Validation of Self-Reported Power Take-Off Shielding Using On-Site Farm Audits

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ABSTRACT. *Despite the substantial contribution of power take-off (PTO) entanglements to workplace morbidity and mortality among agricultural workers, the degree of proper PTO shielding on U.S. farms remains poorly characterized. Sampling from the New York data of the USDA National Agricultural Statistical Service (NASS), at least 200 each of dairy, livestock, crop, fruit, and vegetable farms were surveyed by phone to determine the extent of proper PTO shielding. In the same year, on-site audits were performed at 211 randomly selected New York livestock and dairy farms using a four-point scale to assess PTO shielding. Supplemental data were gathered on farm acreage, number of livestock, principal commodity, and operator experience. The phone survey data for livestock and dairy farms were then compared to the on-farm audit data. In the phone survey, 72.5% of farms reported having shields on all implements. The mean percentage of implements reported to be shielded was 90.2%. By on-farm audit, 10% of farms had all implements properly shielded, and the mean percentage of properly shielded implements was 56.7%, with shielding rates differing widely for different classes of implements. No significant predictors of PTO shielding were identified. The phone survey greatly overestimated proper PTO shielding rates when compared with the on-farm audits. These data suggest a lower level of proper shielding among farmers than is mandated by current industry safety standards. The results also identify a principal weakness of phone surveys in accurately assessing the true magnitude of on-farm risk for PTO entanglement.*

Keywords. *Driveline shield, Farm injury, Farm inspection, Farm safety, Phone survey, Power take-off shield, PTO shield.*

Despite technological advances in the industry, farming continues to be one of the most dangerous occupations in the U.S.; farmers are nearly seven times more likely to be killed at work than the average American (BLS, 2014). In 2013, the annual rate of fatal injury among U.S. farmers was 21.8 per 100,000 full-time workers (BLS, 2014).

Machinery entanglements, including those involving power take-off (PTO) drivelines, are the third leading cause of fatal injuries on farms (Gerberich et al., 2001). A retrospec-

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tive analysis of PTO entanglements occurring between 1970 and 2003 found that 40% of PTO driveline entanglements resulted in fatalities (Beer and Field, 2005). Nonfatal PTO entanglements also result in substantial morbidity among farmers. This same study found that another 40% of driveline-related injuries resulted in amputation (Beer and Field, 2005). These severe injuries contribute disproportionately to healthcare costs. For instance, entanglements account for 15% of farm injury hospitalizations in Canada, yet these injuries are responsible for 40% of agricultural injury-related healthcare costs (Narisimhan et al., 2011).

Elevators, augers, and conveyors have been identified as the equipment most commonly involved in PTO entanglements (Beer and Field, 2005). Because such machinery is often stationary and operated near farmhouses and barns, farm children are particularly susceptible to entanglements, either while operating the equipment themselves or spending time with an older operator. Of all PTO driveline-related injuries, 21% are to children under the age of 18 (Beer and Field, 2005).

Regulatory efforts to improve PTO safety and decrease the incidence of entanglement-related injury and death have only affected a small percentage of the at-risk population. While OSHA standards require that all PTO guards be in place during operation of equipment (OSHA, 1976), farms that employ fewer than eleven workers are exempt from enforcement of OSHA regulations (OSHA, 1997). In 2007, out of approximately 2.2 million farms in the U.S. (USDA, 2007a), 43,113 (less than 2%) employed more than ten workers (USDA, 2007b). Absence of proactive oversight is only one factor that allows machinery to continue in operations despite damaged or dysfunctional shields. The cost of shielding, difficulty finding correct parts, and lack of time to perform needed repairs all contribute to the problem (Weil et al., 2014). Finally, given the fact that missing guards do not prevent a machine from functioning, farmers have no immediate need to replace PTO shields in order to complete their daily work (Athanasiov et al., 2006).

Estimating the prevalence of improper PTO shielding is a crucial component in addressing the morbidity and mortality of PTO entanglements. Multiple studies have already been conducted to do this, using both in-person inspection and telephone surveys. In one study, surveyors visited 36 agricultural equipment auctions and performed inspections on 351 PTO-powered implements. On the equipment inspected, more than one-third of the PTO shields were completely missing, and an additional 20% did not function properly (West and May, 1998). In 1992, Oklahoma State University performed on-farm inspections of machinery on 209 farms. The study found that 81% of the PTO shields were in place but did not attempt to distinguish shields that were fully functional from those that were damaged (Horne, 2002). In a 2006 study, the Australian Centre for Agricultural Health and Safety inspected 201 implements and found that 78% of PTO shields had some damage, with 33% designated as being in need of immediate attention (Athanasiov et al., 2006). In 2006, the USDA National Agricultural Statistics Service (NASS) and the National Institute for Occupational Safety and Health (NIOSH) conducted a Farm and Ranch Safety Survey, which collected phone survey data from 12,278 farm operators. The resulting NASS report estimated proper shielding rates to be from 84% to 93%, based on farmer self-report (USDA, 2008).

PTO entanglement injuries have also been studied by examining written records of farm injuries and determining which injuries were caused by PTO entanglement. A Purdue University study examined 674 incidents using information from a variety of sources, including newspaper clippings, published scientific articles, farm injury reports, and litigated farm injury cases. Using this approach, the researchers found that, in 17.4% of the cases studied, the PTO driveline shield was not in place (Beer and Field, 2005). A Canadian analysis of 41 entanglement events combined secondary data from farmer interviews, self-reported data, and on-farm inspections of farm machinery. This study found that 79% of shields were in place at the time of injury but, as in other studies cited, did not distinguish between fully functional and damaged shields (Narisimhan et al., 2011).

Past studies that estimated the proportion of shielded implements have yielded varied results. Self-reported survey data reported the highest rates of shielding, while studies that included physical inspection of farm machinery reported much lower rates. This discrepancy can be attributed not just to the self-report bias inherent in survey data but also to the failure of the survey instruments to distinguish between fully functional shields and shields that were in place but damaged.

Although phone surveys are generally less expensive and less labor-intensive, allowing for a larger sample size, there is typically no way to verify the subjects' responses. Conversely, on-farm inspections are expensive and time-consuming but provide greater consistency in evaluation of PTO shielding across multiple farming operations. Not surprisingly, these two methods have been found to produce considerably different results.

In addition to these issues, surveys do not provide the opportunity for a thorough examination of all farm equipment, which would provide a more complete picture of on-farm PTO shielding. The purpose of this study is to compare results from a NASS phone survey of PTO shielding versus on-farm PTO shield inspections conducted by the Northeast Center for Occupational Health and Safety in Agriculture, Forestry, and Fishing (NEC) in order to (1) provide information on proportions of PTO shielding using methods that distinguish between fully functional shields and shields that are in place but damaged and (2) to assess the accuracy of phone surveys in making these estimates.

Methods

The complete PTO shielding system includes three shields: the tractor master shield, the driveline shield, and the implement connection shield. However, the focus of our research was restricted to PTO driveline shielding (henceforth referred to as PTO shielding) in order to clarify the discussions. Further, the phone survey and on-farm audits only considered drivelines that were physically attached to an implement at the time of observation.

NASS Phone Survey Methods

The sampling frame was taken from the list of New York farms maintained by the NASS. To be eligible, a farm had to report at least $1,000 in annual sales. Five commodity groups were included in the study: dairy, livestock, crop, fruit, and vegetable. Farms were contacted at random until approximately 200 were surveyed from each group. Only two of these five groups (dairy and livestock) are considered in this report. This is due to dairy and livestock farmers being the most commonly injured by PTO entanglements (unpublished data from CAISP, provided in personal communication with D. Voaklander, 2012).

The farms were contacted using two daytime, two afternoon, two nighttime, and one weekend phone call. The caller asked to have the questions completed by the principal operator. If the principal operator was not available, other persons, who felt they could answer as the principal operator would, were permitted to answer. The caller recorded who answered the survey questions according to their role on the farm. If the farm could not be contacted with this protocol, it was classified as a non-responder and replaced with another farm until the desired number of participants was obtained.

Each of the survey respondents was asked to list all of the PTO-driven implements currently on the farm and to give an estimate of their annual hours of operation. The respondent was also asked, “Is the PTO on [*implement*] shielded?” Shielded was defined for participants as having a shield that was “not cracked or damaged in any way and properly connected.”

NEC On-Farm Audit Methods

A random sample of livestock and dairy farms was selected using an approach adopted in a similar PTO shielding study (Luoma et al., 1985). In this method, the auditing team (which consisted of NEC staff, outreach educators, and others who were familiar with farming and farming implements) randomly selected a road and drove along it until they sighted a dairy or livestock farm suitable for auditing. Prior to the audit, the auditors introduced themselves and explained the study. They also verified that the farm’s primary commodity was either dairy or livestock. Using this method, the auditors covered the same geographic area included in the NASS phone survey (fig. 1).

The auditors asked for permission to examine all PTO-driven implements on the farm. When permission was given, the auditors inspected the driveline shield on each implement and assessed its condition using a four-point scale (fig. 2) adapted from the FARM-

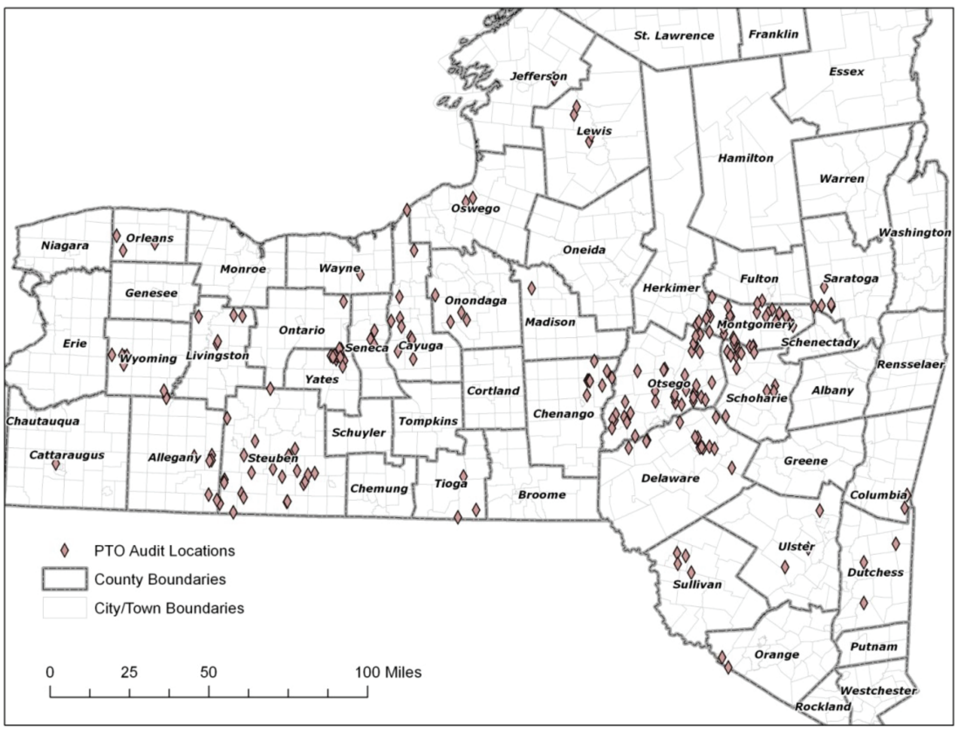
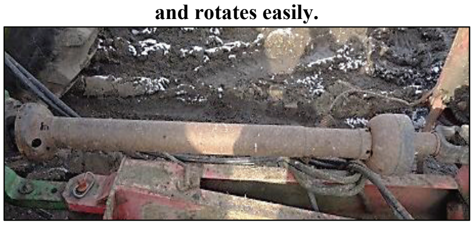


Figure 1. Locations of on-farm audits in New York State.

1: Driveline shield is in place, in good condition, and rotates easily.

3: Driveline shield is in place but is bent, cracked, sliced, and/or does not rotate.



4: Driveline shield is in place but is bent, cracked, sliced, and/or bearing is missing or damaged.

5: Driveline shield is missing, or the machine never had a driveline shield.

Figure 2. Examples of the four grades (1, 3, 4, and 5) in the four-point grading scale for PTO shields.

HAT Tool, developed by researchers at Pennsylvania State University (PSU, 2013). Adaptations specific to this study include defining grade 4 to improve consistency between reviewers and removing grade 2, as it could not be clearly defined.

In addition to making this assessment, the auditors photographed the implement and recorded additional information, including the type of implement. Demographic data about the farm, including acreage, average annual head of cattle, and the farming role of the person who had given consent for the audit, were also recorded. Prior to data entry, all auditing forms were edited and reviewed for accuracy. The photographs of implements were used to ensure that the ratings were consistent between auditors.

Data Analysis

For purposes of comparing the telephone survey results with the audit results, only an audit grade of 1 (driveline shield is in place, in good condition, and rotates easily) was considered to indicate proper shielding and to be analogous to an answer of “yes, the PTO is shielded” on the phone survey. Grades 3, 4, and 5 were considered to indicate PTO drivelines that were not properly shielded and were analogous to an answer of “no, the PTO is not shielded” on the phone survey. The proportion of correctly shielded implements was then calculated for each farm that was surveyed or audited. For example, a farm with four of its five implements properly shielded was scored as 0.80. This proportion was then multiplied by 100 to create the corresponding percentage.

The means of these farm-level percentages were then compared between the phone survey and on-farm audit results using an independent samples t-test. This comparison involved only the livestock and dairy farms, as these were the only two commodity groups included in the on-farm PTO audits. Acres and number of cattle were also compared between the telephone survey respondents and the audited farms using an independent samples t-test.

The percentages of properly shielded implements was also compared between the NASS phone survey and on-farm audit data for the most common implement types, including manure spreaders, manure pumps, post-hole diggers, self-unloading wagons, rakes and tedders, hay balers, rotary mowers, silo blowers, and grain augers.

Results

NASS Phone Survey

As previously discussed, only farms with dairy or livestock as their primary commodity were considered in the statistical analysis of this study. Results, therefore, are not reflective of data obtained from fruit, vegetable, or crop farms, unless otherwise noted.

A total of 3,211 farms participated in the NASS survey, resulting in a response rate of 31.5% for all commodities. Of the farms that responded to the survey, 412 reported dairy or livestock as their primary commodity. Fifty-five percent of these were dairy farms, and 45% were primarily livestock farms. These 412 farms contained a total of 2,632 PTO-driven implements. The distribution of the number of acres of the farms surveyed by phone was strongly skewed to the right, with a median of 240 (mean = 350). The distribution of the number of livestock was also skewed to the right for the phone survey data, with a median of 100 (mean = 232).

NEC On-Farm Audits

Of the 220 qualifying farms that were visited, 211 permitted an audit of their implements, resulting in a participation rate of 95.9%. The total number of PTO-driven implements examined on these farms was 1,470. The distribution of the number of acres of the farms audited was strongly skewed to the right, with a median of 280 (mean = 507). The distribution of the number of livestock was also skewed to the right and had a median of 110 (mean = 215). Average years of farming was 30.6 (median = 30). Dairy was the primary commodity on 76.7% (162) of the farms; on 21.8% (46) of the farms, the primary commodity was livestock. The primary commodity (dairy or livestock) on three farms (1.4%) is unknown.

Contrast of the Phone Survey and On-Farm Audits

The mean number of implements on the farms in this study was 6.4 (median = 5) for the phone survey and 7.1 (median = 6) for the on-farm audits. The mean percentage of properly shielded PTO-driven implements was 90.2% for the phone survey and 56.7% for the on-farm audits. There was little variation in this endpoint between dairy and livestock farms that were audited (57.5% versus 53.2%, $p = 0.35$). Because of this, stratified analyses were not performed. Data from the phone survey indicated that 72.5% of the responding farms had all of their implements shielded. In contrast, complete shielding of all of the implements was observed on only 10% of audited farms. Detailed results, including stratification by implement type and farm commodity, are listed in table 1. The percentage of proper PTO shielding was found not to vary according to farm acreage, years of farming, average number of livestock, and number of implements.

Discussion

The results from the phone survey and on-farm audits provide detailed information on the proportion of farm implements that have functional driveline shields in place (as stated in the Methods section, information on tractor master shields or implement connection

Table 1. Results of phone survey and on-farm audits by implement type and farm commodity.

	On-Farm Audits (211 farms)					Phone Survey (412 farms)	
	Total Number of Implements	Grade Distribution (mean percentages of all implements) 1	3	4	5	Total Number of Implements	Properly Shielded (%)
All implements	1,470	56.7	13.7	21.4	8.2	2,632	90.2
	Number of Farms	Grade Distribution (mean percentages by farm) 1	3	4	5	Number of Farms	Properly Shielded (%)[a]
Stationary implements							
Manure pump	24	53.5	16.7	25.7	4.2	62	86.3*
Silo blower	52	71.5	8.3	16.3	3.8	143	96.2*
Grain auger	20	70.0	12.5	10.0	7.5	110	88.5**
Pulled/moved implements							
Post-hole digger	5	20.0	40.0	20.0	0.0	120	79.7**
Rotary mower	67	47.0	15.7	29.1	8.2	86	90.1*
Rake and tedder	103	47.8	20.0	25.0	7.2	127	90.2*
Manure spreader	165	57.1	9.3	22.3	11.2	351	89.5*
Self-unloading wagon	77	61.4	11.4	19.4	7.8	164	88.5*
Baler	127	61.8	14.6	17.8	5.8	267	95.1*
Farm commodity							
Dairy	162	57.5	13.4	21.9	7.2	227	91.7*
Livestock	46	53.2	15.0	19.8	12.0	185	88.4*

[a] Asterisks indicate statistical significance: * significant at $p = 0.001$; ** significant at $p = 0.05$.

shields was not collected in the survey or audits). In the past, self-report surveys and on-farm audits have both been used to identify unshielded equipment, although never in the same study. In a 2006 survey conducted by NASS, participants indicated proper shielding rates of 84% to 93%, similar to the NASS survey results in this study (USDA, 2008). Prior to that, other studies, including those conducted among New York farmers, have often used audit methods and have identified shielding rates similar to those found by the on-farm audits in this study (Beer and Field, 2005; Hallman et al., 1997; West and May, 1998; Athanasiov et al., 2006). In such studies, farmers have been shown to place low priority on keeping PTO drivelines adequately shielded, with a higher percentage left in a dangerous state (Beer and Field, 2005; West and May, 1998; Athanasiov et al., 2006). A collaborative effort in New York, which included audits similar to those applied in this study, found that although 78.2% of PTO-driven equipment had driveline guards in place, only 65.4% of those guards were in good condition (Hallman et al., 1997).

One striking feature of the data obtained in this study is the discrepancy between farmers' self-reports of adequate PTO shielding in the phone survey versus the assessment of adequate PTO shielding by on-farm audit. Two aspects of this are particularly noteworthy. First, farmers tended to grossly overestimate the proportion of their equipment that was properly shielded, with absolute overestimations by category ranging from 19% to 60% and an absolute overall discrepancy between the on-farm audits and phone survey of 33.5%. Second, farmers did not report the broad range of shielding between implement types that was seen in the on-farm audits. Excluding post-hole diggers due to low sample size, the on-farm audits found adequate shielding rates ranging from 47% for rotary mowers to 71.5% for silo blowers (an absolute range of 34.5 percentage points), while the phone survey yielded a range of 86.3% for manure pumps to 96.2% for silo blowers, for an absolute range of just 10 percentage points.

Together, these results indicate that farmers may have a lower threshold for defining "adequate PTO shielding" than individuals tasked with conducting on-farm PTO audits. Another possible explanation includes lack of awareness on the part of farmer (or other survey respondent) as to the condition of every PTO shield on the farm, or a tendency to over-report PTO shielding when participating in random surveys. One final explanation for the discrepancy between the shielding rates estimated by the two methods may relate to the large difference in their response rates (95.9% for the audits versus 31.5% for the survey). It is possible that the 31.5% response rate to the survey represents farmers who are more likely to have their implements shielded.

Our data indicate no clear difference in shielding between implements that are largely stationary (i.e., manure pump, silo blower, and grain auger) and implements that are intended to be pulled or moved in their routine use. Multiple factors may contribute to the relative level of damage in stationary or towed implements. For instance, stationary items may be less susceptible than towed implements to mechanical damage from collisions or contact with other moving equipment. On the other hand, farmers' perceptions of safety hazards posed by stationary equipment may differ from perceived hazards from moving implements, which may, in turn, affect maintenance. These factors and their possible impact on PTO shield maintenance were not specifically investigated in this study.

Identifying the factors that are most strongly predictive of improperly shielded PTO shafts would be of considerable use in future on-farm outreach efforts promoting greater PTO safety. However, our data did not find any significant difference in proper shielding rates between farms on the basis of principle commodity, size of farm in terms of acreage or head of livestock, or farmer experience. This was particularly surprising in the case of farm size, as we had initially expected that larger farms might possess more modern equipment and dedicate greater resources to equipment maintenance. However, it is possible that using a different sampling method or surveying a greater number of farms would, in fact, find differences in PTO shielding on the basis of some or all of these factors, which may provide a basis for more targeted safety interventions in the future.

In addition to confirming the expected conclusion that a substantial proportion of implements, as assessed by detailed on-farm audits, do not have proper PTO shielding, this study reveals an important methodological problem. Namely, the study demonstrates that surveying farmers by phone to assess equipment maintenance suffers dually from woefully low response rates (just 31.5% in this case) and a significant self-report bias. This calls into serious question the use of phone surveys to assess on-farm maintenance.

Our study has certain limitations that must be considered in designing future research on this topic. First, selecting farms for audit by stopping at random farms that appear to be beef or dairy operations is susceptible to a number of biases. Namely, because the road choice cannot be ensured to be truly random, farms closer to main thoroughfares may be overrepresented in our study. Second, randomized choice of farms by the auditors cannot be guaranteed; for instance, farms that were better maintained or had more modern equipment may have appeared innately more inviting to our auditors, skewing the sample. Finally, a large segment of small, less conspicuous farming operations may have been broadly excluded from our study due to difficulty in identifying these farms from the road. If these unsampled small farms represent a disproportionate number of improperly shielded PTO shafts, this may result in an upward bias in the estimate of properly shielded implements. Finally, participants in the NASS phone survey may have been more likely to practice safe habits and keep their equipment shielded, while farmers who do not practice these behaviors may have declined participation. This is of less concern in the audits, which had a participation rate of 95.9%. The degree to which any one of these factors biases our data cannot be precisely determined, but they may, alone or in combination, significantly affect the farm population sampled.

The study also had some noteworthy strengths. In particular, the response rate for the on-farm audits was exceptionally high. In addition, this study benefitted from the ability to compare similar farming populations in upstate New York. This allowed us to evaluate the state of PTO shielding as well as the utility of a commonly used survey method.

Recommendations for further study include linking shielding data to injury outcomes. A study of this type would involve examining how a piece of equipment is used, how often it is shielded, and how these factors are related to entanglements. If it is possible to link PTO shielding to farm injury surveillance data, it will be possible to assess whether implements that are less frequently shielded are also more frequently involved in PTO-related injuries. If this is, in fact, the case, then particular high-risk groups of implements could be targeted specifically in PTO shielding efforts, and on-farm audits may prove a powerful tool for reducing PTO-related injury and death.

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