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The effects of roadway characteristics on farm equipment crashes: a GIS approach

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THE EFFECTS OF ROADWAY CHARACTERISTICS ON FARM EQUIPMENT CRASHES: A GIS APPROACH

by

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CERTIFICATE OF APPROVAL

MASTER'S THESIS

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To my family, as your least and most favorite child, I cannot thank you enough for the wonderful support throughout my education

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ABSTRACT

Tractors and other self-propelled farm equipment, such as combines, sprayers, and towed grain carts, are often used on public roadways as the primary means for traveling from homestead to homestead or from homestead to a distributer. Increased roadway exposure has led to a growing concern for crashes involving farm equipment on the public roadway. A handful of studies exist examining public roadway crashes involving farm equipment using crash data, but none thus far have evaluated road segment data to identify road-specific risk factors. The objective of this study is to identify if roadway characteristics (traffic density, speed limit, road type, surface type, road width, and shoulder width) affect the risk of a crash involving farm equipment on Iowa public roadways.

A retrospective cohort study of Iowa roads was conducted to identify the types of roads that are at an increased risk of having a farm-equipment crash on them. Crash data from the Iowa Department of Transportation (to identify crashes) were spatial linked to Iowa roadway data using Geographic Information Systems (GIS). Logistic regression was used to calculate ORs and 95% CL.

Out of 319,705 road segments in Iowa, 0.4% segments (n=1,337) had a farm equipment crash from 2005-2011. The odds of having a farm equipment crash were significantly higher for road segments with increased traffic density and speed limit. Roads with an average daily traffic volume of at least 1,251 vehicles were at a 5.53 times greater odds of having a crash than roads with a daily traffic volume between 0-30 vehicles. (CI: 3.90-7.83). Roads with a posted speed limit between 50mph and 60mph were at a 4.88 times greater odds of having a crash than roads with a posted speed limit of 30mph or less. (CI: 3.85-6.20). Specific roadway characteristics such as roadway and shoulder width were also associated with the risk of a crash. For every 5 foot increase in

road width, the odds for a crash decreased by 6 percent (CI: 0.89-0.99) and for every 5 foot increase in shoulder width, the odds of a crash decreased by 8 percent. (CI: 0.86-0.98). Although not statically significant, unpaved roads increased the odds of a crash by 17 percent. (CI: 0.91-1.50) Lastly, it was found that Farm to Market routes increased the odds of a crash by two fold compared to local roads (which make up roughly 67 percent of Iowa public roads). (CI: 1.72-2.43) When the same model was stratified by rurality (urban/rural), it was found that high traffic density leads to a higher risk of a crash in rural areas. Iowa routes and Farm to Market routes had a greater odds of a crash in urban than rural areas, and road and shoulder width were more protective in rural than urban areas. When only using roads with a crash involving an injury versus all other roads as the outcome, Iowa routes and roads with increased speed limits had higher odds for an injury-involved crash, while increased road width were more protective against crashes involving injuries.

Findings from the study suggest that several roadway characteristics were associated with farm-equipment crashes. Through administrative and engineering controls, the six static explanatory variables used in this study may be modified to decrease the risk of a farm equipment crash. Speed limit can be modified through administrative controls while traffic density, road and shoulder width, road type, and surface type can be modified through engineering controls. Results from this study provide information that will aid policy-makers in developing safer roads for farm equipment.

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INTRODUCTION

The agricultural sector has one of the highest fatality rates of all US industries (CDC, 2013). In 2011, agricultural-related fatalities accounted for 12% of all occupational deaths in the United States while the agricultural sector made up less than 1% the total workforce (BLS, 2011). In 2012, there were 152 agricultural worker fatalities, and 78 of them (51%) were transportation-related (meaning that they occurred involving the use of mobile agricultural equipment); of the 78 fatalities, 38% occurred on a US public roadway. Fatalities involving farm equipment were the leading cause of work-related deaths for agricultural workers, and roadway fatalities were the second most common cause of a fatality (BLS, 2012). Of all 50 states, Iowa reported the highest rate of farm equipment crashes on public roads at 10.7 crashes per 100,000 population per year (Peek-Asa et al. 2007). In 2011, the Bureau of Labor Statistics reported that Iowa still led all 50 states in the number of agricultural transportation-related fatalities.

Despite the overwhelming evidence that farm equipment crashes are a significant problem, only a handful of Iowa and national studies exist to explain how and why these crashes were occurring. Table 1 lists past studies in the fields of agricultural transportation safety and roadway engineering referenced in this thesis to highlight gaps for future study. Studies pertaining specifically to farm equipment investigated crash configuration, as well as vehicle, operator, and temporal information, yet did not examine how road's characteristics impact farm equipment crashes on public roads.

Table 1 Prior studies investigating roadway characteristics

Farm equipment studies investigating roadway characteristics	**Level of analysis**
1. Peek-Asa et al. (2007)	Crash/crash with injury
2. Harland et al. (2014)	Crash- by level of rurality
3. Gerberich et al. (1996)	Descriptive
4. Costello et al. (2009)	Crash/No crash
5. Gkritza et al. (2010)	Crash/crash with injury
Motor vehicle (non-farm equipment) studies investigating roadway characteristics	
6. Karlaftis et al. (2002)	Highway segments- crash/no crash
7. Ackaah et al. (2011)	Road segments- crash/no crash
8. Hadi et al. (1995)	Road segments- crash/no crash
9. Wang et al. (2009)	Geographical ward
10. Wang et al. (2009)	Road segments- crash/no crash
Farm equipment studies investigating roadway characteristics	**Findings in study**
1. Peek-Asa et al. (2007)	"Other/unknown" road risk factor for crash resulting in injury
2. Harland et al. (2014)	Crash characteristics differ by level of rurality
3. Gerberich et al. (1996)	Speed limit and road surface type differ between farm equipment crashes and all MV crashes
4. Costello et al. (2009)	Increase road exposure and traffic density do not statistically affect risk of a crash
5. Gkritza et al. (2010)	Roads 55mph or greater are a risk factor for farm equipment-related crashes
Motor vehicle (non-farm equipment) studies investigating roadway characteristics	
6. Karlaftis et al. (2002)	Traffic density, lane width, and pavement type- significant predictors of MV crashes
7. Ackaah et al. (2011)	Traffic density and increased road segment length increased the likelihood of a crash
8. Hadi et al. (1995)	Increased traffic density and decreased shoulder width increases crash risk frequency.
9. Wang et al. (2009)	Increased speed limit is a risk factor on crash fatalities and injuries
10. Wang et al. (2009)	Traffic density and the length of the road segment are risk factors for a crash

Farm Equipment Crash Studies Investigating Road and Environmental Characteristics

The first published study investigating roadway characteristics was conducted in 1996. Gerberich et al. (1996) conducted a national descriptive study that included all US fatal crashes occurring on a public road involving non-truck farm vehicles coded by the National Highway Traffic Safety Administration's Fatal Accident Reporting System (NHTSA, 2014). The study focused on driver characteristics as well as crash-level information; however, several road characteristics were collected and used for the study. It was found that 98% of farm vehicles crashed occurred on a 2-lane road while 94% of non-farm vehicle crashes occurred on a 2-lane road. Of all farm vehicle crashes, 81% occurred on a road with a speed limit of 55mph, compared to 73% for non-farm vehicle crashes. Last, it was found that 25% of farm vehicles crashed on an unpaved road while only 6% of non-farm vehicle crashes occurred on an unpaved road. Although at the time, this was seen as an emerging trend, the descriptive nature of this case-only study did not allow for the calculation of risk; however it did provide a foundation of research to be built upon.

Nearly a decade later, Peek-Asa et al. (2007) conducted a similar study involving farm equipment crashes that occurred in Iowa from 1995-2004. Results concluded that non-farm vehicle drivers were 5.23 times more likely to be injured (95% CI =4.12-6.46) in a crash than farm equipment drivers. When considering road classification, the majority of crashes occurred on a county highway or road; however, 32.4% of crashes occurred on an “other/unknown” type of road. Given a crash, those that occurred on a road type classified as “other/unknown” had a 70% greater chance of resulting in an injury (95% CI =1.06-2.73). This study indicated a need for additional research on road characteristics such as road type to help further understand what types of roads are unknown that can lead to the risk of a crash. Gkritza et al. (2010) conducted an empirical study through Iowa State University that found that farm equipment crashes occurring on a road with a speed limit 55 mph or greater had a greater risk of an injury. Based on these two studies, clearly, research is needed to understand what types of roads increase the risk of crash that results in injury. The third aim of this study addresses this gap.

In a more recent study of farm equipment crashes involving nine Midwest states, Karissa Harland et al. (2014) assessed the geographic location of farm equipment crashes and described their rural-urban distribution and proximity to towns. Farm-equipment crashes involving multiple vehicles or within a town occurred more frequently in urban than rural zip codes. Crashes occurring in or within a mile of a city or town were more likely to take place in an urban setting. This suggests that locations near fringes of city or town boundaries are risky areas for farm-vehicle crashes. The location of a crash is clearly an influential factor; however, it is important to understand that there are distinctive road features in different levels of rurality. The second aim of this thesis investigates road features that can be stratified by rurality since the level of analysis is a road segment.

Altogether, past research pertaining specifically to farm equipment crashes on public roadways was completed using crashes as the unit of analysis, which therefore makes it impossible to identify risk factors for crashes. To identify specific risk factors, one would ideally compare an index group (e.g., farm equipment, the operator, the road, or the environment involved in a crash) with a reference group (equipment, operator, road, environment) not involved in a crash. To conduct such a study on individuals or farm equipment operators, one feasible design is a cross-sectional survey of farmers about their driving exposure and crash experiences which is precisely what was done by Costello et al. (2009) in a study out of North Carolina. This cross-sectional study examined 15 potential risk factors (Table 2) and their association with crashing farm equipment. In this survey, farm operators or owner/operators were asked to report if they had been involved in a farm equipment-related crash on a public North Carolina road during an 11 year period from 1992-2003. While this study did not look at specific road characteristics (since farmers were the unit of analysis), it measured various farmer/driver and vehicle-level exposures. Farm injury history and vehicle type statistically affected the risk of a farm vehicle crash; however, increased self-reported driving exposure and driving on roads with high traffic density were not statistically associated with crashing.

Table 2 Potential Risk Factors Included in (Costello et al. 2009) Analysis

Potential Risk Factors
Age of youngest farm vehicle driver on public roads (mean)
Age of oldest farm vehicle driver on public roads (mean)
Non-family hired farm help drive farm vehicles on public roads (*D*, %)
Non-English speaking (*D*, %)
Farm injury history (mean number of events)
Total number and variety of non-farm vehicle public road uses (mean)
Farm vehicle age (i.e., years of age of oldest farm vehicle driven)
Use of farm truck (*D*)
Use of large-size farm vehicles (*D*)
Driving exposure (i.e., number of hours driven farm equipment on public roads
Number of farm operations managed
Low income (<$25K) (*D*, %)
High income ($100K or more) (*D*, %)
Low traffic density
High traffic density

<u>Non-farm Equipment Roadway Crash Studies Evaluating Roadway Characteristics</u>

While there have been few studies examining roadway characteristic's effects on farm-equipment crashes, there have been several studies investigating how roadway characteristics affect ***non***-farm equipment motor crashes. Although the following studies did not investigate farm equipment crashes, it is equally important to understand how roadway characteristics affect motor vehicle crashes in general since prior research i.e. Peek-Asa et al. (2007) as well as the crash Department of Transportation data used for our study has found that a majority of farm equipment crashes on public roadways also include non-farm equipment. Roadway-based studies have not been limited to the geographic boundaries of the United States. In 2002, the Department of Transportation Planning at the University of Athens in Athens Greece investigated the effects of road geometry on rural roadway crashes. Karlaftis & Goilas (2002) utilized hierarchical tree-based regression and found that traffic density, lane width, serviceability index (road quality), access control (amount of access control), and pavement type were all significant predictors of motor vehicle crashes. The analysis was stratified by number of lanes, and it was found that for rural two-lane roads, traffic density was the greatest predictor of a crash followed by lane width and serviceability index (road quality). For multi-lane rural roads, traffic density was once again the strongest predictor followed by median width and access control. When controlled for traffic density, pavement type and friction levels became significant contributors to traffic crashes. Road sections were used as the unit of analysis for this study to analyze crash risk.

In another international study from the Building and Road Research Institute in Ghana, Ackaah & Salifu (2011) found that increased traffic density, increased road segment length, and decreased terrain increased the likelihood of a crash; however, road curvature, speed, and shoulder and road width were not found as statistically significant risk or protective factors of motor vehicle crashes. Road sections were used as the unit of analysis for this study. The final pertinent roadway characteristic risk-based study was a US study conducted by Hadi et al. (1995) of the Transportation Research Center at the University of Florida. This study was confined only to highways and found that increased traffic density and decreased shoulder width increases crash risk frequency. Road sections were used as the unit of analysis for this study. While these studies did not study farm equipment specifically it is also important to know how road characteristics affect non-farm equipment on public roadways since a substantial portion of farm equipment crashes involve non-farm equipment. Road type, number of lanes, road width, shoulder width, traffic density, pavement type, and speed limit are all factors that prior research has investigated. These variables were examined in this thesis. Prior roadway research, has fortunately analyzed crash risks at the road segment level; however, using this technique for farm equipment, not just all motor vehicles, and specific to injuries, is an innovation and contribution to the traffic, agricultural and public health literature.

State and National Rural Transportation Safety Programs

Despite the lack of comprehensive studies on roadway characteristics, efforts have still been put forth to raise awareness of potentially dangerous roadway characteristics on Iowa roads. The Iowa Department of Transportation (IDOT) and the Committee on Agricultural Safety and Health Research which is a transportation-based extension of the USDA have identified specific road characteristics that may increase farm equipment-related crashes on a public roadway and provided control methods to be implemented based on these risks. The information given from the IDOT campaign is based on expert opinions of road engineers and highway sheriffs as well as unpublished crash analysis conducted by the Iowa Traffic Safety Alliance as part of the Iowa Comprehensive Highway Safety Plan. In August of 2011, the Iowa Department of Transportation (IDOT) disseminated a state-wide campaign for rural road safety titled "Rural road crashes – they're preventable". This traffic safety campaign covered points on how all road users can be safer on *rural* Iowa roads. By identifying road characteristics that could pose a risk to rural roadway crashes, (Table 3) the IDOT road safety campaign used these characteristics to target prevention primarily through education (IDOT Driver services, 2014). While this campaign was impressive and targeted safety on rural roads, it should be noted that farm equipment crashes in the Midwest are not just a rural problem with roughly 30% of farm equipment crashes occurring in urban zip codes (Harland et al. 2014).

Table 3 Iowa Department of Transportation (IDOT) - identified risky roadway characteristics

Rural Road Characteristics	**Gravel Road Characteristics**
Little or no shoulder	Loose gravel
Narrow lanes	Washboarding
Soft shoulders	No center line
Steep hills	No edge makings
Fewer traffic signals	Unmarked curves
Narrow bridges	Seasonal roadbed changes
Sharp curves	Limited snow removal
Less maintenance	Few signs
Rough road surface	Obscured road edges
Changes in road surface	Soft road edges
Poor drainage	Dust- reduced visibility
Crowned road surface	Varied gravel depth
Limited sight distance	No marked passing zones
Blind driveways	Mud and standing
Intersections without stop signs	
Potholes	
No street lights	
Faded or hidden signs	

The Committee on Agricultural Safety and Health Research is an extension research service of the USDA. In 2009, they put out a 48-page document titled: “Agricultural Equipment on Public Roadways.” An entire section of this report is dedicated towards targeting where research in agricultural roadway safety is needed. In this section, the committee emphasizes the need for engineering design standards and policy to be based on research identifying hazards and risks of agricultural equipment on public roadways. Research on road and environmental conditions were also identified as important to understand the interaction between the roadway user, their vehicle and the environment (Committee on Agricultural Safety and Health Research, 2009).

Use of GIS in roadway safety research

Geographical Information Systems (GIS) is a universal tool that can be applied to all fields of research to effectively answer a research question with a spatial component. ESRI, the leading producer of GIS-based software defines GIS as:

> An organized collection of computer hardware, software, geographic data, and personnel designed to efficiently capture, store, update, manipulate, analyze, and display all forms of geographically referenced information.
> (Environmental System Research Institute, 2002)

There has not been any past research investigating farm equipment crashes on rural roads that use GIS; however, there have been several GIS-based studies that have used GIS to investigate which roadway characteristics affect the odds of a crash varied by levels of crash severity. Wang et al. (2009) used a negative binomial (NB) regression model to investigate the effects of curvature and road speed on roadway fatalities and injuries. This study was conducted in England at the ward level of analysis. A ward is comparable to a US zip code. Crashes were mapped and aggregated to the ward level and GIS was used to calculate and average curvature and speed limit per ward. Results found that speed limit had a statistically significant positive association with traffic fatalities. In another England study, Wang et al. (2009) used a Poisson-Gamma model to investigate traffic density's effect on roadway crashes. The unit of analysis for this study was the road segment. GIS was used to link locations of the crash to the road segment; however non-spatial statistics were run to calculate risk of a crash. In the analysis, traffic flow, segment length, number of lanes, curvature and gradient were controlled for. Findings revealed that traffic density and the length of the road segment had a significant association with motor vehicle crashes. A multitude of GIS spatial analyses that can be used in essentially any field, and especially in the field of transportation safety where roads are a non-continuous surface. Another useful application of GIS in this field is the derivation of geographic data and its integration with road network spatial data. The next step is to use this GIS-based data in epidemiologic studies to calculate the risk of a crash - this is something that is addressed in the analysis of our study.

Specific Aims

The overarching goal of this research is to provide information based on road characteristic risk factors to prevent farm-equipment road crashes and their injuries. We conducted a cohort study of road segments to understand the role of roadway characteristics in motor vehicle crashes involving farm equipment on public roads. By utilizing road segment as the unit of analysis, road segments where a crash occurred was compared to road segments where a crash did not occur. This analysis allows the calculation of risk by specific roadway characteristics. Past research has found that roads with a speed limit of 55mph or greater (Gkritza et al. 2010) and specific types of roads are involved in farm equipment crashes. (Peek-Asa et al. 2007) Harland et al. (2014) also found that crash characteristics differ by where the crash occurred (rurality). In one study, increased road exposure and traffic density did not increase the odds of a farm equipment crash (Costello et al. 2009). Yet, in studies of all motor vehicle crashes, prior research found that uniformly traffic density increases the odds of a crash, lane width and pavement type were strong predictors of a crash (Karlaftis & Goilas, 2002). In addition, increased driving exposure, (Ackaah & Salifu, 2011) and decreased shoulder width (Hadi et al. 1995) all increased the risk of a motor vehicle crash. Costello et al. (2009) found that traffic density and road exposure did not increase the odds of a crash while Ackaah & Salifu (2011) found the opposite findings. Ackaah & Salifu (2011) also found that speed limit and shoulder width do not impact the risk of a crash, which is not consistent with other literature. Last, Peek-Asa et al. (2007) found that certain types of roads increased the odds of an injury given a crash; however these roads were classified as unknown. The methodologies used in this paper will fill gaps present in prior research pertaining to agricultural transportation safety. There are three specific aims of this paper:

1. Calculate the risk of specific roadway characteristics by comparing Iowa road segments where a farm vehicle crash has occurred with road segments where a crash has not occurred. The road characteristics in this analysis include traffic density, speed limit, road type, surface type, road width, and shoulder width.

2. Determine if risk by road characteristics is affected by whether a crash occurred in an urban area or a rural area.

3. Identify which road characteristics increase the risk of an injury verses a crash. For this aim, road segments where a crash with an injury occurred will be compared with road segments where a crash with an injury did not occur.

CHAPTER II

THE EFFECTS OF ROADWAY CHARACTERISTICS ON FARM EQUIPMENT CRASHES: A GIS APPROACH

Introduction

As one of the most hazardous occupations, (CDC, 2013) the agricultural sector has a significant proportion of deaths occur while using a piece of agricultural equipment on a public roadway (BLS, 2011). While crashes involving farm equipment on public roads are a national problem, crash, injury and fatality numbers in the state of Iowa are magnified. Of all 50 states, Iowa reported the highest rate of farm equipment crashes on public roads at 10.7 crashes per 100,000 population per year (Peek-Asa et al. 2007). In 2011, Iowa led all 50 states in the number of agricultural transportation-related fatalities (BLS, 2011). Prior motor vehicle roadway studies have found that increased traffic density (Ackaah & Salifu 2011) and speed limit (Wang et al. 2009), while decreased shoulder width (Hadi et al. 1995) increases the risk of a motor vehicle crash. The only substantive finding from farm equipment crash studies pertaining to roadway risks is that roads 55mph or greater are risk factors of crashes (Gkritza et al. 2010). There are a number of additional roadway characteristics that have not been examined by past farm equipment studies. This thesis has been conducted to fill in the gaps of prior research and provide a content and analytic-based foundation to be built upon.

While farm-equipment crashes are a significant problem, there are a multitude of different risk factors may increase the risk of a crash. Based on the epidemiologic triangle (Bowering & Arcand, 2008) that considers the host, agent, and environment, we can conceptualize three types of factors that might explain the increased risk: characteristics specific to the operator (host) of the farm implement, the farm implement itself or the other piece of motor equipment if these were multiples vehicles involved (agent), the static surrounding environment, (i.e. road type, number of lanes, speed limit) and the dynamic environment (i.e. weather conditions, traffic density, manner of collision). The majority of prior research on farm equipment transportation safety has focused on the host and agent; however, the little research that has been done on the environment has been incomplete and inconclusive as demonstrated by Peek-Asa et al. (2007) who found that an unknown type of road is a risk factor and by Costello et al. (2009) who found that traffic density and the amount of road exposure were not significant indicators or a farm equipment crash-related injury. This study will identify risky road characteristics that may contribute to farm equipment crashes on public Iowa roadways. The primary aims of this study are to investigate which roadway characteristics affect the odds of a crash and of an injury. The analysis was also stratified by rurality to investigate if the effect of roadway characteristics will differ by location. Through the analysis of this study, physical engineering can be applied to roadway characteristics that are found to increase crash risk.

Methods

Design and Study Population

A retrospective cohort study was conducted on 319,705 Iowa road segments using data from 2005-2011. Iowa roads comprised an ideal study population for farm equipment crashes because of the high use of farm equipment by Iowa farmers. In 2007, 78 percent of Iowa land was cropland and 10 percent of Iowa's population lived on a farm. Out of all 50 states, Iowa has the second most registered tractors and the most combines which are two of the most common types of farm equipment involved in farm equipment-related crashes on Iowa public roads. In 2007, Iowa had 243,403 registered tractors servicing 92,856 farm operations (USDA, 2007). Furthermore, in 2011, Iowa had the second most agricultural-related fatalities and the most agricultural transportation-related fatalities out of all 50 states (BLS, 2011). From 2005-2011, based on the data that we were given by the Iowa Department of Transportation (IDOT), there were 790 reported injuries and 43 reported fatalities resulting from crashes involving farm equipment on public Iowa roadways. This study population is important because the state of Iowa has such a high number of crashes involving farm equipment.

Data Sources

Road Segment Data

The unit of analysis for this study was the road segment. Using geospatial technologies, the IDOT created a road network spatial dataset which accounts for every primary, secondary, and municipal road in the state of Iowa. The road network that was used for this study was from 2007. A new road segment is demarcated each time any of the boundaries listed in Table 4 are crossed or any of the road characteristics (e.g., type of road, speed, road width) change. The average road segment length across Iowa is 0.36 miles while the minimum is 2 feet, the maximum is 4.48 miles and the standard deviation is 0.35 miles. Figure 1 gives an example of how a road is demarcated into road segments. This example is roughly a mile of an Iowa interstate that is demarcated into 4 road segments. Segment 1 is split into segment 2 since there is a decrease in surface width from the loss of the exit lane. Segment 2 is split into segment 3 due to a loss in traffic density from the cars that have exited to the ramp and 3 to 4 is split due to the increase in road width and traffic density.

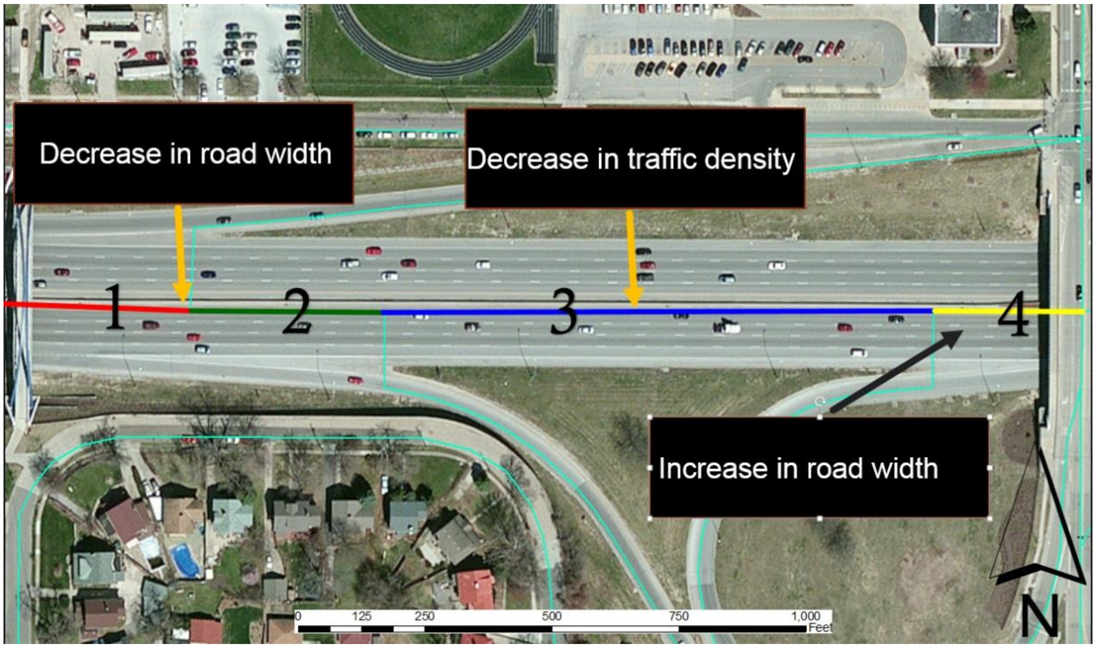

Figure 1 An example from an Iowa interstate demonstrating how roads are demarcated into road segments

Table 4 Influential factors of road segments used for demarcation of IDOT road network dataset

Change in type section- divided roadway to non-divided roadway, or vice versa
Significant change in outside shoulder width (0.6 meters or more)
Significant change in median width (0.6 meters or more)
Change in surface type
Change in surface width
Change from two-way to one-way street, or vice versa
Section with “Y” in SPECIAL STUDY
Change in surface condition rating (two points or more)
Change in state functional classification
Significant change in AADT
County line
Corporation line
Urban area line
Junction with primary route

Although there are hundreds of variables pertaining to road and environmental characteristics available at the road segment aggregate level, six roadway variables were used in this analysis to answer the research questions proposed in this paper. These six variables were chosen due to the completeness of the data. They were also variables identified by previous research as being potentially associated with roadway crashes involving farm equipment. By running the analysis at the road segment level of these same variables, risk can be assessed pertaining to these six influential variables by comparing road segments with a crash to road segments without a crash. The geospatial technologies division of the IDOT (2014) created 18 different road network GIS shapefiles (geography-specific files) with information containing road data on the road segment level. Two of the 18 were merged into one for this study by a unique link ID specific to each road segment and provided in each IDOT dataset. With 324,769 road segments in this merged dataset, every primary, secondary, and municipal road in the state of Iowa was represented. Of these road segments, 5,064 with missing speed limit, road width (n=4,139), and surface type (n=3,871) were excluded. As shown in Figure 2, the segments that were removed were distributed throughout the state with a few pockets in the densest areas. This suggests that data were not missing systematically. The excluded segments make up 1.6% of the original dataset. The removal of these records left the final sample as 319,705 road segments.

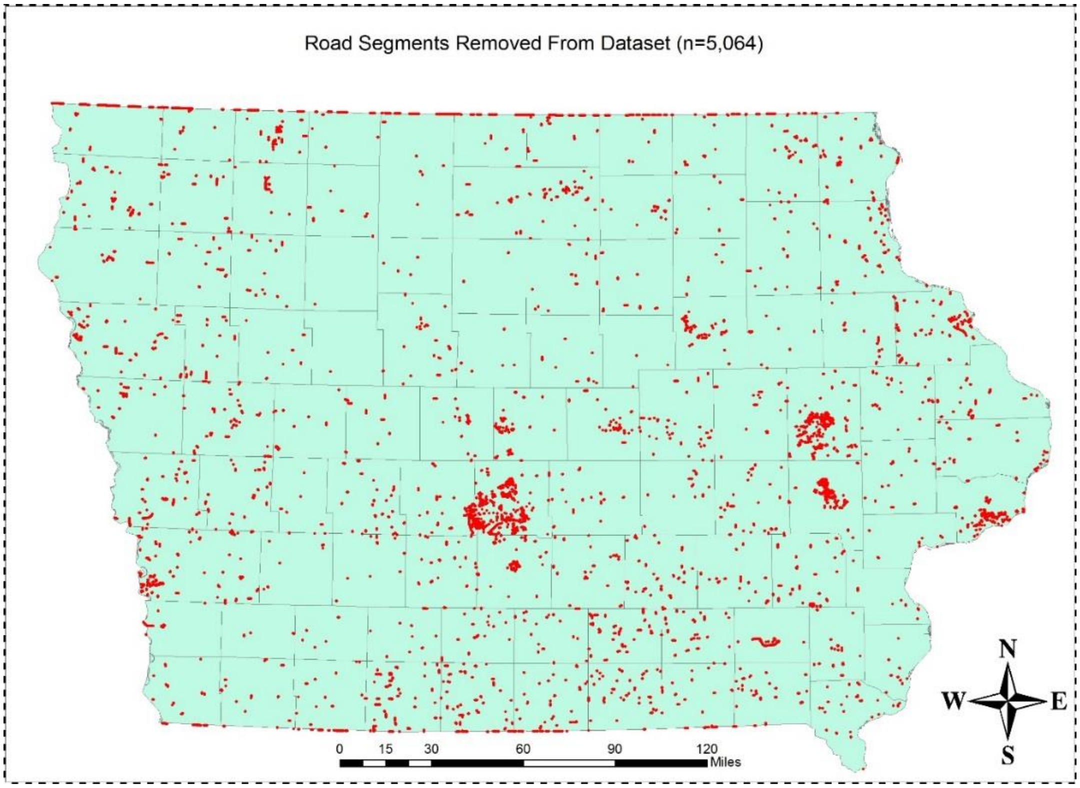

Figure 2 Red dots represent the road segments that was removed due to missing road data

Farm Equipment Crash Data

Data on farm equipment crashes from 2005 through 2011 were accessed from the IDOT. During 2005-2011, there were 1,401 crashes (identified as farm-equipment related) that occurred on a public Iowa road. Cases were identified by the officer who filled out the crash report and determined whether or not the vehicles involved were farm equipment based on the IDOT definition. Farm equipment is defined by IDOT's Truck Information Guide as equipment specifically designed for agricultural operation (The Iowa Legislature, 2014). Implements were classified as either self-propelled or towed. SUVs, cars, motor trucks, truck-tractors, pickups, farm trailers, and semi-trailers were not considered farm equipment even if they are used in agriculture. Combines, farm tractors, fertilizers, feeders, towed grain carts, and wagons *were* considered farm equipment and were coded as farm equipment by the officer who was the first responder to the scene.

For the purpose of this study, we are only interested in self-propelled farm equipment. We were unable to verify the coding of farm equipment, except for the 25% of the records which specified vehicle make, model or style. Of these 25% (N=339), 12 coded farm equipment as either as a Buick, Chevrolet pickup, Ford SUV, or GMC SUV, these cases were removed from the dataset leaving 1,389 farm equipment crashes that occurred on a public Iowa road from 2005-2011.

Linking Road Segment with Crash Data using GIS

The next step of the process involved the utilization of GIS. For each crash that occurred, the first responder on the scene of the crash logged the XY geographic coordinates that allow for mapping into a geographic space. An imbedded automated GPS device in the respondent's vehicle is used to record the XY location of the crash. Of the remaining 1,389 crashes, 18 crashes contained no location-based data and were removed from the dataset. The final number of mapable crashes was 1,371.

Using ArcMap 10.2, all 1,371 crashed were projected onto a map in a UTM zone 15 as a projected coordinate system. GIS analysis was conducted to spatially join each crash to the road segment where it occurred. This is an automated GIS process that assigns a common ID to the road segment that is closest to each crash. A new column was created so that each of the 319,705 road segments had a count field which indicated the number of crashes that occurred on each road segment. Crashes were then dichotomized so that if there had been at least 1 crash on a given road, the count field would be coded as a "1" and if there has not been any crashes, it would be coded as a "0". A total of 1,371 mapable crashes occurred on 1,337 road segments over the 7-year study period. Only 34 road segments had 2 crashes that occurred on them, therefore a binomial classification of the crash outcomes was utilized. Figure 3 is a map that shows where in the state of Iowa the crashes occurred. Figure 4 is a map that gives an example of how the analysis was run. The specific area highlighted in Figure 4 is in the Dubuque, Iowa area.

There are 3 crashes that are highlighted. They all occurred on different road segments that had different roadway characteristics.

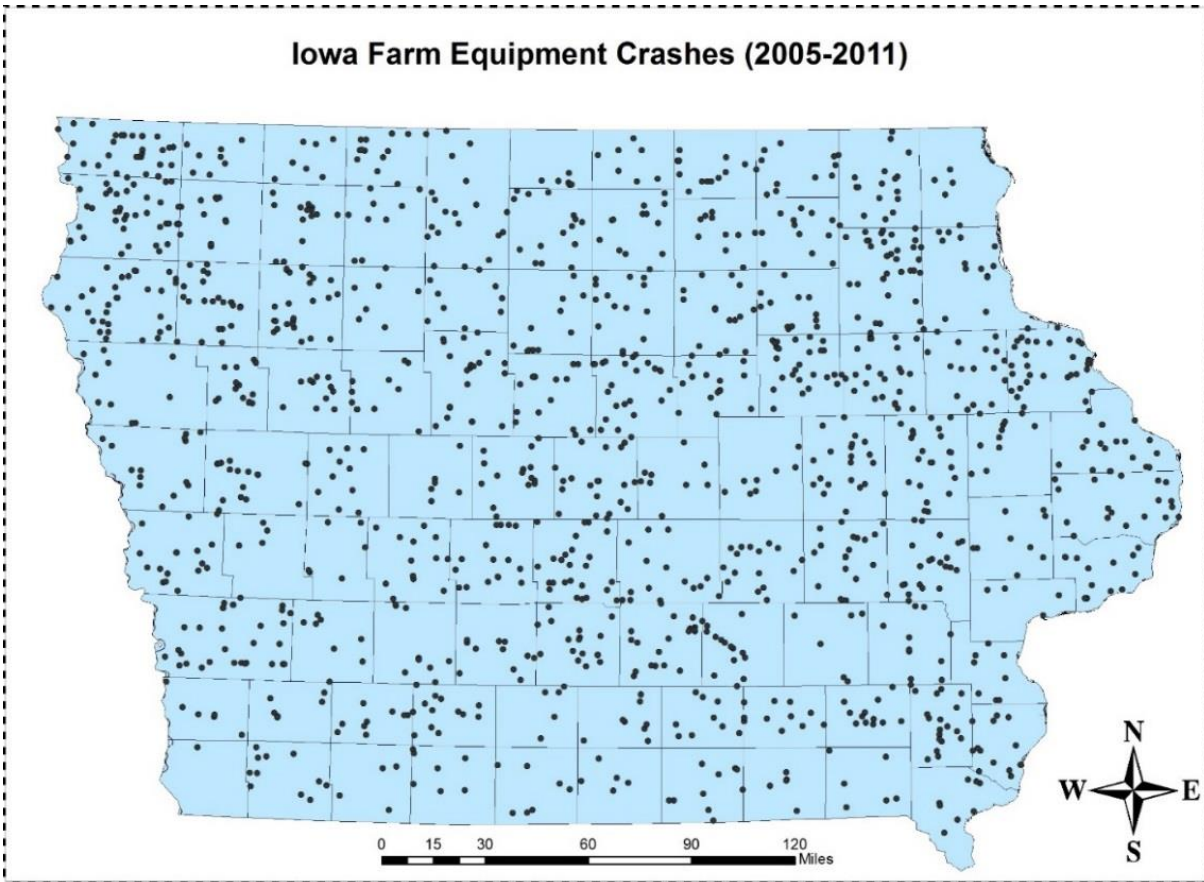

Figure 3. Location of the 1,371 farm equipment-related crashes used in this analysis.

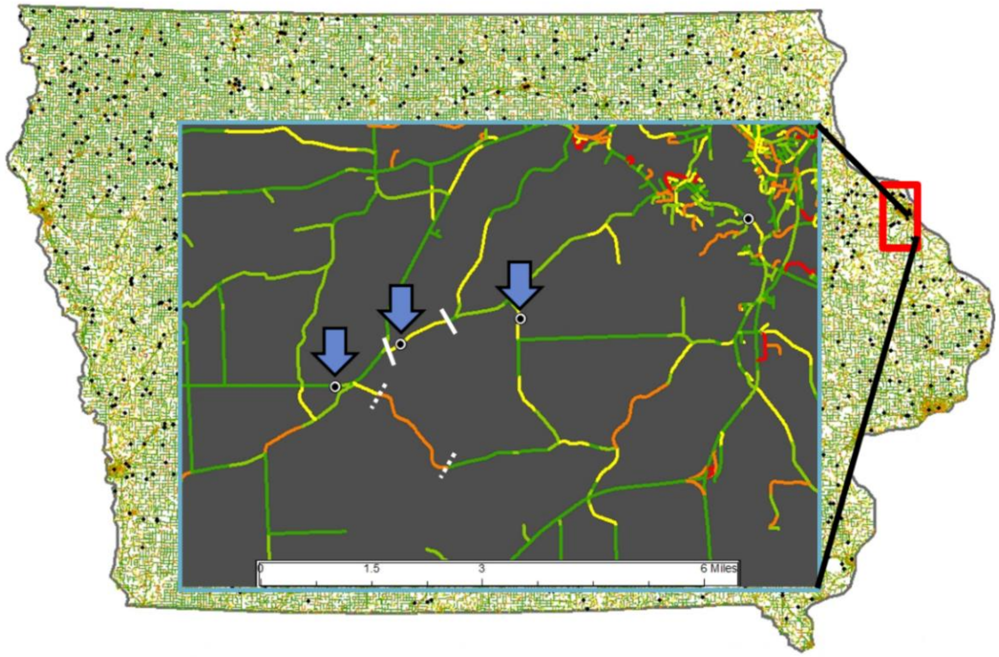

Figure 4 Example of analysis- comparison of roads with a crash to roads without a crash.

Variables

Exposure Variables

Traffic density, road width, shoulder width, speed limit, road type, and surface type were the variables included in this analysis. These variables were used for all Aims of the study.

Traffic Density (Categorical)

Traffic density was assigned through AADT (annual average daily traffic). AADT is calculated by the IDOT as the number of motor vehicles driven through a given road segment in a day. Traffic density is either physically counted or counted through an automated vehicle detector. For roads not sampled, a counted value is estimated through a spatial extrapolation method used by the IDOT that assigns AADT based on surrounding AADT values and AADT values of similar road types and numbers of lanes.

Only 16% of the road segment AADT values are calculated through statistical estimation. For all Iowa road segments, AADT values ranged from 0-113,100 with a mean AADT of 1,600.6, and the standard deviation is 5,042. Quintiles were used to categorize the continuous variable into 5 classifications. A total of 1.9% of road segments had an AADT of zero. The IDOT did not create a "missing" value, so roads with an AADT of zero were assumed to be under-travelled roads. When mapped, AADT values of zero are distributed throughout the state suggesting that there was not a geographic-specific area that was missing data.

Road Width (Continuous)

The road width variable is defined as the total width of a road, not including the shoulders of a road, and it is measured in feet. Only 172 road segments had a road width of zero. These road segments were all narrow local roads that were either connecting dirt roads, alleys, or offset roads that lead to businesses. Figures 5 and 6 show two examples of roads with a width of zero. These 172 roads only made up 0.05 percent of the total road segments in the study.

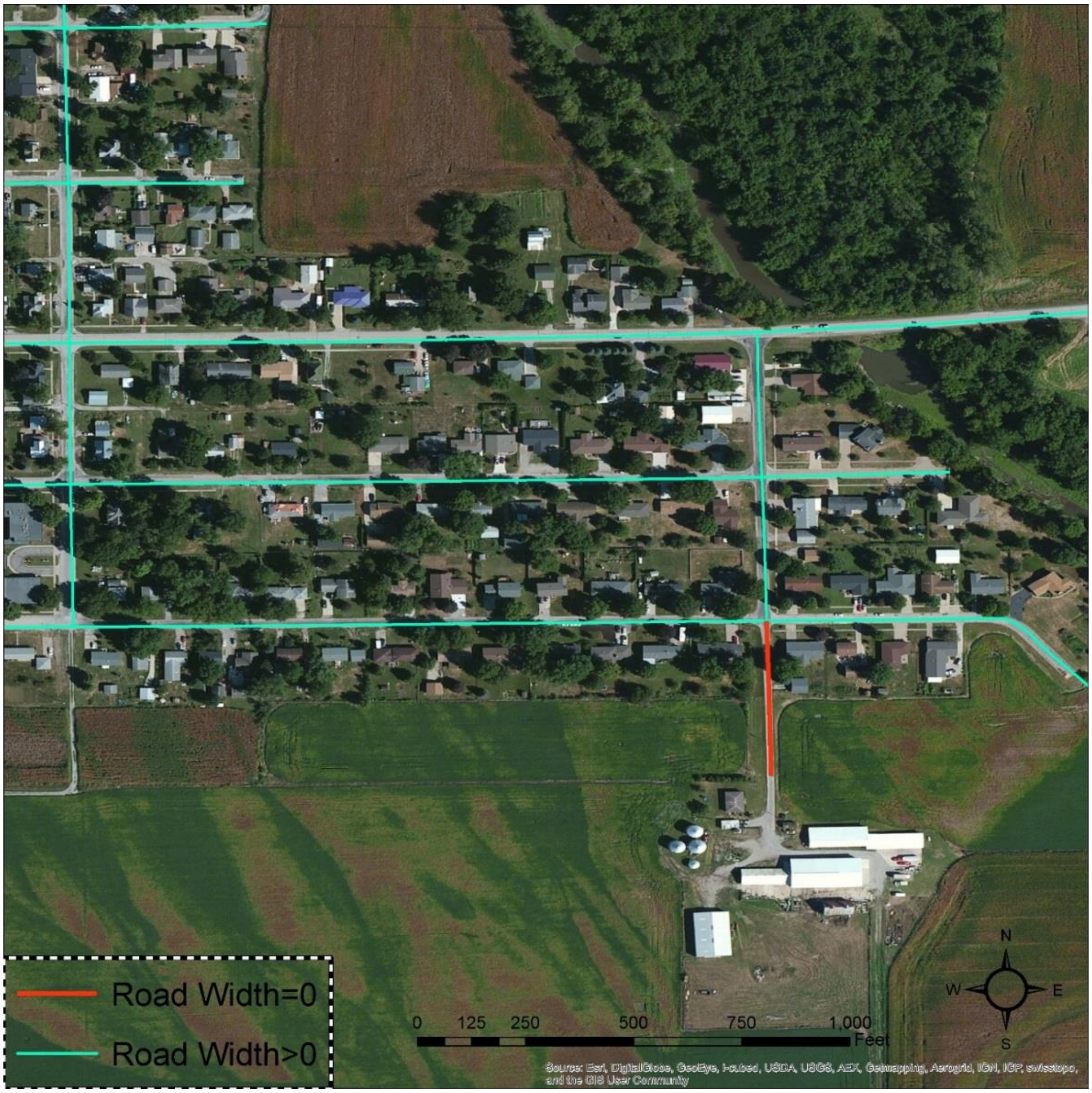

Figure 5 Road width of zero is a public road leading to a private establishment.

Figure 6 Road width of zero is a public road leading to a private establishment.

Shoulder Width (Continuous)

Shoulder width was defined as the sum of the left and right shoulders of a road. Of all Iowa roads, 26% (N=84,678) did not have a shoulder and were coded with a 0. Of those 84,678 road segments, 41% were urban local roads and 54% were rural local roads. Shoulder width was also measured in feet.

Speed Limit (Categorical)

Speed limit was defined as the lowest posted speed limit per road segment. This variable was broken into four categories: (<35 MPH, 35 - 45 MPH, 50 - 60 MPH, and 60+ MPH).

Road Type (Categorical)

The Iowa Department of Transportation classified each road segment using five road system classifications. Each road segment was either an Interstate, a US route, an Iowa route, a farm to market route or a local route. Interstate roads are defined by the secretary of the US DOT as primary road systems that are not physically bounded by states. Farm equipment cannot legally drive on interstate roads (The Iowa Legislature, 2014). U.S. routes are also interstate roads as in they are not bound by state boundaries; however U.S. routes have intersections with secondary roads while interstates have exit and entrance ramps. Farm to market routes are public roads meant specifically for the transport of goods from farms to towns or cities. Local routes are primarily either 25mph residential roads, or 55mph rural roads. Of the rural local roads defined by RUCA, 95 percent of them were unpaved.

Surface Type (Categorical)

The IDOT classified surface type into 42 categories (Figure 7). For the analysis, these 42 categories were dichotomized so that roads were either paved or not paved. There were 3 sub-categories for the roads that were not paved: gravel or stone without admixture, grade and drained earth without borrow topping - no shoulder, and unknown. Paved roads were the remaining categories and were different derivatives of asphalt, concrete, and brick.

Paved	**Unpaved**
Generic bituminous	Primitive - no shoulder
Bituminous on gravel or stone without admixture	Unimproved - no shoulder
Bituminous on gravel or stone with admixture	Drained earth- no borrow topping
Mixed bituminous	Drained earth- with borrow topping
Bituminous penetration	Soil surface without admixture
Generic asphalt	Soil surface with admixture
Asphalt on soil-surface without admixture	Gravel or stone without admixture
Asphalt on soil-surface with admixture	Gravel or stone admixture unknown
Asphalt on gravel or stone base without admixture	Gravel or stone with admixture
Asphalt on gravel or stone base with admixture	
Asphalt on old Portland cement concrete	
Asphalt on new Portland cement concrete (not reinforced)	
Asphalt on new Portland cement concrete (reinforced)	
Asphalt on brick or block	
Asphalt on asphalt	
Generic concrete	
Old type Portland cement concrete	
Old type Portland cement concrete (fully reinforced)	
New type Portland cement concrete	
New Type Portland cement concrete (partially reinforced)	
New type Portland cement concrete (fully reinforced)	
Special Portland cement concrete resurfacing	
Continuous Portland cement concrete with no joints	
Portland cement concrete on asphalt	
Brick	
Block	
Combination surface-bituminous and asphalt	
Combination surface-asphalt and asphalt	
Combination surface- concrete and asphalt	
Combination surface-brick or block and asphalt	
Combination surface-concrete and concrete	
Combination surface-concrete and brick or block	

Figure 7 IDOT Defined Road Surface Type Categories

Rural-Urban Commuting Area Codes (RUCA): (Categorical)

Rural-Urban Commuting Area Codes (RUCA) codes are a classification scheme based on commuting patterns as well as urban rural status that was developed through the Rural Health Research Center at Washington University. Each zip code is given a RUCA code from 1.0-10.6. There are 33 codes listed in Table 5 that were dichotomized by the *Rural Health Research Center* (RHRC) as either urban or rural. Each zip code is given a RUCA code and each road segment is assigned the RUCA code of the zip code in which the majority of it falls within. Table 6 illustrates how rurality is distributed by the outcome.

Table 5 33 dichotomized (urban/rural) RUCA classifications by RHRC

1 Metropolitan area core: primary flow within an Urbanized Area (UA)
1.0 No additional code
1.1 Secondary flow 30% through 49% to a larger UA
2 Metropolitan area high commuting: primary flow 30% or more to a UA
2.0 No additional code
2.1 Secondary flow 30% through 49% to a larger UA
3 Metropolitan area low commuting: primary flow 10% to 30% to a UA
3.0 No additional code
4 Micropolitan area core: primary flow within an Urban Cluster (UC) 10,000 through 49,999 (large UC)
4.0 No additional code
4.1 Secondary flow 30% through 49% to a UA
4.2 Secondary flow 10% through 29% to a UA
5 Micropolitan high commuting: primary flow 30% or more to a large UC
5.0 No additional code
5.1 Secondary flow 30% through 49% to a UA
5.2 Secondary flow 10% through 29% to a UA
6 Micropolitan low commuting: primary flow 10% to 30% to a large UC
6.0 No additional code
6.1 Secondary flow 10% through 29% to a UA
7 Small town core: primary flow within an Urban Cluster of 2,500 through 9,999 (small UC)
7.0 No additional code
7.1 Secondary flow 30% through 49% to a UA
7.2 Secondary flow 30% through 49% to a large UC
7.3 Secondary flow 10% through 29% to a UA
7.4 Secondary flow 10% through 29% to a large UC

8 Small town high commuting: primary flow 30% or more to a small UC
8.0 No additional code
8.1 Secondary flow 30% through 49% to a UA
8.2 Secondary flow 30% through 49% to a large UC
8.3 Secondary flow 10% through 29% to a UA
8.4 Secondary flow 10% through 29% to a large UC
9 Small town low commuting: primary flow 10% through 29% to a small UC
9.0 No additional code
9.1 Secondary flow 10% through 29% to a UA
9.2 Secondary flow 10% through 29% to a large UC
10 Rural areas: primary flow to a tract outside a UA or UC (including self)
10.0 No additional code
10.1 Secondary flow 30% through 49% to a UA
10.2 Secondary flow 30% through 49% to a large UC

10.3 Secondary flow 30% through 49% to a small UC 10.4 Secondary flow 10% through 29% to a UA 10.5 Secondary flow 10% through 29% to a large UC 10.6 Secondary flow 10% through 29% to a small UC

Table 6. Distribution of Farm Crashes by Rurality*

	All Iowa Road Segments		Road Segments with a Crash		Road Segments without a Crash	
Road Characteristics	(n=319,705)	%	(n=1,337)	%	(n=318,368)	%
Rurality (RUCA)						
Urban	96,690	30.24	308	23.04	96,382	30.27
Rural	223,015	69.76	1,029	76.96	221,986	69.73

*P<0.01

Outcome Variables:

The outcome variable for the first and second aims of this study are road segment where a crash occurred vs. road segment where a crash did not occur. If there was a road segment on which a farm equipment-related crash occurs it is coded as a “1”, all other road segments are coded as a “0”. For the third aim, the outcome variable was road segments where a crash involving an injury occurred vs. road segments where a crash involving an injury did not occur. If there was road segment on which a farm equipment-related crash that resulted in an injury occurred, it is coded as a “1” all other road segments are coded as a “0”. Road segments where a crash occurred that did not result in an injury is coded as a “0”.

Statistical Analysis

All statistical analysis was run using SAS 9.3. With road segments as the unit of analysis, we were interested in identifying the types of roads in which farm crashes were more likely to occur. Univariate analysis was used to investigate the frequency distribution of variables stratified by roads with a crash, roads without a crash, and all Iowa roads. For continuous variables, means and standard deviations were compared between roads with a crash and roads without a crash. Bivariate analysis was used to examine the relationships between exposure variables (road characteristics). For the first aim of this study, three multivariable logistic regression models were then run. Because road width and shoulder width may be measuring similar characteristics, three models were explored: one that excluded road width, one that excluded shoulder width, and one that included all six variables. The model that contained all six variables had no significant correlation between variables. Of the three models run, the full model had the lowest AIC indicating the most optimal model fit and thus was chosen as the model used for the first aim of this study. For the second aim of the study, the model used in the first aim was stratified by rurality. RUCA classifies zip codes as either rural or urban. If the majority of the road segment resides within an urban zip code, for example, that road segment is classified as an urban road segment. For the third aim, the model used in aim 1 was used; however the outcome was road segments where injuries resulted from a farm vehicle crash occurred rather than just a farm vehicle crash. Chi squared tests were used to measure significance and logistic regression is used to measure risk. Odds ratios were estimated with 95% Confidence Intervals. The odds ratios were interpreted as an increased odds that a specific road segment would have a farm equipment crash compared with a reference road segment type. Notably, because we did not actually measure farm equipment roadway exposure (i.e., we did not know how many farm equipment travelled on the road), ORs were not controlled for number of farm equipment on the road.

Results

Univariate and Bivariate analyses

Bivariate analysis (Table 7) revealed a steady increase in crashes as traffic density increased. The highest percentage of crashes (33%) occurred on a road with an AADT of at least 1,251 vehicles driven per day on average. 55 MPH roads make up 54% of the Iowa roads in this study, and 25 MPH make up 32% of the roadway segments leaving only 14% for the remaining speed limits. For all segments with a crash, 78 percent occurred on a 55 mph road and only nine percent occurred at 25 mph. Of all Iowa roads, 67% are local and 20% are farm to market routes. For all roads with a crash, 31% were local routes and 43% are farm to market routes indicating that farm to market routes are the most common road type where a farm vehicle crash has occurred. While the perception is that most farm equipment operates on dirt roads, only 30% of crashes occurred on an unpaved road. Of all Iowa roads, 40% are unpaved.

Table 7 Categorical Iowa Road Segment Characteristics*

	All Iowa Road Segments		Road Segments with a Crash		Road Segments without a Crash	
Road Characteristics	(n=319,705)	%	(n=1,337)	%	(n=318,368)	%
Traffic Density1						
0-30	68,191	21.33	123	9.20	68,068	21.38
31-101	63,385	19.83	220	16.45	63,165	19.84
102-360	62,998	19.71	192	14.36	62,806	19.73
361-1250	62,650	19.60	367	27.45	62,283	19.56
1251+	62,481	19.54	435	32.54	62,046	19.49
Speed Limit						
(MPH)	119,102	37.25	156	11.67	118,946	37.36
<35	18,142	5.67	85	6.36	18,057	5.67
35-45	174,260	54.51	1053	78.76	173,207	54.40
50-60	8,201	2.57	43	3.22	8,158	2.56
65+						
Road Type						
Interstate	5,329	1.67	6	0.45	5,323	1.67
US Route	18,424	5.76	159	11.89	18,265	5.74
Iowa Route	17,616	5.51	191	14.29	17,425	5.47
FTM Route2	63,531	19.87	569	42.56	62,962	19.78
Local Route	214,805	67.19	412	30.82	214,393	64.34
Surface Type						
Paved	191,504	59.90	930	69.56	190,576	59.86
Unpaved	128,201	40.10	407	30.44	127,794	40.14

1Average Annual Daily Traffic (Total annual traffic volume/365)
2Farm to market route
*P<0.01 for all variables

Road width and shoulder width are the two continuous variables that were used in this analysis. Table 8 shows that the road width where a crash occurred was smaller than where a crash had not occurred; however the shoulder width was on average higher where there was a crash involving farm equipment. The mean road width of roads where a crash occurred was 24.68 (range 12-70) feet compared to 25.17 (range 0-99) feet for Iowa roads where a crash did not occur. The mean shoulder width of roads where a crash occurred was 7.39 (range 0-24) feet compared to 4.18 (range 0-76) feet for Iowa roads where a crash did not occur. All p-values conducted in the univariate analysis were less than 0.01.

Table 8 Continuous Iowa Road Segment Characteristics

	Road Segments with a Crash (1,337)		Road Segments without a Crash (318,368)		P-Value
Road Characteristics	Mean (feet)	SD	Mean (feet)	SD	
Road Width	24.68	5.75	25.17	7.32	<0.01
Shoulder Width	7.39	6.16	4.18	5.55	<0.01

To examine correlations between road variables, Pearson Correlation Coefficients were calculated for every pair of ordinal data (AADT, speed limit, road width, and shoulder width). Table 9 shows that there were no correlations greater than 0.39 indicating a strong positive relationship. The strength of a relationship was assessed using a correlation scale (Quinnipiac University, 2014). The relationships between speed limit and shoulder width and shoulder width and traffic density are the two most correlated relationships with correlation coefficients of 0.38 and 0.31 respectively; these are moderately positive relationships while the remaining 4 relationships between speed limit, traffic density, road width, and shoulder width are weak relationships.

Table 9 Pearson Correlation Coefficients of Iowa Road Segment Characteristics*

Road Segment Characteristics	Speed Limit	Traffic Density	Road Width	Shoulder Width
Speed Limit	**1.00**	0.11	-0.23	0.38
Traffic Density	0.11	**1.00**	0.28	0.31
Road Width	-0.23	0.28	**1.00**	-0.05
Shoulder Width	0.38	0.31	-0.05	**1.00**

*P<0.001

Multivariable Modeling

Aim 1

The first aim of this paper was to calculate the risk of specific roadway characteristics through logistic regression where the outcome is either an Iowa road segment where a farm vehicle crash has occurred or a road segment where a crash has not occurred. Unadjusted and adjusted odds ratios were calculated for each of the six variables to highlight individual variable influence on the model (Table 10). The model was mutually adjusted for all six variables. Five of the six variables in the model were found to be statistically significant. Adjusted odds ratios of traffic density (AADT), speed limit, and road type were similar to the findings from the univariate analysis. As traffic density increased, the odds of a crash also increased. As shown in Table 11, roads with at least 1,251 vehicles travelled per day have over 5.5 times the odds of a crash than roads with 30 or less vehicles. (CI: 3.90-7.83) Speed limits between 50-60mph have the greatest odds of a crash. Roads with a speed limit of 50-60 mph have a 4.88 greater odds of having a crash involving farm equipment than roads 30mph or less. (CI: 3.85-6.20) Compared to local routes (which are the most common Iowa roadway), US routes (OR= 1.59, 95% CI = 1.20, 2.11), Iowa routes (OR= 1.93, 95% CI = 1.50, 2.49), and farm to market routes (OR= 2.04, 95% CI = 1.72, 2.43) all have a significantly greater odds of a crash involving farm equipment. An increase in roadway width was a protective factor for crashes involving farm equipment. For every 5 foot increase in roadway width, the odds of a crash decreased by 6 percent. (OR= 0.94, CI: 0.89-0.99) Shoulder width was also found to be a protective factor. For every 5 foot increase in shoulder width, the odds of a crash decreased by 8 percent. (OR = 0.92. CI: 0.86-0.98). Although not statistically significant, there is still evidence that indicates that unpaved roads are a risk factor for farm equipment crashes. Roads that are unpaved have a 17 percent greater risk of a crash than roads that are paved. (OR= 1.17, CI: 0.91-1.50). Unadjusted, shoulder width was a potential risk factor and when adjusted into the model the odds ratio was reversed to become a protective factor. For the surface type variable, this same flip is seen. This reversal of odds ratio when adjusted can be explained by confounding factors in the other variables that are included in the model; adjusted models controlled for potential confounding effects, when focused on shoulder width as the primary road exposure.

Table 10 Adjusted and Unadjusted Odds Ratios of Road Segment Characteristics

Road Characteristics	OR	95% CI		aOR1	95% CI	
Traffic Density2						
0-30	REF	REF	REF	REF	REF	REF
31-101	1.93	1.54	2.40	1.70	1.35	2.13
102-360	1.69	1.35	2.12	2.71	2.04	3.59
361-1250	3.26	2.66	4.00	5.18	3.76	7.13
1251+	3.88	3.17	4.74	5.53	3.90	7.83
Speed Limit (MPH)						
<35	REF	REF	REF	REF	REF	REF
35-45	3.59	2.75	4.68	2.08	1.56	2.79
50-60	4.64	3.92	5.49	4.88	3.85	6.20
65+	4.02	2.87	5.64	3.66	2.42	5.52
Road Type						
Interstate	0.59	0.26	1.31	0.22	0.09	0.50
US Route	4.53	3.77	5.44	1.59	1.20	2.11
Iowa Route	5.70	4.80	6.78	1.93	1.50	2.49
FTM Route*	4.70	4.14	5.34	2.04	1.72	2.43
Local Route	REF	REF	REF	REF	REF	REF
Surface Type						
Paved	REF	REF	REF	REF	REF	REF
Not Paved	0.65	0.58	0.73	1.17	0.91	1.50
Shoulder Width3	1.44	1.39	1.49	0.92	0.86	0.98
Road Width3	0.95	0.91	0.99	0.94	0.89	0.99

1Mutually adjusted for AADT, Speed Limit, Road Type, and Road Width
2Average Annual Daily Traffic (Total annual traffic volume/365)
3 Unit: 5 feet
*Farm to market route

Table 11 Adjusted Odds Ratios of Road Segment Characteristics Stratified by Rurality

Road Characteristics	Urban Roads			Rural Roads			All Roads		
	aOR1	95% CI		aOR1	95% CI		aOR1	95% CI	
AADT2									
0-30	**REF**	REF	REF	**REF**	REF	REF	**REF**	REF	REF
31-101	**1.98**	1.07	3.66	**1.72**	1.34	2.20	**1.70**	1.35	2.13
102-360	**3.34**	1.73	6.38	**2.68**	1.94	3.72	**2.71**	2.04	3.59
361-1250	**4.61**	2.25	9.43	**5.81**	4.01	8.42	**5.18**	3.76	7.13
1251+	**4.18**	1.97	8.86	**7.36**	4.87	11.11	**5.53**	3.90	7.83
Speed Limit									
<35	**REF**	REF	REF	**REF**	REF	REF	**REF**	REF	REF
35-45	**1.82**	1.09	3.03	**2.62**	1.82	3.76	**2.08**	1.56	2.79
50-60	**4.60**	2.91	7.26	**5.07**	3.82	6.72	**4.88**	3.85	6.20
65+	**4.12**	1.95	8.74	**3.91**	2.36	6.47	**3.66**	2.42	5.52
Road Type									
Interstate	**0.29**	0.10	0.89	**0.19**	0.04	0.80	**0.22**	0.09	0.50
US Route	**1.58**	0.90	2.77	**1.39**	0.99	1.95	**1.59**	1.20	2.11
Iowa Route	**2.27**	1.32	3.89	**1.56**	1.15	2.10	**1.93**	1.50	2.49
FTM Route*	**2.84**	2.01	4.03	**1.78**	1.45	2.17	**2.04**	1.72	2.43
Local Route	**REF**	REF	REF	**REF**	REF	REF	**REF**	REF	REF
Surface Type									
Paved	**REF**	REF	REF	**REF**	REF	REF	**REF**	REF	REF
Not Paved	**1.18**	0.74	1.86	**1.10**	0.81	1.47	**1.17**	0.91	1.50
Road Width3	**0.98**	0.90	1.08	**0.93**	0.87	0.99	**0.92**	0.86	0.98
Shoulder Width	**0.94**	0.82	1.07	**0.88**	0.81	0.95	**0.94**	0.89	0.99

1 Mutually adjusted for all variables 2 Average Annual Daily Traffic 3 Unit: 5 feet *Farm to market route

Aim 2

The second aim of this study is to perform a stratified analysis of the same model and including rurality to investigate if road characteristic risk is affected by whether a crash occurred in an urban area or a rural area. The univariate analysis in Table 6 shows that roughly 70% of Iowa roads were classified as rural based on their RUCA code and that 77% of farm equipment crashes occurred on a rural roadway. In Table 11, the same six variables as aim 1 are investigated; however, the roads are stratified by rurality. For all Iowa roads, as traffic density increases, the risk of a crash also increases, this same trend is found for the rural roads; however for urban roads, the highest traffic density is not the riskiest bracket. For urban roads, roads with between 361 and 1250 vehicles travelled per day had the highest odds for a crash. Roads with between 361 and 1250 vehicles travelled per day have 4.61 times the odds of a crash than roads with 30 or less vehicles in urban areas. (CI: 2.25-9.43).

Aim 3

The third and final aim of this study is to perform the statistical analysis in aim 1, but change the outcome to roads where a crash occurred that resulted in an injury. A total of 541/319,705 (0.02%) of the road segments in Iowa had a motor vehicle crash involving farm equipment that resulted in an injury. Compared to Table 7 which accounts for all crashes, traffic density and surface type showed similar distributions as in the third aim; however, for the remaining four variables, univariate analysis differed between aims 1 and 3. In Table 7 (aim 1), 12% of crashes occurred at 30mph or lower; in the injury model (aim 3), as shown in Table 12, only 5% occurred at 30mph. In Table 6, 79% of crashes occurred at 55mph, and in the injury model 85% of crashes occurred at 55mph. In Table 7, 31% of crashes occurred on a local road compared to 26% in the injury model. On average, crashes resulting in an injury (Table 13) occurred on roads with a road width of 23.94 feet, which is 0.74 feet smaller than general farm equipment crashes as shown in Table 8. On average, crashes resulting in an injury occurred on roads with a shoulder width of 8.25 feet, which is 0.86 feet larger than general farm equipment crashes as shown in Table 8.

Table 12 Categorical Iowa Road Segment Characteristics (Crashes with Injuries)*

	All Iowa Road Segments		Road Segments with a Crash Resulting in an Injury		Road Segments with no Crash Resulting in an Injury	
Road Characteristics	(n=319,705)	%	(n=541)	%	(n=319,164)	%
Traffic Density1						
0-30	68,191	21.33	46	8.50	68,145	21.35
31-101	63,385	19.83	89	16.45	63,296	19.83
102-360	62,998	19.71	74	13.68	62,924	19.72
361-1250	62,650	19.60	160	29.57	62,490	19.58
1251+	62,481	19.54	172	31.79	62,309	19.52
Speed Limit (MPH)						
<35	119,102	37.25	27	4.99	119,075	37.31
35-45	18,142	5.67	22	4.07	18,120	5.68
50-60	174,260	54.51	462	85.40	173,798	54.45
65+	8,201	2.57	30	5.55	8,171	2.56
Road Type						
Interstate	5,329	1.67	1	0.20	5,328	1.67
US Route	18,424	5.76	70	12.94	18,354	5.75
Iowa Route	17,616	5.51	88	16.27	17,528	5.49
FTM Route2	63,531	19.87	243	44.92	63,288	19.83
Local Route	214,805	67.19	139	25.69	214,666	67.26
Surface Type						
Paved	191,504	59.90	376	69.50	191,128	59.88
Unpaved	128,201	40.10	165	30.50	128,036	40.12

1Average Annual Daily Traffic (Total annual traffic volume/365)
2Farm to market route
*P<0.01

Table 13 Continuous Iowa Road Segment Characteristics (Crashes with Injuries)

	Road Segments with a Crash Resulting in an Injury (541)		Road Segments with no Crash Resulting in an Injury (319,164)	
Road Characteristics	Mean (feet)	SD	Mean (feet)	SD
Road Width	23.94	4.57	25.17	7.32
Shoulder Width	8.25	6.03	4.18	5.55

A logistic regression was run as shown in Table 13 which compared the odds ratios calculated in aim 1 to odds ratios calculated in aim 3. This comparison was conducted to help answer the question that asks if certain road characteristics are more of a factor for crashes or crashes involving injuries. It was found that crashes with injuries had the greatest odds of occurring on a roadway with between 361-1,250 vehicles travelled per day which was different from the other models in aims 1 and 2. In the third aim, as shown in table 14, it was found that roads with a traffic density between 361-1,250 vehicles have a 7.62 times greater odds of a farm crash resulting in an injury than roads with a traffic density less than 31 vehicles per day. (CI: 4.51-12.88) Although 50-60mph roads had an increased percentage of injury crashes, logistic regression showed that roads with a speed limit of 65 or greater had the highest odds of a farm crash resulting in injury. Roads with a speed limit 65mph or greater have a 17 times greater odds of having a crash injury than roads less than 35mph. (CI: 8.88-31.71). It was also found that Iowa routes are at a greater odds of a crash injury than farm to market routes even though farm to market routes are at a greater odds of a farm crash in general. Finally, it was found that road width is more protective against crashes involving injuries. For every 5 feet increase in road width, the odds of a crash resulting in an injury decreased by 14 percent, (CI: 0.77-0.95) a 6 percent increase from the model looking at all farm crashes in aim 1 indicating that road width is more protective for injuries than crashes.

Table 14 Adjusted Odds Ratios of Road Segment Characteristics (Crashes with Injuries)

Road Characteristics	Farm Equipment Crashes with Injuries			Farm Equipment Crashes		
	aOR1	95% CI		aOR1	95% CI	
Traffic Density2						
0-30	REF	REF	REF	REF	REF	REF
31-101	1.93	1.34	2.79	1.70	1.35	2.13
102-360	3.48	2.21	5.48	2.71	2.04	3.59
361-1250	7.62	4.51	12.88	5.18	3.76	7.13
1251+	6.83	3.84	12.12	5.53	3.90	7.83
Speed Limit						
<35	REF	REF	REF	REF	REF	REF
35-45	3.34	1.84	6.09	2.08	1.56	2.79
50-60	12.02	7.47	19.35	4.88	3.85	6.20
65+	16.78	8.88	31.71	3.66	2.42	5.52
Road Type						
Interstate	0.06	0.01	0.42	0.22	0.09	0.50
US Route	1.48	0.94	2.33	1.59	1.20	2.11
Iowa Route	2.04	1.36	3.06	1.93	1.50	2.49
FTM Route*	1.92	1.44	2.55	2.04	1.72	2.43
Local Route	REF	REF	REF	REF	REF	REF
Surface Type						
Paved	REF	REF	REF	REF	REF	REF
Not Paved	1.29	0.86	1.93	1.17	0.91	1.50
Road Width3	0.86	0.77	0.95	0.92	0.86	0.98
Shoulder Width3	0.93	0.84	1.04	0.94	0.89	0.99

1Mutually adjusted for AADT, Speed Limit, Road Type, and Road Width
2Average Annual Daily Traffic (Total annual traffic volume/365)
3 Unit: 5 feet
*Farm to market route

Summary of Results

Overall, this study found that increased traffic density, speeds from 50-60 mph, unpaved roads, farm to market routes, and decrease in road and shoulder width were all statistically significant road characteristics that influence the odds of a motor vehicle crash on a public road that involves farm equipment. Of roads in urban areas, there is not a consistent increase in associations for traffic density; roads with between 361-1250 travelers per day were at increased odds than those even at a higher traffic density of 1251 or greater. Last, while observing injury as an outcome, it was found that the same 361-1250 group of traffic density posed the greatest odds for a farm equipment crashes that resulted in injury. It was also found that as speed limit increased, so does the risk of have an injury-involved crash. Iowa routes were found to be riskier for injuries than farm to market routes, and increased road with was protective of injury-involved farm equipment crashes. It is very important to understand that it is uncertain how much direct influence roadway characteristics have on actually causing a crash involving farm equipment on a public roadway. As shown in previous research, operator behaviors, vehicular actions, and spatial and temporal factors also affect the odds of a crash. The odds ratios computed from this analysis investigate the characteristics of the road where farm equipment crashes occur and do not occur. Something that we do not know is where farm equipment are driving that do not get into crashes. One of the reasons that Iowa has such numbers of crashes is due to the fact that there are more pieces of agricultural equipment on the roadway. This is an important factor to consider when analyzing odds ratios when a research project has some sort of spatial component. Since we do not have this exposure data, it is difficult to understand if 50-60mph roads are a risk factor due to higher speeds or just the fact that more farm equipment are driving on roads with this speed limit since Iowa rural roads are 55mph. Bivariate analysis and adjusted odds ratios help to address confounding variables; however with our limited exposure data of where farm vehicles are travelling and not getting in crashes make it very difficult to assess how much specific road characteristics influence the risk of a crash.

Discussion

The primary goal of this study is to fill gaps in prior agricultural transportation safety studies through an innovative study design made possible by technological advances in data collection and data analysis. By running our analysis at the road segment level, this study was able to not only measure risk, but also stratify risk based on geographic location. From the literature, there has been a small but growing body of work that has highlighted person, vehicle, and crash level characteristics that increase the risk for a farm equipment-related crash. This prior research has led to dissemination of driver's education on rural roads. It has also led to the construction of safer farm equipment and laws requiring lights and vehicular and road signage to increase driver awareness about farm equipment. While this has all been extremely important for the fields of transportation safety and agricultural safety and health, there has been little research that has been done on the role of road characteristics on farm equipment crashes. A significant limitation in prior research has been the unit of analysis. In the Harland et al. (2014) and Peek-Asa et al. (2007) study, the crash was the unit of analyses. Only one study used farmers as the unit of analysis. While informative, these studies did not measure roadway characteristics for roads not involved in crashes. Without this universe of at-risk road segments, risk of roadway characteristics cannot be measured. Our research fills this significant gap. In the Gerberich et al. (1996) study, there was no exposure to measure risk of the studied characteristics, and in the Peek-Asa et al. (2007) paper, over 30 percent of crashes occurred on an "unknown" road that increased the risk of a crash by 70 percent. In the Harland et al. (2014) paper, it was shown how farm equipment crashes occur by rurality and proximity to town and city boundaries; however it is interesting to investigate what road and environmental characteristics are specific to certain areas and aggregate levels of rurality. Last, the Hadi et al. (1995) study found that speed, and shoulder and road width were non-significant exposure variables. All of these gaps in these highly cited papers were addressed by our study which can help contribute to the needed research in transportation and agricultural safety.

We consistently found in our paper that an increase in traffic density increases the risk of a crash. If a piece of farm equipment is on the road with a greater number of vehicles, the increased density leads to a greater chance of being involved in a crash. One explanation is that roads that were primarily used for agriculture are beginning to be more travelled due to urban sprawl (Costello et al. 2009). Urban sprawl can then potentially lead not only to elevated values of traffic density, but also could increase the interaction of farm equipment with other motor vehicles who are not accustomed to sharing the roadway with farm equipment.

The most effective way to minimize farm vehicle crashes on public road ways is to remove them from public roads. This is precisely what SWOV (2013) is researching – methods for reducing roadway risks for farm equipment. SWOV is a road safety institute in the Netherlands. The primary goal of this institute is to conduct research in the areas of road infrastructure, telematics, and overall roadway safety to disseminate results to the public so that road users can be informed and policy makers can allocate projects to conduct engineering controls of roads and route networks to help minimize motor vehicle crashes on Netherlands public roads. SWOV discusses that in order to do this, logistic agricultural routes need to be constructed that are engineered specifically for farm equipment. An alternative option is another form of primary prevention that involves farmers buying their farm land and organizing their farm in a way that minimizes the amount of driven public road necessary for farming operations. Another option that is given is the construction of a two-way cycle track along the sides of primary roads. The construction of overtaking bays and passing strips can also be constructed where non-agricultural equipment road users can pass farm equipment without having to significantly reduce their speed (SVOW, 2013). While these are all effective methods, they are also expensive. While changes to existing roads may be difficult fiscally and practically, when new roads are built, or improvements to roads are made, findings from this study can be used to determine how roads can be engineered to maximize safety for all types of roadway users. Further research is needed to investigate the cost benefit analysis of these suggested methods.

The primary method of prevention is to segregate farm equipment from other motor vehicles, while this is not always feasible, road engineering and education of farm equipment operators and other drivers on the road are important as methods of secondary prevention to construct safe roads and provide users with the necessary information to make safe decisions on these roads. Urban sprawl increases interaction between farm equipment and other motor vehicles. Roads that used to be travelled only by farm equipment are now starting to be travelled by other vehicles since more and more non-farm equipment vehicles are commuting further distances and taking alternative routes to avoid traffic congestion (Costello et al. 2009). Given this new interaction between the farm equipment and other motor vehicles, educating both users on how to safely drive in these areas of interaction can help minimize crash risk in higher traffic density areas. Currently, the rural roadway safety campaign through the IDOT provides all road users with the information necessary to make safer decisions in higher traffic areas. This is disseminated through driver's education and through pamphlets and other safety material that is distributed throughout Iowa (IDOT Driver services, 2014).

Our study also found that unpaved 50-60mph streets were another significant risk factor of a crash involving farm equipment. Drivers on roads with higher speeds have less of a reaction time to stop for slow moving vehicles (IDOT Driver services, 2014). Much like traffic density, this is once again an exposure issue- meaning more farm equipment are on these types of roads. Most farms are located on rural roads which in Iowa are unmarked and typically unpaved roads (IDOT Driver services, 2014). Analysis from this study found that 54% of Iowa road segments are unpaved and that 67% of Iowa roads with a 55mph speed limit are unpaved. A total of 78% of the crashes in the study occurred on a 55mph road. The two primary ways to decrease risk on these 55 mph roads is to lower the speed limit of rural roads or to educate drivers how to drive safety on these roads. Studies such as this one can be used to help guide policy decisions to change the speed limit of Iowa rural roads from 55mph to a lower speed.

Although not many studies have examined the effect of road width and shoulder width and its effect on crashes involving farm equipment, there were several sources in the literature that addressed road characteristics on rural roads. Ackaah & Salifu (2011) did not find any significant findings pertaining to shoulder or road width while the Hadi et al. (1995) study did find that an increase in shoulder width decreases the risk of a crash, but this analysis did not pertain to farm equipment. Our study found that in all models, an increase in shoulder and road width decreased the odds of a crash. Farm equipment is much wider than typical motor vehicles, and generally takes up multiple lanes. If there is inadequate room for farm equipment to pull over for other cars to pass, motor vehicles have less room to pass farm equipment which can lead to sideswipes. Smaller or lack of shoulders can contribute to farm equipment running off the road and being involved in one-vehicle crashes. This is why past Iowa farm equipment roadway studies investigating crash configuration are so important to this field of research. While the third aim of this study changed the outcome to crashes involving an injury, the same concept can be used with this same study design for crash configuration in future studies that could compare road segments with a crash that was a sideswipe to all other road segments.

In the second aim of this study, in comparing urban to rural roads, effects were much more pronounced in rural roads for traffic density and speed limits (50-60). A 7.36 OR for higher traffic density and a 5.07 OR suggest that these are predictors of significant risk. On average 3,290 vehicles travel on a given urban road in a day and only 868 travel on a rural roadway, yet we find that higher traffic densities on rural roads are a significant risk factor. There are a couple of reasons for this. First, RUCA's definition of rurality is based on work commute and each zip code is given one RUCA code so if a portion of a zip code has a higher population density than the rest due to urban sprawl even though it is primarily a rural area, the road would be classified as urban while residences may be rural. On average there are 73 farmers per urban zip code in Iowa and 129 farmers per rural zip code in Iowa (USDA, 2007). Therefore, although there are more vehicles on urban roads, there are more farmers living near rural roads suggesting that there are more farm vehicles on rural roads. All rural roads in Iowa are 55mph (IDOT Driver services, 2014). The same interaction is true for speed limit: the average number of farmers is greater on 55mph roads compared to all other speeds. (USDA, 2007) Last, Iowa routes and farm to market routes are higher risks in urban areas indicating that perhaps non-farm equipment motor vehicles are taking these roads near urban fringes to avoid traffic on the busier interstates and US routes.

Aim 3 assessed road characteristic's effect on farm equipment crashes leading to an injury. Findings revealed that an increase in traffic density and speed limit are greater risk factors for injury while a decrease in road width and shoulder width are more protective against injury than they are for crashes in general. The greatest risk of a crash is on a road that is 65mph when the outcome is a farm equipment crash that involves an injury. Aim 3 is the only aim that discovered this finding. In Iowa, a total of 16% of the interstates, 21% of the US routes and 5% of the Iowa routes are 65 mph. US routes and Iowa routes are both risk factors for crashes in aims 1 and 2. In the third aim where injury is the outcome, risks are significantly elevated for US and Iowa routes. As continuous variables, shoulder width and road width are both significant protective factors compared to all crashes indicating that physically engineering more room for farm equipment to drive will minimize the risk of a crash and even more so for injuries.

Implications

This is an innovative scientific study that found that statistically significant road characteristics affect the odds of a crash. From the IDOT crash reports used in this analysis, it was found that over 6 fatalities and 111 injuries occur each year resulting from motor vehicle crashes involving farm equipment of public Iowa roadways. Such findings can then be used to effectively guide policy through education and engineering controls to help minimize the number of crashes occurring on public roads. By separating farm equipment from other vehicles, traffic density is reduced which decreases the risk of a farm equipment crash. By lowering the speed limit of rural roads, this can reduce the risk of a crash. By creating new paved farm to market routes with a sufficiently wide road with and shoulders, the risk of a crash is also being minimized. Also, by educating agricultural equipment operators to plan their route to avoid high speed roads with a higher traffic density and narrow roads with small shoulders while educating all other roadway users to avoid unpaved and farm to market routes when possible can help to minimize the interaction between farm equipment and other roadway users. This unique study design using GIS-derived road segments as the unit of analysis, allows us to calculate risk of variables specific the characteristics of the road. This original methodology, abundance of viable data, and statistically significant results effectively fill in gaps in prior literature pertaining to roadway safety for farm equipment.

Limitations

While this study has opened a number of new doors to research in this field, there were several limitations to this study. To begin, the findings are limited to Iowa due to the scarce available GIS road network data in the Midwest area. Although data on roadways were collected in only one year (2007) and crash data were collected between the years of 2005-2011, we expect minimal changes in roadway characteristics during the time period in which the crashes occurred. To assess the accuracy of the roadway data, we compared selected roadway characteristics available in both the roadway segment and the crash databases. Of all crashes from 2005-2011 in Iowa, the average speed limit recorded by the officer in the crash report was 50.36. The average speed limit of the roads in which these crashes occurred on as indicated by the IDOT street shapefile was 50.86. These comparable estimates suggest that both sources were accurate measures of actual variable values.

Another limitation is that *actual* exposure of farm equipment to roadway characteristics could not be measured. The ideal study design to assess that level of individual-level exposure would be to conduct a cohort study of farm equipment operators to measure exposure (length of time and distance) to specific Iowa roadways driven from 2005-2011. Another limitation in this study is misclassification bias. When law enforcement code what type of vehicle was involved in a crash, there is some subjectivity when it comes to what they consider farm equipment. This study assumes that farm equipment is coded according to the IDOT definition; however, as seen in the methods section, there were several passenger motor vehicles coded as farm equipment. Although these miscoded items were removed, 75% of farm equipment-related crashes could not be verified because the data did not include information on vehicle type. Another important limitation is the presence of spatial dependence. Spatial dependence is defined as the interdependence of spatially proximal data. Hence, values in close spatial proximate of another given value are dependent on that given value (Wieczorek & Delmerico, 2009). For example, the average road segment is 0.36 miles long in the state of Iowa. Although the factors listed in Table 4 show all of the situations in which a road segment is demarcated, speed limit and road type on a given road are less likely to vary frequently and may be correlated. However, changes in shoulder and road width, surface type, and AADT changes warrant a demarcation of road segments, indicating that values within these variables will be not likely be correlated between adjacent road segments.

CHAPTER III

CONCLUSION

Road characteristics are not the only risk factors for farm equipment crashes. Prior research indicates that behavioral actions, crash configurations, vehicle characteristics and temporal and location-based characteristics also contribute to crash risk. We do not know exactly how much road characteristics affect crashes due to our lack of exposure data; however, we do know which specific values of characteristics affect the odds of a crash. There have been 43 fatalities and 778 injuries in Iowa resulting from crashes involving farm equipment on public Iowa roadways (IDOT, 2005-2011). The ability to detect odds by comparing road segment attributes with and without a crash allow us sufficient evidence to make engineering adjustments to help minimize the time that farm equipment are exposed to attributes that have led to higher odds of a crash.

There are a number of populations that are affected by farm equipment-related crashes. It is an issue of public health, public safety, transportation safety, and agricultural safety. It is an occupational hazard to those in the agricultural industry, transportation industry and essentially any industry requiring commute on roadways on which farm equipment are operating. This is also a hazard for all public roadway users, not only are they exposed to the risk of a crash, distraction from seeing a piece of farm equipment or a crash involving farm equipment could then lead to another crash not involving farm equipment that would not be included in our analysis.

There is also the issue of safety culture that can affect the outcome of a crash that is very difficult to model and integrate into this study. Non-farm equipment may behave differently in certain areas due to the fact that they are familiar with the road characteristics present where farm equipment operates on the roadway. If people reside in a farming community, they know the rules of the road and how to effectively share the road with farm equipment. Another consideration is that those non-farm vehicles who are not from a farming background may make riskier decisions than non-farm vehicles from a farming background due to the fact that their top priority is to get from point A to point B as quickly as possible. Non-farm vehicles may have a greater patience for farm equipment since they can relate to and further respect the occupation and understand that not any type of vehicle is more important on the roadway. While this idea is quite difficult to quantify, it is important to consider when factoring exposure into the investigation of this analysis. More farm equipment on the roadways may increase the risk of a crash; however, if there are vehicles more familiar with driving with farm equipment in these areas with more farm equipment, this could potentially be safer than areas with less farm equipment and higher traffic density of non-farm equipment with less exposure to driving with farm equipment. This is subjective and difficult to quantify which is why having the quantitative data highlighting road characteristics associated with odds of a crash is such an important implication of this study.

There are several important future steps for this study. There are over 200 IDOT street file variables were not used for this analysis. These include road quality, junctions, stop lights, stop signs, and slope. There are also several variables that can be computed through GIS that provide geometrical road characteristics that may be studied as potential risk factors such as road curvature, visual obscurement, and grade. While it is important to investigate all variables that have the potential to affect the risk of a crash, there is a point in which road characteristics will begin to confound one another. The most important information needed to expand this research is that exposure data that this study lacked. This is data that should be integrated into the Ag Census collected by the USDA every five years. Currently, the USDA collects information on registered agricultural equipment; however, this is on the county level meaning that we only can know the number of tractors and combines per county. Ideally to expand on this study, we would need the address of each registered farm equipment, the address of the most common market destination as well as their most common routes. This analysis could still be run at the road segment level; however can be adjusted for the traffic density of agricultural equipment.

Looking down the road, GIS is a tool that drives innovation in the fields of agricultural and transportation safety. Findings from this study revealed that higher speed limits, traffic density, farm to market routes, and smaller road and shoulder width are all significant risk factors for farm equipment crashes and injuries resulting from those crashes. This thesis is a foundation which can be built upon to affect policy to influence administrative and engineering controls on roadways to help reduce crashes involving mobile farm equipment.

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