Summary of Agricultural Confined-Space Related Cases: 1964-2013

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ABSTRACT. *Since 1977, the Purdue University Agricultural Safety and Health Program has managed a database with ongoing efforts to identify, document, and analyze information on injuries and fatalities in all forms of agricultural confined spaces, with special attention given to incidents involving grain, forage, and manure storage structures and agricultural transport vehicles. The database contains over 1650 cases from 1964 to the present and two cases before 1964. The average number of cases in the last ten years remains at a high of 63 cases per year. Overall, confined-space related cases were documented in 43 states, with the most occurring in the Corn Belt region. More than 1000 (62%) of these cases were grain-related entrapments; however, in recent years the proportion of grain-related cases has declined with more aggressive surveillance for all types of agricultural confined-space incidents including falls and entanglements inside grain storage structures. Grain entrapments represented 49% of all confined space cases in 2013 as compared to earlier years when nearly all documented cases were grain entrapment related. There has also been a shift in location distribution of cases, with the southern states now representing 18% of all recent cases. These findings are critical for informing the discussion on developing regulations, design standards, and safety programs to reduce the frequency and severity of these incidents.*

Keywords. *Agriculture, Asphyxiation, Confined space, Engulfment, Entanglement, Entrapment, Fall, Farm fatality, Forage storage structure, Grain, Grain storage facility, Grain transport vehicles, Manure storage structure, PACSID, Poisoning.*

Since 1977, the Purdue University Agricultural Safety and Health Program (PUASHP) has managed a database with ongoing efforts to identify, document, and analyze information on injuries and fatalities on grain entrapments. This effort has led to multiple publications, such as Freeman et al. (1998), Kingman et al., (2001), Roberts et al. (2011), and Riedel and Field (2013), that summarized and analyzed cases documented in the grain entrapment database. In addition, PUASHP has published annual summaries of U.S. grain-related entrapments and engulfments for the last decade (Roberts and Field, 2010; Riedel and Field, 2011; Roberts et al., 2012; Issa et al., 2013).

Financial support from the U.S. Department of Labor over the past three years (2011-2014) gave PUASHP the capability of expanding the search for incidents and code previously undocumented incidents to include not only entrapments at grain storage and handling facilities but also asphyxiations, entanglements, falls, and electrocutions in and

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around all forms of agricultural confined spaces. This expanded search effort, in combination with the previous grain entrapment database, was developed into a new database called Purdue's Agricultural Confined Space Incident Database (PACSID). This database included cases involving manure storage and handling facilities summarized by Beaver and Field (2007). In 2011, Riedel (2011) reported on the methodology for the creation and maintenance of the PACSID database and the first summary on agricultural confined-space related cases. Since then, 399 new cases have been added to the database, including 167 cases added since the publication of the 2012 Summary of Grain Entrapments in the United States (Issa et al., 2013). This article reports on this expanded effort to better understand the most critical hazards associated with a broader array of agricultural confined spaces by analyzing the frequency, severity, demographics, distribution, and trends of agricultural confined-space related incidents. The purpose of this article is to provide a better understanding of confined-space related incidents in order to influence curricula development for injury prevention and emergency first-response training that effectively targets the most significant causes of injuries and fatalities.

Methodology

This work builds on the grain entrapment and confined-space related incidents documented by Kelley and Field (1996), Freeman et al. (1998), Kingman et al. (2001), Roberts et al. (2011) and Riedel (2011). The PACSID is an electronic database developed to assist in uniformly coding, storing, adding, querying, and analyzing agricultural confined-space related incidents. The definition of an agricultural confined space being used is the definition developed by the North Central Extension Research in Agriculture (NCERA) 197 committee: "any space found in an agricultural workplace that was not designed or intended as a regular workstation, has limited or restricted means of entry or exit, and has associated with it potential physical and/or toxic hazards to workers who intentionally or unintentionally enter the space." The OSHA definition for confined spaces was not, under current regulatory language, chosen because it was not developed for agricultural confined spaces and does not, under current regulatory language, regulate most agricultural confined spaces (OSHA, 1993). Each case in the database contains the available data parameters, such as date, time, age, state, farm type, incident type, agent of injury, and name, and is searchable by each. A complete list of the data inputs the database supports is found in table 1. The parameters required for the case to be entered into the database are identified with asterisks (*). These required parameters are intended to reduce the probability of duplication. A description of each parameter can be found in Riedel (2011). At any given time, there have been approximately 75 cases in the queue for entering into the database that lack sufficient information for the required parameters.

Since the publication of the 2012 Summary of Grain Entrapments in the United States (Issa et al., 2013), 167 previously undocumented cases were entered into the PACSID. This includes data both from cases (67) occurring in 2013 and from cases (100) occurring in

Table 1. List of input parameters for the PACSID.[a]

Case No.*	Month	Day	Year*	Time*
Age	Sex	State*	Relationship	Residence farm
Farm type 1	Farm type 2	Incident type*	Agent of injury*	Location
Classification	Work status	Fatality	Narrative	Medium
Grain movement	Last name	First name	County	

[a] Parameters required for the case to be entered into the database are identified with asterisks (*).

prior years (1964-2012) but not previously documented or meeting the required parameters. Cases in the database have been obtained from internet searches, interviews, personal contacts, and recently acquired safety datasets. A more thorough summary of how the PACSID data were collected was reported by Riedel (2011).

To properly analyze the database, the following categories were created based on PACSID parameters: age group, region, agent category, and incident category. Age group is based on the input parameter "age" and is split into ten-year intervals ranging from 1 to 90. Region is based on the input parameter "state" and is divided into Midwest, Northeast, South, West, and unknown based on U.S. Census Bureau region definitions. The agent category is based on the input parameter "agent of injury," which is the vector or agent that caused the injury, such as an auger (in entanglements), grain bin (in entrapments), or manure lagoon (in asphyxiation). The agent category is divided into agricultural transport vehicles, food processing and storage facilities, forage storage structures, grain storage facilities, manure storage structures, and other/unknown based on table 2. The incident category is based on incident type and is divided into asphyxiation/poisoning, drowning, electrocution, entanglement, fall, grain entrapment, pinned by object (struck by flying/falling object or underneath/between objects), and other/unknown based on table 3. The incident category can include fatal and non-fatal incidents.

For this article, the database was analyzed and queried for the following parameters: age group, year, sex, state, region, incident category, agent category, and fatality. All data involving trends use a five-year or ten-year average. This average is calculated by averaging the number of cases for the year of interest with the four or nine preceding years, respectively. In addition, grain entrapment reports for the years 2008-2012 were reviewed from published PUASHP annual summary reports (Roberts and Field, 2010; Riedel and Field, 2011; Roberts et al., 2012; Issa et al., 2013) and compared to latest number of incidents for each of those years. A standard linear regression analysis was run using Microsoft Excel,

Table 2. Possible parameter inputs for the agent of injury used in developing the agent category.

Agent Category	Agent of Injury
Agricultural transport vehicles	Feed grinder/mixer portable, unspecified; feed wagon; forage wagon (self-unloading); grain wagon auger-type, gravity-flow, unspecified; manure transport vehicle; rail car; truck pickup, semi-tractor/trailer, straight/grain/flatbed, unspecified; wagon/cart (miscellaneous).
Food processing and storage facilities	Food storage tank/bin; fruit storage (environmentally controlled unit).
Forage storage structures	Silo bunker/pit, horizontal/bunk, non-oxygen-limiting, oxygen-limiting/airtight, unspecified[a]; silo unloader (bottom, top).
Grain storage facilities	Auger non-portable/in-bin, unspecified; corrugated steel bin; dump pit; elevator/conveyor (non-portable); feed bin; feed grinder/mixer stationary; feed storage structure (wooden); flat grain storage building; flat storage; grain bin; grain crib; grain dryer; grain storage under facility (sumps and galleys), unspecified; open pile; outside of bin, of silo; silo concrete stave/poured, grain, unspecified[b]; steel tank (grain); storage dome.
Manure storage structures	Manure lagoon/pond, pit (below ground), storage tank (above ground); slurry pit.
Other/unknown	Barn/livestock building; combine (self-propelled/unspecified), corn crib (ear corn); fertilizer tank; trench/field tile/other on-farm construction sites; wells/cisterns/dry-well/septic tank; other/unknown.

[a] Silo (unspecified) with a medium parameter of hay, molasses, screenings, or silage placed in forage storage structure.

[b] Silo (unspecified) with a medium parameter of barley, corn, corn cobs, cotton seed, rice soybeans, wheat, or unknown placed in grain storage facility.

Table 3. Possible parameter inputs for the incident type used in developing the incident category.

Incident Category	Incident Type
Asphyxiation/poisoning	Asphyxiation/poisoning in/inside multiple locations such as: pond/lagoon, livestock building, manure storage pit, manure storage tank, silo, inside tank; entrapped/covered by manure; loss of consciousness and well or cistern.
Drowning	Drowning in pond/lagoon/water tank, inside manure storage pit and flooded grain bin/silo.
Electrocution	Electrocution by contact with electricity.
Entanglement	Entanglement in augers, rotating shafts, and other equipment used inside agricultural confined spaces. Does not include portable augers used outside the structure.
Fall	Fall (from or into an agricultural confined space).
Grain entrapment	Entrapped or engulfed inside a grain storage structure including grain transport vehicles.
Other/unknown	Other/unknown.
Pinned by object	Pinned against/between/underneath object; struck by flying/falling/rotating object.

comparing the cumulative number of incidents in each state with the number of farms with grain storage capacity. In addition, a regression analysis was conducted on yearly trends of non-fatal and fatal incidents.

Findings

Frequency and Geographic Distributions

Overall, the PACSID currently contains 1654 documented cases of agricultural confined-space related injuries and fatalities. The earliest case recorded occurred in 1956; however, it is not until 1964 that cases are reported every year. Data reported include the two cases before 1964. In the last 30 years (1984-2013), the average number of documented confined-space related cases per year was 49. In the last ten years (2004-2013), the average number of confined-space cases per year was 63, indicating that the problem is increasing (fig. 1) even though the number of farms with grain storage capacity and the number of

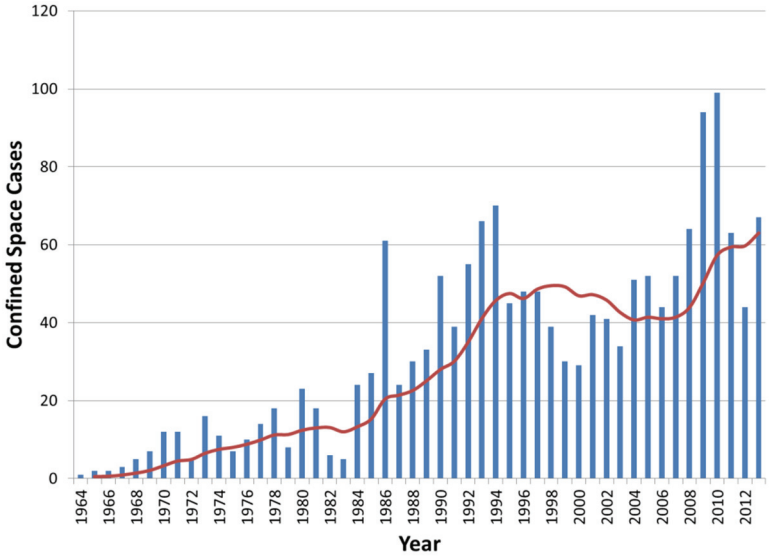

Figure 1. Agricultural confined-space cases distributed by year. The line represents the ten-year average.

commercial, off-farm grain storage facilities has been decreasing since 1988 (NASS, 2014). However, there are significant gaps during the early years due to the lack of surveillance efforts and the need to report cases. It is also believed that numerous other types of agricultural confined-space incidents occurred but were unreported, such as falls into wells and cisterns and exposure to toxic gases in forage storage structures. The fatality rate for the recent decade (2004-2013) was 50.3% (317 cases out of 630), in comparison to 68.1% (290 out of 426) for the previous decade (1994-2003) and 62.6% (1036 out of 1654) overall. The growth in the overall numbers of confined-space related cases since 1984 reflects more aggressive documentation of non-fatal cases and the increased media exposure given to these events, which have increased at a rate of one case per year ($\mu = 0.96$, $R^2 = 0.4$). This is in comparison to fatal cases, which have averaged around 30 cases per year since 1984, with a standard deviation of eight cases per year. The fatal cases do not show any significant trends ($\mu = 0.12$, $R^2 = 0.02$).

Agricultural confined-space related cases were documented in 43 different states (fig. 2). The only states without documented incidents were Hawaii, Maine, Nevada, Rhode Island, Vermont, West Virginia, and Wyoming. The vast majority of the cases were in the Midwest (75%), with the South a distant second (13%). In the last five years, Midwest cases have decreased to 72% of cases, with the South steadily increasing to about 18% of cases. Over time, the Western and Eastern regions of the U.S. have fluctuated between 5% and 12% of cases and together represent 10% of cases in the last five years (fig. 3).

Category and Type of Confined-Space Related Cases

The vast majority of all agricultural confined-space related cases involved the storage and handling of grain and grain by-products, with almost 1200 cases, including entrapments, falls, and entanglements (fig. 4). The majority (62%) of these cases involved entrapment or engulfment in free-flowing agricultural materials, primarily grain, while working inside a grain storage structure.

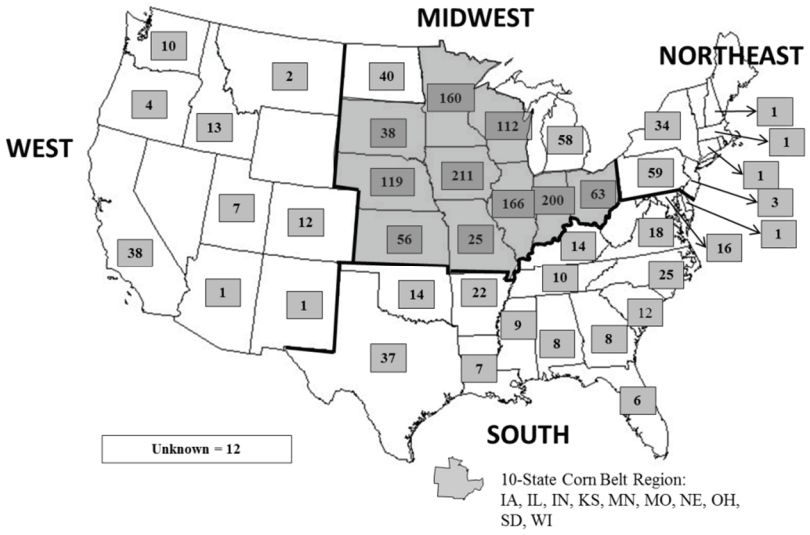

Figure 2. Geographic distribution of agricultural confined-space cases (1964-2013).

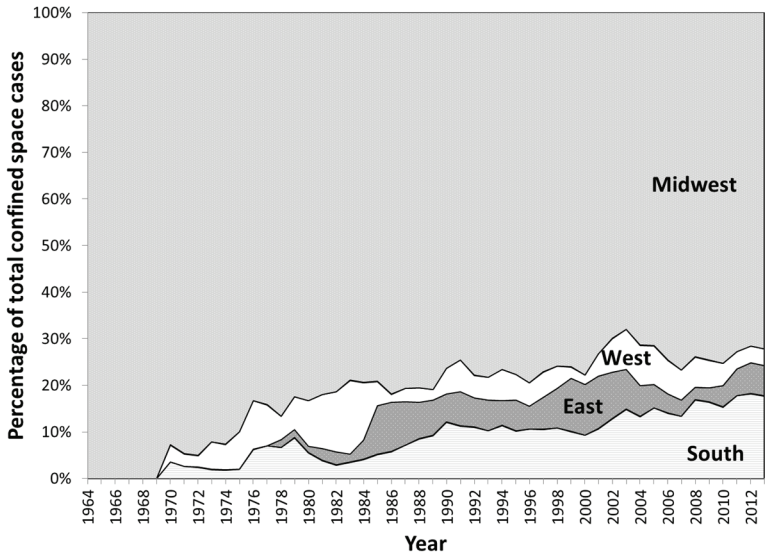

Figure 3. Agricultural confined-space cases distributed by region. Each year represents the percentage (by region) of the average number of cases over five years.

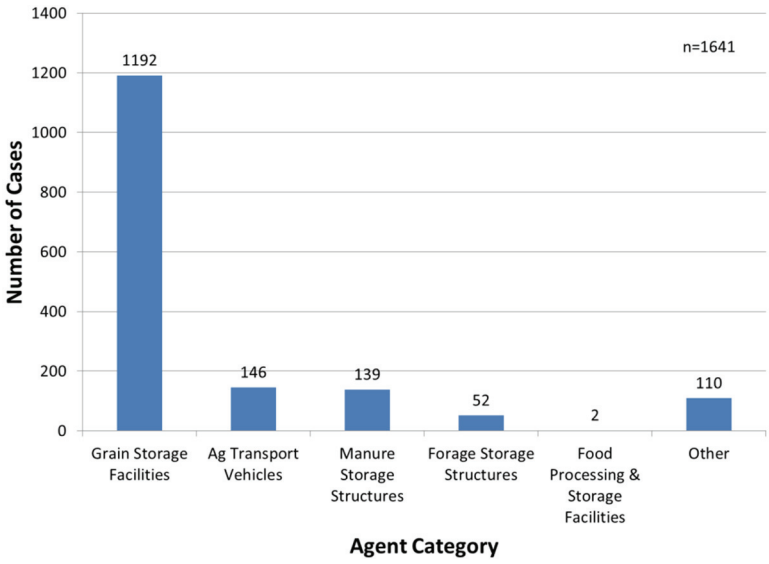

Figure 4. Agricultural confined-space cases documented between 1964-2013 based on agent category.

In the 1970s and 1980s, grain entrapments represented about 80% of all cases in the PACSID. Interest in related incidents has since increased, and the database contents were expanded with other confined-space related incidents, resulting in a greater percentage of other cases now making up the database. In 2013, the frequency of grain entrapment cases had dropped to slightly less than half of all cases documented. Meanwhile, documented

cases of falls involving agricultural confined spaces have steadily increased since the 1990s and now represent about 21% of all cases, the second highest category (fig. 5).

In 2013, there were no fewer than 33 grain entrapment cases, 14 falls, 12 equipment entanglements (including augers inside of confined spaces), and four asphyxiations (fig. 6). Grain entrapments accounted for 49% of documented cases in 2013. For any confined-space incident type with more than one case, asphyxiations were the most dangerous, with a reported 100% fatality rate, while grain entrapments ranked second with a 43% fatality rate.

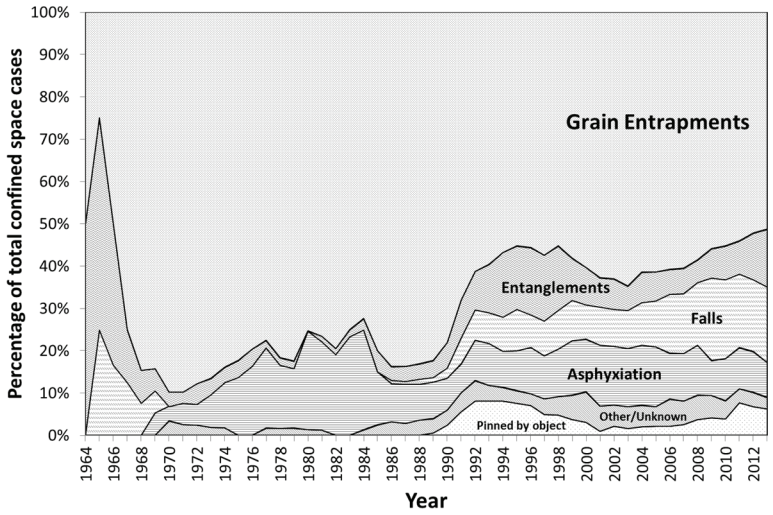

Figure 5. Agricultural confined-space cases distributed by type. Each year represents the average number of cases over five years.

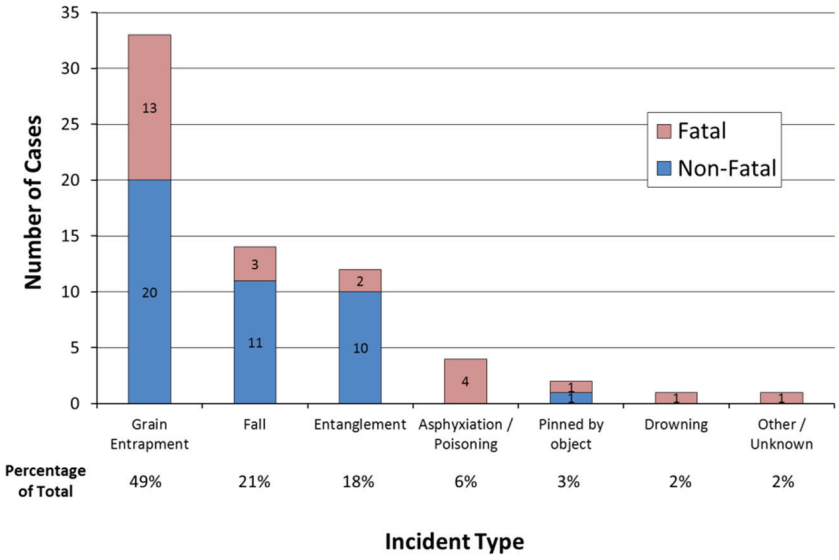

Figure 6. Distribution of 2013 agricultural confined-space cases by type of incident.

Demographics

Cases involving children and youth under the age of 21 represent a major portion of the cases contained in the PACSID. The upper threshold age of 20 was selected to understand the grain entrapment risks as youth transition into adult workers. In other words, the study was attempting to focus on young and beginning workers. This population was involved in 26% of all documented cases, and nearly all were male (fig. 7). In total, there were only 47 cases involving females and eleven cases in which the gender was unknown. Together, these two groups (females and unknown) represent only 4% of all documented cases. The disproportionate number of young males involved is especially noteworthy considering the state and federal workplace safety regulations that prohibit employment of youth under the age of 16 for work inside most agricultural confined spaces found on family farms and under the age of 18 for commercial grain storage and handling facilities. These restrictions, however, do not apply to the children of farm owners. Cases were documented in which a young or beginning worker died in an agricultural confined space on the first day or first week on the job.

Trends

The addition of 167 cases in the last year significantly ($p < 0.001$) affected the number of cases per year. On average, the numbers of previously reported cases increased by three or more cases ($M = 2.78$; $SD = 2.06$). These new additions even changed the results for recent years, which are generally considered to be more reliable. This can be seen vividly when comparing previous grain entrapment reports (Roberts and Field, 2010; Riedel and Field, 2011; Roberts et al., 2012; Issa et al., 2013) to the latest numbers of documented cases. For example, there were 51 grain entrapment cases initially reported for 2010, which was revised to 57 in 2012 and again to 59 in 2013. Figure 8 compares the initially reported case totals and the current case totals for the last five years. It is anticipated that the totals will continue to be adjusted as additional cases are documented.

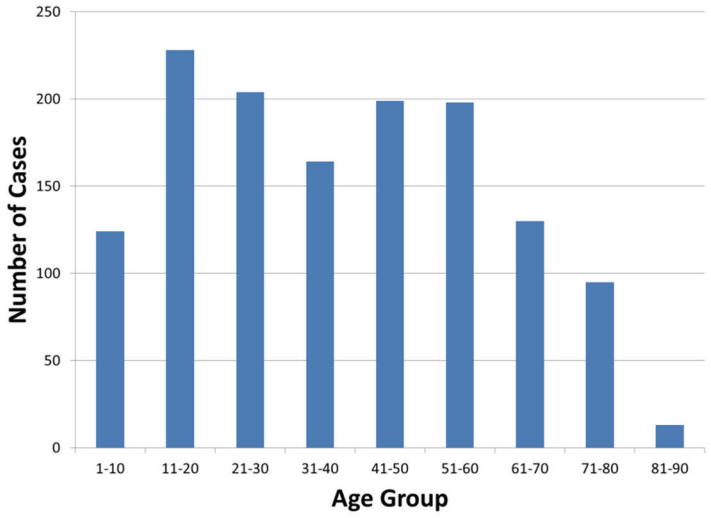

Figure 7. Distribution of agricultural confined-space cases by age group.

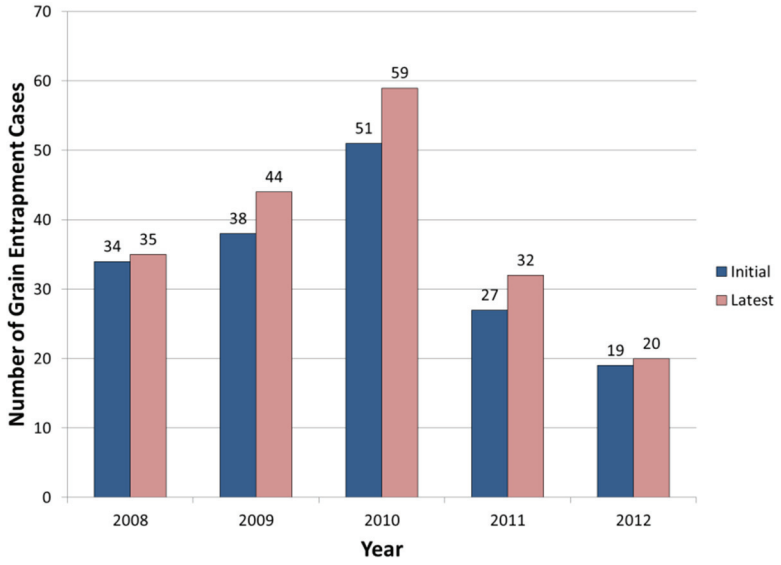

Figure 8. Initial numbers of cases announced for the five previous years and most recent counts.

Grain entrapments represent 41% of all new cases added, with entanglements representing 33% and falls representing 18% of new cases. All together, these three categories represented 92% of new cases entered in the database.

Comparison between the number of farms with grain storage structures (grain capacity greater than one bushel) in each state (NASS, 2014) with the number of confined-space incidents in the last ten years shows a very strong correlation for all states (fig. 9; r(40) =

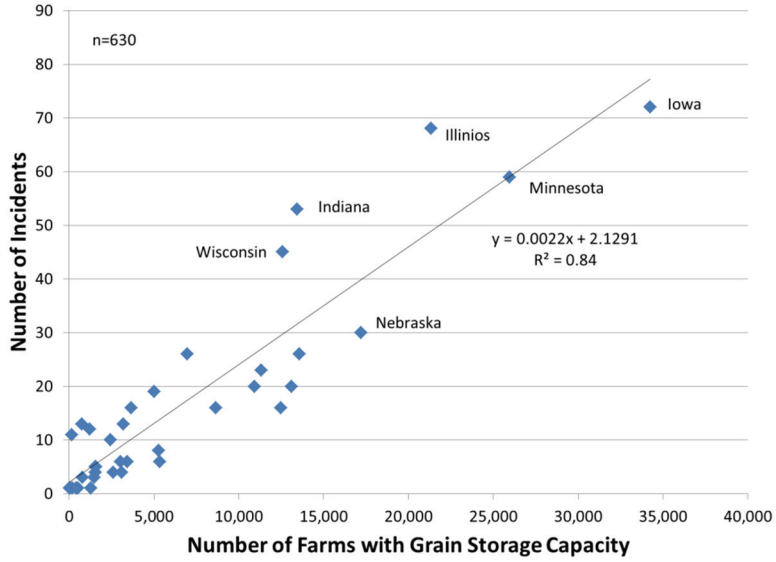

Figure 9. Confined-space incidents from the last ten years (2004-2013) for all U.S. states compared with the number of farms with grain storage capacity in each state according to NASS 2012 Census data.

0.92). The last ten years were chosen because they represent a period of continuous effort to collect confined-space incidents on a national scale. In this period, a total of 630 incidents were collected, which is about 40% of all the incidents in the database. The number of incidents was compared against the latest (2012) census information on the number of farms with grain storage capacity as a representative snapshot of grain storage on farms. Using the earlier census data does not alter the strength of the correlation, and the result is not significantly different from figure 9. This is due to the fact that while the number of farms with grain storage capacity decreased by 17% from the previous (2007) census, the decrease occurred equally in all states.

Discussion

One of the most interesting results of this summary is that while the overall trends in confined-space related cases appear on the rise, this appears to be mainly attributed to increasing documentation of non-fatal cases, which have significantly increased at a rate of one case per year. In comparison, fatal cases appear to have plateaued at around 30 cases per year since the mid-1980s. Since fatal cases are much more likely to be reported in the media or official government documents, it is expected that fatal cases would have plateaued earlier than non-fatal cases. With increased awareness and more aggressive surveillance, it is expected that the proportion of non-fatal cases being documented will initially increase before plateauing. In other words, the increase in the frequency of these events may have been due to better documentation. However, other factors, such increasing production of grain and increasing sizes of grain bins, might also be contributing factors to the increase in incidents. Due to the fluid nature of the database and the variables contributing to the occurrence of these incidents, it remains difficult to make definitive conclusions regarding future trends in the number of agricultural confined space and grain entrapment incidents. However, the data remain the best currently available, and one can make strong recommendations on what demographics and locations to target to significantly reduce the number of incidents. It is also important to note that the database tends to undercount non-fatal occupational injuries even in situations where injury reporting is mandatory under OSHA regulations, such as at commercial grain storage, handling, and processing facilities. For example, in 1999, it was found that workplace injuries were underreported by BLS by 33% to 69% depending on occupation (Leigh et al., 2004).

Another noted trend was the increase in the number of cases occurring in the South. One contributing factor may be the significant increase in corn production in the South in the last ten years along with the corresponding increase in on-farm storage. In the last ten years, corn production in the South has increased by 54% to 1.4 billion bushels of corn (NASS, 2014). With the majority of cases in the database involving grain entrapments and about half of all grain entrapments involving corn, there is a strong correlation between corn production and storage and the number of cases (Issa et al., 2013). This can be seen by comparing documented incidents with the number of farms with grain storage reported in 2012, as shown in figure 9. In addition, with the warmer, more humid weather in much of the South, there may be more situations in which out-of-condition grain becomes a storage problem, especially for corn.

The expansion of the PACSID database has significantly altered the distribution of incident types, with grain entrapments representing 49% in 2013 and the remainder involving

other confined-space related cases at the time the database was queried. This shift in distribution is likely to continue, and awareness of these trends is important for agricultural producers, safety educators, and regulators. Prevention measures should take into account all types of agricultural confined spaces, not just grain storage and handling facilities, and all related incidents including falls and entanglements, if the number and severity of incidents are to be reduced.

Lastly, it is important to state that while this database provides the best known information available on this type of agricultural workplace hazard, it is by no means comprehensive. Due to a past emphasis on grain entrapments and manure storage incidents, and a lack of aggressive surveillance efforts for all types of agricultural confined spaces, incidents involving forage silos, chemical storage structures, wells, and cisterns are definitely underreported. In addition, falls and entanglements around agricultural confined spaces, especially grain storage structures and silos, are most likely to be significantly under-reported since these incidents are rarely published in the general media. As noted, each type of incident is believed to be under-reported, including grain entrapment cases, as evidenced by the increase in the number of cases over time, even for recent years. Another factor contributing to a lack of a complete understanding of the problem is the influence that federal regulations may have, especially with respect to the documented incidents at OSHA non-exempt facilities. For example, as of December 2013, over half of grain storage capacity in the U.S. is now found on OSHA exempt farms (13.0 million bushels) versus 10.4 million bushels at OSHA non-exempt commercial operations (NASS, 2014). This raises a valid question: if both types of facilities were treated equally, including injury reporting requirements, would the frequency and severity of these incidents be substantially different from what is currently found in the PACSID?

While the findings presented might not be exhaustive, they provide a good representation of the problem, and they provide the best evidenced-based resource available to support future prevention efforts.

Observations

As evidenced by on-going media coverage, the level of interest regarding agricultural confined spaces, especially grain entrapments, has remained high. There continues to be ongoing development, including new prevention resources, enhanced access to training opportunities, and efforts such as by ASABE to draft engineering standards designed to make grain and manure storage and handling facilities safer for workers. This attention has been further intensified with OSHA's targeted enforcement of workplace safety standards at commercial grain storage and handling operations, which has had a trickle-down effect at exempt farms, feedlots, and seed processing operations. OSHA has also invested substantial funding in developing new training resources for grain storage and handling facilities under the Susan Harwood Training Program.

Other factors that have contributed to the public attention being given to these incidents have been the high media profiles of incidents involving younger workers at grain storage operations and the large settlements and awards from civil litigation resulting from injuries and deaths at these facilities. The message is clear that future incidents have the potential to be very costly to those who fail to comply with recognized or required workplace safety and health practices.

Conclusion

Occupational safety and health resource allocation should be evidence-based and targeted for the greatest probability of effective, long-term impact. These results and discussions were presented to this end.

One of the most significant outcomes from an expanded surveillance effort to document injuries and fatalities associated with agricultural confined spaces could be a better platform from which to develop and implement more effective and comprehensive prevention strategies. For example, falls involving confined spaces in 2013 accounted for no less than 21% of documented cases, but this topic has received little attention in current discussions on risk reduction at these facilities. The confirmation of the high proportion of incidents involving young and beginning workers and the clarification of the problem of auger-related incidents inside agricultural confined spaces are other outcomes that should result in more effective prevention efforts.

Finally, it appears that the perception of injury susceptibility among those exposed to agricultural confined spaces is low. This is reflected in the literature (Pate and Dai, 2014) and the multiple incidents involving multiple victims, including first responders, in these spaces. Unlike other high-profile agricultural safety issues, such as tractor overturns, childhood injuries, and pesticide exposure, only recently have there been national initiatives to address the problem of injuries and death in agricultural confined spaces. This includes NCERA 197 and OSHA's Susan Harwood projects, which are currently funding efforts in Indiana, Illinois, and Iowa.

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