuries is higher than the rate of fatalities among all occupational injuries, the average direct medical cost of fatal injuries from tractor overturns is probably lower than the average direct medical cost of all occupational fatal injuries, because the time interval between an overturn and the resulting death is very short. According to data from Kentucky, 64% of persons who suffered agricultural machinery fatalities from 1982 to 1992 died immediately and 79% of such persons died within an hour (Mouton, 1994), while a study in Wisconsin concluded that all deaths from overturns examined occurred within a day regardless of age (Karlson and Noren, 1979).

According to data from 12 interviews with surviving family members of individuals who died from tractor overturns in New York from 1985 to 1987, the estimated income forgone due to death from an overturn was $243,615 in 1987 dollars (Kelsey, 1992). This estimate did not include medical costs and property damage, but included off-farm income, opportunity cost of on-farm labor, and value of household work. Estimates of indirect costs of fatalities have been low in studies of tractor overturns, because the victims are on average older than the victims of

other occupational fatal injuries. In the study from New York, the average age was 51 years (Kelsey, 1992) and according to data based on two national occupational surveillance systems for the years 1990 through 1995, farmers 65 years old and older accounted for 40% of overturn fatalities (Myers et al., 1998).

While the average total cost of fatal injuries from tractor overturns is probably less than the respective cost of all occupational injuries, it seems that the opposite trend is true for nonfatal injuries. According to Tormoehlen and Field (1995), total lifetime costs of a spinal cord nonfatal injury, an example of a permanent disabling non-fatal agricultural injury, would be approximately $447,000 in 1995 dollars. Of the agriculture-related nonfatal injuries treated in Allegheny General Hospital, Pennsylvania, from July 1991 to December 1993, tractor overturns had the highest mean cost of $24,447, while the highest single agricultural nonfatal injury cost was a tractor overturn at $115,909 (Rausch and Young, 1993).

The high costs of nonfatal injuries from tractor overturns are due to both the severity of the injuries and the wide age range of the victims. Especially costly are injuries incurred by farmers over 65 years of age. In a study on older Kentucky farmers, 57.6% of machine injuries including amputations, fractures, and cuts were severe (Browning et al., 1998). Data from five states collected in 1990 indicate that 27.7% of injured persons from tractor-related injuries had persistent health problems, 87.7% missed more than four hours of work (with 20% missing more than a month), and 16.9% were treated in an emergency department (Lee et al., 1996). According to Rausch and Young (1993), of all nonfatal agricultural injuries that resulted in hospitalization, injuries from overturns had the highest rate of Intensive Care Unit (ICU) admissions and spent the most time in the Trauma ICU. Overturns had the highest Injury Severity Score of all agricultural injuries, while the mean cost of all agricultural injuries for ages 18 to 65 was 19% higher than the respective cost for non-agricultural injuries (Rausch and Young, 1993). For persons over 65 years of age, the mean cost of all agricultural injuries was 47% higher than the respective cost of non-agricultural injuries (Rausch and Young, 1993).

Willingness to Pay. The Viscusi (1993) estimates discussed in Leigh et al. (1996) were used for willingness to pay to prevent fatal and nonfatal injuries. They are derived mostly by labor market studies that address the tradeoffs of fatal and nonfatal risks and wages. As Viscusi (1993) mentions, even though willingness to pay estimates are not accurate, they are widely used throughout the Federal government as values of statistical life based on risk tradeoffs and they are an improvement over lost present value of future earnings estimates, because they recognize the non-pecuniary aspects of life and provide a broad index of the overall desirability of policies. The estimates were adjusted for inflation and are presented in table 2.

Cost of Prevention Strategies

The costs of the strategy “install ROPS” should include the costs of available ROPS and all other additional costs associated with this strategy, such as costs for personnel, materials, installation, maintenance, transport, educational materials, training, and participants' time. The cost of retrofitting a ROPS was approximately $700 in 1987 dollars (Kelsey and Jenkins, 1991), $937 in 1993 dollars (Myers and Snyder, 1995), and $1,000 in 1997 dollars (Scharf et al., 1998). For the base-case estimation it is assumed that the cost of a ROPS is on average $1,000. The base-case cost is doubled and reduced to half its base-case value in the sensitivity analyses.

For the strategy “replace tractor”, it is assumed that the replacement tractor is a newer tractor that was manufactured with a ROPS as opposed to having one

retrofitted. In order to estimate an average cost for such a tractor, information on tractors for sale is needed that includes the manufacturing year, horsepower, whether they have a ROPS, and the selling price. A review of publications targeting farmers and an Internet search in late February 1999, resulted in retrieval of fragmented information, with the exception of "Equipment Locator Service" (ELS), an electronic site in which 287 tractors for sale from several states across the United States were listed that were manufactured in years 1985 through 1994 and ranged from 16 to 400 hp (ELS, 1999). There were 12 tractors without ROPS and there was no information on horsepower on 37 of the tractors with ROPS (ELS, 1999). It was assumed that all tractors for sale manufactured in the period of interest were manufactured with ROPS. The average selling price for tractors with less than 60 hp was deflated to $11,243 in 1997 dollars, for all tractors with less than 100 hp to $19,574, and for all tractors with any enclosure, including two-post ROPS, four-post ROPS, and cabs, to $41,607. Tractors with less than 100 hp are considered to perform similarly to older tractors without ROPS, so the average selling price for such tractors is used for the base-case estimate. The average selling prices for tractors with less than 60 hp and for all tractors with enclosures are used as a high and a low cost alternative, respectively.

It is assumed that only used tractors will replace tractors lacking ROPS, which are mostly manufactured before 1985. While tractors without ROPS manufactured in 1970 are probably very different from tractors manufactured after 1985, it is assumed that they are more similar to such (used) tractors than to new tractors manufactured after 1994. In any case, the results of the strategy "replace tractor" can be considered lower bounds of an analysis that would include new tractors as replacements.

Results

Cost-effectiveness

The cost-effectiveness base-case results for the period 1997 to 2019 are presented in table 3. Without an intervention, the direct and indirect costs of fatal injuries would be $36 million and $484.9 million, respectively, while the direct and indirect costs of nonfatal injuries would be $4.2 million and $8 million, respectively. Installing ROPS would save $381 million in total cost of injuries (compared to doing nothing), while replacing tractors lacking ROPS would save $384.8 million in total cost of injuries (compared to doing nothing). If both direct and indirect costs are considered, the cost per injury prevented compared to doing nothing is $489,373 for the strategy "install ROPS" and $14.3 million for the strategy "replace tractor". If only direct costs are considered, the cost per injury prevented is $733,858 for the strategy "install ROPS" and $14.6 million for the strategy "replace tractor". The incremental cost per injury prevented, which shows how much it would cost to prevent an additional injury by using the next most effective intervention when strategies are ranked in order of effectiveness, would be $1.3 billion to prevent an additional injury with the strategy "replace tractor" compared to the strategy "install ROPS".

Tables 4, 5, and 6 show the cost-effectiveness summary results from sensitivity analyses performed using the same variables that were used in part II of the study and for several additional cost-related variables. Table 4 presents results for probabilities variables. If all injuries are fatal, the cost per injury prevented by installing ROPS is $75,065 and if all injuries are nonfatal, it is $667,996. Installing ROPS would cost over $1.2 million per injury prevented if the ROPS would fail

Table 3. Cost-effectiveness base-case results

Variable	Do Nothing	Install ROPS	Replace Tractor
	All Costs (in 1997 dollars)		
Intervention cost		$1,087,615,172	$21,288,979,373
Outcomes cost			
Fatal injuries			
Direct	$36,022,655	$10,073,809	$9,811,852
Indirect	$484,886,455	$135,599,483	$132,073,393
Total	$520,909,110	$145,673,292	$141,885,245
Nonfatal injuries			
Direct	$4,196,112	$2,221,052	$2,201,108
Indirect	$7,967,253	$4,217,161	$4,179,292
Total	$12,163,365	$6,438,213	$6,380,400
Total outcomes cost	$533,072,475	$152,111,505	$148,265,645
Total cost	$533,072,475	$1,239,726,677	$21,437,245,018
Cost per injury prevented		$489,373	$14,327,740
Incremental cost per injury prevented		$489,373	$1,346,501,223
	Direct Costs Only (in 1997 dollars)		
Intervention cost		$1,087,615,172	$21,288,979,373
Outcomes cost			
Fatal injuries	$36,022,655	$10,073,809	$9,811,852
Nonfatal injuries	$4,196,112	$2,221,052	$2,201,108
Total outcomes cost	$40,218,767	$12,294,861	$12,012,960
Total cost	$40,218,767	$1,099,910,033	$21,300,992,333
Cost per injury prevented		$733,858	$14,572,155
Incremental cost per injury prevented		$733,858	$1,346,738,820

Table 4. Cost-effectiveness summary results of sensitivity analyses of probabilities

Probability*	Cost per Injury Prevented (in 1997 dollars)	
	Install ROPS	Replace Tractor
Overturns result in fatal injuries only	$75,065	$10,110,050
Overturns result in nonfatal injuries only	$667,966	$13,108,221
Retrofitted ROPS function properly 50% of the time after an overturn	$1,228,000	$14,327,740
Retrofitted ROPS always function properly after an overturn	$481,706	$14,327,740
Tractor operators never wear their seatbelts on tractors with ROPS	$497,102	$14,517,989
Tractor operators always wear their seatbelts on tractors with ROPS	$412,082	$12,408,947

* For definitions and base-case values of the variables the reader should refer to Part II.

Table 5. Cost-effectiveness summary results of sensitivity analyses of effectiveness variables

Effectiveness Variable*	Cost per Injury Prevented (in 1997 dollars)	
	Install ROPS	Replace Tractor
Effectiveness Variable to Prevent Fatal Injuries		
ROPS without seatbelts are not effective to reduce fatal injury after an overturn	$1,471,178	$29,434,089
ROPS without seatbelts are 100% effective to reduce fatal injury after an overturn	$468,729	$14,036,221
ROPS with seatbelts are 95% effective to reduce fatal injury after an overturn	$491,485	$14,358,353
ROPS with and without seatbelts are 50% effective to reduce fatal injury after an overturn	$831,199	$19,595,304
Effectiveness Variable to Prevent Nonfatal Injuries		
ROPS without seatbelts are 39% effectiveness to reduce nonfatal injury after an overturn	$821,894	$23,896,378
ROPS without seatbelts are 88% effective reduce nonfatal injury after an overturn	$431,984	$12,683,556
ROPS with seatbelts are 76% effective to reduce nonfatal injury after an overturn	$494,959	$14,496,755
ROPS with seatbelts are 100% effective to reduce nonfatal injury after an overturn	$483,578	$14,162,618
ROPS with and without seatbelts are 39% effective to reduce nonfatal injury after an overturn	$710,134	$25,766,813
ROPS with and without seatbelts are 100% effective to reduce nonfatal injury after an overturn	$383,004	$11,273,289

* For definitions and base-case values of the variables the reader should refer to Part II.

Table 6. Cost-effectiveness summary results of sensitivity analyses of cost variables

Probability*	Cost per Injury Prevented (in 1997 dollars)	
	Install ROPS	Replace Tractor
Cost of replacing tractor = $11,243	$489,373	$8,117,375
Cost of replacing tractor = $41,607	$489,373	$30,752,294
Cost of retrofitting ROPS = $2,000	$1,242,569	$14,327,740
Cost of retrofitting ROPS = $500	$112,775	$14,327,740
Discount rate = 0%	$177,373	$10,280,814
Discount rate = 8%	$713,378	$17,700,777
Interventions take place during the first year	$312,729	$10,089,414

50% of the time. If tractor operators would always wear their seatbelts, the cost per injury prevented for installing ROPS would be $412,082.

Table 5 shows that the range of the cost per injury prevented for installing ROPS is $468,729 to $1.5 million for the effectiveness of ROPS without seatbelts being 100% and not effective, respectively, to prevent fatal injuries from overturns (keeping nonfatal injuries constant). The cost per injury prevented for installing ROPS ranges between $383,004 and $821,894 for ROPS with and without seatbelts being 100% and ROPS without seatbelts being 39% effective to prevent nonfatal injuries from overturns, respectively (keeping fatal injuries constant).

Table 6 presents results for cost variables. The discount rate used is an important variable, causing the cost per injury prevented for installing ROPS to range between $177,373 at 0% and $713,378 at 8% (readers are reminded that lifetime injury costs are calculated at 4%). If the interventions take place in the first year, installing ROPS would cost $312,729, which is over $176,000 less per injury prevented than it would cost in the base-case. Doubling the cost of a ROPS increases the cost per injury prevented by approximately 2.5 times, while reducing the cost of ROPS by half decreases the cost per injury prevented by more than four times.

Cost-benefit

The base-case results of the cost-benefit analysis are presented in table 7. While installing ROPS would save $1.5 billion, replacing the tractors would cost $18.7 billion. Sensitivity analyses show that installing ROPS would be cost- saving for all alternative variables values discussed in the cost-effectiveness section, except when overturns result in nonfatal injuries only that results in the strategy costing $1 billion

Table 7. Cost-benefit base-case results

	All Costs (in 1997 dollars)		
Variable	Do Nothing	Install ROPS	Replace Tractor
Intervention cost		$1,087,615,172	$21,288,979,373
Outcomes cost			
Fatal injuries	$3,582,464,506	$1,001,843,483	$975,791,832
Nonfatal injuries	$44,601,605	$23,608,156	$23,396,163
Total outcomes cost	$3,627,066,111	$1,025,451,639	$999,187,995
Total cost	$3,627,066,111	$2,113,066,811	$22,288,167,368
Net cost (savings)		($1,513,999,300)	$18,661,101,257

and when ROPS without seatbelts are ineffective to prevent death that results in the strategy costing $850.2 million. Replacing the tractors always results in a net cost to society.

Break-even Cost per Tractor

A "break-even" intervention cost per tractor retrofitted or replaced is calculated that shows how much a ROPS or a newer tractor with a ROPS would have to cost in order for the interventions to "pay for themselves". If costs are calculated according to the cost of illness approach, the results indicate that if a ROPS costs $350, the costs of retrofitting a tractor would equal the (monetary) benefits of doing so. Similarly, if a newer tractor with a ROPS costs $354, the costs of replacing tractors would equal the (monetary) benefits of such an intervention.

The purpose of cost-effectiveness analyses in public health is not to identify cost-saving (benefits exceed the costs) interventions, or interventions that result in breaking even (benefits equal the costs). Instead, the purpose of such analyses is to provide information that helps policy makers prioritize interventions given limited (societal) resources. From a societal perspective, retrofitting tractors with ROPS seems to be cost-effective. However, if costs are calculated according to the cost of illness approach, a reduction of the cost of a ROPS from its current level of $1,000 to an amount closer to $350, would make retrofitting with ROPS "more" cost-effective. While we do not examine specific mechanisms that might cause such a reduction in costs (for example, technological change that would allow for lower costs of manufacturing ROPS), we believe that this additional information would further guide policy makers.

If costs are calculated according to the willingness to pay approach, the results indicate that if a ROPS costs $2,392, the costs of retrofitting a tractor would equal the benefits, while if a newer tractor with a ROPS costs $2,416, the costs of replacing tractors would equal the benefits.

Discussion

According to the results of the cost-effectiveness analysis presented, while retrofitting tractors lacking ROPS and for which ROPS are available would prevent a total of 1,444 (discounted) fatal and nonfatal injuries, replacing such tractors with newer ones with ROPS would prevent only 15 additional injuries (table 1). The cost per injury prevented incurred by retrofitting tractors (compared to doing nothing)

would be $489,373, while the additional cost per injury prevented by replacing the tractors (compared to retrofitting them) would be $1.3 billion (table 3). These results indicate that replacing the tractors with newer ones is not a cost-effective intervention. Moreover, the cost-benefit analysis indicates that the "install ROPS" strategy is the least expensive of the three strategies at a social cost of little over $2 billion as compared to the cost of the "do nothing" strategy at $3.6 billion and the "replace tractor" strategy at $22.3 billion (table 7).

Cost-effectiveness ratios of other injury-preventing interventions indicate that $489,373 per injury prevented by retrofitting tractors with ROPS is within the range society considers acceptable. A community-wide intervention to increase bicycle helmet use was estimated to cost $37,732 per head injury prevented in 1992 dollars and not including indirect costs (Hatziandreou et al., 1995), while implementing mandatory airbags and the 55 mph speed limit cost $408,000 and $1,200,000 per life saved, respectively (Graham and Vaupel, 1981). The results of the cost-benefits analysis indicate that under the assumptions used, retrofitting with ROPS is a cost-saving intervention.

The cost-effectiveness and cost-benefit results would be more accurate if data existed on the cost of fatal and nonfatal injuries from tractor overturns. More research is needed to identify the cost of agricultural injuries in general and more specifically injuries from tractors and tractor overturns.

A model is only as good as the assumptions and data used for its estimation. While the authors believe they constructively used the data available to them, more detailed and overturn-specific data would result in a better analysis. Especially limiting was the use of cost of illness estimates that reflect all occupational injuries rather than differentiating injuries from tractor overturns. Further research into the cost of injuries related to tractor overturns would provide an improved assessment of the cost-effectiveness of retrofitting with ROPS.

While both the seatbelt use and the effectiveness of seatbelts influenced the cost per injury prevented, the fact remains that the majority of farmers do not currently use seatbelts and will probably continue not using them. In Sweden where ROPS have been mandated on all new farm tractors since 1959, policymakers opted for the more "passive" intervention of cabs without any seatbelt requirements, versus the relatively "active" intervention of installing two-post or four-post ROPS that must be used with a seatbelt (Springfeldt et al., 1998). The implications of adopting an active versus a passive ROPS intervention can be examined in a future study.

The focus of the analysis presented was on voluntary interventions. Therefore, the economic analysis did not include the additional costs of a "social control" policy in which ROPS would become mandatory by law, such as the one implemented in Sweden and discussed above. Examining such a policy would require the inclusion of enforcement costs at minimum and possibly other additional costs depending on the specifics of the policy. The comparison of a voluntary versus mandatory policy could also be examined in a future study.

While the break-even intervention costs per tractor retrofitted can be used to guide a subsidy to farmers or manufacturers in order to encourage either group to retrofit with ROPS, the distributional consequences of such a subsidy would need to be examined. The analysis presented included all costs and benefits, but the consequences of a subsidy would have different equity-related consequences depending upon who pays, for example, all taxpayers, and who benefits, for example, farmers, some of whom are taxpayers as well.

This study examined the societal perspective, which is the recommended first step for assessing a public health intervention. Examining the farmer's perspective would

provide additional insight to the research question. Farmers are expected to bear the bulk of the costs of installing ROPS, but they would also probably bear most of the injury costs after an overturn. According to the study by Lee et al. (1996), among farmers who required care for tractor-related injuries, 35% had no health insurance coverage, 57% had more than 50% of their costs covered, and 8% had less than 50% of their costs covered.

It would also be interesting to study the consequences that a catastrophic event such as serious injury or death from an overturn would have on the victim's family. Farming is usually a household operation involving several family members some of whom may be employed off the farm. Temporary or permanently losing the contribution of a family member may cause a series of adverse events beyond high health-related expenses, ranging from losing off-farm income either to recover or to care for the victim to ultimately declaring bankruptcy and losing the farm.

This study did not address the issue of whether ROPS are available consistently and in sufficient numbers to provide retrofits for all tractors that could have them. Myers et al. (1998) found that while an additional 30,000 to 40,000 tractors for which ROPS were not available in 1993 had ROPS available in 1997, 200,000 tractors for which ROPS were available in 1993 did not have them available in 1997. Understanding the dynamics of retrofit availability is a potential subject for a hazard surveillance program.

Furthermore, additional research into reducing the cost of an installed retrofit ROPS toward the break-even point is needed. The results presented indicate that reducing the cost of ROPS by half would reduce the cost per injury prevented by more than four times. New technology could reduce the current cost of ROPS and make “install ROPS” an even more cost- effective strategy for preventing fatal and nonfatal injuries.

Part III of this study shows the importance of conducting economic analysis in addition to decision analysis. In part II, both the “install ROPS” and “replace tractor” strategies were nearly indistinguishable as preferable choices over the strategy to “do nothing”. The economic analysis used in part III shows that the “install ROPS” strategy is decidedly preferable over the “replace tractor” strategy. However, this analysis overestimated the costs associated with replacing tractors, because it did not consider desirable attributes that newer tractors have, beyond manufacturer-installed ROPS. In addition to being safer, a newer tractor with ROPS might be easier and more comfortable to operate, and more productive than an older tractor lacking ROPS in ways that were not examined.

Conclusion

The implications of this study are numerous. The cost-benefit analysis shows that the “install ROPS”strategy provides savings of 1.5 billion and the “replace tractor” strategy costs $18.7 billion to society, compared to the “do nothing” strategy. The results of the cost-effectiveness analysis presented suggest that it would cost $489,373 per fatal and nonfatal injury prevented to install ROPS on tractors that lack them and for which a ROPS is available. The break-even ROPS cost per tractor retrofitted or replaced was identified as well, according to both the cost of illness and willingness to pay approaches. While these results help guide decisions on the protections needed to reduce injuries from tractor overturns, several additional analyses are needed as listed below:

- Investigations of the distributional consequences of voluntary and mandatory policies.

- Investigations on the costs of fatal and nonfatal injuries from tractor overturns.
- Studies of the type of injuries incurred as a result of a tractor overturn.
- A prevention effectiveness study of passive versus active operator restraints.
- Investigations into economic incentives to encourage the retrofitting of ROPS onto non-ROPS tractors using the "break-even" cost of ROPS as a guide.
- A decision and cost-effectiveness analysis of retrofitting ROPS on non-ROPS tractors from the farmer's perspective.
- Investigation of the catastrophic consequences of overturn injuries upon the sustainability of the family farm enterprise.
- Establishment of a hazard surveillance program to monitor the availability of ROPS retrofits for non-ROPS tractors.

ACKNOWLEDGMENTS. Appreciation is extended to Mr. John R. Myers and Drs. Karl A. Snyder, David L. Hard, and John R. Etherton at NIOSH, and to Drs. Henry P. Cole, Steven R. Browning, Larry R. Piercy, and Robert H. McKnight, and Mr. Tim W. Struttmann and Ms. Susan Westneat at the University of Kentucky, for providing the authors with data and valuable comments on earlier drafts of this article, and to Messrs. John R. Myers and Lewis A. Martin, and Drs. David L. Hard, Laura A. Blanciforti, and Scott D. Deitchman in NIOSH, for reviewing the final document.

This research was supported in part by an appointment to the Prevention Effectiveness Postdoctoral Fellowship Program at the CDC, Epidemiology Program Office, Division of Prevention Research and Analytic Methods administered from July 1996 to June 1997 by the Association of Teachers of Preventive Medicine through an interagency agreement with CDC, and from July 1997 to July 1998 by the Oak Ridge Institute for Science and Education through an interagency agreement between the US Department of Energy and CDC.

References

Browning, S. R., H. Truszczynska, D. Reed, and R. H. McKnight. 1998. Agricultural injuries among older Kentucky farmers: The Farm Family Health and Hazard Surveillance Study. *Am J Ind Med* 33(4): 341-353.

Clemmer, B., and A. C. Haddix. 1996. Cost-benefit analysis. In *Prevention Effectiveness: A Guide to Decision Analysis and Economic Evaluation*, eds. A. C. Haddix, S. M. Teutsch, P. A. Shaffer, and D. O. Dunet, 85-102. New York, N.Y.: Oxford University Press.

Equipment Locator Service, Agricultural Site. Http://www.equipment-locator.com.

Gold, M. R., J. E. Siegel, L. B. Russell, and M. C. Weinstein, eds. 1996. *Cost-effectiveness in Health and Medicine*. New York, N.Y.: Oxford University Press.

Graham, J. D., and J. W. Vaupel. 1981. Value of a life: What difference does it make? *Risk Analysis* 1(1): 89-95.

Haddix, A. C., and P. A. Shaffer. 1996. Cost-effectiveness analysis. In *Prevention Effectiveness: A Guide to Decision Analysis and Economic Evaluation*, eds. A. C. Haddix, S. M. Teutsch, P. A. Shaffer, and D. O. Dunet, 103-129. New York, N.Y.: Oxford University Press.

Haddix, A. C., S. M. Teutsch, P. A. Shaffer, and D. O. Dunet, eds. 1996. *Prevention Effectiveness: A Guide to Decision Analysis and Economic Evaluation*. New York, N.Y.: Oxford University Press.

Hatziandreou, E. J., J. J. Sacks, R. Brown, W. R. Taylor, M. L. Rosenberg, and J. D. Graham. 1995. The cost-effectiveness of three programs to increase use of bicycle helmets among children. *Public Health Reports* 110(3): 251-259.

Karlson, T., and J. Noren. 1979. Farm-tractor fatalities: The failure of voluntary safety standards. *Am J Public Health* 69(2): 146-149.

Kelsey, T. W. 1992. The economic cost of farm tractor rollover deaths in New York. *J Rural Health* 8(2): 143-46.

Kelsey, T. W., and P. L. Jenkins. 1991. Farm tractors and mandatory roll-over protection retrofits: Potential costs of the policy in New York. *Am J Public Health* 81(7): 921-923.

Lee, T. Y., S. G. Gerberich, R. W. Gibson, W. P Carr, J. Shutske, and C. M. Renier. 1996. A population-based study of tractor-related injuries: Regional Rural Injury Study-I (RRIS-I). *J Occup Environ Med* 38(8): 782-793.

Leigh, J. P., S. B. Markowitz, M. C. Fahs, J. Bernstein, L. Mishel, C. Shin, and P. J. Landrigan. 1996. Costs of occupational injuries and illnesses, 1992. In Final Report for Cooperative Agreement Inc U60/CCU902886. Atlanta, Ga.: NIOSH.

Lipscomb, J., M. C. Weinstein, and G. W. Torrence. 1996. Time preference. *Cost-effectiveness in Health and Medicine*, eds. M. R. Gold, J. E. Siegel, L. B. Russell, and M. C. Weinstein, 214-246. New York, N.Y.: Oxford University Press.

Mouton, A. J. 1994. The epidemiology of farm machinery deaths in Kentucky: 1982 to 1992. M.S. thesis. Lexington, Ky.: Department of Preventive Medicine, University of Kentucky.

Myers, J. R. 1997. *Injuries Among Farm Workers in the United States, 1993.* Cincinnati, Ohio: U.S. DHHS, PHS, CDC, NIOSH.

Myers, J. R., K. A. Snyder, D. L. Hard, V. J. Casini, R. Gianfrocco, J. Fields, and L. Morton. 1998. Statistics and epidemiology of tractor fatalities: A historical perspective. *J Agric Safety & Health* 4(2): 95-108.

Myers, J. R., and K. A. Snyder. 1995. Roll-over protective structure use and the cost of retrofitting tractors in the United States, 1993. *J Agric Safety & Health* 1(3): 185-197.

Rausch, T. J., and J. C. Young. 1993. Agricultural injuries: Financial impact on health care. Poster presented at the National Institute for Farm Safety Conference, National Institute for Farm Safety, Columbia, Mo. 13-17 June.

Scharf, T., P. Kidd, H. Cole, T. Bean, L. Chapman, K. Donham, and D. Baker. 1998. Intervention tools for farmers: Safe and productive work practices in a safe work environment. *J Agric Safety & Health* Special Issue 1: 193-203.

Springfeldt, B., J. Thorson, and B. C. Lee. 1998. Sweden's thirty-year experience with tractor rollovers. *J Agric Safety & Health* 4(3): 173-180.

Tengs, T. O., M. E. Adams, J. S. Pliskin, D. Gelb Safran, J. E. Siegel, M. C. Weinstein, and J. D. Graham. 1995. Five-hundred life-saving interventions and their cost-effectiveness. *Risk Analysis* 15(3): 369-390.

Tormoehlen, R. L., and W. E. Field. 1995. Projecting economic losses associated with farm-related permanent disabilities. *J Agric Safety & Health* 1(1): 27-36.

U.S. Office of Management and Budget. January 1999. *Report to Congress on the Costs and Benefits of Federal Regulations.* Washington, D.C.: GPO.

Viscusi, W. K. 1993. The value of risks to life and death. *J Econ Lit* 31(4): 1912-1946.