MACHINERY-RELATED OPERATIONAL FACTORS AS DETERMINANTS OF INJURY ON CANADIAN PRAIRIE FARMS

by

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Abstract

Background: Agriculture remains one of the most hazardous occupations in Canada. Approximately one-half of all agricultural injuries are due to machinery. The etiology of machinery-related injury remains poorly understood.

Objectives: (1) To evaluate the relative importance of two representative safety practices (i.e. safety device use and routine maintenance) and their relationship with machinery-related injury; (2) To evaluate the roles of situational factors and safety practices in the occurrence of entanglement injuries caused by machinery.

Methods: Objective 1. Participants were administered the Saskatchewan Farm Injury Cohort Study baseline survey for a one-year period of recall (2006). Relationships between the machinery-related injury outcome and two safety practices were analyzed cross-sectionally using the farm as the unit of analysis; Objective 2. A descriptive case-series was analyzed for factors surrounding 41 machinery entanglements using data from the Case-Control Farm Machinery Injury Study (2000-2005).

Results: Objective 1. Limited use of safety devices on machinery during farm operations was associated with higher risks for injury (RR 1.94; 95% CI 1.13 to 3.33; p_trend=0.02). Lower routine maintenance scores were associated with significantly reduced risks for injury (RR 0.54; 95% CI 0.29 to 0.98; p_trend=0.05). Objective 2. The majority of entanglements occurred during a few machinery-related tasks, namely (1) field adjustments of machinery; (2) product handling and conveyance; and (3) driveline attachments and servicing. Both expected and unanticipated hazards inherent to these tasks affected the behaviour of farmers, leading to entanglements.

Conclusions: Objective 1. The first finding implies that injury prevention programs require continued focus on the use of safety devices on machinery. The second finding could indicate that
maintenance itself is a risk factor, or that more modern equipment that requires less maintenance places the operator at lower risk. These findings provide etiological data that confirm the practical importance of operational safety practices as components of injury control strategies on farms. **Objective 2.** Systemic changes are required to improve existing machinery safety practices through engineering, work methods and work practice modifications. In addition to design solutions, occupational health and safety strategies should consider activities associated with hazardous situations to inform the content of training and educational efforts.
Co-Authorship

This thesis represents the work of Gopinath Narasimhan in collaboration with his supervisors, Dr. William Pickett and Dr. Yingwei (Paul) Peng, with Dr. Trever Crowe serving as an external advisor from the University of Saskatchewan.

Manuscript 1: “Operational safety practices as determinants of machinery-related injury on Saskatchewan farms”. The idea of using the Saskatchewan Farm Injury Cohort Study to examine the role of safety practices in the occurrence of machinery-related injury was suggested by Dr. Pickett and Dr. Crowe. Gopinath Narasimhan developed the factor analytic scales for the operational exposures and covariates in collaboration with Dr. Pickett. The statistical analysis, interpretation of results and the writing of the manuscript were done by Gopinath Narasimhan, with supervisory and editorial feedback provided by Dr. Pickett and Dr. Peng as supervisors and Dr. Crowe as an external advisor. Also, Dr. Dosman, Ms. Hagel, Dr. Marlenga and Dr. Day reviewed the manuscript as members of the Saskatchewan Farm Injury Cohort Team.

Manuscript 2: “Machinery entanglement injuries among adult Prairie farmers in Canada: task-based analysis of injury patterns”. The idea of using data from the Case-Control Farm Machinery Injury Study to analyze machinery injuries in a descriptive case-series framework was suggested by Dr. Pickett and Dr. Crowe. Dr. Pickett, Dr. Crowe and Gopinath Narasimhan had input into the design and methodological approaches taken in this manuscript. Gopinath Narasimhan was responsible for the analysis, interpretation of the results and writing the manuscript. Dr. Pickett and Dr. Peng provided guidance and editorial input into the creation of the manuscript. The other components of the thesis (i.e. Introduction, Literature Review and General Discussion) were the work of Gopinath Narasimhan with suggestions and feedback from Dr. Pickett and Dr. Peng.
Abbreviations and Definitions

Abbreviations

AHSN: Agricultural Health and Safety Network
ASAE: American Society for Agricultural Engineering
BS: British Standards Institute
CCFMI: Case-Control Farm Machinery Injury Study
CI: 95% Confidence interval
RR: Relative Risk
SFIC: Saskatchewan Farm Injury Cohort Study

Definitions

Accident: A dynamic mechanism that begins with the activation of the hazard and flows through the system as a series of events in a logical sequence, giving rise to ill-health, injury, damage, other loss, or death. Temporally, it occurs as an unplanned event (Roland and Moriarty 1983; BS 8800 1998).

Agricultural/Farm Machine: An assembly of linked parts or components, at least one of which moves, using appropriate actuators, control and power circuits, etc. joined together for a specific application, in particular processing, treatment, moving or packaging of material (Directive 98/37/EC).

Hazard: A physical source with the potential for harm in terms of human injury, ill-health, damage to health, damage to property or damage to the environment (EN 292-1 1992; BS 8800 1998).

Hazardous situation: Any situation in which a person is exposed to hazard or to hazards (EN 292-1 1992).
**Machinery-related Injury:** Any pathological or traumatic discontinuity of tissue or loss of function of a part of the human body due to contact with machinery or one of its constituent mechanisms.

**Risk:** A combination of the frequency, or probability of occurrence and the consequences, degree of possible injury or damage to health in specific hazardous situations (EN 292-1 1992).

**Safety devices:** Generic term for a shield or guard covering hazardous areas of a machine to prevent contact with body parts or to control hazards like chips and noise from exiting the machine

**Safety of a machine:** The quality or ability of a machine to perform its function, to be installed, adjusted, maintained, transported, dismantled and disposed of, under pre-determined conditions of normal intended use specified by the manufacturer without causing damage to health, injury or accidental loss (adapted from EN 292-1 1992; Roland and Moriarty 1983).
Acknowledgements

At the outset I would like to thank all my teachers, colleagues and friends who have made my experience at Queen’s most enjoyable.

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My warmest gratitude is extended to my mother, father and brother who have stood by me through thick and thin and been unwavering in their encouragement and motivation. Finally, this acknowledgement and this thesis would not be complete if I did not thank my father for being a sounding board for presentation ideas throughout the thesis writing process.
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Chapter 1
Introduction

1.1 Introducing the problem

Agriculture remains one of the most dangerous occupations in North America [1-4], exposing workers to hazards that are among the highest of all professions [5]. Farming mortality and morbidity rates attributable to injury remain high. Farm populations experience an unacceptably high risk for traumatic injury [6]. Mackenzie reports the percentage of Canadian farm workers (7.3%) who sustained non-fatal, activity limiting injuries as almost double the average (3.8%) for other occupations [7, 8]. Injury trends in production agriculture are at least partially attributable to the progressive mechanization of farms and larger farm areas [9]. Approximately half of all agricultural injuries occur due to machinery [10]. Farm workers are increasingly exposed to physical safety hazards inherent to machinery. Tractors, combines and augers account for most injuries requiring hospitalization in all age groups [11]. Across Canada, 177 hospitalizations per 100,000 people are reported annually due to machinery injury [12]. The high farm injury rates carry a substantial economic toll. The overall societal burden of machinery-related injuries in terms of lost potential, medical treatment, disability and rehabilitation are also substantial [13], [14]. Thus, it is necessary to reduce the occurrence of farm injuries.

1.2 Rationale

In general, the perception that accidents (injuries) can be predicted and prevented has only gained traction over the last few decades. Unlike other occupations, farming is unique in that farmers often work alone over vast tracts of land and work on largely independent operations. Regulations and reporting requirements governing agriculture are minimal.
Non-fatal farm machinery injuries contribute to a significant public health burden, yet there are few focused studies and population-based analyses from which to develop prevention initiatives. Injuries have a complex etiology with many factors. This has resulted in a paucity of informative etiological studies. Some of the contributing factors are: (1) farm machinery presents a wide variety of hazards; (2) some hazards are hard to recognize; and (3) machinery injury is multi-factorial in nature. It is difficult to assign a single cause, reason or origin for the occurrence of machinery injuries. Many variables like individual characteristics (e.g. psychosocial stresses), the farm environment, work practices, work place design, physical and machinery exposures need to be investigated to gain an understanding of injury.

The few epidemiological studies of non-fatal machinery injury that use the population health model have primarily focused on social, demographic and behavioral factors as injury determinants [3, 15-17]. Studies relating machinery work practices to injury have been limited. Safety practices as basic determinants of machinery injury are the subject of a recent paper but the evidence is inconclusive [18]. Although the risk for injury associated with absence of safety features on specific types of machinery has been studied [19], there is a recognition that other safety-related factors may be involved [3, 18, 20, 21].

Murphy [22, 23] suggested a safety hierarchy to eliminate an injury hazard that included the following elements: (1) design and manufacture equipment according to standards; (2) guard moving parts by using shields, casings or interlocks; (3) train operators with respect to machinery operation and safety; and (4) prescribe personal protective equipment. While standard design and provision of safety features for farm machinery are ‘built-in’ and are the responsibility of the manufacturer, the farm owner or employer is responsible for operator training and ensuring compliance with standard safety practices. Implicit in this human factors engineering approach is the behavioural aspect associated with the implementation of safety practices. Few studies have
evaluated elements of this safety hierarchy as injury determinants. These factors are part of the engineering domain of established injury control theory.

Approaches to injury control and prevention can be summarized into three categories as the “3 Es” : Education, Engineering/Environmental modification, and Enforced regulation of legislated safety standards [23]. Traditionally, efforts to reduce the injury burden have relied on educational interventions and on engineering approaches used by equipment manufacturers. These initiatives are discipline-specific. A large number of injury prevention programs developed have typically relied on educational strategies alone [24, 25]. Injury prevention approaches that rely solely on educational modalities are of limited efficacy [24-26]. Systematic reviews on the efficacy of injury control measures show educational intervention is necessary but insufficient by itself to influence outcomes [26]. An effective evidence-based approach using the full public health model is the ideal option to bring about behavioral modification, best practice and technical changes. Causes of farm injuries can then be studied via epidemiology and other tools for public health research.

A recent agricultural engineering thesis suggested that the overall philosophy of maintenance and safety guarding (i.e. safety practices) on all types of machines may be more informative than an individual functional assessment [27]. A different approach to the study of safety practices as an organizational variable, is proposed in accordance with accident causation theory [28]. Results using this approach could inform the content and direction of interventions to reduce the burden of machinery injuries on Canadian farms, while adding to etiological knowledge.
1.3 Objectives and hypotheses

This thesis investigated possible determinants of machinery-related injury on the farm. Safety device use and routine maintenance were the key exposures under study. The primary purpose was to investigate the underlying etiological relationship between safety practices and the occurrence of machinery-related injury. A secondary goal was to explore the practical relevance of these practices in common machinery tasks. This is a manuscript-based thesis.

1.3.1 Manuscript 1: Operational safety practices as determinants of machinery-related injury on Saskatchewan farms

The objective of this manuscript was to evaluate the relative importance of two representative safety practices, i.e., routine maintenance and use of safety devices and their relationship with machinery-related injury in a cross-sectional analysis. The exposure-outcome relationship was evaluated using data collected as part of the Saskatchewan Farm Injury Cohort Study (SFIC [29]; baseline survey). My hypothesis was that: (1) reduced presence of safety devices on machines; and (2) the amount of time committed to conduct routine maintenance would each be important operational determinants of machinery-related injury on farms.

1.3.2 Manuscript 2: Machinery entanglement injuries among farmers in Western Canada: a task-based analysis

The objective of the second manuscript was to evaluate the roles of safety device use and routine maintenance (i.e. safety practices) during farm machinery tasks in the occurrence of entanglement injuries. A further objective was to examine the situational factors associated with farm machinery entanglement events. A descriptive case series design was employed.

1.4 Thesis Organization

This thesis has been organized according to the Queen’s University School of Graduate Studies and Research guidelines [30]. The second chapter reviews the literature surrounding
machinery-related injury and its relationship with safety practices in the context of accident causation theory. The third chapter of this thesis is Manuscript 1, and it examines the relationship between machinery-related injury and safety device usage and routine maintenance in a cross-sectional analysis. This manuscript conforms to the submission guidelines to the journal Accident Analysis and Prevention. The fourth chapter is Manuscript 2, which describes the role safety practices in the occurrence of machinery entanglement injury during common farming tasks in a case-series framework. This manuscript is formatted according to the requirements of the Journal of Agricultural Safety and Health. Chapter 5 discusses some of the methodology behind each of the manuscripts. Finally, the sixth chapter summarizes both studies, followed by a general discussion of the policy implications and study conclusions.

1.5 References


Chapter 2
Literature Review

2.1 Scope of literature review

The purpose of this chapter is to assess the literature with respect to agricultural machinery injury (outcome) and key safety practices in the operational environment (exposures) that could result in a difference in injury rates. First, characteristics of machinery-related agricultural injury will be discussed. Second, research surrounding risk factors related to agricultural machinery injuries will be reviewed. Third, literature surrounding the relationship between safety practices (i.e. safety device use and routine maintenance) and agricultural machinery injury will be discussed. Fourth, these variables and their relationship to injury will be explored in the context of accident causation models [1] and their relationship will be discussed. Fifth, literature that informed the development of a priori hypotheses in this thesis will be summarized.

2.2 Characteristics of machinery-related agricultural injury

Injuries from agricultural machinery and their constituent mechanisms have been identified as a principal source of non-fatal injuries and disability [2]. Non-fatal machinery-related injuries tend to be more severe and result in longer periods of hospitalization and lost work time when compared with other types of farm injury [3]. The percentage of farm injuries attributable to machinery ranges from 33% to 43% [4-6].

There is a need for reliable information on machinery-related injuries to develop prevention strategies. Rates of injury are usually underestimated since data collection instruments
often capture limited data. Many studies are conducted using case data, coronial reports or emergency department records. Other minor, yet medically treated injuries are seldom captured in hospital data. Further, family farms are not always covered by regulatory reporting requirements such as workers’ compensation systems. Population-based epidemiological approaches that rely upon questionnaires or direct interviews with farmers can correct for these drawbacks and provide more accurate data [7].

Population health studies of farm injury can be either descriptive or etiological in nature. Descriptive studies have explored the scope of, and identified patterns related to machinery-related injury for further study. As descriptive studies do not simultaneously adjust for factors related to outcome and exposure(s) of interest (i.e. confounders), evidence from such sources cannot be used by themselves to formulate evidence-based injury prevention strategies. Analytic epidemiological studies can inform the planning of such interventions and contribute to the development of causal theories.

2.3 Characteristics of potential risk factors

Causes of machinery-related injuries are multi-factorial in nature. Exposure to a wide variety of hazards on the farm renders the identification of causal factors a complex task. Several features unique to farm work contribute to this complexity. The farm is both a place of work and a residence where few industrial safety regulations are applicable [8]. The type of farm, the intermittent nature of agricultural work, the work environment and the prolonged hours of farm work can expose the worker to different hazards. Machinery is used for many tasks on the farm including: building maintenance and repair, construction and transport in addition to production activities and crop processing.
There are many types of machines used in production agriculture. Each of these machines share hazards. The action or motion of their components can result in injury to the farmer. Some of these machine hazards are as follows: (1) pinch point hazards, common to belts, chains and gear drives used in power transmission systems, occur when two parts move together with at least one of them moving in a circle; e.g. where drive belts contact pulley wheels or gear sprockets; (2) wrap point hazards exist due to rotating shaft devices either in primary power take off (PTO) drive lines (e.g. tractors) or on secondary shafts (e.g. silage transport); (3) shear or cutting point hazards are where the edge of one part moves across another (one of the two parts could also be stationary) e.g. small grain combine harvesters, forage harvesters, grain augers; (4) hitching implements or attaching trailed equipment to tractors creates crush point hazards; (5) freewheeling hazards exist when rotating components take time to come to a complete halt after being switched off; e.g. grinders, forage harvesters. These injuries are not “random accidents or events” and can be controlled through the elimination of, or protection against hazards [9].

The relative importance of demographic and health factors may vary when considered in the context of machinery-related injuries compared to farm injuries in general. Therefore, it becomes necessary to review prior studies that have dealt with machinery-related injuries as the outcome, as outlined in the next section.

2.4 Review of studies on machinery-related injuries

Machinery-related farm injuries can be considered as the outcome of a dynamic interaction between host, agent and environment in a traditional epidemiological triangle [9]. Here, the farmer (host) suffers an injury influenced by factors related to the machine (agent) and the surrounding farm environment. A number of independent demographic, machinery and farm risk factors have been identified in past multivariate analyses (Table 1).
Table 1. Risk factors identified from prior multivariate analyses with machinery-related injury as the outcome.

<table>
<thead>
<tr>
<th>Risk Factor</th>
<th>Citation</th>
<th>Categories</th>
<th>R.R.</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hours worked per week</td>
<td>Layde, 1995</td>
<td>continuous</td>
<td>1.02</td>
<td>1.01-1.03</td>
</tr>
<tr>
<td></td>
<td>Gerebrich, 1998</td>
<td>19 h</td>
<td>1.00</td>
<td>referent</td>
</tr>
<tr>
<td></td>
<td></td>
<td>20-39</td>
<td>1.73</td>
<td>0.69-4.36</td>
</tr>
<tr>
<td></td>
<td></td>
<td>40-59</td>
<td>3.22</td>
<td>1.31-7.95</td>
</tr>
<tr>
<td></td>
<td></td>
<td>60-79</td>
<td>4.88</td>
<td>1.97-12.08</td>
</tr>
<tr>
<td></td>
<td></td>
<td>80+</td>
<td>3.87</td>
<td>1.41-10.65</td>
</tr>
<tr>
<td>Years of farming experience</td>
<td>Sprince, 2002</td>
<td>&gt; 50 h/wk in last year</td>
<td>2.02</td>
<td>1.38-2.94</td>
</tr>
<tr>
<td>Position on farm</td>
<td>Sprince, 2002</td>
<td>≤ 25 years experience</td>
<td>1.79</td>
<td>1.14-2.79</td>
</tr>
<tr>
<td>Male gender</td>
<td>Baker, 2008</td>
<td>Owner/manager</td>
<td>1.00</td>
<td>referent</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Employee/contractor</td>
<td>2.83</td>
<td>1.61-5.00</td>
</tr>
<tr>
<td>Nature of involvement in farming</td>
<td>Baker, 2008</td>
<td>Seasonal</td>
<td>7.04</td>
<td>2.38-20.81</td>
</tr>
<tr>
<td>Machines not purchased new</td>
<td>Baker, 2008</td>
<td></td>
<td>6.11</td>
<td>2.38-15.69</td>
</tr>
<tr>
<td>Male gender</td>
<td>Lee, 1996</td>
<td></td>
<td>6.91</td>
<td>3.15-15.15</td>
</tr>
<tr>
<td></td>
<td>Gerebrich, 1998</td>
<td></td>
<td>3.79</td>
<td>1.81-7.92</td>
</tr>
<tr>
<td></td>
<td>Carlson, 2005</td>
<td></td>
<td>7.23</td>
<td>4.27-12.26</td>
</tr>
<tr>
<td>Prior/residual agricultural injury</td>
<td>Carlson, 2005</td>
<td></td>
<td>2.02</td>
<td>1.39-2.94</td>
</tr>
<tr>
<td></td>
<td>Zhou, 1994</td>
<td></td>
<td>3.71</td>
<td>1.83-7.52</td>
</tr>
<tr>
<td>High CAGE score (alcohol and smoking)</td>
<td>Sprince, 2002</td>
<td>&lt; 16 y/never married</td>
<td>2.41</td>
<td>1.03-5.59</td>
</tr>
<tr>
<td>Marital status</td>
<td>Gerebrich, 1998</td>
<td>Never married/ ≥16 y</td>
<td>1.00</td>
<td>referent</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Married/≥16 y</td>
<td>2.07</td>
<td>1.16-3.68</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Separated/≥16 y</td>
<td>3.82</td>
<td>1.5-9.74</td>
</tr>
</tbody>
</table>

Demographic characteristics that have been shown to be independently associated with risk for machinery-related injury include: (1) being a male farmer (gender); (2) prior or residual agricultural injury; (3) substance use; (4) being married or ever having been married. Male farmers are more involved with the operation and upkeep of machinery on farms, resulting in a greater exposure to machinery components [10, 11].

Risk factors surrounding farm work with machinery include: (1) increased work hours; (2) having low levels of farming experience; (3) being a farm employee; (4) engaging in seasonal farm work; (5) using machines that were not purchased in new condition; (6) working with an
auger [11, 17]. Although tractors are the most common machinery type associated with injuries, other machines responsible for farm injuries include balers, combines, augers and tilling equipment. Independent farm-level risk factors are as follows: (1) increased farm size [6]; (2) an increased number of work hours per week [5, 11, 12]. Both of these factors could result in a greater exposure of the farmer to machinery-related risks.

Prior research has primarily focused on demographic and health behaviors as risk factors [11, 13-15]. Some of these studies serve to establish the reliability of injury statistics through effective survey instruments and measures of specific exposure [11]. However, these studies only relate to the conceptual underpinnings of this thesis since they do not include the exposures of interest. Only three studies modeled the relationship between the safety practices considered and machinery-related injury [12, 16, 17]. Of these, Layde et al [12] was the earliest proponent to identify potential risk factors for machinery-related injury in demographic and behavioural domains. Too few injuries were associated with machines to permit an adequate analysis of machine-specific risk factors. This analysis was conducted for a region where the predominant agricultural activity was dairy farming, so the results were also limited in external validity to other types of farms. There were no on-site inspections to confirm poor maintenance or the removal of safety devices and shields. Finally, this study also did not consider the number of hours of exposure to different types of machinery which would be necessary to calculate the ideal hazard of injury for each exposure. Given these constraints, there was a lack of evidence of an association between safety devices and the occurrence of injury.

Both Ingram [16] and Baker et al [17] conducted multivariate logistic regression analyses that sought to correct the shortcomings identified by Layde et al [12]. Both these analyses shared a similar matched case-control study design and conducted on-site investigations of machinery to follow-up on the presence/absence of safety devices and condition of machinery. These studies
controlled for a number of demographic and behavioural factors while examining the relationship between individual and machine characteristics using a human factor analysis approach.

Ingram [16] studied the relationship between machinery-related injury and compliance with guarding standards and maintenance scores. Neither variable was found to be associated with injury. Although no statistically significant relationship was detected, maintenance was directly or indirectly implicated in the injury event in 14 (58%) of the cases. Also, farmers commonly reported performing maintenance to return their machines to operational condition rather than in a regular manner. This study suffered from recruitment difficulties that resulted in a limited statistical power during analysis. Only one-half of the injured cases volunteered to participate in the on-site portion of the study, versus almost all of the controls, suggesting an element of selection bias.

Baker et al [17] advocated the use of error-tolerant machinery systems during agricultural practice. A safe systems approach to injury control and management was also proposed. No evidence of an association was found between machinery-related injury and either of the following safety practices: (1) different schemes of maintenance; (2) the adherence to safety device standards. The study may have suffered from selection bias due to recruitment of hospital based cases, although control recruitment did not seem to have the same problem. Although the authors attempted to compensate for the limited number of injury cases by employing a control to case ratio of 2:1, this study still suffered from a lack of statistical power.

2.5 Machinery-related safety devices

Hazards cannot be eliminated even in a safe machine that performs its normal intended function without causing injury. Occupational safety guidelines on farms vary depending on the jurisdiction (i.e. province or state) in North America. In Canada, provincial regulations regarding
agricultural safety vary widely. In the United States, conformance to current occupational safety guidelines on farm machinery is required only for farms that have more than eleven employees per farm [13]; this may apply to less than 10% of the farms there. Safety features are often available only as optional accessories to buyers of machinery at additional cost. Economic considerations may also influence the decision to install safety devices on machinery [34]. The fact that production agriculture has few if any safety regulations undoubtedly influences the safety behaviour of farmers. Additionally, farm safety only requires voluntary compliance by the farm operator. Safety features (e.g. guarding) on machinery may also be removed or modified to gain performance advantage or for operational convenience.

Safety devices like power-take off shields are standard on machinery but can be easily circumvented [15]. Older farm machinery that did not originally have safety features can be retro-fitted to extend operating life. Such actions increase the potential for injury (Table 2).

Table 2. Injury mechanisms, moving parts and safety features on different types of farm machinery

<table>
<thead>
<tr>
<th>Machine (example)</th>
<th>Examples-moving parts</th>
<th>Injury mechanism</th>
<th>Safety feature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Augers</td>
<td>Flighting</td>
<td>Wrapping/Pull-in (entanglement)</td>
<td>Guarding, accessible emergency stop-switch</td>
</tr>
<tr>
<td>Combines</td>
<td>Rollers</td>
<td>Pinching</td>
<td>Blocking device to prevent movement during reactive maintenance</td>
</tr>
<tr>
<td>Combines, swathers</td>
<td>Cutting knives</td>
<td>Cuts and lacerations</td>
<td>Guarding or encased design</td>
</tr>
<tr>
<td>Trailed equipment</td>
<td>Hitching</td>
<td>Crushing</td>
<td>Interlocks, blocks to prevent movement</td>
</tr>
</tbody>
</table>

Use of safety devices can be considered as an exposure indicative of the safety practices on a farm. Literature describing the association between safety practices and injury is inconclusive. Ingram [16] studied the relationship between machinery injury and compliance with
guarding standards. This measure was assessed through on-site investigations, yet no evidence of an association was found. Another recent study [17] found no evidence of an association between a composite safety feature score and injury risk. The safety feature score was a functional measure assessed at the individual level. Both studies modeled exposure-outcome relationships with the individual as the unit of analysis. Research into these operational factors may benefit from a different approach. Injuries represent the failure of occupational safety management at the farm-level. Hence, there is a need for additional studies to investigate the use of safety shields and guards on machinery as an injury determinant particularly in the North-American context, but at the farm-level. Accident causation theory postulates that safety is an organizational quality rather than that of the individual [1]. Therefore, it may be advantageous to consider safety practices and injuries on a per farm basis.

2.6 Machinery maintenance

Regular maintenance is considered to be a basic tenet of injury prevention, as it is one indicator of safety practices [18]. Maintenance refers to the general upkeep and repair of machinery to keep it in sound working order, regardless of the age of the machine. Improper maintenance of farm machines in either a planned or reactive scheme may result in hazards that create the potential for injury [19]. Routine maintenance of machinery not only depends on the state of the machine, but also reflects the safety attitudes and safety behaviour prevalent on farming operations. From a behavioural perspective, farmers who are more concerned with safety will be more likely to engage in maintenance activities regularly. Maintenance and repairs often follow reactive rather than planned schemes, either due to economic considerations, or due to lack of time and training [20].

Etiological studies in this area are limited. Little if any quantitative evidence of an association between machinery maintenance and farm injury has been found thus far, probably
due to poorly powered studies [17]. Additionally, statistical analyses consider maintenance as an individual variable. Consideration of maintenance as a farm level variable may offer a better insight regarding its relationship with injury.

2.7 The relationship between safety practices and machinery-related injury using Accident Causation Theory

2.7.1 Background

Many potential hazards present in machinery and its constituent mechanisms can create conditions where injury can occur once the hazard is activated [21]. Hazardous situations created due to farm environmental hazards and individual behaviour can both cause injury [22]. Since injury is the result of a logical sequence of events, it is not a random occurrence and can be controlled or prevented. Farm machinery hazards cannot cause injury if the chain of events is interrupted or altered. Figure 1 illustrates this concept. The likelihood of an injury occurring when a person is exposed to a hazardous situation can be evaluated using risk assessment methods [23].

![Epidemiological accident model](image)

**Figure 1.** Epidemiological accident model (adapted from Hollnagel [24])

Assessment of risk in such a farm environment requires a multi-disciplinary effort involving agricultural engineering, medicine, sociology, and operational research.
Epidemiological models describe accidents as the outcome of a number of factors interacting together, some manifest and others latent. Manifest factors are clearly identifiable as factors contributing to an accident (e.g. cutting blades on a combine) where as the role of latent factors are less apparent (e.g. training).

Epidemiological injury models address performance deviation relating to the function of a human or technological component outside normal parameters. They also consider fluctuations in the work environment. Barriers impede the sequence of events leading to an injury. Latent conditions are dormant within a system well before an accident sequence is initiated. They result in performance deviations or render protective barriers in a system ineffective. Latent conditions can exist in several forms. Examples include a lack of functional (procedures and rules; e.g. training, maintenance) or physical barriers (e.g. safety devices) on farms, and these are most relevant to this thesis.

Using these accident models, and depending on the exposures or outcomes of interest, a number of theories surrounding farm injuries have been developed. These theories are useful in developing \textit{a priori} hypotheses, and aid in the development of conceptual models for \textit{post hoc} analyses of injury occurrence. The two manuscripts explore farm injuries in the context of the \textit{West Jutland Model of Farm Accidents} [25]. This model will be used to study the relationship between machinery-related injuries and safety practices.

\subsection*{2.7.2 West Jutland Model of Farm Accidents}

The \textit{West Jutland model} ([25], Figure 2) assumes that the farmer reacts to physical hazards and hazardous situations based on individual and environmental factors. Individual factors include knowledge, safety attitudes and perceptions. Environmental factors include farm size, type and variables associated with farm management like safety practices. Economic pressure and psycho-social stresses influence farm management. The farmer has a strong
influence on their working environment through planned safety checks and machine maintenance to avoid physical machine hazards [25] (Behavior A) or avoid unsafe practices when facing a hazardous situations during field work [25] (Behavior B). Organizational farm safety practices are an example of behavior A, while response to hazardous situations in field tasks is an example of behavior B. The two manuscripts explore farm injuries in the context of this model.

Safety practices are a farm-level trait. The statistical analysis employed in this thesis considers injury and safety practices at the farm level. Prior etiological studies have typically used the individual as the unit of analysis. Although individuals are often considered to be the focal point for safety interventions [26], this approach may be inadequate by itself.

![Figure 2. Model for machinery-related injury events on the farm adapted from the West Jutland Study model of farm accidents (Glasscock et al., 1997 [25]).](image)

2.8 Summary

Injuries caused by agricultural machinery are a major public health problem in terms of their societal burden, treatment costs, disability and lost potential to farming operations. Most etiological studies have focused on demographic and health behavioral determinants of injury.
The few studies that have considered machinery-related determinants may be under-powered to
detect an association with the injury outcome. Although the level of intervention for safety
practices is typically at the farm-level, most of these studies have been conducted at the
individual level. Thus, there is a need to study the relationship between these safety practices and
the occurrence of machinery-related injury at the farm-level. Additionally, it is important to
explore the role of these safety practices in the occurrence of machinery entanglements.
Collectively, this should inform the content and development of education and training initiatives
for injury prevention. Therefore, this thesis considers the use of safety practices (i.e. safety device
use and routine maintenance) as possible determinants.

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Manuscripts 1 and 2

**Note:** The methodology for each of the studies is discussed as part of each relevant manuscript. Supplemental details about study methods are also provided in Chapter 5.
Chapter 3

Operational safety practices as determinants of machinery-related injury on Saskatchewan farms

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Abstract word count: 205 words; Article word count: 2,516 words; Tables 4.

Abbreviations used: RR, Relative Risk; CI, Confidence interval; SFIC, Saskatchewan Farm Injury Cohort Study.
3.1 Abstract

Agricultural machinery is a major source of injury on farms. The importance of machinery safety practices as potential determinants of injury remains incompletely understood. We examined two such safety practices as risk factors for injury: (1) the presence of safety devices on machinery; (2) low levels of routine machinery maintenance. Our data source was the Saskatchewan Farm Injury Cohort baseline survey (n=2390 farms). Factor analysis was used to create measures of the two operational safety practices. The farm was the unit for all analyses and associations were evaluated using multiple Poisson regression models. Limited presence of safety devices on machinery during farm operations was associated with higher risks for injury (RR 1.94; 95% CI 1.13 to 3.33; \( p_{\text{trend}}=0.02 \)). Lower routine maintenance scores were associated with significantly reduced risks for injury (RR 0.54; 95% CI 0.29 to 0.98; \( p_{\text{trend}}=0.05 \)). The first finding implies that injury prevention programs require continued focus on the use of safety devices on machinery. The second finding could indicate that maintenance itself is a risk factor or that more modern equipment that requires less maintenance places the operator at lower risk. These findings provide etiological data that confirms the practical importance of operational safety practices as components of injury control strategies on farms.

Key-words: Farming; Agriculture; Occupational Injury; Operational exposure; Safety practices.
3.2 Introduction

Agriculture remains one of the most hazardous occupations in North America [1-5]. In 2003, almost double the percentage of Canadian farm workers sustained non-fatal, activity limiting injuries relative to a 3.8% average for other occupations [6]. Activities related to farm machinery were responsible for about half of these agricultural injuries [3, 7]. On average, 177 hospitalizations per 100,000 people are reported annually due to agricultural machinery injuries in Canada [8]. The annual economic burden of these injuries in terms of lost potential, disability, treatment and rehabilitation costs is substantial [9].

The etiology of machinery-related farm injuries remains incompletely understood. Existing theory suggests that the contextual nature of farm work environments plays an important role in the occurrence of injury [10]. Contextual factors that could lead to injury include operational safety practices associated with farm machinery use. For example, use of safety devices on machinery is a practice that can attenuate exposure of workers to physical safety risks [11]. These risks have been evaluated descriptively [5, 12, 13], and analytically [2, 14-18]. Existing analytic studies have primarily evaluated demographic factors related to machinery use and only two have dealt specifically with safety device usage [15, 16]. The upkeep or state of machinery may play a role in the occurrence of injury. With the exception of one recent study, no etiological analyses evaluate the relationship of both maintenance and safety devices and risk for injury in the same multivariate model [16]. Despite routine maintenance of agricultural machinery being advanced as a prevention strategy, there is a lack of etiological evidence that confirms its importance as a protective factor.

We had the opportunity to model potential relationships between these two sentinel safety practices and the occurrence of farm machinery injury using a cross-sectional analysis of data from an existing population-based survey. We initially hypothesized that: (1) reduced presence of
safety devices on machines; and (2) the amount of time committed to conduct routine
maintenance would each be important operational determinants of machinery-related injury on
farms.

3.3 Methods

3.3.1 Sample

Data were analyzed from an existing baseline survey conducted as part of the
*Saskatchewan Farm Injury Cohort Study* (SFIC). The SFIC used a multi-staged cluster procedure,
with 2390 farms sampled in clusters nested within fifty rural Saskatchewan municipalities.
Sampling, recruitment and response rates are described in full elsewhere [10]. In brief,
approximately one-half (4,234 farms; 52%) of 8,169 farms that were initially approached returned
the baseline questionnaire; 923 farms were ineligible, 887 farms refused participation and 34
farms returned partially completed questionnaires. This left 2,390 eligible farms (out of 7,246; or
33%) for consideration in the current analysis [10, 19].

3.3.2 Data collection and Study design

Data collection was conducted for a one year period of recall using a mailed
questionnaire and standard survey methods [20]. To ensure face validity, the questionnaire was
piloted on a sub-sample of fifty farm people who were not subsequently enrolled in the study [10,
21]. In the full baseline survey, a designated adult respondent on each participating farm
completed the baseline questionnaire. Each respondent provided information that characterized
farm residents, safety hazards, safety practices and the occurrence of injury on the farm. Ethics
approvals were obtained from the University of Saskatchewan Research Ethics Board and the
Queen’s University Health Sciences Research Ethics Board.
We chose to conduct all analyses with farms as the unit of analysis consistent with the anticipated level of intervention. Measures consisted of: (1) indicators of safety behavior and practices measured at the farm level, as well as, (2) other individual level indicators aggregated to the farm level for analytical purposes.

3.3.3 Study Variables

3.3.4 Outcome: machinery-related injury

Total counts of machinery-related injuries were calculated for each farm over a one-year period of recall (calendar year 2006). For the purposes of this study, farm machines were defined as any machine that: (1) involved moving mechanisms and parts; (2) was powered mechanically or physically; and (3) was applied to an agricultural production activity.

3.3.5 Exposures-Operational Safety Practices

Summary scores were developed for each of the two sentinel exposures as measures of safety practices on the farm. These are described below.

3.3.6 Exposure 1- Presence of safety devices on sentinel machines

The SFIC questionnaire contained a set of questions that were used to estimate the proportion of sentinel farm machine types that had safety devices in place. Responses were then compiled as a composite measure. Sentinel machines included: (1) farm tractors; (2) combines; and (3) augers. For each sentinel machine type, respondents were asked “How many of these [machines] have safety shields and guards in place (none/some/all of them). The three items were then reduced to a single factor score using common factor analysis. As the tractor item did not load on the created factor, it was removed from further consideration. The final safety score included measures of safety shields or guards on combines and augers (Cronbach’s alpha value: 0.84; factor loading=0.63).
3.3.7 Exposure 2-Routine maintenance on sentinel machinery

Routine maintenance of sentinel farm machinery was reported using two separate questionnaire items for tractors and combines. Initial questions asked: “During 2006, how many hours per year did this person perform maintenance on [machine type]?” The separate items were then reduced to a single routine maintenance score using common factor analysis. Both items were retained in the created factor scale as they had a high degree of internal consistency and high factor loading values (Cronbach’s alpha: 0.88; factor loading: 0.71) [22].

3.3.8 Potential Mediator-Machinery operational hours score

Operating hours for machinery were reported using two separate questions for tractors and combines. Initial questions asked: “During 2006, how many hours did the individual operate the [machine type]?” The two items were then reduced to a single score factor analytically, displaying a high internal consistency and factor loadings (Cronbach’s alpha=0.82; factor loading=0.57).

3.3.9 Potential confounders

Covariates were selected based on published evidence [2, 15, 17, 18, 23] and a contemporary definition of confounding [24]. Some potential confounders were measured at the farm level directly (debt worry, cash-shortage worry; [25], total acreage, total number of farm residents) while others were aggregate measures for individuals on the farm (an alcohol consumption index, a farm co-morbidity index, education level of the farm owner-operator).

3.3.10 Statistical analysis

All statistical analyses were performed at the farm level. Analyses were conducted using SAS version 9.1 (SAS Institute, Cary NC). First, the number of machinery-related injuries was profiled by machinery type, as well as by key individual and farm-level characteristics. Next, relationships between the injury outcome and exposures were examined. Key exposures and
potential confounders were divided into categories for analytical purposes. The SAS GENMOD procedure with a Poisson distribution and log link function was used in regression analyses. The effects of the exposures on machinery-related injuries were initially examined through crude models. A series of hierarchical models were developed to estimate the strength and significance of focal associations after controlling for various sets of potential confounders. The final adjusted model retained confounders if they resulted in a 10% or greater change in either exposure effect estimate relative to the base model [26]. Operational hours on machinery was controlled for as a potential mediating mechanism, by which machinery safety practices could be related to injury.

3.4 Results

3.4.1 Descriptive analysis

A total of 159 machinery-related injuries on 2,390 Saskatchewan farms were identified during the one-year study period (2006 calendar year). 143 farms and 8 farms reported one and two machinery-related injuries, respectively. Table 3 describes the distribution of machinery-related injuries by the type of machine involved. Overall, tractors, combines and augers were the largest single types of machinery responsible for injuries.

Table 4 describes machinery-related injuries by key demographic and farm characteristics. Farm residents in the 45-64 and 20-44 years age groups reported the highest number of machinery-related injuries and the majority of these were male victims. Similar numbers of injuries occurred on farms of various acreages. Greater number of injuries occurred on farms having 2 to 6 farm residents relative to other categories. The education level of the owner-operator did not seem to be related to the occurrence of injury on farms. Most injuries occurred on farms where grain was produced, consistent with common types of farming in Saskatchewan.
3.4.2 Analysis of potential confounders

Table 5 describes relationships between potential confounders and the injury outcome. Although the farm alcohol consumption index and total number of farm residents were associated with machinery-related injury in crude analyses, only the latter variable retained its significance within the adjusted analysis. Multivariable modeling of potential confounders simultaneously showed that injury risk was significantly elevated for farms that had one to two persons relative to a larger numbers of farm residents.

After controlling for selected confounders, relationships identified in crude analyses (Table 6; and adjusted (1)) persisted in an adjusted model (Table 6; adjusted model (2)). Farms where safety devices were used on a lower proportion of the equipment were 1.49 times more likely to report machinery-related injuries. Farms with low routine maintenance scores experienced a lower risk of injury. These farm maintenance scores were related to injury risk (p_trend=0.05); farm residents were 52% and 54% less likely to experience a machinery-related injury with annual maintenance hours in quartile 3 (0 to 13 hours) and quartile 4 (14 to 28 hours) compared to the highest score quartile of maintenance (53 to 321 hours). The relationship between maintenance and machinery-related injury became statistically non-significant when the machinery operational hours score was added to the analysis (Table 6; adjusted model (3)). However, the strength and direction of the effect between safety devices and machinery-related injury still persisted. The goodness of fit estimates for the final model does not indicate any significant overdispersion (\(\chi^2/df=1.06\)).

3.5 Discussion

The main findings of this analysis suggest the following: (1) an increased risk of machinery-related injury is associated with less frequent use of safety devices on sentinel machines; and (2) lower risks for injury may be related to lower routine maintenance score for these farm machines, being partially mediated by hours of machinery operation. These etiological
findings provide insight into the safety awareness, attitudes and behaviour of workers that shape the contextual environment of farms.

3.5.1 Exposure 1: Presence of safety devices on sentinel machines

In line with existing information [7], we hypothesized that regular use of safety devices on machinery lowers the risk for injury. The absence of safety devices on machinery represents an obvious operational hazard. However, prior etiological studies have not demonstrated the relative importance of the absence of safety devices as a risk factor. Of existing studies, self-made safety devices, disabling safety devices, inconvenient safety features and safety features that hamper operation have not been found to be significantly associated with elevated injury risks [15, 16]. Depending on the operational hazard, safety devices may range from shields to tractor roll over protection structures. Our study findings were expected and are consistent with our analytical hypothesis.

3.5.2 Exposure 2: Routine maintenance on sentinel machines

Agricultural safety guidelines stress the need for maintenance as a practice to prevent premature machinery failure and injury [27]. However, these guidelines are not grounded in evidence that distinguishes between the relative effects of different approaches to maintenance on risks for injury. Further, maintenance itself is a complicated concept as it may involve an intermittent activity pattern for farm machinery. Maintenance tasks can be classified into three categories – preventive, condition-based and routine [28]. By developing familiarity with the machine, through routine upkeep and inspection, the operator can make more intelligent decisions to reduce the potential safety hazards that the machine presents. Therefore, this study tested the hypothesis that less routine maintenance would be associated with higher risks for injury.

Our initial study findings were somewhat counterintuitive to our original hypotheses, in that low maintenance scores were found to be related to a reduced risk for injury. We attempted
to control for farm level exposure to machinery by adding a machinery operational hours variable to the model (Table 6; adjusted model (3)). Operational hours partially mediated the relationship between maintenance and injury, resulting in its statistical non-significance. This is logical as longer operation of machinery necessitates a greater need for maintenance that in turn increases exposure to machinery hazards. Interestingly, reductions in risk for injury persisted to some degree after we controlled for the operational hours score. This finding can be explained through two competing theories.

First, maintenance tasks often bring farmers into intimate contact with machinery hazards (e.g. moving parts, cutting blades). This could indirectly lead to a greater risk for injury [29, 30]. Second, many Saskatchewan farms may use modern machinery that requires less maintenance, and are therefore associated with a reduced injury risk. Unfortunately, the age of sentinel machines was not collected as part of this study. This interpretation is supported by a recent study that demonstrated that machinery age was a determinant of injury. The odds of injury increased by 4% for every year a machine ages [16]. Other studies have not identified such an association [14]. One case-control study did not find evidence of a statistically significant association between occurrence of injury and different types of maintenance (preventive/condition-based, unplanned/planned, frequency of maintenance) [16]. The lack of a statistically significant association does not mean that one does not exist; only that there is insufficient evidence to detect a relationship due to the reasons outlined above.

### 3.5.3 Strengths and Limitations

This study has a number of strengths. First, we employed a unique and practical approach to exposure assessment. Safety practices on sentinel machinery types (tractors, combines and augers) were considered as these are common exposures that also account for the largest proportion of injuries on North American farms [3, 5, 15]. Second, we conducted analyses of focal relationships while controlling for known confounders [31]. Third, the study was of a
rigorous etiological nature rather than the traditional descriptive approach used to document machinery-related injury. Limitations of this analysis also warrant comment. First, our ability to establish the temporality of cause and effect is limited due to the cross-sectional study design [32]. Second, assessment over a single year may be too short to assess the cumulative nature of the exposures, especially given that they represent safety attitudes and habitual behaviors that develop over a lifetime. As the SFIC is an on-going initiative, both of these shortcomings can be addressed in subsequent analyses. Third, the risk measures may be residually confounded by variables not controlled for but shown to be associated with machinery-related injury, such as prior injuries sustained [18, 23]. The exposures are sentinel in nature but the outcome is a composite count for all types of machinery. This was done because: (1) the three machines were most common types in use; (2) they were the responsible for the largest proportion of injuries; and (3) mechanisms inherent to these sentinel machines can be found in other types of machinery. Hence, the exposures and outcomes under study have different levels of specificity. There is a potential misclassification of effect estimates because of this situation; but this effect should be minimal because of the arguments stated previously.

3.6 Implications for Injury Prevention

This analysis represents an attempt to evaluate operational safety practices as determinants of machinery-related injury on farms. Injury prevention programs clearly need to focus on enhanced use of safety shields on farm machinery. The fact that less routine maintenance was related to decreased risk of injury could be attributable to contact of operators with machinery, mediation by hours of machinery operation, or differences in the use of modern machinery. Further investigation into the role of machinery age, tasks being performed during injury events and maintenance schemes are required to clarify the role of machinery maintenance as an injury determinant. In total, it is hoped that the findings from this novel analysis will
encourage appropriate decision making and the establishment of operational factors as important components of injury control strategies, based upon etiological evidence.

3.7 Acknowledgements

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3.8 References


Table 3. Distribution of machinery-related injuries by machinery type (2006; Saskatchewan Cohort).

<table>
<thead>
<tr>
<th>Type of machinery</th>
<th>Number (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tractor</td>
<td>37 (23)</td>
</tr>
<tr>
<td>Transportation equipment</td>
<td>26 (16)</td>
</tr>
<tr>
<td>Harvesting equipment</td>
<td>23 (14)</td>
</tr>
<tr>
<td>Combine</td>
<td>17 (11)</td>
</tr>
<tr>
<td>Auger</td>
<td>17 (11)</td>
</tr>
<tr>
<td>Maintenance equipment</td>
<td>11 (7)</td>
</tr>
<tr>
<td>Other machine</td>
<td>28 (18)</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>159 (100)</strong></td>
</tr>
</tbody>
</table>
Table 4. Description of machinery-related injuries by key characteristics of people and farms: age, sex, farm acreage, total number of people on farm and farm commodity type.

<table>
<thead>
<tr>
<th>Demographic variable</th>
<th>Number (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age</strong></td>
<td></td>
</tr>
<tr>
<td>0-19</td>
<td>1 (1)</td>
</tr>
<tr>
<td>20-44</td>
<td>39 (25)</td>
</tr>
<tr>
<td>45-64</td>
<td>98 (62)</td>
</tr>
<tr>
<td>≥ 65</td>
<td>21 (13)</td>
</tr>
<tr>
<td><strong>Sex</strong></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>136 (86)</td>
</tr>
<tr>
<td>Female</td>
<td>23 (14)</td>
</tr>
<tr>
<td><strong>Size of farm (acreage)</strong></td>
<td></td>
</tr>
<tr>
<td>Q1: Minimum to 482 Acres</td>
<td>39 (25)</td>
</tr>
<tr>
<td>Q2: 483 acres to 1200 Acres</td>
<td>37 (23)</td>
</tr>
<tr>
<td>Q3: 1201 acres to 2160 Acres</td>
<td>43 (27)</td>
</tr>
<tr>
<td>Q4: 2161 acres to 19000 Acres</td>
<td>40 (25)</td>
</tr>
<tr>
<td><strong>Total number of people on farm</strong></td>
<td></td>
</tr>
<tr>
<td>One</td>
<td>4 (3)</td>
</tr>
<tr>
<td>Two</td>
<td>53 (34)</td>
</tr>
<tr>
<td>3 to 6</td>
<td>84 (53)</td>
</tr>
<tr>
<td>≥ 7</td>
<td>17 (11)</td>
</tr>
<tr>
<td>Missing</td>
<td>1 (1)</td>
</tr>
<tr>
<td><strong>Education of owner-operator</strong></td>
<td></td>
</tr>
<tr>
<td>Less than high school</td>
<td>36 (23)</td>
</tr>
<tr>
<td>Completed high school</td>
<td>53 (33)</td>
</tr>
<tr>
<td>Institution other than above</td>
<td>46 (29)</td>
</tr>
<tr>
<td>Completed university</td>
<td>21 (13)</td>
</tr>
<tr>
<td>Missing</td>
<td>3 (2)</td>
</tr>
<tr>
<td><strong>Type of farm (commodity)</strong></td>
<td></td>
</tr>
<tr>
<td>Grain</td>
<td>143 (90)</td>
</tr>
<tr>
<td>Beef and Dairy Cattle</td>
<td>78 (49)</td>
</tr>
<tr>
<td>Pigs and Other animals</td>
<td>17 (11)</td>
</tr>
<tr>
<td>Poultry</td>
<td>8 (5)</td>
</tr>
<tr>
<td>Vegetable/Fruit</td>
<td>7 (4)</td>
</tr>
</tbody>
</table>

*Commodity categories are not mutually exclusive.
Table 5. Poisson regression analysis examining potential confounding factors under study and their association with agricultural machinery injury.

<table>
<thead>
<tr>
<th>Potential Confounders</th>
<th>Adjusted RR (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Debt worry on farm</strong></td>
<td></td>
</tr>
<tr>
<td>Q1: Lowest (referent)</td>
<td>1.00</td>
</tr>
<tr>
<td>Q2</td>
<td>0.81 (0.43, 1.54)</td>
</tr>
<tr>
<td>Q3</td>
<td>0.57 (0.29, 1.11)</td>
</tr>
<tr>
<td>Q4: Highest</td>
<td>1.05 (0.58, 1.92)</td>
</tr>
<tr>
<td><strong>Cash-flow shortage worry on farm</strong></td>
<td></td>
</tr>
<tr>
<td>Q1: Lowest (referent)</td>
<td>1.00</td>
</tr>
<tr>
<td>Q2</td>
<td>1.25 (0.67, 2.34)</td>
</tr>
<tr>
<td>Q3</td>
<td>1.77 (0.93, 3.37)</td>
</tr>
<tr>
<td>Q4: Highest</td>
<td>1.04 (0.56, 1.92)</td>
</tr>
<tr>
<td><strong>Farm Alcohol Consumption Index</strong></td>
<td></td>
</tr>
<tr>
<td>T1: Low (referent)</td>
<td>1.00</td>
</tr>
<tr>
<td>T2</td>
<td>1.07 (0.70, 1.65)</td>
</tr>
<tr>
<td>T3: High</td>
<td>1.46 (0.98, 2.16)</td>
</tr>
<tr>
<td><strong>Farm Co-morbidity Index</strong></td>
<td></td>
</tr>
<tr>
<td>T1: Low (referent)</td>
<td>1.00</td>
</tr>
<tr>
<td>T2</td>
<td>1.24 (0.83, 1.85)</td>
</tr>
<tr>
<td>T3: High</td>
<td>1.18 (0.75, 1.86)</td>
</tr>
<tr>
<td><strong>Total number of farm residents</strong></td>
<td></td>
</tr>
<tr>
<td>High: 3 to 55 people (referent)</td>
<td>1.00</td>
</tr>
<tr>
<td>Low: Up to 2 people</td>
<td>1.52 (1.04, 2.23)</td>
</tr>
<tr>
<td><strong>Farm acreage</strong></td>
<td></td>
</tr>
<tr>
<td>Q4: 2161 to 19000 (referent)</td>
<td>1.00</td>
</tr>
<tr>
<td>Q3: 1201 to 2160</td>
<td>1.04 (0.56, 1.92)</td>
</tr>
<tr>
<td>Q2: 484 to 1200</td>
<td>1.77 (0.93, 3.37)</td>
</tr>
<tr>
<td>Q1: ≤ 483</td>
<td>1.25 (0.67, 2.34)</td>
</tr>
<tr>
<td><strong>Education of owner-operator</strong></td>
<td></td>
</tr>
<tr>
<td>Q4: Completed University (referent)</td>
<td>1.00</td>
</tr>
<tr>
<td>Q3: Other institution</td>
<td>1.58 (0.91, 2.74)</td>
</tr>
<tr>
<td>Q2: Completed high school</td>
<td>0.96 (0.56, 1.63)</td>
</tr>
<tr>
<td>Q1: Less than high school</td>
<td>0.99 (0.56, 1.76)</td>
</tr>
<tr>
<td><strong>Machinery operating hours</strong></td>
<td></td>
</tr>
<tr>
<td>Q1: Lowest (referent)</td>
<td>1.00</td>
</tr>
<tr>
<td>Q2</td>
<td>1.75 (0.99, 3.11)</td>
</tr>
<tr>
<td>Q3</td>
<td>1.38 (0.75, 2.55)</td>
</tr>
<tr>
<td>Q4: Highest</td>
<td>2.24 (1.23, 4.06)</td>
</tr>
</tbody>
</table>

*aSimultaneously adjusted for all other potential confounders under study*
Table 6. Poisson regression analysis examining relationships between key operational safety practices and machinery-related injury counts on Saskatchewan farms (2006).

<table>
<thead>
<tr>
<th>Key exposure</th>
<th>n</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>Crude</th>
<th>RR (95% CI) Adjusted (1)</th>
<th>Adjusted (2)</th>
<th>Adjusted (3)</th>
<th>P&lt;sub&gt;trend&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Safety devices installed</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q4: High (referent)</td>
<td>667</td>
<td>636</td>
<td>31</td>
<td>0</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>0.20</td>
</tr>
<tr>
<td>Q3</td>
<td>577</td>
<td>537</td>
<td>37</td>
<td>3</td>
<td>1.60</td>
<td>(1.01,2.54)</td>
<td>1.45 (0.87,2.44)</td>
<td>1.31 (0.78,2.21)</td>
<td>1.37 (0.79,2.38)</td>
</tr>
<tr>
<td>Q2</td>
<td>426</td>
<td>399</td>
<td>26</td>
<td>1</td>
<td>1.41</td>
<td>(0.85,2.36)</td>
<td>1.45 (0.83,2.54)</td>
<td>1.25 (0.70,2.24)</td>
<td>1.21 (0.65,2.27)</td>
</tr>
<tr>
<td>Q1: Low</td>
<td>562</td>
<td>518</td>
<td>40</td>
<td>4</td>
<td>1.84</td>
<td>(1.17,2.89)</td>
<td>2.15 (1.27,3.66)</td>
<td>1.94 (1.13,3.33)</td>
<td>2.08 (1.19,3.64)</td>
</tr>
<tr>
<td><strong>Hours of annual maintenance</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q4: 53 to 321 (referent)</td>
<td>475</td>
<td>434</td>
<td>40</td>
<td>1</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>0.05</td>
</tr>
<tr>
<td>Q3: 29 to 52</td>
<td>505</td>
<td>473</td>
<td>26</td>
<td>6</td>
<td>0.85</td>
<td>(0.55,1.32)</td>
<td>0.82 (0.52,1.29)</td>
<td>0.94 (0.59,1.50)</td>
<td>1.00 (0.61,1.64)</td>
</tr>
<tr>
<td>Q2: 14 to 28</td>
<td>469</td>
<td>447</td>
<td>21</td>
<td>1</td>
<td>0.55</td>
<td>(0.33,0.92)</td>
<td>0.51 (0.30,0.86)</td>
<td>0.52 (0.30,0.92)</td>
<td>0.58 (0.32,1.04)</td>
</tr>
<tr>
<td>Q1: 0 to 13</td>
<td>480</td>
<td>458</td>
<td>22</td>
<td>0</td>
<td>0.52</td>
<td>(0.31,0.87)</td>
<td>0.43 (0.25,0.76)</td>
<td>0.54 (0.29,0.98)</td>
<td>0.59 (0.29,1.19)</td>
</tr>
</tbody>
</table>

*Adjusted Model (1): Controls for other key exposure

*Adjusted Model (2): Controls for other key exposure + debt worry, cash-flow worry, alcohol consumption index, co-morbidity index, total number of farm residents, farm acreage, education of farm owner-operator

*Adjusted Model (3): Controls for other key exposure + confounders in Adjusted (2) + machinery operating hours
**Note:** To address reviewer comments, the analyses presented in Table 6 were re-run using the log-binomial model without offset and using Poisson Regression with offset. These supplemental results can be found in Appendix D.
Chapter 4

Machinery entanglement injuries among farmers in Western Canada: a task-based analysis

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Abstract word count: 164 words; Article word count: 2,022 words; Figures 2; Tables 3

Abbreviations used: CCFMI Case Control Farm Machinery Injury Study.
4.1 Abstract

Machinery entanglements are a leading cause of hospitalized injury on Canadian farms. This study evaluates the role of safety practices followed during routine farm machinery tasks in the occurrence of entanglement events. A retrospective case-series of 41 injuries involving 35 farm-machinery types was assembled from the Case-Control Farm Machinery Injury Study. The majority of entanglements occurred during a few machinery-related tasks, namely (1) field adjustments of machinery; (2) product handling and conveyance; and (3) driveline attachments and servicing. Both expected and unanticipated hazards inherent to these tasks affect the behaviour of farmers leading to entanglements. This study establishes a need to identify hazards and assess risks associated with different tasks involving the use of farm machinery under actual field situations. Systemic changes are required to improve existing machinery safety practices through engineering, work methods and work practice modifications. In addition to design solutions, occupational health and safety strategies should consider activities associated with hazardous situations to inform the content of training and educational efforts.

Key-words: Agriculture, Farming; Occupational Injury; Safety practices.
4.2 Introduction

Machinery entanglements are a leading cause of hospitalized agricultural injuries in Canada, and carry substantial costs in terms of their societal burden [1]. Entanglements occur when a body part or exposed clothing comes in contact with pinch, shear, crush, pull-in, wrap or compression points on machinery [2]. In Canada, entanglements are responsible for 22.5% of all agricultural injury hospitalizations and account for 40% of associated hospital costs [3, 4]. Studies of entanglements in the agricultural environment have largely examined anatomical sites of injury and demographic factors [5-7]. Agricultural activities identified with machinery injury events include repair/maintenance, working with field machinery, adjusting or hitching a load or equipment, and handling or transporting feed/grain and equipment [8-11]. While these studies have described sources of injury [8], temporal characteristics, and locations of injury [9, 10] there is a dearth of studies that evaluates safety practices and behaviours during farm machinery tasks leading up to entanglement injuries [12]. Hence this study was conducted to evaluate safety practices followed during farm machinery tasks to understand the nature of entanglements and the circumstances that lead to this injury event. A further objective of our study was to explore situational factors associated with these injury entanglements during common farm tasks. This approach can aid in the development of focused interventions to prevent or reduce entanglements.

4.3 Methods

Adult entanglement injury events were identified from the Case-Control Farm Machinery Injury Study (CCFMI) conducted in provinces of Manitoba, Saskatchewan and Alberta between 2000 and 2005. The study protocol was approved by the Human Research Ethics board at the University of Saskatchewan, and the analysis was approved by the Queen’s University Health Sciences Research Ethics Board.
Data for this study was sourced from the CCFMI that compiled data on machinery-related injury risk factors as well as on demographic, physical and health behavioral factors. Data was collected using a baseline survey administered during 2000 through 2005 to a study population in three Prairie Provinces (Alberta, Saskatchewan and Manitoba). Injury events that met the definition for entanglements and involved machinery mechanisms were included in this case series. Among cases, the response rate to baseline operational questions was 80% (41/52). Descriptive statistics were used to characterize the 41 entanglement injury events by demographic, operational and machinery factors. Injuries were further described by their nature, human body anatomical site, work activities and operational circumstances. A Pareto chart was used to highlight tasks that lead to a large proportion of entanglements [13]. Safety attitudes and work habits were further assessed in a sub-sample of 30 injury victims who responded to a supplemental questionnaire. All data management activities were conducted in Microsoft Excel 2003 (Redmond, WA) and statistical analyses were performed using SAS 9.1 (Cary, NC).

Illustrative vignettes for the identified tasks on the farm were created. Each vignette described common patterns leading to occurrence of entanglements during three tasks. Injury events were described using the epidemiological triad (person, machinery agent, and farm environment). Narrative description in each vignette was informed by these descriptive results. Narratives are meant to be illustrative, and do not represent individual injury events.

### 4.4 Results

Table 7 profiles various characteristics of the 41 injury cases. All but one of the victims were male. Injury victims were largely of typical working ages (i.e. 20-64 years; 87.5%). Three-fourths of those injured possessed greater than 20 hours of experience with the machine involved in the injury event. Of the latter number, two-thirds had at least 200 hours or greater hours of experience. While 57.8% worked in grain production, a considerable proportion of the injuries
(31%) took place in animal production activities. Many of the injuries (39%) occurred on farms of equal to or less than 1000 acres.

Table 8 describes the machine, mechanism and implements involved in machinery entanglements as well as operational, maintenance and safety characteristics. Augers were the leading machine involved (36%), followed by PTO drivelines (17%) and tractors and attached implements (14%). Safety features were in place on the machinery at the time of injury in 70% of the cases. These features consisted of manufacturer-made shields, guards, lids and covers (safety devices) and decals (safety signs). The condition of the machinery involved was assessed by the farmer as “above average” or “excellent” in the majority of the cases (62%). Of those who answered questions on repair and maintenance, 76% had their equipment repaired and about 97% of all machinery had undergone maintenance during the last year.

Table 9 describes the nature and anatomical sites of injury. These were most commonly amputations to digits of the hand (13/41; 36%). A substantial proportion of the events involved lacerations, and broken bones were present in 22% of the cases.

Figure 3 is a Pareto chart depicting the occurrence of injury by tasks that involve contact with machinery. A few tasks were responsible for the bulk of the entanglements, namely field adjustments of machinery, product handling and conveyance, driveline attachments and servicing.

4.5 Discussion

A number of clear situational patterns related to machinery use emerged from this analysis. In almost all entanglement events the operator displayed the following behaviours that resulted in injury: (1) being proximal to operational components before the machine came to a complete halt; (2) accessing drivelines for attaching implements or servicing by circumventing safety devices; (3) close contact with moving components to render the machinery or implement
operational. In addition, the following three tasks were associated with the majority (80%) of reported entanglements (Figure 3): (1) field adjustments of machinery; (2) product handling and conveyance; and (3) driveline attachments and servicing. These patterns are obvious priorities for prevention and are highlighted in the following illustrative vignettes.

4.6 Illustrative Vignettes

Pattern 1-Field adjustment. A 44 year old farmer was using a combine for grain harvesting operations on his 1750-acre farm. He was well experienced with operating the machine and had been working for about 3 hours into the afternoon. The 10 year-old combine had been repaired during the last year, and was in an “above average” condition. When the feeder house of the combine becomes plugged, the machine stopped functioning abruptly. The farmer left the machine idling with the header engaged and dismounted to manually push in the plugged material. After the unthreshed crop was dislodged, the auger in the platform resumes rotating and grabbed the farmer’s right hand. He received treatment for a partially amputated finger and lacerations at the local hospital.

Entanglements associated with field adjustments of machinery have the following typical characteristics: (1) The farmer has extensive operational experience with the machine; (2) The injury occurred in the crop field of a grain farm; (3) The injury occurred at a peak time during harvest activity; (4) Safety features were in place on the machine; (4) Anatomically, common injuries sustained were to the hands or digits.

Consistent with other studies [14, 15] the largest proportion of entanglement injuries in our study occurred during field adjustment of machinery. Major machines, implements and
mechanisms involved in these entanglements include the air seeder shank, cultivator harrow/shovels, balers and screw type conveyers (augers). Field adjustments of farm machinery typically include the removal of obstructions that result in temporary stoppage. Manual intervention was required to return the machine to operational status. This brings the farmer in close contact with machinery parts that presents an entanglement hazard. Automatic reversing mechanisms introduced in late 1990’s [16, 17] on machinery can eliminate the risk for injury though not all equipment possess these safety devices. In the absence of reversal mechanisms, the problem is aggravated by a lack of standard operating protocol to deal with field adjustment situations.

**Pattern 2- Product handling and conveyance.** A 35 year old farmer was using an auger to load grain onto a truck in the yard of his 500-acre farm. He was experienced in the operation of machinery and was working for the last five hours on a late summer afternoon. The 11 year-old auger is operational, but the safety cage around the flighting has been removed. The farmer attempts to clean up leftover grain by pushing it toward the auger intake with his hand while the auger is running. The farmer’s finger was drawn into the flighting. He was then admitted for treatment of several amputated fingers at a community hospital, and then transferred to a tertiary care facility for additional surgery.

This entanglement pattern has the following typical characteristics: (1) The farmer has extensive experience with the machine involved in the injury event; (2) The injury occurred during harvest at a time of prolonged activity; (3) The machinery was functional yet poorly guarded, probably for convenience or performance reasons; (4) The farmer was pre-occupied with checking the status of the product; (5) Entanglement leads to amputations. A large
proportion of these entanglements also occurred in a similar manner when the farmer attempted to check the status of the equipment before the machine came to a complete halt.

Manual inspection of machinery or agricultural products is hazardous when machinery is in operation. Such tasks can entice a farmer to circumvent safeguards on the machine to check whether the machine is operating within normal parameters. In addition, automatic sampling devices and equipment status devices are not always provided on agricultural machinery. The absence of safety guards and shields on augers poses an entanglement hazard to the farmer [12, 18]. Augers can be separate implements or embodied within a larger machine and consist of a number of rotating screw type flights to convey grain. When the operator is in close proximity to these flights their clothing or appendages can be drawn in resulting in entanglements.

**Pattern 3-Driveline attachments and servicing.** A 40 year old farmer was servicing a baler in the yard of his 1000-acre farm. The baler had undergone repairs during the last year and all its safety devices were operational. The farmer was working on this older machine for hours, and was oiling and testing the chains in preparation for use. While leaning against the guard, the farmer’s hand slipped and got caught in a moving chain. He was treated at the local emergency room for multiple lacerations and abrasions.

Entanglements during routine maintenance and repair activities have the following typical characteristics: (1) These events involve farmers with considerable experience; (2) A lack of complete guarding or factory designed maintenance systems places the farmer in close proximity to a mechanical hazard; (3) Injuries involve major trauma to the hand and digits. Similar types of entanglements also occurred while the farmer was powering implements attached to the driveline.
Driveline injuries due to entanglement in chains, belts or spinning shafts are among the more common forms of agricultural injury [19]. The driveline assembly is typically used to transfer power to various components on agricultural equipment from a centralized source [20]. When designed according to ASAE design standards [21], driveline assemblies on agricultural machines are shielded from unintentional human contact. In this vignette, the absence of banks of grease zerks or other factory designed systems for routine servicing presumably required at least partial exposure of the driveline to facilitate access. Although the machines surveyed were in an excellent state of repair, it is likely that the operator’s contact with machinery mechanisms was for this purpose.

In the discussed vignettes, the majority of injuries occurred after prolonged activity (greater than 6 hours), to farmers who had at least 20 or more hours of operational experience with the machine involved. These events were also more common on larger acreage farms, but particularly on those farms that had a smaller number of workers (between 2 to 6 people). We speculate that the stress and/or fatigue associated with farm task may have played a role in the occurrence of entanglement injury on these larger farms. Therefore, modification of work practices should take into account methods to deal with such work situations.

4.7 Implications for injury prevention

In each of the patterns identified via the case series, contact with machinery hazards resulted in an injury to an operator during common farm tasks. By self-report, the sub-sample (30/41) of surveyed farmers reported a high level of safety awareness (84%) and frequent use of safety devices on machinery during farm work (80%). While their intentions towards safety may appear sound, the farmers’ actions in atypical hazardous situations do not always seem to reflect the same attitudes (Table 10). This may be due to the nature of hazardous situations that they
encounter during farm work. Situational factors are often in flux and can affect the expression of a safety behavior, causing an inconsistency between expressed attitudes and action [22].

Most entanglements occur when the farmer is required to resort to field adjustments at the spur of the moment, to the machine or during product handling or while attaching implements and servicing inadequately guarded drive lines or implements. We adapted the West Jutland Farm Accidents conceptual model to explain the occurrence of farm machinery entanglements (Chapter 2; Section 2.7.2; [23]). The conceptual model considers hazardous situations and activities to be a function of personal and environmental factors. The former includes knowledge, safety attitudes and perception. The latter includes farm organizational processes such as maintenance, safety standard of farm machines and farming procedures. We have described in the vignettes safety behavior leading up to the hazardous situation (behavior A) and during (behavior B) the injury event using associated factors to identify recurrent patterns of injury.

Commonly there appears to be a fundamental disconnect between safety attitudes and safety behavior when a farmer faces a hazardous field situation. Increased safety awareness and competency training measures alone may not result in corresponding behavioral changes to reduce injury occurrence [24]. Our study demonstrates the need for physical and engineering solutions to accompany educational and regulatory approaches. Design solutions should meet worker needs and expectations to minimize the gap between perceptions and behaviors that leads to these hazards. This can be done through continual interaction between farmers, machine manufacturers and other stakeholders in farming operations through an iterative quality planning during the design process. [13]. In addition, strategies to ensure a safe farm environment should include risk assessment of work practices [25].

Farm workers can manage physical hazards by adopting the following engineered field practices: (1) use of automatic grain sampling interlocks with yield monitors installed [26]; (2)
installation of equipment status devices and reversal mechanisms that limit the need for manual adjustment; (3) use of factory designed features like grease zerks that facilitate servicing. These design solutions are passive modifiers of behaviour and limit the contact of the operator with machine parts. However, effective solutions also require active behavioral modification through education and training efforts that focus on changing work practices and dealing with long hours of farm work.

4.8 Conclusions

Situations arise during routine tasks bring the farmer in close proximity to machinery hazards. The analysis of tasks in the assembled case series helped us identify frequently encountered hazardous situations and suggest possible solutions. The following tasks contributed to the majority of entanglements: (1) field adjustment of machinery; (2) product handling and conveyance; and (3) driveline attachments and servicing. Farmers were injured during these common tasks either due to intimate contact with moving machinery parts or by not adopting adequate safe work practices. In each of the tasks, self-reported safety attitudes did not correspond to actual behavior. These task patterns should form the basis for future injury control efforts through risk assessment to develop design interventions and work practice modifications.

4.9 Acknowledgements

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Emergency Medicine Student Research Group respectively, at Kingston General Hospital during the course of the analysis.

### 4.10 References


Table 7. Characteristics of the person and farm (environment) in occurrence of entanglements.

<table>
<thead>
<tr>
<th>Descriptor (N=total responses)</th>
<th>n</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Person characteristics</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male (N=41)</td>
<td>40</td>
<td>97.6</td>
</tr>
<tr>
<td>Age in years (N=40)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20 to 44</td>
<td>18</td>
<td>45</td>
</tr>
<tr>
<td>45 to 64</td>
<td>17</td>
<td>42.5</td>
</tr>
<tr>
<td>≥ 65</td>
<td>5</td>
<td>12.5</td>
</tr>
<tr>
<td>Hours of operational experience with machine (N=41)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>≤ 19</td>
<td>10</td>
<td>24.4</td>
</tr>
<tr>
<td>20 to 199</td>
<td>10</td>
<td>24.4</td>
</tr>
<tr>
<td>≥ 200</td>
<td>21</td>
<td>51.2</td>
</tr>
<tr>
<td>Hours worked prior to injury (N=40)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 to 5</td>
<td>5</td>
<td>12.5</td>
</tr>
<tr>
<td>6 to 10</td>
<td>19</td>
<td>47.5</td>
</tr>
<tr>
<td>≥ 11</td>
<td>16</td>
<td>40</td>
</tr>
<tr>
<td><strong>Farm characteristics</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Main farm commodity produced (N=41)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grains</td>
<td>23</td>
<td>56.1</td>
</tr>
<tr>
<td>Cattle dairy and meat</td>
<td>13</td>
<td>31.7</td>
</tr>
<tr>
<td>Poultry, Swine and others</td>
<td>5</td>
<td>12.2</td>
</tr>
<tr>
<td>Total number of workers on farm (N=41)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>One</td>
<td>5</td>
<td>12.2</td>
</tr>
<tr>
<td>Two</td>
<td>13</td>
<td>31.7</td>
</tr>
<tr>
<td>3 to 6</td>
<td>20</td>
<td>48.8</td>
</tr>
<tr>
<td>&gt; 6</td>
<td>3</td>
<td>7.3</td>
</tr>
<tr>
<td>Farm acreage (N=41)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>≤ 1,000</td>
<td>16</td>
<td>39</td>
</tr>
<tr>
<td>1001-2500</td>
<td>12</td>
<td>29.3</td>
</tr>
<tr>
<td>≥ 2501</td>
<td>13</td>
<td>31.7</td>
</tr>
<tr>
<td>Season (N=39)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fall</td>
<td>13</td>
<td>33.3</td>
</tr>
<tr>
<td>Spring</td>
<td>12</td>
<td>7.7</td>
</tr>
<tr>
<td>Winter</td>
<td>11</td>
<td>28.2</td>
</tr>
<tr>
<td>Summer</td>
<td>3</td>
<td>30.8</td>
</tr>
</tbody>
</table>
Table 8. Characteristics of machine involved in entanglement – type, operational, repair/maintenance and safety status.

<table>
<thead>
<tr>
<th>Descriptor (N=total responses)</th>
<th>n</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Major machines/mechanisms/implements involved (N=41)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Augers (screw and bucket type grain conveyers)</td>
<td>15</td>
<td>36.6</td>
</tr>
<tr>
<td>Balers (round and square)</td>
<td>4</td>
<td>9.8</td>
</tr>
<tr>
<td>Harvesting equipment and combines</td>
<td>3</td>
<td>7.3</td>
</tr>
<tr>
<td>Other equipment</td>
<td>6</td>
<td>14.6</td>
</tr>
<tr>
<td>PTO Drivelines (mechanism)</td>
<td>7</td>
<td>17.1</td>
</tr>
<tr>
<td>Tractor and attachments (implements)</td>
<td>6</td>
<td>14.6</td>
</tr>
<tr>
<td><strong>Safety feature in use at time of injury (N=41)</strong></td>
<td>29</td>
<td>70.7</td>
</tr>
<tr>
<td><strong>Safety Feature present on machine (N=29)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Guards, cages and shields</td>
<td>16</td>
<td>55.2</td>
</tr>
<tr>
<td>Guard around PTO and Full/partial cages</td>
<td>5</td>
<td>17.2</td>
</tr>
<tr>
<td>Decals/Signs</td>
<td>2</td>
<td>6.9</td>
</tr>
<tr>
<td>Lid/cover</td>
<td>2</td>
<td>6.9</td>
</tr>
<tr>
<td>Other safety features</td>
<td>4</td>
<td>13.8</td>
</tr>
<tr>
<td><strong>State of Repair (N=41)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Excellent</td>
<td>13</td>
<td>32.5</td>
</tr>
<tr>
<td>Above Average</td>
<td>12</td>
<td>30.0</td>
</tr>
<tr>
<td>Average</td>
<td>12</td>
<td>30.0</td>
</tr>
<tr>
<td><strong>Maintained within last year (N=29)</strong></td>
<td>28</td>
<td>96.6</td>
</tr>
</tbody>
</table>

*Effective sample=37; Don’t Know/Cannot Recall=2; Refused=2

<table>
<thead>
<tr>
<th>Descriptor</th>
<th>Fingers or Thumb</th>
<th>Anatomical Site of injury</th>
<th>Total</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Arm, Wrist, Hand</td>
<td>Legs</td>
<td>Trunk</td>
</tr>
<tr>
<td>Nature of injury</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amputation</td>
<td>13</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Lacerations, puncture wounds</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Broken bones, fractures, crushed body parts</td>
<td>0</td>
<td>4</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Strains, tears, tissue damage</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>20</td>
<td>11</td>
<td>6</td>
<td>4</td>
</tr>
</tbody>
</table>
Table 10. Safety attitudes and work habits on Prairie farms (2000-2005)

<table>
<thead>
<tr>
<th>Safety attitudes</th>
<th>Always</th>
<th>Frequently</th>
<th>Occasionally</th>
<th>Never</th>
</tr>
</thead>
<tbody>
<tr>
<td>Caution working family members/ employees about dangers of operating farm equipment properly (n=30)</td>
<td>14 (47%)</td>
<td>11 (37%)</td>
<td>4 (13%)</td>
<td>1 (3%)</td>
</tr>
<tr>
<td>When operating farm machinery, all safety shields and guards in place (n=29)</td>
<td>8 (27%)</td>
<td>16 (53%)</td>
<td>4 (13%)</td>
<td>1 (3%)</td>
</tr>
</tbody>
</table>
Figure 3. Occurrence of entanglement injury by task type shown by a Pareto chart.
Chapter 5
Supplemental Methods

5.1 Introduction
This chapter provides details on the data sources used in the manuscripts that comprise this thesis and is divided into the following sections: (1) Data source for first manuscript: Saskatchewan Farm Injury Cohort Study (SFIC); (2) Statistical power calculations for the first manuscript; (3) Creation of factor analytic scales for key exposures; (4) Creation of farm-level indices for potential confounders; and (5) Data source for second manuscript: Case-Control Farm Machinery Injury Study (CCFMI).

5.2 Data source for first manuscript – Saskatchewan Farm Injury Cohort Study
The methodology of the SFIC Study is described in detail elsewhere [1]. Briefly, the SFIC Study was developed to evaluate the relative influence of several potential causes of injury among farmers and members of farm families. The risk factors studied include physical, demographic, socioeconomic, and cultural factors. Theoretically, the SFIC investigates farm injury risk factors at two levels: (1) contextual (e.g. cultural, physical or economic environment); (2) individual (e.g. health practices, human biology).

The first manuscript sources data from the SFIC baseline survey (Appendix A) that recruited 5,492 farm people on 2,390 Saskatchewan farms. The baseline survey was cross-sectional for a one year period of recall (2006). The study base consisted of operational and active farms as of January 1, 2007. Sampling was performed based on a multistage stratified sample from this study base. The study sample was stratified by two parameters: agricultural soil zone...
and by *Agricultural Health and Safety Network (AHSN)* participation (Figure 4). Agricultural practice can vary by soil zone, (e.g. ranching in brown; grain farming in dark brown; mixed farming in black; grey zone is primarily non-agricultural shield topography). The *AHSN* is a longstanding safety initiative administered to a large sample of Saskatchewan farms (26,500 farm families) that covers 165 (56%) of the province’s rural municipalities, and by extension farms [2]. Out of a total of 296 rural municipalities in Saskatchewan, 50 were proportionally sampled from this master list. In case of refusals, equivalent rural municipalities were substituted by randomly selecting farms from the same strata defined by *AHSN* participation and soil region (Figure 4). All listed farms were then contacted regarding participation. Inactive farms were excluded.

*Figure 4.* Sampling frame for SFIC Study selected to be representative of the Saskatchewan farming population.

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Table 11 lists the measures, data types and relevant question numbers for the variables considered in the first manuscript. The following section describes the creation of indices at the farm-level for key exposures and potential confounders evaluated in the first manuscript.

**Table 11.** Relevant sections in the Saskatchewan Farm Injury Cohort baseline survey. Questions related to operational exposures during the preceding twelve-month period.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Measure</th>
<th>Type</th>
<th>Question no. (Appendix A)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Primary Outcome</strong></td>
<td>Machinery-related injury during period 2006-2007</td>
<td>Count</td>
<td>B-25 and B-28</td>
</tr>
<tr>
<td><strong>Key Exposures</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Safety features (presence/absence)</td>
<td>Rollover protection on tractors</td>
<td>Scale</td>
<td>D-2, D-6, D-8, C-11, C-24</td>
</tr>
<tr>
<td></td>
<td>Guarding on augers and combines</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maintenance</td>
<td>Total hours of maintenance (separately for tractors and combines)</td>
<td>Scale</td>
<td>B-17, B-19</td>
</tr>
<tr>
<td><strong>Covariates at the farm-level</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alcohol intake</td>
<td>Alcohol drinking in the last year considering the number people drinking above 2-3 drinks per day</td>
<td>Ordinal (converted to score)</td>
<td>B-13</td>
</tr>
<tr>
<td>Education</td>
<td>Level of education of the operator assumed to be the proxy for the entire farm</td>
<td>Categorical</td>
<td>B-3 using affirmative answer for B-16 or B-18</td>
</tr>
<tr>
<td>Total number of people on farm</td>
<td>Family members</td>
<td>Continuous</td>
<td>A-5</td>
</tr>
<tr>
<td>Number of hours spent operating machinery</td>
<td>Tractors</td>
<td>Continuous (converted to score)</td>
<td>B-16, B-18</td>
</tr>
<tr>
<td></td>
<td>Combines</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Co-morbid conditions</td>
<td>Number of people on farm with sleep-related, mental, respiratory, gastric, cardiovascular conditions, hearing loss</td>
<td>Categorical (converted to an index)</td>
<td>B-7, B-10</td>
</tr>
<tr>
<td>Socioeconomic status</td>
<td>How often were cash flow shortages and debt a source of worry on the farm</td>
<td>Categorical</td>
<td>D-13 and D-14</td>
</tr>
</tbody>
</table>
5.2.1 Creation of factor analytic scales for the key exposures

Factor analytic scales were created for both exposures only and did not consider the outcome measure. The measures of the key exposures of interest to this thesis were addressed by the following: (1) Safety device use through three categorically scored items on tractors, combines and augers; (2) Routine maintenance through two items that were continuous in nature. Each of these exposures represents a safety construct and was a surrogate for safety behavior at the farm level. Here the statistical approach involved finding a way to condense the information contained in these variables into one or two factors representative of safety with a minimum loss of information. Since factor analysis is based on the concept of common variance i.e. the proportion of variance shared between these variables, it was performed by the maximum likelihood method with these standard steps [3, 4]: (1) Setting up the correlation matrix; (2) Extracting the underlying factors; (3) Defining the number of factors.

First the common variance was estimated using the squared mean correlation or maximum correlation approach. Since only one common factor could be extracted that accounted for all the variability among the items rotation was not necessary. Next the factor loading was calculated that measured the correlation between each of the variables and their created factors and determines the decision to retain or drop items from a factor analytic scale. A conservative factor loading cutoff of 0.4 was considered necessary to retain an item as part of a created factor scale [5, 6]. If the factor loading fell below 0.4, the item was dropped from the created scale and the factor loading was recalculated. Hence, the decision to drop from further consideration the item related to use of roll over protection structures on tractors in the safety device use scale. This may indicate that safety device usage on tractors follows a different construct either due to one or more of the following reasons: (1) The nature of safety devices used on tractors versus other
equipment (e.g. roll over protection structures); (2) Pattern of usage of tractors on the farm; (3) The wide variety of tasks that require the use of a tractor.

The factor loading for safety device and maintenance variables is 63 and 71 respectively. Since only two items were involved in the creation of each factor scale, the factor loadings were equal for both the items. Further, Cronbach’s alpha value was used as a measure of internal consistency reliability of a scale indicates how well each individual item in a summated factor analytic scale correlates with the sum of the remaining items. Both the created scales have Cronbach alpha values of 0.84 and 0.88 respectively indicating a high degree of internal consistency and low level of redundancy. These factor analytic scales are also described in the methods section of the first manuscript (Chapter 3).

5.2.2 Potential confounders

The potential confounders evaluated in the first manuscript are summarized in Table 3. Operational characteristics such as (1) number of hours exposed to farm machinery work [7]; and (2) the type of farm (e.g. [8]) that are associated with machinery-related exposures and injury were explored as potential confounders. The following potential confounders assessed at an individual-level in the survey were also evaluated as potential covariates namely: alcohol intake, level of education, hours of work using sentinel machinery and co-morbidities [8-11]. Individual-level variables were converted to the farm unit of analysis of the study as follows: (1) alcohol intake was summarized at the farm-level by grouping the ordinal categories by weights. The weights were as follows: ‘0’ for drinks in the categories ‘never’, ‘less than once a month’, and ‘once a month’; ‘1’ for ‘categories ‘2 to 3 times a month’, ‘once a week’ and ‘2 to 3 times a week’; and ‘2’ for ‘4 to 6 times a week’ and ‘every day’. The number of people in each category on the farm was then multiplied by the respective weight and summed. The total was then divided
by the total number of people on the farm to obtain an aggregate alcohol consumption index. (2) education level of the machinery operator was considered as a proxy for the entire farm; (3) The number of hours of operation of sentinel farm machinery per year was summarized at the farm-level as a factor analytic scale; (4) A co-morbidity index was constructed from a list of surveyed sleep-related, mental, respiratory, gastric, cardiovascular, and hearing loss conditions. Each condition was assigned an equal weight and multiplied by the number of people suffering from each condition then summed. This total was divided by the total number of people on the farm to obtain a co-morbidity score that can be used at the farm-level. The following section estimates the statistical power necessary to detect relative risk effects in the first manuscript.

5.2.3 Statistical Power
Statistical power was estimated a priori using classical calculations that examine the focal relationship between each exposure and the injury outcome individually, after dividing the exposures into groups (Appendix C). Illustrative power calculations focused on the expected power obtained given the number of farms surveyed. Assumptions made in the power calculations were as follows: (1) A 5% difference in injury rates over a year was assumed to be occupationally meaningful based on published estimates; (2) Baseline rates for medically treated farm injury were assumed to be between 5-10% annually [8, 12]. Power was calculated for the highest group versus the referent group for exposures divided into quartiles, tertiles or into two groups (Appendix C). From the appended calculations, the estimated power was found to be adequate to detect associations between the key exposures and injury outcome.

Power was greater than 80% to detect relative risks between 2.0 and 3.0. Effect estimates for small relative risks at or below 1.5 cannot be detected with an acceptable power (i.e. greater than 80%). This was due to the limited sample size available. As expected, the power followed an
increasing trend with increased group size. The power was insufficient for certain sub-group analyses.

5.3 Data source for second manuscript – Case Control Farm Machinery Injury Study

The second manuscript sources data from the Case-Control Farm Machinery Injury Study (CCFMI) conducted in the Prairie Provinces from 2002 to 2004. The CCFMI study is described in detail elsewhere [13]. Only data for injury cases arising from entanglement in machinery were abstracted from the data source. A retrospective series of 41 machinery-related entanglement injury cases was assembled from the CCFMI data set (the thesis analysis was not a case-control analysis).

The parent study was conducted in two phases. The first phase focused on individuals and the second phase on machinery. Only data from the first phase was evaluated in this thesis. In the first phase, adult (≥ 16 years) farm workers from one of three Canadian Prairie provinces (Manitoba, Alberta and Saskatchewan) were identified as cases if they suffered from a machinery-related injury. Cases were identified in one of the two following ways: (1) through health providers located at participating hospitals; (2) through hospital records.

In both of these methods, cases were invited to take part in the study. As participation was voluntary, only those participants that provided informed consent were considered in the study. Phase 1 involved the administration of two questionnaires. The first questionnaire (Appendix B) gathered information through a 15-minute phone interview on demographic, health, and farm characteristics for injury cases. Data was also collected on the circumstances surrounding the injury event and regarding characteristics of the machinery involved (e.g. use of safety devices, repair and maintenance). The second self-administered questionnaire (Appendix
B) collected detailed information about the person’s machinery exposure history (e.g. hours of operation of the machinery). As well, behavioral characteristics such as their attitude towards safety and risk were also collected.

5.4 References


Chapter 6
General Discussion

6.1 Bridging the Two Manuscripts – a Summary of Key Findings

The overall purpose of this thesis was: (1) to analyze and describe the role of specific safety practices as potential determinants of machinery-related injuries on farms; and (2) to recommend effective injury prevention strategies based on these analyses.

Both manuscripts confirm the relative importance of safety device usage and routine maintenance in the occurrence of agricultural injury. In terms of key findings, the first manuscript identified the following effects: (1) an increased risk for machinery-related injury associated with the infrequent use of safety devices on sentinel farm machinery; (2) lower risk for injury associated with less maintenance, partially mediated by the number of hours spent operating machines. The first finding suggests a need for enhanced safety device use during machinery operation. This manuscript was the first to confirm the intuitive relationship between poor guarding of sentinel machinery and an increased risk for injury. The second finding was counterintuitive to our initial hypothesis, in that we expected less maintenance to be associated with higher risk for injury. Further investigation into the following factors may help clarify this relationship: contact of operators with machinery, use of modern machinery on Saskatchewan farms, and mediation by hours of machinery operation.

The second manuscript identified situational hazards associated with entanglement injuries during common farming tasks. The majority of entanglement events (80%) occurred during the following tasks: (1) field adjustment of machinery; (2) product handling and
conveyance; and (3) driveline attachments and servicing. These findings also show that the safety behaviour of farmers faced with atypical situations did not reflect their self-reported safety attitudes. This may be due to the factors inherent to the hazardous situations that they encounter during farm work. These task-based patterns may be used to provide useful information and direction for future interventions and prevention studies designed to decrease the risk for entanglement injury related to the use of machinery.

6.2 Thesis Limitations

Each of the manuscripts shares common limitations. First, there was a modest response rate in each study (SFIC: 33% and Case-Control Farm Machinery Injury Study (CCFMI): estimated 80% among cases). SFIC and CCFMI study participants could differ from other non-participating farmers within the provinces. External validity of the study findings is also limited to those provinces/states in North America where similar agricultural practices are used.

A second potential limitation is recall bias, in that the self-report of health behavioural information and safety practice data may differ between injured and non-injured participants. The self-reported nature of machinery-related variables like safety features and maintenance, without external validation, could result in an overestimation of protective effect among farms that experienced an injury.

Third, reports of machinery-related injuries were not validated through medical or hospital records for the injury outcomes which are only based on self-reported responses to the SFIC baseline survey. External validation is not deemed to be possible as it would require further record linkage, violating privacy laws.
Fourth, assessment over a single year may be too short to assess the cumulative nature of the exposures, especially given that safety practices represent attitudes and habitual behaviors that develop over a prolonged period of machinery use.

In addition to the common limitations, each of the manuscripts is limited due to their respective study designs. Since the first manuscript is cross-sectional in nature, we cannot be certain of the temporality of cause and effect for risk factors and machinery-related injury [1]. As the SFIC Study is an on-going initiative, the opportunity exists to address this issue of temporality in subsequent longitudinal analyses. The second manuscript employed a descriptive case-series design. This too is limited as it does not use a comparison group and is therefore of lower methodological rigor. In addition, the modest sample size for many of the factors considered was restrictive.

6.3 Thesis Strengths

Each of the manuscripts that comprise this thesis had different strengths. In the first manuscript, we employed a unique and practical approach to exposure assessment. Safety practices on sentinel machinery types (tractors, combines and augers) were considered as common exposures that could lead to injury types that account for the largest proportion of injuries on North American farms [2-4]. This study measured the overall routine maintenance and safety device usage on sentinel machinery on a farm, rather than measured on a machine-specific basis. This was consistent with the level of intervention. Second, the large sample size recruited to the underlying cohort study allowed us to evaluate the risk factors for machinery-related injury to farmers and farm workers. Third, we conducted analyses of focal relationships while controlling for known confounders (Layde 1990). Fourth, the study was etiological in nature rather than the traditional descriptive approach used to document machinery-related injury. Fifth,
this manuscript used equipment-specific operating hours in a multivariate framework to control for the degree of exposure to machinery, unlike previous studies [5].

The second manuscript adopts a novel approach by considering the role of safety practices in the occurrence of machinery entanglements, and analyzing features of common farm tasks that contribute to injury. Such a case-series approach lends itself well to identifying situational factors that could characterize entanglement injuries and generate evidence for prevention efforts.

6.4 Revisiting the West Jutland Model for farm accidents

Knowledge, attitude levels, awareness and perceptions as well as the farm environment influence the implementation of planned safety practices by farmers (Behavior A; Chapter 2, Section 2.7.2). Since these practices are planned, they are distal to the actual injury event. Conformance with these practices should reduce individual risks for injury. Non-conformance may increase the risk for injury. A priori we felt that regular use of safety devices and performing routine maintenance regularly could be considered as barriers that lower risks for injury.

Results obtained on safety device use agree with our original interpretation of the West Jutland model (Chapter 2.7.2). Results obtained with respect to maintenance were counter to this model. This result could have been moderated by the age of the machinery involved. Each of these variables may also have different relationships with machinery injury depending on the predominant scheme of maintenance practiced on farms. Therefore, future work into these two variables and different schemes of maintenance is required to clarify the relationship of maintenance with machinery injury. Additional study is required to determine if the hypothesis on routine maintenance is in agreement with the model.
The second manuscript evaluated machinery entanglements in the context of common farm tasks. Conditions such as poor maintenance or low usage of safety devices on machinery remain latent but may get activated when the farmer is faced with hazardous field situations. At this stage, whether or not the farmer gets entangled in the machine depends on his behaviour (Behaviour B; Chapter 2.7.2). The hazards faced by the farmer could manifest during common tasks (e.g. checking on a forage cutter blade) or be latent (e.g. not using safety devices due to monetary considerations) or both conditions may be present (e.g. an unguarded combine that has not been oiled regularly which the operator is now attempting to adjust at harvest time in the field). Performance deviations from normal operating procedures in a farm environment facilitate the sequence of events leading to injury. The inherent hazards present in common tasks get activated due to the farmer's behavioral response leading to entanglement events. This sequence of events is adequately explained by the West Jutland conceptual model.

6.5 Future Research Directions

In Saskatchewan, guidelines listed in the Occupational Health and Safety Act (1993 and 1996) [6, 7] largely govern the implementation of safety practices in the agricultural occupation. These guidelines are similar in the other Prairie Provinces as well [8, 9]. With respect to the safety practices evaluated as exposures in this thesis, the regulations applicable to the farming occupation are listed below:
These guidelines are broadly applicable to all occupations and are not specific to farming. Thus, there is a need to evaluate risks specific to machinery in the farm environment. The study of the safety environment surrounding machinery has gradually been gaining traction in the injury field. Studies of such factors can contribute to evidence-based decisions and injury prevention initiatives.

Future multivariate analyses will need to consider covariates that can influence the implementation of safety practices. Such covariates may include: (1) the actual age of machinery; (2) tasks that expose the operator to greater contact with machinery mechanisms and (3) total hours spent operating machinery. All of these variables may mediate or confound the focal relationship. Further, consideration of the different schemes of maintenance in the occurrence of machinery-related injury could disentangle the relationship between maintenance and injury and inform the development of targeted interventions to benefit Saskatchewan farms.

The original thesis protocol also called for an assessment of operator training/supervision and machinery age as etiological factors. However, for both the training and machinery age variables, data was only collected for two vulnerable age groups i.e. teenagers (12-18 years) and seniors (greater than 65 years) excluding the largest category of farmers suffering injury, between
the ages of 20 to 64 years. Due to insufficient sample size and resulting model convergence issues, these relationships could not be assessed in a multivariate framework. One possible option for future work could be the development of a focused machinery-related injury questionnaire administered to a sub-sample of the original surveyed population that has the following features: (1) it delineates the different schemes of maintenance through the use of illustrative examples; (2) it asks focused questions on both operator training and absolute machinery age at the time of injury; (3) it includes other known confounders, including but not limited to prior (or residual) injury.

Existing literature has largely assessed injury prevention methods within single domains of the 3-E model [10-12]. Another possibility for future work includes an assessment of the joint effect of injury prevention initiatives such as education/training and engineering modifications as a follow-up to educational intervention studies performed [10]. Given the paucity of research in these areas, further study is required to achieve a more complete understanding of how other aspects of the farm safety environment may influence the occurrence of injury to farmers in Canada and elsewhere.

6.6 Public Health and Policy Implications

Increasing farm size and decreasing profitability coupled with a migration towards more urban areas have compelled a move towards more machinery-dominated farm work on Western Canadian farms. In agriculture, this trend towards increased mechanisation, together with the growing power of machinery has introduced new risks to farming operations [13, 14]. As machinery accounts for a large proportion of farm injuries, there is a concomitant need to evaluate the safety practices that accompany the machinery usage in an effort to reduce the burden of injury on farms.
In Manuscript 1, a distinct monotonic relationship was observed between safety device usage and the occurrence of machinery-related injury. Clearly, injury prevention programs need to focus on the enhanced use of safety devices on machinery at all times. Although the relationship between routine maintenance and machinery-related injury was partially mediated by the hours of machinery operation, there seems to be other factors involved. Therefore, further study is required before policy measures can be developed. These relationships need to be understood so that farm-level interventions can be employed to modify operational behaviour(s) and reduce injury occurrence.

In Manuscript 2, situational factors that influence the occurrence of injury were explored. Three common farm tasks were identified that account for the vast majority of entanglement injuries namely (1) field adjustment of machinery; (2) product handling and conveyance; and (3) driveline attachments and servicing. Safety behaviours during these hazardous situations should be considered while preparing the content of educational and competency training interventions.

6.7 References


Appendix A

Relevant portions from the Saskatchewan Farm Injury Cohort (SFIC) baseline survey

Machinery-related Injury Outcome:

B-25 Has this person had a farm injury during 2006?
   Yes ☐ No ☐

B-26 In the space below, please provide details about how the injury occurred. Please describe what the person was doing, where it happened, and what went wrong. Please tell us the type of injury and body part injured.

   Example:
   1. J.S. was hitching a grain auger to a tractor in the farm yard. He slipped on the wet ground, and strained his lower back while trying to regain his balance.
   2. S.E. was learning to ride a horse in the pasture. The horse stopped suddenly for no obvious reason and she fell to the ground. She broke her wrist.

Use of safety devices:

D-2 How many of these tractors are equipped with a rollover protection structure?
   None of them ☐ Some of them ☐ All of them ☐ No tractors ☐

D-6 How many of these combines have all safety shields and guards in place?
   None of them ☐ Some of them ☐ All of them ☐ No combines ☐

D-8 How many of these augers have all safety shields and guards in place?
   None of them ☐ Some of them ☐ All of them ☐ No augers ☐
Maintenance:

During 2006, how many hours per year did this person:

B-17 Do routine maintenance on tractors? ___

B-19 Do routine maintenance on combines? ___

Alcohol consumption:

B-13 During the past 12 months, how often did this person drink alcoholic beverages?

- Never
- less than once a month
- once a month
- 2 to 3 times a month
- once a week
- 2 to 3 times a week
- 4 to 6 times a week
- every day

Education-level of operator:

B-3 Highest level of education:

- Less than High School
- Completed High School
- Completed University
- Institution other than the above

Total number people on farm:

A-5 What is the total number of people in your farm family? _____ (number)

A-6 What is the total number of other (non-family) people who worked on your farm during 2006? _____ (number)
Number of hours spent operating hours for machinery

During 2006, how many hours per year did this person:  
B-16 Operate tractors?  ____  
B-18 Operate combines?  ____  

Comorbidity Index:

B-7 Has a doctor diagnosed this person with (check all that apply):  
a. Sleep Apnea  
b. Arthritis  
c. High blood pressure  
d. Heart disease  
e. Stomach or intestinal problems  
f. Asthma or other lung conditions  
g. Problems with balance (physical)  
h. Attention deficit disorders (children only)  
i. None of the above  

B-10 Does this person have a known hearing loss?  
Yes ☐ No ☐  

Socioeconomic status:

FARM ECONOMICS:  
Here are two statements about your farm and its financial health. Please choose one response for each statement and farm season.

D-13 During 2006, how often were cash flow shortages a source of worry on your farm? (Please mark one box for each season)

<table>
<thead>
<tr>
<th>Every day</th>
<th>At least once a week</th>
<th>At least once a month</th>
<th>Less than once a month</th>
<th>Never</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Summer</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Fall</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Winter</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
</tbody>
</table>

D-14 During 2007, how often was debt a source of worry on your farm? (Please mark one box for each season)

<table>
<thead>
<tr>
<th>Every day</th>
<th>At least once a week</th>
<th>At least once a month</th>
<th>Less than once a month</th>
<th>Never</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Summer</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Fall</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Winter</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
</tbody>
</table>

90
Type of farm:

From the list below, please check each commodity that is produced for sale on your farm or ranch (check all that apply).

Commodity

1. Grain crops
   (e.g., cereals, pulse, oil seeds, forage crops)
2. Cattle (beef)
3. Cattle (dairy)
4. Pigs
5. Poultry
6. Vegetable/Fruit
7. Other animals
Appendix B

Relevant portions of the Case-Control Farm Machinery Injury (CCFMI) Study

A-1 What is your birth date? _________ (dd/mm/yy)

<table>
<thead>
<tr>
<th>Question</th>
<th>Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>D-10a. Prior to the injury how many hours did you work that day?</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>D-10b. In the 48 hours preceding the injury how many hours did you work?</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>E-12. How long were you using this machine on the day of your injury?</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>E-11. What was your experience level with this machine prior to your injury?</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

92
C Farm Characteristics

Type of farm:

<table>
<thead>
<tr>
<th>Commodity Produced</th>
<th>C-1. From the list I will read, what was the main commodity produced on your (the) farm?</th>
<th>C-2. From the list I will read, what was the second most important commodity produced on your (the) farm?</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Grains (cereals, oilseeds, pulse crops, others)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Cattle (meat)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Cattle (dairy)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Swine</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Poultry (meat)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Poultry (eggs)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Vegetables/ Fruits</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. Exotic animals</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. Customs services, specify</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10. Other, specify</td>
<td></td>
<td></td>
</tr>
<tr>
<td>88. Can’t recall/ don’t know</td>
<td></td>
<td></td>
</tr>
<tr>
<td>99. Refused</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

C-3. As I read the following list, please indicate whether the commodity is produced on your (the) farm?

☐ 1. Cereal grain
☐ 2. Oilseeds
☐ 3. Pulse Crops
☐ 4. Other crops, specify ________
☐ 5. Vegetables/Fruit
☐ 6. Cattle (meat)
☐ 7. Cattle (dairy)
☐ 8. Swine
☐ 9. Poultry (meat)
☐ 10. Poultry (eggs)
☐ 11. Exotic animals
☐ 12. Other, specify ________

☐ 88. Don’t recall/ don’t know
☐ 99. Refused
C-10. Including family workers and hired workers, how many people work on your (the) farm?

Number of workers

C-4. What size is the farm?

- 1. < 320 acres
- 2. 320 to 1000 acres
- 3. 1000 to 2500 acres
- 4. 2500 to 5000 acres
- 5. 5000 to 10,000 acres
- 6. > 10,000 acres

Temporal and anatomical aspects of injury:

D-1. Did your injury occur on ________, __/__/___? (Complete from medical record)

- 1. Yes
- 2. No

If no, when did it occur: ________, __/__/___?

D-2. What time of day did your injury occur?

a.m./p.m.

- 1. 8 a.m. - 10 a.m.
- 2. 10 a.m. - noon
- 3. noon - 2 p.m.
- 4. 2 p.m. - 4 p.m.
- 5. 4 p.m. - 6 p.m.
- 6. 6 p.m. - 8 p.m.
- 7. 8 p.m. - 8 a.m.
Type of Activity:

D-5. What activity were you actually performing at the time of the injury?

☐ (100) Animal Production → If Yes for Animal Production, please go to table D-5a.

→ ☐ (200) Crop Production → If Yes for Crop Production, please go to table D-5b.

☐ (300) Forestry → If Yes for Forestry, please go to table D-5e.

☐ (400) Farm Maintenance of Buildings → If Yes for Farm Maintenance of Buildings, please go to table D-5d.

☐ (500) Transport → If Yes for Transport, please go to table D-5e.

☐ (600) Other Tasks → If Yes for Other Tasks, please go to table D-5f.
## D-5b. (200) Crop Production

<table>
<thead>
<tr>
<th>Crop Production</th>
<th>Crop Task</th>
</tr>
</thead>
<tbody>
<tr>
<td>201...Grain</td>
<td>01......Cultivating/tilling</td>
</tr>
<tr>
<td>202...Oilseeds</td>
<td>02......Fertilizing</td>
</tr>
<tr>
<td>203...Pulse Crops</td>
<td>03......Applying Pesticide, Aerial</td>
</tr>
<tr>
<td>204...Fruit/vegetables</td>
<td>04......Applying Pesticide, Ground</td>
</tr>
<tr>
<td>205...Hay/Fodder</td>
<td>05......Applying Pesticide, Other</td>
</tr>
<tr>
<td>206...Greenhouse/incl mushrooms</td>
<td>06......Seeding/planting</td>
</tr>
<tr>
<td>207...Trees</td>
<td>07......Irrigating</td>
</tr>
<tr>
<td>208...Crop, NEC, specify</td>
<td>08......Pruning</td>
</tr>
<tr>
<td></td>
<td>09......Burning off</td>
</tr>
<tr>
<td></td>
<td>10......Harvesting/picking/cutting</td>
</tr>
<tr>
<td></td>
<td>11......Augering/elevating</td>
</tr>
<tr>
<td></td>
<td>12......Cleaning/grading</td>
</tr>
<tr>
<td></td>
<td>13......Storing</td>
</tr>
<tr>
<td></td>
<td>14......Haymaking</td>
</tr>
<tr>
<td></td>
<td>15......Manual loading/unloading</td>
</tr>
<tr>
<td></td>
<td>16......Mechanical loading/unloading</td>
</tr>
<tr>
<td></td>
<td>17......Transporting</td>
</tr>
<tr>
<td></td>
<td>18......Inspecting</td>
</tr>
<tr>
<td></td>
<td>19......Other, specify:</td>
</tr>
</tbody>
</table>

### Safety devices used:

#### E-3. Did this machine have any safety features? (ie. Guards, ROPS, seatbelt, safety switches, etc.)

- [ ] 1. Yes  
- [ ] 2. No  

If No, please skip to E-4.

If Yes, please describe:

If Yes, (can select more than one category)
<table>
<thead>
<tr>
<th>Features</th>
<th>Was this in use at the time of your injury?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feature #1</td>
<td>□ Yes □ No</td>
</tr>
<tr>
<td>Feature #2</td>
<td>□ Yes □ No</td>
</tr>
<tr>
<td>Feature #3</td>
<td>□ Yes □ No</td>
</tr>
<tr>
<td>Feature #4</td>
<td>□ Yes □ No</td>
</tr>
<tr>
<td>Feature #5</td>
<td>□ Yes □ No</td>
</tr>
<tr>
<td>Feature #6</td>
<td>□ Yes □ No</td>
</tr>
<tr>
<td>Feature #7</td>
<td>□ Yes □ No</td>
</tr>
<tr>
<td>Feature #8</td>
<td>□ Yes □ No</td>
</tr>
</tbody>
</table>

E-7. When was this machine last serviced prior to your injury?

(Day/no/yr)

31. Exceeds recall date

E-8. When was the last major maintenance check of this machine prior to your injury?

(Day/no/yr)

31. Does not recall/don’t know

39. Refused

E-9. When was this machine last repaired prior to your injury?

(Day/no/yr)

31. Does not recall/don’t know

39. Refused

E-10. How would you describe the state of repair of this machine at the time of your injury?

□ □ 1. Excellent
□ □ 2. Above average
□ □ 3. Average
□ □ 4. Below average
□ □ 88. Does not recall/don’t know
□ □ 99. Refused

E-5. Did you purchase this machine new?

□ □ 1. Yes □ □ 2. No

□ □ 88. Does not recall/don’t know
□ □ 99. Refused
If No, where did you purchase this machine?

- 1. Privately
- 2. Machinery dealer
- 3. Manufactured on your farm
- 4. Other, specify

E-6. Had there been any modifications made to this piece of machinery prior to your injury?

- 1. Yes
- 2. No

If No, please skip to E-7.

- 88. Does not recall/don't know
- 99. Refused

If Yes, please describe what these were:

E-13. Do you have any other comments to make about the machinery involved?
Appendix C
Statistical Power Calculations

- The farm is the unit of analysis; N = 2390 farms.
- Power to detect a meaningful absolute risk difference of 5-10% risk for injury is calculated.
- Calculations compare highest exposure group and referent group in each case.

\[ \text{Power} = \Phi Z_{(1-\beta)} \]
\[ = \Phi \left\{ d^* \left[ \left( n_{\text{exposed}} \cdot r \right) / \left( p \cdot (1-p) \cdot (1+r) \right) \right]^{1/2} - Z_{\alpha/2} \right\} \]

where:

Group 1 and Group 2 represent the highest and referent category for each of the focal machinery-related exposures

- \( r \) is the ratio of number of farms in the two groups = 1 (groups are of equal size)
- \( p \) is the proportion of individual farmers/farming workers that have been injured by machinery
- \( p_0, p_1 \) are the prevalence of non-fatal machinery-related injuries in the referent and highest exposure category respectively

Detectable difference \( d^* = p_1 - p_0 \)

RR is the relative risk defined as the ratio of \( p_1 \) and \( p_0 \).

\( z_{\alpha/2} \) is the level of significance = 1.96 for \( \alpha = 0.05 \).
<table>
<thead>
<tr>
<th>Exposure</th>
<th>Group 1 (highest)</th>
<th>Group 2 (referent)</th>
<th>RR</th>
<th>p</th>
<th>p_o</th>
<th>p_t</th>
<th>d</th>
<th>Z_{1-p}</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Divided into quartiles</strong></td>
<td>598</td>
<td>598</td>
<td>2.00</td>
<td>0.0750</td>
<td>0.05</td>
<td>0.1</td>
<td>0.0500</td>
<td>1.32</td>
<td>91%</td>
</tr>
<tr>
<td></td>
<td>598</td>
<td>598</td>
<td>3.00</td>
<td>0.1000</td>
<td>0.05</td>
<td>0.15</td>
<td>0.1000</td>
<td>3.80</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>598</td>
<td>598</td>
<td>1.50</td>
<td>0.1250</td>
<td>0.1</td>
<td>0.15</td>
<td>0.0500</td>
<td>0.65</td>
<td>74%</td>
</tr>
<tr>
<td></td>
<td>598</td>
<td>598</td>
<td>2.00</td>
<td>0.1500</td>
<td>0.1</td>
<td>0.2</td>
<td>0.1000</td>
<td>2.88</td>
<td>100%</td>
</tr>
<tr>
<td><strong>Divided into tertiles</strong></td>
<td>797</td>
<td>797</td>
<td>2.00</td>
<td>0.0750</td>
<td>0.05</td>
<td>0.1</td>
<td>0.0500</td>
<td>1.83</td>
<td>97%</td>
</tr>
<tr>
<td></td>
<td>797</td>
<td>797</td>
<td>3.00</td>
<td>0.1000</td>
<td>0.05</td>
<td>0.15</td>
<td>0.1000</td>
<td>4.69</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>797</td>
<td>797</td>
<td>1.50</td>
<td>0.1250</td>
<td>0.1</td>
<td>0.15</td>
<td>0.0500</td>
<td>1.06</td>
<td>85%</td>
</tr>
<tr>
<td></td>
<td>797</td>
<td>797</td>
<td>2.00</td>
<td>0.1500</td>
<td>0.1</td>
<td>0.2</td>
<td>0.1000</td>
<td>3.63</td>
<td>100%</td>
</tr>
<tr>
<td><strong>Divided into two groups</strong></td>
<td>1195</td>
<td>1195</td>
<td>2.00</td>
<td>0.0750</td>
<td>0.05</td>
<td>0.1</td>
<td>0.0500</td>
<td>2.68</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>1195</td>
<td>1195</td>
<td>3.00</td>
<td>0.1000</td>
<td>0.05</td>
<td>0.15</td>
<td>0.1000</td>
<td>6.19</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>1195</td>
<td>1195</td>
<td>1.50</td>
<td>0.1250</td>
<td>0.1</td>
<td>0.15</td>
<td>0.0500</td>
<td>1.74</td>
<td>96%</td>
</tr>
<tr>
<td></td>
<td>1195</td>
<td>1195</td>
<td>2.00</td>
<td>0.1500</td>
<td>0.1</td>
<td>0.2</td>
<td>0.1000</td>
<td>4.89</td>
<td>100%</td>
</tr>
</tbody>
</table>
### Appendix D

**Comparison of Log-Binomial Model without offset and Poisson Regression with offset**

**Table 12.** Log-binomial regression with no offset examining relationships between key operational safety practices and machinery-related injury on Saskatchewan farms.

<table>
<thead>
<tr>
<th>Exposure</th>
<th>n</th>
<th># Injuries</th>
<th>RR (95% CI)</th>
<th></th>
<th></th>
<th></th>
<th>p_trend</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0</td>
<td>1</td>
<td>Crude (1)</td>
<td>Adjusted (1)</td>
<td>Adjusted (3)</td>
<td></td>
</tr>
<tr>
<td>Safety devices installed</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.0488</td>
</tr>
<tr>
<td>Q4: High (referent)</td>
<td>667</td>
<td>636</td>
<td>31</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>Q3</td>
<td>577</td>
<td>537</td>
<td>40</td>
<td>1.49 (0.95, 2.35)</td>
<td>1.33 (0.80, 2.22)</td>
<td>1.28 (0.77, 2.13)</td>
<td></td>
</tr>
<tr>
<td>Q2</td>
<td>426</td>
<td>399</td>
<td>27</td>
<td>1.36 (0.83, 2.25)</td>
<td>1.39 (0.80, 2.41)</td>
<td>1.21 (0.68, 2.14)</td>
<td></td>
</tr>
<tr>
<td>Q1: Low</td>
<td>562</td>
<td>518</td>
<td>44</td>
<td>1.68 (1.08, 2.63)</td>
<td>1.86 (1.10, 3.15)</td>
<td>1.78 (1.05, 3.02)</td>
<td></td>
</tr>
<tr>
<td>Hours of annual maintenance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.0005</td>
</tr>
<tr>
<td>Q4: 53 to 321 (referent)</td>
<td>475</td>
<td>434</td>
<td>41</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>Q3: 29 to 52</td>
<td>505</td>
<td>473</td>
<td>32</td>
<td>0.73 (0.47, 1.15)</td>
<td>0.70 (0.44, 1.12)</td>
<td>0.75 (0.47, 1.21)</td>
<td></td>
</tr>
<tr>
<td>Q2: 14 to 28</td>
<td>469</td>
<td>447</td>
<td>22</td>
<td>0.54 (0.33, 0.89)</td>
<td>0.51 (0.30, 0.85)</td>
<td>0.49 (0.29, 0.83)</td>
<td></td>
</tr>
<tr>
<td>Q1: 0 to 13</td>
<td>1929</td>
<td>1812</td>
<td>117</td>
<td>0.53 (0.32, 0.87)</td>
<td>0.46 (0.27, 0.79)</td>
<td>0.53 (0.30, 0.92)</td>
<td></td>
</tr>
</tbody>
</table>

**Legend**

* aAdjusted (1): Controls for other key exposure

* bAdjusted (3): Controls for other key exposure + debt worry + machinery operating hours
Table 13. Poisson Regression with offset examining relationships between key operational safety practices and machinery-related injury on Saskatchewan farms. Here, offset is defined as $\log(\text{average work hours per year per farm})$.

<table>
<thead>
<tr>
<th>Exposure</th>
<th>n</th>
<th># injuries</th>
<th>RR (95% CI)</th>
<th>Adjusted (1)</th>
<th>Adjusted (3)</th>
<th>ptrend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety devices installed</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q4: High (referent)</td>
<td>667</td>
<td>636</td>
<td>0.00</td>
<td>1.00</td>
<td>1.00</td>
<td>0.017</td>
</tr>
<tr>
<td>Q3</td>
<td>577</td>
<td>537</td>
<td>1.60 (1.01,2.54)</td>
<td>1.45 (0.86,2.43)</td>
<td>1.45 (0.84,2.50)</td>
<td></td>
</tr>
<tr>
<td>Q2</td>
<td>426</td>
<td>399</td>
<td>1.41 (0.85,2.36)</td>
<td>1.44 (0.82,2.52)</td>
<td>1.23 (0.66,2.30)</td>
<td></td>
</tr>
<tr>
<td>Q1: Low</td>
<td>562</td>
<td>518</td>
<td>1.84 (1.17,2.89)</td>
<td>2.14 (1.26,3.64)</td>
<td>2.22 (1.28,3.86)</td>
<td></td>
</tr>
<tr>
<td>Hours of annual maintenance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q4: 53 to 321 (referent)</td>
<td>505</td>
<td>473</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>0.055</td>
</tr>
<tr>
<td>Q3: 29 to 52</td>
<td>469</td>
<td>447</td>
<td>0.86 (0.55,1.34)</td>
<td>0.82 (0.52,1.30)</td>
<td>0.97 (0.59,1.59)</td>
<td></td>
</tr>
<tr>
<td>Q2: 14 to 28</td>
<td>480</td>
<td>458</td>
<td>0.55 (0.33,0.91)</td>
<td>0.51 (0.30,0.86)</td>
<td>0.56 (0.31,1.00)</td>
<td></td>
</tr>
<tr>
<td>Q1: 0 to 13</td>
<td>1929</td>
<td>1812</td>
<td>0.52 (0.31,0.86)</td>
<td>0.43 (0.25,0.75)</td>
<td>0.59 (0.30,1.16)</td>
<td></td>
</tr>
</tbody>
</table>

Legend

aAdjusted (1): Controls for other key exposure

bAdjusted (3): Controls for other key exposure + debt worry + machinery operating hours