Frequency and Severity of Injuries to Operators During Overturns of Farm Tractors

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ABSTRACT. *Previous estimates of operator death from farm tractor overturn events range from 0.03 to 0.68. This study provided population-based estimates of the denominator of total farm tractor overturns and the frequency of six classes of overturn injury outcomes for tractors with and without rollover protective structures (ROPS). A 40-item telephone survey collected information from a random sample of 6,063 (8.0%) Kentucky farms about each farm's most recent overturn. A total of 551 (9.1%) farms reported overturns, and 5,512 (90.1%) reported no overturns. Injury outcomes for 443 overturns of non-ROPS tractors and 89 ROPS tractors were distributed as follows: no or minor injury (non-ROPS: 70.43%; ROPS: 82.02%), outpatient treatment (non-ROPS: 21.90%; ROPS: 9.00%), hospital admission (non-ROPS: 15.35%; ROPS: 3.37%), temporary disability (non-ROPS: 13.54%; ROPS: 14.61%), permanent disability (non-ROPS: 3.16%; ROPS: 0.00%), and death (non-ROPS: 5.42%; ROPS: 1.12%). (Percents total to more than 100 because some operators treated as outpatients were subsequently hospitalized, disabled, or died.) The observed 0.054 probability of death from overturn of non-ROPS tractors in this sample was corrected for the proportion of farms that went out of business prior to the survey and thus were excluded from the sampling frame. The adjusted 0.08 probability of death from overturn of a non-ROPS tractor is five times smaller than the NIOSH estimate of 0.40. The discrepancy lies in the much larger denominator of all non-fatal and fatal overturns than assumed previously.*

Keywords. *Injury outcomes, Injury severity, Overturns, Rollover protective structures, Rollovers, ROPS, Tractors.*

When farm tractors equipped with rollover protective structures (ROPS) and seatbelts overturn, the tractor operator is restrained in the seat by the seatbelt within the protected zone provided by the ROPS. This prevents crush injuries to operators that can occur when tractors without ROPS overturn (Myers, 2000). Multiple studies suggest that ROPS and seatbelts are 98% effective in preventing overturn fatalities (CDC, 1993; Springfeldt et al., 1998). In 1985, ASAE Standard S318.10 (*ASAE* Standards, 1985) led to an industry-wide policy that all new tractors manufactured in the U.S. be equipped with ROPS. Yet, more than 15 years later, only 50% of the nation's farm tractors were equipped with ROPS (Myers, 2003), primarily because many older tractors re-

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main in service. In many states, the prevalence of ROPS is lower. In Kentucky, only 29% of farm tractors are equipped with ROPS (Cole, 2003), and in Ohio only 34% (Wilkins et al., 2003). In 2002, there were 2.7 million non-ROPS farm tractors in the U.S. No approved ROPS retrofit design existed for half of these tractors (Myers, 2002a). Thus, a large proportion of the farm tractor operator population remains at risk of injury and death from tractor overturns. In this article, the term "farm tractor" refers to wheeled tractors that are used by farmers for a variety of agricultural-related tasks (Census of Agriculture, 1997).

National Safety Council (NSC) surveys estimate that the number of U.S. operator deaths from farm tractor overturns ranges from 150 to 200 per year (NSC, 2000). In Kentucky, tractor overturn-related deaths averaged about 14 per year for many years (Cole, 2003; Cole et al., 2000). No single nationwide surveillance system tracks all tractor overturn fatalities, but three national surveillance efforts have provided annual estimates of farm tractor overturn-related deaths. These include the NSC's Injury Facts, the Bureau of Labor Statistics' Census of Fatal Occupational Injuries (CFOI), and the National Institute for Occupational Safety and Health's National Traumatic Occupational Fatalities (NTOF). Each of these systems operates differently, uses different data sources, and reports different estimates of the frequency of operator deaths from tractor overturns (Hard et al., 2002). No national surveillance system monitors the frequency and severity of non-fatal tractor overturn injuries. A few state and regional surveillance projects have monitored non-fatal injuries related to tractors and farm machinery, but not on a regular basis and not with population-based random samples (Hard et al., 2002). At the local and regional levels, overturn-related deaths are identified mainly from newspaper accounts, police and coroner reports, death certificates, county-level agricultural extension reports, and reviews of emergency medical service and hospital emergency department records.

The Problem

There is substantial uncertainty in estimates of farm tractor overturn deaths and virtually no information about the denominator of the total number of tractor overturns that include fatal injury, non-fatal injury, and non-injury events. The overturns reported in newspapers and the media tend to be those that result in fatalities and to some extent those that result in newsworthy severe injury. Estimates of the frequency of non-fatal injuries from tractor overturns are even more problematic because data about these events are not systematically collected by surveillance systems or reported by news media or other sources. For these reasons, previous estimates of the frequency of operator death resulting from overturns of farm tractors not equipped with ROPS are inaccurate because: (1) not all overturn deaths are captured, and (2) the denominator of all tractor overturn events is unknown.

Earlier studies calculated the costs of tractor overturn fatalities and the cost effectiveness of ROPS and seatbelts for preventing these injuries (Myers, 2000b; Myers et al., 2004; Myers and Pana-Cryan, 2000; Pana-Cryan and Myers, 2002). Permanently and temporarily disabling injuries are much more costly than fatal outcomes (Leigh et al., 2001; Vyrostek et al., 2004). Prior to this study, accurate estimates of the frequency and cost of non-fatal overturn injuries to operators of non-ROPS and ROPS-equipped tractors could not be calculated because population-based estimates of the denominator of all farm tractor overturns including fatal injury, non-fatal injury, and non-injury events were not available.

Study Goals

The first goal was to review and summarize briefly the relevant prior research related to the frequency of farm tractor overturns. The second goal was to provide a population-based estimate of the denominator of all farm tractor overturn events including fatal injuries, non-fatal injuries, and non-injury outcomes. The third and primary goal was to estimate the frequency and severity of six classes of operator injury outcomes that result from overturns of non-ROPS and ROPS-equipped farm tractors.

Previous Research

Using the keywords "tractors" and "rollovers," Myers (2002b) conducted a Medline literature search and a manual search of Buchele's (1989) comprehensive annotated bibliography of the tractor stability, rollovers, and ROPS systems literature. Buchele's bibliography includes unpublished technical papers and studies (fugitive literature) as well as documents too old to be included in current electronic databases. A total of 123 journal articles and papers were identified. Ten studies spanning the period from 1965 to 2001 provided estimates of the probability of death during farm tractor overturns that ranged from 0.03 to 0.68. The most frequently cited value of 0.40 is based on Schnieder's extensive analyses of news articles and reports from a network of law enforcement agencies and other groups in Nebraska (CDC, 1993). These studies are summarized in table 1.

Six studies conducted during the 1965 to 2002 period reported the probability of non-fatal overturn injuries to operators with values ranging from 0.09 to 0.70. Five studies for the 1972 to 2001 period reported the probability of no injury to operators during overturns with values ranging from 0.04 to 0.92. The previous University of Kentucky study listed in table 1 (Cole et al., 2000) estimated the number of fatalities from tractor overturns by using data from three independent sources. These included an 11-year death certificate study by Mouton (1994), a six-year data set collected by the Kentucky Fatality Assessment and Control Evaluation (FACE) project, and statewide records of overturn deaths compiled from county extension reports and newspaper stories by U.K. Agricultural Extension Safety Specialist Larry Piercy. Each of these sources revealed that Kentucky tractor overturn fatalities averaged about 14 per year over many years. This information was combined with data from the Kentucky Farm Family Health Hazard and Surveillance study (Browning et al., 1998) and Kentucky Census of Agriculture farm tractor and farmer population data to calculate the probability of operator fatality during an overturn (P_{fOT}) using equation 1:

$$P_{fOT} = f / (f + nf) \quad (1)$$

where f is the number of fatal operator injury cases, and nf is the number of non-fatal operator injury cases. The three estimates of P_{fOT} are listed in table 2.

Although informative, the previous Kentucky study had two limitations shared by the other studies listed in table 1. First, the data were not based on a survey instrument designed specifically to gather detailed information about farm tractor overturns and operator injury outcomes including fatal, non-fatal, and non-injury events. Second, except for the Lee et al. (1996) study, the data were not collected from population-based random samples of farms.

To overcome these limitations, a new survey measure was specifically designed to determine the number, age, and other characteristics of the tractors used on farms, the characteristics of the operators, as well as the frequency of tractor overturns and the associated frequency and severity of operator injury outcomes for overturns of

Table 1. Previous estimates of farm tractor overturn fatal and non-fatal injury outcomes.

Study	Sample Size	Years Included	$Pr_{fatality}$	Pr_{injury}	$Pr_{no\ injury}$	Comments
Lee et al., 1996	13,144	10	0.03	0.16	0.82	Farm household survey in Minn., Wisc., N. Dak., S. Dak., and Neb., 1980-1989.
Lee et al., 1996	13,144	1		0.09	0.92	Farm household survey in Minn., Wisc., N. Dak., S. Dak., and Neb., 1990.
McKnight et al., 1996	998	Approx. 30		0.20	0.80	Farm household survey of 60 randomly selected Ky. counties.
Reed et al., 2001	537	5			0.72	Tractor safety intervention survey of vocational education students in Ky., Iowa, and Miss., mean age 15.5.
Rees, 1965	443	5	0.30	0.70		Operators killed and injured in England and Wales, 1959-1963.
CDC, 1993	250	25	0.40			Operators killed or injured in Neb. during 1967-1992 based on news, police, and extension reports collected by R. Schnieder.
Lawrence and Bean, 1992	100	6	0.68	0.32		News reports and insurance records of accidents in Ohio.
Lehtola, 1992	90	3	0.57			Iowa news clippings, Dept. of Public Health sentinel reports, and farm visits.
Schnieder and Baker, 1972	175	6	0.53	0.43	0.04	Based on Nebraska news, police, and extension reports, 1966-1971.
Cole et al., 2000	2,132[a]	20	0.13			Three separate estimates based on FFHHS, FACE, and death certificate data combined with USDA Census of Agriculture data.
	1,202	11	0.14			
	491	6	0.15			

[a] These three sample sizes represent the total number of fatal and non-fatal overturns during three multi-year periods as estimated from known overturn fatalities from three independent studies, the total number of non-fatal overturns calculated from the prevalence of tractor overturns, and the numbers of farms and tractors as determined from Kentucky Census of Agriculture data.

Table 2. Three independent estimates of the probability of operator fatality during a farm tractor overturn.

P_{fOT}	=	f	/	$(f + nf)$	=	Estimate	Data Source	Period (years)
P_{fOT}	=	280	/	(280 + 1,843)	=	0.13	Extension reports	20
P_{fOT}	=	164	/	(164 + 1,038)	=	0.14	Death certificates	11
P_{fOT}	=	75	/	(75 + 416)	=	0.15	Kentucky FACE	6

non-ROPS and ROPS-equipped tractors. It was reasoned that data from a large population-based random sample of Kentucky farms would generalize to many other states. The seven states that border Kentucky include farm sizes, crops, production, equipment, and topography nearly identical to farms located in Kentucky's six agricultural districts.

Methodology

A random sample of 6,063 (7.98%) of Kentucky farmers were interviewed about their farm's history of fatal and non-fatal tractor overturn injuries. The Kentucky Agricultural Statistics Service (KASS) constructed the sampling frame using its 2001 updated 1997 Census of Agriculture comprehensive list of Kentucky's farms. Farms were randomly sampled proportional to their number in each of the state's six agricultural districts.

The U.K. research team and KASS statisticians collaboratively designed the 40-item Kentucky Farm Tractor Overturn Telephone Survey (KY T/O Survey) to provide a population-based estimate of the denominator of all tractor overturns as well as estimates for each of six categories of operator injury outcomes. After receiving four hours of training in using the KY T/O Survey, 25 KASS enumerators conducted a field test with a random sample of 39 Kentucky farmers. The survey was then revised slightly and administered to the statewide random sample of Kentucky principal farm operators. Most of the enumerators previously had conducted one or more Census of Agriculture surveys.

Detailed information about overturns and their injury outcomes were recorded only for each farm's most recent tractor overturn. This lessened the response burden for the participants and facilitated their recall of the event. The most recent event included any overturn on a given farm by anyone who was working on that farm, as well as anyone who, while working for that farm, overturned a tractor on another farm. This method captured overturn events for farmers who lease additional farmland or who help other farmers with farm work. Double counting of overturn events was minimized in two ways. First, farmers were randomly selected from among Kentucky's 76,017 farms that operated a total of 150,268 wheeled tractors (Census of Agriculture, 1997). Second, details including the age and gender of the operator, the year the tractor was manufactured, its brand name and model, the date and location of the overturn, the chore being performed, and the manner in which the tractor overturned also were collected.

The 6,063 completed surveys represent a 79% response rate. Farmers' most frequent reason for non-participation was the time required to respond to the survey questions. To ensure accuracy, the data were independently double-entered into two Statistical Analysis System (SAS) files. A computer scan of the two data files identified any discrepancies in variable values. Discrepancies were then corrected by examining the original data recorded on the completed paper survey forms.

Results

In the full sample of 6,063 farms surveyed, 5,512 (90.9%) reported no tractor overturn events in the history of their farm. The remaining 551 farms (9.1%) reported experiencing one or more tractor overturn events. For this study, the unit of analysis was the most recent overturn event experienced by each farm. Among this sample of 551 farms, 445 overturns involved tractors without ROPS and 92 involved tractors with ROPS. In 14 cases, the ROPS status of the tractor was unknown. Table 3 reports the frequency of non-ROPS and ROPS tractor overturns for the 537 overturns for which the tractor ROPS status was known.

Operator Injuries for Overturns of Non-ROPS Tractors

Table 4 presents the frequency of six classes of injury outcomes that resulted from 443 overturns of tractors without ROPS. The injury outcomes were known for 443 of the 445 overturn cases. Of the 443 overturns, 312 (70.43%) were reported as non-injury events and 131 (29.57%) as resulting in injuries. The year of the overturn was known for 428 of the 443 events. The overturns were distributed across the period from 1925 to early

Table 3. Frequency of most recent overturns by tractor ROPS status (*n* = 537).

Overturns by ROPS and Non-ROPS Tractors	Frequency	Percent
Tractors with ROPS	92	17.13
Tractors without ROPS	445	82.87

Table 4. Operator injury outcomes from overturns of non-ROPS tractors (*n* = 443).

Overturn Injury Outcomes for Non-ROPS Tractors	Frequency[a]	Percent
No injury or minor injury – no treatment required	312	70.43
Required treatment by doctor/clinic/hospital	97	21.90
Required hospital admission	68	15.35
Resulted in ≥1 day to ≤365 days of lost work	60	13.54
Injury resulted in permanent disability	14	3.16
Injury resulted in death	24	5.42

[a] Frequency values sum to 575, which is 132 more than the 443 overturn injuries (and 23% more than 100%). Among the 443 individuals, 132 had injuries that resulted in multiple categorizations. Twenty-three percent of those injured who were first seen at a clinic also required hospital admission, were temporarily and/or permanently disabled, or died. Conversely, a few who died were never treated or admitted to a hospital. The values in the last column are the fraction of persons in each category divided by the 443 overturns for which injury outcomes were known.

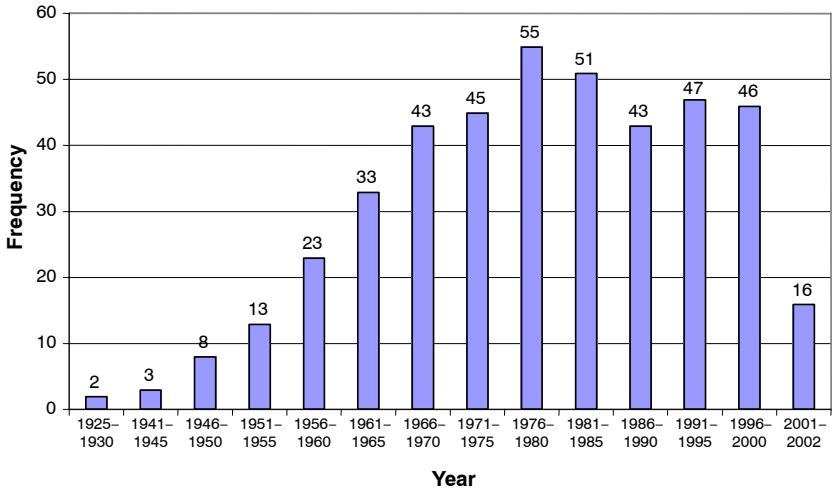

Figure 1. Overturns of 428 non-ROPS tractors in five-year intervals.

Table 5. Type of non-ROPS tractor overturns (*n* = 419).

Rollover Classification	Frequency[a]	Percent
On side, lateral roll (approximately 90°)	217	51.79
Sideways and upside down (approximately 180°)	121	28.88
Complete roll ≥1 time (360° or more)	37	8.83
Flipped over backward	44	10.50

[a] Type of overturn was unknown in 16 cases.

2002, as shown in figure 1. The 1925 to 1960 period accounted for only 49 (11.06%) of the total 443 overturns, with 88.94% occurring across the 1961 to February 2002 period. The frequencies for four types of non-ROPS tractor overturns are reported in table 5.

Table 6 presents tractor ROPS status and wheel stance (narrow vs. wide front end) for the 487 overturns for which both ROPS status and stance were known. Wide front-end tractors were involved in 64.1% of overturns, compared to 35.9% for narrow front-end tractors. Only 9 (5.14%) of the 175 narrow front-end tractors were equipped with ROPS, compared to 78 (25.00%) of the wide front-end tractors ($p < 0.0001$).

Table 6. Stance by ROPS status for tractors involved in overturns (*n* = 487).

	Number of non-ROPS Tractors		Number ROPS Equipped[a]	
Tractor Wheel Stance	f	Percent	f	Percent
Narrow front end	166	41.50	9	5.14
Wide front end	234	58.50	78	25.00

[a] $\chi^2 = 30.13$, df = 1, $p < 0.0001$. Tractor stance was unknown in 50 cases.

Five characteristics of figure 1 deserve comment. First, there were no overturns reported for the 1931 to 1940 period. Second, the frequency of overturn events from the 1925-1930 through the 1961-1965 interval are underrepresented. It is likely that people whose farms experienced overturns events during these years were no longer farming at the time of the survey because they had either retired or died. Third, a small portion of the underreporting for these intervals, and for all other intervals as well, may be related to farms going out of business because of a serious injury or fatality resulting from a tractor overturn and, therefore, not being included in the sampling frame. Fourth, because the survey was conducted in January and February 2001, the last interval represents only a 14-month period, or about 23% of the full five-year 2001-2005 period, whereas all the other intervals represent a 60-month period. Fifth, the histograms displayed do not include all overturn events, only a total of the most recent overturn of a non-ROPS tractor as reported by each farm. Taken together, these factors suggest that the data presented are most robust for the most recent overturns on non-ROPS tractors for the 1966 to 2000 period.

Probability of Death During Overturns of Non-ROPS Tractors

While accurate for the sample surveyed, the value of 0.054 (based on the percentage of fatalities listed in table 4) for the probability of operator death during an overturn of a tractor without a ROPS does not include those fatal overturn cases not counted in the survey because the death resulted in the cessation of the farm operation prior to the survey. The KASS 2001 list included only the population of all currently active Kentucky farms from which the survey sample was drawn. Thus, the observed 0.054 value is likely lower than the actual value for an unbiased sample that did not exclude farms where overturn deaths resulted in cessation of farm operations.

The Kentucky FACE project database provided a means to correct for the undercounting of overturn-related fatalities in the KY T/O Survey sample. FACE documented 70 tractor overturn deaths statewide during the 1994 to 2001 period. During this same eight-year period, the KY T/O Survey of 8% of Kentucky's farms identified 5 most recent overturn deaths. Eight percent of the 70 deaths reported by FACE for this period is 5.6 overturn deaths. Because the KY T/O survey asked for the most recent overturn event, and not the most recent fatal overturn event, it may have missed a few fatal overturn events that were not the most recent overturn events. However, the number missed would be small because most farms that reported overturns experienced only one event. When the FACE value of 5.6 overturn deaths for the eight-year period is taken as a more accurate numerator, the adjusted probability of death per overturn event is 5.6/70, or 0.080, rather than the 0.054 listed in table 4.

Table 4 reports a probability of 0.32 for a permanently disabling injury to an operator when non-ROPS tractors overturn. Again, this is an accurate estimate for the random sample of 6,063 farms listed in the 2001 KASS database. But it also underestimates the true value because farms that went out of business as a result of a permanently disabling overturn injury prior to December 2001 were not included in the KASS master list of Kentucky farms. No comparison data were available from FACE or other sources with

which to calculate a correction for the KY T/O Survey's underestimate of the probability of permanently disabling injuries.

Operator Gender and Age Characteristics

The gender of the operator was reported for 442 of the 445 overturns. Male operators were involved in 433 (98.0%) overturn events and female operators in 9 (2.0%) events. Table 7 presents the mean age and standard deviation for 417 of the 445 operators whose age at the time of the overturn was known and reported. Figure 2 presents the operators' ages in five-year intervals at the time of the overturns. Operators age 16 to 20 years had the highest risk of overturns.

Age of Tractors at the Time of Overturns

Of the 551 most recent overturns reported, only 343 (62.3%) of the farmers knew the year the tractor was manufactured, and many of those who responded could estimate only the approximate year. The 280 non-ROPS tractors accounted for 81.6% of most recent overturns for which tractor age was reported. These results are presented in figure 3 in ten-year intervals. Means and standard deviations were not calculated because of the large amount of missing data and farmers' imprecision in estimating the age of their tractors. The proportion of older tractors in figure 3 is consistent with earlier findings from a 1997 random sampling of 1,648 farms in four central Kentucky counties (Cole and Westneat, 2001). That earlier study found that half of all farm tractors currently in use were more than 25 years old (i.e., manufactured prior to 1972).

Table 7. Mean age (years) for people who overturned tractors without ROPS.

Statistic	Observed Value
n	417
Mean	37.89
Standard deviation	17.32
Median	38
Mode	50
Range	76
Interquartile range	27

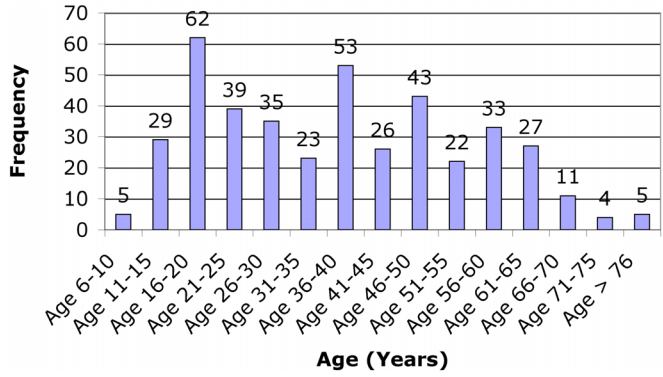

Figure 2. Age in five-year intervals of 428 operators who overturned non-ROPS tractors.

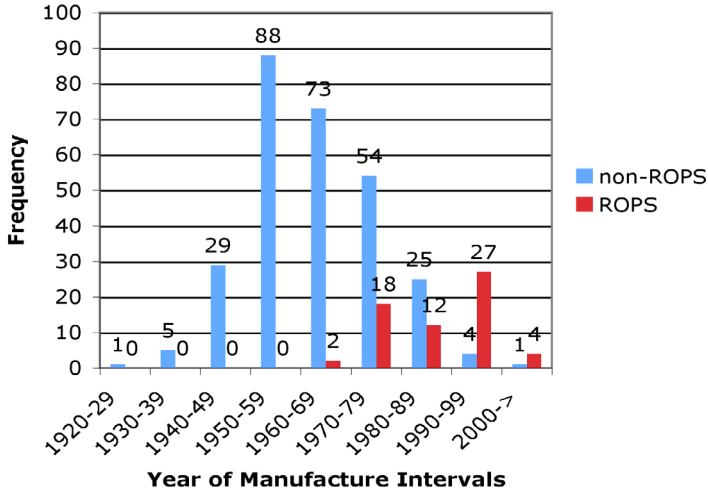

Figure 3. Year of manufacture for 343 non-ROPS and ROPS tractor overturns.

Table 8. Frequency of operator injury outcomes for overturns of 89 ROPS-equipped tractors.

Overturn Injury Outcomes for ROPS-equipped Tractors	Frequency[a]	Percent
No injury or minor injury – no treatment required	73	82.02
Required treatment by doctor/clinic/hospital	8	9.00
Required admission to hospital	3	3.37
Resulted in ≥ 1 day to ≤ 93 days of lost work	13	14.61
Injury resulted in permanent disability	0	0.00
Injury resulted in death	1	1.12

[a] Frequency of treatment events sum to 98, or nine more than the 89 overturn cases. These nine cases include individuals who were injured and received medical treatment at a clinic or an emergency department but also required hospital admission and were temporarily disabled or subsequently died, as was the case for the 19-year-old involved in a roadway overturn (see text). The values in the last column are the fraction of persons in each category divided by the total 89 overturn events for which injury outcomes were known.

Table 9. Days farm work lost from overturn injuries by tractor ROPS status.

Tractor ROPS Status	Mean	SD	Median	Range	Mode
No ROPS (n = 60)	97.8	122.6	36	364	365 (8)
With ROPS (n = 13)	21.9	28.5	7	92	1 (3)

Wilcoxon signed-rank one-tailed t-test for paired comparisons for non-normal distributions, $p < 0.0085$.

Operator Injuries for Overturns of ROPS-Equipped Tractors

Operator injury outcomes were examined for the 92 ROPS-equipped tractors that overturned. In this set of 92 cases, there was one fatality. However, complete data for the other injury outcomes was obtained for only 89 of the 92 cases. Table 8 reports the six categories of operator injury outcomes for these 89 cases. Comparing the data in tables 4 and 8 demonstrates the injury protection that ROPS provided during overturns. The frequency of temporarily disabling overturn injuries to operators is about the same for non-ROPS and ROPS tractors. However, injury severity and days of work lost are significantly greater ($p < 0.0085$) for operators involved in overturns of non-ROPS

tractors than for operators who overturned ROPS-equipped tractors (table 9). Temporary disability classification for both ROPS and non-ROPS tractor overturns included only operators whose injuries resulted in a maximum of 365 lost work days. Operators whose injuires prevented them from returning to work within a year generally were never able to return to farm work.

The one fatality among the 92 ROPS-equipped tractor overturns resulted from a 1990 highway motor-vehicle incident. In order to allow following vehicles to pass, the 19-year-old male operator was driving the tractor straddling the right lane and the emergency lane. A car pulled in front of the tractor. When the tractor operator attempted to avoid the collision, the tractor overturned onto its side. The tractor was equipped with a ROPS, but the operator was not wearing the seatbelt. He was severely injured and died after one day in the hospital.

Limitations

The sample upon which these results are based was drawn from the KASS 2001 comprehensive listing of Kentucky farms, which did not include farms that ceased operation prior to 2001 because of overturn death or disability. Kentucky FACE operator overturn death data for an eight-year period were used to calculate an adjusted probability of 0.080 for operator death during an overturn of a non-ROPS tractor. A second limitation is that FACE fatality reports for agricultural tractors include only those overturns in which the operator and tractor were engaged in farming-related activities. Overturn deaths from farm tractors engaged in non-agricultural work are not included.

With a truly unbiased sample of farms, the actual values reported for death and permanently disabling injuries may be higher than the values obtained from the KY T/O Survey. In a future study, we will use empirical data from multiple sources to calculate an adjustment to correct for attrition of farms from the KASS database related to disabling and fatal tractor overturns.

Conclusion

To the best of our knowledge, this is the first study to provide population-based estimates of frequencies of six classes of operator injury outcomes that result when farm tractors without ROPS overturn. The probability of operator deaths during these overturns is estimated at about 8 deaths per 100 overturns, or a little less than 1 chance in 13. This value is five times smaller than the 40 operator deaths per 100 overturns reported by NIOSH in 1993 (CDC, 1993).

Inspection of tables 4 and 8 reveals that 82% of operators who overturn ROPS-equipped tractors sustain no injuries or minor injuries that do not require medical treatment, as compared to 70% of operators who overturn non-ROPS tractors (χ^2, df = 1, $p < 0.025$). Examination of table 4 also reveals that when non-ROPS tractors overturn, about 22% of operators require medical treatment at a doctor's office, clinic, or hospital but not hospital admission. About 15% require hospital admission. About 14% result in temporary disability that prevents the operator from continuing with farm work for an extended period of time, with a mean of 97.8 workdays lost (SD = 122.6 days). About 3% result in permanent disability. Comparing the frequency of these injury outcomes for overturns of non-ROPS tractors to ROPS-equipped tractors, as presented in tables 4, 8, and 9, demonstrates the injury prevention effectiveness of ROPS.

The study results do not suggest that fewer people are killed when non-ROPS tractors overturn than is reported by the many groups that monitor these fatalities at the local and

national levels. Overturns of non-ROPS tractors remain a major contributor to agricultural fatalities and injuries. This study's main contribution is its population-based estimates of non-injury, non-fatal injury, temporary and permanently disabling injuries, and fatal outcomes to operators who overturn tractors. Even with its limitations, this study provides the best available population-based estimates of six classes of increasingly severe injury outcomes (from no injury to fatal injury) that result from overturns of non-ROPS tractors.

Cost of operator fatalities from overturns of non-ROPS tractors and the cost effectiveness of ROPS for preventing fatal injuries have been calculated previously (Myers et al., 2004; Pana-Cryan and Myers, 2002). Severe and disabling injuries typically are more prevalent and cost much more than fatal injuries. The results of this study can be used to update fatality cost calculations as well as to calculate the costs of non-fatal and disabling operator injuries that result from overturns of non-ROPS tractors and the cost effectiveness of equipping these older tractors with ROPS and seat belts.

Kentucky's central geographic location in the U.S., and its borders with seven states, also suggest that the study results may be generalizable. Kentucky's six agricultural districts are representative of farming in many other states. Western Kentucky has large flatland grain and soybean farms similar to those in the west in terms of size, topography, crops, and equipment. Extreme western Kentucky has large farms located on flood plains bordering the Mississippi River similar to farms in other southern states along the Mississippi River delta region. Many central Kentucky farms are located on rolling land interspersed with urban populations and cut by interstates and high-speed rural highways similar to farms in Ohio, Indiana, Illinois, Pennsylvania, New York, Tennessee, Virginia, and North Carolina. Eastern Kentucky farms have topography, production, and equipment typical of small farms located in rural hilly and difficult terrain found in portions of Ohio, West Virginia, Pennsylvania, New York, Tennessee, Virginia, and North Carolina.

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