

Utilizing Construction Safety Leading and Lagging Indicators to Measure Project Safety

Performance: a case study

by

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Authors Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

Background

Construction accounts for 22% of all workplace fatalities in Ontario (Association of Workers' Compensation Boards of Canada, 2015), although construction only accounts for 7% of Ontario's workforce (Statistics Canada, 2017a). Due to the dangers of the construction industry, safety indicators, termed leading and lagging, have been developed to measure safety performance and prevent further injury.

Objective

The objective of this thesis is to determine whether the relationship between safety leading and lagging indicators have predictable relationships, as they are on an industry level, when measured on a company level using company administrative data.

Methods

The case study involved the collection of safety indicators from 47 construction projects. An evaluation of available safety indicators was conducted and in the end 5 indicators were chosen for use in this study. These being counts of site inspections, toolbox talks, subcontractor notice of offenses, medical injuries, first aid injuries and project length. Since counts for the outcome variables exhibited an excess of zeros, the counts are assumed to be produced by two distributions, one being described by a standard Poisson process and the other a process that always produces a zero count. Four zero-inflated Poisson models were run to determine whether the leading indicator, site inspections or toolbox talks, led to a decrease in the value of the lagging indicators, medical injuries or first aid injuries. Model 1 tested the effect of site inspections on zero counts of medical injuries. Model 2 tested the effect of toolbox talks on zero

counts of medical injuries. Model 3 tested the effect of site inspections on zero counts of first aid injuries. Model 4 tested the effect of toolbox talks on zero counts of first aid injuries.

Results

Models 1 and 2 found that number of medical injuries were not significantly related to either site inspections or toolbox talks. Models 3 and 4 found that first aid injuries were significantly related to site inspections and toolbox talks, when run independently. Yet, the estimate sizes of all four models were very small. Goodness of Fit tests were run to ensure that the sample distributions fit the hypothesized distributions of the models selected. These results showed that the lagging indicators were either not related to or had a small association to each of the leading indicators.

Discussion

This study showed that identifying the relationship between leading and lagging indicators may not be as easy as the theory suggests. This study had several limitations including use of administrative data, small sample size, and concern about data quality. Furthermore, theories about accident prevention and prevention research are also discussed. One theory discussed is that early accident prevention models suggest that some accidents are unpreventable. In the context of this study, it is possible that the few accidents that did occur were unpreventable in nature and could not be prevented through leading indicators. The second theory discussed was that Geoffrey Rose' Theory of Prevention suggests that concepts tested on a population level may not work on an individual level. For this study, it means that the leading and lagging indicators developed on an industry level, may not be appropriate for testing on a company level. Finally, suggestions to how the participating company could improve safety research and their

safety performance were given including collecting a safety climate indicator, conducting bi-annual meetings with safety reporting personnel, improving documentation of subcontractor safety performance, and reorganizing MB's administrative data.

Conclusion

In conclusion, despite the fact that leading and lagging indicators have been developed on a simple assumption, there needs to be more research in order to better understand this relationship on a company level. Research needs to be completed to determine how the legislated paperwork that companies collect can be used to support injury prevention and decision making.

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List of Abbreviations

Abbreviation	Full Name
COR	Certificate of Recognition
IHSA	Infrastructure Health and Safety Association
MB	Melloul Blamey Construction
MOL	Ministry of Labour
OHSA	Occupational Health and Safety Act
NFA	Number of First Aid Injuries
NI	Number of Injuries requiring Medical Attention
OSHA	Occupational Safety and Health Administration
PL	Project Length
PPE	Personal Protection Equipment
SI	Number of Site Inspections
TT	Number of Toolbox Talks
WSIB	Workplace Safety and Insurance Board

List of Definitions

Accident: “an unplanned event that interrupts the completion of an activity, and that may (or may not) include injury or property damage” (Canadian Centre for Occupational Health and Safety, 2018). For the purpose of this study, only accidents that lead to injury are included.

Accident Prevention: “any activity that studies the causes of accidents, makes predictions about their frequency and puts into practice intervention and remedial measures” such as safety inspections (Avery, 1995, p.1). In this thesis, accident prevention is completed by the general contractors, and subcontractors.

Substantial Completion: determined through the Construction Lien Act (1990)

2. (1) For the purposes of this Act, a contract is substantially performed,
 - (a) when the improvement to be made under that contract or a substantial part thereof is ready for use or is being used for the purposes intended; and
 - (b) when the improvement to be made under that contract is capable of completion or, where there is a known defect, correction, at a cost of not more than,
 - (i) 3 per cent of the first \$500,000 of the contract price,
 - (ii) 2 per cent of the next \$500,000 of the contract price, and
 - (iii) 1 per cent of the balance of the contract price. R.S.O. 1990, c. C.30, s.

Chapter 1: Introduction

Construction is one of Canada's most dangerous occupations. The Workplace Compensation Boards in Canada found that construction has the third highest injury rate of the 19 surveyed Canadian industries. (Association of Workers' Compensation Boards of Canada, 2015). Specifically, in Ontario, construction accounts for 11% of all lost-time injuries, 26% of all falls from heights (Ministry of Labour, 2016), and 22% of all workplace fatalities (Association of Workers' Compensation Boards of Canada, 2015). These are very high percentages considering that construction only accounts for 7% of Ontario's workforce (Statistics Canada, 2017a). With these high levels of injuries and fatalities, construction safety has become of great importance for lawmakers, employers, and researchers. As a result, researchers are developing safety indicators to determine how accident prevention impacts safety outcomes (Manuele, 2009). Yet, most safety indicator studies have been large population studies using government workplace safety datasets, such as comparisons between multiple companies' injury rates. These studies aim to create a theoretical basis for legislation, but with the exception of some large companies, these studies have not shown how preventative measures work on a smaller level, such as within a company or project. Because research has been focused on safety indicator development, very little research has been completed on a company's implementation of these indicators and preventative measures, especially for midsized and small companies. By understanding the impact within the company, research can be more relevant for decision-makers, such as company management, and industry members, and not just used for research or legislative purposes. This study aims to determine what relationships are found when contractor administrative data is used to measure safety performance.

1.1 Safety and the Construction Industry

In order to better understand research on construction safety, it is important to understand the nature of the construction industry and their safety responsibilities. The following sections provide an introduction to the construction industry, section 1.1.1, and the safety responsibilities of the construction industry in section 1.1.2. Finally, safety leading and lagging indicators are introduced in section 1.1.3.

1.1.1 Introduction to the Construction Industry

The construction industry is very broad consisting of three main forms of construction: building construction, heavy construction, and specialty trades (Standard Industrial Classification, 2018). Building construction is a group that includes general contractors that construct residential, farm, institutional, commercial and industrial buildings. Heavy Construction includes general contractors that take part in construction, other than building construction, and includes roadways, bridges, irrigation, and marine projects. Finally, Specialty Trades is a subsector of construction that specializes in specific activities, such as metal prefabrication, mechanical, concrete pouring or painting (Standard Industrial Classification, 2018). Specialty contractors will work for the general contractors in building or heavy construction projects. Together, in Canada, the construction industry included nearly 370,000 businesses (Government of Canada, 2018) and contributed 7% of Canada's Gross Domestic Product (GDP) (Statistics Canada, 2018).

This thesis focuses on building construction, using administrative data from a building construction general contractor. General contractors manage the construction process which includes scheduling and coordinating of the construction process, maintaining onsite safety, ensuring building quality, and managing project finances. Additionally, many general contractors employ carpenters and labourers to complete site work, including housekeeping, carpentry,

formwork and hardware installation (Levy, 2006). The rest of the building work is completed by specialty contractors that are overseen by the general contractor (Standard Industrial Classification, 2018).

The construction industry experiences many challenges including low profit margins and worker mobility. First, the construction industry is known for its very low profit margins. Despite their growing profit margins (Tal, 2015), these small margins make it difficult for construction companies to implement expensive equipment and procedures, such as safety equipment. General contractors are always working to balance the needs of the workers, production quality, and business success. Construction industry also experiences a large amount of worker mobility. Construction workers may work on a construction project for as short a time as a day, and then move to the next site. Few construction workers will be part of the same project from start to finish (Construction Sector Council, 2005). This results in labour being difficult to track, and safety hard to enforce, and safety training and equipment being hard to maintain.

The broad nature of construction and the many challenges faced by the industry makes research on the construction industry very difficult. The broad nature can make large studies lack generalizability as they cannot capture the differences within smaller populations, such as a company. Additionally, the many challenges of the industry can make research methodology difficult, as researchers have to create their studies to adapt to the challenges, while still meeting their research goals.

1.1.2 Safety in Ontario

In Ontario, construction safety is highly legislated and carried out by the general contractors and subcontractors on a building project. Construction safety is legislated under the

Occupational Health and Safety Act, OHSA (1990). Construction Projects, a government regulation, also details the many expectations for construction safety performance (Construction Projects, 1991). Lastly, the OHSA and the additional regulation also require compliance with some standards from the Canadian Standards Association such as CSA-Z259.10-06 Full Body Harnesses (Construction Projects, 1991). The OHSA and the additional regulations require construction employers to take part in various forms of accident prevention and safety documentation in order to meet 'due diligence'. Due diligence requires every employer, including general contractors and subcontractors, to take all reasonable steps to ensure the safety of their employees in order to satisfy legal requirements (Ontario Health and Safety Act, 1990).

Construction safety can voluntarily be audited in Ontario under the Infrastructure Health and Safety Association's (IHSA) Certificate of Recognition (COR) audit tool. Contractors are audited both internally and externally by the IHSA. If the contractors meet the safety standards outlined in the audit tool, they are provided with a certificate. The certificate is valid for three years and then allows them to work on specific projects where a COR certificate is required (IHSA, n.d.). Due to the legislation and audits, there is much administrative data available for researchers to explore. Furthermore, many project indicators are collected during construction in order to monitor the project and aid its completion. These include budgets, recycling rates, and construction schedules. Companies, if they are following legislative requirements, have documents on the reports of injuries, safety inspections, safety talks, MOL inspections, and much more. Yet, very little research has been done with this data. It is currently not understood how this data can support decision-makers, except being used to meet legislated goals.

1.1.3 Leading and Lagging Safety Indicators

In light of the previous research on safety indicator development, safety indicators have been divided into two groups: leading and lagging. Leading indicators are primarily aimed at measuring accident prevention, while lagging indicators are aimed at measuring accident outcome (Toellner, 2001). Over time, leading indicators have become the preferred methods for measuring construction safety as they are more preventative in nature.

The study of leading indicators started over 30 years ago by developing the concept of safety climate, an indicator of the psychosocial safety environment in the workplace, so safety climate can be used to predict injuries before they happen. Workplaces with low safety climate, would be more likely to have more injuries and vice versa (Zohar, 2010). Over time, researchers have developed many tools to measure safety climate, and have worked to measure safety climates relationship to factors such as injuries (Zohar, 2002), workplace leadership (Zohar, 2002), and safety assessment programs (Sparer, Murphy, Taylor & Dennerlein, 2013) with mixed results. Although conceptually leading and lagging indicators make sense, there has been very little consistency among the research over time, including disagreements on how leading and lagging indicators interact and how they should be measured (Manuele, 2009). For example, a study in 2005 found that safety climate was negatively correlated with self-reporting injuries, suggesting that companies with better safety climate, had fewer injuries (Huang, Ho, Smith & Chen, 2006). In contrast, a later study found that when safety climate and injury relationships were studied with industry injury risk as a confounding factor, there was no longer a negative correlation. This suggests that it is not safety climate that is related to injuries, but industry injury risk (Smith, Huang, Ho & Chen, 2006). Furthermore, most research has been completed on large, industry wide bases, or on very small sample size, such as one small company, or one crew, leaving the effect of leading indicators in mid-sized companies relatively unknown.

1.2 Research Question

This research examines whether the relationships between safety leading and lagging indicators, as seen on an industry level, can also be seen when comparing different working groups within a construction company. In other words, do construction projects with high levels of positive leading indicators have fewer lagging indicators, and therefore fewer accidents, than projects from the same company with lower levels of positive leading indicators? If the assumption is correct, the relationships that companies find in their own data would support current research and legislation. If the assumption is incorrect, the relationships that companies can see through their own data would be counterintuitive to what is being promoted to them by research and legislation. Further research needs to be done to determine if the leading and lagging assumption can be seen with company data.

1.3 Overview of Thesis

This thesis contains six chapters all written to further research of leading and lagging indicators while using company data. Chapter 1, as seen above, contains an introduction to construction safety. Chapter 2 contains a comprehensive scoping review on leading and lagging indicators measured on a construction project level. Chapter 3 contains a detailed report on the methods and materials used. Chapter 4 contains the results of this study. Chapter 5 contains a discussion of the results, and finally, Chapter 6 contains a conclusion and further implications of this research.

Chapter 2: Literature Review

This literature review is a scoping review. A scoping review is a literature review that maps key concepts related to the research area using a rapid timeline (Arksey & O'Malley, 2007). Leading and lagging indicators have been studied in construction project research. This research works to summarize the current research on construction project leading and lagging indicators. Additionally, this review will identify gaps to focus further studies.

2.1 Literature Review Research Methodology

First, it is important to develop a list of safety indicators that have been researched, in order to determine which administrative data should be selected by contractors for research. To develop a comprehensive list of the leading and lagging safety indicators that have been used in construction projects to monitor safety, a scoping review was completed. In addition to providing a comprehensive list, this literature review also summarized how the leading and lagging indicators relate with each other in previous research. The information found through this literature review was used to choose what indicators would be included in this study.

Table 1

Literature Review Search Terms

Variable	Search Term
Population <i>And</i>	Construction
Indicator <i>And</i>	Indicator*
Safety <i>And</i>	Safety
Type of Indicator	Leading Lagging
	OR

Relevant studies were selected using the electronic database PubMed and Scopus. These databases provide comprehensive coverage of the research available in both the medical and engineering fields, necessary when completing research in construction safety. The search terms used in the databases can be seen in Table 1. References were excluded if they were books, duplicates, not in English, or unavailable in full-text by the researcher. The scoping

Note: results of this review would have been affected by the search terms chosen. Use of different search terms may have led to different results.

review process was completed using DistillerSR (DistillerSR, Ottawa, ON). A two-step screening process was completed on the articles selected through the databases and this process is further explained below.

In phase one, eighty-one articles were selected using the search strategy shown above. After duplicates were removed, 79 articles were reviewed for inclusion based on the following criteria: (1) be related to construction, (2) include safety indicators, (3) identify leading and lagging indicators and (4) be an academic journal article. After phase one, 33 of the 79 articles remained with 46 exclusions.

In Phase 2, thirty-three articles underwent further examination. Only articles that measured safety indicators at a construction project level were included. A total of 21 articles were excluded.

The remaining 12 articles were eligible for full-text review. Two articles were removed as the full text was not available, leaving 10 articles remaining for full text review and data extraction. Data extraction was completed using an excel spreadsheet to track the author, date, journal, safety indicators used and relationships between safety indicators used. A summary of the article selection process can be seen in Figure 1 below.

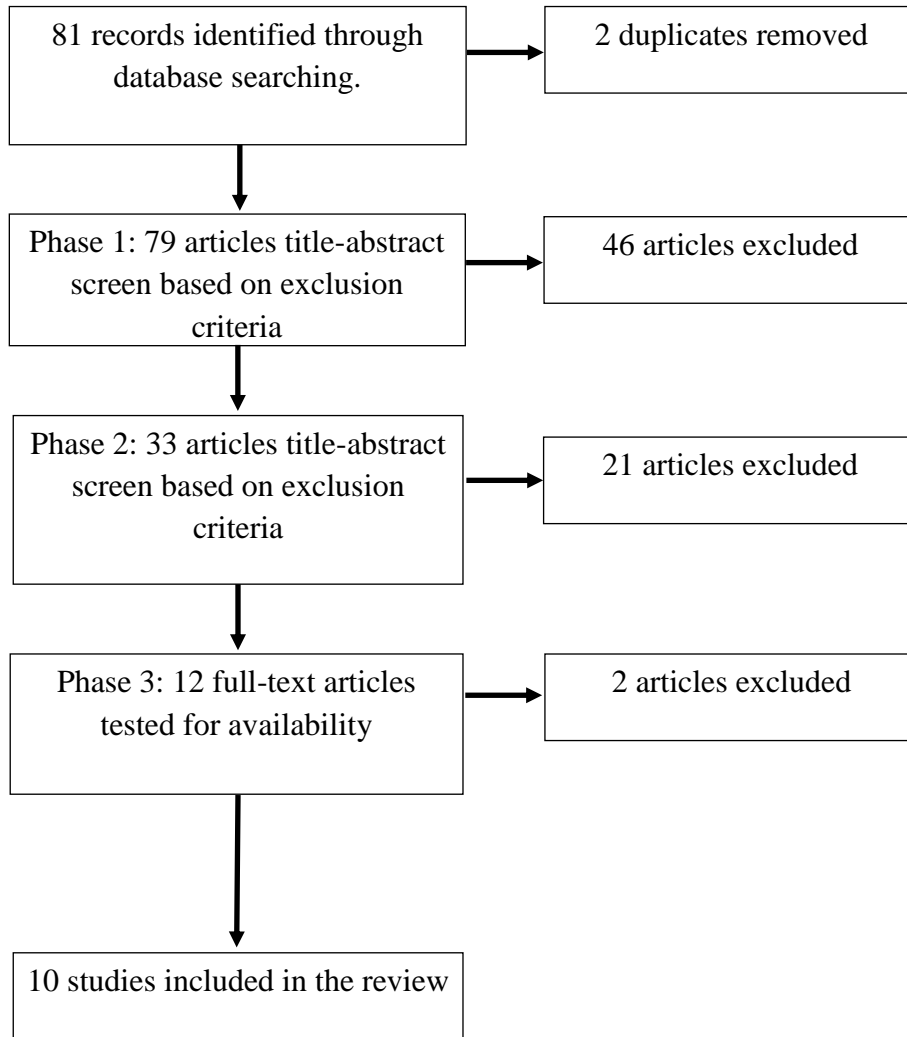


Figure 1. Flow Diagram of Article Selection Process

Overall, the studies included small sample sizes including case studies, pilot studies, and literature reviews. No large population study was completed. Additionally, the articles contained many recurring authors, showing that few researchers are involved in this area of study. Table 2 below provides the title, author(s), year and brief summary of each study's research goal.

Table 2

Summary of Literature Review Articles

Author(s), Year	Study Type and Research Goal
Ng, Laurlund, Howell, & Lancos, 2010	Case Study: to measure the impact of a 5-S assessment tool and safety leading indicators on project safety.
Lingard, Wakefield, & Cashin, 2011	Case Study: a monthly weighted safety index score and safety climate survey were used to measure safety performance on a construction project.
Ng, Laurlund, Howell, & Lancos, 2012	Case Study: analysis of use of a 5-S assessment tool on one construction project to observe how safety leading indicators were reported over the course of the project.
Hinze, Therman, & Wehle, 2013	Review Article: discusses the difference between passive and active leading indicators within construction safety performance
Rajendran, 2013	Case Study: analysis of leading and lagging indicators of one project to evaluate leading indicators under real project conditions
Guo & Yiu, 2015	Theoretical Article: this article works to create a conceptual framework for developing safety leading indicators for use within the construction industry.
Sparer, Herrick, & Dennerlein, 2015	Pilot Study: this research developed a leading indicator based incentive program for construction projects.
Schwatka, Hecker, & Goldenhar, 2016	Review Article: discusses the literature on the leading indicator, safety climate, including on a project level.
Lingard, Hallowell, Salas, & Pirzadeh, 2017	Case Study: analysis of the temporal relationships of leading indicators within one five-year construction project.
Niu, Leicht, & Rowlinson, 2017	Focus Groups: this research works to develop indicators that influence site safety that can be measured using safety climate tools.

As is evident by Table 2 above, the research questions of the final ten articles varied. As mentioned earlier, for leading indicators to be used on construction projects, first, the indicators need to be developed, and then second, tested in a construction project setting (Rajendran, 2013). Many of these articles were focused on the first step – development of indicators. This includes defining (Hinze et al., 2013; Schwatka et al., 2016), developing (Guo & Yiu, 2015; Lingard et al., 2011; Niu et al., 2017), or measuring indicators (Ng et al., 2010; Ng et al., 2012). Fewer focused on the second step, testing on construction projects through completion of validation testing of the leading on the lagging indicators (Lingard et al., 2017; Rajendran, 2013).

Within the articles in this scoping review, this study categorized the safety indicators used in the studies identified through the scoping review into either leading or lagging indicators. In the studies, 15 leading and 4 lagging indicators were included. As not all authors used the same name for similar indicators, indicators that were similar were grouped together for the purpose of this scoping review. The most popular indicators that were categorized as leading were attitudes and safety climate, site inspections/audits, training and safety talks, and worker safety behaviour. The most common indicators that were categorized as lagging were first aid injuries and lost time injuries. More information can be seen in Table 3 below.

Table 3
Summary of Safety Indicators

Author(s), Year	Safety Indicator Type																		
	Leading											Lagging							
	Alcohol / Dug Testing	Attitudes and Safety Climate	Fall Protection	Housekeeping	Ladders and Stairs	Near Miss	Pre-Task Safety Plans	PPE	Railings and Covers	Safety Corrections	Safety Positive Reinforcements	Site Inspections / Audits	Subcontractor Safety	Training / Job Safety Talks	Worker Safety Behaviour	First Aid Injuries	Lost Time Injuries	Members of the Public Injured	Reported Incidents
Ng, Laurlund, Howell, & Lancos, 2010			X	X	X			X	X	X									
Lingard, Wakefield, & Cashin, 2011	X									X	X	X	X	X	X	X	X		
Ng, Laurlund, Howell, & Lancos, 2012.			X	X	X			X	X	X									
Hinze, Therman, & Wehle, 2013	X					X				X	X	X	X						
Rajendran, 2013						X	X				X			X	X	X	X		
Guo & Yiu, 2015	X		X			X						X	X	X					
Sparer, Herrick, & Dennerlein, 2015											X	X	X						
Schwatka, Hecker, & Goldenhar, 2016	X													X					
Lingard, Hallowell, Salas, & Pirzadeh, 2017	X						X				X	X				X			
Niu, Leicht, & Rowlinson, 2017	X												X	X					
Total	1	5	2	3	2	2	3	2	2	3	1	5	3	6	5	2	3	1	1

If the indicators were found in two or more studies they are discussed in the results section. In some cases, indicators were only used by Ng et al. (2010; 2012). However, these authors did not define their indicators or identify what was counted, beyond a broad categorization, such as fall protection. Therefore, indicators that were only used by Ng et al. (2010; 2012) are not further explained. These include fall protection, ladders and stairs, personal protection equipment (PPE), and railings and covers.

2.2 Results of Comprehensive Literature Review

Through a scoping review, ten leading indicators, and two lagging indicators were identified as being previously used in studies that focused on contractor project data. These indicators will be further explained below.

2.2.1 Summary of Leading Indicators

Leading indicators were more commonly discussed than lagging indicators in the studies included in this review. Within the studies, there seemed to be a focus on attitude and behaviour based leading indicators such as safety climate, in comparison to counting prevention measures such as site inspections. The common leading indicators are further explained below.

Attitudes and Safety Climate: Many of these articles broadly studied the attitude of employees or managers in the workplace. One particular measure of this is safety climate. Safety climate is broadly defined as the employee perceptions of safety in the workplace, specifically as it related to manager perceptions (Schwatka et al., 2016).

Housekeeping: Housekeeping is an indicator of the physical hazards in the working environment (Guo & Yiu, 2015). Housekeeping is a broad term regarding the cleanliness of a site. It includes aspects such as waste removal, and material and equipment storage (Construction Projects, 1991).

Near Miss: A near miss is an incident that is considered a close call. It is an incident that could result in injury or property damage, but no damage was caused (Rajendran, 2013).

Pre-task Safety Plan: Guo and Yiu (2015), define pre-task safety planning as the discussion of hazard controls to eliminate, or manage hazards in the work tasks. This planning is done by controls such as guards, change in task sequence, or use of personal protection equipment.

Safety Corrections: Ng et al. (2010; 2012) measured the number of safety corrections as the number of non-compliance of project safety regulations made by the workers on an ad hoc basis. In contrast, Lingard et al. (2012), measured non-compliance as determined through site inspections alone.

Site Inspections: Site inspections, and their similar counterpart, site audits, are tests that measure the number of hazards on a site. Rajendran (2013) used a scoring system where points were deducted based on the number of safety violations that occurred on the site. Site inspections are checklists completed by a knowledgeable individual such as a supervisor or safety representative (Lingard et al., 2016).

Subcontractor Safety: Subcontractor safety was seen at many different levels. Guo and Yiu (2015) used subcontractor safety leadership as an indicator in their developed construction project safety condition map, yet they did not provide a method for measurement. Sparer et al. (2015) measured subcontractor safety performance based on a weighted calculation that involved counting unsafe and safe work observations to provide a single score. Hinze et al. (2011) measured subcontractor safety score not from on-site actions, but rather provided examples of how subcontractor safety can be used prior to subcontractor contract award based on subcontractor safety history, safety policy and their site-specific safety program.

Training/Job Safety Talks: Guo and Yiu (2015) indicated safety talks, safety coaching, and safety training for supervisors as safety practices that can change safety conditions. Training is often considered an aspect of safety climate (Niu, et al., 2017; Schwatka et al., 2016). Toolbox talks, or job safety talks, are a form of safety communication that occurs on a regular basis to exchange information between management and workers (Lingard et al., 2016).

Worker Safety Behaviour: Worker safety behaviour was measured in many studies. It involves measures such as worker involvement in safety (Schwatka et al., 2016), worker safety motivation, and worker safety competency (Guo and Yiu, 2015). Rajendran (2013) instead measured worker safety actions by using a safety professional to mark worker safety behaviour based on a checklist.

As shown by the leading indicators explained above, the leading indicators focused on hazard identification or correction such as site inspections or training, as well as attitudes and behaviours such as safety climate. All indicators were related to behaviours or attitudes that promote accident prevention rather than negative safety outcomes.

2.2.2 Summary of Lagging Indicators

Lagging indicators, having been researched for a longer time than leading, are typically easily accessible and well documented, yet, lagging indicators were less commonly used in the studies in this review. Lagging indicators are generally accessible as they are reporting measures that are required by various health and safety authorities in order to track company performance and to monitor injury trends (OHSA, 1990). This makes research on lagging indicators convenient. Yet, despite the convenience, there seems to be a shift towards leading indicators in the current research. This shift leaves common lagging indicators such as first aid injuries and lost time injuries, less used in research.

There are many reasons as to why lagging indicators are less commonly researched. One being the focus on injury prevention in research and in occupational health and safety practice. Researchers and practitioners have chosen to focus on indicators that can lead to injury prevention, such as site inspections, instead of indicators that document safety outcomes, such as injuries. The thought is that leading indicators allow for research to be more proactive, rather than retroactive with lagging indicators.

First Aid Injuries: First aid injuries include any injury that can be treated with minimal first aid and require no further medical treatment (Rajendran, 2013). First aid injuries are recorded on site as part of the reporting requirements in Ontario, Canada, the location of this study, in the OHSA (1990). This reporting requirement is similar across many jurisdictions. This measure was included by Lingard et al. (2010) as well as Rajendran (2013).

Total Recordable Injury Rate or Lost Time Injuries: A total recordable injury rate is a rate used for the United States Occupational Safety and Health Administration (OSHA) and includes any injuries that require any medical treatment beyond first aid (Rajendran, 2013). A subset of the Total Recordable Injury Rate is the Lost Time Injuries, where workers miss work leading to loss of earnings (Ontario Health and Safety Act, 1990). As the documentation of lagging indicators is related to safety authority documentation requirements, the type of indicator used, whether total recordable injury rate or lost time injuries, is often based on the safety authority in the research area. In Ontario, lost time injury is the more commonly used metric, as it is used by the Workplace Safety and Insurance Board (WSIB) under the reporting requirements of the OHSA (Ontario Health and Safety Act, 1990).

As shown by the summary of the indicators identified in the scoping review, the lagging indicators were related to negative safety outcomes, specifically varying levels of injuries. Lagging indicators are readily available based on government reporting requirements but are being less commonly used in research in favour of leading indicators.

2.2.3 Interaction of Leading and Lagging Indicators

The focus of this literature review was to determine how leading and lagging indicators relate to each other on construction projects. Only two articles addressed this, and thus they are the focus for this discussion. Unfortunately, while these articles provide some research into leading and lagging indicators in construction projects, the occurrence of few articles being available showed the need for more research in this area.

The first study, Lingard et al. (2017) completed temporal analysis of leading indicators. The authors asked whether leading indicators are actually leading, and how long until the implementation of leading indicators leads to improvements in lagging indicators. They studied 11 leading indicators including safety talks, hazards reported and safety inspections. These researchers used frequency data collected by subcontractors and contractors on a large, 5-year construction project in Australia. This frequency data underwent many levels of pre-processing such as adjustment for man hours prior to being included in results. This study determined that the 'leading' aspect of leading indicators is actually dynamic in nature. Leading indicators did not improve the lagging indicator, specifically the total recordable injury rate, in the expected, predictable way. This left the authors to acknowledge that safety leading indicators are very complex. Furthermore, they suggest that there is a bidirectional relationship between leading and lagging indicators. In other words, the assumed unidirectional temporal aspect of leading indicators was not supported by their study. In their study they found that leading indicators both led and lagged. For example, toolbox talks led to a decrease in injuries for the first four months,

then injuries led toolbox talks for the next two months. In this case, both indicators, injuries and toolbox talks, spent time as a leading and lagging indicator, and were therefore bidirectional. This shows that concept that forms the basis leading and lagging indicators is much too simple for the complex nature of construction. These authors propose focusing less on leading and lagging categories, and rather label indicators as positive and negative. While this study greatly enhanced the research on leading and lagging indicators, they failed to acknowledge how the significance of their study impacts construction companies and management. Instead they focused on their studies significance on other research. For example, if the use of leading and lagging terminology may be causing difficulties in the research setting, would it not also cause difficulties in management intervention? This question and many more remain unacknowledged.

In the second study, Rajendran (2013) collected both leading and lagging indicators for one construction project to determine if there was correlation between the leading and lagging indicators. The three leading indicators used were pretask plan review, worker safe behaviour observation score, and site safety audit score. These leading indicators were then tested for correlation between the four lagging indicators: first aid, near miss incidents, OSHA recordable incidents, and all project incidents. This information was collected for 37 weeks by safety professionals. This author found correlations between pretask plan review and total incidents ($r = -0.507$), pretask plan review and first aid ($r = -0.573$), worker safe behaviour observations and total incidents ($r = -0.588$), and worker safe behaviour observations and first aid ($r = -0.635$). While these correlations looked promising, the statistical significance for the correlation coefficients was not provided. In addition, the study focused on positive findings without making clear that only four of the twelve correlations supported the study hypothesis. The author provided little discussion of the negative results or provide results that did not support their

hypothesis. While this study did start dialogue on leading and lagging indicators on construction projects, more vigorous research needs to be done.

Both of the two studies mentioned above provided information about how leading and lagging indicators work in construction projects but both were completed on a case study of only one project. The pilot/case study nature of the research provided insight into the real-life relationships of these indicators, but larger samples need to be used in further research.

Additionally, the studies examined in this literature review also showed that leading and lagging indicators in construction projects are very complex and may not relate to each other as expected.

Although there was very little information available to how leading and lagging indicators relate to each other, some conclusions can be made based on the articles examined. Lagging indicators focused on injuries and incidents. All lagging indicators had negative outcomes, matching the definition of lagging indicators. The leading indicators, on the other hand, can be put into two categories: attitudes and prevention measures. Examples of leading indicators that measure attitudes include safety climate and manager attitude towards safety. Examples of leading indicators focused on preventive measures: worker safe behaviours, site safety inspections and pre-task safety plans. Leading indicators focused on attitudes were more common, this may be because the preventative measure leading indicators, such as pre-task plan review and site inspections, were not always negatively correlated with lagging indicators as expected in the research environment as shown by Rajendran (2013) and Lingard et al. (2010). In conclusion, although the small sample size of 10 articles for analysis led to minimal research being available to make confident conclusions. This small sample size may be in part due to the search terms selected for this scoping review. Yet, this scoping review showed the need for more research in the future.

Chapter 3: Methods and Materials

3.1 Study Sample

Melloul Blamey Construction (MB) is a general contractor in Ontario, provided the project data used in this case study. MB specializes in several types of construction including industrial, commercial and institutional sectors as well as multi-residential buildings, such as student apartment buildings. Between 2012 and 2016, the time period of this study, MB completed 78 projects ranging with a cost from \$100,000's to multi millions. MB is COR certified, meaning that they have passed regular audits to show their excellence in safety, see section 1.1.2 (IHSA, n.d.).

3.1.1 The Projects

Data from construction projects completed from 2012 through 2016 were used for this study. In 2012, MB changed to storing project information on electronic databases, which made the data readily available for research. The end date, 2016 was the last full year of data available at the time of research collection. Although data collection for this study was conducted in 2017, no construction projects started in 2017 were included in this study as the projects were not completed in time for data analysis. Through MB's electronic data base, 78 projects were identified and evaluated for research eligibility. Reasons for excluding projects can be seen in Figure 2 below. Project inclusion in this study was based on the following criteria:

1. Construction contract was either fixed bid, design build or construction management
2. Project was completed by time of data collection
3. Project was recorded consistently across MB departments (further explained below)

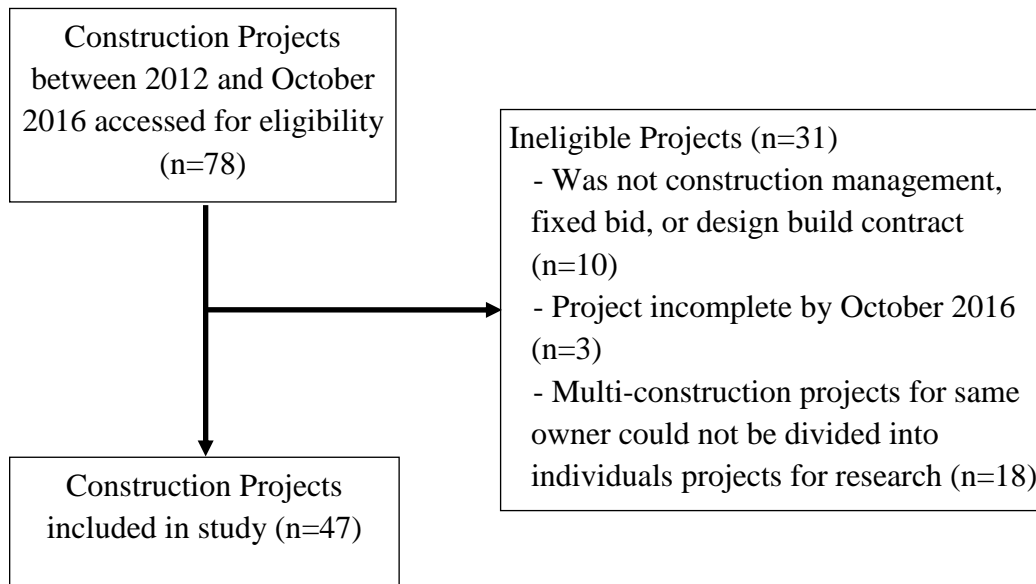


Figure 2. Construction Project Removals

As shown in Figure 2, and mentioned in criteria 3, projects had to be recorded consistently across departments within MB. As a result of this criteria, 18 projects were excluded. An example of failure to meet this criteria is with the creation of a strip mall and box store centre. In the safety department, this entire property and construction was recorded as one large project, as the many buildings were completed at the same time, at the same location, and by the same superintendent. Yet, in the project management department, this build was considered to be four separate projects based on who the building contract was with, one for the developer to prepare the site for construction, one for the owner of the grocery store, one for the owner of the strip mall, and another for the owner of the box store. Unfortunately, the discrepancy in records logged differently between the safety and project management department did not allow these projects to be included in the research studies. There were 47 eligible projects available for this research.

3.2 The Indicators

For the 47 projects, 8 indicators were used based on the indicators logged by MB. These indicators consisted of 8 safety indicators, and 1 project length indicator. The indicators were logged using reports previously collected by the company and stored by the safety department. This type of data is considered administrative data, meaning data that is collected for reasons other than research or statistics, such as legislation requirements or part of the regular business process (Hashimoto, Brodt, Skelly & Dettori, 2014; Statistics Canada, 2017b). Many safety indicators are reported by construction companies due to the legislative reporting requirements of the Ontario Health and Safety Act (1990) and the Workplace Safety and Insurance Act (1997). The strength of administrative data as it is a readily available source for ‘real world’ data. It also can lead to very large databases for research use (Hashimoto et al., 2014). Yet, the accuracy of administrative data can vary based on the data’s original purpose and how it was collected. For example, insurance injury reports could be completed less than necessary, or reported to downplay the extent of the injury, in order that a company’s safety reputation or insurance premiums are not affected. Due to the limitations of administrative data, it is imperative to evaluate the quality of administrative data prior to its use.

3.2.1 Safety Indicator Selection

Safety indicators are divided into two groups: leading and lagging. Leading indicators are aimed at measuring accident prevention, while lagging indicators are aimed at measuring accident outcome (Toellner, 2001). Through MB, eight safety indicators were evaluated for inclusion in this research. Additional indicators were considered as part of the literature review in Chapter 2, but they were not accessible at the time of research. Available indicators were evaluated for inclusion based on three criteria: (1) Whether or not the data was available, (2) whether or not they are indicators commonly used in research, (3) and whether the indicators

collected with reasonable consistency across the projects. The available leading and lagging indicators were:

1. Leading Indicators

- Number of Toolbox Talks
- Number of Site Inspections
- Number of Near Misses

2. Lagging Indicators

- Number of Subcontractor Notice of Offenses:
- Number of Lost Time Injuries
- Number of Medical Injuries
- Number of First Aid Injuries
- Number of MOL citations per inspection

Leading Indicators.

Three leading indicators were selected to be tested for inclusion in this study: number of toolbox talks, number of site inspections and number of near misses. While there were more leading indicators available, they were used less commonly and changed regularly over the course of the four years. Examples of these indicators would be supervisor safety review scores, daily hazard assessments, and pre-construction safety meetings. While they would have provided more options for leading indicators, the changes in legislation and reporting made them too variable to be included. Therefore, only the three chosen leading indicators will be examined below.

First, number of toolbox talks and number of site inspections have very similar strengths and limitations. A toolbox talk is a short onsite training session that occurs on a regular basis to educate the workers on site specific hazards as well as refresh workers safety training (Lingard et al., 2011). Site inspections are walkarounds completed by the superintendent or site safety representative that involves looking for safety hazards using a standardized checklist (Rajendran, 2013). The strength of these indicators is that they are indicative of the emphasis on safety that occurs on a site. In this study, both of these indicators were measured using counts as that was the data that was available from the company; although count data is highly reliable, counts do not allow for detail, such as the breadth of the talk or site inspection to be taken into consideration. Thus, certain questions such as the reason a talk occurred, the number of hazards noted, and the preventative measures taken as a result, cannot be determined using these indicators. During 2012-2016, according to Deb Henhoeffler, a safety practitioner at MB, the toolbox talks and site inspections were reported consistently across sites regarding frequency, but the details within the documentation were not consistent across sites, which only allows for frequency counts, rather than more detailed analysis (D. Henhoeffler, personal communication, May 23, 2018). Despite the limitations, toolbox talks and site inspections met the criteria, as they were available, commonly used and research and consistently collected.

Second, the final leading indicator, near misses is an unplanned incident that does not result in injury or loss of property (Lingard et al., 2011). A near miss is an indicator of potential risk on a construction site and relies on individual judgement and reporting. For example, a worker nearly fell from the second floor of a construction site when he lost his balance. He managed to correct himself. This would be reported as a near miss because if he fell, it could have resulted in injury. Additionally, near misses can be underreported because they can be hard

to identify and are not regularly scheduled as talks and inspections are. This underreporting is evident in this data set, as the range for near misses was 0 to 5 per project. Additionally, identifying near misses requires the knowledge of safety requirements, and the foresight to see potential dangers. For example, a worker may not report a near miss because they did not identify the situation as dangerous. If a worker dropped a tool while working on an elevator shaft while alone, no one was at risk from being hit by the falling object because no one was working below them. Still, this situation is a near miss because if someone had entered the elevator shaft, an injury may have occurred. The worker may not report the near miss because they did not have the knowledge to see how the incident may have caused an injury. At MB, near misses go largely underreported, their safety practitioner suggests that it is not because of a lack of safety knowledge or foresight, but rather because of the extra paperwork and because of a feeling of blame and embarrassment associated with reporting a near miss (D. Henhoeffler, personal communication, May 23, 2018). This feeling of embarrassment has also been noted in research as a cause of underreporting (Toellner, 2001), and is noted to occur if near misses are used as a preventative indicator, rather than an outcome indicator, such as injuries (Hinze et al., 2013). As a result, only more severe near misses are reported, such as if it is clear that an individual could have been gravely injured, and the near miss had witnesses (D. Henhoeffler, personal communication, May 23, 2018). Furthermore, as near misses are not regularly scheduled, a worker or superintendent may prefer to act on the near miss verbally with their coworkers, rather than documenting it for the safety department. As it is not scheduled, the safety department cannot remind them if they are behind on documentation, as there is no set expectation (D. Henhoeffler, personal communication, May 23, 2018). As a result of these limitations, near misses did not meet the third criteria, consistency, and were not included in this research.

After evaluation of the leading indicators, toolbox talks and site inspections were included for data analysis, while near misses were excluded.

Lagging Indicators.

First, lost time injuries are workplace injuries that require a person to miss at least the next day of work after an injury, or injuries that lead to permanent injury or death (Workplace Safety and Insurance Act, 1997). Injuries requiring medical attention are also lost time injuries and must be reported to the WSIB if modified work lasts more than seven days. However, lost time injuries were not included as a safety indicator as MB did not experience any lost time injuries between 2012 and 2016. MB did not experience any lost time injuries because the medical injuries that did occur were dealt with, if necessary, with a successful Return to Work program where modified work is given lasting only up to seven days (D. Henhoeffler, personal communication, May 23, 2018). In Ontario, using modified work is legal and promoted, as long as the worker does not need modified work for longer than 7 days and earns their regular wage (Workplace Safety and Insurance Act, 1997). In the United States, medical injuries need to be reported to OSHA whether or not the worker can complete modified work. As a result, medical and modified work are often under-reported to reduce the burden of insurance costs on the company. Likely, this effect is minimized in Ontario due to the seven day modified work grace period (Pransky, Snyder, Dembe, & Himmelstein, 1999). However, since fewer medical injuries are required to be reported in Ontario, a different measure of injury may have been better for this research, such as injury severity that accounts for whether modified work was used.

Second, the number of medical injuries and first aid injuries were also evaluated for inclusion. An injury is a workplace injury that requires medical intervention, while a first aid

injury is a workplace injury that can be treated on site using first aid. Number of medical injuries and number of first aid injuries are more reliably recorded since they are defined events with an outcome in contrast to less defined events such as near misses. Furthermore, the workers are more likely to report them if they affect their work (D. Henhoeffler, personal communication, May 23, 2018), such as a first injury that impedes their ability to complete their task on time. Workers know that they are supposed to report all injuries, and they seem to report the more severe injuries reasonably consistently. The most common injuries underreported are for very minor first aid injuries, such as small cuts. Some people may have reported these injuries, while some may have not. For example, an injured worker may prefer to treat their first aid injury by themselves and not report it. Yet, this underreporting of first aid injuries is likely consistent across projects (D. Henhoeffler, personal communication, May 23, 2018). Overall, injury information, both medical injuries and first aid injuries, was available for all 47 projects, commonly used in research, and had reasonable consistency across the projects. As these two indicators met all three criteria, they were included in this study.

Third, subcontractor notices of offenses are used when subcontractors are given written warning about their safety violations. This warning may include fines. For example, MB has a policy that requires immediate removal of a subtrade from the job site if they fail to use fall protection (D. Henhoeffler, personal communication, May 23, 2018). Subcontractor notice of offenses can be used to gauge if the violations on site are being completed by the general contractor's employees or by the subcontractors. Unfortunately, many superintendents prefer to only use these in severe cases, as they would prefer to verbal warnings (D. Henhoeffler, personal communication, May 23, 2018). As a result, subcontractor notice of offences did not occur many times in the 47 projects, with the frequency of offences ranging from 0 to 5 (mean of just 0.617).

This low occurrence may be due to the nature of subcontractor offenses, or it may be because they are underreporting. Similarly to near misses, the nature of subcontractor notice of offense requires the ability to foresee potential dangers and the judgement of when to report it. This can be very difficult for workers and is consequently inconsistently reporting across sites. As a result, they were excluded from data analysis due to a lack of consistency and too small of a sample size.

Finally, information based on Ministry of Labour (MOL) citations was also available, but it was not used as MOL inspections did not occur on every site. Additionally, often MOL inspections occur with a certain purpose in mind, based on the goals of the MOL at the time. For example, the MOL may choose to do a series of investigations focused on fall protection, called a blitz (Government of Ontario, 2018). With the purpose of the inspections changing over time, it makes their measure across time to lack consistency.

As a result of the evaluation of the lagging indicators, number of medical injuries and number of first aid injuries were included for data analysis, while lost time injuries, subcontractor offenses and MOL citations were excluded.

3.3 Data Analysis

The goal of this research was to examine whether the relationships between safety leading and lagging indicators, as seen on an industry level, can also be seen when comparing different projects within a construction company.

3.3.1 Outcome, Control and Hypothesis Variables

For the purpose of statistical analysis, five indicators were used: number of toolbox talks, number of site inspections, number of medical injuries, number of first aid injuries and project length. These indicators can be seen in Table 4 below.

Table 4
Model Variables

Indicator	Acronym	Variable Type
Number of Toolbox Talks ^a	TT	Hypothesis
Number of Site Inspections ^a	SI	Hypothesis
Number of Injuries requiring Medical Attention ^{ab}	NI	Outcome
Number of First Aid Injuries ^{ab}	NFA	Outcome
Project Length ^a	PL	Offset

^a all safety indicators were measured as a count

^b data contained excess zero counts

The five indicators were collected as counts and divided into hypothesis variables, outcome variables, and a control variable. The two hypothesis variables were the leading indicators, site inspections and toolbox talks. The two outcome variables were the lagging indicators, number of medical injuries and number of first aid injuries. In order to determine what statistical model would best fit the data, frequency graphs for the outcome variables suggested that the lagging indicators had excess zeros. Based on these distributions, the hypothesis was that projects with higher values for the hypothesis variables, and therefore more site prevention, would have more zeros in the outcome variable as a result. In order to model this hypothesis, zero-inflated Poisson models were selected as the form of data analysis.

3.3.2 Zero-Inflated Poisson Model

A zero-inflated Poisson model is a form of regression analysis which is used to analyze data with excess zero counts. The models consist of two parts: a Poisson count model and a logit model for predicting extra zeros. A zero inflated Poisson model is given by the three equations below:

$$\log\left(\frac{\lambda_i}{n_i}\right) = \mathbf{x}'_i\boldsymbol{\beta} \quad (1)$$

$$\log(\omega_i) = \mathbf{z}'_i\boldsymbol{\gamma} \quad (2)$$

$$\Pr(Y_i = y_i) = \begin{cases} \omega + (1 - \omega)e^{-\lambda} & \text{for } y = 0 \\ (1 - \omega)\frac{\lambda^y e^{-\lambda}}{y!} & \text{for } y = 1, 2, \dots \end{cases} \quad (3)$$

λ_i is the rate of observed counts y_i are observed for subject i ,

ω_i is the proportion of zeros in the counts of y_i observed for subject i ,

n_i is the offset variable that accounts for the length of exposure under which the counts of y_i are observed.

In our application,

λ_i is the rate of observed counts of NI or NFA are observed for project i ,

ω_i is the proportion of zeros in the NI or NFA are observed for project i ,

n_i is the project length, since more NFAs or NIs will be observed for longer project lengths.

To assess the association between the hypothesized variables (SI and TT) and the outcome variables (NI and NFA), we ran a series of zero-inflated Poisson models as shown in Table 5 below.

Table 5
Statistical Models

Model Number	Hypothesis Variable	Outcome Variable
1	TT	NI
2	SI	NI
3	TT	NFA
4	SI	NFA

Note: all models were run with PL as an offset variable

Model 1 tested run with hypothesis variable TT, control variable PL, and outcome variable NI. This model was used to test the hypothesis that toolbox talks would lead to increased zero counts in the number of medical injuries.

Model 2 tested run with hypothesis variable SI, control variable PL, and outcome variable NI. This model was used to test the hypothesis that site inspections would lead to increased zero counts in the number of medical injuries.

Model 3 was tested with hypothesis variable TT, control variable PL, and outcome variable NFA. This model was used to test the hypothesis that toolbox talks would lead to increased zero counts in first aid injuries.

Model 4 was tested with hypothesis variable SI, control variable PL, and outcome variable NFA. This model was used to test the hypothesis that site inspections would lead to increased zero counts in first aid injuries.

Additional models were also run when the hypothesis variables were not run independently of each other. Models were run with both a zero-inflated Poisson and a Poisson distribution with NI and NFA as the outcome variables. Early analysis found that the zero-inflated models better fit the observed frequencies. Additionally, models were run with SI and TT jointly as well as independently. Only models with SI and TT run interpedently led to significant results. Models were SI and TT were run jointly can be seen in Appendix A. As a result of the early analysis, zero-inflated Poisson models were developed with SI and TT run independently of each other. All models were run using the statistical software package SAS Studio version 3.5 with a significance cut off of $p < 0.05$.

Chapter 4: Results

4.1 Descriptive Statistics

Descriptive statistics for the variables of interest are given in Table 6. PL ranged from 2 months to 24 months with a mean of 10.936. The four variables SI, TT, NI, and NFA are summary counts per project. For the hypothesis variables, SI had a mean and standard deviation of 51.021 and 31.232, while TT had a mean and standard deviation of 45.149 and 30.399.

Table 6
Descriptive Statistics for Model Variables

Variable	N	Mean	Std Dev	Min	Max
PL (month)	47	10.936	5.980	2	24
SI (count)	47	51.021	31.232	3	120
TT (count)	47	45.149	30.399	2	115
NI (count)	47	1.489	1.943	0	8
NFA (count)	47	3.191	3.651	0	15

For the outcome variables, NI ranged from 0-8 with many of these values being low, hence reducing the mean to 1.489. These low values can be seen in Figure 3, where 42% of the values were 0, and 21% were 1. Similarly, NFA had a reduced mean of 3.191 due the many low values. Figure 4 shows that 27% of the projects experienced zero first aid injuries, and 21% only experienced one first aid injury.

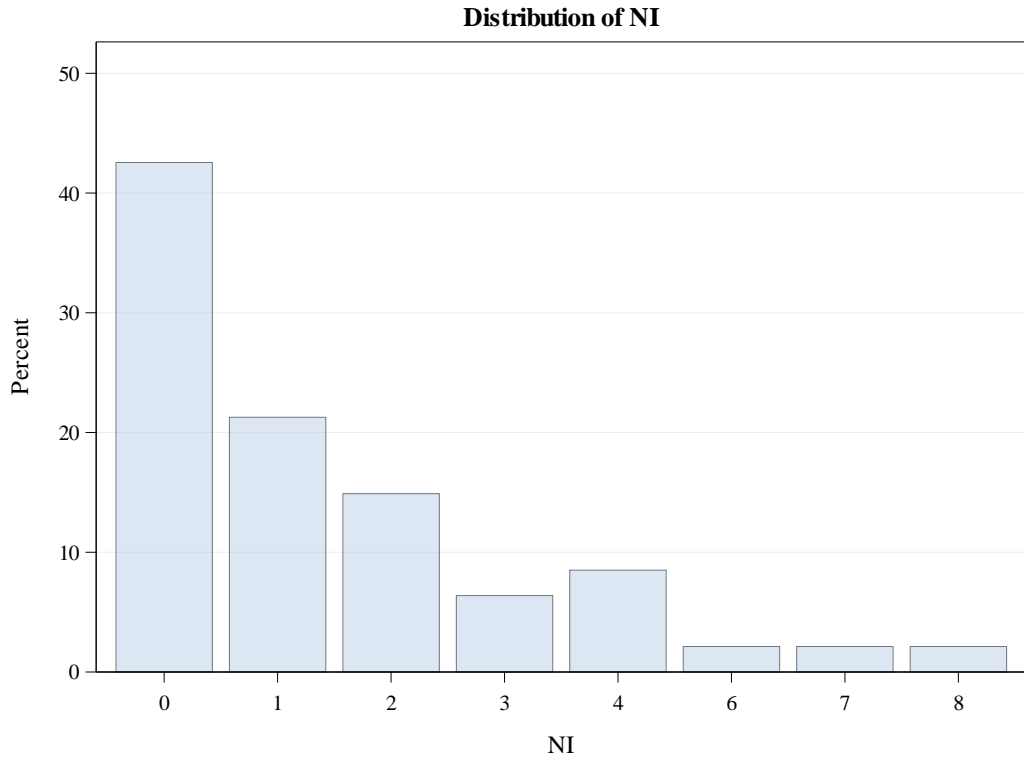


Figure 3. Frequency histogram for NI

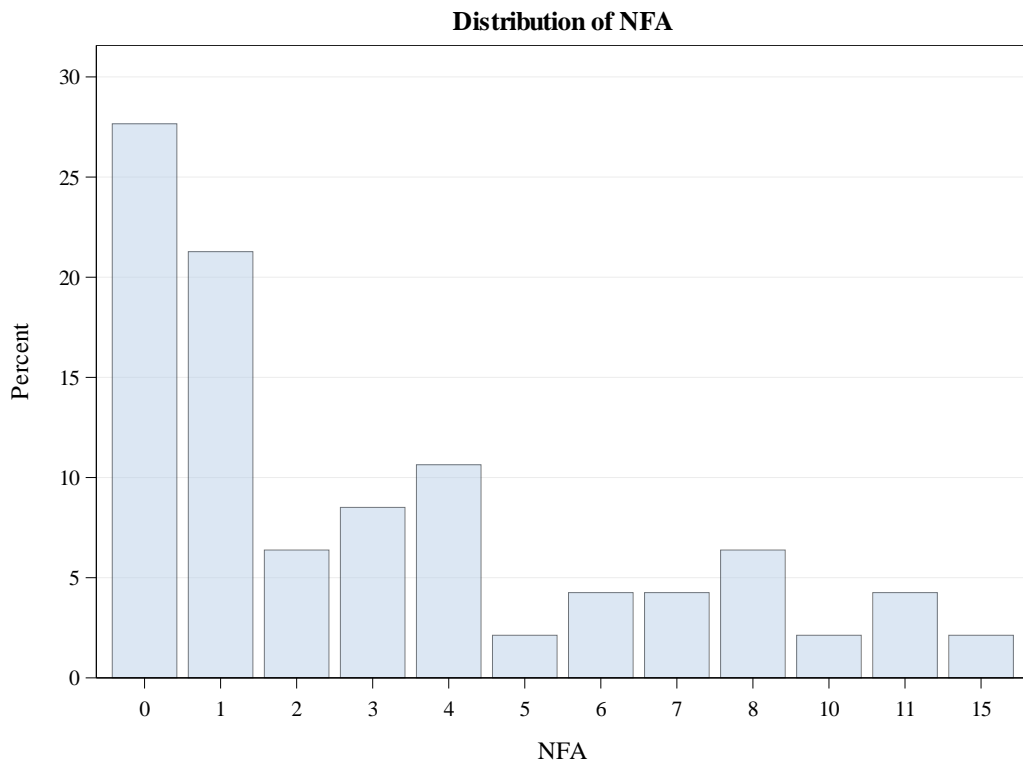


Figure 4. Frequency histogram for NFA

4.2 Impact of Leading Indicators on Number of Medical Injuries

Model 1 tested for a negative association between NI and TT, for which the results are given in Table 7 which suggests that TT was not significantly associated with zero medical injuries per project. Hence, this model implies that a unit increase in TT is associated with a decrease in NI by a rate of 0.032, but this reduction is not significantly different from zero.

Table 7

Model 1 Parameter Estimates From Zero-Model Regressing NI on TT with Offset PL

Parameter	DF	Estimate	Standard Error	Wald 95%		Pr > ChiSq
				Confidence Limits		
Intercept	1	0.312	0.939	-1.527	2.152	0.739
TT	1	-0.032	0.018	-0.068	0.003	0.076

Similarly, Model 2 tested for a negative association between NI and SI, for which results are shown in Table 8 which suggests that SI was not significantly associated with zero medical injuries per project. As a result, this model implies that a unit increase in SI is associated with a decrease in NI by a rate of 0.028, but again, this reduction is not significantly different from zero.

Table 8

Model 2 Parameter Estimates From Zero-Model Regressing NI on SI with Offset PL

Parameter	DF	Estimate	Standard Error	Wald 95%		Pr > ChiSq
				Confidence Limits		
Intercept	1	0.151	1.238	-2.274	2.577	0.903
SI	1	-0.028	0.020	-0.067	0.011	0.157

In order to test model goodness of fit, the predicated counts under the zero-inflated Poisson model were compared to the observed counts. The chi square for goodness of fit was not significant for Model 1 ($p > 0.999$) and Model 2 ($p > 0.999$) suggesting that the lack of significant results in the zero-inflated Poisson was not due to model fit. Thus, this analysis suggests that

increasing the leading indicators, did not affect the number of zeros in the lagging indicators. It is possible that a significance cutoff of $p < 0.05$ may have been too conservative since this study had a small sample size of just 47. A significance cut off of $p < 0.1$ would have led to Model 1 being significant, however, the estimated effect size of model 1 of -0.032 is so small, that the reduction in NI is very little. An additional model was run with SI and TT jointly but is not considered one of the main models of these results as it did not give any additional significant results above Model 1 and 2 (see Appendix A).

4.3 Impact of Leading Indicators on Number of First Aid Injuries

Next, Model 3 and 4 as described in section 3.3.2 were run to determine the association of leading indicators (TT and SI) and NFA. Model 3 tested for a negative association between NFA and TT, for results are shown in Table 9.

Table 9
Model 3 Parameter Estimates From Zero-Model Regressing NFA on TT with Offset PL

Parameter	DF	Estimate	Standard Error	Wald 95% Confidence Limits		Pr > ChiSq
Intercept	1	1.104	1.003	-0.861	3.070	0.271
TT	1	-0.081	0.037	-0.153	-0.009	0.028

Model 3 shows that TT is significantly associated with NFA zero counts, however the effect is very small; specifically, a unit increase in toolbox talks is associated with log-odds of NFA reducing by a multiplicative factor of 0.081 (CI = -0.153, -0.009; $p=0.028$). In other words, a unit increase in TT is associated with the odds of NFA going down by a multiplicative factor of 0.992 (CI = 0.858, 0.991; $p=0.028$). Similarly, Model 4 tested for a negative association between NFA and SI, for which the results are given in Table 10.

Table 10

Model 4 Parameter Estimates From Zero-Model Regressing NFA on SI with Offset PL

Parameter	DF	Estimate	Standard Error	Wald 95%		Pr > ChiSq
				Confidence Limits		
Intercept	1	1.650	1.049	-0.406	3.706	0.116
SI	1	-0.076	0.029	-0.132	-0.019	0.009

Model 4 shows that SI is significantly associated with NFA zero counts, however this effect is very small. A unit increase in SI is associated with log-odds of NFA reducing by a multiplicative factor of 0.076 (CI = -0.132, -0.019; p=0.009). In other words, a unit increase in SI is associated with the odds of NFA going down by a multiplicative factor of 0.927 (CI=0.876, 0.981; p=0.009). The goodness of fit test was not significant for Model 3 (p>0.999) and Model 4 (p>0.999) suggesting good model fit. Despite the significance of these models, they suggest that increasing leading indicators leads to very little change in the lagging indicators. An additional model was run with SI and TT jointly but did not give any additional significant results above Model 3 and 4 (see Appendix A).

The significance of Model 3 and 4 and insignificance of Model 1 and 2, may be due to the increase of occurrence in NFA compared to NI. The larger numbers of NFA led to increased power in the models which made it easier for the models to be statistically significant. In other words, there may be a relationship between NI and SI or TT, but a larger sample is required to see these results as NI occurred very infrequently. The frequency differences between NI and NFA can be seen in Figure 3 and 4.

4.4 Resulting Implications of Model Development

This research included multiple Zero-Inflated Poisson models to test the associations of leading indicators and lagging indicators independently and jointly. The question remains, which model identifies the best leading indicator for use in accident prevention? NI (Model 1 and 2),

did not yield significant associations with TT and SI (independently). Thus, suggesting that TT and SI, when run independently, did not increase the odds of a project having zero first aid injuries. In contrast, NFA (Models 3 and 4) showed significant associations with TT and SI independently.

When evaluating Model 3 and 4 to determine which model is best, both have very similar effects. With Model 3, TT is associated with NFA by a multiplicative factor of 0.922, while Model 4 and SI, and has a multiplicative factor of 0.927. The difference of 0.005 is very small and does not clearly identify that one model is better than the other. As a result, the decision for the best model goes beyond statistical associations and into the preventative measures themselves.

Despite that both TT and SI meet statistically reduce NFA, site inspections would be the more practical preventative measure when it comes down to labour costs. Site inspections take 1 or 2 people approximately an hour and occur about 1 time per week. Assuming the average pay of \$35 per hour per person, this would cost the company \$70 per week or approximately \$280 per month. For \$280 per month the company can reap the benefits of the increased number of zero first aid injuries. In comparison, toolbox talks require the attendance of all members on site. Toolbox Talks take 30 minutes, require all people on site to attend, and also occur on a weekly basis. If eight people (\$35 per hour) were on site, the toolbox talk would cost approximately $\$35/2 \times 8 = \140 per week, or \$560 per month. Additionally, when completing a site inspection, the six additional people would be necessary for the toolbox talk can continue working, increasing productivity. Since toolbox talks did not show any additional safety advantage, the contractor might as well go with the more economical option.

It is worth noting, that labour costs are not the only item that can be used to determine which model is better. Another individual could take the exact issue, that less people are required

for site inspections as a basis of argument in favour of toolbox talks. It could be argued that toolbox talks ensure that all individuals are involved in safety on site, rather than just the superintendent and safety representative. While this is true, a site with a good working safety climate and safety system does not need toolbox talks for everyone to get involved. Workers should already be thoroughly trained in safety, and safety should regularly be a topic of conversation during work processes and meetings. Furthermore, preventative measures, such as guardrail installations or hazard identification, would be completed by many different people over the course of a project. As a result, whether or not the toolbox talks occur, all workers on site would be involved in safety.

Despite, the recommendation towards site inspections, either would work. The best leading indicator is the one that the company can commit to, so the decision should be based on the individual needs of the company.

Chapter 5: Discussion

The goal of this research was to examine the relationship between leading and lagging indicators while using company administrative data. This study can lead to two conclusions. First, that finding quality research data can be very difficult when using company administrative data, and second, that with the data available, there seemed to be very little or no relationship between leading and lagging indicators. These two conclusions will be further examined in the discussion below.

5.1 Limitations of Administrative Data

As explained in the introduction (Chapter 1), there is much administrative data available to researchers of construction. Yet, although there is much available, there is still the question as to whether the data available is of good enough quality to be used in research. For example, this study identified eight possible safety indicators, see section 3.2.1. Out of these indicators, only four were considered to be of high enough quality to be used in this study based on the criteria selected. This small number of quality indicators alone emphasizes the fact that not all administrative data is of research quality. Despite having used the best quality indicators available, it is important to question whether there were errors in the data collected that led to the null findings. The following section identifies issues related to data quality. First section 5.1.1 shows that data quality is an issue across many studies, largely due to the fact that there is no standard way of assessing data quality. Second section 5.1.2 identifies potential quality errors in the dataset used for this study.

5.1.1 Data Quality Assessment

Ultimately, in order to assess data for quality, there needs to be an understanding of what good quality data is. Over the past number of years, many researchers have been working to develop an understanding, yet there has been very little consistency. Part of the inconsistency is

because data is unique to its associated research question and purpose. As a result, data quality assessment tools are often based on a specific set of data, rather than providing assessment tools that can be used in many research fields. Currently, there is no specific research tool for safety. However, to develop a tool for safety data, researchers should examine the tools available in similar fields. Three of these available tools are:

1. Canadian Institute for Health Information. The CIHI Data Quality Framework
2. World Health Organization. The Immunization Data Quality Self-assessment (DQS) Tool;
3. MEASURE Evaluation. PRISM: Performance of Routine Information System Management Tool

All of these tools vary in their purpose and their components. First, the CIHI Data Quality Framework was developed by the Canadian Institute for Health Information in order to foster data quality in the Canadian health research system. The tool consists of five major measures. The major measures are accuracy, timeliness, comparability, usability and relevance. These measures are evaluated using a questionnaire that provides a quantitative tally at the end. The participant is asked to rate the performance of their data based on 61 criteria (Canadian Institute for Health Information, 2009). As this survey is done internally, it is more prone to bias.

Additionally, due to the broad nature of the survey, not all questions will be as relevant to all research. Second, the World Health Organization's Immunization Data Quality Self-Assessment Tool was developed to ensure that the data used to manage child immunizations was of quality to create a reliable reporting system. The tool has four major measures: completeness of reporting, report availability, timeliness of reporting, and a verification factor. This self-assessment is completed by a combination of Ministry of Health workers and an external auditor from the

World Health Organization. The data is evaluated quantitatively (World Health Organization, 2003). This tool is an example that was developed for a very specific purpose, to ensure the quality of WHO immunization data. The final tool developed by MEASURE evaluation Inc. is the PRISM: Performance of Routine Information System Management Tool. This tool was developed for organizations in health to ensure that their data is of quality in order to be best used for internal management decisions and research. This tool uses four major attributes: relevance, completeness, timeliness, accuracy and is completed internally by using a questionnaire (Measure Evaluation, 2011). As the assessment is completed internally it is prone to bias. Still, this tool provides an example of a quality assessment that is relevant not just to researchers but also to business management. As shown by the examples by Chen, Yu, et al (2014), as well as the differences between the three examples of quality assessment tools, different data quality tools vary. Despite these inconsistencies, there are some major attributes that are prevalent among these data quality tools (see Table 11).

Table 11
Example Attributes of Data Quality. Adapted from Chen, Hailey, Wang & Yu, 2014

Item	Attribute
High Quality Data	Completeness, accuracy, timeliness, validity, reliability, data security, comparability, internal consistency, repeatability, transparency, collection method
Poor Quality Data	Missing data, underreporting, errors, illegible data, inappropriate fields

As shown in Table 11, there are many different common attributes that can be used to assess the quality of data. Additionally, there are many other attributes used to assess quality of data not included in this table such as reporting procedures and expectations. Ultimately, these attributes

need to be determined based on the purpose of the study and the data itself. As shown by the CIHI, some data quality assessment tools have been developed for generic use, yet, due to the generic nature, some attributes are not as relevant to safety as others. Safety research would benefit from the development of a data quality assessment tool that can be relevant to the data quality measures needed both for researchers and management. Then researchers could confidently evaluate, use, and improve safety administrative data sets that are easily available due to the reporting nature of legislations. Similarly, management can make well informed decisions using the information the company has already compiled.

5.1.2 Potential Quality Errors in the Dataset

Beyond data quality, data needs to be evaluated for its appropriateness and its ability to form conclusions within the study itself. For instance, this study is limited by its use of counts rather than scales for data. For example, toolbox talks were only counted, not evaluated for attendance, effectiveness, or relevance. A conclusion more related to the expectation of leading and lagging indicators, may have been found if the study examined the relationship between toolbox talk number and quality, and the effect on injury rates. This study found no or very little relationship between the leading and lagging indicators measured in this study. However, if this study measured the indicators differently, it may have led to different results.

Second, this study may have been influenced by the self-reporting nature of construction safety. Legislation requires that companies self-document their safety procedures and outcomes. Construction safety reports at MB are completed by either the superintendent or site safety representative. In some cases, another worker or manager may complete documentation, but a knowledgeable person, such as a safety representative or superintendent, is available for help. With the self-reporting nature of safety reporting, it is possible that some of the differences in

safety performance on sites were caused by the varying reporting styles of individuals. In order to minimize this effect in future research, regular check-ins should be completed with the reporting individuals to ensure that the reporting is equal across the projects. For example, all the individuals could complete a site inspection together, to test the differences in site inspection results in hopes to increase consistency between the reporters. Another method would be to change study design from retrospective to prospective. The retrospective nature of this study meant the researcher was unable to be involved in reporting. A prospective study can allow the researcher to develop consistent reporting procedures that allow for better quality data.

These limitations are important to note because the conclusion of this research – the relationship between leading and lagging indicators being insignificant or of very small effect size – may be incorrect compared to the widely held assumption. This assumption is that high levels of leading (preventative) indicators should lead to low levels in lagging (accident) indicators.

5.2 The not so Leading and Lagging Indicators

Despite that section 5.1 detailed the how limitations of the administrative data could lead to error in this study. This section details, what, besides error, could cause the leading indicators to show very little effect on accident prevention. This section provides a review of previous research on leading and lagging indicators at the project level then outlines two theories. Theory 1 (explained in section 5.2.2) suggests that not all accidents are preventable. Theory 2 (explained in section 5.2.3) is about Geoffrey Rose' Theory of Prevention and the impact of the research population on results.

5.2.1 Review of Leading and Lagging Safety Indicators on Project Level Studies

This study found that there was no relationship between Number of medical Injuries and either Safety Talks or Site Inspections. There was a significant relationship between Number of

First Aid Injuries and both Safety Talks and Site Inspections, but the relationships were very small in size. As explained earlier, the nature of leading and lagging indicators suggests that as leading indicators increase, lagging indicators decrease. This means that this study should have found significant relationships, with negative estimates, for all four analysis models. Yet, as shown in the earlier literature review (see Chapter 2), the lack of expected outcome is not uncommon among leading and lagging indicator studies at a project level.

Lingard et al (2017) researched leading indicators and found that leading and lagging indicators did not match the predicted behaviors of what would be expected based on their definition. In fact, they found that leading indicators did not necessarily lead, and that, at times, lagging indicators took on a leading role. For example, when safety talk frequency increased in the studied project this change led to a short term decrease in total recordable injury rates. In the long term, the decrease in total recordable injury rates led to a decrease in safety talk frequency. These authors determined that the relationship between leading and lagging indicators was much more complex than suggested by the terminology and that the use of leading and lagging terminology does not accurately depict the complexity of these indicators (Lingard et al., 2017). The issue with the nature of leading indicators is also mentioned by Lingard et al (2011), where they indicate that the relationship between leading indicators is unknown and very underdeveloped.

A second study, by Rajendran (2013) found similar complexity in the results. Specifically, 12 correlations were analyzed, but only 4 of the 12 tested correlations between leading and lagging indicators led to significant results. Again, if the definitions of leading and lagging indicators are true, all twelve of the correlations tested in this study should have led to high variance explained, a negative t value, and significant predictive ability of the leading

indicator on the lagging indicator. Both the two studies explained above, this research study, and additional research indicated in the scoping review demonstrate a trend in the research that leading indicators are either not working as designed, or not appropriately defined and measured at a project level.

5.2.2 Are All Accidents Preventable

The idea of leading and lagging indicators relies on the concept that accidents are preventable. To date, very little research has been done to determine if all accidents are preventable (vanBeeck, 2001), but it is regularly debated by safety professionals (Davidson, 2015; van Beeck, 2001, Wilson, 2005). What is unanimously agreed by safety professionals is that most accidents are preventable. Yet, are there some accidents, that despite preventative measures, will occur anyway? Those that believe that all accidents cannot be prevented use many arguments. One of the most common is that there is randomness to the world that cannot be predicted. Prevention relies on the idea, that the accidents are predicted in advance, and then prevented accordingly. This argument argues that there are some phenomena in the world that are too random to be predicted (Davidson, 2015). A second common argument is that you cannot completely control for human error. This revolves around the idea that prevention measures often require people to perform to a certain measure. Still, prevention cannot account for all human error, such as a quick lapse of judgment (Wilson, 2005). One final argument is that our preventative measures do not always prevent injury. A good example is fall protection. If a worker is caught by a fall protection harness during a fall, they may still be injured (ELCOSH, 2003). Therefore, despite the correct use of a preventative measure, an injury may still happen.

Although whether or not all accidents are preventable is not largely researched in safety, it is a part of safety theory, in particular accident prevention. In 1931, W.H. Heinrich developed one of the original theories of accident prevention, the domino theory. The domino theory

suggests that there is a five-step accident sequence that leads to accidents. This sequence is social environment, worker fault, unsafe act with a mechanical or physical hazard, accident, and damage or injury. The idea of this sequence is that if you remove one of the steps of the sequence, or domino, the accident will not occur (Raouf, 2011). This theory is now used in research as a framework to view accident causation (Chi & Han, 2013). Under the domino theory Heinrich proposes that 88% of all accidents are due to unsafe acts of people, 10% due to unsafe acts not from people, and 2% due to 'acts of god.' This theory identifies the term 'acts of god' which refers to accidents that are of pure chance and no intervention could prevent them. Even though Heinrichs theory is still commonly used, it is having often been critiqued for simplifying human behaviour. This critique led to the creation of new theories, such as the management-based theories.

Management-based theories argue that the cause of accidents are due to management, not the workers, as Heinrich proposed. In order to create management theories, many researchers adapted the domino model to include management. In 1974, Bird and Loftus updated the model sequence to the following: lack of management control, basic causes (origins), immediate causes (symptoms), incident (contact), and people-property loss. By the time of Bird and Loftus, the 2% due to 'acts of god' was already being removed as a part of safety research. This removal was not due to the fact that the 'acts of god' did not occur, but rather because they are not preventable (Hosseinian, & Torghabeh, 2012). Research instead focused on accidents that were preventable. As a result, even more recent models focused on tracking root causes of accidents, human error, and developing safety prevention measures, not 'acts of god'. Furthermore, research is focused on increasing the understanding of management and worker responsibility for safety. Over time, the idea of 'acts of god' has become rarely mentioned in safety, yet, it is still relevant today.

The sample used in this study, MB, has an excellent safety record, as proven by the IHSA COR certification (see section 1.1.2 for more information). Therefore, one can assume that most accidents are being prevented through the many measures used on their sites. What is still being debated where there is a baseline of unpreventable accidents. If so, are the few accidents that are being recorded by MB ‘acts of god’, and therefore, immune to preventative measures?

It is safe to say that this concept is complex and in desperate need of further research. Still, it does emphasize the fact that research into safety is very complicated, and there are many reasons why the outcome of this study may have occurred.

5.2.3 Geoffrey Rose Theory of Prevention

With multiple studies suggesting that leading and lagging indicators are not leading to the expected relationships, I suggest that these results can be explained using Geoffrey Rose’s theory of prevention. In 1985, Geoffrey Rose, authored an article “Sick individuals and sick population.” This article outlined his theory that research on a population level does not adequately provide insight into the individual level (Rose, 2001). Individuals and populations are fundamentally different, and thus, need to both be studied as conclusions made on one level, may not be correct on the other (Doyle, Furey, Flowers, 2006). This theory emphasizes the issues related to a study’s chosen population, and the context of the study (Zieliński, 2014). In construction terms, this theory suggests that large industry level (population level) construction safety studies may not be correctly identifying relationships on a company level (individual level).

When it comes to leading and lagging indicators there are two explanations when considering the Theory of Prevention. First, preventative measures that work on a population level (industry), may not work on an individual level (company). Leading and lagging indicators have largely been studied on a large population (industry) level. Yet, per the Theory of

Prevention, it is possible that leading indicators are not preventative on an individual (company) level. While this may seem like a technicality, it is of great importance due to the safety promotions strategies currently being used in construction. Construction companies are often instructed by government, researchers and suppliers that by increasing their safety prevention, they will decrease their negative safety outcomes. Safety promotion is based on large population level (industry) outcomes. As a result, those who take part in safety promotion may fail to understand the effect of safety prevention on a company (individual) level. Therefore, companies may be receiving information that is not relevant for them. This inconsistency may lead to confusion of company management when they do not experience the outcomes they expect in their own company and decrease the industries trust in safety research and legislation.

The second explanation for the results of this study, as per the Theory of Prevention, may be that a way for measuring the prevention may not be yet developed on an individual level. This study used metrics that were created for an industry level to test for the prevention in one company. The lack of results may be because the methods developed at a population level (industry), are not appropriate for identifying prevention on an individual level (company). As a result, it is possible that methods regarding leading and lagging indicators need to be developed for studying the prevention effect on an individual level. Furthermore, population level studies allow for data sets with a lot of variability. For example, a study of the construction industry will include companies with very bad safety outcomes and very good safety outcomes. MB has very good safety performance, with very little variability between projects. It is possible that the population level methods are not appropriate for individual level studies that have less variability.

When examining the results of this study under the lens of the Theory of Prevention, it is possible that either the preventative effect is not there, or that the study methods could not identify it. Either way, this section highlights the importance of further research to investigate these two possible theories to best understand what prevention looks like on a company level. In order for research and legislation to have a lasting, positive effect on companies, it needs to be explainable when using company data. This leads the safety promotion strategies to be less abstract, and more relevant to decision makers.

5.3 Recommendations for MB and Further Research

This study was the first time that MB had provided data for research. Previously MB had used other sources of data for use in project management and accounting such as cost flow analysis, yet very little had been done using the safety information available. With the completion of this study it provides a chance to reevaluate the use of safety data for research and within their own occupational health and safety management system. Overall, MB should continue using their safety data to evaluate trends within their company, but in order for the data to become more useful, both for research and company decision making, reporting procedures should be put in place to improve data quality.

As mentioned in Chapter 1, construction companies have large amounts of administrative data available. This administrative data is created as the company works to meet the legislative requirements as laid out in the OSHA (1990) and Construction Projects (1991). Due to these government legislations, companies will document many safety measures including site inspections, injuries, training completion, training programs, as well as human resources measures such as number of employees. When evaluating MB's documentation from a legislative lens, MB clearly meets the requirements. All measures are clearly documented and

organized in order to ensure that the company meets ‘due diligence’. In short, the documentation serves its intended purpose. Yet, this study asked the question, what if the documentation can be used for more? Can this documentation be used to inform management and promote research instead of just providing a legal paper trail? Ideally, if MB will continue to use their safety documentation to further research or to inform management, steps must be taken to improve the data. As a result of this study, this section discusses the following changes to improve their safety reporting measures: collecting a safety climate indicator, conducting bi-annual meetings with safety reporting personnel, improving documentation of subcontractor safety performance, and reorganizing MB’s administrative data.

In order to improve the usability of MB’s safety indicators, MB should consider collecting a safety climate or safety attitudes indicator. As shown in the literature review at section 2.2.1, safety climate or safety attitudes was the second most popular indicator found through the literature review. Safety climate is an individual’s perceptions of safety at the workplace. A large subset of safety climate is based on workers’ perceptions of management’s commitment to safety (Griffin & Neal, 2000). The idea is that companies with high perceived safety climate have better safety outcomes. Within the context of this study, if MB had safety climate data available from each individual, this data could then be used with the labour schedules to develop a safety climate value for each construction project. With safety climate measures for each project, safety climate could be included either as a covariate in model analysis, or as a leading indicator (hypothesis variable) in analysis. Unfortunately, in order to combine labour schedules and safety climate reporting, it requires an individual, or individuals to know which workers provided which safety climate scores. This leaves the workers without complete confidentiality of their scores. Alternatively, MB can use safety climate scores for the

whole company, with each worker remaining anonymous. This allows for MB's safety practitioners to use safety climate to determine weaknesses in the company's climate and leadership in order to allow for better informed prevention in the future without compromising the confidentiality of the workers. Since MB has over 200 employees, each individual's safety climate score would be lost in the masses. This alternative provides increased confidentiality, but will not work to determine individual project scores, but rather the company's score as a whole. Currently, many types of surveys are available that could be used by MB to determine safety climate. The CPWR, or Centre for Construction and Research Training, reviewed many different safety climate tools available for construction companies (CPWR, 2014). After evaluation, they developed their own tool, the SCAT, or Safety Climate and Assessment Tool (CPWR, 2017). This tool is created for management to strengthen their safety performance by developing an understanding of the strengths and weaknesses of their safety climate. It consists of 8 sections as shown below:

1. Demonstrating management commitment
2. Aligning and integrating safety as a value
3. Ensuring accountability at all levels
4. Improving supervisory leadership
5. Empowering and involving employees
6. Improving Communication
7. Training at all levels
8. Encouraging owner/client involvement

These eight sections are also available in Microsoft Word form so that the company can customize the survey based on the needs. This is necessary for MB, as MB would have to adjust

some of the questions to match Canadian legislation rather than the American which is standard for the SCAT. While this survey is comprehensive and thoroughly researched, at 12 pages long it is very long to have all workers complete on a regular basis, for example annually (CPWR, 2017). The CPWR recommends having this survey completed by some people at the company, not necessarily all. Yet, if a company wants to track safety climate across projects, it is better if all complete it. Since, all workers would need to complete it, it would be best if the CPWR developed a shorter version of the SCAT in order to decrease the time and labour burden on the company. Alternatively, MB could collect this using a small sample, but this sample could only be used for overall company safety climate, not project safety climate. With collection of a safety climate measure MB will be able to inform management decision making, include a safety indicator that is relevant in current research, and account for a potential covariate in data analysis.

The second recommendation for MB is for safety practitioners to schedule peer reviews with individuals who complete safety reporting in order to increase reporting consistency across projects. These peer reviews would involve different reporting personnel who evaluate the same project and compare the results in order to determine inconsistencies between their reporting. When evaluating indicators for inclusion into this project in section 3.2.1, two indicators were not included due to a lack of consistent reporting: near misses and subcontractor notice of offense. Additionally, one included indicator, number of first aid injuries, likely also suffers from underreporting as workers may prefer not to report very minor first aid incidents that can be easily treated. If MB reporting personnel completed peer reviews, more consistent reporting of these indicators could be developed, leading to more frequent use. Furthermore, increased consistency across safety indicators such as site inspections, allows the indicators to not be used

not only as counts but as scaled. These scaled could be used by MB to better gauge the prevention needs of a project. Finally, adding peer reviews also helps MB meet one of the requirements of the OSHA, ongoing safety training (1990).

The third recommendation for MB would be to improve documentation of subcontractor safety performance. As explained in section 1.1.1, a general contractor is involved in project management and scheduling. MB employs site superintendents, carpenters and labourers. Besides MB's employees, subcontractors complete specialty contracts, such as mechanical fit out, painting or glass installation. At any time the number of people on site that are employees of the general contractor will likely be the minority of the total number of people on site. General contractors are fully responsible for the safety of their employees but share responsibility of subcontractor safety with the subcontractors' management (Construction Project, 1991). General contractors have overarching responsibility of the subcontractors when the subcontractors are on the general contractor's site. Thus, an important way to control safety performance onsite is to stay informed of the safety performance of the subcontractors. MB currently does keep some track of subcontractor safety performance including ongoing discussions and subcontractor notice of offenses. Yet, this could be improved. Rather than discussing poor performance of the subcontractors or issuing offenses, it would be worth providing a safety grade or evaluation of all subcontractors. Through these evaluations, individuals involved in hiring of subcontractors can more easily hire based on the subcontractor's safety performance. Additionally, site superintendents and project managers can read past reports and be aware of potential safety needs from past projects. This evaluation of subcontractors could also help MB with further research as it provides another indicator that can be used in analysis.

The final recommendation for MB is related to its reporting procedures. As a result of the many legislative and technology changes, tracking safety performance over time is difficult. Many of the reports have different sections over time and are stored in different mediums. In order for a safety practitioner and MB decision makers to make the most of the administrative data they have, a better system needs to be available to measure trends over time. Better access can make administrative data not just a legislative paper trail but valued information to promote safety and decision making in the company.

This section discussed the following changes to improve MB's safety reporting measures: collecting a safety climate indicator, conducting peer reviews with safety reporting personnel, improving documentation of subcontractor safety performance, and re-organizing MB's administrative data. While all the suggestions will help research and safety performance, it is worth noting that they can be time consuming and expensive. As MB is already meeting their legislative requirements and COR certification, they do not have any additional requirement to take part in these actions. Thus, these suggestions may not be feasible when taking into account other aspects of construction such as labour needs and project scheduling. The construction industry is very complex with every decision effecting the outcome of many different companies, departments and projects. Still, it should be noted, that these recommendations are based on data collected up to 2016. MB has made many improvements to their safety system in the last two years that may change the effectiveness of their documentation in the future.

5.4 Re-evaluation of Hypothesis

This thesis began by asking whether construction projects with higher values for leading indicators experience fewer adverse events and lower values of lagging indicators because of the projects' preventative measures. The assumption was that if the relationship between leading and

lagging indicators could be seen in this case study, it would support current research and safety promotion. Yet, if the relationship between leading and lagging indicators could not be seen through company data, the results would be counterintuitive to the preventative measures promoted by researchers, safety professionals, and legislators. This study found that the relationship between leading and lagging indicators when studied through one company's data was either not there or a minimal prevention effect. While the results of one company's data cannot disprove past research, this research does show the difficulties of investigating safety prevention from a company perspective.

One major struggle for safety professionals has been to get companies to take part in safety prevention. Companies will often say that they do not have time, it costs too much, it will not work, or they are not interested. This study shows that part of the difficulty of safety promotion, may lie in the fact that companies cannot see the positive effect of injury prevention in their workplace. This may be because the metrics that we use to evaluate safety prevention are not effectively showing the strengths of safety prevention when measured within a company. If companies could easily see the benefits of their safety prevention based on their administrative data, it would be much easier to promote safety prevention. Future research should work to improve the indicators that form the basis of safety promotion, so that safety can become more relevant to the companies that the promotion is designed for.

Chapter 6: Conclusion

The goal of this study was to determine if the relationship between leading and lagging safety indicators that is seen on an industry level, could also be seen on a company level. This study found that there was either no found relationship, or relationships with very small effect sizes. Throughout the discussions many future implications for research were identified, including a need for a comprehensive data assessment tool for administrative data, discussion among researchers as to whether all injuries are preventable, and implementation of the Geoffrey Rose Theory of Prevention into safety research. Potential improvements to MB's safety system were discussed, yet the difficulties of introducing these safety measures were also mentioned. In summary, despite that leading and lagging indicators rest on a simple assumption, a negative association, it is not simple to successfully incorporate them into company data. Thus, much research is needed for safety indicators to best serve companies, legislators and researchers.

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Appendix A: Joint SI and TT Zero-Inflated Poisson Models

Two models were run on NI and NFA, with SI and TT¹– jointly included in the model.

As the models did not lead to significant results, they were not included in the results section but are available below. Table 12 shows a model where a negative association between NI and SI and TT jointly was tested. Table 12 suggests that SI and TT are not significantly associated with NI when run jointly in the model. This model implies that a unit increase in SI is associated (not significantly) with a decrease in NI by a rate of 0.005 and NI is further decreased by a unit increase in TT by a rate of 0.028. Both SI and TT estimated effect size decreased when they were run jointly compared too independently (see Table 7 and 8). This change suggests SI and TT are competing with each other, rather than being complementary to each other.

Table 12

Parameter Estimates From Zero-Model Regressing NI on SI and TT with Offset PL

Parameter	DF	Estimate	Standard Error	Wald 95% Confidence Limits		Pr > ChiSq
Intercept	1	0.364	1.038	-1.670	2.398	0.726
SI	1	-0.005	0.042	-0.088	0.078	0.910
TT	1	-0.028	0.043	-0.111	0.056	0.512

Similarly, Table 13 suggests that SI and TT are not significantly associated with NFA when tested jointly. This model implies that a unit increase in SI is associated (not significantly) with a decrease in NFA by a rate of 0.123 and NFA is increased by a rate of 0.048 by TT. When run independently, both SI and TT had significant and negative effects on NFA, but when run jointly, they lost their significance, and TT went in the opposite direction. These results further suggest that when run jointly, TT and SI are competing with each other, rather than

¹ For acronym definitions see Table 4 on page 29

complementing each other. These results seem to suggest that SI and TT are not effective in a safety program together but this implication is unlikely.

Table 13
Parameter Estimates From Zero-Model Regressing NFA on SI and TT with Offset PL

Parameter	DF	Estimate	Standard Error	Wald 95% Confidence Limits		Pr > ChiSq
Intercept	1	1.790	1.103	-0.371	3.952	0.105
SI	1	-0.123	0.055	-0.230	-0.016	0.025
TT	1	0.048	0.043	-0.035	0.132	0.259

Typically, the more safety programs that a company takes part in, the better their prevention. These results do not support that concept, yet they may be due to error. Two potential causes of this error are sample size, or measurement techniques. First, having a low sample size leads to a lack of statistical power. The sample size of this study was just 47 projects. Second, these results could be due to measuring technique. This study used counts as the measurement technique, but the counts do not measure the quality of the site inspection or toolbox talks. It is possible that if quality was accounted for, these results would not have happened. Despite the potential errors, this research does raise the question as to whether adding more safety programs leads to better safety results or can lead to a loss of impact of other programs.