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Chores at Times of Fatal or Serious Injuries Associated with Tractor Overturns with and without Rollover Protection

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Abstract: This study describes chores when farmers were either fatally or seriously injured and required emergency medical treatment as a result of overturns of tractors with or without rollover protective structures (ROPS). Data from the *2002 Kentucky Farm Tractor Overturn Survey* were used for this study. The data were collected by a telephone survey of a population-based random sample of 6063 (7.98%) of Kentucky's 76,017 farm operators as listed in the Kentucky Agricultural Statistics Service database. Of farm operators interviewed, 551 (9.1%) reported 603 overturns and 5512 (90.9%) reported no overturns in the history of their farm, covering a period from 1925 to February 2002. Only the latest overturn was considered to improve recall accuracy. In addition, since the 1925 to 1959 time period had only 49 (8.1%) of the overturns reported, (14 farmers did not provide the year of most recent overturn); only data from the 1960 to 2002 period (approximately 41 years) were used. After making these adjustments, incidents evaluated included 25 cases (one fatal and four serious nonfatal injuries) that involved ROPS-equipped tractor overturns and 88 cases (24 fatal and 64 serious nonfatal injuries) that involved non-ROPS tractor overturns. Chores at highest risk for tractor overturns were identified for which educational and ROPS retrofit interventions could be emphasized. The highest frequency of overturn-related fatalities and nonfatal injuries were associated with hay harvesting, rotary mowing, and on-farm travel chores. These three chores represented 68.2% of fatal events and 50.0% of permanent and 56.6% of temporary disability overturn incidents. Tragically, in countries such as India and China with emerging mechanization, a large majority of tractors are produced without ROPS that can be expected to result in the same overturn-related epidemic of deaths experienced in highly mechanized countries, despite evidence of the protection provided by ROPS.

Keywords: tractors; overturns; rollover protection; ROPS; chores; safety; fatalities

1. Introduction

In 1966, Knapp warned that implements added to the tractor can "radically" change its stability in different and unexpected ways [1]. Unstable conditions may lead to tractor overturns that are responsible for thousands of deaths and serious injuries [2]. While studies have addressed the overturn hazard related to tractor design, training, environmental conditions, including slope and terrain, and public policies, scant attention has been given to tractor use at the time of an overturn incident with one exception, roadway travel [3–6]. To this day, tractor overturns remain the leading cause of

death on farms in the United States and continue to merit attention regarding the dimensions of the hazard, including chores associated with the overturns [7]. The history of success of rollover protective structures (ROPS) for reducing overturn-related deaths and serious injuries is well-documented [8]. ROPS are known to reduce overturn-related fatalities by up to 98% [9].

1.1. The Non-ROPS Tractor Legacy

In 2004, Day et al. reported the success of a program in the state of Victoria in Australia to retrofit tractors with ROPS. Their program offered rebates for ROPS retrofits on tractors prior to a mandate that required that all tractors be equipped with ROPS [10]. The program reduced the number of non-ROPS tractors from 17,420 in 1996 by 70% in 1998. With the rebates, the eventual prevalence of ROPS-equipped tractors reached 93% before the mandate became effective [11]. In their study, Day et al. found that the most common decade for the manufacture of non-ROPS tractors was 1960 to 1969 [10].

In the United States, tractors dating back to the 1940s lacked a ROPS until 1985, when tractors were manufactured with a ROPS as standard equipment [12]. Rules for ROPS on new tractors in eight European countries preceded this year ranging from 1959 in Sweden to 1978 in Spain; New Zealand required ROPS on new tractors in 1970 and six Australian states required them on new tractors in 1982 [8]. While many of these countries required older tractors to be retrofitted with ROPS, other countries, such as the United States and Canada, have struggled with reducing tractor-related deaths from overturns regarding pre-1985 tractors that lack ROPS.

In 2010, Murphy et al. reported that the average age of farm tractors in use in the United States was more than 25 years, dating back before 1985 [13]. Indeed, tractor longevity is the most critical issue regarding farm-related injuries in the United States and, more particularly, overturn-related deaths [14]. From 1992–2007, as older tractors were retired in the United States (and Canada), ROPS-equipped tractors increased from a prevalence of 41% and 34% relative to the total tractor population, for crop and livestock farms, respectively, to 53% and 49%, respectively. The US has not yet reached the ROPS prevalence rate of 75% to 80% proven in Nordic countries to result in zero overturn deaths for farm tractors. However, there is more to a potential prevention strategy than the overall rate: Myers and Hendricks found that crop farmers and farmworkers experienced 1352 overturn-related deaths for the period, 1992 to 2007, at a rate of 7.8 deaths per 100,000 workers, whereas livestock farmers and farmworkers experienced 183 overturn-related deaths over the same period at a rate of 1.27 deaths per 100,000 workers. Thus, crop farming was 7.4-fold and 6.1-fold higher than livestock farming for fatality frequency and rate in 1992 and 2007, respectively. The authors claimed that more research was needed to identify the factors that continue to place crop farmers at a higher risk of overturn-related deaths [2]. Moreover, older unprotected tractors are still in use for avocational chores on small acreages [15]. Countries, such as India and China, have multiple small, widely-dispersed rural communities of farmers with less mechanized agricultural equipment. As a result many farm tractors lack ROPS and other safety features. This issue is examined in the Discussion section.

1.2. Tractors and Chores

Tractors are considered utility vehicles on farms and are used for a variety of tasks. As an example, a 2016 issue of the magazine, *Hobby Farms*, listed chores for a tractor that demonstrate the range of farm-related tasks for which tractors are currently known to be useful [16]. The *Hobby Farms* article suggests either vintage or new tractors for doing the chores listed in Table 1 along with the categories of chores used in the current paper.

Table 1. Tractor chores listed in 2016 and associated chore categories used later in this article.

Tractor Chores	Associated Chore Categories
Brush hogging	rotary mowing
Land clearing,	pulling logs, stumps; logging
Cultivating	tillage
Livestock care and feeding	farm transport
Landscaping	scraping
Fence building	fence work
Construction projects	farm transport
Firewood friend	farm transport
Recreation: hayride	farm transport
Trail maintenance	pulling logs, stumps; farm transport, rotary mowing
Harvesting	hay harvesting
Snow removal	farm transport
Backup power	farm transport

Source: Boyt 2016 [16].

Few studies have addressed the task being performed with the exception of travel-related incidents on public roads, as noted earlier. Other studies that examined activities at the time of the overturn depended upon death certificate narratives and were limited by the small number of documented tasks during the overturn. These studies did not address non-fatal injuries associated with tractor overturns and did not use a population-based sample.

In a 1984 study of 1163 overturn-related deaths based upon death certificate narratives, McKnight found that 24 (2.0%) fatalities occurred while operating mowers and 39 (3.4%) deaths occurred when attempting to pull a tree, log, or other vehicle [17]. In 12 cases, tractor front loader buckets that were loaded and/or raised contributed to the overturn.

Lehtola collected use data on 173 tractor incidents, 87 of which were fatal, from newspaper reports in Iowa for the years, 1988–1990 [18]. She found that the highest number of incidents and fatalities occurred during the summer months of May, June, July, and August when tractors were used for mowing, hay harvesting, planting, cultivating, spraying, and routine chores. Of 90 tractor overturns recorded, 42% occurred on roadways, and 58% occurred in the field or the farmyard. Overturns were responsible for 58.6% of the fatalities, all of which involved tractors not equipped with a ROPS [19].

Lehtola et al. conducted another analysis of 136 tractor-related fatalities in Iowa for the years 1988–1992 based on newspaper reports [20]. Of 77 overturn-related deaths in the cohort, 44 (59%) occurred in a field or farmyard, and 28 (37%) occurred on public roads in which no other vehicle was involved. Overturns in the field included carrying loads high with a loader (large round bales or soil), spraying weeds along fence lines, driving along a dead furrow, hay harvesting, and mowing of untilled ground and terraces. In this study, 41% of deaths regarding tractor overturns occurred on roadways, many when mowing ditches, while the remaining chores involved carrying loads high with a loader, spraying weeds along fence rows, herding cattle, driving along the edge of a dead-furrow, performing haying operations, or mowing untilled ground and terraces.

Lehtola and Rautiainen published a tractor safety facilitators' manual that identified chore-specific risk factors that contribute to tractor overturns [21]. The risk factors included: roadway travel, rotary mower use, front-end-loader use, round bales hauled in front, and chores usually taking less than an hour each time.

In 1999, Bernhardt and Langley reported a North Carolina study that examined both death certificates and medical examiners' reports [22]. They identified 344 deaths related to tractors for the period 1979–1988. Of these deaths, 56% were classified as an overturn event. The activities most closely aligned with an overturn event along with the number of events included the following: plowing, harrowing or discing (28), pulling something (28), driving on or beside a road (25), brush cutting (22), mowing (22), and dragging logs (16).

In 2011, DeGroot et al. used Canadian Agricultural Injury Surveillance Program data for the years 1990–2005 to examine fatal machine-related fatalities in agriculture. They found that an average of 21 deaths per year were associated with tractor overturns and reported the activity related to each death: transportation (40%), field work (19%), forestry (16%), towing (9%), farm yard work (6%), mowing (4%), and other (6%). They also reported contributing factors to the overturn that included dragging logs or implements (7%) and pulling stumps or trees (4%). Transportation included both public road and off-road transport [23].

1.3. Aims

We are responding to a need to identify factors that continue to place farmers and farmworkers at risk of tractor overturn-related deaths and serious injuries. We found no population-based study that specifically reported the type of tractor work or chore conducted when farmers were either fatally or seriously injured during overturns of tractors with or without a ROPS. This paper describes the chores involved in overturn-related fatal and nonfatal injuries to operators of tractors fitted with or without a ROPS.

2. Methods and Materials

This study used data from the 2002 Kentucky Farm Tractor Overturn Survey [24]. This unique survey collected data from a large population-based random sample of farmers regarding the chore being performed when a tractor overturn occurred and included documentation of whether or not the tractor had a ROPS. The survey is unique in another way since it includes nonfatal injuries, as well as fatal injuries. Indeed, this survey has been used as a resource in other ways as recently as 2012 in which the relationship of terrain with tractor overturns was determined [25]. We also describe below what is meant by a chore and chore classification terms.

2.1. The 2002 Kentucky Farm Tractor Overturn Survey

Tractor overturn cases, which resulted in farmers' fatal and nonfatal injuries that required emergency medical treatment (EMT)—defined as treatment by emergency response technicians or in a hospital emergency room—were extracted from data collected by the Kentucky Farm Tractor Overturn Survey conducted by the Kentucky field office for the US Department of Agriculture (USDA) National Agricultural Statistics Service (NASS). The survey data were collected from a 7.98% (n = 6063) population-based random sample of Kentucky farm operators who were interviewed by telephone. A 40-item survey collected information at the county level about each farm's history of overturns that included details about their single most recent tractor overturn event. The response rate was 79% [24]. The sample was selected randomly from 76,017 farms statewide documented by USDA in 1997, which was stratified by six agricultural districts in Kentucky and farm size [24].

A total of 551 (9.1%) respondents reported 603 overturns for the period, 1925 to February 2002; whereas 5512 (90.9%) respondents reported no known overturn events in the history of their farm. To reduce respondent recall error, the analysis considered only the most recent overturns on the 551 farms, and since only 49 (8.1%) of the reported overturns occurred during the period, 1925–1959, we considered only those overturns that occurred over the period, 1960 to February 2002 [24,25].

As shown in Table 2, when we reduced the incidents to the most recent overturns reported, the total was 537 overturns in which 92 and 445 overturns occurred on ROPS-equipped and non-ROPS tractors, respectively (not included were 14 overturns for which the ROPS status was unknown). Five respondents did not report the type of injury regarding these incidents, reducing the number to 532 overturns, and to 89 overturns on ROPS-equipped and 443 on non-ROPS tractors. When we truncated the analytic period to the years 1960 to 2002, 49 previous non-ROPS tractor overturns were dropped from the analysis resulting in a study population of 483 overturns for which injury outcomes were known and, thus, reducing the number of non-ROPS incidents to 483 overturns [24,25].

Additionally, as shown in Table 2, we considered only fatal and serious nonfatal injuries. Accordingly, overturns of ROPS-equipped tractors were associated with one fatality and four nonfatal EMT injuries, and overturns of non-ROPS tractors were reported as the cause of 24 fatalities and 64 nonfatal EMT injuries [24].

The survey was conducted in two tiers in which the first tier asked general questions regarding the tractors on the farm and farmstead demographics, which included whether the farm entity or a member of the farm household had experienced an overturn. If so, they were asked a second tier of questions related to only the most recent tractor overturn [24].

Table 2. Background data collected about overturns from the 2002 Kentucky Farm Tractor Overturn Survey (6063 farms).

Item	Number of Tractors		
	ROPS-Equipped	No ROPS	Total
Overturns reported (most recent per farm) *	92	445	537 †
Reports for which injury outcomes were known	89	443	532
Reports for the period, 1960-February 2002	89	394	483
Fatal overturns in which chore was reported	1	24	25
Non-fatal overturns in which chore was reported	16	131	147
Serious non-fatal overturns reported ‡	4	64	68

* The ROPS status on another 14 overturns was unknown; † 9.1% of farms that reported one or more tractor overturns; ‡ Required hospital admission; Source: Cole, et al. [24].

2.2. Tractor Chore Descriptions

A chore is typically a routine job or task but includes atypical tasks by farmers who use the tractor as a source of power for traction (pulling or pushing loads) and hydraulic or mechanical power for implements. Informed by the chores identified in the introduction and terms used by farmer responses in our study, chores were categorized, first, for the fatal overturns of non-ROPS tractors. This set of chore names then was used to classify the type of chores for nonfatal injuries with a few additions and for fatal and nonfatal injuries associated with overturns of ROPS-equipped tractors.

Tractor chore descriptions were available for 23 of the 24 reported fatal events and from 443 non-ROPS tractor overturns. Chore description and eight other variables were collected for each event and placed into one of 10 non-overlapping chore categories in an Excel™ (Microsoft Corporation, Redmond, WA, USA) spreadsheet. Events that involved more than one possible chore category were classified based on the primary chore being performed. For example, an overturn that occurred while a farmer was "bush hogging" a ditch or on a sloped-bank at the side of a public roadway that bordered farm property was classified as rotary mowing as opposed to roadway travel or hay harvesting.

We also identified 64 nonfatal injury cases from non-ROPS tractor overturns that required EMT. The chore at the time of the overturn and the other data collected for each nonfatal event were entered into a spreadsheet in non-overlapping categories consistent with the procedure used for chore classification of fatal events described above.

From 92 overturns of ROPS-equipped tractors, we identified one fatality. In addition, we identified four serious nonfatal injuries related to overturns of ROPS-equipped tractors, none of which involved a permanent disabling injury.

3. Results

This study examined both fatal and nonfatal injuries associated with overturns by non-ROPS and ROPS-equipped tractors. For non-ROPS tractors, there were 24 fatal and 64 serious nonfatal injuries associated with overturns. The 64 nonfatal injuries were serious enough to require hospital admission and were further divided into temporary and permanent disabling injuries. The results are

summarized in Figure 1, and the five leading chores associated with fatal and nonfatal injuries are shown in Table 3.

Table 3. Top five chores associated with fatal and nonfatal injury overturns of tractors without rollover protective structures.

Rank	Fatal Overturns, n = 24		Nonfatal Overturns, n = 64	
1	Farm travel	6 (25%)	Hay Harvesting	17 (26%)
2	Rotary mowing	6 (25%)	Farm travel	12 (20%)
3	Road travel	4 (17%)	Rotary mowing	7 (11%)
4	Hay Harvesting	3 (13%)	Pulling logs, stumps; logging	7 (11%)
5	Scraping	2 (8%)	Tillage	4 (7%)

More specifically, we found the following percentages of types of chores with fatal overturn incidents (n = 24): farm travel (25.0%), rotary mowing (25.0%), road travel (16.7%), hay harvesting (12.5%), scraping (8.3%), and other or unknown (8.3%). The nonfatal injuries (n = 64) were separated into permanent and temporary disabilities, as shown in Figure 1. The association of permanent disabilities with tractor overturns (n = 10) were farm travel (40.0%), hay harvesting (20.0%), road travel (10.0%), pulling logs or stumps and logging (10.0%), scraping (10.0%), and fence work (10.0%); The association of temporary disabilities with tractor overturns (n = 54) were hay harvesting (28.8%), farm travel (14.8%), rotary mowing (13.0%), pulling logs or stumps and logging (11.1%), road travel (5.6%), applying chemicals (5.6%), fence work (3.7%), and other or unknown (11.1%).

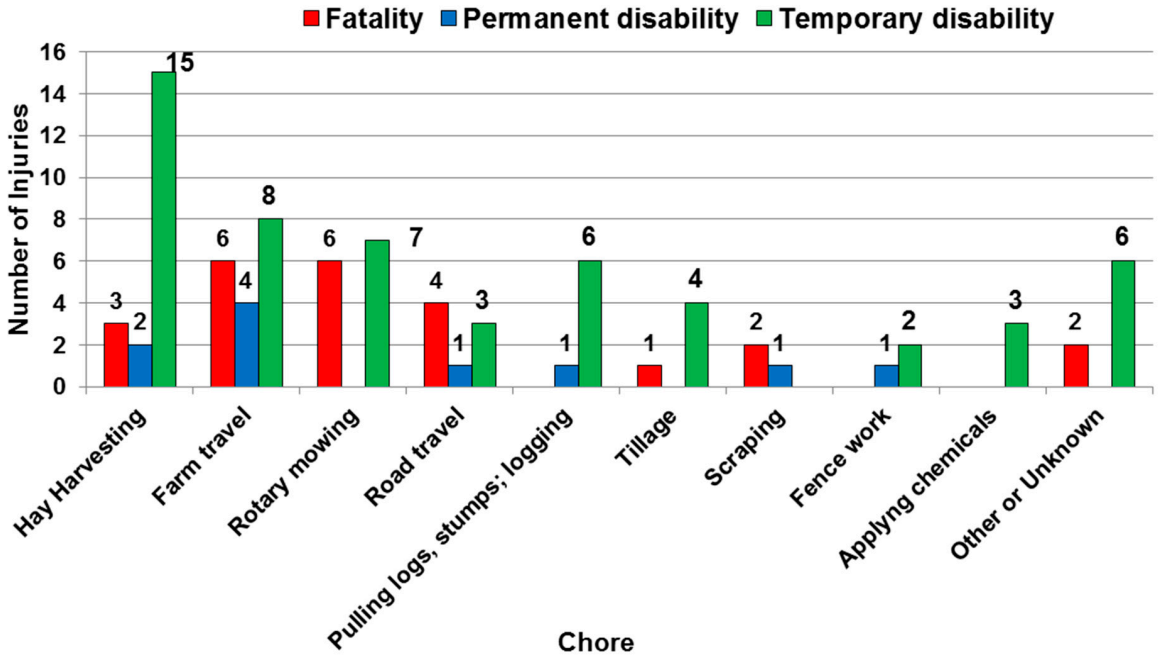

Figure 1. Number of fatal, permanent, or temporarily disabling injuries associated with overturns of tractors that lacked rollover protective structures in Kentucky,1960–2002, n = 88.

3.1. Chores at Time of Fatal Non-ROPS Tractor Overturn

Descriptions of chores for 23 of the 24 fatal non-ROPS tractor overturns were distributed within the non-overlapping categories shown in Table 4. Of these 24 fatally injured operators, 11 received EMT, nine did not, and EMT was unknown for four individuals. Of the 24 operators, 14 died in $\leq$1 h. Of the five who were admitted to a hospital, one lived for 24 h (one day), one for 48 h (two days), two for 72 h (three days), and one for 336 h (14 days). Four operators, none of whom were admitted to a hospital, lived for an unknown period of time before their death. All 24 decedents were males.

Twenty were family members (i.e., kin) of the survey respondents, and three were not. Family status was unknown for one individual. Operator age at the time of death was known for 21 individuals and distributed as shown in Figure 2.

Table 4. Details of fatal non-ROPS tractor overturns by chore category, n = 24.

Chore Category		Overturn Chore and Location	Overturn Type and Degrees	EMT *	Hours Death ‡	Kin	Age Died
Farm travel **	1	farm travel, hit trench silo	rear 180°	no	-	Yes	-
	2	farm travel, stream bank	Unknown	no	0	Yes	64
	3	hauling tobacco sticks, across farm, hit ditch	lateral 90°	no	0	Yes	54
	4	moving equipment, hit low place field	lateral 90°	no	0	No	18
	5	spreading tobacco stalks in pasture	unknown	yes	24	-	30
	6	traveling farm road	lateral 90°	yes	72	Yes	62
Hay Harvesting	7	mowing hay, hit farm road	lateral 90°	yes	0	No	57
	8	pulling hay baler, hit gully	lateral 90°	yes	-	Yes	50
	9	pulling heavy hay baler, hill	lateral 90°	-	0	Yes	78
Horse play	10	youths ramming tractors, steep hillside	rear 180°	no	0	Yes	13
Road travel	11	hit chuck hole, ran into tree	unknown	no	-	Yes	35
	12	looking for cow, ran off road	lateral 90°	no	0	Yes	22
	13	ran into roadside ditch	lateral 180°	yes	72	Yes	62
	14	returning home with plows	lateral 180°	yes	0	Yes	42
Rotary mowing	15	Bush Hog † by silo, hit farm road	lateral 90°	no	0	Yes	82
	16	Bush Hog farm access road, hill	lateral 90°	-	1	Yes	52
	17	Bush Hog public road side	lateral 90°	yes	0	Yes	72
	18	Bush Hog public road side	lateral 180°	yes	0	Yes	-
	19	Bush Hog public road side	lateral 360°	Yes	336	Yes	70
	20	Bush Hog public road side	lateral 90°	No	0	No	25
Scraping	21	cleaning silo, hit gully	lateral > 360°	Yes	0	Yes	50
	22	leveling ground, hillside	lateral 180°	No	48	Yes	69
Tilling	23	cultivating tobacco, field	rear 180°	Yes	0	Yes	55
Unknown	24	unknown chore, hillside	lateral 90°	No	-	Yes	-

* EMT: emergency medical treatment; ‡ all deaths >1 h required hospital admittance; ** Farm travel refers to driving the tractor from one location to another between tasks; † This is a term used by farmers.

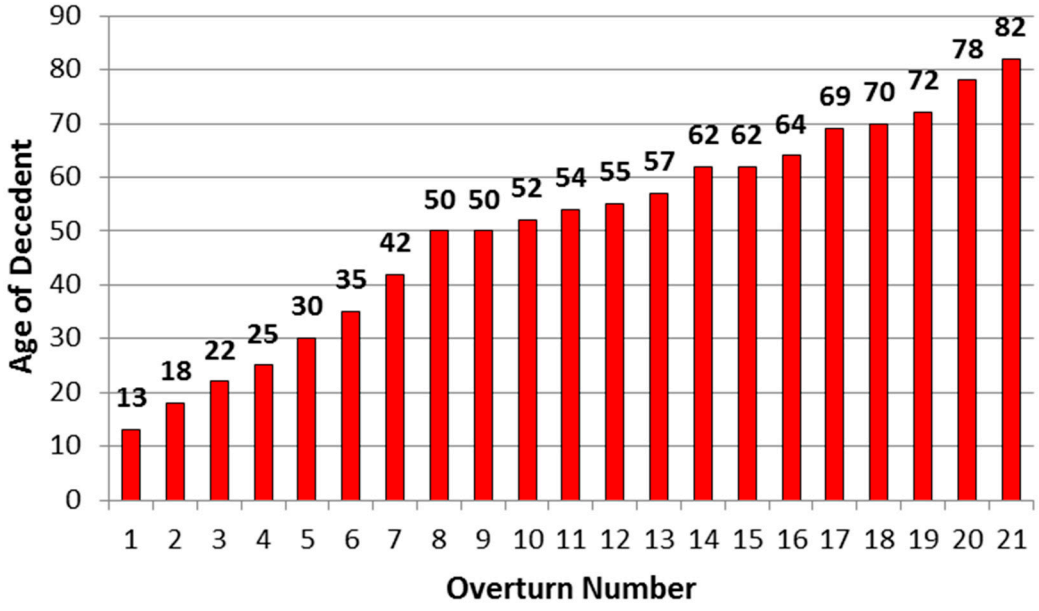

Figure 2. Age of operators killed in an overturn of non-ROPS tractors in Kentucky, 1960–2002, n = 21.

As shown in Figure 3, chores that were known for 23 of 24 fatal non-ROPS tractor overturns include rotary mowing = 6, farm travel = 6, road travel = 4, and hay harvesting = 3. Farm travel involves driving from one location to another on farm property as opposed to road travel.

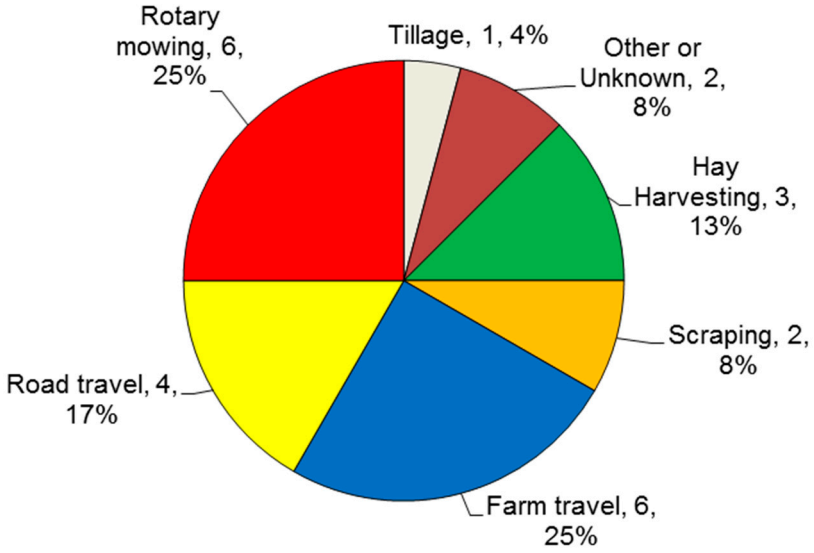

Figure 3. Chores associated with fatalities related to non-ROPS tractor overturns, n = 24.

3.2. Chores at Time of Serious Nonfatal Non-ROPS Tractor Overturns

A total of 64 nonfatal operator injuries from overturns of non-ROPS tractors received EMT. For 62 individuals, 59 (95.2%) were male and three (4.8%) were female. Chore categories, as reported at the time of overturn, and other selected variables were distributed as shown in Table 5. Fifty-seven of the injured operators were family members, and three were non-family members. Space does not permit a table that tallies values for all 19 variables for which data were collected. Chore category was known for 58 cases. As shown in Figure 4, chores involved were: hay harvesting = 17; farm travel = 12; rotary mowing = 7; pulling logs, stumps; logging = 6; tillage = 4; road travel = 4; fence work = 3; applying chemicals = 3; scraping = 1; lawn mowing = 1; and unknown = 6.

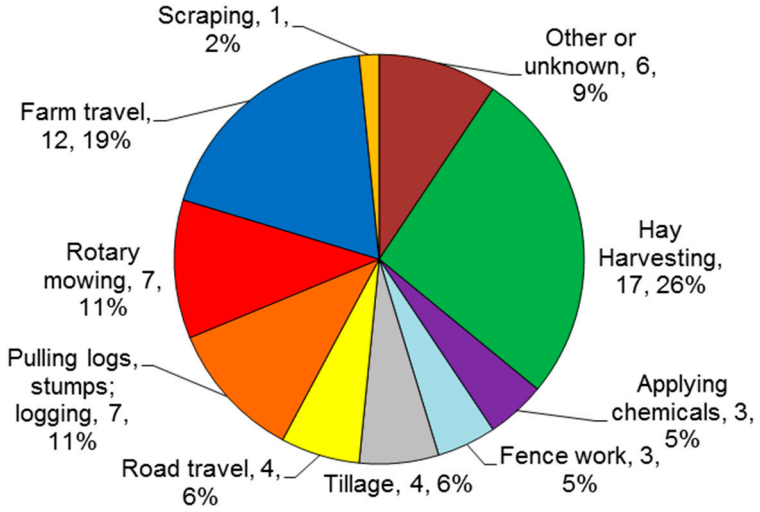

Figure 4. Chores associated with nonfatal injuries related to non-ROPS tractor overturns, n = 64.

Table 5. Chore category and selected variables for overturns of non-ROPS nonfatal injuries, n = 64.

Chore Category	Overturn Direction & Degrees					Disability Outcomes		Total
	Lateral			Rear	Unknown	Temporary	Permanent	
	90°	180°	≥360°	180°				
Applying chemicals	3	0	0	0	0	3	0	3
Farm travel	2	9	1	0	0	8	4	12
Fence work	1	1	0	0	1	2	1	3
Hay harvesting	8	5	2	2	1	15	2	17
Pulling logs (6), stump (1); logging (1)	1	1	2	2	1	6	1	7
Road travel	1	1	1	0	1	3	1	4
Rotary mowing	2	2	1	0	2	7	0	7
Scraping	1	0	0	0	0	0	1	1
Tilling, cultivate (3), plow (1)	1	2	1	0	0	4	0	4
Unknown or other	2	2	1	0	1	5	0	6
Totals	22	23	9	4	7	54	10	64

Days in the hospital were strongly skewed to the right of the distribution as shown in Figure 5. About one-third of the farmers spent less than five days in a hospital, and about one-half of them spent less than 10 days in a hospital. Days hospitalized for 56 farmers totaled 1118 (M = 19.96, SD = 30.28). Days of farm work lost for 48 farmers totaled 6742 (M = 140.46, SD = 133.24). Ten were permanently disabled.

Operator age at the time of nonfatal, non-ROPS tractor overturns was known for 60 farmers as shown in Figure 6.

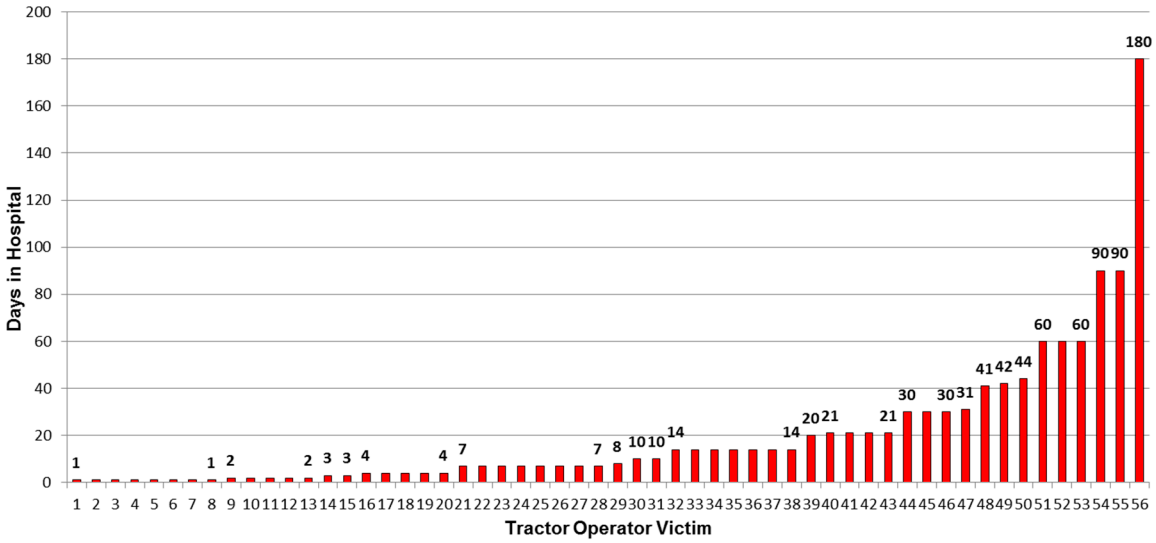

Figure 5. Days in hospital for operators injured as a result of non-ROPS tractor overturns, n = 56.

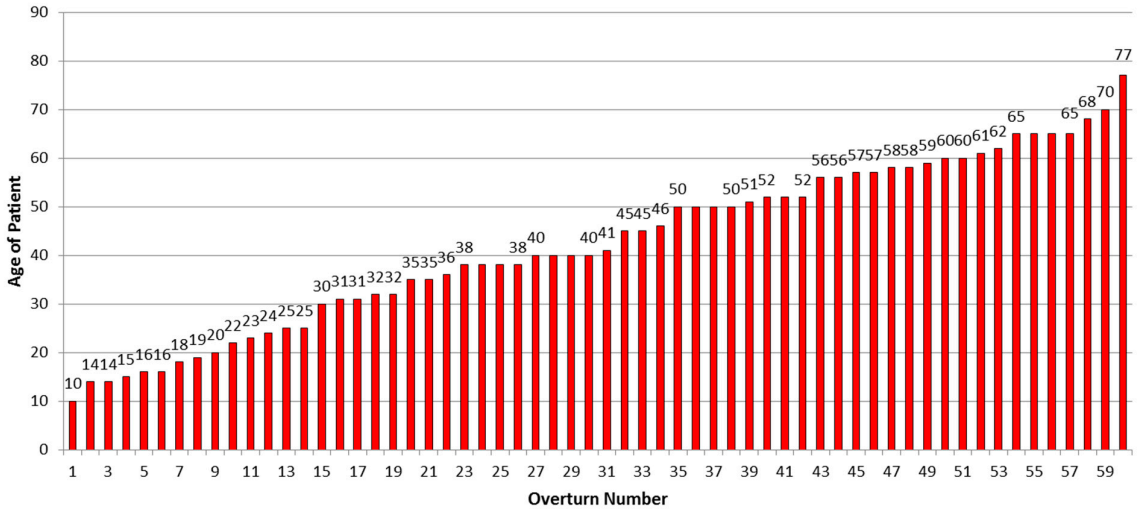

Figure 6. Age of seriously injured operator in an overturns of non-ROPS tractors in Kentucky, 1960–2002, $n = 60$.

Eleven farmers were reported to have sustained permanently disabling injuries that resulted from overturns of non-ROPS tractors. See Table 6. Six of the 11 recovered sufficiently to resume farm work. The reported disabilities for these six farmers included broken ankle, knee, rib, and shoulder bones, as well as torn muscles in shoulders and legs.

Five of the 11 farmers with permanent disabilities were never again able to perform farm work, and three were never able to do any other type of work. Of three fully-disabled farmers, one had a crushed chest; and one had injuries that required walking with a cane. The injury description for the third farmer was unknown. None of these fully-disabled farmers required special care typical of that provided by nursing homes.

Excluding eight farmers whose permanent disabilities prevented them from performing farm work or other work, the days of farm work lost were known for 48 farmers. These 48 farmers lost a total of at least 6742 farm work days with a mean of at least 140.46 days each (SD = 133.24) with a median of 90 days. Days of farm work lost are strongly skewed to the right, which suggests that non-ROPS tractor overturns result in high injury severity rates as shown in Figure 7.

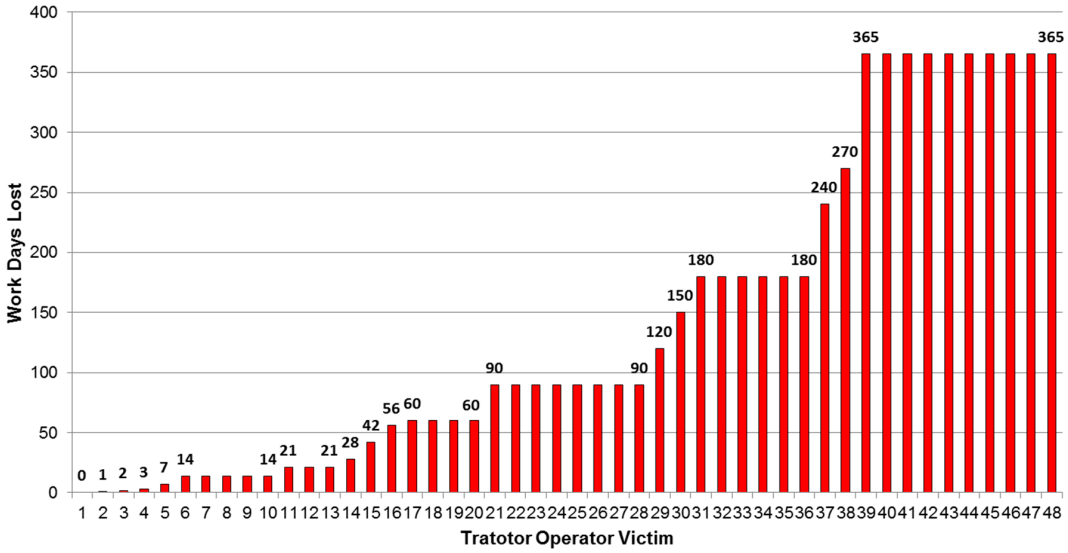

Figure 7. Operator farm workdays lost following nonfatal injuries related to non-ROPS tractor overturns, $n = 48$.

Table 6. Details of nonfatal non-ROPS tractor overturns by chore category, $n = 64$.

Chore Category	No.	Overturn Chore and Location	Overturn Direction and Degrees	Days Unable to Farm †	Age
Applying chemicals	1	spreading fertilizer, sloping area	Lateral, 90°	7	38
	2	spraying, hillside	Lateral, 90°	90	51
	3	spraying the corn, field	Lateral, 90°	90	52
Farm travel	4	driving around edge of fence-repairing fence, field	Lateral, 180°	30	50
	5	going from 1 work site to other on dirt trail, woods, dirt trail, woods	Lateral, 180°	240	70
	6	moving wagons to load tobacco, side of highway	Lateral, 180°	28	52
	7	coming from a job	Lateral, 180°	60	14
	8	going from 1 tobacco patch to another, hillside	Lateral, 180°	42	68
	9	hit ditch while pulling load, ditch	Lateral, 180°	3	45
	10	driving out in field turning corner, wheel went in rut, field	Lateral, 180°	21	18
	11	fencing, farm road	Lateral > 360°	50	22
	12	pulling a load of corn, field *	Lateral, 90°	180	38
	13	farm road *	Lateral, 180°	-	16
	14	coming in for lunch, field - hit hole *	Lateral, 90°	Never	-
	15	hauling a load of tobacco, creek bank on black top *	Lateral, 180°	-	35
Fence work	16	Fencing, fence line *	Rear, 180°	-	40
	17	moving fence post, slight hill	Lateral, 90°	-	30
	18	trimming around fence-got off it and it ran into fence-grabbed his leg, fence line	Unknown	365	61
Hay Harvesting	19	Picking up hay, field *	Rear, 180°	365	23
	20	making hay, hillside	unknown	60	25
	21	raking hay on hillside on farm, hillside	Lateral, 90°	-	15
	22	hauling hay, in front of hay barn	Lateral, 90°	365	77
	23	round baling hay-park brake broke-rolled to hollow, field	Lateral > 360°	365	56
	24	raking hay, hillside	Lateral, 90°	90	56
	25	mowing, field	Lateral, 180°	180	31
	26	mowing, field	Lateral, 90°	90	50
	27	mowing, field	Rear, 180°	14	59
	28	mowing, field	Lateral, 90°	14	57
	29	hauling hay, hill	Lateral, 90°	-	65
	30	rolling hay, farm	Lateral, 180°	-	56
	31	pulling a load of hay down a hill, bottom of hill	Lateral, 90°	180	38
	32	hauling hay, hill	Lateral, 180°	365	38
	33	mowing, hill	Lateral, 90°	365	45
	34	raking hay, hill	Lateral > 360°	150	65
	35	raking hay, field *	Rear, 180°	90	14
Lawn mowing	36	mowing the lawn, on a bank that broke away	Lateral > 360°	2	40
Pulling logs, stumps; Logging	37	Logging, field	Rear, 180°	365	19
	38	pulling logs—reared	Unknown	90	-
	39	pulling logs, hillside in woods	Lateral, 180°	180	58
	40	pulling a log and ran over a stump, woods	Rear, 180°	60	57
	41	trying to get a stump out of ground, field	Lateral, 90°	56	50
	42	dragging out wood-back wheel caught a stump, woods	Lateral > 360°	365	31
	43	pulling logs, hill *	Lateral 360°	180	60
Road travel	44	pulling combine, public road	Lateral 360°	120	25
	45	going from 1 farm to other-father had stroke, fell off, tractor hit tree and overturned, county road	Lateral, 90°	14	65
	46	moving tractor from 1 farm to another, public road	Lateral, 180°	365	16
	47	going from one farm to another on tractor, public road *	Unknown	Never	65

Table 6. *Cont.*

Chore Category	No.	Overturn Chore and Location	Overturn Direction and Degrees	Days Unable to Farm †	Age
Rotary mowing	48	bushhogging, field	Lateral, 180°	-	50
	49	bushhogging, hillside	Lateral > 360°	21	35
	50	bushhogging, pasture, slightly steep	Lateral, 180°	60	32
	51	bushhogging, hill	Lateral, 90°	-	62
	52	bushhogging, hill	unknown		31
	53	bushhogging, road	Lateral, 90°	1	46
	54	Bushhogging a pasture, sinkhole	Unknown	270	-
Scraping	55	blading, bulldozing work, ditch *	Lateral, 90°	Never	40
Tillage	56	setting tobacco on cultivating tractor-hit hill of rocks, field	Lateral, 90°	365	40
	57	cultivating tobacco, small hill	Lateral, 180°	-	60
	58	plowing, turn around at end of road	Lateral > 360°	-	50
	59	cultivating -run on rock and turned over, garden	Lateral, 180°	14	24
Unknown	60	Don't know, field	Lateral, 90°	30	-
	61	Don't know		14	20
	62	Sitting on tractor	Lateral, 90°	-	10
	63	Unknown *	Lateral, 180°	-	58
	64	-	Lateral, 180°	-	32

* Permanent disability (red colour); † 365 days unable to farm is ≥365 days.

3.3. Injury Prevention Effectiveness of ROPS and Seatbelts

Of 24 overturns of ROPS-equipped tractors only one tractor operator died. He was not wearing a seatbelt when driving a ROPS-equipped tractor on a public road. He was ejected and crushed by the overturning tractor when he ran off the road while attempting to avoid a collision with an approaching motor vehicle. Myers et al. presented a separate analysis of seatbelt use regarding this cohort [26].

We identified only four of the 89 ROPS-equipped tractor overturns for which data were complete that produced operator injuries severe enough to require hospital admission [15]. Details of these four ROPS-equipped tractor overturn events are summarized in Table 7. Three of the nonfatal injuries were related to chores of road travel, farm travel (hauling hay as feed), and rotary mowing (bush hogging) while one chore was unknown. All four overturns were to the side and involved violent overturns—one upside down and three with complete 360° rolls—which resulted in neither death nor disabling injuries of the operators. None of these operators were known to be wearing seatbelts.

Table 7. Chore category, overturn type, injury outcome, and operator age and gender for overturns of four ROPS-equipped tractors.

Parameter	Case			
	1	**2**	**3**	**4**
Chore Category	Road travel, steering failed	Carrying hay to cattle in pasture	Bush hogging on hillside	Unknown
Overturn type and degree	Lateral, 180°	Lateral, 360°	Lateral, 360°	Lateral, 360°
Seatbelt use	No	Unknown	No	No
Emergency medical treatment	Yes	Yes	Yes	Yes
Days in hospital	3	6	4	1
Farm work days lost	30	60	90	42
Age (years)	30	47	60	58
Gender	Female	Male	Male	Male
Permanent disability	None	None	None	None

It is worth noting that hospital stays regarding serious injuries associated with ROPS-equipped tractor overturns ranged from one to six days with a mean of 3.5 days, which is in sharp contrast with non-ROPS tractor overturn-related injuries that are strongly skewed toward much longer hospital stays as shown in Figure 5 with a mean of 20 days. Indeed, the length of hospital stays regarding ROPS-equipped tractor overturn injuries would reside at the low end of the non-ROPS tractor scale for hospital stays, rising up across two-thirds of the scale beyond six days to 180 days for a hospital stay, showing improved safety provided by ROPS. Improved safety of ROPS-equipped tractors was also shown by no permanent injury and many fewer days lost from work.

4. Discussion

No studies with survey data were conducted from a population-based random sample of this magnitude before or since the 2002 study documenting both fatal and nonfatal injuries associated with tractor overturns. Study limitations are noted below. Finally, the application of the study findings are discussed, and the prevalence of non-ROPS tractors is considered in some countries experiencing increasing agricultural machinery mechanization.

4.1. Limitations

Six limitations are described below: three regard the underreported number of fatal and nonfatal injuries, a fourth addresses the issue of exposure measurement, another discusses the current relevance of the 14-year-old study, and a sixth describes the generalizability of the results to a broader population.

First, the healthy worker effect may cause underreporting [27]. Farmers' whose operations went out of business because of a severe or fatal tractor overturn injury were removed from the NASS state and national list of farm operations. During the approximate 41-year period spanned by the survey, the overturn events were those reported by healthy farmers, or by the family members of injured or deceased farmers' whose operations remained in business and were, therefore, included in the Kentucky NASS 2001 comprehensive farm list. Thus, data for nonfatal and fatal tractor overturn events from farm operations no longer in business were not counted.

Second, the number of overturn injuries and fatalities reported includes only each farm's *most recent* tractor overturn event of Kentucky's 75,780 farms at the time of the survey. One item at the beginning of the survey asked farmers to report the *total* number of all tractor overturns that had occurred in the history of their operation. A total of 551 farms reported 603 overturns during the history of their operation. However, to minimize the response burden for the farmers, and to help ensure accuracy of reporting, each farm operator was asked to report *only* the details for their most recent tractor overturn event. Thus, details for these additional 52 overturn events were not collected.

Third, the survey included only a 7.98% random sample of Kentucky farmers for an approximate 41-year period, As a consequence the total number of fatal and nonfatal tractor overturns within the Kentucky farm operator population over the period are 12.5 times greater than those identified by the survey. Even so, the survey results are robust and useful because they are based on a large statewide, population-based random sample stratified by farm size and USDA agricultural district.

Fourth, while this study addresses qualitative exposures (i.e., exposures to chores), quantitative exposure data would be useful for similar studies. These exposure data could better indicate priorities for educational or ROPS retrofit programs. However, the challenge for measuring exposure is problematic: (1) recall is a problem, especially considering the use of multiple tractors on a farm over a long period of time; and (2) tractor meters are a source of engine running time, but the meters do not differentiate between stationary and mobile operations, and the meters may become defective over time or by damage.

Fifth, this analysis is based on a study conducted 14 years ago in 2002, and the relevance of its results might be questioned. In a 2008 study, investigators found that non-ROPS prevalence on farm tractors in the United States decreased from 62% in 1993 to 54% in 2001, and to 49% in 2004. In 2004, there were 4 million tractors in the United States [28]. A 2010 study found that, by 2006, the non-ROPS

prevalence had dropped to 41%. Over the period, from 1992 to 2007, tractor overturns accounted for 1412 deaths, and for each 1% decrease in non-ROPS tractor prevalence, there was a decrease of 0.07 overturn-related deaths per 100,000 workers [2]. The non-ROPS tractors reported in the current study are the same older tractors reported in the 2008 and 2010 studies. Nearly two million non-ROPS tractors manufactured prior to 1985 remain in service and a threat to life today [12,13].

Sixth, the current study was conducted in the state of Kentucky, so generalizability might be questioned. This data have been found to be generalizable to the non-ROPS problem in the high risk areas of the United States [24]. Another study, using the same dataset, found that Kentucky and five other nearby states had the highest fatality rate regarding overturn-related deaths among all 50 states in the country. These six states have rugged terrain and small farms in common [29]. Indeed, another study using the same data set affirmed that rough terrain was typical of small farms in the Appalachian Mountains' foothills that had a higher tractor overturn rate than large farms on relatively level ground [25].

4.2. Application

This study provided detailed information about the frequency, type, and extent of injuries associated with non-ROPS and ROPS-equipped tractor overturns across an array of chores. Data about these chores and other variables provide information about EMT received, hospital admission rates, days in the hospital, days of work lost, and disability outcomes and their duration. These data are useful in at least three ways.

First, the data can be used to provide more accurate estimates of the costs of tractor overturn injury outcomes as related to the chore performed, as well as for calculating cost effectiveness estimates for preventing injuries. For example, differentiating the potential cost savings of injuries prevented for crop-type chores (e.g., mowing) relative to livestock-type chores (e.g., fence work) would help to counter the averaging effect in cost analyses for ROPS retrofit interventions. As described earlier, ROPS-equipped tractors are less prevalent on crop farms than livestock farms [2]. Thus, a cost savings case could potentially be made for targeted education and ROPS retrofit programs and retrofitting tractors used for crop farming where the overturn-related injury risk is higher and the potential benefit is higher.

Second, the results can be used to design educational materials and interventions. These can be used to inform farmers and others who have a stake in preventing tractor-related injuries about the circumstances and details of chores that result in tractor overturn injuries and methods for their prevention.

Third, this study reinforces the need to encourage retrofitting older tractors with ROPS. Four overturns involving ROPS-equipped tractors resulted in nonfatal hospital admissions—however, none resulted in permanent disabilities.

4.3. Non-ROPS Tractors in Countries with Emerging Mechanization

Economically-challenged small farms and rough terrain, including unpaved roadways, are present in Kentucky [30] as well as in other countries such as China and India. While farm mechanization has come late to many countries, there is emerging interest regarding tractor overturning incidents and safety [31]. Tractors are coming into increased use in these countries, and they typically lack ROPS protection. India and China have numerous tractor manufacturers. Major tractor manufacturers in India include Escorts, Crossword Agro Industries, Mahindra Gujurat Tractor Limited, Punjab Tractors Ltd. (Swaraj), and MARS Farm Equipment Ltd. In India, tractors are a common mode of road transport in rural areas and often involve multiple riders per tractor [32]. Based upon product lines viewed at the webpages of these companies, none of the models shown were equipped with ROPS. China has more than 60 companies that manufacture tractors, which vary from 1960s technology to modern designs. Some of these companies have partnered with international companies, such as John Deere and AGCO [33]. One company that manufactures tractors in China, Wuzheng Agricultural Equipment Co.,

shows 94 tractor models on its website, 38% with cabs (whether ROPS outfitted or not), 2% fitted with a roll bar, and 60% with no ROPS [34].

The lack of ROPS on these tractors can be expected to result in the same tragedies that continues to be experienced in some highly mechanized countries despite the knowledge of the protection provided by ROPS. Regarding chores, studies need to be conducted in these countries to better understand risks associated with tractor overturns. While a tractor is likely the only motorized vehicle operating on a farm, its broader use as a utility vehicle (e.g., people transport) needs to be better understood so as to guide priorities for education and, more importantly, fitting the tractors with rollover protection.

5. Conclusions

This is the first population-based random sample study of tractor chores during operator fatal and nonfatal overturns of non-ROPS and ROPS-equipped tractors. Furthermore, the data used in this study reflect the problem of non-ROPS tractors and the chores for which they are used. These older tractors persist in being used for farm chores, and our study provides a lens into the type of chores that represent overturn hazards. Taking the perspective of tractor use in farm chores reinforces the need for ROPS retrofits on non-ROPS tractors. In addition, high hazard chores have been identified for which educational and ROPS retrofit interventions can be targeted, especially for travel on the farm, rotary mowing, and hay harvesting. These three chores represent 68.2% of fatal events and 50.0% of permanent and 56.6% of temporary disability overturn incidents. In addition, we found that the hospital residence time of people with nonfatal injuries related to overturns of non-ROPS tractors greatly exceeded the residence time of those patients with nonfatal injuries that resulted from ROPS-equipped tractor overturns. Despite the knowledge of the protection provided by ROPS, an implication of this study concerns countries with emerging mechanization where most tractors are produced without ROPS. The lack of ROPS on tractors in these countries can be expected to result in the same overturn tragedies experienced by the highly-mechanized countries.

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