

Analysis of 151 Agricultural Driveline-Related Incidents Resulting in Fatal and Non-Fatal Injuries to U.S. Children and Adolescents under Age 18 from 1970 through 2004

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ABSTRACT. Agricultural driveline-related incidents have been identified as an important cause of farm-related injury resulting in death and permanently disabling conditions to children and adolescents. A database of driveline-related injuries, including both PTO drivelines and secondary shafts and drivelines on agricultural equipment, developed at Purdue University was mined to identify all cases involving children and adolescents under age 18 who had been involved in a driveline-related incident from 1970 through 2004. Although these incidents did not account for a high percentage of all childhood farm-related injuries, this age group was found to make up nearly one in four documented agricultural driveline incidents. Of the 685 cases in the database with known ages, 151 were identified as youth under age 18. Findings indicated that these incidents often resulted in catastrophic injuries including amputation, spinal cord injuries, and compound bone fractures. Over the period studied, the trend in documented cases is declining, with recent years reporting below the yearly average and 2004 reporting no fatalities. Youth, primarily males, age 13 had the highest frequency of incidents, and over 50% of all cases occurred to youth ages 12 to 17. Fall was identified as the season with the most reported incidents. Amputations were documented in nearly 50% of all cases, and augers, elevators, and conveyors were the machines most frequently identified as being involved in the incident. Recommendations and strategies that specifically target the childhood injury problem related to agricultural drivelines are provided.

Keywords. Adolescents, Agricultural safety, Children, Driveline, Farm, Fatality, Injury, Power take-off, PTO, Safety, Youth.

Agricultural drivelines are used to transfer power from tractors or stationary power sources to a variety of machines and implements used in agricultural production. The primary driveline is technically referred to as the implement input driveline (IID) (ASAE Standards, 2004) or in common usage as the power take-off shaft (PTO), PTO shaft, or PTO driveline because it is driven by the PTO stub shaft of a power source. In addition, agricultural equipment can also be designed with secondary drivelines that transfer power to outlying components, such as gearboxes. The term "driveline"

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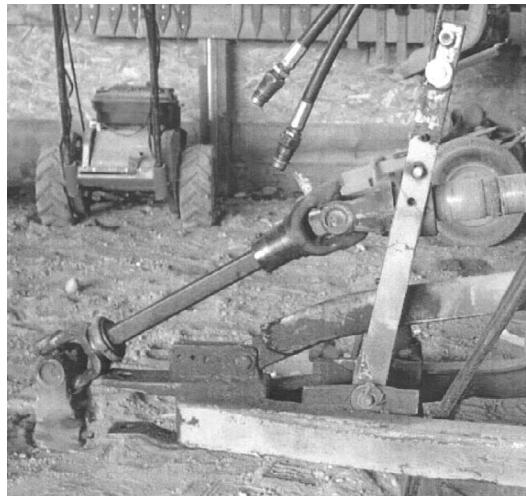


Figure 1. Manure spreader with exposed implement input driveline (IID) components.

is used here to identify any portion of the agricultural machinery driveline, from the tractor PTO stub shaft to the final point of power delivery.

Implement input drivelines and their components, as well as secondary drivelines powered by the IID, have been designed to be either fully or almost fully shielded from unintentional contact on nearly all machines that have been designed and manufactured over the past four decades, in accordance with guarding standards adopted and published by ASABE (ASAE Standards, 2002a). When, however, the driveline shielding, whether IID or secondary, has been allowed to deteriorate, has fallen off, or has been removed due to damage, misuse, or to enhance access to driveline components, and not replaced, the potential of contact with operating components resulting in entanglement increases greatly.

Unguarded IIDs (fig. 1), secondary drivelines (fig. 2), and related components used on farm operations have been historically recognized as serious hazards that can cause severe, permanently disabling injuries and death when unintentional contact and entanglement occur. In addition, children and adolescents have been found to be among



Figure 2. Auger with exposed top shaft and implement input connection (IIC) components.

those most at risk of unintentional contact with agricultural driveline-related components. This article reports on an analysis of agricultural driveline-related incidents, involving both IID and secondary shaft components, that have specifically involved children and adolescents under age 18.

Statement of the Problem

Farm operations are not only places of work, but also places of residence and recreation where children and adolescents live and play. Children and adolescents have been historically recognized to make up a considerable portion of the farm workforce in comparison to most other sectors of the industrial workforce. It has been well-documented that children and adolescents are frequently involved in both work and non-work farm-related incidents resulting in fatal and non-fatal injuries. Although there has been and continues to be much epidemiological research documenting farm-related incidents resulting in fatal and non-fatal injuries occurring to children and adolescents, little research has specifically focused on agricultural driveline-related incidents occurring to this portion of the farm population.

Currently, there are no federal or state-mandated injury reporting requirements applicable to most farm operations that allow for identification of driveline-related incidents for the entire farm population or for children and adolescents that live on, work on, or visit farm operations. In addition, until the development of the Purdue University Agricultural Power Take-Off Incident Database (PUAPTOID) (Beer and Field, 2003; 2005), there has been no known searchable repository of reported driveline-related incidents that would allow for ongoing summary and analysis. In the past, these deficiencies have presented considerable barriers to developing effective engineering, educational, and regulatory intervention strategies for preventing childhood driveline-related incidents.

Prior Findings

In order to gain a better understanding of the scope, magnitude, and severity of driveline-related incidents involving children and adolescents, prior research was reviewed, including research that addressed the following topics: PTO and driveline-related injury and fatality, farm youth injury and fatality, and type and severity of PTO and driveline-related injuries. A summary of the findings is presented below.

PTO and Driveline-Related Injury and Fatality Studies

Knapp and Piercy (1966) conducted one of the earliest studies specifically focused on PTO-related injuries. They investigated 110 PTO-related incidents occurring over a 20-month period in Iowa and found that 2% were fatal and 67% required hospitalization, with many resulting in severe injuries, such as amputations. No age distribution was reported in this study; however, it was reported that “youngsters of ages 5 to 16 with only limited experience and knowledge of the danger of the PTO mechanism were involved” in these incidents.

In a nationwide study of 3,229 farm machinery fatalities from 1975 through 1981, McKnight (1984) classified 11% of the documented fatalities as “entanglement” or “caught in machinery,” and 127 (3.9%) were clearly identified as driveline-related. Of the 127 fatalities considered PTO-related, 120 involved entanglement, and of these, one-fourth of the victims were under age 19. McKnight noted that “of the 14 female deaths [classified as PTO entanglement], five were under 15 years of age.”

Wilkinson (1991), who built upon the research conducted by Sell (1984) and Campbell (1987), reported on 130 injuries and 29 fatalities occurring from 1970 through 1990 resulting from PTO/IID-related incidents that were investigated using in-depth surveys completed by the victims or their family members. He separated the 159 cases into 5-year age groups to report the age distribution of the identified cases. No victims were identified in the 0- to 5-year-old age group. In the 6- to 10-year-old age group, six injuries and two fatalities were identified. The largest number of incidents occurred in the 11- to 15-year-old age group with 21 cases, one of which was fatal. The 16- to 20-year-old age group had 13 injuries and three fatalities. Of all the identified PTO/IID-related incidents in Wilkinson's study, 28.3% were under age 21, and 18.2% were under age 16.

Beer and Field (2005) analyzed cases documented during the 34-year period from 1970 through 2003 that were coded and stored in the Purdue database (PUAPTOID). At the time of the report, 674 driveline-related incidents, resulting in 271 fatal and 403 non-fatal injuries occurring in the U.S., had been documented and stored in the database. Beer and Field noted that 133 (21.2%) of the victims whose age was known were under age 18. As Wilkinson had done, Beer and Field also separated the 674 cases into 5-year age groups to report the age distribution of the identified cases. In the 0- to 5-year-old age group, there were 17 incidents, 11 fatal and six non-fatal. In the 6- to 10-year-old age group, there were 33 incidents, 11 fatal and 22 non-fatal. The 11- to 15-year-old age group again had the highest number of incidents of all age groups with a total of 60 documented incidents, 18 fatal and 42 non-fatal. There were 50 incidents documented in the 16- to 20-year-old age group, 19 fatal and 31 non-fatal. In 26% of all identified driveline-related incidents in Beer and Field's study, where exact age was known, the victim was under age 21, and 17.9% were under age 16, which compares with the figures found in Wilkinson's study (28.3% and 18.2%, respectively).

Farm Youth Injury and Fatality Studies

Previous farm-related injury and fatality studies have documented the causes of injuries occurring to children and adolescents. However, it is difficult to develop estimates of driveline-related injuries from these studies due to the reporting methods used. Often these studies group driveline-related incidents with machinery or tractor-related incidents, and these incidents cannot be separated. Some studies report primarily on the injuries and document little about the cause of injury. Another common reporting method is to use the phrase "caught in" or "entangled in" to classify incidents. When injuries are classified in these categories, there are no means to determine how many, if any, were driveline-related (NIOSH, 2001a, 2001b; Castillo et al., 1999; Rivara, 1997; Stueland et al., 1991; Stallones, 1989; Rivara, 1985; Walker and Raines, 1982).

However, some studies reporting on farm-related injuries and fatalities involving children and adolescents have mentioned driveline-related incidents. In a study documenting farm-related injuries occurring to patients under age 19 admitted to the La Crosse Lutheran Hospital in La Crosse, Wisconsin, over a 6.5-year period ending June 1984, two (1.9%) of the 105 documented cases were classified as "PTO-related" (Cogbill et al., 1985).

Salmi et al. (1989) reported on 62 Wisconsin and 32 Illinois farm-related fatalities among children under age 10 occurring from 1979 through 1985. The causes of six of these farm-related fatalities were classified as "caught in moving parts of machinery," which included an IID, silage auger, hay hoist, or pumpjack. Utilizing this information, driveline-related fatalities would make up 1.1% to 3.2% of all fatalities documented in this study.

Sheldon (1992) reported on 460 farm work-related fatalities involving children and adolescents under age 19 occurring in Indiana and Wisconsin from 1970 through 1990.

He classified 53 (11.5%) of these 460 identified incidents occurring to youth as “equipment or PTO entanglements,” and eight (1.7%) were clearly identified as IID entanglements.

Zietlow and Swanson (1999) identified “PTO-related injuries” in their study of 143 children and adolescents under age 18 who were admitted for agricultural-related trauma at Saint Mary’s Hospital in Rochester, Minnesota, from 1991 through 1997. They reported that 66 (46%) injuries were caused by a “mechanized piece of equipment,” and four (2.8%) were clearly identified as IID-related.

Building upon Sheldon’s (1992) research, Sutherlin (2001) conducted a study of farm-related injuries among children and adolescents under age 18 in Indiana and Wisconsin. Of the 536 identified childhood incidents occurring during the period 1970 through 1999, 57 (10.6%) were caused by equipment or IID entanglements, and 14 (2.6%) were clearly identified as PTO-related. Sutherlin also noted that “the proportion of PTO and equipment entanglement fatalities decreased from 12.8% in the 1970s to 3.3% in the 1990s.”

Due to the fact that these earlier studies did not distinguish between IID and secondary driveline-related incidents, it could not be determined which part of the machine caused the injury. For example, if a report read “entangled in driveline of portable auger,” there was no way of knowing if the injury occurred with the IID or with the secondary shaft of the auger.

Type and Severity of PTO-Related Injuries

Schnieder (1986) reported on Nebraska farm injuries occurring during the period 1969 through 1985 and observed that “PTO-related incidents” were “a most gruesome type of [incident].”

McElfresh and Bryan (1973) reviewed 49 PTO-related injury cases treated at the Mayo Clinic during their 15 years of experience with such injuries. There were 117 total injuries reported, including 54 fractures, 39 soft tissue lesions, 11 traumatic amputations, eight nerve injuries, and five joint dislocations. Fourteen (28.6%) of the 49 patients were under age 20, and four (8.2%) were under age 10. The authors did not distinguish between incidents involving the IID or those involving secondary drivelines.

A case study report by Kalenak et al. (1978) described in detail the injuries of seven separate IID-related cases. Of the seven cases, two involved children. One involved a 10-year-old male and another involved a 4-year-old male. The 10-year-old’s left leg was “severely mutilated.” The 4-year-old “sustained massive compound injuries of the left arm.”

Heeg et al. (1986) reported on 14 patients admitted to a hospital in the Netherlands for treatment of injuries caused by IID-related incidents during 1975 through 1983. These incidents resulted in 38 fractures, 21 soft tissue lesions, seven visceral lesions, two dislocations, and two nerve injuries. The authors described in detail the injuries occurring to three victims, two of whom were children. A 10-year-old male “sustained multiple injuries, including 14 fractures, and blunt abdominal and thoracic injuries,” and his right forearm was amputated. A 6-year-old male sustained a severe shoulder contusion, and one of his arms was amputated.

Swanson et al. (1987) reported that “power take-off injuries resulted in total or partial amputation in 30% of [incidents] versus 16.2% for corn auger injuries and 4.5% for tractor injuries.” Swanson et al. (1987) also reported that “corn augers and PTOs cause more devastating injuries as demonstrated by the associated increased hospital stay and amputation rate,” and “power take-off and corn-auger injuries resulted in the highest percentage of severe injuries with a high incidence of permanent disability.” No data were

reported concerning the age of victims, nor could it be determined what portion of the driveline was involved.

Of the 130 driveline-related incidents resulting in non-fatal injury documented by Wilkinson (1991), the following were reported: 44 amputations, 42 bone fractures, 22 bruises, 21 burns, 21 soft tissue removals, 17 lacerations, and ten joint separations. Thirty percent (30%) of these 130 incidents involved children and adolescents under age 21.

Of the 403 driveline-related incidents resulting in non-fatal injuries documented by Beer and Field (2005), 329 cases documented a total of 575 different injuries. The following were the seven most frequently reported injuries: 140 bone fractures, 131 amputations, 65 major bruises, 63 lacerations, 38 burns, 38 soft tissue removals, and 21 crushing injuries. Other injuries of note were nerve damage, scalping, emasculation or degloving of the genitals, brain stem injuries, ruptured organs, punctured lungs, joint separations, scratches, and partial suffocation. Children and adolescents under age 21 represented 29% of the incidents resulting in non-fatal injury when age was known, and children and adolescents under age 16 represented 20%.

Summary of the Prior Findings

The review of the literature revealed several important findings concerning driveline-related injuries and fatalities among children and adolescents. The review showed that driveline-related incidents consistently occur, but do not represent a large proportion of all farm-related incidents involving children and adolescents. One study investigating treatment of the most severe farm-related, non-fatal injuries involving children showed that 11.4% of documented injuries were driveline-related. However, the bulk of the studies documented proportions of driveline-related incidents among all farm-related incidents involving children and adolescents ranging from 1% to 3%.

Although the prior research did not show that driveline-related incidents were a large proportion of all farm-related incidents among children and adolescents, findings suggested that children and adolescents represented a considerable proportion of all documented PTO-related incidents resulting in fatal and serious non-fatal injuries, possibly near one in four of all documented cases. McElfresh and Bryan (1973) reported that 28.6% of the 49 patients involved in driveline-related incidents were under age 20. McKnight (1984) reported that 25% of the victims were under age 19. Wilkinson's study (1991) reported that 28.3% of all documented driveline-related incidents involved victims under age 21, and 18.2% were under age 16. Beer and Field (2005) reported that 21.1% of all documented incidents involved victims under age 18.

The review of the literature also documented that the severity of the injuries associated with these incidents has been high and often fatal or permanently disabling. Amputations and severe bone fractures often occurred, while other documented injuries included soft tissue lesions, visceral lesions, nerve injuries, brain stem injuries, joint dislocations, scalping, emasculation or degloving of the genitals, ruptured organs, punctured lungs, lacerations, partial suffocation, bruises, burns, and scratches. Because children and adolescents represented a significant proportion of previously documented driveline-related incidents and since these incidents were predominately catastrophic in nature, ongoing investigation of these incidents was considered justified to search for commonalities and strategies to reduce the risk and severity of this type of injury.

Methods

Building on the prior work of Sell (1984), Campbell (1987), and Wilkinson (1991), a project was conducted to develop an agricultural driveline-related injury data management system, including an electronic database designed to document, consistently code, store, and allow for analysis of data on agricultural driveline-related incidents resulting in fatal and non-fatal injuries (Beer and Field, 2005). The outcome of this effort was the development of the PUAPTOID, in which a total of 740 driveline-related incidents occurring from 1970 through 2004 have been documented and entered. Of these 740 incidents, 685 involved victims with known ages or age ranges. Of these 685 documented incidents, 151 (22.0%) involved children and adolescents under age 18. The analysis of these 151 incidents is the basis for this article.

Data Collection

The PUAPTOID was originally established to code and store data gathered concerning PTO or IID-related incidents. However, it was expanded shortly after its introduction to include any agricultural driveline-related injuries from the PTO stub shaft to the end of any secondary shaft used on agricultural equipment. The PUAPTOID was built upon data mined from the following sources:

- An estimated 12,000 news clippings from newspapers nationwide reporting farm-related injuries and fatalities dating back to the 1970s.
- An estimated 720 articles from daily Google news alerts for the year 2004 tracking key phrases such as “farm injury,” PTO, and “farm accident.”
- 636 farm-related injuries and fatalities identified through news clippings for the year 2003 and 512 for the year 2004 provided by the University of Iowa Great Plains Center for Agricultural Health.
- 215 PTO-related injury investigations conducted by Sell (1984), Campbell (1987), and Wilkinson (1991).
- Over 75 published annual statewide farm-related injury reports and fatality summaries from 1970 through 2003 collected from multiple states.
- Materials such as depositions and expert witness correspondence from proceedings of 22 cases litigated in state courts involving driveline-related injuries.
- Case studies developed from 15 personal interviews of victims or family members of victims involved in driveline-related incidents.
- Voluntary reports of driveline-related incidents that have been collected by Purdue University’s Agricultural Safety and Health Program (PUASHP) over the past four decades.
- NIOSH *Alert* publications and 255 online Fatality Assessment and Control Evaluation (FACE) reports.
- Hundreds of death certificates, mostly dating in the 1970s and 1980s, collected as part of a cooperative agreement with the Indiana Department of Health to identify farm-related fatalities.
- Farm Accident Data Coding Sheets completed by Purschwitz (1989).
- Other sources including *Morbidity and Mortality Weekly Report*, *Purdue University Old Order Anabaptist Injury Database*, California Nurses Using Rural Sentinel Events (NURSE) Project, non-fiction books, and magazine articles.

Due to the infrequency of these events, multiple sources documenting the same incident were often found. This allowed for validation of the cases and provided a more comprehensive review of the incident (Beer and Field, 2005). Sources were identified as either primary or secondary based on how the incident was identified. In over 35% of the cases, the primary source was a newspaper clipping that was then complemented by other

Table 1. Primary sources of driveline-related incidents.

Source of Information	Total	Percent
Newspaper clipping	53	35.1
Investigation from earlier study	45	29.8
State report	27	17.9
Voluntary report	10	6.6
Proceeding of prior litigation	5	3.3
NIOSH publication or FACE report	2	1.3
Personal interview	2	1.3
Magazine article	2	1.3
Death certificate	1	0.7
Other	4	2.6
Total	151	99.9 ^[a]

[a] Not 100.0% due to rounding.

sources. In only one case was the sole source of information derived from a death certificate. Table 1 shows the distribution of the primary sources of information used for documenting each child and adolescent case. Only proceedings of prior litigation provided relatively comprehensive information on the incidents documented. As noted by other researches, newspaper clippings, death certificates, and other sources have weaknesses, especially with respect to identifying causative factors. Using the name of the victim, age, date of incident, and other variables, all potential for duplication of cases was removed.

Analyzing the Data

Documented incidents resulting in fatal and non-fatal injuries were coded using a standardized form. The coding process used a review of the data by three individuals with experience in agricultural safety, engineering, and injury investigation. The data were then entered in an electronic database using Microsoft Access 2002 (Beer and Field, 2005). Data on incidents involving children and adolescents under age 18 were queried. These data were analyzed by developing tables and charts using Microsoft Excel.

Findings

A summary of the findings from the analysis of the 151 child-related driveline incidents is presented below.

The Incidents

The outcome of the incident was non-fatal for 99 (65.6%) and fatal for 52 (34.4%) of the 151 cases, resulting in the ratio of 1.9 to 1, non-fatal to fatal incidents. For the 35-year period investigated, the average number of fatal incidents per year was 1.5 and the average number of non-fatal incidents was 2.8 per year. Based on earlier work, the average number of non-fatal incidents would likely have been higher if non-fatal injury data were reported at the same level of intensity as fatality data (Beer and Field, 2005).

The distribution of cases among the states is shown in figure 3. States that provided more comprehensive documentation of farm-related incidents and had more extensive farm fatality records recorded more driveline-related incidents. This observation is indicated in the Indiana data, where an aggressive driveline-related injury surveillance effort has taken place over the past 30 years. Because of this, figure 3 is not intended to be a representation of the distribution of driveline-related incidents involving children



Figure 3. Nationwide distribution of documented driveline-related incidents occurring to youth under 18 from 1970 through 2004 ($n = 145$). Not shown are six cases in which the state is unknown.

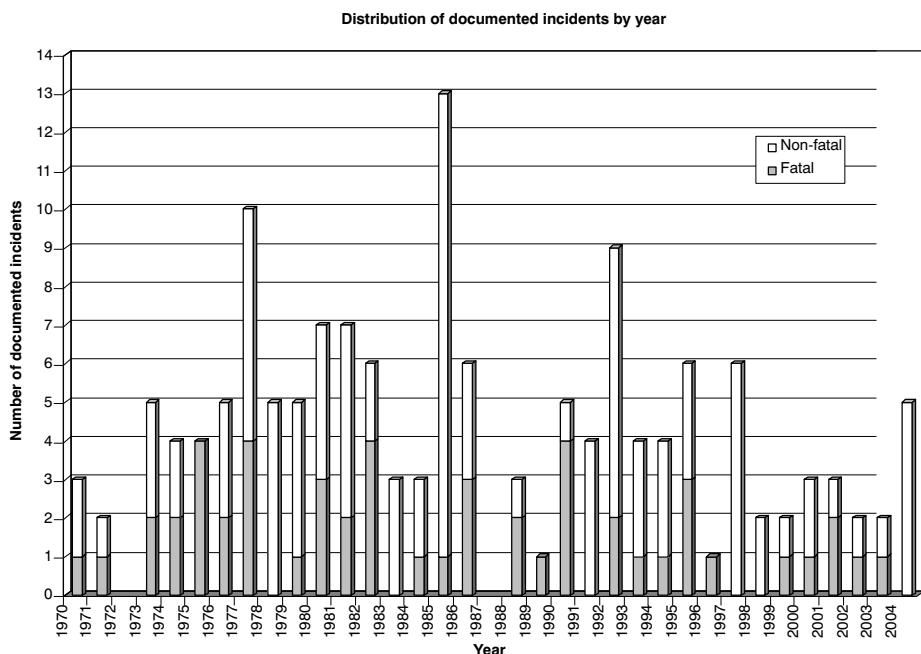


Figure 4. Yearly distribution of documented driveline-related incidents occurring to youth under 18 from 1970 through 2004 ($n = 150$). Not shown is one case in which the exact year is unknown.

and adolescents under age 18 from state to state. However, it may give some indication as to which states most often experience these types of incidents.

Figure 4 shows the number of documented cases during each year of the study period (1970 through 2004). Due to the methods used in identifying cases, this is not meant to represent the yearly trend of all driveline-related incidents, although it is believed to be the best possible representation developed to date. The average rate was 4.3 incidents per year. The trend in documented incidents per year is declining, with recent years (1998 to 2003) reporting below the average yearly incident rate. With intense PTO-related incident surveillance, including on-line searches, occurring during the most recent period (2002 through 2004), only seven non-fatal childhood injuries and two fatal childhood injuries were documented nationwide, with no documented fatalities in 2004. Sell (1984) and Campbell (1987) conducted their studies between 1982 and 1987, which may have contributed to the high number documented in 1985; however, they documented no cases in 1987.

The month in which each incident occurred was known for 142 (94.0%) of the cases. Figure 5 shows the distribution of the number of cases by month. Fall, which included September, October, and November, was the season with the highest frequency of cases, accounting for 63 (44.4%) of the 142 cases where season was known, followed by winter, spring, and summer, which accounted for 32 (22.5%), 27 (19.0%), and 20 (14.1%) of the cases, respectively.

The day of the week was known for 125 (82.8%) of the cases. Friday and Saturday were the days with the highest frequency, each accounting for 18.4% of the cases in which the day was known. Monday had the lowest frequency, with 7.2% of the cases.

The actual time when the incident occurred was estimated by using the sources of information that gave the actual time or at least a good estimate of what time the incident

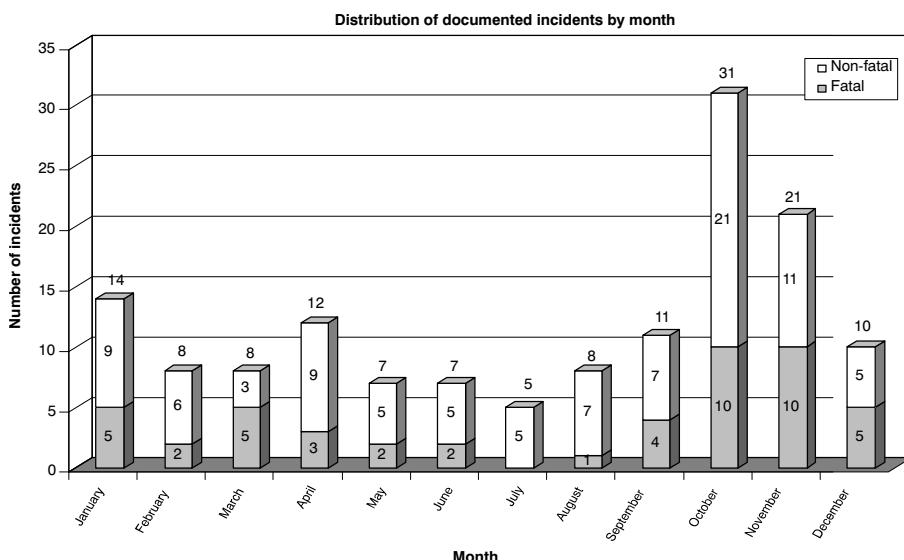


Figure 5. Monthly distribution of documented driveline-related incidents occurring to youth under 18 from 1970 through 2004 (n = 142). Not shown are nine cases in which the month is unknown.

occurred. Some sources indicated the time the emergency personnel arrived or were contacted, and these times, along with other clues presented in reports, were used. The actual time of the incident could be estimated for only 68 cases (45.0%), of which over one-half (52.9%) occurred between 3:00 and 10:00 p.m.

The Farm and Agricultural Injury Classification (FAIC) code adopted and published by ASABE (ASAE *Standards*, 2002b) could be determined for 106 (70.2%) of the 151 cases. Only two of the 11 FAIC codes were applicable to driveline-related injury. FAIC 1 (defined by farm production work) was used to classify cases in which it could be determined that the victim was engaged in agricultural work-related activity. FAIC 6 (defined by farm hazard exposure, non-workers: equipment, tools, objects, and products) was used to classify cases in which it could be determined that the victim was engaged in an activity that was not agricultural work-related, such as visiting, watching, or wandering near the workplace. Of the 106 cases where the FAIC was known, it was determined that 67 (63.2%) were FAIC 1 and 39 (25.8%) were FAIC 6. Fifty-two (77.6%) of the 67 cases determined to be FAIC 1 were adolescents in the 12- to 17-year-old age group.

The Victims

The exact age of the victim was known for 149 of the 151 cases in this study. The remaining two victims were known to be under age 18, one of whom was known to be between 12 and 14. Figure 6 shows the distribution of cases by age for the 149 incidents where exact age was known. Age 13 represented the highest frequency of incidents, with

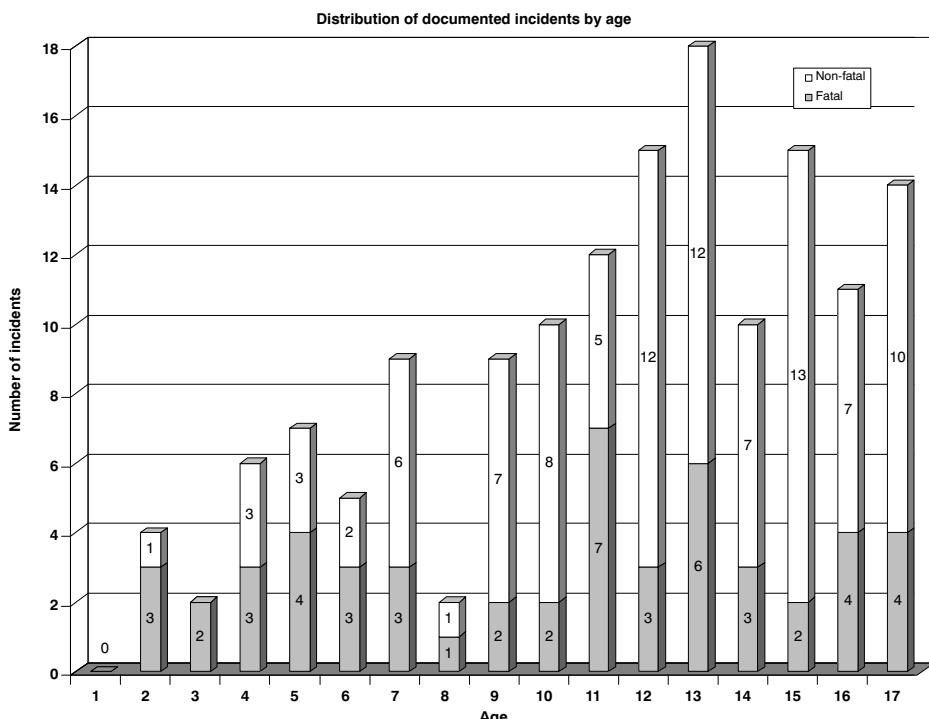


Figure 6. Age distribution of documented driveline-related incidents occurring to youth under 18 from 1970 through 2004 (n = 149). Not shown are two cases in which the exact age is unknown.

18 (12.1%) of the cases where age was known. Ages 0 to 5, ages 6 to 11, and ages 12 to 17 accounted for 19 (12.8%), 47 (31.5%), and 83 (55.7%) of the cases, respectively.

The gender of the victim was known for every case, and males accounted for 131 (86.8%) of all cases. The male to female ratio was 6.6 to 1, while the non-fatal to fatal ratio for both males and females was the same (1.9 to 1).

The type of clothing initially entangled was known for 81 cases (53.6%). Pants or blue jeans accounted for the most frequently identified types of clothing initially entangled with 22 cases (27.2%), followed by jackets or sweatshirts with 16 (19.8%). Other recorded types of clothing were coats, coveralls, shirts, shoes/boots, gloves, sweaters, snowmobile suits, and shoelaces.

The general activity of the victim at the time of the incident was reported for 93 (61.6%) of the cases. The most commonly recorded general activity was "standing on the ground near the equipment," which accounted for 50 (53.8%) of these 93 cases. Some of the specific activities identified were: standing on implement tongue, trying to look inside implement, climbing on or off tractor from rear, applying pressure to post-hole digger, cleaning manure or clearing ice from manure spreader, releasing hitch, bending over to retrieve a dropped object, and slipping and falling onto shaft.

The Injuries

There were 52 incidents that resulted in injuries that were fatal. Limited access to reports from medical examiners or death certificates prevented an accurate determination of causes of death. The causes most frequently identified in the reports available included multiple injuries, head trauma, loss of blood, or strangulation.

There were 99 non-fatal cases, and known injuries were reported in 83 (83.8%) of them. From these 83 non-fatal incidents, 140 different injury types were reported (table 2). If multiples of the same injury occurred in a single case, only one of the injuries was recorded for the purposes of this table. For example, if a victim lost more than one extremity, amputation was recorded only once for that case. Minor injuries, such as scratches and bruises, were usually recorded if they were the only injuries that occurred and were rarely recorded when a major injury was reported, although they very likely

Table 2. Distribution of 140 reported non-fatal injuries from the documented driveline-related incidents occurring to youth under 18 from 1970 through 2004 (n = 83).^[a]

Injury	Total Recorded	Percentage of cases (where injury is known) reporting this injury type (n = 83)
Amputation	41	49.4
Bone fractures	38	45.8
Lacerations	13	15.7
Burns	11	13.3
Bruises	10	12.0
Soft tissue removal	6	7.2
Crushing injuries	5	6.0
Scalping	5	6.0
Scratches	5	6.0
Nerve damage	2	2.4
Emasculation	1	1.2
Joint separations	1	1.2
Punctured lung	1	1.2
Suffocation	1	1.2
Total	140	--

[a] Not included in the table are 16 incidents in which the type of non-fatal injury is unknown.

occurred in most of the documented incidents. Amputations were reported in nearly one-half (49.4%) of the cases where injury was known, and bone fractures, usually severe compound fractures, were reported in just under one-half (45.8%) of the cases. Nearly two-thirds (27) of the amputations were upper extremities, and slightly over one-fourth (11) were lower extremities.

It is difficult to summarize the extent of injuries that occurred for each case because full descriptions of the injuries are rarely reported; however, two cases were chosen to represent the severe nature of these incidents. A 9-year-old male entangled in the IID of a feed wagon experienced the following injuries: partial scalping, left arm nearly amputated at site of incident and later surgically amputated, right arm severely mutilated but reconstructed through surgery, right thigh severed in two places and most of the flesh torn off but reconstructed through surgery, and compound exposed fractures to left leg, also reconstructed through surgery. The second case involved a 14-year-old male entangled in the IID of an auger that resulted in the following injuries: right arm traumatically amputated at site of incident, compound fractures to left arm, compound fractures to one leg, major nerve damage to arm, collarbone broken, and other major cuts and bruises.

The Implements

The type of implement involved was reported for 116 of the childhood cases (76.8%). The most frequently reported implement category was “auger, elevator, or conveyor.” Table 3 lists the types of implement reported and the total number of incidents involving each. Augers, elevators, and conveyors were included in one category because of their similarity in purpose and because it was determined that these terms were sometimes used interchangeably by various reporting sources. For the same reasons, other implements of a similar nature were combined into single categories for reporting in table 3.

Seven implement types were involved in only one case each and were grouped together in the single classification of “other.” These implements were: irrigation equipment, manure pump, pull-type corn picker, portable welder, grain bagger, sawmill, and stack mover.

Table 3. Distribution of the reported implement types involved with driveline-related incidents occurring to youth under 18 from 1970 through 2004 (n = 116).^[a]

Type of Implement	Total	Percent
Auger/elevator/conveyor	44	37.9
Manure spreader	14	12.1
Forage wagon	12	10.3
Feed grinder/mixer/grain wagon	12	10.3
Post-hole auger/digger	8	6.9
Hay baler	3	2.6
Fertilizer spreader	3	2.6
Corn grinder/sheller/shucker	3	2.6
Mower/conditioner	2	1.7
Rotary mower	2	1.7
Hay rake	2	1.7
Forage blower	2	1.7
Sprayer/spray pump	2	1.7
Other	7	6.0
Total	116	99.8 ^[b]

^[a] Not included in the table are 35 incidents in which the implement is unknown.

^[b] Not 100.0% due to rounding.

Entanglement in the primary driveline (the IID and/or universal joints) was documented in 116 (82.9%) of the 140 cases where specific shaft type or location was known, which is much greater than the 22 (15.7%) reported secondary driveline entanglements. Over two-thirds (15) of these secondary driveline incidents occurred on an auger, elevator, or conveyor top shaft or side shaft. Two occurred on the side shaft of a manure spreader. For 11 cases, it could not be determined on which component of the driveline the entanglement occurred. In two cases, the victim was reported as having been entangled in the exposed stub shaft of a tractor with no IID attached.

Initial entanglements occurred more frequently in areas near the tractor PTO stub shaft and the implement input connection (IIC), locations where universal joints, spring-loaded push pins, shear pins, and protruding replacement bolts are frequently found, especially on older machines. When the object that caused the initial contact was known, it was most commonly recorded as a spring-loaded pushpin or a through-bolt described as "too long" or "protruding."

Examination of the data concerning shield condition resulted in similar observations to those reported by Beer and Field (2005) for driveline-related incidents involving all ages. They noted that "information on the existence, type, and condition of shields was not reported for a large portion of the incidents; however, the shielding was reported as being 'not in place' more often than 'in place' when information on the existence of shields was known."

Conclusions

Agricultural driveline-related incidents resulting in fatal and non-fatal injuries occurring to children and adolescents under age 18 have not been shown to make up a large portion of all farm-related non-fatal and fatal injuries. However, this age group does represent a considerable portion of documented injuries caused by drivelines, and when this type of injury occurs, it is frequently catastrophic in nature. Although drivelines are not the most frequent source of injuries in the agricultural workplace, the nature and extent of the resulting injuries graphically demonstrate the importance of continued research of these incidents, especially with respect to the need to develop strategies for preventing youth-related agricultural driveline incidents.

The analysis of the 151 childhood driveline-related incidents resulted in findings somewhat comparable to earlier findings, but with added insights into incidents that specifically involve children and adolescents. For example, there was a slightly higher ratio of non-fatal to fatal incidents for youth (1.9 to 1, as compared to 1.5 to 1 for all ages), which suggests that children and adolescents are more likely to survive driveline-related incidents. However, the injury outcome is often more severe. Amputations and bone fractures were both shown to occur at a higher rate among youth than for all ages as reported by Beer and Field (2005). They reported that 39.8% of injuries reported for all ages combined resulted in amputation and 42.6% resulted in bone fractures. In this study, amputation was found to occur in almost 50% of the childhood cases where injury was known, approximately ten percentage points higher than for all ages combined.

The male to female ratio was lower for children than for all ages combined (6.6 to 1, as compared to 8.8 to 1), which indicates that female youth are more likely to be involved in driveline-related incidents than female adults.

Nearly 45% of the childhood cases, similar to the 43.3% for all ages, occurred during the fall months of September through November, busy harvest months when augers, elevators, and conveyors are extensively used. The implement category accounting for the most incidents was augers, elevators, and conveyors, which are the implements reported to be most frequently involved in earlier findings.

Age 13, accounting for 18 incidents, represented the peak age for driveline incidents occurring to youth under age 18. The age group 12 to 17 accounted for 55.7% of the cases. Over 75% of the cases found to be work-related (FAIC 1) involved adolescents age 12 to 17. These findings give an indication of the extent to which inexperienced and untrained adolescents involved in the agricultural workforce are exposed to PTO-operated equipment.

The victim was most commonly “standing on the ground near the equipment,” and upper extremities accounted for two-thirds of the amputations. These findings may suggest a relationship between the approximate height of the upper limbs of youth, the typical height of agricultural drivelines, and the potential for upper limb entanglement.

There were several commonalities between the cases investigated, such as the severity of injuries, time of year, and lack of shielding, but there was no specific causative factor, other than exposure, that, if reduced or modified, would have prevented the bulk of the incidents. In other words, the key to preventing youth-related driveline entanglements is to reduce their exposure to operating drivelines, especially those that are unguarded.

Recommendations

Three main areas of intervention strategies (education, engineering, and enforcement) were developed based on the research findings and the observations of the authors during this study.

Education

Because children and adolescents represent a considerable portion of those injured in PTO-related incidents and their injuries often result in permanently disabling injuries and death, and because this population is generally inexperienced and/or untrained in the use of PTO-operated equipment, educational efforts should primarily focus on parents and guardians of children who live on, work on, or visit farm operations where exposure to drivelines is likely. Strategies might include:

- An interactive website utilizing games, puzzles, and lessons that would assist parents and guardians in understanding the causes of driveline-related injuries and possible prevention strategies. The site should explain current regulations concerning youth under age 16 working on farms and restrictions related to working near PTO-operated machinery.
- Updated printed educational information on general farm safety, including the hazards of unguarded agricultural drivelines, that targets youth, parents, students, educators, and employers, should be produced and distributed widely to key stakeholders and to rural physicians and pediatricians. Information dissemination models such as those used to promote child safety seats for automobiles could be utilized.
- Driveline-related safety should continue to be included and strengthened in current tractor safety certification and farm safety curriculums taught in agricultural education classrooms, 4-H programs, FFA programs, farm safety day camps, or any other setting where farm safety is taught. Emphasis should be placed on the catastrophic nature of driveline-related injuries. Certification training should continue to focus on the requirements prescribed by the Agricultural Hazardous Occupation Orders (AgHOs). Although exempt from this law, sons and daughters who plan to work on their family farms should be encouraged to attend certification programs where they would be exposed to driveline-related safety information. Educators who teach these programs should be adequately trained on agricultural

workplace safety, including the hazards associated with driveline-related entanglements.

- Concisely written articles and short audio clips on driveline safety should be developed and then distributed to key farm and rural media to raise awareness within the rural community of the potential hazards and catastrophic injuries associated with unguarded agricultural drivelines.
- Managers and owners of farm operations should be educated on the importance of driveline safety training for employees and that it is unlawful to hire youth under age 16 to operate PTO-operated equipment, unless they are certified as prescribed by the AgHOs or exempt from the law.

Engineering

Because driveline-related injuries involving children and adolescents largely involve exposed drivelines or driveline components, engineering efforts should primarily focus on continued enhancement and durability of guarding for drivelines and driveline components as well as innovative methods to maintain and replace damaged driveline guards.

- Driveline, tractor, and agricultural equipment manufacturers should continue to comply with ASABE, SAE, and ISO minimum standards and, where feasible, exceed these standards in regard to durability of driveline shielding components.
- Research should be conducted to assess the condition of driveline guards currently used on agricultural operations to determine the extent of guarding failures and potential causes.
- Retrofit and replacement guards for older and refurbished equipment should continue to be made commercially available and should be made easily accessible for owners of PTO-operated equipment.
- The impact of warning decals located on guards should be assessed, and consideration should be given to other warnings that might discourage the presence of children near operating PTO equipment. Warnings should also include statements that discourage the use of replacement bolts, nails, or other objects in place of manufacturer-recommended or supplied pins.
- The current use of secondary warning decals that become visible when primary guarding is removed from IIDs should be expanded to include all secondary shafts.

Enforcement

There are currently effective design standards in place that apply to guarding agricultural drivelines. In addition, there are workplace safety standards (OSHA, 2005) that apply to guarding of farm equipment on farms with eleven or more employees or farms that provide migrant housing, and for hiring youth to work on farm operations. Support and enforcement of these standards and laws should continue. In addition:

- The Occupational Safety and Health Administration (OSHA) standards concerning guarding of agricultural drivelines for farms with eleven or more employees should be enforced. Consideration should be given to the value of expanding these standards to all farm operations that employ outside labor.
- Existing ASABE, SAE, and ISO standards should be applied to foreign manufacturers of tractors, PTO-operated equipment, and IIDs that export this equipment to the U.S.
- The AgHOs should continue to be enforced. No children under age 16 should be allowed to be employed on a farm to operate PTO equipment or to perform other hazardous tasks unless they are exempt for the reasons in the amendment or have received appropriate certification training. Consideration should be given to more

strongly encouraging youth who are currently exempt to participate in AgHOS training programs

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