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Injury severity related to overturn characteristics of tractors

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ABSTRACT

Introduction: Early studies of injuries associated with overturns indicate that more fatalities occurred when a tractor overturned beyond 90° (continuous roll) relative to the impact plane. Recently, the principle of preventing continuous rolls has re-emerged for the protection of riding lawnmower operators. *Method:* Related to tractors, a population-based study was conducted that compared the severity of fatal and nonfatal injuries between a 90° and continuous roll for tractors equipped with rollover protective structures (ROPS) and not equipped with a ROPS (non- ROPS). In 2002, the Kentucky Farm Tractor Overturn Survey was administered to an 8% random sample (6,063) of Kentucky farm operators. The farmers responded to questions that differentiated between the types of overturns and operator injury outcomes for ROPS-equipped and non-ROPS tractors during overturn events. Overturn characteristics were collected that included 90° to the side, beyond 90° to the side, and to the rear for both ROPS-equipped and non-ROPS tractors. *Results:* Of the 541 overturns reported in this study, 535 (99%) of the respondents reported the most recent overturn characteristics of the tractor: 92 (17%) were ROPS-equipped and 443 (83%) were non-ROPS. For side overturns, 67% of the rolls occurred with ROPS-equipped tractors, and 54% occurred with non-ROPS tractors. The percentages of deaths related to rolls to the side for ROPS-equipped and non-ROPS tractors were, respectively, 1.6% and 3.7%. There was one (2%) deaths related to 90° rolls for ROPS-equipped tractors, whereas for continuous rolls there were 6.4% fatalities related to side overturns, 13% resulted in non-fatal injuries with an average of 1 day of hospitalization for ROPS-equipped tractors, and 39% resulted in non-fatal injuries with an average of 18 days of hospitalization for non-ROPS tractors. The results from this study indicated that a ROPS was more effective at stopping an overturn at 90° than no ROPS, with an associated reduction in the severity of injury in the event of a tractor overturn.

1. Problem

The problem of tractor overturns started with the first mass produced small gasoline engine tractor in 1914. The tractor, manufactured by M. Hartsough and named the Little Bull, was driven by one of its two rear wheels, which was larger and heavier than the opposite rear wheel. When the operator turned with the smaller wheel uphill up a slope, the tractor would roll over (Myers, 2003; Ertel, 2001). In 1971, Arndt of John Deere estimated that 30,000 farmers had been killed in tractor incidents in the previous 50 years. The leading cause of these deaths was tractor overturns. Rollover protective structures (ROPS)—roll bars designed to reduce the possibility of a serious injury or death to an operator in the event of a vehicle overturn—have long been a proven intervention to virtually eliminate fatalities (Arndt, 1971; Myers, 2000). Nevertheless, in 1998, 32% of agriculture-related fatalities were associated with tractor-related incidents averaging 270 deaths per year, with an additional 264,651 restricted-workday and 10,939 lost-time injuries per year (Myers, 2002).

A survey in Nebraska for the period January 1, 1966 to January 1, 1972 compiled data for 175 tractors overturns. Thirty overturns occurred on inclines, and 26 (87%) of the total occurred to the rear (longitudinal), of which 17 resulted in fatalities and 9 resulted in nonfatal injuries. Overall, side (lateral) overturns to 180° or more resulted in a mortality rate of 50% whereas rolls stopped at 90° resulted in a mortality rate of 27%. No fatalities occurred on the tractors equipped with overturn protection (Schnieder & Baker, 1972).

A Kentucky farmer applied for a patent in 1952 for a guard mounted on a tractor to protect the operator against injury in the event of an overturn (Maybrier, 1952), and then in the late 1950s, anti-roll bar technology was developed in New Zealand (Crosbie, 1961). In 1962, a roll bar design was tested in Michigan to limit a lateral overturn of a tractor to the "on-side" position (Buchele, 1962). In 1963, Great Britain issued an application for a patent for an anti-roll bar designed to prevent a tractor rolling beyond its side (Duncan, 1966).

The anti-roll bar—which became today's ROPS on tractors—was designed to prevent or reduce the likelihood of a continuous overturn to the side or to the rear. Indeed, this principle of preventing continuous overturns has become a current issue for reducing the risk to operators of riding lawnmowers from overturn-related injury.

The concept of limiting an overturn to 90° evolved from the principle that a restricted overturn is inherently safer than a continuous overturn beyond 90° relative to the impact surface (Skromme, 1986). This concept

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was developed with an anti-roll bar designed and used by state highway departments (Hansen, 1966; Hanson, 1962). In 1958, a logging tractor outfitted with a canopy provided the germ of the idea to the Car and Safety Coordinator of the North Dakota Highway Department for an anti-roll bar on the tractors used to mow roadsides. The highway department built 14 prototype designs for anti-roll bars in 1959 and equipped all of its roadside mower tractors with anti-roll bars in 1960 (Skromme, 1986). The design concept was of a wide and high frame that would stop a roll on its side or a tip to the rear when the frame hit the ground, preventing the machine from tumbling over beyond 90°. Based upon an evaluation of several designs the department equipped all 190 tractors used to mow roadsides with an anti-roll bar. During the two years after the installation of anti-roll bars, no operators died from a tractor overturn, although six overturns had occurred. The injuries were neither fatal nor disabling, and the injuries resulted in a total of 54 days of lost time. The operators were convinced that the anti-roll bars, while not preventing the overturn, did protect them from serious crushing injuries (Skromme, 1986).

The Illinois Division of Highways calculated that for every 28 tractors, one fatal overturn death would occur over a 55-year working lifetime. Thus, they followed the North Dakota lead, using anti-roll bars to reduce serious and fatal injuries (Kuhns, 1966). In 1961, the Division used the anti-roll bar design from North Dakota, as well as a safety frame design from the University of California (Lamouria, Lorensen, & Parks, 1964), to make an anti-roll bar. The Division tested the anti-roll bar by pushing the tractor that it was mounted on sideways over two different slopes. The anti-roll bar successfully stopped the overturn at 90° in both tests with no damage to a dummy or to the tractor. After the tests, the Division proceeded with outfitting all of its tractors with anti-roll bars. By 1965, the Division had outfitted 630 of its 941 tractors with anti-roll bars and seatbelts.

The Chairman of the Farm Safety Committee of the American Society of Agricultural Engineers (ASAE), who was also affiliated with Deere & Co., expressed a belief that the concept of limiting the roll in an overturn to 90° for tractors was more acceptable than the protection assumed for racing cars with indefinite rolls, typically multiple lateral and sometimes end-over-end overturns (Zink, 1963). A general aim to reduce serious injury or death in a tractor overturn was to limit the roll to 90° with "rather simple devices" (Stephanson, 1966). The Chairman of the ASAE Safety Committee wrote that various studies show that when overturns are limited to 90°, they seldom result in serious injury (Zink, 1966).

An engineer from John Deere stated that a tractor with no roll-over protection will roll more than 90°, a roll more than 180° or more will "invariably" crush the operator, and a roll guard will usually limit the vehicle roll to 90° (Hansen, 1966). Bucher (1966) of John Deere stated, "In most cases, when the tractor upset is limited to a 90° roll, the operator is seldom crushed." In 1967, Hansen drafted a recommendation for a test procedure for protective frames for tractors in which he wrote that most vehicle configurations for field performance, but lacking roll-over protection, will roll 180° or more in an overturn and crush the occupant. He stated that a properly made protective device will usually limit the roll to less than 180°. Deere & Co. published editions of a manual that spanned the 20-year period of 1974 to 1994, which stated that ROPS were designed to limit overturns to 90° (Bittner et al., 1974, 1987, 1994).

A demonstration in Nebraska of lateral overturns by a non-ROPS tractor that rolled onto its top and a safety frame equipped tractor that rolled onto its side showed, using straw dummies to simulate operators, the protective value of the frame (Anon, 1966). The test dummies emerged unharmed. A demonstration illustrated the protective value of a safety frame by arresting the roll at 90° rather than the typical overturn without protection at the upside-down position, which crushes the operator (Knapp, 1968).

The National Safety Council (NSC) published data to encourage designs for the restriction of tractor overturns to 90° through the use of anti-roll bars (NSC, 1966). The Council defined the anti-roll bar as "essentially a frame installed on a tractor to prevent the machine from turning over past 90° in case of an upset" (Suino, 1966). John Deere engineers found that without overturn protection a tractor overturn will roll more than 90°, an unprotected overturn of 180° or more will likely crush the operator, and a roll guard will usually limit the roll to 90° (Anon, 1967). In many cases, a protective frame will limit the roll of a tractor to 90° rather than allow the roll to continue to an upside-down position (Berge & Swanson, 1967). The NSC recommended that a protective frame should limit an overturn to 90° (Suino, 1967). The NSC launched a Tractor Overturn Protection Program (TOPP) to protect tractor operators with a device to restrict an overturn to 90° (NSC, 1968). Similarly, the Council issued a data sheet and later updated the sheet that stated that the design of a protective frame should tend to limit an overturn to 90° (Anon, 1972; NSC, 1978).

A study of road compactors in 2004 showed that ROPS were effective at stopping continuous rolls during an overturn for all 18 ROPS-equipped compactors evaluated. Conversely, overturns of 28 compactors without ROPS had rolls that averaged 301°, three of which stopped at 90°. The overturn of compactors without a ROPS ranged from 90° to 1,080° (Myers, 2008).

Similar to the challenge of tractor use on uneven farm terrain, one of the necessities of lawn care has been cutting grass on slopes, which has resulted in the deaths of operators from continuous rolls (>90°; Wang, Ayers, & Comer, 2005). An American Society of Agricultural and Biological Engineers (ASABE) standard provided for tip-over protective structures (TOPS) designs to ensure that front wheel drive turf and landscape equipment will not roll onto its top (ASABE, 2002). Simply stated, TOPS are to riding lawnmowers as ROPS are to agricultural tractors. Hence, both terms shall be used in the remainder of this article.

The investigators of the TOPS design found that deck size, yaw, and slide downhill must be considered (Wang & Ayers, 2006). Wang, Ayers, Womac, and Depauw (2007) found that continuous rolls for front drive mowers were sensitive to the tip angle as altered by the height and width of the deck, the lateral distance between the center-of-gravity, and the TOPS contact point in a roll. A slight change in these parameters could produce a significant change in the roll potential.

In Australia, the State of Queensland issued rules that required compliance with an Australian standard (AS 1636) for ROPS testing (State of Queensland, 2006). The rules stated that the ROPS design should reduce the likelihood of continuous overturn while protecting the operator.

Prior to the current study, no population-based study had been conducted to compare the severity of injuries between 90° and continuous rolls for both ROPS-equipped and non-ROPS tractors. This study provides a population-based analysis that compared the severity of operator injury outcomes resulting from overturns of farm tractors with and without ROPS. Estimates of the frequencies for six classes of severity of operator injury outcomes resulting from overturns of farm tractors with and without ROPS as well as the types of overturns are presented.

2. Method

A Kentucky Farm Tractor Overturn Survey was administered in 2002 to 6,063 randomly selected farm operators who responded to questions differentiating between ROPS-equipped and non-ROPS tractors that had overturned (Cole, Myers, & Westneat, 2006). From this population, 541 (9%) reported experiencing one or more tractor overturns. Overturn characteristics were collected that included 90° to the side, and beyond 90° to the side for both ROPS-equipped and non-ROPS tractors. Questions asked during the interview regarding the most recent overturn are listed in the Appendix. From these questions, we were able to determine the presence of a ROPS and a seatbelt, whether the seatbelt was used, the extent and characteristics of the

Table 1
Comparison of the frequency and percentage of overturns by their direction and extent of ROPS-equipped and non-ROPS tractors.

ROPS Status	Extent of side overturn		Rear overturn	Unknown	Total
	90°	≥180°			
ROPS-equipped	61 (66%)	20 (22%)	6 (7%)	5 (5%)	92 (100%)
Non-ROPS	216 (49%)	156 (35%)	44 (10%)	27 (6%)	443 (100%)
Total	277 (52%)	176 (33%)	50 (9%)	32 (6%)	535 (100%)

overturn, and the injury consequence from the overturn. A side or lateral overturn may be referred to as a roll.

The first step in this analysis was to evaluate the efficacy of ROPS to prevent a continuous overturn by comparing the percentage of rolls limited to 90° by ROPS-equipped tractors to rolls among non-ROPS tractors. The second step was to compare the percentage and severity of injuries incurred in a 90° roll versus >90° continuous overturns between ROPS-equipped and non-ROPS tractors. The severity of injury was segmented into a spectrum starting with no injury, then minor injury, outpatient, hospitalized, permanent disability, and death. The method was to determine in cascade fashion if there was an overturn without injury, if there was an associated injury, if that injury was untreated or led to outpatient treatment or to hospitalization, if the injury was permanently disabling, or if it resulted in death. If the injury was disabling, then the characteristics of that injury and the circumstance associated with the injury were examined. To avoid double counting, permanent disabilities were subtracted from other injury categories.

3. Results

Of the 541 most recent overturns reported in this study, 535 (99%) of the respondents reported the overturn characteristics of the tractor; 92 (17%) were ROPS-equipped, and 443 (83%) were not. Most of the reported overturns were to the side, and of these rolls, ROPS-equipped tractors had proportionately fewer continuous rolls than non-ROPS tractors. Out of a total of the 535 reported overturns, 453 (85%) were to the side. For continuous rolls to the side, 156 (35%) of 443 occurred with non-ROPS tractors, a 13% higher percentage than the 20 (22%) of 92 that occurred with the non-ROPS tractors.

However, when we narrow our analysis to side overturns as shown in Table 1, the difference between non-ROPS tractors and ROPS-equipped tractors increased to 17%, for 148 (42%) out of 354 rolls of non-ROPS tractors were continuous, whereas 20 (25%) out of 81 rolls of ROPS-equipped tractors were >90°. This difference indicated that, in the event of a side roll, a ROPS provided a safety factor of 1.7 for averting a continuous overturn compared to a tractor that lacked a ROPS. It is noteworthy that only 50 (9%) of all 536 reported overturns were to the rear.

For ROPS-equipped tractors—the subject of Table 2—81 (88%) of the 92 overturns were to the side, and of these 61 (75%) stopped rolling at 90°. With tractor rolls limited to 90°, 52 (85%) of 61 side rolls resulted in no injury. In the 90° rolls, 8 (13%) injured operators received outpatient care, but one died (2%). The death shown in Table 2 occurred during the 1990s to an unbelted 19-year-old male as he drove on a public highway. He applied the brakes to avoid a collision with a car and the tractor overturned on its side. He died one day after the overturn (Myers, Cole, & Westneat, 2006).

Table 2
Injury severity associated with overturns of 92 ROPS-equipped Kentucky tractors*.

Injury Severity	Extent of side overturn		Rear overturn	Unknown	Total
	90°	≥180°			
No injury	52 (85%)	12 (60%)	5 (83%)	3 (60%)	72 (78%)
Minor injury	-	2 (10%)	-	1 (20%)	3 (3%)
Outpatient	8 (13%)	2 (10%)	1 (17%)	1 (20%)	12 (17%)
Hospitalized	-	4 (20%)	-	-	4 (4%)
Permanent Disability	-	-	-	-	-
Dead	1 (2%)	-	-	-	1 (1%)
Total	61 (100%)	20 (100%)	6 (100%)	5 (100%)	92 (100%)

*Model year was known for 86% of the cases, average = 1969.

Table 3
Injury severity associated with overturns of 443 Non-ROPS Kentucky tractors‡ .

Injury Severity	Extent of side overturn		Rear overturn	Unknown	Total
	90°	≥180°			
No injury	169 (78%)	101 (65%)	26 (59%)	16 (59%)	312 (70%)
Minor injury	9 (4%)	8 (5%)	1 (2%)	-	18 (4%)
Outpatient	6 (3%)	8 (5%)	7 (16%)	-	21 (5%)
Hospitalized	19 (9%)	25 (16%)	3 (7%)	6 (22%)	53 (12%)
Permanent Disability*	5 (2%)	4 (3%)	4 (9%)	2 (7%)	15 (3%)
Dead	8 (4%)	10 (6%)	3 (7%)	3 (11%)	24 (5%)
Total	216 (100%)	156 (100%)	44 (100%)	27 (100%)	443 (100%)

*One, three, and 11 of the disabling injuries were subtracted from the minor injury, outpatient, and hospitalized frequencies, respectively. See Table 4.
‡Model year was known for 65% of the cases, average = 1955.

Continuous rolls resulted in fewer non-injuries with 12 (60%) out of 20 rolls, but 8 (40%) were injured. The injured operators included 2 (10%) with minor injury, 2 (10%) with outpatient care, and 4 (20%) hospitalized. The percentage of injuries resulting from continuous rolls exceeded the percentage associated with 90° rolls by 25%.

For all overturns of ROPS-equipped tractors, 72 (78%) operators had no injury, 3 (3%) had minor injury, 12 (17%) had outpatient care, 4 (4%) were hospitalized, and 1 (1%) died. However, no permanent disabilities occurred. Of note, 5 (83%) rear overturns resulted in no injury—a pattern similar to 90° side overturns—and the one injured operator receiving outpatient care. Of the 92 ROPS-equipped tractors that overturned, 79 (86%) reported the tractor model year, which averaged 1969.

While most non-ROPS tractors stopped in a side roll at 90°, those that experienced a continuous roll resulted in more severe injuries. Furthermore, non-ROPS tractor overturns were associated with injuries across the spectrum of injury severity. Of the operators of non-ROPS tractors who experienced 90° rolls, 39 (22%) out of 216 operators were injured. Of the 90° rolls as shown in Table 3, 9 (4%) operators had a minor injury, 6 (3%) received outpatient medical care, 19 (9%) were hospitalized, 5 (2%) had a permanent disability, and 8 (4%) were killed.

Tractor operators had 55 (35%) injuries out of 156 continuous rolls. Continuous rolls had higher injury rates than 90° rolls with the exception of minor injuries affecting 8 (5%) operators. Regarding continuous rolls, 8 (5%) operators receiving outpatient care, 25 (16%) were hospitalized, 4 (3%) were permanently disabled, and 10 (6%) were fatally injured.

Rear overturns resulted in 18 (41%)—more than the side rolls—of the operators experiencing an injury: 1 (2%) was minor, 7 (7%) were treated as outpatients, 3 (7%) were hospitalized, 4 (9%) were permanently disabled, and 3 (7%) were dead as a result of the roll. Of the 443 tractors that lacked a ROPS, 290 (65%) reported the model year of the tractor, averaged at 1955.

By contrast, non-ROPS tractor rolls were associated with an increase in severity of injuries as compared to ROPS-equipped tractors, and whereas ROPS-equipped tractor overturns were associated with no disabling injury, non-ROPS tractor overturns were associated with 3% disabling injuries. As shown in Table 2, 1% of the injuries associated with ROPS-equipped tractors were fatal, whereas Table 3 shows that of the injuries associated with non-ROPS tractors that 5% were lethal. As for rear overturns, ROPS-equipped tractors were associated with only one injury (17%), an outpatient injury. Conversely, injuries related to non-ROPS tractors were more severe with 10 (23%) either dead, permanently disabled, or hospitalized.

Fifteen respondents reported details regarding permanent disabilities, with descriptions of each disability shown in Table 4. One

Table 4
Descriptions of 15 permanent disabilities experienced by tractor operators during non-ROPS tractor overturns.

Event	Description of Consequence
Minor Injury	
1. 90° side overturn on farm road	59-year-old male bush-hogging, hurt back, was unable to farm again
Outpatient	
2. overturn on public highway, details unknown	52-year-old male hauling hay and struck by car from behind, never able to farm again, shoulder crushed and back injured
3. 90° side overturn on hillside	23-year-old male bush-hogging, back trouble, unable to farm for 240 days, wore seatbelt on a non-ROPS tractor
4. rear overturn into creek	40-year-old female pulling another tractor out of swamp with a tricycle type tractor, permanent limp, unable to farm or do other kind of work
Hospitalized	
5. rear overturn in field	23-year-old male picking up hay, 90 days hospitalized, compound fracture, broken ankle, could farm again after one year
6. rear overturn on hill	14-year-old female raking hay with tricycle type tractor, 60 days hospitalized, able to farm after 90 days
7. rear overturn along fence line	40-year-old male fencing, crushed knee
8. 90° side overturn into ditch	40-year-old male blading soil with tricycle type tractor, never able to farm again
9. 90° side overturn in field	30-year-old male pulling load of corn, 180 days in hospital, walked with a limp, could farm again
10. 90° side overturn in field	Male hit hole when returning in field for lunch, never able to farm again or do other type of work, walked with a cane
11. 180° side overturn on hill	60-year-old male pulling logs, 8 days in hospital, 180 days unable to farm, broken rib, torn muscles in leg, unable to do some farm chores and non-farm work
12. 180° side overturn on farm road	16-year-old male 60 days in hospital, unable to farm
13. 180° side overturn on creek bank	35-year-old male hauling a load of tobacco, 90 days in hospital, lost left shoulder muscle, unable to farm
14. 180° side overturn	58-year-old male, 4 days in hospital, 21 days unable to farm
15. overturn on public road, details unknown	65-year-old male driving between farms, crushed chest, lost breathing capacity, never able to farm again

farmer with a minor injury (so coded because he never sought medical care) injured his back and, as a result, never farmed again. Three of the farmers received only outpatient care, and 11 were hospitalized. Of the three who received outpatient care, none could farm again because of the disability. Of the 11 who were hospitalized, five were unable to farm again, one reported the inability to do some farm chores, and the remainder reported their ability to farm again following their recuperation but with their permanent disability.

A 40-year-old male outpatient involved in a rear overturn on a hill when pulling trees while logging did not report the details of his injury but "went into another line of work." However, he remained on the farm as did the other injured operators or their families. The sample frame included only those individuals or family members still engaged in farming, so those persons or next of kin who left the farm because of a permanent disability or a death, respectively, were not counted in this survey (Cole et al., 2006).

Respondents reported that 58 (63%) of the 92 ROPS-equipped tractors had functioning seatbelts, and 19 (33%) of the operators wore a seatbelt that was functional. As shown in Table 5, only one (5%) out of the 19 operators that wore seatbelts during an overturn of ROPS-equipped tractors was injured, and that injured operator was treated as an outpatient.

The majority of these overturns were to 90° rolls, 38 (66%) of 58. Of these 90° rolls, 17 (45%) operators wore their seatbelts. Of the 90° rolls, four resulted in injuries, all with outpatient treatment, and one in which the operator wore a seatbelt. The remaining 34 operators of these rolls experienced no injury, 16 (47%) of whom were wearing a seatbelt. One out of five operators wore his or her seatbelt during a rear overturn with no injury, and likewise, one operator in an overturn with unknown direction and extent wore a seatbelt with no injury.

Thirteen of the tractors with functioning seatbelts were involved in a continuous roll, but none of the operators wore a seatbelt. Eight had no injury, one had a minor injury, one was treated as an outpatient, and three were hospitalized. The effect of seatbelt use upon injuries averted was consistent with an earlier study using the same data by Myers et al. (2006).

Conversely, seven non-ROPS tractors also had a seatbelt, which was worn by two individuals, not by three operators, and unknown regarding two other operators. Of the two who wore their seatbelt, one was uninjured in a rear overturn, and one was injured with outpatient care in a 90° lateral overturn. This patient suffered a back injury and was unable to farm for 240 days.

Table 5
Operator injury outcomes for ROPS-equipped tractors that overturned, including seatbelt availability and use (seatbelt available/seatbelt used).

Injury Severity	Extent of side-overturn		Rear overturn	Unknown	Total
	90°	≥180°			
No injury	34/16	8/0	3/1	1/1	46/18
Minor injury	-	1/0	-	1/0	2/0
Outpatient	4/1	1/0	2/0	-	7/1
Hospitalized	-	3/0	-	-	3/0
Permanent Disability	-	-	-	-	-
Dead	-	-	-	-	-
Total	38/17	13/0	5/1	2/1	58/19

4. Discussion

The results of this population-based study confirmed the value of ROPS in limiting most tractor overturns to the side to 90° and by so doing reducing operator injury severity that is associated with continuous rolls. Although we did not collect data regarding the extent of the overturn to the rear, the implication was that the ROPS would stop the overturn at 90°. Of the ROPS-equipped tractors that overturned to the rear, one person was injured and treated as an outpatient. In contract, the 44 non-ROPS tractors that overturned to the rear resulted in 18 (41%) injured, with three dead and four permanently disabled.

The success of the ROPS to prevent injury from rear overturns is striking as found in our study. But, there is more to this success than the ROPS. As described in the introduction, a Nebraska study during the 1966 to 1972 period found that 87% of the overturns were to the rear, most with fatal consequences (Schnieder & Baker, 1972). Our study recorded 9% rear overturns, 77% fewer than reported 50 years earlier. Thus, tractors have become inherently safer in avoiding rear overturns, perhaps with the adoption of the three-point hitch that lowers the longitudinal force of towed loads down to the ground well below the axle as the tractor tips.

The Kentucky USDA 2002 Census of Agriculture sampling frame included only currently active farm operations. Thus, severely injured operators may be undercounted, since farms that had ceased operation because of a tractor overturn injury or death were not included in the sampling frame. An earlier study calculated the size of this "healthy worker effect" with respect to the probability of death

during a non-ROPS tractor overturn. The raw uncorrected probability was .054 and the corrected value .080. Data needed to calculate the undercounting of the healthy worker effect for non-fatal injuries because of a disability were not available (Cole et al., 2006).

As described in the introduction, ROPS are effective at stopping road compactor rolls at 90°, yet ROPS-equipped tractors do roll continuously beyond 90°. Two ROPS design features for tractors may contribute to this difference. Whereas the uprights on ROPS on compactors project up the side of the compactor, many tractor ROPS designs project up from the axle inside the wheels, thus allowing an easy roll and added momentum beyond 90° before the ROPS makes contact with the impact plane. Some ROPS designs counter this feature by bending the ROPS frame over and up along the same line of initial impact as the tire, so both the tire and upright strike the impact plane concurrently. Another design issue has emerged as ROPS are manufactured using bent frames rather than the perpendicular attachment of the upright to the crossbeam. The rounded bent frame aids a roll, whereas most compactor ROPS have the abrupt 90° upright-to-crossbeam connection to resist the roll.

Nonetheless, this study suggests that many tractor operators survive an overturn in the presence of a ROPS even when not wearing a seatbelt. Although ROPS are effective at stopping road compactors from overturning beyond 90°, operators are still killed when not wearing a seatbelt. The most mentioned cause of crushing injuries on ROPS-equipped compactors was being struck by the canopy and not the ROPS upright (Myers, 2004). This is in contrast with the survivability of operators of ROPS-equipped tractors when not wearing a seatbelt in the event of an overturn (Myers & Pana-Cryan, 2000). Whereas compactor operators are seated on a flat platform high on the vehicle, tractor operators are protected by large, energy absorbing tires on the side, by their position in straddling the tractor chassis, and by their ability to grasp onto the steering wheel while seated in the tractor compartment (which on newer tractors includes protective fenders and an operator seat with back and arm rests). During an overturn a compactor operator easily can slide off of or be ejected from the elevated operator's platform, while a tractor operator is nestled within an energy absorbing envelope during an overturn. This work platform design appears to be a factor in the survivability of unbelted operators on ROPS-equipped agricultural tractors.

Extrapolating from the study of ROPS on agricultural tractors, it appears reasonable that TOPS would protect lawnmower operators from serious injury in the event of overturns. The TOPS was to be designed to prevent continuous lateral overturns of front-drive lawnmowers (ASABE, 2002), but research indicated that the mower deck that extends laterally beyond the side of the lawn tractor changes the tip-over line in a way that renders impractical the design of a TOPS to prevent a continuous roll (Wang & Ayers, 2006). As a result, ASABE withdrew its TOPS standard in 2007 (ASABE, 2007). Nonetheless, ensuring operator protection within a clearance zone remains critical to his or her safety in the event of an overturn (Hsiao et al., 2005). Research is needed regarding “anti-roll” technology for lawnmowers that may address the integration of hinged decks to correct this feature of lawnmowers.

In addition, foldable ROPS are prevalent on lawnmowers, and research is needed to understand approaches to deploy ROPS in the event of an overturn, such as the NIOSH AutoROPS (Powers et al., 2001), or to develop a ROPS that gives way to overhead obstructions when struck from the front but redeploys after the obstruction has been passed.

Our study described an unusual result regarding seatbelt usage in which 33% of those with a functional seatbelt wore the belt during the overturn. This is a higher percentage of seatbelt usage than earlier studies have described. A possible explanation is that operators who perceive an overturn hazard are more likely to wear their seatbelt (Myers et al., 2006). The earlier studies were of tractor operators whether they experienced an overturn or not. Another important observation is that some non-ROPS tractors are equipped with seatbelts, and tractor operators do wear them; a dangerous act indeed.

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Appendix—2002 Kentucky Farm Tractor Overturn Survey, (n = 6,063): Questions asked during the interview regarding the most recent overturn incidents.

- Did the tractor have a ROPS?
- Did it have a seatbelt that worked?
  - If so, was the person wearing the seatbelt?
- In what way did the tractor overturn?
  - Rolled over on its side (90°)
  - Rolled over sideways and upside down (180°)
  - Rolled all the way over more than once
  - Flipped over backward
- Did the person die as a result of the overturn injuries?
  - If yes, how long after the overturn did the person die?
- If the person did not die, was the person injured during the overturn?
  - Was the person taken to a doctor, clinic, or hospital because of the injuries?
  - Was the person admitted to a hospital?
  - If the person was taken to a hospital, how long did he or she have to stay in the hospital?
  - Was the person able to continue farming because of the overturn injuries?
  - As a result of the injuries, how long was the person not able to do his or her usual farm chores?
- As a result of the injury, was the person permanently disabled in any way?
  - If yes, describe the disability.
  - Does the disability prevent the person from doing farm work?
  - Does the person currently require special care because of this disability?
  - What type of care does the disabled person receive?

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