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Evaluation of trauma response to agricultural injuries

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EVALUATION OF TRAUMA RESPONSE TO AGRICULTURAL INJURIES

by

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CERTIFICATE OF APPROVAL

PH.D. THESIS

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ABSTRACT

Agriculture is a hazardous industry with high rates of occupational industry. Due to a variety of occupation-related factors, farmers may also be at risk for delays in reaching trauma services. Though the state of Iowa has a comprehensive trauma system implemented to provide an efficient response to traumatic injuries, it is unknown how farmers fare in this system. The aims of this study were to determine if the use of emergency medical services (EMS), the occurrence of interfacility transfers, the time to definitive care in severely injured patients, and the length of prehospital intervals for those using EMS differs between farmers and other workers.

A population-based, retrospective observational study was performed using data from the Iowa State Trauma Registry for the years 2005-2011. Eligible entries included adults (≥15 year old) sustaining an occupational injury within the state of Iowa and treated in an Iowa trauma center. Multiple imputation was performed to replace values for missing covariates. Logistic regression modeling was performed to examine the use of EMS and the occurrence of interfacility transfers among farmers compared to non-farmers. Survival analysis was performed to determine the time to definitive care for severely injured farmers compared to severely injured non-farmers; similarly, a survival-based multi-state

model was performed to compare the prehospital time intervals for farmers to non-farmers among EMS users.

The study demonstrated that the likelihood of EMS use was dependent on injury severity. For lower severity injuries, farmers were less likely to use EMS, but there was no difference in EMS use for high severity injuries. The occurrence of interfacility transfers was also dependent on injury severity as well as rurality. Farmers tended to be less likely to receive an interfacility transfer in more rural areas; in large town and urban areas, farmers tended to be more likely to receive an interfacility transfer, particularly for moderate and severe injuries. These trends were slightly stronger for EMS non-users than EMS users; however, the results did not reach statistical significance for most levels. The median time to definitive care for farmers was nearly an hour longer for farmers compared to non-farmers (1h48m vs. 2h46m, respectively). In the survival analysis, time to definitive care for severely injured farmers compared to severely injured non-farmers was found to be time-dependent, and was only significant in the first hour after injury. When the prehospital time intervals for farmers using EMS (included all severities) were compared to non-farmers, farmers took longer to complete the discovery, response, and transport intervals; the scene interval was the only interval that did not reach statistical significance.

The results obtained from this study provide useful information about the operation of the Iowa State Trauma System. While EMS use was lower for minor injuries, farmers with severe injuries had no significant difference in EMS use compared to non-farmers, suggesting comparable access. Likewise, the probability of transfer was only higher in specific instances when the patient did not use EMS. However, the fact that both time to definitive care and several prehospital intervals were longer suggest that occupation-specific factors may contribute to delay. Further research is needed to identify these barriers and develop new strategies to improve the response to traumatic agricultural injury.

PUBLIC ABSTRACT

Farming is very dangerous work. This is worsened by the fact that farmers may face delays in receiving medical treatment after an injury. The state of Iowa has a trauma system that is designed to respond to emergencies, but it is unknown whether it functions adequately for farmers.

Data about injuries treated in Iowa hospitals are submitted to a state registry; this data was used to compare features of the trauma response to work-related injuries in farmers to that of other workers. In particular, the study examined whether farmers used an ambulance, whether farmers were as likely to need transport to a second hospital for additional treatment, and how long it took farmers to complete the process of getting to care.

The most severely injured farmers were just as likely to use an ambulance as other workers and, in most cases, were not more likely to need treatment at a second hospital. These findings suggest that the trauma system is similarly able to deliver farmers to a hospital with the appropriate capabilities. However, it took longer for the ambulance to be notified that the farmer had been injured, for the ambulance to reach the farmer, for the ambulance to drive to the hospital, and, overall, for the farmer to reach their final destination. Further research is needed to determine the cause, the effects, and possible solutions for these delays.

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CHAPTER I: INTRODUCTION

For decades, agriculture has been recognized as one of the most hazardous occupations in the United States. In 1988, a report released by The National Coalition For Agricultural Safety and Health warned of an "unabating epidemic of traumatic death and injury in American farming" and outlined initiatives to improve the working conditions of agricultural workers (1), yet the burden of injury in agriculture has remained high with an estimated one in 20 farmers experiencing an injury yearly (2–5). One strategy for improving the outcomes following an injury is rapid access to capable trauma services. For example, a common cause of death following injury is central nervous system damage (6,7), often caused by increased intracranial pressure and decreased tissue perfusion. Access to a computed tomography scanning and subsequent treatment by a neurosurgeon can decrease neuronal loss (8,9). However, the time it takes for agricultural workers to reach trauma care has not been evaluated previously.

Though organized trauma systems have been developed to reduce delays in definitive care, it is unknown how effectively these systems perform for agricultural workers. Previous work demonstrates that trauma systems have effectively improved survival in the general population (10); a timely response by Emergency Medical Services (EMS) and rapid transport to a trauma care facility can be life-saving. However, farmers may be less likely to utilize EMS following an injury, limiting the ability of prehospital providers to make strategic triage decisions and potentially necessitating more transfers due to mismatches between injury type and the availability of services.

Furthermore, though expedient response by EMS should be universal, certain factors have also been shown to predispose individuals to delays. For example, rural populations repeatedly have been shown to require more time to reach definitive care (i.e. the level of care required to treat one’s injuries) (11–17); a recent meta-analysis examined the prehospital times from studies between 1975 and 2005 (11) and showed that all prehospital times are longer in rural compared to urban settings. Since agricultural work is often carried out in rural environments, rurality likely influences the timeliness of care for farm workers.

In addition to rurality, other risk factors specific to the agricultural industry may also contribute to delays by affecting how the trauma system responds to the injured worker. Injuries to agricultural workers in isolated environments are less likely to be witnessed, causing injuries to go undiscovered for longer periods of time. Even if EMS is notified, the responder may be impeded from reaching the injured worker due to features of the scene such as inability to locate the victim, limited road access, or hazards at the scene (e.g. weather, animals, machinery, and chemicals). Additionally, certain injuries, such as entanglements in machinery, may require prolonged extrication by rescue workers with specialized tools or equipment.

Given the high incidence of injury in agriculture coupled with the high risk for delay in definitive care, studies are needed to determine whether delays exist and identify what aspects of the trauma response might be targeted to improve expediency. Studies examining this issue are hindered by a lack of trauma datasets that identify injuries associated with working and/or with agriculture. This study used the occupation and agriculture identifiers from injury reports collected as part of the Iowa State Trauma Registry to identify a sample of agriculture injuries and characterize their prehospital experience in comparison to other occupational injuries. The study aims were as follows:

Specific Aim 1: Describe patterns in trauma system use for agriculture workers (farmers) compared to other workers (non-farmers). Specifically, determine whether differences exist in rates of EMS use and interfacility transfer to the definitive care hospital.

Hypothesis 1: Farmers are less likely to use EMS and less likely to be transported directly to the definitive care hospital.

Specific Aim 2: Determine whether time to definitive care differs for severely injured farmers compared to severely injured non-farmers.

Hypothesis 2: Severely injured farmers experience a delay in reaching definitive care compared to non-farmers even when adjusted for rurality.

Specific Aim 3: For injured workers transported by EMS, determine whether differences exist in specific prehospital time intervals (Figure 1), including discovery interval, response interval, scene interval, and transport interval, for farmers compared to non-farmers.

Hypothesis 3: Because injuries may go undiscovered and scenes may be more difficult to access in the agricultural setting, the discovery and scene intervals will be longer for farmers even when adjusted for rurality.

CHAPTER II: LITERATURE REVIEW

Trauma systems were borne out of a need to provide care for the numerous injuries that occur among the general population. While farmers certainly are among those served by trauma systems, the processes that comprise these systems were not established specifically with farmers in mind, and there is reason to suspect that farmers have greater difficulty in reaching trauma care. In this chapter, we will first summarize the development of trauma systems and their effects on patient outcomes. Then, we discuss how farmers may face specific barriers that may predispose them to delays in the current trauma system.

Trauma Systems in the United States: History, Effects, and Evaluation

Trauma systems in the United States have their origins in military protocols to treat soldiers with battlefield injuries (18). Injured soldiers were initially stabilized at aid stations near the battlefield before being transferred to subsequently higher levels of care. Evacuation processes eventually became streamlined to deliver soldiers with severe injuries directly to the highest level treatment centers without requiring successive stops at intermediate levels, thus reducing time to medically necessary services. During the 1960s traumatic injury became a more publicized issue in the civilian population, and formal recommendations were made to apply these military strategies leading to the development of emergency medical services (EMS), complete with ambulance services and physicians trained in acute care (19).

Following the introduction of EMS programs, trauma systems were further improved by classifying hospital trauma centers based on their treatment capabilities (18). Modern trauma systems follow guidelines put forth by the American College of Surgeons (ACS) Committee on Trauma which classify trauma centers into four tiers of care (20). Level I – also called "high level" or "tertiary care" – facilities have a full complement of specialty services and can provide comprehensive trauma care for even the most severe injuries, while Level IV facilities provide basic care for minor injuries and stabilization of more severe injuries prior to transfer to a higher level trauma center. Studies have shown reductions in mortality for patients treated at designated trauma centers compared to those treated at other non-designated hospitals (21,22), suggesting that this formal recognition of available trauma services aids in organizing the coordination of patient care.

Concomitant triage guidelines have also been developed and dictate that EMS providers initially assess the patient at the scene of the injury incident and triage the patient to the appropriate level facility based on predetermined clinical criteria (23). The goal of these guidelines is to optimize the efficiency with which patients reach the hospital capable of definitively treating their injuries, termed the definitive care hospital. The definitive care hospital need not be the same for all injuries; severe injuries may require treatment at a high level facility, while minor injuries may be aptly managed locally. Judicious guidelines are necessary to avoid the increased mortality associated with undertriage (24) and the excess healthcare costs associated with overtriage (25,26).

The need for trauma systems is still evident today as injury rates in the United States remain high. The National Health Interview Survey estimates that medically consulted injuries occurred at a rate of 120 episodes per 1,000 people in 2012 (27). Other studies suggest that 18% of Americans experienced a medically treated injury in 2000 resulting in $80 billion in medical costs and $326 billion in lost productivity (28). Injuries are the primary diagnosis for nearly a quarter (22.5%) of all emergency department visits (29) and are the leading cause of death for people 1-45 years of age (30).

Evidence does suggest that trauma systems have been beneficial at a population level. The results of a recent meta-analysis of 6 population-based studies indicated that trauma system implementation was associated with an estimated 15% reduction in mortality (10). However, despite this improvement in outcomes, the benefits may not have been realized in all populations. For example, while the implementation of the Oregon trauma system resulted in a decreased risk of death on a state-level (adjusted OR = 0.80, $CI_{95\%}$ = 0.70-0.91) (31), the same benefit could not be replicated in a remote rural sample from the same state (32).

One way of identifying populations that may be underserved by the trauma system is to examine delays in system processes. Several previous studies provide evidence that delays in trauma care may be associated with poorer outcomes. Feero et al. showed that mean total EMS time was longer for trauma patients who experienced an unexpected death compared to those who experienced an unexpected survival (29.3 vs. 20.8 minutes, p = 0.02) (33). Esposito et al. showed, compared to urban trauma patients, rural trauma patients had prehospital times that were nearly twice as long and preventable mortality rates that were twice as high, but these results did not reach statistical significance (12). The only large, population-based study examining the relationship between prehospital time and mortality did not find a difference (34), but this study only considered direct transports to Level I/II hospitals. Furthermore, this study was unclear about the proportion of rural patients in the sample; commenters have suggested that truly rural patients were underrepresented in this study and that these findings may not be true in all settings (35). One criticism of examining delays is that the harm resulting from particular durations of delay are not well-known; no comprehensive guidelines exist for benchmarking prehospital care times. Historically, a popular policy was that trauma patients should be delivered to care within one hour, the so-called "golden hour." However, this idea has come under scrutiny (36), in part because it is unachievable in many cases, but also because delays over one hour may not equate to poorer patient outcomes for many injury types; some studies have begun to categorize injury-specific benchmarks for trauma systems (37). Examining relative delays in a trauma system may allow us to identify populations which face challenges accessing care and may provide more nuanced information than looking at coarser measures, such as mortality.

Farmers: A Population at Risk for Delays in Trauma Care

With regards to the burden of trauma, farmers represent a high risk group. Occupational injuries account for an estimated 11% of medically consulted injuries (27), but certain occupations, such as farming, are known to have a higher injury incidence and mortality than other occupations. Employer-reported injury rates are higher for workers in crop and animal production – 5 and 6 injuries per 100 FTE workers, respectively, compared to the average of 3.5 injuries per 100 FTE – , though these rates may be underestimated since injury data is not collected from farms with <11 employees (38). Population-based survey data from the Traumatic Injury Surveillance in Farmers (TSIF) survey (2–4) and Regional Rural Injury Study (RRIS) (5) are largely consistent with incidence rates of 4.7-6.9 and 5.8 injuries per 100 FTE workers, respectively. With regards to fatal occupation injuries, the fatality rate is higher in the agriculture, forestry, and fishing sector than in any other occupational sector (39). For workers in crop and animal production the fatality rates are 21.4 and 14.8 respectively, compared to an overall average 3.2 per 100,000 FTE (40). Therefore, one could argue that the provision of trauma services is particularly important in the farming population.

Though no studies have been performed to evaluate the trauma response to agricultural injuries, several risks associated with farming indicate that care may be delayed. Among these risks, delays in care due to rurality have been most clearly documented. The highest level trauma centers are typically concentrated in cities; as of 2002, 98.4% of level I facilities and 90.5% of level II facilities were located in metropolitan areas (41). Estimates suggest that approximately a third of rural residents in the United States are more than a 60-minute drive from even the nearest level III trauma center (42). Rural populations have been repeatedly shown to require more time to reach definitive care (11–17); a recent meta-analysis examined the prehospital times from studies between 1975 and 2005 and showed that all prehospital times are longer in rural compared to urban settings. Additionally, the death rate for unintentional injuries is higher in rural areas (43), further highlighting the disparity in access to trauma care for rural populations. Since over 90% of farming-dependent counties are located in non-metro areas, rurality likely plays a major role in the trauma response to agricultural injuries (44).

While rurality would inhibit the transfer of patients from the injury scene to the trauma center, delays may also arise from other phases of the trauma response due to other features of farm work (45). Farmers often work unsupervised for long periods of time making injuries more likely to go undiscovered. If an injured farmer is able to contact help, describing their physical location within the field may be challenging in the absence of street systems. Furthermore, even if EMS providers are able to locate the injured farmer, poor road access and hazards at the scene, such as animals, machinery, and inclement weather, may complicate removing the patient from the scene. Attributing delays in response to agricultural injuries solely to rurality may cause missed opportunities to improve efficiency by targeting barriers at other stages.

A final potential barrier to efficient agricultural trauma response may be the reluctance of farmers to use trauma services. In a retrospective study of emergency department visits by trauma patients at six rural Iowan hospitals (n = 11,541), Young et al. showed that, among those with minor injuries, farm-related injuries had a decreased odds ratio of ambulance use (adjusted OR = 0.27, 95% CI = 0.10-0.73), yet among those with major injuries, ambulance use was not significantly different between farm- and non-farming injuries (46). These results suggest that when injury severity is low, farmers forgo EMS services, opting instead to transport themselves to a treatment facility which may undermine established triage protocols; however, this study was performed before the Iowa Trauma System was fully implemented and only sampled a small fraction of hospitals receiving trauma patients, limiting the generalizability of these findings. These findings could also represent a preference among farmers for local services in easy driving distance. Lastly, the potential for bias exists due to the choice of non-occupational controls; the farmers in the study may be healthier and more resilient than the controls, and thus better able to transport themselves.

Summary

Though trauma systems have been designed to optimize the care of injury victims, some studies suggest that certain populations may be underserved by current implementations. In particular, farmers are a high-risk injury group that may pose a challenge for trauma systems due to the social or environmental barriers faced at each stage of the response. Studies are needed to understand how injured farmers arrive at trauma care and to identify opportunities for improvements in the trauma system. Our study seeks to add to the present literature by examining how farmers enter and are triaged in the current system (Aim 1). Furthermore, this study will compare the time it takes for farmers to arrive at care compared to other workers in an attempt to detect delays (Aim 2) and will further dissect the trauma response into specific intervals to identify potential sources of delay (Aim 3).

CHAPTER III: RESEARCH DESIGN AND METHODS

This study used injury surveillance data to perform a retrospective cohort study among those experiencing occupational injuries in the state of Iowa. The study sample was obtained by querying the Iowa State Trauma Registry (ISTR) data from 2005-2011 for occupational injuries. Eligible individuals were categorized into two exposure groups: agriculture-related (farm) and non-agriculture-related (non-farm) occupational injury. The full cohort was used to calculate the rates of EMS use and interfacility transfer (Aim 1). Next, the severe occupational injuries were used to model time to definitive care using survival analysis (Aim 2). Finally, multi-state survival modeling was used to determine whether specific prehospital time intervals were longer among farmers using EMS compared to non-farm EMS users (Aim 3).

The Iowa Trauma Program and the Iowa State Trauma Registry (ISTR)

The Iowa Trauma Program, developed under the direction of the Iowa Department of Public Health, has been fully operational since 2001. Iowa uses an inclusive trauma system model in which all hospitals within the state are periodically reviewed and categorized based on the facility's available trauma services. Each trauma center is designated as either a level I (resource), level II (regional), level III (area), or level IV (community) (47). EMS providers statewide use standard triage protocols to evaluate the severity of a given injury and determine the appropriate level of care required. Both level I and level II facilities are capable of providing the highest level of care and can provide definitive care for the most severe injuries.

The ISTR is a state-mandated, active injury surveillance registry implemented as part of the Trauma Program (48). Trauma centers in the State of Iowa report demographic, prehospital, and injury information for patients with injury ICD-9 codes that are evaluated or treated at a trauma center (see Appendix A for more details). Reporting at level I and level II trauma centers has been mandatory since the inception of the registry and became mandatory for level III facilities in 2005. While not mandatory, reporting by level IV centers is highly recommended and is voluntarily performed by approximately 50% of the community trauma centers. Operationally, this means that moderate to severe injuries presenting to care are more reliably reported than minor injuries; additionally, injury data from patients seeking treatment at level III hospitals prior to 2005 or at level IV hospitals are more likely to be incomplete or missing. To minimize under-reporting, analysis will be restricted to 2005-2011, when reporting was mandatory for all but the level IV facilities.

ISTR eligibility includes injured individuals if they are evaluated or treated at a trauma center or at the point that the hospital trauma team, which often includes physicians (including general surgeons), nurses, and support staff, is activated. Activation refers to the process of mobilizing the services and personnel needed to care for an injured patient; in this way, the patient's arrival at the trauma facility may be anticipated, and the appropriate care can be rapidly initiated. Trauma team activation may occur when an individual arrives at the trauma center, as with patients arriving by personal vehicle, but may also occur during EMS transport. For example, if a patient died en route to the hospital, the individual would be listed in the registry because the EMS provider would have already initiated the alert at the receiving facility. Individuals not captured by the registry would include injured persons who were deceased when EMS arrived at the scene, expired en route to the hospital in a private vehicle, or did not seek medical care at an Iowa trauma center. This would tend to under-sample very minor injuries that never presented to care and very severe injuries that did not survive to care.

Though an individual may receive care from more than one provider and/or at more than one institution, the final injury report is filed by the definitive care hospital using an electronic reporting tool. Thus, the data are structured as a collation of all of the health and demographic information associated with an injury event and includes approximately 20,000 injuries per year.

Eligibility

The study sample was obtained by querying the ISTR from 2005 to 2011 to identify eligible patients; this corresponds to the time period in which all level I-III facilities were required to report to the registry (Appendix A).

The following inclusion criteria were applied to identify eligible patients:

- Occupational Injury: the study compares injuries in agricultural workers to those in non-agricultural workers. Therefore, only injuries classified in the ISTR as "work-related" were included. The ISTR definition of work-related is as follows: "To qualify as work-related, patient was compensated at time of injury, injury occurred at place of work or while traveling yet was part of their work, and activity was related to work-function of job (e.g., traveling to a meeting)" (48).
- Age ≥15: though farms sometime employ young workers, triage patterns and the availability of resources differ for pediatric patients. The American College of Surgeons and the CDC recommend that patients <15 years of age be transported to a pediatric trauma center when available (49). Thus the distribution of trauma services likely differs for those 14 and younger and may lead to different experiences within the trauma system. Therefore, only those ≥15 years of age at the time of injury were included.
- Injury in Iowa: to limit the effects of any differences in triage protocols among neighboring states, only patients who were injured in the state of Iowa were included.
- Treatment only within Iowa hospitals: to ensure that all individuals in the study received care from the same system, only patients treated exclusively at Iowa hospitals were included. Transfers within the state of Iowa were permissible and

patients receiving treatment at multiple Iowa trauma centers were therefore included. In contrast, transfers to/from out of state trauma centers were excluded (approximately 10% of occupational injuries).

This query returned 5490 injured workers who were eligible for this study. Specific subsets of these 5490 workers were used in the analysis for each aims as described further in the individual analysis description (see Analysis).

Variables

Definition of Exposure and Outcomes

In each of the three aims, the main exposure of interest is whether the occupational injury was farm compared to non-farm, but the response variable differs (Figure 7). These variables are further described below.

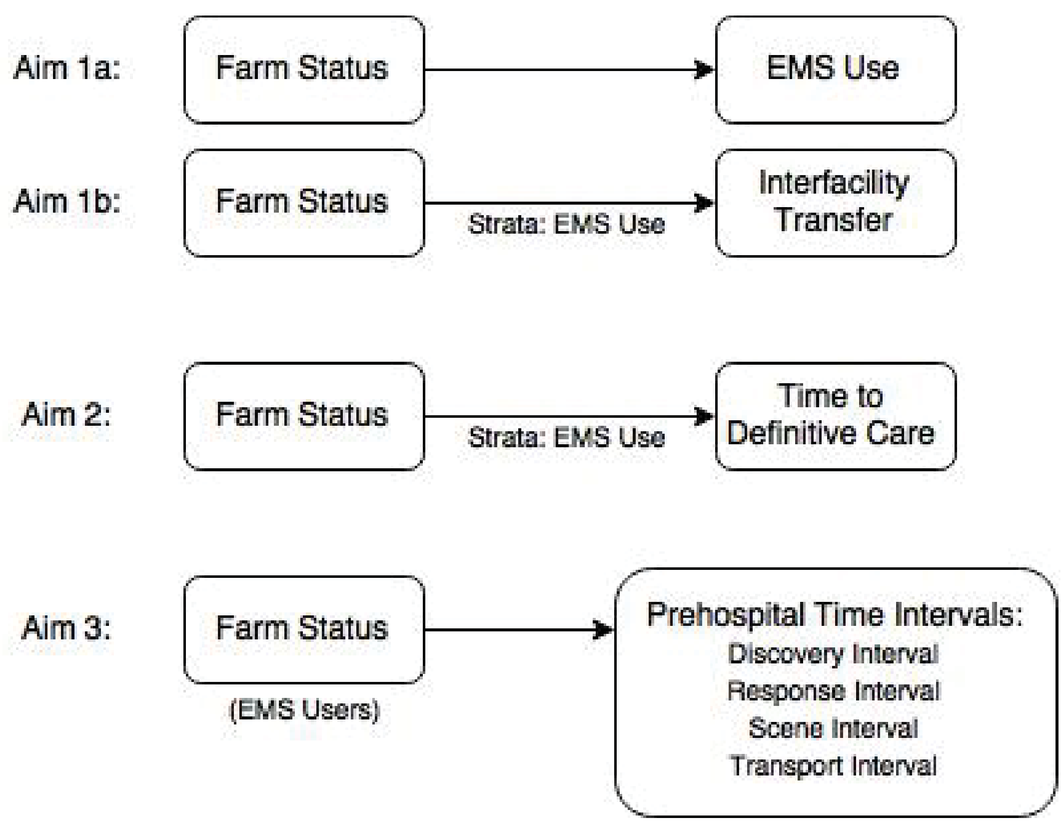


Figure 1. Overview of the exposure-outcome relationship examined in each specific aim.

Farm Status: Eligible participants were categorized into two groups based on whether the injury was classified as "farm-related" in the ISTR. The ISTR definition includes individuals who were injured while "in the course of handling, producing, processing, transporting, or warehousing farm commodities," but excludes injuries that were specifically in the farmhouse (i.e. home) environment (Appendix A).

The farm group was therefore comprised of those individuals who reported an injury that was both "work-related" and "farm-related" in the ISTR. The comparison group included individuals who reported a "work-related" injury that was not "farm-related" and included individuals from many occupations throughout the state of Iowa; the comparison group will be termed non-farmers. This exposure was used in all aims.

EMS Use: The ISTR contains information regarding the mode of transport to and between trauma centers. Throughout this study, EMS was determined based on the mode of transport from the injury scene to the first hospital, regardless of whether this was the definitive care hospital. For example, a person arriving at a level IV hospital by personal vehicle who was later transferred by ground ambulance to a level I facility was classified as an EMS non-user. Those individuals transported from the scene to the first hospital by a ground or air ambulance were classified as an EMS user. EMS was used as the outcome variable in Aim 1a and as a stratifying variable in Aim 1b and Aim2; additionally, EMS use was also included in the eligibility criteria for entry into Aim 3 (see Analysis section).

Interfacility Transfer: In the event of an injury, the injured patient may proceed directly from the scene of the injury to the definitive care hospital (non-transfers) or they may be treated/stabilized at a lower level facility before being transferred to the definitive care facility (transfers). Both transfers and non-transfers can be EMS users or non-users. For example, a person who drove themselves directly to the definitive care hospital was classified as a non-transfer.

Patients were classified as transfer patients if they met one of two criteria. First, the ISTR indicates at what point the patient was identified by the definitive care hospital as a trauma patient meeting inclusion criteria for the registry (Appendix A): prehospital, at definitive care hospital, via transfer from another facility, via transfer from another unit in the definitive care hospital, and by retrospective chart review. Individuals who were identified as arriving from another facility were classified as transfers. Second, the ISTR identifies which hospitals were involved in the treatment of an injured patient when this information is available. Patients were classified as transfers if their treatment at the definitive care hospital was preceded by care at another facility.

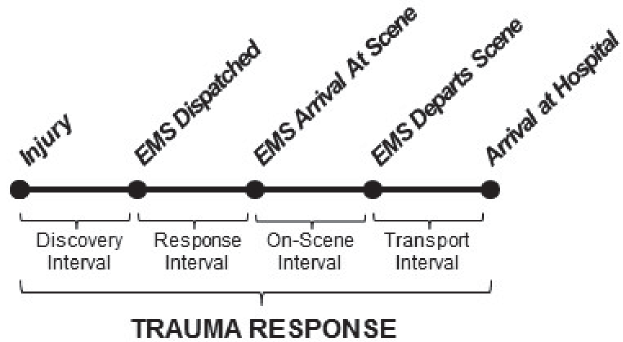


Figure 2. Prehospital time intervals experienced by patient using EMS.

Time to Definitive Care: Time to definitive care is defined as the interval of time between the injury event and the patient's arrival at the final treating hospital (i.e. the definitive care hospital). For patients who underwent an interfacility transfer, time to definitive care includes any time that was spent at the transferring hospital.

Prehospital Time Intervals: For those patients transported by an ambulance, time to definitive care can be further segmented into smaller time periods to allow for further study of more specific processes. Based on the EMS time interval model developed by Spaite et al. (15), we defined four smaller time intervals for analysis, as depicted in (Figure 2):

- *Discovery Time* = the time between the injury event and the ambulance dispatch.
- *Response Time* = the time between the ambulance dispatch and arrival at the injury scene.

- *Scene Time* = the time between the ambulance arrival at and departure from the injury scene.
- *Transport Time* = the time between the ambulance departure from the scene and arrival at the definitive care hospital. For those patients who underwent an interfacility transfer, transport time includes all stays at intermediate hospitals.

Additional Covariates

Additional variables were chosen to adjust for differences in patient, scene, and injury characteristic (Table 1). These variables were used as potential covariates in the models for all three aims. The variables describing the nature of injury were chosen because these conditions are part of the triage decision process; in other words, EMS providers consider the presence of these conditions when choosing to transfer a patient to the nearest hospital or directly to a higher level facility. The variables describing nature of injury were defined by ICD-9 codes associated with any of the twenty-seven possible injury fields collected in the ISTR and were not mutually exclusive. Variables related to mechanism of injury were chosen empirically as they were most strongly associated with both farm status and EMS use; these variables are based ICD-9 codes contained in the primary cause of injury field collected by the ISTR and were mutually exclusive. All variables were treated categorically with more detailed

Table 1. Additional covariates used in modeling derived from the ISTR data.

Patient Characteristics
Age
Sex
Insurance Type
Scene Characteristics
Day vs. Night
Weekday vs. Weekend
Rurality
Injury Characteristics
Injury Severity Score
Injury Type: Blunt, Penetrating, Burn
Nature of Injury
Pelvic Fracture
Amputation
Long Bone Fracture
Spinal Injury
Crush Injury
Brain Injury
Chest Injury
Mechanism of Injury
Motor Vehicle Crash
Other Transportation Injury
Fall
Machinery

information regarding the definitions and cutoffs given in Appendix B.

Of note, we did not include level of care (i.e. Level I-IV) in our analyses for Aim 2. Though the choice to pursue a higher level of care may increase the time to definitive care, we hypothesized that these effects were on the causal pathways between rurality-time, severity-time, as well as those involving the other injury characteristics. Since we adjusted for these other covariates, we deemed it unnecessary to further adjust for level of care. Additionally, at the time of injury, it is unknown what hospital the patient will eventually be treated at; therefore, it is more valid and clinically consistent to adjust for information observable at the time of injury.

Rural Urban Commuting Area (RUCA) Codes

The Rural Urban Commuting Area (RUCA) Codes were initially developed to describe rurality as defined by population and commuting patterns at the census tract level (50); these codes incorporate information from the 2000 Census work commuting information and Census Bureau defined Urbanized Areas (pop. >50,000) and Urban Clusters (pop. 2,500-49,999). Unlike other rural classification systems, an approximation has been developed for zip code level data which allows for easier application of these definitions to routinely collected registry data (50,51). Additionally, the structure of this classification system allows for flexible categorization into as few as two or as many as thirty-three groups.

While many classification schemes are possible, the creators suggest several common classification schemes, including a 4-level categorization consisting of Urban focused, Large Rural City/Town focused, Small Rural Town focused, and Isolated Small Rural Town focused (Appendix C) (50). Urban focused includes zip codes that are either in metropolitan area (i.e. containing an urbanized area) or have at least 30% commuting flow to an urbanized area. Large Rural City/Town focused includes zip codes in Micropolitan areas (i.e. containing a large urban cluster pop. 10,000-49,999) with less than 30% commuting flow to an urbanized area. Small Rural Town focused includes zip codes in a small town (i.e. containing a small urban cluster pop. 2,500-9,999) with less than 30% commuting flow to an urbanized area. Lastly, Isolated Small Rural Town focused includes zip codes outside of metropolitan areas, micropolitan areas, and small towns that have less than 30% commuting flow to an urbanized area.

For the purposes of this study, we categorized rurality as described above referring to Urban focused, Large Rural City/Town focused, Small Rural Town focused, and Isolated Small Rural Town focused as Urban, Large Town, Small Town, and Rural, respectively.

Injury Severity Score (ISS)

The injury severity score (ISS) was designed as a cumulative index to describe injury severity in trauma patients with one or more injuries (52). First, an individual score of 1-6 is applied to the most severe injury in individual body regions. The three most severe individual region scores are then squared and summed to produce the ISS value. The resulting ISS score is between 1 and 75 (unsurvivable) with scores >15 considered severe. Of note, if a score of 6 is assigned to any single body region, that individual is automatically given an ISS = 75, since by definition an individual body region score of 6 is unsurvivable.

This measure of severity is commonly used in trauma research and has been validated previously (52,53). The ISS for each injury is calculated by the treating hospital and is included in the ISTR. Previous research has suggested that ISS be treated as a categorical value since the index is restricted to discreet values (54). For the purposes of this study, we categorized ISS into three levels of severity: 1-8 (minor), 9-15 (moderate), and >15 (severe).

Multiple Imputation Methods for Missing Data

Of the 5490 injuries eligible for this study, only 3275 (59.7%) had non-missing values for farm status, all covariates (Table 2), and stratifying variables, including EMS use and transfer status. However, the multivariable methods used to complete the aims for this project are optimized with minimal missing data. Though we could have proceeded by analyzing only the complete cases, this restriction would have ignored the information contained in the 2215 subjects with one or more missing values; Table 2 shows the frequency of observations by the number of missing values. Other options, including replacing the missing value with the sample mean, are computationally simple, but do not provide a precise estimate; moreover, modeling singly imputed data yields artificially precise effect estimates since the replaced value is analyzed assuming no error (55). Instead, we chose a regression-based, multiple imputation approach to better approximate the missing values and estimate the standard error in subsequent analyses.

Table 2. The variation in the number of missing values per case. The majority of cases were missing only 1-2 values.

# Missing Values	n	%
0	3275	59.65
1	1661	30.26
2	474	8.63
3	70	1.28
4	9	0.16
5	1	0.02

In order to retain individuals with missing values, missing data were imputed using Multiple Imputation by Chained Equations (MICE). Briefly, MICE uses a series of regression equations to iteratively replace missing values in one or more variables. Initially, a set of variables thought to be predictive of each other is selected. Then each missing value is replaced using a simple imputation technique to initiate the process. Each variable in the set is regressed using the other variables as predictors. All values that were initially missing are then replaced with the predicted values from the fit regression model. This process is repeated several times replacing the missing data with the newly predicted values after each round of regression (56). Typically this entire procedure is then repeated to create multiple imputed datasets whose results are combined to more appropriately account for the error associated with the uncertainty in the imputed values (55).

This method has two advantages that make this method amenable to this study. First, MICE allows the researcher to simultaneously impute missing values for more than one variable, which is particularly useful when dealing with registry data that often contain missing values in numerous fields. Furthermore, missing values can be resolved even if more than one variable is missing within the same individual. Second, MICE software allows the user to specify the distribution of the variable being regressed and can, therefore, be used with categorical variables with two or more levels. Additionally, while MICE is a relatively new imputation technique, several software programs have been created to carry out the necessary computations (56).

For this study, SRCware, a stand-alone program developed by statisticians at the University of Michigan (57), was used to create 10 imputed datasets (i.e. multiples). Variables included in the imputation process included farm status, EMS, and all additional covariates listed in (Table 3). In other words, the imputation procedure included both variables with missing data as well as the other complete variables as potential predictors of the missing values. Additionally, an interaction term between farm status and ISS (farm*ISS) was included in the imputation procedure based on preliminary modeling with the complete cases. Missing values were imputed through 10 iterations per dataset using simple logistic regression for dichotomous variables and polytomous logistic regression for categorical variables with greater than two levels. The imputed datasets were then imported into SAS v.9.4 (58) or R v.3.1.2 (59) for analyses and the subsequent pooling of the results, as described in the individual aims below.

MICE was performed on two overlapping samples to examine the effects of excluding subjects with missing data required for subsequent aims. First, imputation was performed on the entire eligible sample (n = 5490). However, many of these eligible individuals were missing time to definitive care, the outcome variable in Aim 2. Therefore, imputation was repeated using only the subset with complete time to definitive care (n = 4747). To examine the results of the imputation, the frequencies of imputed variables were compared for the observed values (prior to imputation), imputed values (generated during the imputation), and the final combined set (Table 3); the frequencies of the imputed and combined sets were represented as the average of the ten singly imputed datasets generated during the MICE process.

To determine whether the result of multiple imputation differed by using the entire eligible sample vs. those with complete time to definitive care, the averaged frequencies were compared using Pearson's χ^2 tests. No significant differences in average frequencies were observed for any imputed variable (Table 3). Additionally, during analysis for Aim 1, models for EMS utilization were constructed using the complete cases (unimputed), the imputed set that had complete time to definitive care, and the imputed set of all eligible cases. We found that the effect estimates were similar for all three models, but the associated standard errors were smaller for the model using the imputed sample of all eligible cases, likely due to the increased sample size (Appendix D). Therefore, the imputed datasets generated from all eligible cases (n= 5490) were chosen for the final analyses because they incorporated information from a larger sample size, which should have produced more stable estimates for regression models during the MICE procedure, and produced the most precise effect estimate in models of EMS utilization.

The variables most often imputed were rurality (16.4%), EMS use (13.6%), and day vs. night (11.5%); the frequency distribution of these variables following the MICE procedure was similar to that observed pre-imputation (Table 3). Of all eligible cases with complete (observed) EMS values, 2765 (58.3%) were classified as EMS users. Of the 746 individuals with missing EMS data, 52.9% were predicted to be EMS users, meaning that injuries with imputed values were slightly more likely to be EMS non-users. Similarly those with imputed values for rurality were slightly more likely to be rural (19.4% vs. 18.5%) or large town (15.8% vs. 11.8%) than those observed in the injuries with complete rurality data. The proportion of those with night (15.7% vs 16.3%) or weekend (13.0% vs. 15.4%) was very similar for the imputed vs. observed groups.

Table 3. Distributions of variables generated by imputation using MICE for the sample of injuries with complete definitive care times (left) and for all eligible injuries (right). Frequencies for the imputed and combined groups are averaged over the 10 imputed sets for each sample.

		Complete Time to Definitive Care n = 4747						All Eligible n = 5490						
		Observed		Imputed		Combined		Observed		Imputed		Combined		
	Code	n	%	N	%	n	%	n	%	n	%	n	%	p
EMS	**0**	1676	40.5%	288.1	47.4%	1964.1	41.4%	1979	41.7%	358.7	48.1%	2337.7	42.6%	0.22
	1	2463	59.5%	319.9	52.6%	2782.9	58.6%	2765	58.3%	387.3	51.9%	3152.3	57.4%	
	Total	4139		608		4747		4744		746		5490		
Farm	**0**	3718	79.6%	61.9	83.6%	3779.9	79.6%	4333	80.2%	77.2	85.8%	4410.2	80.3%	0.38
	1	955	20.4%	12.1	16.4%	967.1	20.4%	1067	19.8%	12.8	14.2%	1079.8	19.7%	
	Total	4673		74		4747		5400		90		5490		
ISS	**1**	3099	71.6%	234.6	56.1%	3333.6	70.2%	3587	71.6%	272	56.8%	3859	70.3%	0.98
	2	670	15.5%	90.0	21.5%	760.0	16.0%	787	15.7%	95.8	20.0%	882.8	16.1%	
	3	560	12.9%	93.4	22.3%	653.4	13.8%	637	12.7%	111.2	23.2%	748.2	13.6%	
	Total	4329		418		4747		5011		479		5490		
Sex	**0**	620	13.1%	0.0	0.0%	620.0	13.1%	727	13.2%	0.2	6.7%	727.2	13.2%	0.79
	1	4125	86.9%	2.0	100.0%	4127.0	86.9%	4760	86.8%	2.8	93.3%	4762.8	86.8%	
	Total	4745		2		4747		5487		3		5490		
RUCA Code	**1**	2097	51.8%	319.3	45.9%	2416.3	50.9%	2327	50.7%	425.1	47.3%	2752.1	50.1%	0.85
	2	458	11.3%	105.6	15.2%	563.6	11.9%	526	11.5%	138.7	15.4%	664.7	12.1%	
	3	771	19.0%	137.4	19.7%	908.4	19.1%	908	19.8%	171.6	19.1%	1079.6	19.7%	
	4	725	17.9%	133.7	19.2%	858.7	18.1%	830	18.1%	163.6	18.2%	993.6	18.1%	
	Total	4051		696		4747		4591		899		5490		
Night	**0**	3969	83.6%			3969.0	83.6%	4067	83.7%	526.9	83.8%	4593.9	83.7%	0.92
	1	778	16.4%			778.0	16.4%	794	16.3%	102.1	16.2%	896.1	16.3%	
	Total	4747				4747		4861		629		5490		
Weekend	**0**	4000	84.3%			4000.0	84.3%	4635	84.6%	8.9	89.0%	4643.9	84.6%	0.96
	1	747	15.7%			747.0	15.7%	845	15.4%	1.1	11.0%	846.1	15.4%	
	Total	4747				4747		5480		10		5490		
Type	**1**	3849	81.1%	2.4	80.0%	3851.4	81.1%	4443	81.0%	2.3	57.5%	4445.3	81.0%	0.88
	2	585	12.3%	0.4	13.3%	585.4	12.3%	672	12.2%	0.9	22.5%	672.9	12.3%	
	3	310	6.5%	0.2	6.7%	310.2	6.5%	371	6.8%	0.8	20.0%	371.8	6.8%	
	Total	4744		3		4747		5486		4		5490		

Analysis

Specific Aim 1: Describe patterns in trauma system use for farmers compared to non-farmers. Specifically, determine whether differences exist in rates of EMS use and interfacility transfers to the definitive care hospital.

This aim sought to compare the trauma system experiences of farmers and non-farmers using two outcome measures:

1. **EMS use:** Individuals were dichotomously classified by whether they used EMS (yes/no) for transport from the injury scene to the first hospital. EMS users included those who used either air or ground ambulance. Non-users were those transported from the injury scene by a different mode of transport (e.g. walk-ins, private vehicle, transport by police).
2. **Interfacility transfers to definitive care hospital:** Individuals were dichotomously classified as transfers and non-transfers. Those who did NOT proceed directly to the definitive care hospital were classified as indirect transports (a.k.a. transfers). For example, an individual that presented first to a level IV hospital before being sent to a level I hospital for further treatment was classified as a transfer.

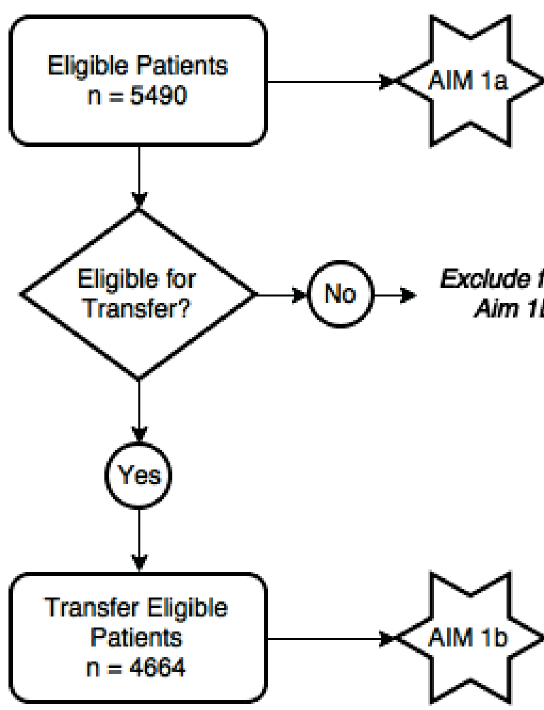


Figure 3. Flowchart of the sampling scheme for Aim 1.

Two different subsets were used in the analysis of Aim 1. To address the question of EMS use (Aim 1a), we used the entire sample of 5490 eligible patients. To model the probability of interfacility transfers, the subset of workers who were likely eligible/ineligible for transfer was defined. Patients were considered ineligible for transfer if they were initially treated at a Level I facility since they already had access to the highest level of care. Eligible patients included any patient treated at a Level II-IV facility, including both EMS users and non-users.

Modeling EMS Use

First, the crude rate of EMS use and unadjusted odds ratio for EMS use among farmers compared to non-farmers was calculated using the multiply imputed sample of all eligible cases. Next, a simple logistic regression model (PROC LOGISTIC) was fit for each imputed dataset using farm status and the variables in Table 1**Error! Not a valid bookmark self-reference.** as covariates; all variables were retained in the model since all variables initially served as predictors during the imputation procedure. In addition, the following interactions between farm, ISS, and rurality (farm*ISS, farm*rurality, ISS*rurality) and between ISS and primary payer (ISS*insurance) were tested and retained in the model if their effect was statistically significant at $\alpha < 0.1$. The results from the ten imputed datasets were pooled with PROC MIANALYZE.

As discussed previously (see Multiple Imputation), the variable indicating EMS use was imputed prior to modeling; thus, the outcome variable was imputed for this model. While the practice of imputing of the outcome variable can be controversial, the imputation of EMS use was deemed necessary due to its importance as a sampling variable in subsequent aims. However, in acknowledgement of this criticism, effect estimates for the identical model were calculated for the complete cases and are reported for comparison in Appendix D; though these estimates differed slightly, the interpretations from these models were largely the same.

Modeling Interfacility Transfers

First, crude rates and odds ratios of interfacility transfers for farmers compared to non-farmers were calculated; results were stratified by EMS use. A simple logistic regression model was fit for transfer status within each model of EMS use using variables in Table 1, with the exception of amputation, as possible covariates. Amputations were not used as a covariate because only 25 amputations were eligible for transfer and produced unstable estimates during modeling. Variables were serially added into the model based on their average reduction in AIC across all ten imputed sets to create a main effects model. An average decrease of at least two units in AIC among either EMS users or non-users was used to determine if the variable improved the fit of the model. Variables that improved model fit were retained in the model. Next, the interactions between farm status, ISS, and rurality (farm*ISS, farm*rurality, ISS*rurality) were evaluated and retained in the models for both strata if the AIC decreased by two units. As above, the modeling was performed using PROC LOGISTIC for each individual imputed dataset, and results were pooled using PROC MIANALYZE.

Specific Aim 2: Determine whether time to definitive care differs for severely injured farmers compared to severely injured non-farmers.

Given an injury, we wanted to determine whether farmer and non-farmers were equally able to access care within a given period of time. The sub-

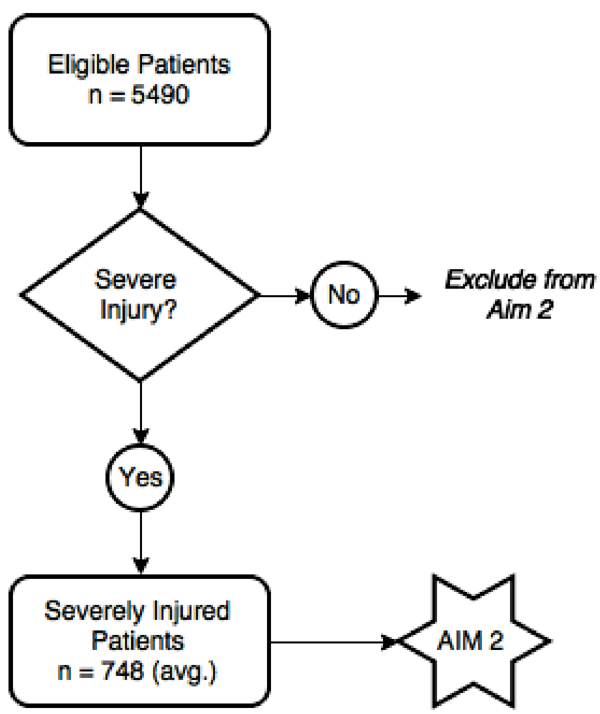


Figure 4. Flowchart of the sampling scheme for Aim 2.

sample of severe injuries (Figure 4) was used in this aim for two reasons. First, in the event of a severe injury, we expected the need for care would be more readily recognized by the patient themselves. In the case of a minor injury, a patient may voluntarily wait for a period of time for the injury to resolve and seek care only if the injury persists; in this situation, a delay in care would result from a failure to recognize the need for care rather than decreased access. We reasoned that patients with severe injuries would be more likely to immediately seek trauma care. Second, severe injuries are most likely to benefit from expedient care. Not all injuries are time-sensitive; the treatment of certain injuries may be delayed hours or even days without any adverse outcomes. Although the precise benefits derived from faster care are difficult to quantify and undoubtedly differ by injury type, we reasoned that faster time to care was preferable for most severe injuries.

Modeling Time to Definitive Care

Survival modeling, using both Kaplan-Meier analysis and Cox proportional hazard modeling, was used to evaluate time to definitive care using right censoring at 4 hours. Although the concept of the "golden hour" – the need to get trauma patients to care within 60 minutes for maximum survival – is a familiar concept in prehospital triage, 60 minutes may not be the most suitable window for evaluation (36) and may be unfeasible, particularly in rural trauma systems. The time period of 4 hours was chosen as a more reasonable window as it coincides with the self-imposed benchmark set by the Iowa Trauma System itself. Individuals with missing time to definitive care data were retained in the analysis, but were also censored at four hours. Note that an alternative analysis excluding those with missing data was performed as a sensitivity analysis (Appendix E), and the results were largely similar.

Initially, Kaplan-Meier curves were constructed for time to definitive care among farmers and non-farmers; the differences between these curves were tested using the log-rank test. Next, a multivariable Cox proportional hazard model was attempted, however analysis of the Schoenfeld residuals (outlined in (60)) showed violations of the proportionality assumption in several variables. The variable showing the highest correlation with the ranked residuals was rurality. Therefore, we chose to proceed using a stratified Cox proportional hazard model using rurality (e.g. Urban/Suburban, Large Town, Small Town, Rural) as the stratifying variable.

Covariates were added into the stratified model based on both a priori hypotheses and empirical analysis. Nature of injury variables were initially forced into the model, with the exception of amputation and crush injury, which were each present in less than 5% of the severe injuries. Next, patient characteristics, scene characteristics, and injury type (blunt, penetrating, burn) were added sequentially based on the decrease in AIC associated with their inclusion. Variables that decreased the AIC by 2 (averaged over the imputations) were considered to improve the fit of the model and were retained.

Once all the variables had been selected for inclusion, the proportionality assumption was again assessed by looking at the association of time to definitive care with the ranked Schoenfeld residuals; variables that had a significant correlation ($p < 0.05$) and a correlation coefficient $|\rho| > 0.1$ for at least 50% of the imputations were considered time-dependent. Of the variables entering the stratified model, both farm status and age showed evidence of time dependency.

To address time dependencies in the model, an extended Cox model was employed. This method uses an interaction with time to account for time-dependent variables (60). The choice for the function of time (e.g. time, log(time), e^{time}) to include is not straightforward and methods for comparing the adequacy of various functions are not well-developed; although the identity function $f(t) = t$ is commonly chosen, this may not be the best choice. This is less of a problem if the time dependency occurs in a covariate since a sensitivity analysis can be performed to compare the effect of different functions on the estimate of the exposure. In our case, there is a time dependency in the exposure itself (farm status), meaning that the choice of function impacts the primary estimate of interest.

To account for the time dependency in farm in our model, an interaction with time was added. Models were constructed using different functions of time and compared using AIC; functions evaluated included t, log(t), √(t), t^2, and e^t, as well as heaviside functions dividing the 4-hour period into two, three, four, and eight equal segments. Based on AIC, log(t) was the best fitting function followed by √(t) and the four-interval heaviside functions, which were comparable (Appendix F); however, we chose to proceed using the four-interval heaviside functions for two reasons. First, the four-interval heaviside functions conveniently divide the period of observation into one-hour blocks for which a separate hazard ratio is computed; we felt this was more interpretable than a change in hazard ratio per log(t). Second, the heaviside functions allow the hazard ratios calculated for each interval to be independent of one another (i.e. the series of estimates are not constrained to a distribution). Though they take more variables to define, we felt they were more objective in their estimation of the beginning and end of the observation period. A comparison of the odds ratios obtained from models using log(t) and the four-interval heaviside functions can be found in Appendix F.

The final model used four heaviside functions to evaluate the farm vs. non-farm relationship for one-hour blocks within the 4-hour observation period. The intervals were defined as follows, where t = time in hours:

$$g_1(t) = \begin{cases} 1 \ if \ t < 1 \\ 0 \ if \ t \ \geq 1 \end{cases}$$
$$g_2(t) = \begin{cases} 1 \ if \ t < 2 \ and \ t \ \geq 1 \\ 0 \ if \ t < 1 \ or \ t \geq 2 \end{cases}$$
$$g_3(t) = \begin{cases} 1 \ if \ t < 3 \ and \ t \ \geq 2 \\ 0 \ if \ t < 2 \ or \ t \geq 3 \end{cases}$$

$$g_2(t) = \begin{cases} 1 \; if \; t \geq 4 \\ 0 \; if \; t < 4 \end{cases}$$

By incorporating an interaction between farm and time as defined by these function, we were able to generate separate hazard ratios for each hour after injury.

Age was also found to be time-dependent using Schoenfeld residuals. After adding the time-dependent variables for farm, a time-dependent variable for age was also tested using the following functions for time: t, log(t), exp(t), t^2, and √(t). None of the interactions between age and time were significant. Additionally, including age as an additional stratifying variable rather than as a covariate led to minimal change in the effect estimates and no change in interpretation. Therefore, age was left in the model as a time-independent covariate; no interaction with time and age was included.

Kaplan-Meier analysis was also performed using PROC LIFETEST for each imputed set individually; results were not pooled, but the level of significance achieved by all imputed sets is reported. Cox proportional hazard modeling was performed using PROC PHREG for each imputed dataset, and results were recombined using PROC MIANALYZE. The results of the Cox proportional hazard modeling are reported for all severe injuries and for the EMS user and non-user subsets.

Specific Aim 3: For injured workers transported by EMS, determine whether differences exist in specific prehospital time intervals, including discovery interval, response interval, scene interval, and transport interval, for farmers compared to non-farmers.

For those patients using EMS, their progression from the injury scene to the definitive care hospital proceeds through several stages described by the defined prehospital intervals: discovery interval, response interval, scene interval, and transport interval. Though all of these intervals may contribute to delays in care, the factors affecting each interval differ. We hypothesized that the nature of agricultural work may predispose farmers to delays in particular intervals. Specifically, we reasoned that farmers are more likely to work in isolation, and an injury may go unnoticed leading to an increase in discovery time. Once EMS is dispatched, we also reasoned that the injury scene may be difficult for the EMS to access due to geographic (e.g. imprecise location) and physical barriers (e.g. mud, animals, hazardous weather). We expected that scene time and transport time were less affected by farm status, particularly when adjusted for rurality and injury severity.

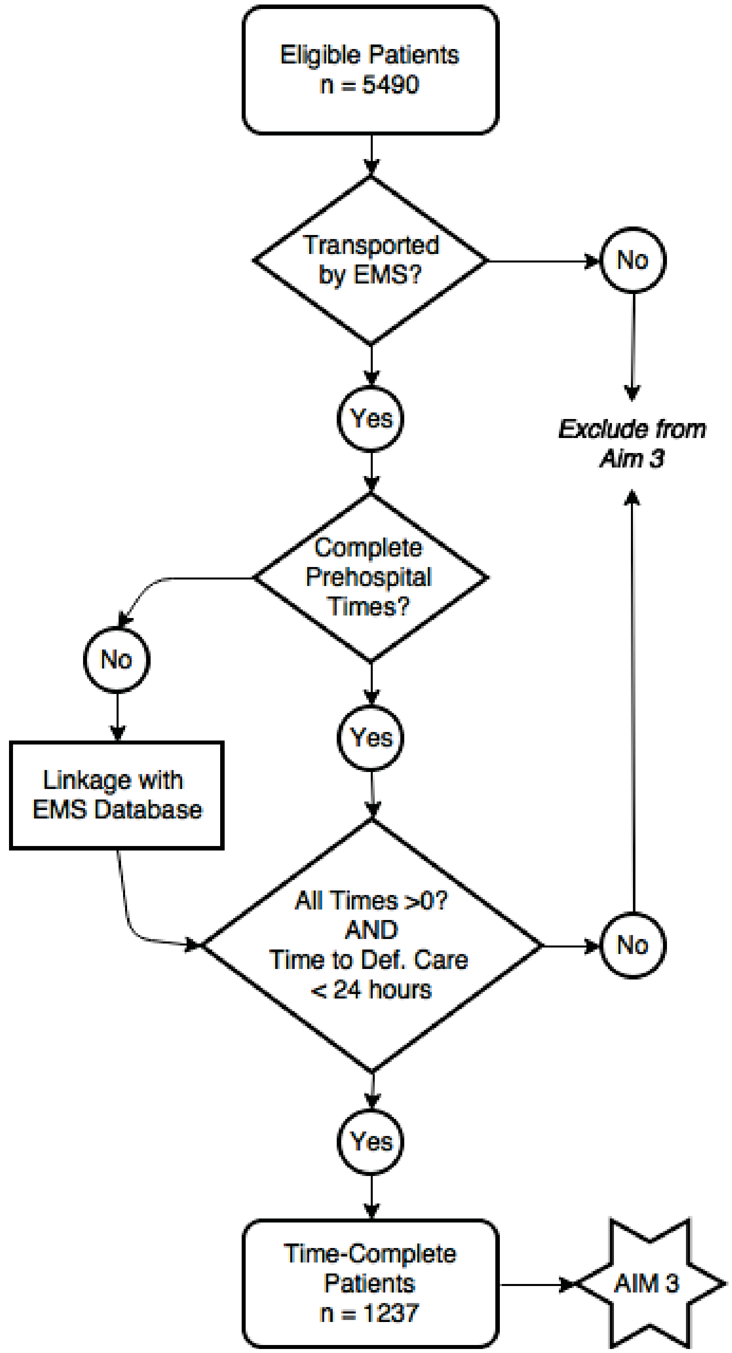


Figure 5. Flowchart of the sampling scheme for Aim 3.

Prehospital interval time points are only available for those patients transported by EMS (Figure 5). Additionally, we wanted to include only those patients who were trying to access care for the acute injury event, as opposed to those that sustained an injury and chose to delay care or sought care for a late complication; therefore, the analysis of prehospital time intervals included only EMS users and was further limited to those reaching care within 24 hours. Of the 3116.3 average eligible cases (from the 10 imputed sets), 1378 (44.2%) had complete time information.

Though the time of injury and the arrival and the definitive care hospital are collected by the hospitals themselves, information regarding the prehospital intervals is collected by the EMS provider. Therefore, prehospital time interval data would be missing if the reporting hospital did not receive this information from the EMS provider. However, this prehospital time data is part of the report generated by the EMS provider per their own protocols. Therefore, we attempted to replace missing prehospital time interval data by performing a probabilistic linkage between the trauma registry and the Iowa EMS Database. This linkage was performed using the Link Plus software program available from Center for Disease Control and Prevention (61); for this linkage date of birth, last name, SSN, arrival date, and sex were used as matching variables. Of the 3116.3 eligible cases, 1051 matched EMS records. Data from matched cases was used to fill in missing values for EMS dispatch time, EMS arrival on the scene, and EMS departure from the scene. Where discrepancies occurred, data from ISTR was retained. This process led to the recovery of complete time information for an additional 146 patients, or 4.7% of the eligible patients. Time intervals were recalculated as described in the variable definitions previously. Time intervals that were ≤0 were considered invalid and set to missing. This led to 1237 complete cases with valid times that were available for analysis compared to 1160 cases prior to matching. The prehospital time interval analysis was performed on the complete valid set of 1237 cases.

Analysis of the Prehospital Time Intervals

The characteristics of the 1237 cases with complete time information were compared using frequency tables. Next, the magnitude of the discovery, response, scene, and transport times were summarized by using a median and interquartile range in each of the ten imputed datasets. Since the distributions of the time intervals were right skewed, the Wilcoxon rank-sum test (non-parametric) was used to compare the distributions for each imputed set individually using PROC UNIVARIATE. Kaplan-Meier curves for farmers and non-farmers were also generated for each time interval using PROC LIFETEST and were compared using the log-rank test.

While calculating the unadjusted analyses (i.e. median and Kaplan-Meier comparisons) provided some insight into the association with farm status, we wanted to create a model that would allow us to adjust for differences in rurality and injury severity. While standard survival analysis only allows for multivariable modeling of the progression from one state to another (Figure 6a), a multi-state model allows one to obtain additional estimates for the transition to intermediate states. For this study, we chose to treat this prehospital time period as a 5-state progressive series (Figure 6b). The progression through this series can be described by modeling the intensity of each of the four transitions (arrows in Figure 6b) using a stratified Cox model; each transition is modeled individually in its own strata (62).

The use of this model assumes that two properties hold for the transition intensities in our data. The first property, called the Markov property, assumes that the future depends only on the currently occupied state and is not influenced by past states (62,63). Multi-state models may be complex with multiple pathways from the starting

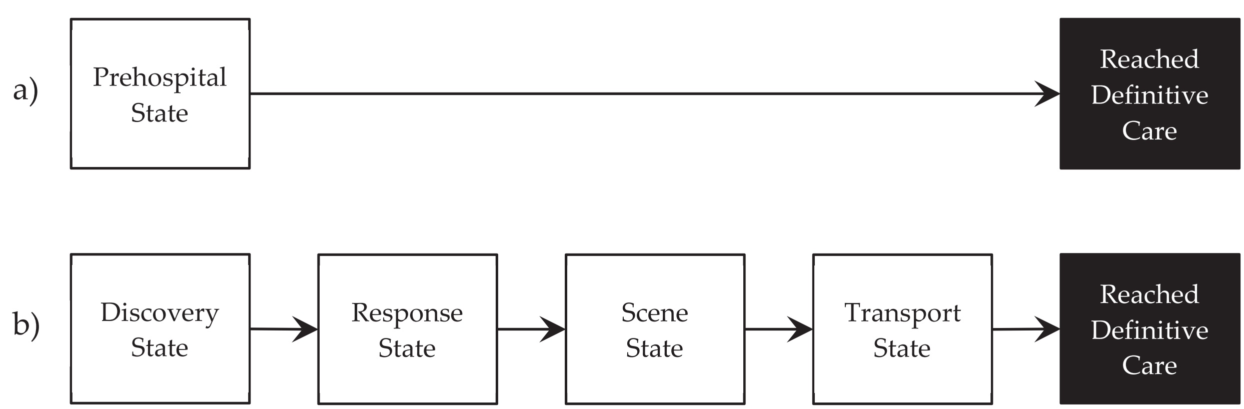


Figure 6. A comparison of model structure between (a) standard survival analysis and (b) a 5-state progressive model. The arrows represent the transitions. Standard survival analysis only models a single transition, while four transitions are included in the 5-state progressive model.

point to the outcome; in these situations, the Markov property would be violated if the order of states entered impacted future transitions. Since our model only has one possible pathway from the injury event to definitive care, the order in which patients enter these states is the same for all patients in our model. The Markov property also implies that the transitions are not related to the times at which previous states were entered. While the provision of services by EMS could theoretically be influenced by past events (e.g. perhaps a patient with a long discovery period will require more on-scene interventions), we assume that EMS providers attempt to perform their duties efficiently without regard for time spent in previous states. For this study, each state is modeled independently without regard for information from previous states.

The second assumption in this model is that proportionality holds within each transition strata. In other words, the hazard of transition between farmers and non-farmers is proportional throughout the interval. This property is merely an expansion of the proportionality assumption made in standard Cox proportional hazard modeling.

Four variables were chosen a priori for inclusion in the model: farm status, rurality, injury severity, and transfer. While farm status, rurality, and injury severity were applied to all four transitions, the transfer variable was only included in the analysis of the final transition (i.e. between the transport state and reaching definitive care). Initially, all variables were added into the model as covariates with transition as the stratifying variable (64). Examination of the correlation with transition time and the ranked Schoenfeld residuals showed evidence of proportionality violation for rurality. Therefore, rurality was changed from covariate to a stratifying variable. There was also evidence that the farm status variable violated proportionality in the modeling of the first transition (discovery state to response state). Graphical analysis showed that the difference in hazards for farm vs. non-farm injuries declined towards the end of the interval. We allowed farm to remain in the model bearing in mind that the estimate for farm in the first transition would be averaged over the interval. The final model contained farm status, rurality, and transfer (fourth transition only) with rurality and transition as stratifying variables.

Modeling was performed in R v.3.1.2 (59). The functions *coxph* and *cox.zph* from the *survival* package v. 2.38.1 (65) were used to fit the model and assess proportionality, respectively. Additional functions from the *survival*, *mstate* v.0.2.7 (66), and *mitools* v.2.3 (67) packages were also used to aid in fit and assessment of the multi-state model with multiply imputed data.

CHAPTER IV: RESULTS

A total of 6392 occupational injuries were recorded in the ISTR from 2005-2011 of which 5614 injuries occurred in the state of Iowa. Patients were excluded if they received care out of state or if they were less than 15 years of age (since this is an occupational injury sample), leaving 5490 observations eligible for analysis

Of the eligible occupational injuries (Table 4), 19.4% were farm-related in the observed data, while 1.6% of injuries had missing values for farm status; after imputation, farm-related injuries comprised an average of 19.7% of the cases. Occupational injuries primarily occurred in middle-aged males with nearly 80% of the injuries identified occurring in those ages 25-64. The majority of those experiencing injuries paid for their care through worker's compensation (53.9%), though nearly 30% either self-paid or insurance information was not available. Injuries most often occurred during the daytime (7am – 7pm) (83.7%) and on weekdays (84.4%). Over half of injuries were observed to occur in urban zip codes, while more than one-third of injuries occurred in zip codes classified as small town or rural. Most injuries had an ISS score from 1-8 (70.3%) and were classified as low-severity; only 13.6% of injuries were classified as severe (ISS >15). With regards to injury type, blunt injuries accounted for the majority of eligible injuries with penetrating injuries and burns comprising only 19.1% of the sample.

Of those natures of injury necessitating a high level of care (Table 5), several types, such as pelvic fractures, amputations, crush injuries, and chest wall instability, were relatively rare with frequencies of less than 5%; however, long bone fractures were relatively common, occurring in nearly 20% of injury events. Spinal injuries and brain/skull injuries were each present in approximately one in ten injuries. Of the mechanisms associated with farm or EMS (Table 5), motor vehicle crashes and falls were more common among non-farmers, while machinery- and other transportation-related injuries were more common in farmers.

Table 4. Characteristics of eligible occupational injuries obtained from the Iowa State Trauma Registry 2005-2011. Percentages are given for observed values and imputed values averaged over 10 datasets. P-values are from chi-square tests pooled over the imputed sets (68,69).

	Observed		Imputed	Farm	Non-Farm	
	n	%	%	%	%	p
Total	5490					
Farm-Related						
Yes	1067	19.4	19.7			
No	4333	78.9	80.3			
(Missing)	90	1.6	-			
Age						<0.0001
15-24	667	12.2	12.2	10.9	12.5	
25-44	2072	37.7	37.7	25.7	40.7	
45-64	2311	42.1	42.1	44.7	41.5	
>=65	440	8.0	8.0	18.7	5.4	
Sex						<0.0001
Male	4760	86.7	86.8	91.3	85.7	
Female	727	13.2	13.2	8.7	14.4	
(Missing)	3	0.1	-			
Primary Payer						<0.0001
Insurance	735	13.4	13.4	31.1	9.1	
Medicaid/Medicare	197	3.6	3.6	10.0	2.0	
Worker's Comp	2961	53.9	53.9	18.0	62.7	
Other/Unknown	1597	29.1	29.1	40.9	26.2	
Night						0.0004
Yes	794	14.5	16.3	12.7	17.2	
No	4067	74.1	83.7	87.3	82.8	
(Missing)	629	11.5	-			
Weekend						<0.0001
Yes	845	15.4	15.4	21.7	13.9	
No	4635	84.4	84.6	78.3	86.1	
(Missing)	10	0.2	-			
Rurality						<0.0001
Urban	2250	41.0	50.1	18.7	57.8	
Large town	544	9.9	12.1	8.2	13.1	
Small Town	949	17.3	19.7	29.0	17.4	
Rural	848	15.5	18.1	44.2	11.7	
(Missing)	899	16.4	-			
Injury Severity						0.1909
ISS 1-8	3587	65.3	70.3	71.1	70.1	
ISS 9-15	787	14.3	16.1	14.3	16.5	
ISS >15	637	11.6	13.6	14.6	13.4	
(Missing)	479	8.7	-			
Injury Type						0.5421
Blunt	4443	80.9	81.0	80.3	81.1	
Penetrating	672	12.2	12.3	13.2	12.0	
Burn	371	6.8	6.8	6.5	6.8	
(Missing)	4	0.1	-			

Table 5. Frequencies of selected natures and mechanisms of injury from observed occupational injuries obtained from the Iowa State Trauma Registry 2005-2011. Variables describing nature of injury were chosen as indicators for conditions that require triage to a high level trauma center according to the Iowa triage protocols. Variables describing the mechanism of injury were chosen empirically to describe mechanisms of injury associated with both farm status and EMS use. P-values are from chi-square tests pooled over the imputed sets according to (68,69).

	All Injuries		Farmer		Non-Farmer		
	n	%	N	%	n	%	p
Total	**5490**		**1081**		**4409**		
Nature of Injury							
Pelvic Fracture	223	4.1	56	5.3	164	3.8	0.0303
Amputation	28	0.5	15	1.4	13	0.3	<0.0001
Long Bone Fracture	1088	19.8	136	12.8	935	21.6	<0.0001
Spinal Injury	591	10.8	128	12.0	450	10.4	0.1274
Crush Injury	257	4.7	32	3.0	219	5.1	0.0043
Brain/Skull Injury	563	10.3	107	10.3	448	10.3	0.7643
Chest Wall Instability	80	1.5	19	1.8	59	1.4	0.3041
Mechanism of Injury							
Motor Vehicle Crash	558	10.2	52	4.9	495	11.4	<0.0001
Fall	1827	33.3	208	19.5	1589	36.7	<0.0001
Machinery	904	16.5	234	21.9	656	15.1	<0.0001
Other Transportation	258	4.7	111	10.4	142	3.3	<0.0001

Factors Predicting EMS Use

Of the 4744 occupational injuries with complete mode of prehospital transportation, 2765 (58.3%) were transported by EMS; 5.0% of these EMS transports were by air ambulance with the remaining 95.0% of injuries transported by ground ambulance. Farmers were less often transported by EMS than non-farmers (45.0% vs. 61.4%, p <0.0001) in the observed data; this was similar to the proportion of EMS users across the imputed datasets, 43.7% among farmers vs. 60.8% among non-farmers.

Using univariate models for EMS, crude odds ratios were calculated for the multiply imputed data for all eligible cases (Table 6). Farm injuries had significantly lower odds of using EMS (OR = 0.50, 95%CI = 0.43-0.58). Crude analysis also showed that increasing rurality corresponded with decreased EMS use; those in rural zip codes had the lowest odds of EMS use compared to those injured in urban areas (OR = 0.58, 95%CI = 0.49-0.68). Other factors associated with decreased odds of EMS use were penetrating injuries and burns (compared to blunt traumas) and machinery injuries (compared to those not injured by machinery). Several factors were associated with significantly increased odds of EMS use including certain insurance types, increasing injury severity, and certain injury types and mechanisms. Those covered by worker's comp had a 62% increase in the odds of EMS use compared to those covered by private insurance (OR =1.62, 95%CI = 1.35,1.94); workers who self-paid or had other/unknown insurance status also had increased odds of EMS use compared to those with private insurance. Those with moderate or severe injuries had more than a two- and five-fold increase, respectively, compared to those with minor injuries. Pelvic fracture, amputation, long bone fracture, spinal injury, brain injury, and chest injury were also significantly associated with increased odds of EMS use, each compared to those without that injury; crush injury was the only injury type to show no association. Lastly, several mechanisms of injury, including motor vehicle collisions, falls, and other transportation injuries, were associated with increased odds of EMS use compared to those not injured in each of these injury types, respectively; machinery injuries were associated with decreased EMS use compared to those not injured by machinery. The occurrence of a motor vehicle collision was the strongest single predictor of EMS causing a 12-fold increase compared to those not involved in motor vehicle collisions (OR = 12.09, 95%CI = 8.22-17.79).

A multivariable logistic regression model was constructed to adjust for potential confounders. Of the interactions tested between farm status, rurality, and ISS, only the interaction between farm status and injury severity (farm*ISS) was significant (p = 0.013). Adjusted ORs for non-interacting and interacting variables are displayed in Table 6 and Table 7, respectively. Farm status did remain significantly associated with decreased EMS use, but only for minor injuries. For injuries with ISS <9, farmers were only half as likely to use EMS compared to non-farmers (OR = 0.50, 95%CI = 0.40-0.63), while EMS use for those with higher severity did not differ.

Other variables remained significant predictors of decreased use after adjustment for confounding. Rurality, which was initially significant in crude analysis, remained associated with decreased EMS use, but the adjusted effect size was smaller than the unadjusted (Table 6). Small town and rural environments showed a 33% reduction in the odds of EMS use compared to those in urban areas (small town: OR = 0.68, 95%CI = 0.56-0.82; rural OR = 0.67, 0.54-0.81), while large town environments were no longer significantly associated with decreased use. Though penetrating injuries and burns compared to blunt trauma showed an association with decreased EMS use in unadjusted analyses, only penetrating injury remained significantly associated with decreased use in the adjusted model (OR = 0.57, 95%CI = 0.46-0.71). Injuries caused by machinery were initially found to be associated with decreased EMS use in the crude analysis, but this association reversed in the adjusted model such that machinery had a marginally significant association with increased EMS use (OR = 1.18, 95%CI = 0.97-1.43).

Other variables were also positive predictors of EMS in the multivariable model. Increasing injury severity was identified in the crude analysis as a positive predictor of EMS use and remained a significant predictor in adjusted modeling (Table 6). However, the effect of ISS was stronger for farmers than for non-farmers; farmers with severe injuries had 4.0 times the odds of using EMS compared to farmers with minor injuries, whereas severe injuries only showed a 2.7-fold increase in odds among non-farmers (Table 7). With regards to insurance, both worker's compensation (OR = 1.42, 95%CI = 1.14-1.77) and other/unknown (OR = 1.69, 95%CI = 1.34-2.13) remained significant predictors of EMS use (Table 6). Numerous injury types also remained significant after adjustment, including pelvic fracture, amputation, long bone fracture, spinal injury, and brain injury (Table 6); however, chest injury was no longer a significant predictor of

EMS use following adjustment. Of the significant injury types, amputations were most strongly associated with EMS use following adjustment, leading to an 8-fold (OR = 8.49, 95%CI = 2.45-28.81) increase in the odds of EMS use, followed by pelvic fractures (OR = 2.71, 95%CI = 1.77-4.16) and spinal injuries (OR = 2.06, 95%CI = 1.58-2.68). Lastly, the injury mechanisms identified as predictors in crude analysis remained associated with EMS following adjustment (Table 6). In crude analysis, motor vehicle crashes were the strongest predictor of EMS use, and this effect was slightly augmented in the adjusted model yielding a nearly 13-fold (OR = 13.08, 95%CI = 8.85-19.34) increase in the odds of EMS use. While other transportation incidents (adjusted OR = 2.18, 95%CI = 1.57-3.03) and falls (adjusted OR = 1.22, 95%CI = 1.02-1.46) had more modest associations, they too remained significant positive predictors of EMS use.

Table 6. Logistic regression model for EMS use controlling for demographic, scene, and injury variables.

	Crude OR	95% CI	Adj OR	(95% CI)
Farm-Related	0.50	(0.43,0.58)	0.59	(0.48,0.72)
Age				
15-24	0.88	(0.72,1.07)	1.07	(0.86,1.34)
25-44	-		-	
45-64	1.16	(1.02,1.33)	1.17	(1.00,1.37)
>=65	1.26	(1.00,1.59)	1.12	(0.81,1.55)
Sex				
Female	-		-	
Male	1.12	(0.94,1.32)	1.20	(0.99,1.45)
Primary Payer				
Insurance	-		-	
Medicaid/Medicare	1.28	(0.92,1.78)	1.32	(0.85,2.03)
Worker's Comp	1.62	(1.35,1.94)	1.42	(1.14,1.77)
Other/Unknown	1.75	(1.45,2.12)	1.69	(1.34,2.13)
Night	1.11	(0.93,1.33)	1.05	(0.85,1.30)
Weekend	0.95	(0.81,1.12)	1.00	(0.83,1.22)
Rurality				
Urban	-		-	
Large town	0.76	(0.60,0.96)	0.78	(0.61,1.01)
Small Town	0.60	(0.51,0.71)	0.68	(0.56,0.82)
Rural	0.58	(0.49,0.68)	0.67	(0.54,0.81)
Injury Severity				
ISS 1-8	-		-	
ISS 9-15	2.25	(1.88,2.69)	1.59	(1.30,1.95)
ISS >15	5.55	(4.37,7.04)	2.96	(2.10,4.17)
Injury Type				
Blunt	-		-	
Penetrating	0.28	(0.23,0.34)	0.57	(0.46,0.71)
Burn	0.55	(0.44,0.69)	1.01	(0.77,1.31)
Pelvic Fracture	4.63	(3.11,6.89)	2.71	(1.77,4.16)
Amputation	5.62	(1.69,18.72)	8.39	(2.45,28.81)
Long Bone Fracture	2.07	(1.79,2.40)	1.77	(1.48,2.12)
Spinal Injury	3.65	(2.92,4.55)	2.06	(1.58,2.68)
Crush Injury	0.78	(0.59,1.03)	1.01	(0.75,1.36)
Brain Injury	3.31	(2.62,4.18)	1.48	(1.07,2.05)
Chest Injury	3.88	(2.14,7.05)	1.85	(0.94,3.65)
Motor Vehicle Collision	12.09	(8.22,17.79)	12.89	(8.49,19.58)
Fall	1.43	(1.26,1.61)	1.22	(1.03,1.46)
Machinery	0.65	(0.56,0.76)	1.18	(0.97,1.43)
Other Transportation	1.78	(1.34,2.35)	2.18	(1.57,3.03)

Table 7. Logistic regression model for EMS use: Selected comparisons for interacting terms.

Fixed Variable	Comparison	OR	(95% CI)
Minor Injuries	Farm vs. Non-Farm	0.50	(0.40,0.63)
Moderate Injuries	Farm vs. Non-Farm	1.05	(0.62,1.79)
Severe Injuries	Farm vs. Non-Farm	0.75	(0.40,1.41)
Non-Farmers	Moderate vs. Minor Injuries	1.39	(1.13,1.72)
	Severe vs. Minor Injuries	2.69	(1.83,3.97)
Farmers	Moderate vs. Minor Injuries	2.91	(1.73,4.91)
	Severe vs. Minor Injuries	4.03	(2.26,7.20)

Factor Predicting Interfacility Transfer

Of the 5490 occupational injuries, 4664 (85.0%) were considered eligible for transfer and used in the modeling of interfacility transfer. Of those eligible, 1632 (35.0%) went on to receive an interfacility transfer. The proportion of farmers eligible for transfer was slightly higher than that of non-farmers (88.9% vs. 84.1%); similarly, the proportion of eligible farmers receiving interfacility transfers was also higher than that of eligible non-farmers (39.4% vs. 33.8%). Transfer rates were similar between EMS users (35.5%) and EMS non-users (34.4%).

Crude odds ratios for EMS non-users and users were generated by constructing univariate logistic regression models for transfer (Table 8 and Table 9). Farm status was significantly associated with transfer among EMS users (OR = 2.00, 95%CI = 1.58-2.52), but not for non-users (OR = 0.90, 95%CI = 0.73-1.13) in crude analysis. Rurality was a predictor of transfer in crude analysis for both EMS users and non-users. Among EMS non-users, those living in large town, small town, or rural zip codes had 3.4-4.4 higher odds of transfer compared to those injured in urban areas; this effect was slightly more pronounced in EMS users, where those in non-urban areas had a 3.5-5.1-fold increase in the odds of being transferred. Increasing injury severity was also predictive of transfer in both EMS users and non-users with moderate and severe injuries having 1.9-3.8 greater odds of transfer. Among the nature of injury variables, brain injury was the most predictive of transfer in both groups with 2.1-2.9 fold increase in the odds of transfer. Other positive predictors of transfer among non-EMS users included male sex, worker's compensation, unknown/other insurance, burns, spinal injuries, and crush injuries, while positive predictors among EMS users included male sex, other/unknown insurance status, burns, pelvic fractures, spinal injuries, and machinery injuries; being injured in a fall negatively predicted transfer among EMS users. Being injured in a fall was the only variable that negatively predicted transfer in either group.

Multivariable logistic regression models were fit separately for EMS users and non-users and included farm status, sex, insurance status, rurality, injury severity, injury type, spinal injury, and machinery injury (Table 8-Table 10). Though pelvic fractures, brain injuries, and falls were significant predictors in crude analysis, they did not improve model fit during multivariable modeling. Spine injuries remained significantly associated with transfer after adjustment for confounders, though the effect was slightly diminished. In contrast, machinery was only a marginally significant in crude analysis for EMS users, but became significant in both groups after adjustment.

Additionally, the second-order interaction terms between farm*rurality was significant and retained in both models (Table 10). The second-order interaction between farm*ISS was significant in non-EMS users and was retained in both models for the sake of comparison (Table 10).

Farm status was initially a risk factor for transfer in crude analysis, but only among EMS users; this effect did not persist in multivariate modeling. Among EMS users, the odds of transfer appeared higher for farmers in urban areas and large towns for all injury severities, but this did not reach statistical significance. Farm status actually was a significant negative predictor of transfer in small town among minor injuries; though not significant, the odds of transfer for farmers tended to be less in small towns and rural areas. A similar trend was observed in the EMS non-user groups with farmers in urban area/large towns having higher odds of transfer and farmers in small town/rural areas having lower odds of transfer. In the EMS non-user group, farm status was a significant risk factor for moderate-severity injuries in urban areas (OR = 3.47, 95%CI = 1.24-9.72) and large towns (OR = 3.76, 95%CI = 1.10-12.87) and a significant protective factor among minor injuries in small towns (OR = 0.20, 95%CI = 0.13-1.85) and rural areas (OR = 0.29, 95%CI = 0.18-0.47).

Table 8. Logistic regression model for transfer (no interactions) among EMS non-users.

	Crude OR	*95% CI*	*Adj OR*	*95% CI*
Farm-Related	0.90	(0.73,1.13)	0.42	(0.31,0.58)
Age				
15-24	1.04	(0.77,1.41)		
25-44	-			
45-64	0.89	(0.71,1.10)		
>=65	1.08	(0.73,1.60)		
Sex				
Female	-		-	
Male	1.52	(1.13,2.05)	1.43	(1.01,2.03)
Primary Payer				
Insurance	-		-	
Medicaid/Medicare	1.48	(0.84,2.59)	1.33	(0.72,2.46)
Worker's Comp	1.45	(1.06,1.99)	1.46	(1.02,2.09)
Other/Unknown	5.10	(3.64,7.15)	4.01	(2.76,5.82)
Night	1.01	(0.77,1.32)		
Weekend	1.17	(0.91,1.50)		
Rurality				
Urban	-		-	
Large town	3.38	(2.28,5.00)	2.75	(1.77,4.28)
Small Town	4.40	(3.21,6.02)	6.43	(4.49,9.21)
Rural	3.60	(2.72,4.76)	6.27	(4.38,8.98)
Injury Severity				
ISS 1-8	-		-	
ISS 9-15	2.75	(2.07,3.65)	2.58	(1.84,3.62)
ISS >15	3.79	(2.45,5.86)	4.34	(2.49,7.57)
Injury Type				
Blunt	-		-	
Penetrating	0.81	(0.64,1.05)	0.80	(0.59,1.08)
Burn	3.70	(2.62,5.20)	3.68	(2.43,5.57)
Pelvic Fracture	1.50	(0.69,3.24)		
Amputation	na			
Long Bone Fracture	1.16	(0.88,1.54)		
Spinal Injury	2.53	(1.67,3.85)	2.29	(1.41,3.73)
Crush Injury	1.64	(1.11,2.45)		
Brain Injury	2.87	(1.84,4.47)		
Chest Injury	1.59	(0.48,5.24)		
Motor Vehicle Collision	1.02	(0.44,2.37)		
Fall	0.79	(0.63,0.99)		
Machinery	1.26	(0.99,1.62)	1.71	(1.30,2.25)
Other Transportation	0.92	(0.53,1.59)		

Table 9. Logistic regression model for transfer (no interactions) among EMS users.

	Crude OR	*95% CI*	*Adj OR*	*95% CI*
Farm-Related	2.00	(1.58,2.52)	0.89	(0.64,1.23)
Age				
15-24	1.31	(0.98,1.76)		
25-44	-			
45-64	1.23	(1.00,1.50)		
>=65	1.34	(0.96,1.86)		
Sex				
Female	-		-	
Male	1.40	(1.07,1.84)	1.14	(0.83,1.56)
Primary Payer				
Insurance	-		-	
Medicaid/Medicare	1.29	(0.72,2.30)	0.99	(0.51,1.92)
Worker's Comp	1.09	(0.78,1.51)	1.39	(0.95,2.03)
Other/Unknown	6.29	(4.45,8.90)	6.40	(4.32,9.49)
Night	0.90	(0.70,1.14)		
Weekend	1.13	(0.90,1.41)		
Rurality				
Urban	-		-	
Large town	3.51	(2.56,4.82)	2.78	(2.00,3.86)
Small Town	5.15	(4.05,6.56)	5.74	(4.35,7.57)
Rural	4.57	(3.48,6.01)	4.24	(3.07,5.87)
Injury Severity				
ISS 1-8	-		-	
ISS 9-15	1.94	(1.51,2.49)	1.85	(1.42,2.41)
ISS >15	3.15	(2.52,3.92)	2.88	(2.19,3.79)
Injury Type				
Blunt	-		-	
Penetrating	0.84	(0.57,1.22)	0.85	(0.54,1.35)
Burn	2.72	(1.90,3.89)	2.17	(1.40,3.37)
Pelvic Fracture	1.63	(1.17,2.28)		
Amputation	na			
Long Bone Fracture	0.99	(0.81,1.20)		
Spinal Injury	1.99	(1.60,2.48)	1.45	(1.10,1.90)
Crush Injury	1.03	(0.67,1.59)		
Brain Injury	2.13	(1.69,2.69)		
Chest Injury	1.24	(0.72,2.11)		
Motor Vehicle Collision	0.89	(0.70,1.13)		
Fall	0.81	(0.68,0.97)		
Machinery	1.29	(0.99,1.68)	1.52	(1.11,2.08)
Other Transportation	1.08	(0.74,1.57)		

Table 10. Logistic regression model for transfer: Odds ratios farm vs. non-farm injuries at different levels of interacting variables.

			Farm vs. Non-Farm	
			Adj OR	**(95% CI)**
EMS Non-Users	*Urban*	*ISS 1-8*	1.30	(0.65,2.61)
		ISS 9-15	3.47	(1.24,9.72)
		ISS >15	3.26	(0.89,12.00)
	Large town	*ISS 1-8*	1.41	(0.55,3.57)
		ISS 9-15	3.76	(1.10,12.87)
		ISS >15	3.53	(0.79,15.80)
	Small Town	*ISS 1-8*	0.20	(0.12,0.33)
		ISS 9-15	0.53	(0.22,1.30)
		ISS >15	0.50	(0.13,1.85)
	Rural	*ISS 1-8*	0.29	(0.18,0.47)
		ISS 9-15	0.78	(0.31,1.96)
		ISS >15	0.73	(0.22,2.43)
EMS Users	*Urban*	*ISS 1-8*	1.36	(0.67,2.74)
		ISS 9-15	1.67	(0.67,4.14)
		ISS >15	1.70	(0.81,3.58)
	Large town	*ISS 1-8*	1.57	(0.62,4.02)
		ISS 9-15	1.94	(0.62,6.06)
		ISS >15	1.97	(0.69,5.67)
	Small Town	*ISS 1-8*	0.44	(0.25,0.79)
		ISS 9-15	0.55	(0.26,1.16)
		ISS >15	0.56	(0.27,1.13)
	Rural	*ISS 1-8*	0.73	(0.41,1.29)
		ISS 9-15	0.90	(0.43,1.89)
		ISS >15	0.92	(0.47,1.80)

Time to Definitive Care among Severely Injured Patients

For the stratified Cox proportional hazard model, only severe injuries were used; this included both EMS users and non-users. Approximately 13.6% of the original sample was severely injured (ISS >15), leaving an average of 748 individuals (range = 729-776) available for analysis per imputation. Farmers comprised an average of 21% of the severely injured patients (range = 20.0-21.9%). Of the severely injured patients, an average of 12.4% had invalid (e.g. <=0) or missing time to definitive care, including an average rate of 8.0% invalid/missing among farmers and 13.6% among other workers; the time to definitive care was set to the maximum of 4 hours for these cases for survival analysis.

Table 11 compares the characteristics of the severely injured farmers and non-farmers averaged over all imputed sets and are generally consistent with trends previously presented in Table 4. Severely injured farmers tended to be significantly older with nearly one-third of injuries occurring in those aged 65+ compared to only 8.5% in non-farmers, which was more pronounced than the original sample. Again, farmers were less likely to pay by worker's compensations, less likely to be injured at night, and more likely to be injured on the weekend. With regards to injury types, pelvic fractures were significantly more frequent among farmers, while long bone fractures and brain injuries were significantly less frequent. Crush injuries and amputations were relatively uncommon and occurred in less than 5% of cases in both groups. Additionally, the majority of severe injuries were transported by EMS, 79% in farmers compared to 86% in non-farmers.

Kaplan-Meier curves were constructed to show the probability of reaching definitive care for farmers and non-farmers, and indicate that farmers are less likely to reach care in a given time period (Figure 7). The median time to definitive care was approximately 1 hour longer for farmers compared to non-farmers. In Figure 7, the median time to definitive care was 1h48m for non-farmers compared to 2h46m among farmers, though some variation was observed among imputed sets (ranges: farmers 2h40m – 2h54m, non-farmers 1h48m – 1h58m). The log rank test in all imputed sets indicated that farmers had a significantly decreased hazard of reaching care ($p < 0.05$).

A stratified Cox proportional hazard model was used to determine whether time to definitive care differed for farmers compared to other workers; these results are reported for all severe injuries and stratified by EMS use (Table 12). Due to time dependency in the farm status variable, the hazard ratio was calculated for each hour individually. For all severe injuries, the hazard of reaching care is lower (i.e. time to definitive care is longer) for farmers in the first hour after injury (HR = 0.44, 95%CI = 0.24-0.83). In contrast, the estimates for hours 2-4 suggest the opposite effect; however, this fails to meet statistical significance. Taken together, this suggests that farmers may face early barriers to reaching care; however, the effects of these barriers do not appear to persist. When stratified by EMS use, the delay in the first hour is significant among EMS users (HR = 0.42, 95%CI = 0.22-0.80), but did not reach significance among EMS non-users. While this could indicate that this delay only exists among EMS users, this could also be a result of the small sample size (avg. n = 116) in the non-user group.

The adjusted hazard ratios for the other variables included in the model are also shown in Table 12. While the types of injury related to trauma triage were adjusted for in the model, only the presence of a long bone fracture was a significant predictor of increased time to definitive care (HR = 1.31, 95%CI = 1.03-1.69). The increased hazard of reaching care (decreased delay) for long bone fracture patients was even stronger among EMS non-users (HR = 3.59, 95%CI = 1.14-11.29), though the wide confidence intervals are again noted; long bone fracture was not a significant predictor among EMS users. Though not significant among all severe injuries or the EMS subset, spine injuries were also associated with decreased delay in EMS non-users (HR = 1.99, 95%CI = 1.01-3.92). Pelvic fractures, brain injuries, and chest injuries all had hazard ratios close to 1 in the all severe injuries model and were not significant predictors of time to definitive care in this model or in either EMS subset.

Primary payer and age also entered the model as informative predictors of time to definitive care. Compared to privately insured patients, worker's compensation and Medicaid/Medicare patients were not significantly different with regard to reaching care; however, self-paying or having an unknown insurance status was associated with a decreased hazard rate of reaching care (HR = 0.58, 95%CI = 0.43-0.80); this was consistent among both EMS subsets. Certain age groups were also associated with decreased hazard of reaching care in the all severe injuries model, particularly younger and older workers. For younger worker aged 15-24 and older workers aged 65 and older, the hazard rate for reaching care was approximately two-thirds the hazard rate of adults aged 25-44. This relationship was less pronounced, but still significant for adults aged 45-64 who had 80% the hazard rate of reaching care compared to those 25-44. The effect estimates for these age groups suggested delay in both EMS subset, but only reached statistical significance for younger and older workers who used EMS.

Table 11. Characteristics of severely injured occupational injuries, by farm status. Percentages are reported as an average across the 10 imputed sets. P-values are from chi-square tests pooled over the imputed sets according to (68,69).

	Farm (n = 158)*	Non-Farm (n = 590)*	
	%	%	p
Age			<0.0001
15-24	6.3	10.1	
25-44	20.4	34.8	
45-64	41.2	46.6	
>=65	32.1	8.5	
Sex			0.3078
Male	94.6	92.0	
Female	5.4	8	
Primary Payer			<0.0001
Insurance	21.7	9.0	
Medicaid/Medicare	12.7	3.8	
Worker's Comp	16.4	47.6	
Other/Unknown	49.2	39.7	
Night			0.4286
Yes	10.0	14.2	
No	90.0	85.8	
Weekend			0.1328
Yes	19.9	14.6	
No	80.1	85.4	
Rurality			<0.0001
Urban	22.9	56.7	
Large Town	11.7	12.7	
Small Town	21.6	15.9	
Rural	43.7	14.6	
Injury Type			0.7133
Blunt	95.1	94.8	
Penetrating	0.6	1.4	
Burn	4.3	3.8	
Nature of Injury			
Pelvic Fracture	18.9	10.6	0.0073
Amputation	0.7	0.5	0.7905†
Long Bone Fracture	7.5	21.3	<0.0001
Spinal Injury	38.9	34.7	0.3798
Crush Injury	3.4	2.4	0.5150
Brain/Skull Injury	49.4	57.9	0.0769
Chest Injury	7.4	7.5	0.8079
EMS Use			0.1315
User	79.0	86.0	
Non-user	21.0	14.0	

*Reported as an average. Numbers for individual imputed sets vary.
†Estimated from Chi-Square test despite cell counts < 5.

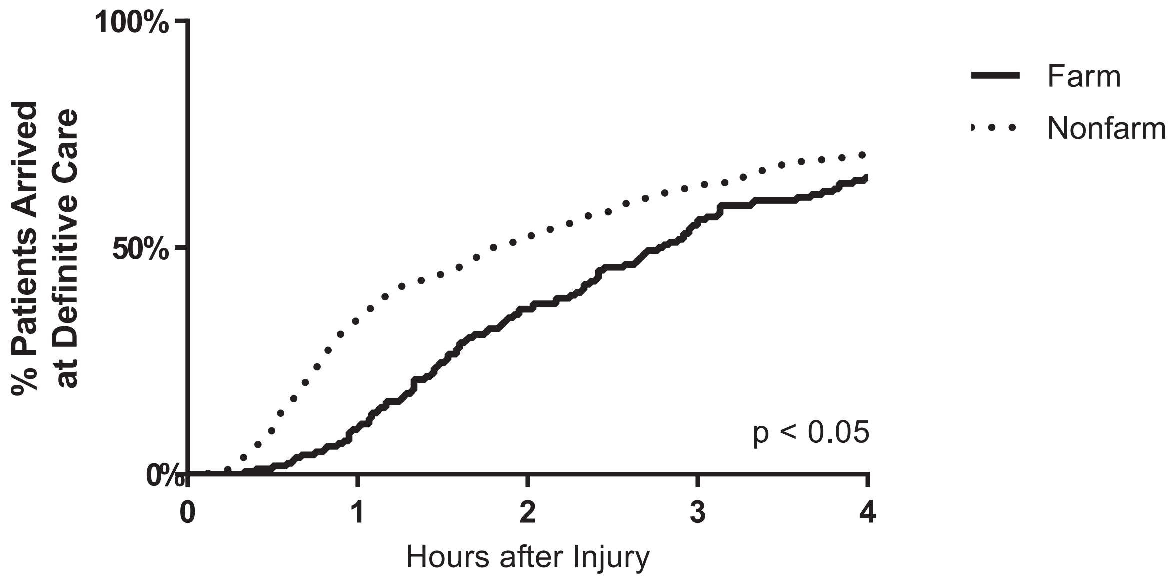


Figure 7. Kaplan-Meier curves showing the probability of having reached definitive care (censored at 4 hours) among severely injured farmers and non-farmers in the first imputed set. P-values were obtained using the log-rank test and are reported as the most conservative (i.e. least significant) value among all imputed sets.

Table 12. Adjusted hazard ratios from Cox proportional hazard model for predictors of time to definitive care among severe occupational injuries. Note: HR < 1 indicates a longer time to definitive care.

	All Severe Injuries		Subset: EMS Non-users		Subset: EMS Users	
	adjHR	95% CI	adjHR	95% CI	adjHR	95% CI
Farm vs. Non-farm						
Hour 1	0.45	(0.24,0.83)	0.71	(0.16,3.09)	0.42	(0.22,0.80)
Hour 2	1.33	(0.89,1.98)	0.81	(0.13,5.07)	1.46	(0.95,2.23)
Hour 3	1.28	(0.79,2.08)	1.96	(0.42,9.12)	1.15	(0.65,2.05)
Hour 4	1.40	(0.77,2.54)	0.63	(0.11,3.65)	1.73	(0.84,3.59)
Injury Type (Yes vs. No)						
Pelvic Fracture	1.05	(0.77,1.42)	1.67	(0.30,9.43)	1.01	(0.74,1.38)
Long Bone Fracture	1.32	(1.02,1.71)	3.59	(1.14,11.29)	1.20	(0.92,1.56)
Spine Injury	1.05	(0.86,1.29)	1.99	(1.01,3.92)	0.96	(0.78,1.18)
Brain Injury	0.94	(0.77,1.15)	0.92	(0.46,1.81)	0.96	(0.78,1.19)
Chest Injury	0.95	(0.67,1.34)	0.25	(0.03,2.35)	1.03	(0.72,1.47)
Additional Covariates						
Payer						
Insurance	ref		ref		ref	
Medicaid/Medicare	0.94	(0.56,1.59)	0.59	(0.12,2.82)	0.93	(0.53,1.64)
Worker's Comp	0.87	(0.63,1.20)	0.67	(0.23,1.93)	0.88	(0.63,1.24)
Other/Unknown	0.58	(0.42,0.80)	0.35	(0.13,0.91)	0.61	(0.43,0.85)
Age						
15-24	0.70	(0.50,0.98)	0.74	(0.19,2.96)	0.67	(0.47,0.97)
25-44	ref		Ref		ref	
45-64	0.80	(0.65,0.99)	0.74	(0.39,1.40)	0.81	(0.64,1.02)
>=65	0.64	(0.45,0.90)	0.84	(0.32,2.24)	0.62	(0.41,0.92)

Analysis of Prehospital Time Intervals among EMS Users

As discussed previously, the prehospital period can be segmented into smaller intervals based on EMS-related events in the trauma response. The goal of this analysis was to determine whether particular intervals in the prehospital period were longer for farmers using EMS compared to non-farmers using EMS, suggesting delays in specific processes.

Information from 1237 cases with complete time information, necessary to calculate the prehospital intervals, is shown in Table 13. For nearly all of the imputed sets, these cases consisted of 142 farmers and 1095 non-farmers; the exception was one set which had 143 farmers and 1094 non-farmers. The characteristics of the farmers compared to the non-farmers were generally similar to those previously observed in the whole dataset (Table 4); famers tended to be older, less frequently covered by worker's compensation, less frequently injured at night, less frequently injured on the weekend, and more frequently injured in rural and small town environments. Though a slightly greater proportion of farm injury victims were male compared to non-farmers, this was no longer significant in the time-complete, EMS-transported subset (Table 13). Whereas injury severities were relatively similar among all cases previously, this subset tended to have more severe injuries among the farmers (25.8% severe vs. 16.9% among non-farmers). Additionally, the distribution of severity seems to be shifted more towards severe injury in this subset, which could be a reflection of the EMS-transported inclusion criterion. The EMS subset also included fewer patients with other/unknown insurance status and fewer patients from rural environments. Compared to all eligible patients, this subset contained fewer transfer cases (10.5% vs. 29.7% for all cases); the proportion of transfers among farmers (19.7%) was twice that of non-farmers (9.3%).

Kaplan-Meier curves were constructed to show the differences in the probability for reaching definitive care (Figure 8) for the subset of cases with complete time information; this comparison is similar to that made in Aim 2, but is carried out on the subset with full time interval data. As with the severe injuries examined in Aim 2, the farmers in this subset (mixed severity) have longer times to definitive care ($p < 0.0001$). The estimated median time to care based on the Kaplan-Meier plots were 1h17m for farmers compared to 50m for non-farmers, or a 27 minute difference; this result was consistent for all imputations.

The prehospital period was segmented into five more specific states/intervals, including the discovery interval, response interval, scene interval, transport interval, and finally the state of having reached definitive care (Figure 9). Median times were computed for each interval for both farmers and non-farmers (Table 14). Overall, median time to definitive care was 27 minutes longer for farmers compared to non-farmers (77 vs. 50 minutes, $p < 0.0001$), as previously shown with the Kaplan-Meier analysis. Further examining the individual intervals, farmers initially had a longer discovery (15 vs. 8 min, $p < 0.0001$) and response intervals (12 vs. 7 minutes, $p < 0.0001$). EMS providers spent a median of 14 minutes on the scene for both groups. Once EMS departed the scene, farmers spent a median 10 minutes longer in the transport interval than did non-farmers (26 vs. 16 min, $p < 0.0001$). The longest interval for both farmers and non-farmers was the transport interval, while the shortest interval was the response interval. The transport interval showed the greatest absolute difference of 10 minutes, while the discovery interval showed the greatest percent increase of 87.5% for farmers. Since transfers were disproportionate between farmers and non-farmers, the transport interval was recalculated stratifying by transfer status. Farmers going directly to definitive care had transport intervals that were 9 minutes longer than non-farmers (23 vs. 14 min, $p < 0.0001$), while farmers that underwent an interfacility transfer actually had shorter transport intervals (177 min vs 181 min), though this result was not significant. These results are also depicted graphically using Kaplan-Meier curves for each segment (Figure 10), which similarly show that farmers spend significantly longer discovery, response, and transport intervals. However, none of these calculations took into consideration the effect of important confounders, namely rurality, on the hazard of transitioning through these intervals.

In order to adjust for confounding variables, a multi-state stratified Cox proportional hazards model was used to model the intensity of the transitions between states, using rurality as a stratifying variable. As shown in Figure 9, four transitions were considered in this model. Given the same level of rurality, farmers had a decreased hazard of transitioning from states, except for the transition from state three to four, which showed no difference (Table 15). The first transition corresponds to the change from the discovery interval to the response interval (state one to two); the model indicated that farmers had a 30% reduction in the hazard (HR = 0.70, 95%CI = 0.58-0.85) of transition between these states indicating a longer time. Likewise, there is approximately a 35% decrease in the hazard for the transition between state two to three (HR = 0.65, 95%CI = 0.53-0.80), corresponding to the switch from response interval to scene interval; a similar decrease was also observed for the transition between state four to five (HR = 0.64, 95%CI = 0.52-0.77), corresponding to the switch from transport interval to finally reaching care. In other words, compared to non-farmers experiencing occupational injuries, injured farmers waited longer for the ambulance to be dispatched, for the ambulance to arrive at the scene, and, once in the ambulance, to reach their final hospital destination. Furthermore, the results from this multi-state model appear to agree with those from the analysis of the medians in Table 13, indicating that farmers are more likely to spend a longer amount of time in the discovery, response, and transport intervals.

Two other predictors – interfacility transfer and severity of injury – were also included in the multi-state model and were significant predictors of particular transitions. For the transition from state four to five, the hazard of reaching definitive care was much lower for those that underwent an interfacility transfer than for those that proceeded directly to care (HR = 0.06, 95%CI = 0.04-0.08), which we would expect since the process of visiting a local hospital before proceeding to the definitive care hospital requires additional time. The effects of severity were insignificant for all transitions except for the transition from state two to three, in which severe injuries had a decreased hazard compared to minor injuries (HR = 0.82, 95%CI = 0.70-0.96). This indicates that, once the ambulance was dispatched, those with severe injuries waited longer for the ambulance to reach the scene.

Table 13. Characteristics of 1237 cases with complete time information used in the analysis of the prehospital intervals. All cases were transported by EMS and reached definitive care within 24 hours.

	Farm (n = 142)*	Non-Farm (n = 1095)*	
	%	%	p
Age			<.0001
15-24	4.2	11.4	
25-44	25.4	39.9	
45-64	47.9	42.7	
>=65	22.5	6.0	
Sex			0.3608
Male	88.7	85.9	
Female	11.3	14.1	
Primary Payer			<.0001
Insurance	31.7	9.0	
Medicaid/Medicare	12.7	2.0	
Worker's Comp	17.6	69.0	
Other/Unknown	38.1	19.9	
Night			0.0018
Yes	7.7	18.2	
No	92.3	81.8	
Weekend			0.0044
Yes	23.3	14.1	
No	76.7	85.9	
Rurality			<.0001
Urban	31.5	73.2	
Large Town	8.0	11.5	
Small Town	25.7	9.1	
Rural	34.8	6.2	
Injury Severity			0.0278
ISS 1-8	53.0	65.1	
ISS 9-15	21.2	18.0	
ISS >15	25.8	16.9	
Injury Type			0.9796
Blunt	90.1	89.7	
Penetrating	5.6	6.0	
Burn	4.3	4.3	
Interfacility Transfer			0.0001
Yes	19.7	9.3	
No	80.3	90.7	

*Reported as an average. Numbers for individual imputed sets vary.

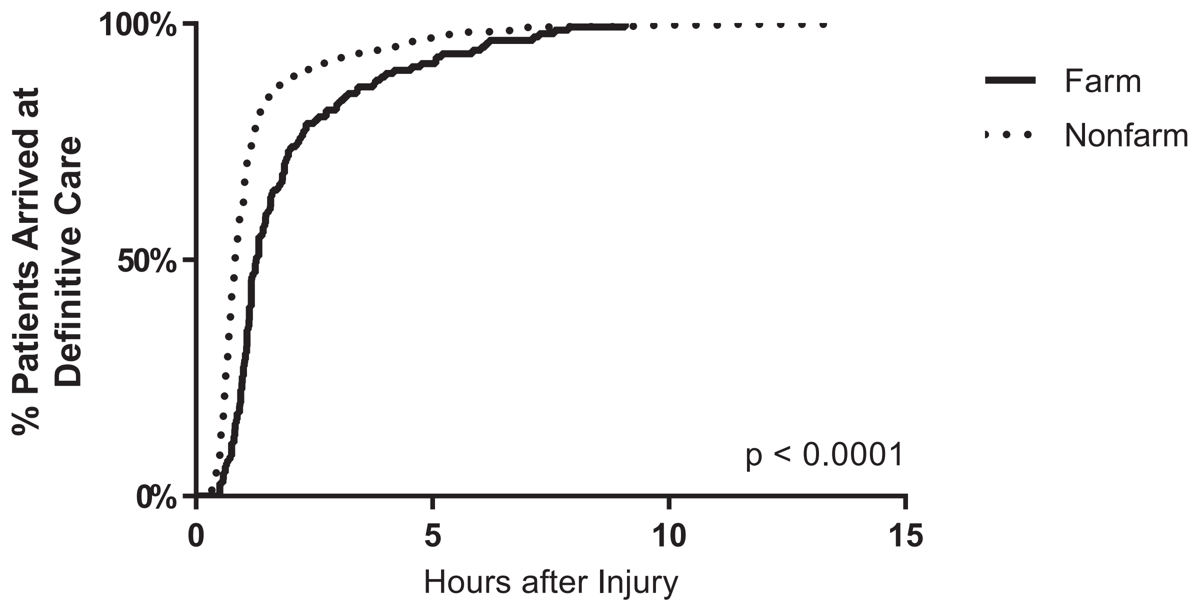


Figure 8. Kaplan-Meier curves showing the probability of having reached definitive care among farmers and non-farmers with complete time information (first imputed set). P-values were obtained using the log-rank test and are reported as the most conservative (i.e. least significant) value among all imputed sets.

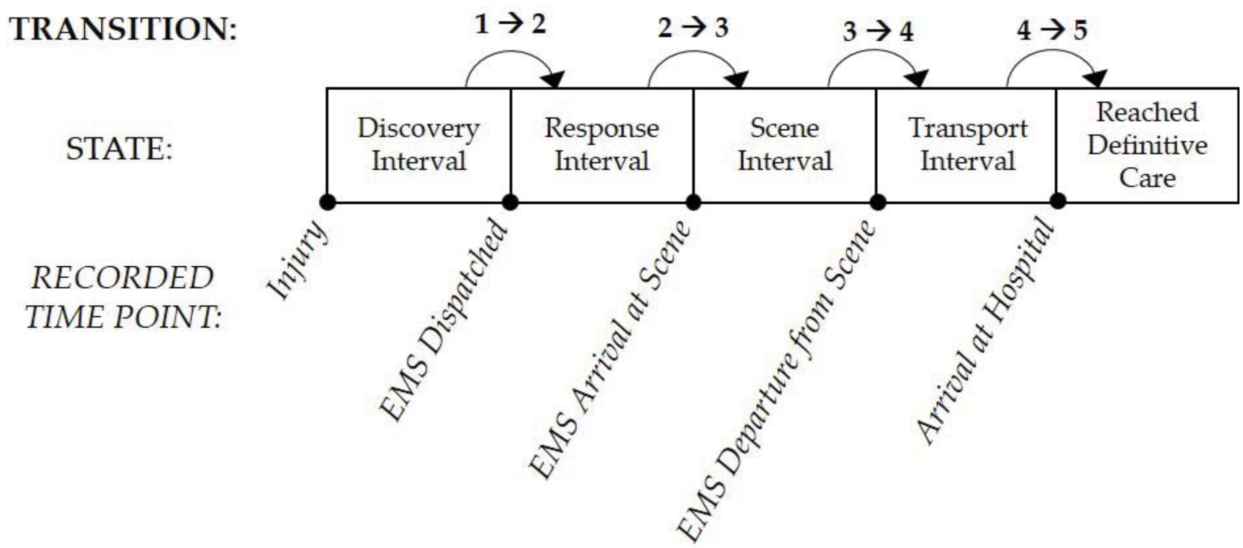


Figure 9. Diagram of prehospital period showing the relationship of the time points recorded in the Iowa State Trauma Registry, the states defined by these time points, and the transitions used in the multi-state modeling of the prehospital intervals (Aim 3).

Table 14. The median times for the prehospital time intervals in the first imputed set, by farm status. Time intervals correspond to the states shown in Figure 9. P-values were calculated from Wilcoxon rank-sum tests for the individual imputed set. Results from the other nine imputed sets were nearly identical.

	Farm			Non-Farm			
Interval	N	Median Time (min)	Inter-Quartile Range	N	Median Time (min)	Inter-Quartile Range	p
Time to Definitive Care	**142**	**77**	**[59-130]**	**1095**	**50**	**[38-72]**	**<0.0001**
Discovery Interval	142	15	[7-30]	1095	8	[4-16]	<0.0001
Response Interval	142	12	[9-20]	1095	7	[4-11]	<0.0001
Scene Interval	142	14	[11-19]	1095	14	[10-18]	0.6438
Transport Interval	142	26	[16-43]	1095	16	[10-25]	<0.0001
Transport: Transfer = No	114	23	[15-32]	993	14	[10-21]	<0.0001
Transport: Transfer = Yes	28	177	[118-254]	102	181	[115-244]	0.9526

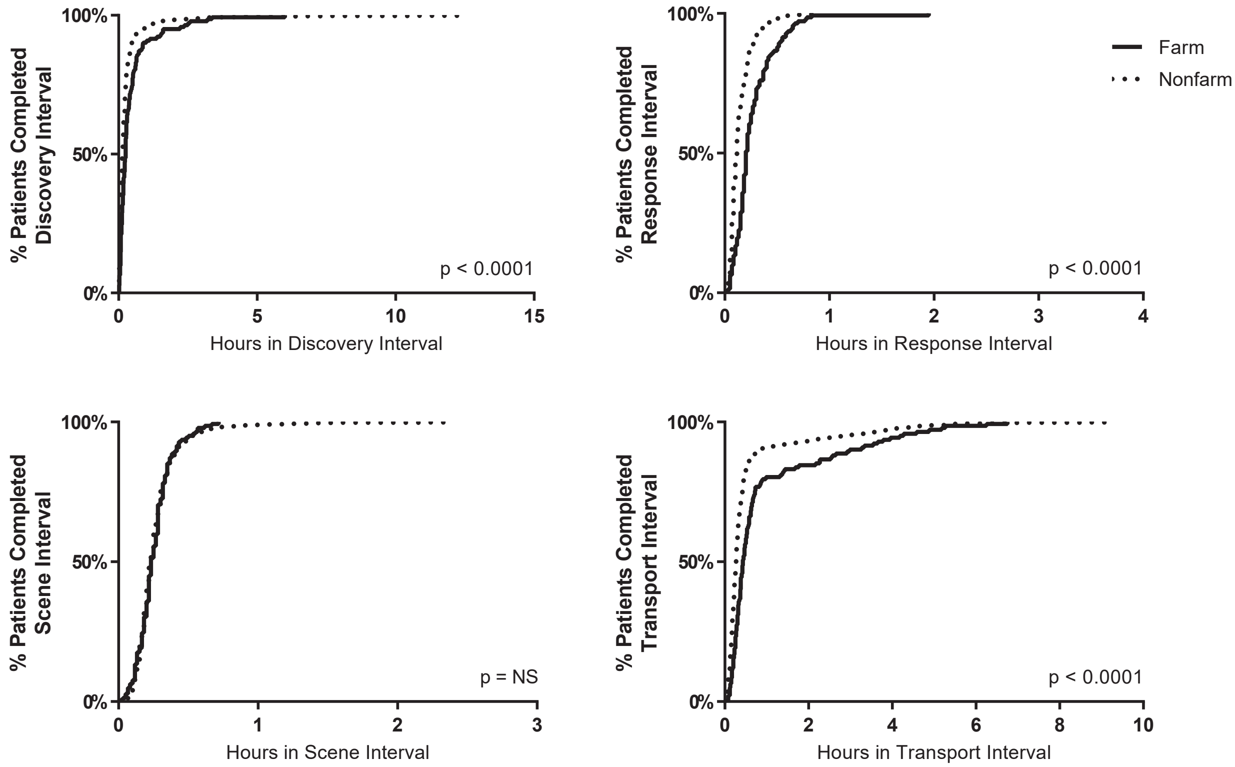


Figure 10. Kaplan-Meier curves showing the probability of having completed discovery, response, scene, and transport intervals for farmers and non-farmers with complete time information (first imputed set). P-values were obtained using the log-rank test and are reported as the most conservative (i.e. least significant) value all imputed sets.

Table 15. The association between variables and the transitions between states in the prehospital period. A hazard ratio < 1 indicates increased delay (i.e. a longer time spent in the initial state before transitioning to the subsequent state). These estimates were adjusted for rurality via stratification in the stratified Cox model.

Transition	Covariate		HR	95%CI	
1 --> 2	**Farmer**	Yes	0.70	(0.58,0.84)	*
		No	ref		
	Severity	Minor	ref		
		Moderate	1.00	(0.85,1.17)	
		Severe	0.95	(0.81,1.11)	
2 --> 3	**Farmer**	Yes	0.65	(0.53,0.80)	*
		No	ref		
	Severity	Minor	ref		
		Moderate	0.95	(0.81,1.11)	
		Severe	0.82	(0.70,0.96)	*
3 --> 4	**Farmer**	Yes	0.96	(0.79,1.17)	
		No	ref		
	Severity	Minor	ref		
		Moderate	0.96	(0.82,1.11)	
		Severe	0.92	(0.79,1.08)	
4 --> 5	**Farmer**	Yes	0.64	(0.52,0.77)	*
		No	ref		
	Severity	Minor	ref		
		Moderate	1.05	(0.90,1.23)	
		Severe	1.11	(0.95,1.31)	
	Transfer	Yes	ref		
		No	0.06	(0.04,0.08)	*

CHAPTER V: DISCUSSION

Our results indicate that approximately 1 of every 5 occupational injuries hospitalized in the state of Iowa was farm-related. The experience of these injured farmers in the Iowa Trauma System differed from other workers in several ways.

Demographic and Injury Characteristics

Descriptive analyses showed that those reporting farm-related compared to non-farm-related injuries were more frequently over the age of 65 (Table 4). Older farmers have previously been identified as a high risk group in agriculture. While the incidence of nonfatal injury has previously been shown to decline with age (70,71), older farmers tend to experience more severe injuries, hospitalizations, and death compared to younger farmers (70). The rate of injuries presenting to an Emergency Department has also been shown to be higher for older workers in agriculture compared to other industries (72). The observed frequency of injuries in the elderly farmer emphasizes the need for injury prevention interventions in this population.

Our data also indicated that the percentage of injuries occurring in males was higher for farmers than non-farmers (Table 4). This finding is consistent with previous work showing that the injury rate of males relative to females is higher in agriculture than in most other occupational groups (72). Women are reported to be more likely to seek off-farm work to supplement the family income (73). Those who do work on the farm are less likely to be involved in tasks directly related to production (73) and would, therefore, less frequently be classified as farm-related in the ISTR.

Farm-related injuries were less likely to occur at night and more likely to occur during the weekend than other occupational injuries (Table 4). This is likely a difference in exposure attributable to the working habits of farmers, whose job tasks are typically completed during daylight hours and may not be confined to a traditional work week. Those in the non-farm group may have more occupational exposure during evening/night hours if involved in industries, such as retail and manufacturing, which may require later hours/shifts.

Farm and non-farm injuries differed by the source of payer (Table 4). Non-farm injuries were more likely to be covered by worker's compensation, whereas farmers were more likely to be privately insured. This observation likely derives from Iowa State law which exempts certain agricultural workers, including farm operators and family members, from worker's compensation coverage (74). Thus, additional worker's compensation coverage is not required for small family farms, and therefore, individuals injured in such operations may instead submit claims to personal insurance providers.

Finally, though injury severity and general injury type (i.e. blunt, penetrating, burn) were not significantly different between farm and non-farm injuries, specific injury diagnoses were more common in farmers vs. non-farmers. Pelvic fractures and amputations where more common among farm injuries, while long bone fractures and crush injuries were more common among non-farmers. Differences in job activities likely play a role as suggested by significant differences in certain mechanisms of injury (Table 5); however, the heterogeneity of occupation types in the non-farm group makes it challenging to attribute such differences to particular job activities.

Aim 1a: EMS Use

As hypothesized, patients with farm-related occupational injuries were less likely to be transported by EMS services than patients with non-farm-related occupational injuries even when adjusted for demographic and injury characteristics. However, this relationship was not consistent at all levels of injury severity (Table 7). For those with minor injuries, farm injuries had half the odds of being transported by EMS services, while EMS use was nearly identical among those with severe injuries. Evidence exists that this difference in EMS utilization predated the trauma system.

Results from a study of six rural Iowan hospitals prior to the full implementation are consistent with our findings (46). Despite improvements in organization, education, and accessibility of EMS providers that occurred during the implementation process, farmers remain less likely to use EMS services for minor injuries.

The fact that farmers are less likely to use EMS for minor injuries, but equally likely for more severe injuries, has several implications. The lack of an association for high and medium severity injuries suggests that the ability of farmers to use EMS is similar to other workers for the most critical of injuries. However, decreasing EMS use associated with lower levels of severity may represent a deliberate choice to forgo EMS transport, rather than an inability to access services. Previous qualitative research examining the culture of farming has highlighted the attitude of stoicism among farmers, which leads them to mask pain as a way of preserving dignity and self-identity (75); this underlying attitudes may impact a farmer's risk-benefit analysis of halting work and seeking EMS assistance. Another influence may be that farmers may already have a vehicle for transport to/from the fields; anticipating the difficulty in having EMS come to the field, farmers may find it simpler to drive themselves directly to the hospital rather than meeting an ambulance at an intersection or at their residence. The motives underlying health decision-making are undoubtedly complex, and further research is needed to understand factors influencing healthcare utilization among farmers as well as examine injury outcomes.

Increasing level of rurality was also associated with decreased EMS use. Those injured in rural or small town zip codes had a greater than 30% reduction in the odds of EMS use compared to those in urban areas. An association between decreased ambulance use and rurality has previously been reported in literature. Analysis of 91,132 traumatic injuries in Pennsylvania's trauma system, found that those in small town/rural counties had a 70% reduction in the odds of EMS use (OR = 0.3, 95% CI = 0.3-0.3); however, this effect disappeared when adjusted for severity (76). However, this study only included those directly transported from the scene to a designated trauma center and did not include those transferred in from other facilities. Thus, if rural patients transported themselves to a local non-designated facility and subsequently required transfer to a trauma center, their findings may actually under-estimate the true effect. Residing outside of a metropolitan area (as defined by metropolitan statistical area) is also associated with decreased ambulance use for all-cause emergency department visits according to a study using National Hospital Ambulatory Medical Care Survey (2004-2006) (77). This reduction in utilization may reflect the decreased availability of EMS service (11) in rural environments relative to that of urban areas.

Several other factors including age, payer type, injury severity, and injury type were also associated with EMS utilization. Age has previously been shown to be associated with increased ambulance use both for all-cause emergency department users (77–80) and for trauma patients, specifically (46,76,81); however, this effect was not seen in our results. Instead, we found a marginally significant increase in EMS use among those 45-64, but not among other age groups. Since our sample only includes occupational injuries, the elderly individuals in our study may be healthier and more robust than unemployed elderly individuals (healthy worker bias), attenuating the age effect seen in these other studies.

Those covered by worker's comp were also more likely to use EMS compared to those who paid by personal insurance. Previous studies have found that insurance type predicts ambulance use (79), though the reasons behind these influences remain unclear. One possible explanation for our results may be that injury victims are more likely to use ambulance services when their employers cover the expenses; alternatively, employers may prefer that injured employees be assessed and transported by EMS to safeguard against future litigation.

The injury characteristics were also important. Consistent with our findings, increased injury severity has been shown to lead to higher EMS use (46,79,81).

Furthermore, most of the injury diagnoses and mechanisms in our model were significant for increased EMS use, which is expected because these types of injuries were selected because they dictate EMS triage protocols; in other words, they tend to be serious injuries that warrant immediate medical care at a high level trauma center. Thus, these were purposefully included as confounders to adjust for the trauma patient case mix. Unexpectedly, penetrating injuries were associated with a decreased EMS use. Penetrating injuries were also less common among farm workers than other occupations. Penetrating injuries often have large blood loss, and it is possible that decisions to transport directly to reach the hospital as quickly as possible are made by individuals at the scene. This finding, however, is not documented in previous literature and warrants further investigation. Since this model was developed a priori and no variables were excluded, adjustment for other related variables such as severity or injury type may have captured the explanatory power of this variable; however, it is unclear why this variable is significantly associated with decreased EMS use.

Aim 1b: Interfacility Transfer

Our original hypothesis posited that farmers would be less likely to proceed directly to care at a definitive care hospital necessitating more interfacility transfers. Though crude analysis offered some support for this hypothesis, the adjusted analysis showed that farmers not using EMS had significantly lower odds of transfer (Table 8), while those using EMS were not significantly different from other workers (Table 9).

However, this relationship was modified by the level of rurality and injury severity (Table 10). Farm status tended to be protective in small town and rural environments, but this effect was only significant for those with minor injuries. This finding may suggest that farmers with minor injuries may prefer to seek care locally at lower level facilities, though research in this area is lacking. Furthermore, while this trend was observed in both EMS users and non-users, it appeared to be stronger among the group that was not transported by EMS. This is consistent with the idea that formalized EMS protocols improve triage efficiency. Ideally, EMS providers should triage all workers to the appropriate level of care regardless of their occupation. In the absence of a formalized health assessment, patients transporting themselves to the hospital may be more influenced by personal preference. While it appears that the differences between farmers and non-farmers are reduced in the EMS group, farmers with minor injuries in small towns still have significantly reduced odds of interfacility transfer even when transported by EMS indicating that some aspect of the farming occupation leads to greater likelihood of local treatment; this could still be reflective of farmer preference given patient preference is a factor in EMS decision-making (82). This may also suggest that non-farmers have greater odds of being over-triaged; however, complete information on the rationale of the decision to transfer is not available making it difficult to determine which transfers of patients with minor injuries were appropriate.

Conversely, farm status increased the odds of transfer in other settings, particularly among patients with moderately severe injuries in more populated areas. Among EMS non-users, those with moderate injuries in urban areas and large towns had significantly higher odds of transfer. One possibility is that farmer's maintain a preference for care at smaller local hospitals, but that these facilities in urban/large town locations are more accustomed to transferring to higher facilities nearby. This effect was not as strong and did not reach statistical significance for severe injuries; perhaps when injuries reach a certain severity threshold, patients more clearly recognize the need for higher level services and bypass local hospitals. As mentioned above, the process of deciding when and where patients seek trauma care is poorly understood. The increase in odds of transfer for farmers is less pronounced and not significant among patients using EMS, which may again suggest that those who have a more objective injury assessment may receive more consistent triage regardless of occupation.

Insurance type was a predictor of transfer. In particular, "other/unknown" insurance was a significant predictor of transfer in both groups compared to those with insurance; this group included those that were uninsured or self-paid. Previous studies have indicated that lack of adequate insurance is associated with an increase rate of transfer from a non-trauma center to a trauma center (83), suggesting that non-trauma hospital choose to admit insured patients due to better reimbursement rates; however, only a quarter of the people in this study resided outside a metropolitan area. While some cases in our study could have been transferred for economic motivations, the wide geographic dispersion would likely make this less common than in metropolitan areas. Instead, this finding is likely a result of a higher proportion of missing insurance status for those transferred compared to non-transferred patients reflecting a data collection inefficiency. Worker's compensation was also significantly associated with transfer, though only in the EMS non-user group. Since this effect is not consistent among both groups, it seems unlikely that this association is due to an inherent pressure to transfer injured workers to high level facilities. However, this could reflect a preference for local care in industries associated with a high level of worker's compensation claims, such as roofers and carpenters (84).

Finally, several injury types were more likely to be transferred including burns, spinal injuries, brain injuries (EMS users only), and machinery injuries. For some injuries, such as burns and spinal injuries, specialized services (i.e. burn treatment centers, neurosurgeons) are limited to high level facilities, and recognition of the need for such services would necessitate transfer. Other injuries may require immediate stabilization at the closest facility before continuing to the definitive care hospital. It is difficult to determine the underlying cause of the transfer and whether under- or over-triage is present without more in depth examination of these injury types individually.

Aim 2: Time to Definitive Care among Severely Injured Patients

Due to the nature of agricultural work, we hypothesized that severely injured farmers were more likely to face delays than their non-farmers, and according to both Kaplan-Meier and Cox analysis among all severely injured workers, there was indeed evidence of significant delay among farmers compared to non-farmers (Figure 7, Table 12). However, the addition of a time-dependent interaction in the Cox analysis showed that this delay was restricted to the early portion of the prehospital period, specifically to the first hour after injury.

To our knowledge this is the first study to identify that a delay in reaching trauma care exists specifically for farmers. While several previous studies have identified delays among rural populations (11–17), none have attempted to separate the effects of rurality from those of farming. Though rurality undoubtedly contributes to increased prehospital time, there are likely additional factors that affect farmers; these factors may include working alone, being injured in locations difficult to access, and the presence of hazards (i.e. animals, machinery, natural elements) at the scene. While our study suggests that farmer-specific factors are contributory, our study is not able to specify which factors are most important. Additional analyses are needed to explicitly identify influential factors and ultimately lead to interventions that reduce delay in trauma care for farmers. Additionally, while we attempt to elucidate the source of these delays by breaking down the prehospital intervals (see Aim 3), further qualitative work examining the barriers to injury response in detailed injury narratives, which are less likely to be available from registry and/or hospital data, is also needed.

An interesting finding in Cox modeling was that the delays experienced by farmers were confined to the first hour after injury; farmers had more than a 50% reduction in hazard of reaching care during this period. The subset analysis of EMS users and non-users (Table 12) showed that EMS users mirrored the results of the entire sample, while the delays among non-users were not significant. One possibility is that delay actually exists for both EMS users and non-users, but the result failed to reach statistical significance among non-users due to the small sample size. The other possibility is that the prehospital experiences of EMS users and non-users truly differ. In either case, the fact that the sample of severe injuries was predominately EMS users means that the findings of the overall model are more reflective of the experience of EMS users.

The fact that delay was present in the first hour could be explained by multiple mechanisms. First, this finding may indicate that the early stages in process of reaching care are delayed (e.g. identifying that an injury has occurred) in farmers, while later stages (e.g. driving to the trauma center) are no different. While Aim 3 attempts to address these questions among EMS users, further analysis of the prehospital period among EMS non-users is not possible because only injury time and time of arrival at hospital are recorded in the ISTR. Another possibility may be that this finding is influenced by the composition of the control group. Since our analysis of time to definitive care for severely injured workers (Table 12) compares farmers to all other non-farm Iowan workers; there could be a subset of controls (e.g. hospital workers) that reach care quickly relative to both the farmers as well as the other controls and could account for the early increase in hazard of reaching care among controls. Since the ISTR does not contain occupational designations for the non-farm workers this is challenging to assess in the current dataset; such a variable would aid future studies of occupational injury using the ISTR. Though the root cause of this delay is unclear, our findings do warrant further investigation into the ability of farmers to access trauma services following a severe injury.

With the exception of long bone fractures, most injury types were not significant predictors of time to definitive care in severely injured workers. This suggests that the recognized need for care and the promptness in delivering the patient to trauma services was similar for most injury types. Long bone fractures were the only injury type to reach significance in this model and were significantly associated with decreased delay in reaching definitive care. Previous studies have shown that the practicing rural general surgeons are known to routinely perform orthopedic procedures (85,86). Additionally, one study of Medicare patients showed that patients had shorter travel times/distances for fractures/dislocations relative to a number of other medical diagnoses, though their sample was not limited to severe cases (87). Therefore, one explanation may be that, while many of the other severe injury types may necessitate a surgical specialist, some patients with long bone fractures may be handled locally by either local orthopedic specialists or general surgeons. Among EMS non-users, spinal injuries were also predictive of decreased delay in reaching care. While this could indicate that those transported by private vehicle are quicker to react to spine injuries, this finding should be interpreted cautiously as the sample size of spine injuries among EMS non-users was relatively small (average n = 26 per imputation). In the overall model, spine injuries were not a significant predictor of delay.

Two additional variables, age and payer status, were included in the model of time to definitive care and were predictors of increased delay. With regards to age, the youngest and oldest workers tended to face greater delays in care that could be due to multiple sources: 1) the need for specific services available at only a few centers (i.e. long transport times), 2) the need for additional stabilization before interfacility transfer, and 3) an increased likelihood of interfacility transfer. From Aim 1, we saw that among injury patients transported by EMS both younger and older individuals are more likely to be transferred (Table 9). This increase in transfer was not observed for EMS non-users (Table 8) and likewise was not significant in the Cox model for time to definitive care among the EMS non-user subset (Table 12). Pediatric specialty services in Iowa are concentrated in two urban regions, so long travel times may contribute to the delays in this demographic. For older adults, previous studies have shown that older adults are more likely to be under-triaged (24,88,89) to lower level trauma centers when higher level facilities were more appropriate; this may lead to delayed transfer and increase the time to definitive care. Older individuals may also be more medically fragile necessitating an initial visit to a local facility before proceeding to definitive care.

With regards to payment status, only other/unknown was a predictor of delay. This category is difficult to characterize since many of the patients in this group are lacking information on insurance. One explanation for this association would be a hesitancy of uninsured patients to seek trauma care following injury; however, given the individuals in this model were all severe injuries, we would expect delay from this cause to be minimal. A more likely explanation is that this variable was strongly associated with transfer in Aim 2 for both EMS users and non-users. This association may be due to data collection inefficiencies or a bias in transferring under-insured patients (discussed in Aim 1) as either cause would serve to increase the time to definitive care.

Aim 3: Prehospital Intervals among EMS Users

In the final model, we used a set of patients with known prehospital time information to identify which prehospital intervals significantly contributed to delay. We initially hypothesized that the discovery and scene intervals would be longer among farmers due to delays in recognition of the injury and difficulties in accessing the patient, respectively. However, our results showed that discovery, response, and transport intervals were all longer among farmers, while the scene interval was not significantly different; these results were consistent for the Wilcoxon rank sum tests (Table 14), the Kaplan-Meier log-rank tests (Figure 10), and the multi-state stratified Cox proportional hazard model (Table 15). Each time interval represents a particular phase of the trauma response and suggests the need for a different approach to reducing delay.

The discovery interval represents the amount of time needed for the injury to come to the attention of EMS. In our sample, the median discovery time was 15 minutes for farmers compared to only 8 minutes in non-farmers ($p < 0.0001$), and delay for farmers remained significant after adjustment for rurality and injury severity in multi-state modeling. Most commonly, EMS becomes aware of an injury after a 9-1-1 call is placed either by the injury victim or a bystander and dispatches an ambulance to the injury scene. If a farmer is injured while working alone in remote areas, a bystander is less likely to be available to provide assistance should the farmer be unable to call for help themselves. Also, though market research indicates that nearly all farmers use cell phones (90), the quality of cellular coverage may vary in rural areas leading to poor quality calls. One way to reduce the discovery interval for farmers would be improved monitoring systems. The literature reports that smartphone apps are already being developed to automatically detect and notify contacts of tractor rollovers (91) or falls (92). Further developments in mobile devices, including wearable technologies, may make monitoring systems more feasible for farmers in isolated conditions.

The response interval represents the period that the ambulance is in transit to the injury scene. Even after adjustment for rurality and severity in the multi-state model, farmers experienced significantly more delay during this interval. One plausible source of delay could be difficulty in initially locating the farmer if the injury occurs in a field/remote area without precise geographic information. Since GPS coordinates are available from smartphones and even some farm equipment, delays may be reduced by integrating this information with EMS response systems. A second cause for delay in this interval could be difficulty traversing the terrain to get the injured farmer. Though this issue is less easily addressed, individual EMS agencies may find specialized equipment for off-road extractions useful depending on the terrain of their coverage area. A final contributing factor may be rurality itself. Though we adjusted for rurality in our modeling, our adjustments were performed on variables derived from zip code level data. A single zip code may contain sub-regions with higher rurality; farmers may be more likely to work and become injured in these more rural sub-regions leading to slightly longer response times.

The scene interval is the period during which EMS assesses the patients, provides on-scene stabilization or treatment, and loads the patient into the ambulance. Initially, we hypothesized that farmers may have longer scene times due to hazards at the scene, such as machinery or animals, which would require prolonged extrications (e.g. entanglements) or interfere with EMS provider activity; however, none of our analyses showed that the scene interval was longer for farmers. This scene interval may also be lengthened when EMS providers perform more procedures at the scene as opposed to minimizing time at the scene in favor of rapid transport. This debate between the philosophies of "scoop and run" versus "stay and play" is ongoing (for review see (93)), and our study was not designed to address this question. Instead our results show no evidence to suggest that farmers receive more time-consuming procedures at the scene.

Finally, the transport interval represents the time it takes for the patient to reach the definitive care hospital once the ambulance has left the scene. A major factor contributing to delay during the transport interval is whether an interfacility transfer occurred. In both farmers and non-farmers, our analysis of the median times (Table 14) showed that transferred patients had a transport interval that was more than 2.5 hours longer than non-transferred patients, though this analysis was not adjusted for rurality. Transfer remained a very highly significant predictor of delay in the adjusted multi-state model. The necessity of transfer depends on the medical needs of the injured patient and the availability of the medical services. In the Iowa trauma system, severely injured patients are to be delivered directly to a high level facility whenever possible, but in cases where immediate stabilization is required, transfers may be unavoidable. Unfortunately, rural areas suffer from a lack of specialty services, but innovations in medical care, such as telemedicine, may make it possible to avoid transfers in the future by 1) offering remote evaluation of patients to determine the necessity of transfer and 2) making it possible for local hospitals to provide additional trauma services to injury victims under the remote supervision of a specialist. Despite the adjustment for interfacility transfer in the multi-state model, farmers still faced more delays during the transport interval. As with the response interval, this could be a residual effect of rurality if the farmers were injured within a more rural sub-region of a zip code.

Limitations

The analyses performed in this thesis are subject to several limitations. First, the ISTR includes only patients who sought care at a hospital or for whom a trauma alert was initiated. Those who chose not to seek medical attention or who sought treatment at an outpatient clinic were not captured in this dataset which would likely lead to under-sampling of injuries in the state, particularly of minor injuries. This under-sampling could affect our estimates of factors predicting EMS use in Aim 1a, especially since the association of decreased EMS use with being a farmer was driven by minor injuries; if a disproportionate number of non-farm workers seek care locally, we may be over-estimating this association. Since Aim 2 was restricted to severe injuries and Aim 3 was restricted to EMS users, the patients under-sampled by the ISTR would not have been included in these analyses, so the results from these aims are less likely to be affected.

Another group of individuals that are not included in the ISTR are patients who are dead when EMS arrives on the scene, though those patients who are pronounced dead at the emergency department are included. This means that the ISTR under-samples not only catastrophic injuries where death is near instantaneous, but also injuries where excessive delay could lead to death prior to EMS arrival. Given that approximately 1 in 1000 occupational injuries is fatal, we estimate that very few individuals were missed due to death prior to EMS arrival (n < 6) and suspect that their exclusion would not have had a major impact on our analyses.

The ISTR also does not collect data for several variables that would have been useful in this analysis. First, GPS coordinates of the injury scene were not available, so rurality was defined based on zip code level data; a more precise definition of rurality based on distances may have allowed for a more complete adjustment for rurality. Second, no information is collected regarding the industry of non-farm workers, which limits our ability to compare farm workers with workers in other specific injuries. This also limits the external validity of our study making it difficult to generalize our findings to other states with a different worker demographic than Iowa. Lastly, while the ISTR does contain information about fatality, no measures of disability are collected. Therefore, though our analyses have identified delays, it is difficult to determine what clinical impact these delays have on patient outcomes. Further studies are needed to determine what level of delay equates with measurable patient harm.

A final limitation based on the ISTR is missing data. While we performed imputation to replace missing values for covariates in our models and for EMS use, the time information used as an outcome in Aim 2 and 3 was also missing in some cases, particularly the EMS-derived data elements used to define the prehospital time intervals. Since time information is routinely collected by EMS providers, we attempted to recover missing time information by merging the ISTR with the EMS database; however, the EMS database is not standardized and the merge was of limited value. The process of standardizing data collection among EMS agencies would be a huge under-taking, but greater standardization of this system would allow for better integration with the ISTR and more complete prehospital data for future analyses.

With regards to imputation, we made the assumption that data are missing at random conditional on the other variables observed. This process allowed us to retain all observations ascertained from the ISTR for subsequent analyses, which reduces but doesn't eliminate the risk of biased results. The results of this study should be interpreted carefully and ultimately corroborated by studies in other datasets. Furthermore, we point out that the logistic regression model of EMS is the direct output from the imputation process which imputed both the covariates and EMS variable; the imputation of the EMS variable was deemed necessary for subsequent analyses. We presented this model because we felt that it contained useful information despite the imputed outcome, but are cognizant of the fact that imputing outcome variables can be frowned upon.

In Aim 2, we encountered time-dependency in the estimate for the association between time to definitive care and farm status. As discussed in the methods, we tested several functions of time and ultimately chose to model the observation period in 1-hour blocks. Though we felt that the heaviside functions were a reasonable compromise between the number of variables needed to define the time-dependent variable and the flexibility to hazard function over time, other functions of times, including tested and untested candidates, could have been used and may have altered the estimates of the hazard ratios from our model.

Finally, with regard to Aim 3 analysis, there were some limitations with regards to the sample analyzed. The fact that this analysis was performed on cases with complete time information may have introduced a selection bias since time data may be more likely to be missing in transferred patients. This sample selected in Aim 3 was more urban and more severely injured than the entire set of eligible patients. Therefore, the Aim 3 sample is less likely to be representative of the general population limiting the generalizability of our findings. Furthermore, we would have preferred to restrict the analysis of prehospital intervals to severe injuries (as done in Aim 2), but were limited by the sample size. Instead, we analyzed the prehospital injuries in a mixed-severity set of cases with complete time information. Inclusion of minor injuries, for whom care may not have been urgent, may have caused the magnitude of the intervals to be overestimated. Similar analysis in a severely injured population would be beneficial to confirm our findings, though to our knowledge, no such data source exists.

Conclusion

To our knowledge, this study represents the first look at how farmers fare in a state trauma system compared to other workers. Our results indicate that farmers appear to be able to access EMS services for higher severity injuries, but may opt to forgo EMS care for minor severity injuries; however, this difference in utilization did not appear to translate into an increase in transfers. Taken together this could indicate a preference among farmers for local care.

We showed that severely injured farmers face delays in reaching definitive care, specifically early on in the trauma response. Furthermore, we used a mixed-severity subset of EMS users to show that the discovery, response, and transport intervals were longer for farmers even after adjustment for rurality. These findings underscore the need for additional studies into the specific barriers that farmers face in accessing trauma services. Additionally, the fact that delays are present in multiple prehospital intervals indicates that there are opportunities for interventions at several phases in the trauma system response to farm injuries.

CHAPTER VI: TRAUMA SYSTEM DEVELOPMENT WITHIN THE TRANSLATIONAL FRAMEWORK

Translation is the process by which scientific discoveries from basic laboratories are used to ultimately improve human health. The term "translational research" has historically caused confusion among the scientific community, and the current paradigm for the translation process has only recently evolved. In an effort to decrease the disconnect between scientific discovery and improved health, the Institute of Medicine formed a Clinical Research Roundtable that originally defined two translational blocks that must be overcome to achieve meaningful changes in health. In the first block, knowledge of disease mechanisms must be applied to develop new diagnostic tests or therapies; in the second block, the tests/therapies must be taken from clinical studies into clinical practice (94). The second block was later divided into two distinct phases: development of evidence-based guidelines and dissemination/implementation of those guidelines (95). A final stage was eventually added to perform population-based studies to evaluate health impact (96). Taken together, these phases, termed T1-T4, comprise the current paradigm for the translation process (Table 16).

Table 16. The phases of the translation process and corresponding examples from trauma research (adapted from Khory et al. (96)).

Phase	Goal	Trauma Examples
T1	Discovery of basic mechanisms to inform interventions	mechanisms of injury and wound healing; tolerances of tissue to insult
T2	Investigate efficacy of an intervention in humans	determine efficacy of interventions/treatments; gain evidence for recommendations
T3	Application of intervention to clinical practice	implement interventions; make policies; set up population-based systems
T4	Evaluate the population health impact	evaluate current interventions or systems

As shown in Table 16, trauma-related research can exist at all phases of the translation process. At the T1 level, researchers would seek to understand how injury affects the body at a molecular level. While this research may take place in a basic or clinical laboratory, the purpose of this research is to provide information to develop interventions to improve injury outcomes. During the T2 phase, the efficacy of the suggested interventions is investigated. Such interventions could be patient-based interventions (e.g. administration of IV fluids) or systemic interventions, such as the development of a trauma system. While pharmaceutical interventions would likely proceed through randomized controlled trials, observational studies are more likely to be feasible for questions regarding trauma systems. During the T3 phase, the intervention is delivered to patients as part of the standard of care. With a trauma system, this may involve obtaining legislative support and creation of new policies. Finally, in the T4 phase, the intervention or system is evaluated to ensure that the desired results are being achieved. The analyses presented in this document have evaluated an aspect of an established clinical system at a population-level to determine its performance in a high risk population, and therefore is primarily aligned with the goals of the T4 phase.

While work in all phases of the translation process is valuable, late phase research has particular benefits. First, late phase research has historically been overlooked and is sorely needed to ultimately provide patients with optimal care. Both the original report from the Institute of Medicine roundtable (94) as well as later commentators (97) have not only recognized the prior focus on T1 research, but have also recommended greater funding for later phase work due to its tremendous potential to impact human health. While trauma systems have been implemented in many states and cities, we have only scratched the surface of identifying barriers for specific populations and understanding how to optimize trauma system operation. To that end, this study has provided some of the first information available detailing how farmers fare in a modern trauma system. Second, as conceptualized by Khory et al. (96) and others, the translation process is not a one-way, linear progression, but rather a self-feeding loop. Specifically, the evaluation of interventions and surveillance conducted in the T4 phase provides fodder for new early phase hypotheses. Our study identified differences in trauma system experiences between farmers and other works, as well as delays in reaching care; however, we cannot yet recommend specific strategies for remedying these delays. Further work is needed to elucidate specific barriers faced by farmers and to propose/test associated interventions.

In summary, the translation of scientific discoveries to clinical populations is essential for impacting human health. Through our T4 study, we provided practical information about the performance of a trauma system in a farming population that will be useful for benchmarking our own trauma system. However, we've also opened the door for future work aimed at improving access to expedient trauma care for farmers.

APPENDIX A: INCLUSION CRITERIA AND RELEVANT DEFINITIONS FOR THE IOWA STATE TRAUMA REGISTRY

Inclusion Criteria (48)***:***

Patients are included in the Iowa State Trauma Registry if they meet one of the following criteria:

1. *with at least one injury ICD-9 diagnosis code between 800.00 and 959.9, including 940-949 (burns), excluding 905-909 (late effects of injuries), 910-924 (blisters, contusions, abrasions, and insect bites), 930-939 (foreign bodies), and isolated hip fractures resulting from a same level fall unrelated to a traumatic event and:*
    a. *who are admissions, to be defined as any patient beyond the Emergency Department, or*
    b. *who died after receiving any evaluation or treatment or were dead on arrival, or*
    c. *who were transferred into or out of the trauma care facility*
2. *the trauma care facility trauma team is activated.*

Definitions (48)***:***

Farm related injury - a non-household injury incurred on the farm (ICD9-CM 849.1) by any farmer, farm worker, farm family member, or other individual, or any non-farm injury incurred by a farmer, farm worker, or farm family member in the course of handling, producing, processing, transporting, or warehousing farm commodities.

- *Indicates injury meets the farm-related injury definition. Agricultural injury may not have been necessarily work-related or directly related to the farm.*
- *Includes:*
    - *motor vehicle accident while hauling livestock or grain (some type of farm commodity)*
    - *motor vehicle collision with a piece of agricultural equipment on the highway*
    - *railroad crash of grain cars*
    - *tractor roll-over*
    - *caught in power take-off*
    - *unloading grain wagon*
    - *being struck by a piece of metal while operating a grinding wheel on the farm*
    - *getting caught in a barbed wire fence on the farm falling or slipping on the farm*
    - *being bitten by, struck by, or fallen on by an animal on the farm*
- *Excludes:*

- *injuries incurred by farmers or non-farmers who are on farm environs for a wide variety of purposes (e.g., visiting, hunting, swimming, and other recreational activities).*
- *farmhouse or home premises of farm*

APPENDIX B: DETAILED DEFINITIONS OF COVARIATES

Variable	Description	Type	Values
Age	age of individual at the time of the injury	categorical	<25, 25-44, 45-64, >64
Sex	sex of individual	dichotomous	male, female
Night	whether the injury occurred between the hours of 7:00pm - 7:00am	dichotomous	yes, no
Weekend	whether the injury occurred on a Saturday or a Sunday	dichotomous	yes, no
Insurance	describes the category of the primary payer	categorical	insurance, worker's compensation, Medicare/Medicaid, other/unknown
Rurality	a measure of rurality based on the RUCA score of the injury zip code (see Appendix C)	categorical	Urban, Large town, Small Town, Rural
ISS	Injury Severity Score (see Chapter 3)	categorical	1-8, 9-15, >15
Penetrating	indicates whether an injury was penetrating	dichotomous	yes, no
Burn	indicates whether an injury was a burn	dichotomous	yes, no
Pelvic Fracture	Indicates one or more injury fields contained the following ICD-9 codes: 808 = Fracture of the pelvis	dichotomous	yes, no
Amputation	Indicates one or more injury fields contained the following ICD-9 codes: 887 = traumatic amputation of the arm/hand 896 = traumatic amputation of foot 897 = traumatic amputation of leg(s)	dichotomous	yes, no
Long Bone Fracture	Indicates one or more injury fields contained the following ICD-9 codes: 812 = fracture of humerus 813 = fracture of radius and ulna 820-821 = fracture of femur 823 = fracture of tibia and fibula	dichotomous	yes, no
Spinal Injury	Indicates one or more injury fields contained the following ICD-9 codes: 805-806 = fracture of vertebral column 952 = spinal cord injury without evidence of spinal bone injury	dichotomous	yes, no
Crush Injury	Indicates one or more injury fields contained the following ICD-9 codes: 925-929 = crushing injury	dichotomous	yes, no
Brain Injury	Indicates one or more injury fields contained the following ICD-9 codes: 348.1 = anoxic brain damage	dichotomous	yes, no

	800-804 = fracture of skull 851-854 = intracranial injuries, excluding concussions 994.1 = drowning and nonfatal submersion 994.7 = asphyxiation and strangulation		
Chest	Indicates one or more injury fields contained the following ICD-9 codes: 860.1 = pneumothorax with open wound into thorax 860.3 = hemothorax with open wound into thorax 860.5 = pneumohemothorax with open wound into thorax 861.1 = injury to heart, with open wound into thorax 861.3 = injury to lung, with open wound into thorax 862.1 = injury to diaphragm, with open wound into cavity 862.3 = injury to other specified intrathoracic organs, with open wound into cavity 862.9 = injury to multiple and unspecified intrathoracic organs, with open wound into cavity 807.1-807.6 = fracture of rib(s), sternum, larynx, and trachea, excluding closed rib fractures	dichotomous	yes, no
Motor Vehicle Crash	Indicates that the primary cause of injury field contained the following one of the following e-codes: 810-819 = motor vehicle traffic accidents	dichotomous	yes, no
Other Transportation Injury	Indicates that the primary cause of injury field contained the following one of the following e-codes: 800-807 = railway accidents 820-825 = motor vehicle nontraffic accidents 826-829= other road vehicle accidents 830-838 = water transport accidents 840-845 = air and space transport accidents 846-848 = vehicle accidents not elsewhere classifiable	dichotomous	yes, no
Fall	Indicates that the primary cause of injury field contained the following one of the following e-codes: 880-888 = accidental falls	dichotomous	yes, no

APPENDIX C: RUCA CODING

Adapted from the University of Washington (50):

For this study, four categories are used for rurality. These categories were condensed from the categories below: Urban = 1-3, Large town = 4-6, Small Town = 7-9, Rural = 10.

1	Metropolitan area core: primary flow within an Urbanized Area
2	Metropolitan area high commuting: primary flow 30% or more to a Urbanized Area
3	Metropolitan area low commuting: primary flow 10% to 30% to a Urbanized Area
4	Micropolitan area core: primary flow within an Urban Cluster of 10,000 through 49,999 (large)
5	Micropolitan high commuting: primary flow 30% or more to a large Urbanized Cluster
6	Micropolitan low commuting: primary flow 10% to 30% to a large Urbanized Cluster
7	Small town core: primary flow within an Urban Cluster of 2,500 through 9,999 (small)
8	Small town high commuting: primary flow 30% or more to a small Urbanized Cluster
9	Small town low commuting: primary flow 10% through 29% to a small Urbanized Cluster
10	Rural areas: primary flow to a tract outside a Urbanized Area or Cluster

APPENDIX D: COMPARISON OF MAIN EFFECTS MODELS FOR EMS USE USING UNIMPUTED AND IMPUTED DATA

	Complete Cases (n = 3275)			DCT Complete Cases (n = 4747)			Eligible Cases (n = 5490)		
Var	**Beta**	**SE**	**p**	**Beta**	**SE**	**p**	**Beta**	**SE**	**p**
farm1	-0.65	0.13	<0.001	-0.53	0.11	<0.001	-0.53	0.10	<0.001
age_d1	0.05	0.13	0.728	0.04	0.12	0.717	0.07	0.11	0.522
age_d3	0.12	0.09	0.180	0.11	0.09	0.219	0.16	0.08	0.044
age_d4	0.12	0.18	0.524	0.18	0.16	0.268	0.11	0.16	0.488
sex_m1	0.26	0.12	0.024	0.19	0.11	0.078	0.18	0.10	0.062
night1	0.02	0.11	0.851	0.03	0.09	0.746	0.05	0.11	0.646
wkend1	-0.08	0.11	0.474	-0.01	0.11	0.913	0.002	0.10	0.983
pay_d2	0.09	0.26	0.739	0.15	0.24	0.543	0.28	0.22	0.213
pay_d3	0.37	0.13	0.004	0.42	0.11	<0.001	0.35	0.11	0.002
pay_d4	0.61	0.14	<0.001	0.61	0.12	<0.001	0.52	0.12	<0.001
rucarc2	-0.26	0.13	0.050	-0.25	0.13	0.048	-0.24	0.13	0.058
rucarc3	-0.41	0.12	<0.001	-0.46	0.10	<0.001	-0.39	0.10	<0.001
rucarc4	-0.44	0.12	<0.001	-0.41	0.12	0.001	-0.41	0.10	<0.001
iss_d2	0.57	0.13	<0.001	0.49	0.12	<0.001	0.46	0.10	<0.001
iss_d3	1.14	0.20	<0.001	1.09	0.17	<0.001	1.09	0.17	<0.001
type_d2	-0.48	0.13	<0.001	-0.57	0.12	<0.001	-0.56	0.11	<0.001
type_d3	-0.02	0.18	0.923	0.01	0.15	0.956	0.01	0.14	0.949
pelvic1	0.77	0.28	0.007	0.94	0.23	<0.001	1.00	0.22	<0.001
amp1	1.69	0.66	0.010	1.97	0.65	0.003	2.13	0.63	0.001
lbfx1	0.47	0.12	<0.001	0.51	0.10	<0.001	0.57	0.09	<0.001
spine1	0.76	0.18	<0.001	0.69	0.16	<0.001	0.72	0.13	<0.001
crush1	0.10	0.19	0.613	0.11	0.18	0.557	0.01	0.15	0.950
brain1	0.39	0.21	0.060	0.32	0.18	0.070	0.39	0.16	0.018
chest1	0.72	0.44	0.101	0.61	0.38	0.103	0.62	0.35	0.076
mvc1	2.70	0.26	<0.001	2.67	0.21	<0.001	2.56	0.21	<0.001
fall1	0.30	0.11	0.006	0.26	0.11	0.014	0.20	0.09	0.023
machine1	0.01	0.12	0.905	0.14	0.12	0.217	0.16	0.10	0.097
misctrans1	0.81	0.21	<0.001	0.87	0.19	<0.001	0.78	0.17	<0.001

APPENDIX E: COMPARISON OF AIM 2 MODEL EXCLUDING THOSE WITH MISSING TIME TO DEFINITIVE CARE

In the model of time to definitive care in Aim 2, we chose to treat those without time to definitive care as lost to follow-up (censored at t = 4 hr). Alternatively, we could have chosen to exclude those individuals from our analysis. The following table compares these two analysis strategies.

	Censor Missing (as in Aim 2):			Exclude Missing (alternate analysis):		
	adjHR	95% CI		adjHR	95% CI	
Farm vs. Nonfarm						
Hour 1	0.45	(0.24,0.83)	*	0.42	(0.23,0.78)	*
Hour 2	1.33	(0.89,1.98)		1.16	(0.77,1.75)	
Hour 3	1.28	(0.79,2.08)		1.07	(0.66,1.74)	
Hour 4	1.40	(0.77,2.54)		1.13	(0.60,2.10)	
Injury Type (Yes vs. No)						
Pelvic Fracture	1.05	(0.77,1.42)		1.03	(0.76,1.39)	
Long Bone Fracture	1.32	(1.02,1.71)	*	1.28	(0.99,1.66)	
Spine Injury	1.05	(0.86,1.29)		1.00	(0.81,1.23)	
Brain Injury	0.94	(0.77,1.15)		0.95	(0.77,1.15)	
Chest Injury	0.95	(0.67,1.34)		1.10	(0.78,1.57)	
Additional Covariates						
Payer						
Insurance	ref					
Medicaid/Medicare	0.94	(0.56,1.59)		0.96	(0.57,1.60)	
Worker's Comp	0.87	(0.63,1.20)		0.90	(0.64,1.26)	
Other/Unknown	0.58	(0.42,0.80)	*	0.55	(0.40,0.75)	*
Age						
15-24	0.70	(0.50,0.98)	*	0.76	(0.54,1.06)	
25-44	ref					
45-64	0.80	(0.65,0.99)	*	0.82	(0.66,1.02)	
>=65	0.64	(0.45,0.90)	*	0.62	(0.44,0.86)	*

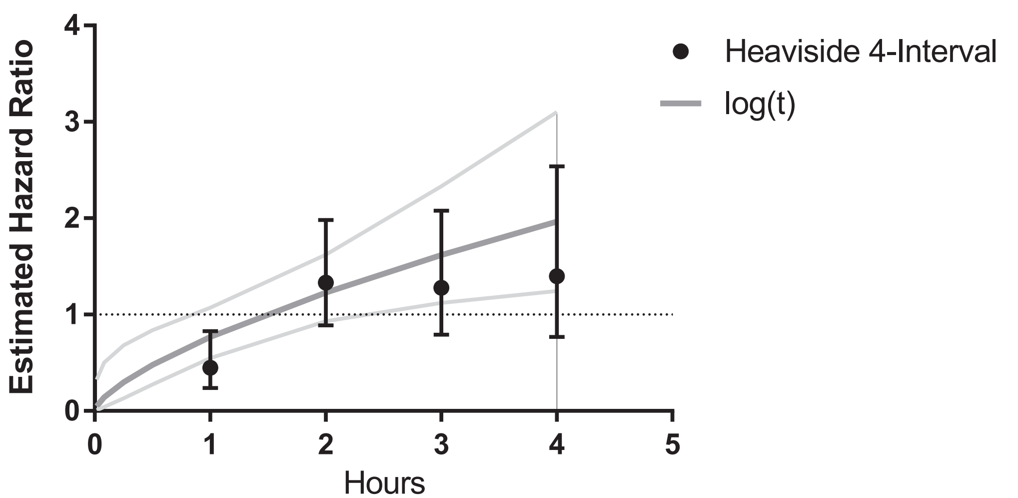
The two analysis methods produced very similar results. Though the magnitude of the effects for the farm vs. non-farm relationship differed slightly, the direction and significance remained the same. Several of the other variables, including long bone fracture, age 15-24, and age 45-64, were marginally significant when missing were censored, but failed to reach significance when missing were excluded which could be due to a loss of sample size (n = 748 vs. 662).

APPENDIX F: COMPARISON OF AIC FOR FUNCTIONS OF TIME

The following functions were tested in Aim 2 as candidates for time-dependent interaction with the farm variable.

Function	AIC	
log(t)	51067.7	
sqrt(t)	51089.4	
heaviside (4 intervals)	51091.1	(chosen)
heaviside (3 intervals)	51099.1	
t	51111.0	
t^2	51144.3	
heaviside (8 intervals)	51149.2	
exp(t)	51167.9	
heaviside (2 intervals)	51170.3	

Graphical comparison of estimates obtained from Aim 2 using log(t) compared the 4-interval heaviside functions:



WORKS CITED

1. Merchant JA, Kross BC, Donham KJ, Pratt DS, editors. Agriculture at Risk: A Report to the Nation. Agricultural and Occupational and Envrionmental Health: Policy Strategies for the Future. Iowa City and Des Moines, IA; 1988.

2. Myers J. Injuries Among Farm Workers in the United States, 1993. DHHS (NIOSH) Publication No. 97–115. Cincinnati, OH: National Institute for Occupational Safety and Health; 1997.

3. Myers J. Injuries among farm workers in the United States, 1994. DHHS (NIOSH) Publication No. 98–153. Cincinnati, OH: National Institute for Occupational Safety and Health; 1998.

4. Myers J. Injuries among farm workers in the United States, 1995. DHHS (NIOSH) Publication No. 2001–153. Cincinnati, OH: National Institute for Occupational Safety and Health; 2001.

5. Gerberich SG, Gibson RW, French LR, Carr P, Renier CM, Gunderson PD, et al. The Regional Rural Injury Study-I (RRIS-I): A Population Based Effort. A Report to the Centers for Disease Control. NTIS No. PB94–134848. Springfield, VA; 1993.

6. Acosta J a, Yang JC, Winchell RJ, Simons RK, Fortlage D a, Hollingsworth-Fridlund P, et al. Lethal injuries and time to death in a level I trauma center. J Am Coll Surg. 1998 May;186(5):528–33.

7. Sauaia A, Moore FA, Moore EE, Moser KS, Brennan R, Read RA, et al. Epidemiology of Trauma Deaths: A Reassessment. J Trauma Inj Infect Crit Care. 1995;38(2):185–93.

8. Vos PE, Diaz-Arrastia R. Traumatic Brain Injury. First. Oxford, UK: Wiley; 2015. 45-54 p.

9. Gabriel EJ, Ghajar J, Jagoda A, Pons PT, Scalea T, Walters BC. Guidelines for Prehospital Management of Traumatic Brain Injury. J Neurotrauma. 2002;19(1):165–72.

10. Celso B, Tepas J, Langland-Orban B, Pracht E, Papa L, Lottenberg L, et al. A systematic review and meta-analysis comparing outcome of severely injured patients treated in trauma centers following the establishment of trauma systems. J Trauma. 2006 Mar;60(2):371–8; discussion 378.

11. Carr BG, Caplan JM, Pryor JP, Branas CC. A meta-analysis of prehospital care times for trauma. Prehosp Emerg Care. 2005;10(2):198–206.

12. Esposito TJ, Maier R V, Rivara FP, Pilcher S, Griffith J, Lazear S, et al. The impact of variation in trauma care times: urban versus rural. Prehosp Disaster Med. 1995;10(3):161–6; discussion 166–7.

13. Grossman D, Kim A, Macdonald S, Klein P, Copass M, Maier R. Urban-rural differences in prehospital care of major trauma. J Trauma Inj Infect Crit Care. 1997;42(4):723–9.

14. Rogers FB, Shackford SR, Hoyt DB, Camp L, Osler TM, Mackersie RC, et al. Trauma Deaths in a Mature Urban vs Rural Trauma System. Arch Surg. 1997;132:376–82.

15. Spaite D, Valenzuela T, Meislin H, Criss E, Hinsberg P. Prospective validation of a new model for evaluating emergency medical services systems by in-field observation of specific time intervals in prehospital care. Ann Emerg Med. 1993;22(4):638–45.

16. Gonzalez RP, Cummings G, Mulekar M, Rodning CB. Increased mortality in rural vehicular trauma: identifying contributing factors through data linkage. J Trauma. 2006 Aug;61(2):404–9.

17. Stripe SC, Susman J. A rural-urban comparison of prehospital emergency medical services in Nebraska. J Am Board Fam Pract. 1991;4:313–8.

18. Mullins R. A historical perspective of trauma system development in the United States. J Trauma Inj Infect Crit Care. 1999;47(3):S8–14.

19. National Academy of Sciences (US) and National Research Council (US) Committee on Trauma; National Academy of Sciences (US) and National Research Council (US) Committee on Shock. Accidental Death and Disability: The Neglected Disease of Modern Society. Washington, DC; 1966.

20. Resources for Optimal Care of the Injured Patient [Internet]. American College of Surgeons. 2006. Available from: http://www.facs.org/trauma/hospitallevels.pdf

21. Papa L, Langland-Orban B, Kallenborn C, Tepas JJ, Lottenberg L, Celso B, et al. Assessing effectiveness of a mature trauma system: Association of trauma center presence with lower injury mortality rate. J Trauma. 2006 Aug;61(2):261–6; discussion 266–7.

22. MacKenzie EJ, Rivara FP, Jurkovich GJ, Nathens AB, Frey KP, Egleston BL, et al. A national evaluation of the effect of trauma-center care on mortality. N Engl J Med. 2006 Jan 26;354(4):366–78.

23. Sasser SM, Hunt RC, Faul M, Sugerman D, Pearson WS, Dulski T, et al. Guidelines for field triage of injured patients: recommendations of the National Expert Panel on Field Triage, 2011. MMWR. Recommendations and reports : Morbidity and mortality weekly report. Recommendations and reports / Centers for Disease Control. 2012 Jan.

24. Haas B, Gomez D, Zagorski B, Stukel T a, Rubenfeld GD, Nathens AB. Survival of the fittest: the hidden cost of undertriage of major trauma. J Am Coll Surg. Elsevier Inc.; 2010 Dec;211(6):804–11.

25. Newgard CD, Staudenmayer K, Hsia RY, Mann NC, Bulger EM, Holmes JF, et al. The cost of overtriage: more than one-third of low-risk injured patients were taken to major trauma centers. Health Aff (Millwood). 2013 Sep;32(9):1591–9.

26. Faul M, Wald MM, Sullivent EE, Sasser SM, Kapil V, Lerner EB, et al. Large Cost Savings Realized from the 2006 Field Triage Guideline: Reduction in Overtriage in U.S. Trauma Centers. Prehospital Emerg Care. 2012;16(2):222–9.

27. Adams PF, Kirzinger WK, Martinez M. Summary health statistics for the U.S. population: National Health Interview Survey, 2012. Vital Health Stat 10. 2013 Dec;(259):1–95.

28. Corso P, Finkelstein E, Miller T, Fiebelkorn I, Zaloshnja E. Incidence and lifetime costs of injuries in the United States. Inj Prev. 2006 Aug;12(4):212–8.

29. Hospital N, Medical A, Survey C. National Hospital Ambulatory Medical Care Survey : 2010 Emergency Department Summary Tables. 2010;

30. 10 Leading Causes of Death by Age Group, United States – 2010 [Internet]. CDC: WISQARS. p. 2010. Available from: http://www.cdc.gov/injury/wisqars/pdf/10LCID_All_Deaths_By_Age_Group_2010-a.pdf

31. Mullins R, Mann N. Preferential benefit of implementation of a statewide trauma system in one of two adjacent states. J Trauma Inj Infect Crit Care. 1998;44(April):609–17.

32. Mann CN, Mullins RJ, Hedges JR, Rowland D, Arthur M, Zechnich AD. Mortality among seriously injured patients treated in remote rural trauma centers before and after implementation of a statewide trauma system. Med Care. 2001 Jul;39(7):643–53.

33. Feero S, Hedges JR, Simmons E, Irwin L. Does out-of-hospital EMS time affect trauma survival? Am J Emerg Med. 1995 Mar;13(2):133–5.

34. Newgard CD, Schmicker RH, Hedges JR, Trickett JP, Davis DP, Bulger EM, et al. Emergency medical services intervals and survival in trauma: assessment of the "golden hour" in a North American prospective cohort. Ann Emerg Med. 2010 Mar;55(3):235–46.

35. Fleet R, Poitras J. Have We Killed the Golden Hour of Trauma? Ann Emerg Med. 2011;

36. Lerner E, Moscati R. The Golden Hour: Scientific Fact or Medical "Urban Legend"? Acad Emerg Med. 2001;8(7):758–60.

37. Remick KN, Schwab CW, Smith BP, Monshizadeh A, Kim PK, Reilly PM. Defining the optimal time to the operating room may salvage early trauma deaths. J Trauma Acute Care Surg. 2014;76(5):1251–8.

38. Bureau of Labor Statistics. Employer-Reported Workplace Injuries and Illnesses - 2012. Bur Labor Stat US Dept Labor. 2013;(202).

39. Statistics B of L. Census of Fatal Occupational Injuries: 2012 Chart Package. United States Department of Labor, Bureau of Labor Statistics. Washington, DC; 2012.

40. Bureau of Labor Statistics. CFOI 2013 - hourly based fatality rates. 2013;6–9.

41. MacKenzie E, Hoyt D, Sacra J, Jukovich G, Carlini A, Teitelbaum S, et al. National inventory of hospital trauma centers. JAMA. 2003;289(12):1515–22.

42. Hsia R, Shen Y. Possible Geographical Barriers to Trauma Center Access for Vulnerable Patients in the United States. Arch Surg. 2013;146(1):46–52.

43. Eberhardt M, Ingram D, Makuc D. Urban and Rural Health Chartbook. Health, United States, 2001. Hyattsville, MD: National Center for Health Statistics; 2001.

44. County Typology Codes: Descriptions and Maps [Internet]. United States Department of Agriculture. 2012. Available from: http://www.ers.usda.gov/data-products/county-typology-codes/descriptions-and-maps.aspx#.UofW_tKKKSo

45. Stueland D, McCarty J, Stamas P. Prehospital care of agricultural injuries. Prehosp Disaster Med. 1993;Apr-Jun:193–7.

46. Young T, Torner JC, Sihler KC, Hansen AR, Peek-Asa C, Zwerling C. Factors associated with mode of transport to acute care hospitals in rural communities. J Emerg Med. 2003 Feb;24(2):189–98.

47. Mellecker M, Torner JC, Young T, Sparling K. Iowa Trauma System Ten Year Report [Internet]. 2010. p. 1–22. Available from: http://www.public-health.uiowa.edu/iprc/resources/IA-Trauma-System_Ten-Year-Report.pdf

48. Iowa Trauma Patient Data Dictionary. Iowa Department of Public Health. 2005;50319(July):1–115.

49. Sasser SM, Hunt RC, Sullivent EE, Wald MM, Mitchko J, Jurkovich GJ, et al. Guidelines for field triage of injured patients. Recommendations of the National Expert Panel on Field Triage. MMWR Recomm Rep. 2009 Jan 23;58(RR-1):1–35.

50. RUCA Zip Code Data [Internet]. University of Washinton: Rural Health Research Center. 2004. Available from: http://depts.washington.edu/uwruca/ruca-download.php

51. Hart LG, Larson EH, Lishner DM. Rural definitions for health policy and research. Am J Public Health. 2005 Jul;95(7):1149–55.

52. Baker S, O'Neill B, Haddon W, Long W. The Injury Severity Score: A Method for Describing Patients with Multiple Injuries and Evaluating Emergency Care. J Trauma Acute Care Surg. 1974;14(3):187–96.

53. Bolorunduro O, Villegas C, Oyetunji T, Haut E, Stevens K, Chang D, et al. Validating the Injury Severity Score (ISS) in different populations: ISS predicts mortality better among Hispanics and females. J Surg Res. 2011 Mar;166(1):40–4.

54. Linn S. The injury severity score--importance and uses. Ann Epidemiol. 1995 Nov;5(6):440–6.

55. Donders ART, van der Heijden GJMG, Stijnen T, Moons KGM. Review: a gentle introduction to imputation of missing values. J Clin Epidemiol. 2006 Oct;59(10):1087–91.

56. Azur MJ, Stuart EA, Frangakis C, Leaf PJ. Multiple imputation by chained equations: What is it and how does it work? Int J Methods Psychiatr Res. 2011;20(1):40–9.

57. University of Michigan. IVEware: Imputation and Variance Estimation Software. 2014.

58. SAS Institute Inc. SAS. Cary, NC: SAS Institute Inc.; 2011.

59. R Development Core Team. R: A Language and Environment for Statistical Computing. Vienna, Austria: R Foundation for Statistical Computing; 2008.

60. Kleinbaum D, Klein M. Survival Analysis: a Self-Learning Text. Biometrical Journal. New York, NY: Springer Science + Business Media; 2012.

61. Registry Plus Link Plus Technical Information and Installation. Atlanta, GA: Centers for Disease Control and Prevention: National Program of Cancer Registries; 2007.

62. Putter H, Fiocco M, Geckus RB. Tutorial in biostatistics: Competing risks and multi-state models. Stat Med. 2007;26:2389–430.

63. Meira-Machado L, de Una-Alvarez J, Cadarso-Suarez C, Andersen PK. Multi-state models for the analysis of time-to-event data. Stat Methods Med Res. 2009;18:195–222.

64. Putter H. Tutorial in biostatistics: Competing risks and multi-state models Analyses using the mstate package [Internet]. 2011. p. 1–43. Available from: https://cran.r-project.org/web/packages/mstate/vignettes/Tutorial.pdf

65. Therneau TM. survival: Survival Analysis. Comprehensive R Archive Network (CRAN); 2015.

66. Putter H. mstate: Data preparation, estimation and prediction in multi-state models. Comprehensive R Archive Network (CRAN); 2014.

67. Lumley AT. mitools: Tools for multiple imputation of missing data. Comprehensive R Archive Network (CRAN); 2014.

68. Li K, Meng X, Raghunathan T, Rubin D. Significance levels from repeated p-values with multiply-imputed data. Statistica Sinica. 1991. p. 65–92.

69. Allison P. SAS Macros: COMBCHI (v.2.1) [Internet]. Statistical Horizons. 2007. Available from: http://statisticalhorizons.com/resources/macros

70. Myers JR, Layne LA, Marsh SM. Injuries and Fatalities to U.S. Farmers and Farm Workers 55 Years and Older. Am J Ind Med. 2009 Mar;52(3):185–94.

71. Myers JR. National surveillance of occupational fatalities in agriculture. Am J Ind Med. 1990;18(2):163–8.

72. Layne L, Landen D. A descriptive analysis of nonfatal occupational injuries to older workers, using a national probability sample of hospital emergency departments. J Occup Environ Med. 1997;39(9):855–65.

73. Lobao L, Meyer K. The Great Agricultural Transition : Crisis , Change , and Social Consequences of Twentieth Century US Farming. 2001;

74. Worker's Compensation [Internet]. Iowa Code 85.1. 2014. Available from: https://coolice.legis.iowa.gov/cool-ice/default.asp?category=billinfo&service=iowacode&input=85#85.2

75. Lovelock K. The injured and diseased farmer: occupational health, embodiment and technologies of harm and care. Sociol Health Illn. 2012 May;34(4):576–90.

76. Johnson NJ, Carr BG, Salhi R, Holena DN, Wolff C, Band RA. Characteristics and outcomes of injured patients presenting by private vehicle in a state trauma system. Am J Emerg Med. 2013;31(2):275–81.

77. Meisel ZF, Pines JM, Polsky D, Metlay JP, Neuman MD, Branas CC. Variations in ambulance use in the United States: the role of health insurance. Acad Emerg Med. 2011 Oct;18(10):1036–44.

78. Gerson L, Skvarch L. Emergency medical service utilization by the elderly. Ann Emerg Med. 1982;11(11 November):1–3.

79. Rucker DW, Edwards R a, Burstin HR, O'Neil a C, Brennan T a. Patient-specific predictors of ambulance use. Ann Emerg Med. 1997 Apr;29(4):484–91.

80. Lishner D, Rosenblatt R, Baldwin L, Hart L. Emergency department use by the rural elderly. J Emerg Med. 2000;18(3):289–97.

81. Demetriades D, Chan L, Cornwell E, Belzberg H, Berne T V, Asensio J, et al. Paramedic vs Private Transportation of Trauma Patients. Arch Surg. 1996;131:133–8.

82. Newgard CD, Nelson MJ, Kampp M, Saha S, Zive D, Schmidt T, et al. Out-of-hospital decision making and factors influencing the regional distribution of injured patients in a trauma system. J Trauma. 2011 Jun;70(6):1345–53.

83. Delgado MK, Yokell M a, Staudenmayer KL, Spain D a, Hernandez-Boussard T, Wang NE. Factors Associated With the Disposition of Severely Injured Patients Initially Seen at Non-Trauma Center Emergency Departments: Disparities by Insurance Status. JAMA Surg. 2014;19104(5):1–9.

84. Davis J, Stern D. National Council on Compensation Insurance: Workers Compensation Claim Frequency -- 2013 Update [Internet]. Change. 2013. p. 1–56. Available from: https://www.ncci.com/nccimain/IndustryInformation/ResearchOutlook/Pages/WC-Claim-Freq-2013Update.aspx

85. Breon TA, Scott-Conner C, Tracy RD. Spectrum of general surgery in rural Iowa. Curr Surg. 2003;60(1):94–9.

86. Landercasper J, Bintz M, Cogbill TH, Bierman SL, Buan RR, Callaghan JP, et al. Spectrum of general surgery in rural America. Arch Surg. 1997;132:494–7.

87. Chan L, Hart LG, Goodman DC. Geographic access to health care for rural Medicare beneficiaries. J Rural Health. 2006;22(2):140–6.

88. Rogers A, Rogers F, Bradburn E, Krasne M, Lee J, Wu D, et al. Old and undertriaged: a lethal combination. Am Surg. 2012 Jun;78(6):711–5.

89. Chang DC, Bass RR, Cornwell EE, Mackenzie EJ. Undertriage of elderly trauma patients to state-designated trauma centers. Arch Surg. 2008 Aug;143(8):776–81; discussion 782.

90. Doering C, Bureau GW. Farmers growing comfortable with mobile devices. USA Today. Washington, DC; 2013 Mar 3;

91. Liu B, Koc a. B. SafeDriving: A mobile application for tractor rollover detection and emergency reporting. Comput Electron Agric. 2013;98:117–20.

92. Sposaro F, Tyson G. iFall: An android application for fall monitoring and response. Proc 31st Annu Int Conf IEEE Eng Med Biol Soc Eng Futur Biomed EMBC 2009. 2009;6119–22.

93. Haas B, Nathens AB. Pro/con debate: is the scoop and run approach the best approach to trauma services organization? Crit Care. 2008;12(5):224.

94. Sung NS, Crowley WF, Genel M, Salber P, Sandy L, Sherwood LM, et al. Central Challenges Facing the National Clinical Research Enterprise. 2003;289(10).

95. Westfall JM, Mold J, Fagnan L. Practice-Based Research -- “Blue Highways” on the NIH Roadmap. JAMA. 2007;297(4):403–6.

96. Khoury MJ, Gwinn M, Yoon PW, Dowling N, Moore CA, Bradley L. The continuum of translation research in genomic medicine: how can we accelerate the appropriate integration of human genome discoveries into health care and disease prevention? Genet Med. 2007;9(10):665–74.

97. Woolf SH. The meaning of translational research and why it matters. JAMA. 2008;299(2):211–3.