Injury risks for on-road farm equipment and horse and buggy crashes in Pennsylvania: 2010–2013

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ABSTRACT
Objective: The purpose of this study was to investigate characteristics associated with farm equipment and horse and buggy roadway crashes in relation to person, incident, and injury characteristics to identify appropriate points for injury incident prevention.
Methods: Information on crashes occurring on public roads during the years 2010–2013 was obtained from the Pennsylvania Department of Transportation (PennDOT) and analyzed.
Results: There were 344 farm equipment and 246 horse and buggy crashes during the 4-year study period. These crashes involved 666 and 504 vehicles and 780 and 838 people, respectively. In incidents with farm equipment, the non-farm equipment drivers had an almost 2 times greater injury risk than farm equipment operators. Horse and buggy crashes were almost 3 times more injurious to the horse and buggy drivers than the drivers of the other vehicles.
Conclusions: The average crash rate for farm equipment was 198.4 crashes per 100,000 farm population and for horse and buggy the crash rate was calculated as 89.4 crashes per 100,000 Amish population per year. This study suggests that road safety and public health programs should focus not only on farm equipment operators and horse and buggy drivers but on other motorists sharing the roadway with them.

Introduction
Farm equipment (FE) and horse and buggy (HAB) crashes on public roads are relatively rare occurrences in the context of total vehicular crashes in Pennsylvania (Pennsylvania Department of Transportation [PennDOT] 2014). Though the numbers of crashes may be small, the effects of these crashes can be severe for the occupants involved and deserve the attention of injury prevention professionals. Both FE operators and HAB drivers are largely engaged in production agriculture activities as part of the agriculture, forestry, and fishing industry, and both move much slower on public roads in both daylight and at night than motor vehicles. FE operators and HAB drivers, when on public roads, face hazards associated with fast-closing vehicles that have greater maneuverability. FE operators and HAB drivers may be unaware of approaching motor vehicles and make maneuvers (e.g., turns) the approaching motorists did not expect. FE operators and HAB drivers may also be younger than motor vehicle drivers and have less experience in reacting to emergency situations. In the case of HAB drivers, horses may bolt or spook unexpectedly.

FE and HABs must display on the rear of their vehicle a slow-moving vehicle (SMV) emblem in a manner that meets PennDOT regulations. An SMV emblem suggests that the FE and HAB vehicle is traveling at a speed of 40 km/h (25 mph) or less (Pennsylvania Vehicle Code—Title 75 2015). In some states, however, legislation permits farm machinery to move at speeds greater than 40 km/h (25 mph) if it is so designed by its manufacturer. In this case, the unit must display an SMV emblem and a speed indicator symbol (Committee on Agricultural Safety and Health Research and Extension 2009). Pennsylvania’s laws and regulations require FE and HABs operated at night or during periods of reduced visibility to have a headlight and hazard light system in safe operating condition and must be equipped with reflectors or reflective tape on the sides of the vehicle (Pennsylvania Vehicle Code—Title 75 2015). For HABs, in addition to the required flashers and SMV emblem, a warning light, reflective tape, and rearview mirror are recommended by Pennsylvania’s Horse and Buggy Driver’s Manual (2008) to improve visibility.

Regarding the operator’s age, Pennsylvania requires that the operator of FE be at least 14 years of age. Operators 14 or 15 years old may only operate FE on 1- or 2-lane roads that bisect or immediately adjoin the premises where the driver resides. Operators of FE are not required to have a motor vehicle driver’s license (Pennsylvania Vehicle Code—Title 75 2015). There are no age restrictions for youth driving an HAB on public roads in Pennsylvania (Anderson 2008).

When considering miles traveled, FE operators appear at a much higher risk for a public road crash than non-FE drivers (Costello et al. 2009). FE and HAB crashes are included only within the general category of “other vehicles” in official traffic
safety facts reports, so specific vehicle miles traveled by FE and HAB are unknown (Traffic Safety Facts 2012). FE and HABs are specifically identified in the PennDOT database but no mileage data are given. The PennDOT database is explained in more detail in the Methods section.

Harland et al. (2014) reported that 2% of crashes with agricultural equipment result in a fatality and less than 1% of all other motor vehicle crashes result in fatalities (Costello et al. 2009; Traffic Safety Facts 2008). Peek-Asa et al. (2007) found that non-farm vehicle drivers were 5.2 times more likely to be injured than farm vehicle/equipment drivers. The large mass and size of FE and lower speeds of FE and HABs make them hazardous for motorists on public roads.

Roadway crashes involving FE were examined for differences between urban and rural crashes. Though FE crashes are generally considered to be a rural problem, recent studies reported that these crashes often occur within close proximity of a town or city (Harland et al. 2014). Several researchers have identified common types of crashes involving FE, including rear-end, left turn, passing crossroads, and oncoming collisions (Costello et al. 2003; Hughes and Rodgman 2000; Schwab and Miller 1995).

One transportation issue that is having a growing impact on some rural communities is the rapidly expanding presence of HABs being operated by members of Old Order Anabaptist communities (including the Amish and Old Order Mennonites) on public roadways. It was reported that the Amish population is doubling approximately every 21 years (Donnermeyer et al. 2013). Between 2008 and 2013, the Amish population has expanded 15% in Pennsylvania and 20% nationwide (Young Center for Anabaptist and Pietist Studies 2014). These numbers include all Amish groups (Old Order and New Order) that use HAB transportation but exclude car-driving groups such as the Beachy Amish and Amish Mennonites.

Few previous studies have explored the causative factors of crashes involving HABs involved roadway crashes. Anderson (2014) examined the primary causes of HAB crashes in Pennsylvania and the main crash types identified include a motorist rear-ending a forward-moving buggy, a motorist striking the buggy while attempting to pass, buggy struck while crossing an intersection, and buggy struck while making a left turn. Buggy incidents have accounted for the second highest (16%) percentage of hospital admissions among Amish patients (Grandizio et al. 2015). About 27% of the trauma admissions (Jones 1990) and 16% of pediatric Amish trauma admissions (Vitale et al. 2006) were related to buggy collisions. Mortality rates are highest in Amish buggy crashes when they involve a motor vehicle (Aaland et al. 2004).

The objectives of this study were to (1) determine the risk of injury of FE and HAB occupants vs. other vehicle occupants and (2) investigate the characteristics associated with FE and HAB roadway crashes in relation to person, incident, and injury variables.

Methods
This study included crashes involving FE and HABs that were reported in the PennDOT crash database for the 4-year period 2010 through 2013. The Pennsylvania crash database is maintained by PennDOT and includes separate hierarchically linked data tables that describe crash, vehicles, person, roadway, and environmental characteristics of each incident. FE, in the PennDOT database, is defined as a vehicle that is specifically designed and manufactured for and used exclusively in agriculture to plant, seed, cultivate, harvest, or apply soil nutrients, fertilizers, or chemicals. The term also includes any other vehicle by the department to be FE (Pennsylvania Vehicle Code—Title 75 2015). HAB is its own category under vehicle type but was not further defined.

The data were requested from PennDOT in 2014. All personally identifiable data were removed by PennDOT before sending the database to the researchers. For each study year, crash, vehicle, and person-level data tables from PennDOT were merged by the authors to obtain one data table containing all variables of interest (Figure A1, see online supplement). Crash record number and vehicle unit number were the key variables used for matching the cases. The crash-level tables from PennDOT included information about crash and environmental factors. The vehicle table in the database includes information about all vehicles involved in the crash such as body type, movement, unit number in the crash, and other vehicle-related information. In the person-level tables, there is information about all people from all units to the crash and contributing driver action with the unit number of the contributing driver. Merging of all of the tables allowed us to relate one table to another by using the common key variables. After the merging process in MS Access, the file was exported to the Statistical Package for the Social Sciences (SPSS) for Windows (IBM Corporation 2012) and analyzed.

In the PennDOT data set, crash injury severity and injury severity of individuals are given in different tables as variables. Injury severity for people involved consisted of not injured, killed, major injury, moderate injury, minor injury, injury–unknown, and unknown. For this study, to calculate the rates of injury, injury severity was categorized into 2 categories: 0 = no injury and 1 = injury. The injury category includes victims killed or who had major, moderate, or minor injuries or unknown injury severity. Because the number of fatalities was small (14 FE related, 7 HAB related), fatalities were included in the injury category. People who fell within the injury–unknown category were excluded from the injury rate calculations. Pearson's chi-square ($\chi^2$) tests were used to determine whether the proportion of FE and HAB occupants who were injured in the crash differed significantly from that for occupants in the other vehicle (OV) and whether the proportion of FE/HAB operators/drivers who were injured differed from that for their passengers. The specific variables were driver of FE or HAB was injured or not injured; at least one passenger in FE or HAB was injured or not injured; driver of at least one OV was injured or not injured; and at least one passenger in at least one OV was injured or not injured. Statistical significance was set at $\alpha = .05$ (Ott and Longnecker 2001).

In order to calculate crash rate, farm household population and Amish population data for Pennsylvania were used. Farm population data obtained from the National Institute for Occupational Safety and Health (NIOSH 2014) and the Amish population data were obtained from the Young Center for Anabaptist and Pietist Studies (2015). The U.S. Department of Agriculture defines farm as any place from which $1,000 or more of agricultural products was produced and sold, or normally would
have been sold, during the year (U.S. Department of Agriculture 2015) and farm household population refers to people living in farms (NIOSH 2014). Amish population data are obtained from the Young Center for Anabaptist and Pietist Studies at Elizabethtown College and data include all Amish groups (Old Order and New Order) that use horse-and-buggy transportation but exclude car-driving groups such as the Beachy Amish and Amish Mennonites. The Amish are a Christian church that traces its roots to the Protestant Reformation in 16th-century Europe. Amish people accept basic Christian beliefs but also have some special interpretations and emphases that have emerged throughout their history (Young Center for Anabaptist and Pietist Studies 2015).

For developing crash prevention strategies and reducing injury severity, the use of harmful event data was investigated. Harmful events are undesirable effects or consequences resulting from traffic crashes. By definition, a harmful event is an occurrence that actually causes damage or injury (American National Standards Institute 2007). Harmful events can be categorized as either first harmful event (FHE) or most harmful event (MHE). FHE and MHE are identified for different purposes. FHEs are intended to provide evidence on crash causes and to help identify prevention strategies. MHEs, on the other hand, are useful for developing severity reduction strategies (Viner 1993). FHE in the crash indicates the first damage- or injury-producing event that occurred in the crash and was used to examine the causes of the damage or injury in FE- and HAB-involved crashes. MHE is the harmful event that contributed the most damage to the unit or victim(s). In the PennDOT data set, for each crash, there was one FHE and one MHE, making the total number of FHEs and MHEs equal.

To determine whether the FE or HAB was responsible for the crash, the FHE and MHE unit numbers were matched to the vehicle unit number. The crash data here are presented in 4 broad FHE and MHE categories as (1) hit other unit; (2) hit fixed object (tree or shrubbery, embankment, utility pole, guard or guide rail, curb, ditch, culvert, bridge rail, boulder or obstacle in roadway, mail box, etc.); (3) struck by other unit; and (4) other (overturn/rollover, jackknife, fire in vehicle, etc.).

**Results**

From 2010 through 2013, there were 494,948 PennDOT-reported crashes in Pennsylvania (PennDOT 2014), with FE and HAB crashes accounting for 0.12% of these crashes. A total of 344 FE and 246 HAB crashes were reported during the 4-year analysis period (2010–2013) and were fairly evenly distributed among the 4 years (Table A1, see online supplement).

In order to calculate crash rates, farm population data by the U.S. Department of Agriculture’s National Agricultural Statistics Service (NIOSH 2014) and Amish population data (Young Center for Anabaptist and Pietist Studies 2015) were used. The Amish population (n = 68,820) was subtracted from the total farm population (n = 112,170) to obtain the crash rate for FE crashes. The average FE crash rate was 198.4 crashes per 100,000 farm population per year in Pennsylvania. The average HAB crash rate was calculated as 89.4 crashes per 100,000 Amish population per year.

The 344 FE and 246 HAB crashes involved a total of 666 and 504 vehicles and 780 and 838 people, respectively. Based on crash severity data, FE and HAB crashes resulted in fatality 4.1 and 2.6% of the time, respectively (Table A1). The fatal crash percentage for all motor vehicle crashes in Pennsylvania was almost 1% (4,727 fatal crashes of total 494,948 crashes from 2010 to 2013; PennDOT 2014). The most common manner of collision for both FE and HAB crashes was rear-end and angle collisions. The majority of crashes involved multiple vehicles and more than one occupant present (FE was involved in single-vehicle incidents 13% of the time and HABs were involved in single-vehicle incidents less than 1% of the time; data not shown).

Approximately one third of the crashes for both groups occurred in the summer. Though the majority of crashes occurred under daylight conditions, 20% of the FE and 30.5% of the HAB crashes occurred when the lighting was dark or during dusk/dawn. Most crashes occurred in rural areas compared to urban areas. Based on the crash location and population of the area, the variable rural/urban was assigned as a crash-level variable in the PennDOT data set. If the population was under 50,000, the area was considered rural. The crash locations for FE and HAB incidents along with the urban areas are shown in Figure A2 (see online supplement). Although the crashes were mostly in rural areas, they were more numerous in rural areas that were closest to urban areas.

In regard to driver-specific variables, there were 327 FE drivers and 232 HAB drivers with known information (Table A2, see online supplement). The mean age of an FE driver was 44 years (±19 years; youngest 12, oldest 85 years old). Almost 10% of FE drivers were younger than 20 years old. The mean age of HAB drivers was 32 (±17 years; youngest 8, oldest 82 years old) and almost 30% were under 20 (Table A2). Male drivers comprised 96.6% of all FE drivers and 73.7% of HAB drivers.

Prime factors are defined by PennDOT as factors that lead to the crash’s occurrence but do not actually cause the damage (PennDOT 2016). Driver actions, vehicle failure, and environmental factors were the 3 most commonly occurring prime factors of the crashes. In 88% of the FE crashes and 85% of the HAB crashes, driver action was the prime factor leading to the crashes (Table A1).

In Table A2, we list specific contributing driver actions by FE operators, non-FE drivers, HAB drivers, and non-HAB drivers. Making an improper or careless turn (by FE operators, 13% and HAB drivers, 33%) was the most observed driver-contributing action followed by making an improper entrance to the highway and proceeding without clearance after a stop (Table A2). Non-FE drivers contributed to incidents by passing and changing lanes carelessly (27%) and driving too fast for the conditions (24%). The most common contributing driver actions by non-HAB drivers were driving too fast for the conditions (27%), carelessness passing or lane changes (20%), and distracted driver (16%; Table A2).

Vehicle-related deficiencies/failures were prime factors in only 5% (n = 17) of the FE crashes and 1% (n = 3) of the HAB crashes (data not shown). In FE crashes, vehicle-related failures were lights (5), brake system (3), and others (tires, steering system, power train, exhaust, driver seating/control, trailer hitch, and unsecure or shifted trailer load). In HAB crashes, tires and
driver seating/control failures were the 2 vehicle failures in just 3 crashes. There was no case involving a lack of lights in HAB crashes.

Environmental/roadway factors were the prime factors in 7% \((n = 24)\) of the FE crashes and 13% \((n = 33)\) of the HAB crashes. Glare was a specified problem in FE (5% or 18 of 344 crashes) and HAB (11% or 28 of 246 crashes) incidents. It has been reported that glare may negatively impact a motorist’s sight and the visibility of vehicles and an abnormal number of HAB crashes occur while a motorist is traveling toward the sun (Anderson 2014). Other environmental/roadway prime factors for FE and HAB crashes were animals in roadways, slippery road conditions, substances/obstacle on the roadway, and sudden weather conditions.

Travel speed recorded by the investigating police officer is the estimated speed at which the vehicle was traveling immediately prior to the crash based upon operator statement or the investigator’s finding (Commonwealth of Pennsylvania Police Officers Crash Report Manual 2016). For 235 FE cases, we were able to analyze speed differences (closure speed) between vehicles in order to assess the effect of speed differential between vehicles. In 227 cases, the non-FE were traveling faster than the FE, with the non-FE vehicle having an average closure speed of \(51 \pm 21\) km/h (32 ± 13 mph) at the time of the incident (data not shown). In 8 cases, police reported that the FE was traveling faster than the other vehicle. In these cases, the average closure speed for FE was 41 ± 29 km/h (26 ± 18 mph). For the HAB incidents, the speed of the other vehicles was known in 225 cases. The average speed of the other vehicle was 63 ± 24 km/h (39 ± 24 mph; data not shown). Our PennDOT database did not include the speed of HABs. However, the Ohio Department of Transportation (2016) states that normal speeds for HABs range from 8 to 13 km/h (5–8 mph). If we assume the average speed as 10 km/h (6.2 mph), the closure speed for the incidents in Pennsylvania would be 53 km/h (33 mph).

**Injury severity and injury risk**

Table 1 provides an overview of injury severity for the persons involved in these crashes. The table also distinguishes between FE or HAB occupants and occupants of OV. To compare injury severity (injured vs. not injured) of FE and HAB occupants to the occupants in the other vehicle, contingency table analysis was used. Results indicate that the proportion of injured drivers in the non-FE vehicle was approximately 2 times higher than for FE operators (43% versus 21%; \(\chi^2 = 34.283, df = 1, P < .0001\)). There was no significant difference between the proportions of injury between FE passengers and non-FE passengers (40% versus 37%; \(\chi^2 = 0.110, df = 1, P = .741\)). For the FE occupants, an injury to FE passengers was significantly more likely than an injury to FE drivers (41% versus 21%; \(\chi^2 = 4.457, df = 1, P = .035\)).

Roadway HAB incidents had an approximately 3 times higher proportion of injury for the HAB drivers than for non-HAB drivers (58% versus 19%; \(\chi^2 = 79.130, df = 1, P < .0001\)). The proportion of injury for HAB passengers was also significantly higher than the injury proportion for non-HAB passengers (53% versus 26%; \(\chi^2 = 14.872, df = 1, P < .0001\)).

Injury for HAB drivers and HAB passengers did not differ significantly (19% versus 25%; \(\chi^2 = 1.273, df = 1, P = .259\)).

**Harmful events**

Harmful events were crash-level variables, and after merging pertinent tables in Microsoft Access, we were able to relate harmful events to the vehicle in the crash. By matching the vehicle unit number and FHE/MHE unit number, it was possible to determine which vehicle involved in the incidents contributed to the FHE and the MHE. The data were categorized as struck by other unit or hit other unit. These 2 categories explain different types of events. For example, in one case, the FE (unit 1) was stopped in a traffic lane (right lane) and a small truck (unit 2) struck the FE. In this case, the FHE was struck by other unit (small truck). In another case, an automobile (unit 1) and an FE (unit 2) were traveling toward each other. The automobile driver sideswiped the FE. In this case, the FHE was the automobile (unit 1) hitting the other unit (FE).

**Farm equipment crashes**

Table 2 shows the FHE and MHE categories by responsible unit information. FE was the responsible unit for the FHE 40% of the time (137 cases of 344) and the MHE 38% of the time (132 of 344). In crashes in which the other vehicle was responsible, the other vehicle hit the FE more than 90% of the time. The same trend was observed in the MHE analyses (Table 2). FE caused crashes by hitting a fixed object in 24 incidents, with the fixed objects usually being utility poles, embankments, trees, guard rails, or other roadside objects. Several categories with only a few incidents were collapsed into an “other” category. In the other FHE category, 10 incidents involved overturn or rollover of FE and 4 incidents involved fire in FE.

FE were involved in single-vehicle incidents in 43 of the 344 FE crashes (12.5%) by hitting a fixed object \((n = 24)\), overturning or rolling over \((n = 9)\), or catching fire in the vehicle \((n = 3\); data not shown).

The analysis related to the vehicle movement showed that 29% (101 of 344) of the crashes involved the FE and other vehicles going straight, and 24% (83 of 344) of the incidents occurred when FE was turning and the other vehicles were either passing/overtaking the FE or going straight (data not shown). Table 3 breaks down the vehicle movements by the FHE. Only FHE categories of hitting other unit and struck by other unit are provided in the table. When FE and the other vehicle were going straight, the other vehicles hit the FE 19% (66 of 344) of the time. This can be explained by the lower speeds of FE. In cases where FE was turning, the other vehicles passing or going straight caused the crash by hitting them 15% (52 of 344) of the time (Table 3).

**Horse and buggy crashes**

HAB-caused crashes were the FHE in 74 crashes (30%) and they contributed to the MHE in 88 incidents (35.8%). In crashes in which HAB caused the FHE, being struck by other units was the major harmful event in 75.3% (55 of 73) of the cases (Table 2). Only 2 of the HAB crashes were single-vehicle incidents (data not shown).
In regard to vehicle movement, 50% (123 of 246) of the time HAB and other vehicles were going straight. About 21% (51 of 246) of the HAB crashes occurred when the HAB was turning and the other vehicles were either passing/overtaking the HAB or going straight (data not shown). In Table 3, vehicle movements of HAB and other vehicles by the FHE are given. Other vehicles hit the HAB or the HAB was struck by other vehicle 19% of the time when the HAB was turning and the other vehicle was passing or going straight (Table 3).

### Discussion

This study builds on previous work by expanding the scope of the analysis to include FE- and HAB-involved roadway crashes and risk of injury for the occupants in these vehicles versus being in the other vehicles.

Although the occurrence of FE and HAB roadway crashes is rare, the outcomes of these crashes are severe. The crash severity analysis showed that 4.1% of the FE and 2.6% of the HAB crashes resulted in a fatality, which is much higher than the fatality rate for all other motor vehicles at almost 1%. In this respect, roadway infrastructure, vehicle characteristics, and driver-related measures should be examined to avoid and reduce crashes to increase the roadway safety.

The most noteworthy findings in this study are the rates of injury computed for FE and HAB occupants vs. other vehicle occupants. The results revealed that non-FE drivers had a 2 times higher rate of injury than FE operators. The rate of injury for HAB drivers is in the opposite direction, with the rate of HAB drivers being injured 3 times greater than the non-HAB drivers. Our results of higher injury risk for non-FE drivers in FE-involved crashes are consistent with those reported by Peek-Asa et al. (2007). The passengers in the FE crashes had greater injury risk than FE drivers. FE is considered safer for their drivers because of their mass (Jaarsma et al. 2014), and many have seat belts. At the same time, passengers, often referred to as extra riders, most often do not have a safe area in which to ride on the FE. Overall, in terms of injury risk, FE crashes were more injurious for the non-FE drivers and FE passengers and HAB incidents were more injurious for HAB drivers and passengers.

This study is one of the first to analyze the harmful events for FE and HAB crashes. With regard to the FHE, which provides evidence on crash causation, both FE and HAB crashes were most commonly caused by non-FE and non-HAB vehicles (about 60 and 70%, respectively).

The majority of incidents were from passing/overtaking, turning (especially left turn), and going straight and rear-ending the FE and HAB. Turning was the major vehicle movement by FE (29% of the time) and by HAB (21% of the time) when the other vehicle was passing/overtaking or going straight. These kinds of crashes could probably be prevented if the lane widths and/or berms were increased as suggested by Mehlhorn et al. (2015). Turning incidents have long been identified as a major causative factor in the movement of agricultural equipment on public roadways (Gkritza et al. 2010; Schwab and Miller 1995).

Almost all HAB incidents (99%) involved another vehicle and 44% of these crashes were of the rear-end type. One solution for a significant reduction of this type of incident is to separate HAB and motor vehicle pathways because simply widening roadways is not likely to be as effective as a complete separation of the 2 pathways. This idea is supported by research that shows that wider lanes are associated with increased traffic injuries and fatalities (Milton and Mannering 1998; Noland and Oh 2004), mostly likely because increased lane widths usually correspond to higher motor vehicle speeds (Manuel et al. 2014), which, in

### Table 1. Injury severity of people involved in the crashes by vehicle type and person type.

| Injury severity | FE-involved crashes | HAB-involved crashes |
|-----------------|---------------------|---------------------|
| Driver, n (%)   | Passengers, n (%)   | Driver, n (%)       | Passengers, n (%) |
| Not injured     | 253 (78.6)          | 17 (56.9)           |                |
| KILLED          | 4 (1.2)             | 8 (2.6)             | 1 (0.9)        |
| Major injury    | 8 (2.5)             | 11 (3.5)            | 4 (1.5)        |
| Minor injury    | 12 (3.7)            | 4 (1.2)             | 12 (10.6)      |
| Injury/unknown severity | 34 (10.6) | 4 (1.2) | 20 (17.7) |
| Total injured   | 69 (21.4)           | 9 (40.91)           | 135 (43.1)     |
| Total           | 322                 | 22                  | 313            |

### Table 2. FHE and MHE for FE and HAB Incidents.

| Farm equipment-involved crashes (n = 344) | Responsible unit—FE | Responsible unit—Non-FE |
|----------------------------------------|---------------------|------------------------|
| Harmful event                          | FHE (n = 137)       | MHE (n = 132)          | FHE (n = 207) | MHE (n = 212) |
| Hit other unit                         | 43 (31%)            | 40 (30%)               | 190 (92%)    | 174 (82%)     |
| Hit fixed object                       | 24 (18%)            | 16 (12%)               | 7 (3%)       | 15 (7%)       |
| Struck by other unit                   | 50 (36%)            | 49 (37%)               | 8 (4%)       | 11 (5%)       |
| Other                                  | 20 (15%)            | 27 (20%)               | 2 (1%)       | 12 (6%)       |
| Overturn or rollover                   | 10 (7%)             | 17                     | 9            |
| Fire in vehicle                        | 4                   | 5                      | 1            |
| Jackknife                              | 1                   | 1                      | —            |
| Other noncollision                     | 5                   | 4                      | 2            |

| Horse and buggy-involved crashes (n = 246) | Responsible unit—HAB | Responsible unit—Non-HAB |
|-------------------------------------------|-----------------------|-------------------------|
| Harmful event                             | FHE (n = 74)          | MHE (n = 88)            | FHE (n = 172) | MHE (n = 158) |
| Hit other unit                            | 16 (22%)              | 15 (17%)                | 165 (96%)    | 144 (91%)     |
| Hit fixed object                          | 1 (1%)                | —                       | 3 (2%)       | 5 (3%)        |
| Struck by other unit                      | 55 (74%)              | 68 (77%)                | 3 (2%)       | 4 (3%)        |
| Other                                     | 2 (3%)                | 5 (6%)                  | 1 (1%)       | 5 (3%)        |
| Overturn or rollover                      | 1 (5)                 | —                       | 1 (1%)       |
| Other noncollision                        | 1                     |                         | 4            |
Another option that might be explored is to use the lane change assistant system to warn drivers if another vehicle is in the other vehicles involved in FE and HAB incidents—for example, a brake or steering failure—numbered only 12 (3%) for FE involved incidents and 3 (1%) for HAB incidents.

The effect of speed differences between FE and HAB and other vehicles has been reported as a significant safety concern by several researchers (Anderson 2008; Garvey 2003; Gkritza et al. 2010). Our study also confirms that the speed differences were a significant factor in FE and HAB crashes. The closure speed between FE and other vehicles was high: the average non-FE vehicle closure speed was 51 ± 21 km/h (32 ± 13 mph) and the average FE closure speed was 41 ± 29 km/h (26 ± 18 mph). The high closing speed for FE may be a result of the FE traveling at its highest speed and hitting slowing, turning, stopped, or parked vehicles.

Our research is subject to certain limitations. The data used in this study reflect information from a single U.S. state and a single data source (PennDOT). A general limitation of using the PennDOT crash database is that these data are based on police reports and may be affected by the discretion of the traffic officer, which could affect the consistency of crash reports. In terms of injury severity, the number of fatalities may not be reported accurately because any injury that causes death after 30 days of a crash is not reported. There is no follow-up information reported in the database for deaths occurring after 30 days. It is also possible that severity of crashes in the PennDOT database is overstated because less severe crashes were not investigated by the state police. We searched for studies that evaluated completeness and or accuracy of crashes within the PennDOT database but did not find any.

It is also possible that a small number of crashes of potential interest were not investigated by the police due to a lack of police availability or because the crash parties agreed not to report incidents involving no or minor injury or property damage. Although the PennDOT crash database includes the variable vehicle failure, the presence of an SMV emblem or the condition of the SMV emblem were not among the vehicle failure categories. Thus, in this study we could not examine whether the absence or poor condition of an SMV emblem had any effect on the occurrence of the crashes. Another limitation of the database was inadequate information about roadway surfaces, preventing any analyses of the effects of roadway surfaces on the crashes.

To conclude, this study has enabled us to understand several characteristics of FE and HAB roadway crashes not previously

| Farm equipment/horse and buggy | Other vehicle | FE crashes (n = 344) | HAB crashes (n = 246) |
|------------------------------|--------------|---------------------|----------------------|
|                              |              | FE hit OV | OV hit FE | FE struck by OV | OV struck by FE | HAB hit OV | OV hit HAB | HAB struck by OV | OV struck by HAB |
| Going straight               | Going straight | 12        | 66       | 20           | —            | 8          | 97        | 16           | 1            |
| Going straight               | Passing or overtaking vehicle | —       | 8        | —            | —            | 1          | 20        | 1            | —            |
| Going straight               | Negotiating curve | 1        | 8        | 1            | —            | —          | —         | —            | —            |
| Going straight               | Slowed/stopped in the lane | 3       | 2        | —            | —            | —          | —         | —            | —            |
| Turning                      | Going straight | 4       | 10       | 11           | —            | 2          | 8         | 23           | —            |
| Turning                      | Passing or overtaking vehicle | 6       | 42       | 3            | 6            | 1          | 11        | 5            | —            |
| Negotiating curve            | Negotiating curve | 4       | 12       | 1            | —            | —          | 7         | 1            | —            |
| Slowed/stopped in the lane   | Going straight | —       | 11       | 5            | —            | —          | 8         | 1            | —            |
| Parked                       | Going straight | —       | 9        | 2            | —            | —          | —         | —            | —            |
explored and to identify their effects on occupants of FE, non-FE, HAB, and non-HAB vehicles. FE and HAB crashes result in fatality in 4.1 and 2.6% of the time, respectively, whereas the fatal crash percentage for all motor vehicle crashes in Pennsylvania is less than 1%. In terms of injury severity, the overall rate of injury is 3 times greater for HAB drivers than for non-HAB drivers.

The responsible unit for the majority of crash incidents in FE and HAB crashes was the other vehicle, supporting the idea that educational programs are needed not only for the drivers of FE and HAB but for motor vehicle drivers. The data also suggest that educational programs should target adults because the drivers of FE and HAB under the age of 16 contribute very little to crash incidents.

Considering driver contributing actions, FE and HAB drivers making an improper or careless turn was the most observed driver contributing actions with 13 and 33%, respectively. The leading non-FE driver contributing actions was careless passing or lane changes (27%), with the leading non-HAB driver contributing actions driving too fast for conditions (27%). Only a small percentage of the FE crashes were due to the lack of lights. The visibility of the FE and HAB appears to not be a significant factor in their involvement in public roadway crashes.

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