Relationships between Leading and Trailing Indicators at Construction Sites in Yanbu Industrial City, Saudi Arabia

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Relationships between Leading and Trailing Indicators at Construction Sites in Yanbu Industrial City, Saudi Arabia

by

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A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy
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Keywords: construction safety management, total quality management, Royal Commission, key performance indicators

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Abstract

**Statement of Purpose:** This study sought to assess the relationship between leading and lagging indicators in construction safety management in the Kingdom of Saudi Arabia. In particular, it sought to determine whether construction sites with higher leading indicators predicted fewer incidents/accidents.

**Rationale for Study:** Construction safety management is a critical occupational health concern globally. Scholars have researched approaches to improve safety measures and performance in construction sites. However, there is little discourse assessing the relationship between the leading indicators and the occurrence of incidents and accidents in construction sites.

**General Methods:** A quantitative analysis was used in this study. Data was collected from 33 Royal Commission construction site projects.

**Results:** Findings from statistical analysis show that an increase in self-inspection was associated with an increase in stop work orders. The beneficial effects of leading indicators on lagging indicators were found for self-inspection and incidences plus near misses, for training and stop work orders, and for disciplinary actions and the rate of incidents.

**Conclusion:** The presence of some leading indicators predicted fewer lagging indicators, particularly incidents and near misses. An increase in self-inspection was associated with an increase in stop-work orders. This relationship was a potential reaction to stop work
orders. Therefore, these findings demonstrate that some leading indicators can predict the occurrence of lagging indicators, a phenomenon that can be used by the Royal Commission and other stakeholders in the construction industry to improve the overall safety performance in the sector.
Chapter One: Background

1.1 Introduction

The importance of safety performance in the construction industry cannot be understated. Discourse on how safety can and should be handled in construction sites continues to grow intensely in the wake of increasing implementation challenges, pressures for rapid development, and more globally dynamic construction industry projects and increasingly diverse teams. In the midst of all ongoing research and discourse, there is a need for deeper understanding of the connection between leading indicators and incidences/accidents in construction sites to help inform safety related policy for the construction industry.

Yanbu comes second after Jeddah in terms of size for the Saudi Arabian cities located along the Red Sea. It is found on the Red Sea coastline in Madinah Province, about 350 km north of Jeddah (Al-sinayah, 2014). Yanbu was established over 2500 years ago by Egyptian traders who used it as a link between them and their market. Yanbu’s population was below 7,000 by the turn of the 20th century. However, due to the gradual industrialization, large oil refineries, desalination plant, and the petrochemical industry, its population has grown (Mortada, 2016). By 1992, the city had a population of 119,819, and to 188,430 in 2004 (“Yanbu Al-Bahr · Population,” n.d.). According to the Saudi national census, the city had the most substantial annual population growth between 2010 and 2014; the increase was estimated to be approximately 9.7% per year. The last recorded population for Yanbu was 337,700 in 2014. Assuming the population
growth rate would be the same as in the period between 2010 and 2014, the city is estimated to have a population of 536,517 in 2019 (“Yanbu Al-Bahr · Population,” n.d.). Yanbu is located on the western coast of Saudi Arabia, as shown in Figure 1.

To build a modern city, a Royal Decree was made to create a Royal Commission to manage the construction of a new city known as the Yanbu Al-Sina’iya. The Yanbu Al-Sina’iya, also known as Yanbu Industrial City, was established in 1975 when the government designated a small settlement to be among the industrial cities in the coastal area of Saudi Arabia along the Red Sea (Al-sinayiah, 2014). Yanbu Al-Sina’iya is in the most southern part of Yanbu City, and it is divided into two sections. A residential area in the north and an industrial area to the south. Since its beginning, the industrial area of
Yanbu Al-Sina’iya has experienced tremendous growth. The main industries in this region are petrochemical installations and oil refineries, which contribute significantly to the country’s Gross Domestic Product (GDP) (Mortada, 2016). The industries have created massive employment opportunities, which have led to an increased population Yanbu City with a residential area located near the Royal Commission Headquarters. By 2014, the region had a population of 96,000 people.

The Industrial City is well connected to other cities in Saudi Arabia through a network of modern highways. Due to these connections, the city’s growth is projected to grow at approximately 6% per year (Mortada, 2016). Since the establishment of Yanbu Industrial City over 40 years ago, the Royal Commission has focused on constructing the much-needed housing units for the growing population. The Royal Commission has engaged private real estate developers in helping with the construction of housing units, which has created many job opportunities for Saudi nationals as well as foreigners (Mortada, 2016).

1.2 2030 Vision of Saudi Arabia and National Transformation Programs

Saudi Vision 2030 is a plan that was introduced in the country to reduce the high level of oil dependence by the country’s economy. Crown Prince Mohammad bin Salman launched Saudi Vision 2030 on 25th April 2016. Three primary pillars form the foundation of this vision: the status of the country as the leader of the Arab and Islamic worlds, its power to invest, and the country's strategic location which will play a significant role in international trade (“National Transformation Program | Saudi Vision 2030,” n.d.).

The vision aims to achieve three main objectives. One, creating a vibrant society by focusing more on its people as well as strengthening the Islamic faith through a series
of commitments. The second theme of the Saudi Vision 2030 is to develop a thriving economy. To achieve this, the government has focused on diversifying its economy from the oil trade through improving the country's infrastructure, the public service sector, health, tourism, among others. These new ventures are expected to empower its citizens through the creation of dynamic job opportunities. Lastly, the 2030 vision aims to make Saudi Arabia a progressive leading country in the region and globally. This is achievable by focusing on transparency and accountability of the government, as well as ensuring the governing policies are effective ("National Transformation Program | Saudi Vision 2030," n.d.).

The government of Saudi Arabia developed the National Transformation Program (NTP) as part of the Saudi Vision 2030. NTP is an economic action plan that aims at achieving the country's goal of diversifying its financial income from the conventional oil industry ("National Transformation Program | Saudi Vision 2030," n.d.). The NTP aids the government in achieving the Vision 2030 plans by fast-tracking the start of major infrastructure projects and engaging stakeholders in identifying challenges, co-creating solutions, and contributing to the implementation of the program’s initiative ("National Transformation Program | Saudi Vision 2030," n.d.). The primary objectives of the NTP include; transforming healthcare, improving living standards and the safety of the citizens, ensuring free and sustainable access of essential resources such as water, enhancing the development of nonprofit sector and aiding the growth of the private sector for an increased contribution to the country's GDP, and growing the tourism sector ("National Transformation Program | Saudi Vision 2030," n.d.).
1.3 Construction & Safety Environment at Royal Commission, Yanbu

The Royal Commission (RC) Safety Group at Yanbu assists contractors and project managers of each construction site to ensure that safety requirements are in place and the construction activities are done safely and in accordance with the safety requirements of Saudi Labor Law & applicable safety standards and procedures.

The RC is responsible for a total of 159 construction contracts valued at $2900M. About 62 of the contracts are on NTP, which are related to the initiatives under the Saudi Vision 2030 and are valued at approximately $770M. These projects include substations, infrastructures & utilities, schools & colleges, facilities & services and housings, which form the basis for this research, as showing in Figure 2.

Figure 2. Illustration of NTP Project Types
1.4 Purpose of This Study
The purpose of the study is to conduct and investigate of the existing leading indicators versus global best practices based on existing data for a select set of NTP construction sites in RC-Yanbu on workplace injuries. Based on this analysis new guidelines that will lead to better utilization of leading indicators and reduced unwanted event thus decreasing lagging indicators at RC-Yanbu.

1.4.1 Safety Performance Indicators
Leading indicators refer to measurable activities that can be monitored and result in the identification and removal of risks at a construction site (Hinze, Thurman, & Wehle, 2013). Leading indicators have been described as measures used to control actions on sites to mitigate accidents (Wehle & Issa, 2016). Leading indicators can also be defined as events, measures, or conditions preceding an event that have predictive value regarding unsafe conditions (“Why the Construction Industry Needs to Adopt Leading Indicators -- Occupational Health & Safety,” n.d.). Leading indicators may show how effective the safety process is. The safety process is linked to actions taken to prevent accidents (“Why the Construction Industry Needs to Adopt Leading Indicators -- Occupational Health & Safety,” n.d.). Theoretically, regulating the leading indicators has an impact on lagging indicators, which measure the incidents at a construction site by recording the accident statistics.

Prior research categorizes leading indicators as those factors that change before economies show any indications of change. In essence, these indicators provide signs of either an upturn or a downturn in other lagging indicators that may be regarded as significant (Hinze et al., 2013). Some of the leading indicators that can be tracked in a
construction site include training, risk assessments and audits, safety meetings, occupational hazard and near-miss reporting, and perception surveys, as well as the availability of funding to support safety management.

1.4.2 Leading Safety Indicators in the Construction Industry

Leading Indicators (LIs) are necessary in construction site safety management globally because, unlike the lagging indicators, they can scrutinize the safety measures and engage actions to help prevent accidents from occurring in the future (Hinze et al., 2013). They offer an insight into the weaknesses and strengths of the safety program for any given organization. Hence, it is easy to determine when additional safety measures are needed. Moreover, LIs play a critical role in a project's continuous improvement cycle. The primary benefit of using LIs in construction sites is they offer a faster and more effective way to control risks and prevent accidents (Wehle & Issa, 2016).

LIs are considered to be effective if they have a strong conceptual and scientific basis that clearly reflect the cause of an accident at a site. Another element that is required for LIs to be considered effective is their ability to provide early indications of safety hazards before an accident occurs. Lastly, safety indicators should not only be cost-effective during the data collection process; but they should also be compatible with practical safety management best practices. In summary, the LIs should be analytically sound, have predictability, be cost-effective, and be practical (Guo & Yiu, 2016).

Safety management in a construction project conducted using LIs involves several steps. The first step is planning. This includes assessing the risk and planning of how risk will be reduced. Second, the plan is implemented, ensuring the threat has been mitigated. The third step in the continuous improvement cycle is checking. The results obtained after
carrying out the plan are checked and analyzed. Lastly, any changes that need to be made in the plan are implemented, and the cycle is repeated from Step 1 ("Why the Construction Industry Needs to Adopt Leading Indicators -- Occupational Health & Safety," n.d.).

1.5 Research Question
This study assessed if there was a relationship between the level of leading safety indicators used at a site and the number of incidents and accidents that occur on that site? To answer this question, safety statistics from the ongoing Royal Commission (RC) construction sites were used. The data from 33 construction projects were used to determine if leading indicators in the RC construction sites can help to predict fewer accidents, incidents or medical illnesses. The data was also analyzed to show if there were any significant gaps in the leading indicators used and the number of accidents reported.

1.6 Research Objectives
Several objectives were formulated to help accomplish the primary goal of this study. The objectives are listed below:

- Reviewing available research works on leading and lagging indicators in the construction industry to gather data on how these indicators are used to avert accidents on work sites.
- Identify additional predictive leading indicators that can be used to assess safety hazards and to support the reduction in accidents, as well as suggesting how these indicators can be used in the RC sites to reduce accidents.
• Highlight and analyze the methodologies used and challenges encountered when using leading safety indicators.

• Defining, evaluating, and offering recommendations on how the Royal Commission construction department at Yanbu can better use leading indicators to minimize the number of accidents and incidents that occur on the construction sites.

1.7 Literature Review Topics and Knowledge Gaps
Chapter 2 covers a review of literature from journals and other publications to assess the landscape of knowledge on the general safety in construction sites, and the leading safety indicators used to predict and prevent accidents. The history of safety in construction sites and the measures that have been used to prevent accidents are reviewed. Lagging and leading indicators are reviewed from other domains where applicable.

1.8 Knowledge Gaps
The construction industry has used lagging safety indicators for safety measurements historically. These indicators have a long history of use in the construction industry compared to the leading safety indicators. Hence, they have become widely accepted standards in safety measurement. Moreover, the leading safety indicators are more complex to use compared to the traditionally used safety measurement methods. This has led to the leading indicators being used in fewer projects. Therefore, there has been minimal data on the success of using leading indicators in the construction industry and how using leading indicators affects the prediction of incidents. Consequently, a knowledge gap exists on how well companies have accepted the use of leading indicators as a means of safety measures.
1.9 Study Limitations

The research conducted in this project was based on existing data on workplace injuries from a de-identified data set from the Royal Commission and a gap analysis on the given data. The cultural variation between international contractors and the Royal Commission creates reporting challenges as well as performance management issues on project oversight. Hence, it could not be concluded that the use of leading safety indicators could cause a reduction of accidents and injuries in construction places. Therefore, the existing data collected from the sites on workplace safety may be incomplete, but it was due to an inherent limitation of current reporting procedures - a priority issue to be addressed beyond the scope of this study.

From the international contractor’s perspective, accidents/injuries slow the progress of a project in the RC construction sites. Hence, the contractors and the people in charge would rather not address the cause of the accident (Al-Kharashi & Skitmore, 2009). From the perspective of the Royal Commission of Yanbu, adoption of leading indicators would generate evidence of quality metrics requiring the contractors to use the money for training, assessments, audits, safety meetings, hazard, near-miss reporting, and perception surveys. In light of international cultural variation and business practices there is variation in the adoption of these activities (Azmat & Saad, 2018). This international dynamic reduced the number of sites that were willing to participate in the study. Last, some international contractors reluctance to adopt policies to track and report leading indicators reduced the overall inclusivity of construction contractors included in the study (Al-Kharashi & Skitmore, 2009).
1.10 Theoretical Framework

The theoretical framework is a structure used to provide a blueprint of the central issue being studied (Osanloo & Grant, 2016). Besides defining the approaches used in the study, it also outlines and explains the concepts of the study in a conceptual model. This framework puts the expected outcome after the research into context. Moreover, data collection and analysis are based on the theoretical framework of the study. Figure 3 shows the theoretical framework with the concepts used in this study.

![Figure 3. Framework Model](image)

The framework depicts that the Royal Commission activities are the backbone of this study. It then indicates that the international contractors are the major undertakers of the
projects placed under the Royal Commission. The model also shows the indicators that will be used to predict the incidents occurring at the worksites as one of the original goals for this study was to identify new indicators that the Royal Commission of Yanbu should consider. The indicators are classified into two categories: external conditions and unsafe behaviors condition. Lastly, the model denotes the expected outcomes when an accident occurs on the site. Since the leading safety indicator is a cycle, the model shows that after an incident, the results should be reported to the Royal Commission and the contractors so that they can strategize on how to achieve fewer incidents on the construction sites.

1.11 Deming’s Total Quality Management Theory
In light of the challenges in this industry, a quality management approach needs to be considered for its application in the discussion and concluding chapters of this study. Total Quality Management (TQM) is defined as a management approach applied by an organization whose primary focus is on the quality of products produced by the business (Best & Neuhauser, 2005). W. Edwards Deming introduced Deming’s Total Quality Management Theory in 1951 after World War II to help the Japanese government rebuild its economy. Deming’s TQM theory mainly focuses on quality improvement in employer-employee relations, product or service, and consumer-business relations (Best & Neuhauser, 2005). Moreover, TQM ensures that the customers are satisfied by the quality of goods and services that a company gives them.

Deming’s TQM theory was guided by the Shewart Cycle and the system of profound knowledge. The Shewart Cycle consists of four elements; Plan- Do- Study- Act (PDSA) (Pietrzak & Paliszkiewicz, n.d.). These four stages are described below and illustrated in Figure 4. (Plan to study, 2023).
- **Plan:** This is the first phase of the cycle, and it involves identifying improvement opportunities in a product. Tests and changes that aim at improving the product are planned at this stage. The problem causes are identified and analyzed using consistent data so that possible solutions can be identified.

- **Do:** The action plan strategized in Phase 1 is implemented in this stage. During this process, any unexpected event, newly acquired knowledge, as well as lessons learned are documented.

- **Study:** Once the plan has been implemented in Step 2, the results obtained are analyzed in this step. The before and after results are compared to determine if the objectives were met and to see if there were any improvements to the quality of the product.

- **Act:** This is the last step of the cycle. It involves making a decision on whether the plan should be adopted or changed. If the objectives are met, and the product shows improvement, the plan is standardized and adopted. If the results did not meet the expectations, the cycle is repeated from Step 1. However, if there were not any notable improvements, the plan is abandoned.
After analysis of the data described in Chapter 3, the PDSA model and its potential in construction sites under the RC was considered.

1.12 Remainder of the Study
The remaining parts of the study were the methods used, analyzing the findings (Chapter 4. Discussion), and (Chapter 5. Conclusion and Recommendations). The methodology section includes data collection for incidents, accidents, and injuries that have been recorded in the RC construction sites for a specific period. The safety statistics for consecutive 24 months of five selected sites were compared to the statistical data for the other five NTP projects. Lastly, a physical audit was conducted using an audit checklist.

The results gathered from the above steps were analyzed and used to conclude if the application of the leading safety indicators was successful in the RC construction sites.
Recommendations to improve the use of leading indicators and or add new indicators in these sites will then be drawn from the analyzed data and discussed in Chapter 5.
Chapter Two: Literature Review

2.1 Introduction

Literature on the issues of safety in the construction industry and safety management issues is extensive. In light of variation in culture, international organizational management and laws, there was a need to consider the implications of findings in the literature with application to this study both from a Middle Eastern and global perspective. A synthesis of literature around the question “do construction sites with higher leading indicators predict fewer incident or accidents?” is the focus of this chapter. Since the goal was to answer the study question after a synthesis of current research, the primary literature sources were peer-reviewed journal articles. The data collected from different studies was used to analyze if the level of indicators used to predict incidents have any effect on the outcome.

Different literature from various authors was also reviewed to show how traditional safety measurement methods have been used to achieve safety in the construction industry. Moreover, the challenges facing the use of leading indicators, methodologies used, and the appropriateness of using these indicators was reviewed as well. Lastly, a review of other industries that use leading indicators and how they have been applied to effectively reduce accidents in these industries was included.
2.2 Literature Review Research Methodology

The methodology first involved developing a list of safety indicators from peer-reviewed sources, to help identify specific administrative data that suits the construction research.

Table 1. List of Search Criteria to Support Literature Review

<table>
<thead>
<tr>
<th>Search Criteria</th>
<th>Google Scholar Number of Hits</th>
<th>USF Online Library Number of hits</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Construction safety performance</td>
<td>627,000 results</td>
<td>5,796 results</td>
</tr>
<tr>
<td>2. Leading and lagging indicators</td>
<td>103,000 results</td>
<td>16,733 results</td>
</tr>
<tr>
<td>3. Occupational health and safety</td>
<td>3,080,000 results</td>
<td>905,903 results</td>
</tr>
<tr>
<td>4. Leading indicators that predict lagging indicators</td>
<td>788,000 results</td>
<td>18,537 results</td>
</tr>
<tr>
<td>5. Safety practices in construction</td>
<td>2,890,000 results</td>
<td>8,117 results</td>
</tr>
</tbody>
</table>

The search term and criteria used in the databases can be seen in Table 1. The next procedure involved completing a review, which generated a comprehensive list of the leading and lagging safety indicators.

Conducting the literature review was instrumental in determining the relationship between the leading and lagging indicators. The information obtained guided the identification of the indicators relevant to the study. The remaining articles were reviewed after considering some factors. The criteria followed in selecting the articles included:

1) whether they address safety indicators,

2) whether they related to construction or other industry, and

3) whether they report on the relationship between the leading and lagging indicators.
After review, there were 79 articles of most relevance. The last review involved selecting the articles addressing indicators that were effectively used in the construction industry from another relevant industry. This screening led to 20 articles remaining for the study. A summary of the article selection process can be seen in Figure 5. Then data was extracted and noted using Excel. With the aid of the review, the study classified the safety indicators and their relationship as either leading or lagging. As a result, 24 leading and 14 lagging indicators were identified.

Figure 5. PRISMA Diagram
Since all authors did not employ the same name for identical indicators, the similar ones were grouped together for the convenience of this study. The decision enabled the determination of the most common leading and lagging indicators. Regardless of the reason that 24 leading and 14 lagging indicators were identified, they were further grouped together into ten leading indicators and five lagging indicators. Such amalgamation of leading and lagging indicators was based on the similarities between the definition and implications of several leading and lagging indicators. Based on the findings of the literature review, the most popular indicators that were categorized as leading were site inspection and safety audit, tool-box talk and safety training, notice of offenses and disciplinary action, management committee, employee awareness/participation, work history/record keeping, safety professional, recognition/incentive, risk management, good routine housekeeping, safety climate, and safety management system (Akroush, 2017; Background and Previous Work on SIF Prevention, n.d.; “Practical guide to leading indicators: Metrics, case studies, and strategies. (n.d.). Campbell Institute,” n.d.; “Reduce incidents with universal metrics for leading indicators | 2018-02-01 | ISHN,” n.d.; Bellamy & Sol, 2012; Bergman, Payne, Taylor, & Beus, 2014; Givehchi, Hemmativaghef, & Hoveidi, 2017; Grabowski, Ayyalasomayajula, Merrick, & McCafferty, 2007; Hinze et al., 2013; Jablonowski, 2012; Kongsvik, Kjøs Johnsen, & Sklet, 2011; Liang, Zhang, & Su, 2018; Lingard, Wakefield, & Cashin, 2011; Manjourides & Dennerlein, 2019; Marahatta, Gautam, Paudel, & Yadav, 2018; Mills, Turner, & Pettinger, n.d.; Ng, Laurlund, Howell, & Lancos, 2010; Payne, Bergman, Rodríguez, Beus, & Henning, 2010; Rajendran, 2013; Sheehan, Donohue,
Moreover, the most common lagging indicators selected included first aid injury, recordable injury, near miss, environmental impact incidents and property damage, and poor climate, and occupational hazard (Akroush, 2017; Background and Previous Work on SIF Prevention, n.d.; “Practical guide to leading indicators: Metrics, case studies, and strategies. (n.d.). Campbell Institute,” n.d.; “Reduce incidents with universal metrics for leading indicators | 2018-02-01 | ISHN,” n.d.; Bellamy & Sol, 2012; Bergman et al., 2014; Grabowski et al., 2007; Hinze et al., 2013; Kongsvik et al., 2011; Liang et al., 2018; Lingard et al., 2011; Manjourides & Dennerlein, 2019; Marahatta et al., 2018; Mills et al., n.d.; Ng et al., 2010; Payne et al., 2010; Rajendran, 2013; Sheehan et al., 2016; Sparer et al., 2015; Versteeg et al., 2019; Wachter & Yorio, 2014).

2.3 Literature Matrix Analysis
A matrix was devised for the identification of different leading and lagging indicators by previous researchers. Based on the uniqueness and direction of each study, only some of the leading and lagging variables were identified and included in this review. For this reason, the matrix was designed to identify the repetition of different leading and lagging variables in the 20 research articles included in this literature review. The repetition of the ten leading and five lagging indicators in the literature supported their credibility and authenticity. The inclusion criteria were not only limited to the inclusion of the leading or lagging indicator in the study but also referred to the interpretation and validation of the leading or lagging indicator by the authors of the study.
It was further observed that the selected articles did not identify the leading and lagging indicators based on primary data but extracted them from previous studies. Such a repetition of leading and lagging indicators further enhances their significance for their importance to occupational health and safety in multiple industries. The industries that were used to identify the leading and lagging indicators included but were not limited to construction, oil and gas, manufacturing, automobile, chemical, machinery, and safety management services. The relationship of the leading and lagging indicators was further categorized into three sections.

### 2.4. Results of Comprehensive Literature Review

Ten leading and five lagging indicators were identified as being employed in previous studies based on review of the literature. The indicators are defined in Tables 2 and 3 below. Each table also identifies the primary literature source associated with each definition.

#### 2.4.1 Summary of Leading Indicators.

In review of the selected articles, the leading indicators were discussed more throughout the literature than the lagging indicators, but all mattered in this review. The outcome of this review established that occupational health and safety is majorly dependent on leading indicators such as risk management as compared to prevention inspection and other indicators. Table 2 provides a definition of each of the leading indicators, as mentioned in the selected literature.
<table>
<thead>
<tr>
<th>Leading Indicators</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Site Inspection and Safety Audit</td>
<td>“Site inspections, and their similar counterpart, site audits, are tests that measure the number of hazards on a site” (Versteeg et al., 2019).</td>
</tr>
<tr>
<td>2 Toolbox talk and Safety Training</td>
<td>“Training is often considered an aspect of safety climate. 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” (Versteeg et al., 2019).</td>
</tr>
<tr>
<td>3 Notice of Offenses and Disciplinary Action</td>
<td>Notice of offenses and disciplinary action refers to the frequency of the unnecessary injuries that have been caused at the workplace due to avoidance of health and safety regulations (Manjourides &amp; Dennerlein, 2019; Ng et al., 2010).</td>
</tr>
<tr>
<td>4 Management Committee, Employee Awareness / Participation</td>
<td>This particular leading indicator is in line with the creation of workplace awareness, development of a management committee for management of health and safety at the workplace and encouraging employees for participation in the committee and awareness campaigns (Liang et al., 2018; Wachter &amp; Yorio, 2014).</td>
</tr>
<tr>
<td>5 Work History / Record Keeping</td>
<td>It is the responsibility of the management to compile a work history by encouraging record keeping of all the fatalities, accidents, and incidents incurred at the workplace due to lack of precautions. For example, it is mentioned, “Each instance of non-compliance with OSHA regulations or the site-specific safety program observed on the Jobsite was recorded – including date, the firm of the individual in non-compliance, nature of the required correction, and implemented correctional measure” (Ng et al., 2010).</td>
</tr>
<tr>
<td>6 Safety Professional</td>
<td>The availability of safety professionals at the workplace is deemed necessary for the implementation of occupational health and safety guidelines (“White paper: Predictive Analytics in Workplace Safety: Four Safety Truths that Reduce Workplace Injuries,” n.d.).</td>
</tr>
<tr>
<td>7 Recognition / Incentive</td>
<td>The employees at the workplace should be recognized and offered incentives for strictly following occupational health and safety standards (Liang et al., 2018; Ng et al., 2010).</td>
</tr>
<tr>
<td>8 Risk Management</td>
<td>The purpose of risk management in line with occupational health and safety refers to the preparation of risk elimination, mitigation, and avoidance strategies, in order to minimize the losses during accidents and incidents (Liang et al., 2018; Pawlowska, 2015).</td>
</tr>
<tr>
<td>9 Good routine housekeeping and Safety Climate</td>
<td>“Housekeeping is an indicator of the physical hazards in the working environment. Housekeeping is a broad term regarding the cleanliness of a site. It includes aspects such as waste removal, and material and equipment storage” (Versteeg et al., 2019; “White paper: Predictive Analytics in Workplace Safety: Four Safety Truths that Reduce Workplace Injuries,” n.d.).</td>
</tr>
<tr>
<td>10 Safety Management System</td>
<td>All the leading and lagging indicators of workplace health and safety are part of the overall safety management system at the workplace (Liang et al., 2018).</td>
</tr>
</tbody>
</table>
The leading indicators were identified through an extensive review of select literature. Leading indicators were defined as, “proactive, preventive, and predictive measures that monitor and provide current information about the effective performance, activities, and processes of an EHS management system that drive and identification and elimination or control of risks in the workplace that can cause incidents and injuries” (Mills et al., n.d.). There are several other definitions and explanations of leading indicators with reference to health and safety. For instance, Ng et al. (2010) have defined leading indicators as “preventive or proactive measure that is taken in order to decrease the possibility of an incident” (p. 254). Another definition was stated as, “proactive or leading indicators provide early warnings and signs that pertain to the effectiveness of occupational health and safety management systems (OHSMSs), and can represent the future safety status of contractors” (Liang et al., 2018). Such evidence from the selected literature shows the importance of leading indicators for ensuring health and safety in the workplace, such as in the construction or manufacturing industry. In addition, some of the leading indicators and the intervening variables that have been mentioned in Table 2.

Site inspection: Many of these articles broadly studied the perception of workforces towards the safety of the working site. A literature review conducted by Bellamy (2012) on safety performance indicators supporting the control of major hazards established that site inspection was a critical concern to most workforces (Bellamy & Sol, 2012).

Safety Training/Education: Akroush (2017) utilized the Tennessee construction companies and workforces to study the leading safety indicators in the construction industry with the outcome revealing that the workforce attitude on safety training and
education was an important factor in adoption of leading safety indicators (Akroush, 2017). Jablonowski conducted similar studies in an old drilling company with the outcome revealing that the perception of workers that education and training was profound in identifying the need for and importance of leading safety indicators in onshore oil drilling (Jablonowski, 2012).

**Safety Audit:** These studies revealed that the safety audit indicators attracted positive attitudes and perceptions of workforces. Versteeg for instance, introduces the safety indicator, which provides companies with predictive indicators and a language. The indicator will be ideal in articulating the present business unit safety performance (Versteeg et al., 2019).

**Safety Culture Survey:** Many of these articles indicated the safety culture survey is an indicator that would generate safety and efficiency at work. Sheehan and colleagues, for instance, argue in their study that the safety culture survey would be instrumental in determining the leading and lagging indicators of occupational safety, which is the concern of most workforces (Sheehan et al., 2016).

**Pre-planned Task:** Pre-planning task indicators are ideal for ensuring work efficiency and minimizing hazardous situations at work. In their studies, Sparer and colleagues noted that qualitative documentation of the development and feasibility testing of an alternative to the traditional lagging-indicator–based safety incentive program can minimize risks and maximize safety to the delight of workforces (Sparer et al., 2015).

**Work History / Record Keeping.** It is the responsibility of management to compile a work history by encouraging record keeping of all the fatalities, accidents, and incidents incurred at the workplace due to lack of precautions. For example, it is mentioned, “Each instance of non-compliance with OSHA regulations or the site-specific safety program
observed on the Jobsite was recorded – including date, the firm of the individual in non-compliance, nature of the required correction, and implemented correctional measure” (Ng et al., 2010).

Risk Management. The purpose of risk management in reference to occupational health and safety refers to the preparation of risk elimination, mitigation, and avoidance strategies, in order to minimize the losses during accidents and incidents (Liang et al., 2018; Pawłowska, 2015).

Management Committee, Employee Awareness / Participation. This leading indicator is in line with the creation of workplace awareness, development of a management committee for oversight of health and safety at the workplace and encouraging employees to participate in committees and awareness campaigns (Liang et al., 2018; Wachter & Yorio, 2014).

Notice of Offenses and Disciplinary Action. Notice of offenses and disciplinary action refers to the frequency of unnecessary injuries that have been caused at the workplace due to avoidance of health and safety regulations (Manjourides & Dennerlein, 2019; Ng et al., 2010).
Table 3. Definition of Lagging Indicator Categories

<table>
<thead>
<tr>
<th>Lagging Indicators Category</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 First Aid Injury</td>
<td>“First aid injuries include any injury that can be treated with minimal first aid and require no further medical treatment” (Versteeg et al., 2019).</td>
</tr>
<tr>
<td>2 Recordable Injury</td>
<td>“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” (Versteeg et al., 2019).</td>
</tr>
<tr>
<td>3 Near Miss</td>
<td>“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” (Versteeg et al., 2019).</td>
</tr>
<tr>
<td>4 Environmental Impact Incidents and Property Damage</td>
<td>The environmental impact incidents and property damage determine the accidents and incidents caused by natural environmental factors (Lingard et al., 2011; Ng et al., 2010).</td>
</tr>
<tr>
<td>5 Poor Climate and Occupational Hazard</td>
<td>Poor climate and occupational hazard refer to a work environment whereby the chances of accidents and incidents are considerably enhanced (Background and Previous Work on SIF Prevention, n.d.; “White paper: Predictive Analytics in Workplace Safety: Four Safety Truths that Reduce Workplace Injuries,” n.d.).</td>
</tr>
</tbody>
</table>

The lagging indicators are readily available because they have been extensively researched. They were, however, less commonly used in the studies in this review.

**Worker Compensation**: Worker compensation is a decision by an organization to compensate the workforce in case they encounter injuries while at work. The studies in this review focused on how to use the leading and lagging indicators to determine the most prevalent contributors to worker compensation. Using lagging and leading indicators can be instrumental in the evaluation of occupational safety and health performance in the construction industry (Pawłowska, 2015). Payne argues that safety climate incidents adhering to leading and lagging indicators can promote safe working conditions and enhance worker compensation (Payne et al., 2010).
Recordable Injury: Recordable work-related injuries and illnesses are those resulting from medical treatment that is beyond first aid. The studies in this chapter emphasize the attitudes of the workforces towards recordable injuries in an organization. According to Bellamy and Sol (2012), most workforces uphold the work environment that embraces the safety performance indicators that support and reduce risk of hazards (Bellamy & Sol, 2012).

Environmental Impact Incidents and Property Damage. Environmental impact incidents and property damage determine the accidents and incidents caused by accidents and incidents that could not have been avoided by the leading indicators (Background and Previous Work on SIF Prevention, n.d.; “White paper: Predictive Analytics in Workplace Safety: Four Safety Truths that Reduce Workplace Injuries,” n.d.)

2.4.3 Interaction of Leading and Lagging Indicators

The review of the studies determined the close relationship between the leading and lagging indicators. According to Liang, Zhang, and Su, “The lagging indicators measure the outcomes of activities or events that have already occurred (e.g., the injuries or fatalities), while the leading indicators precede the accidents” (Liang et al., 2018). This means the leading indicators help in the prevention of accidents and incidents, whereas lagging indicators help in reducing the fatalities, injuries, and negative outcomes of the incidents and accidents that could not have been avoided by the leading indicators. In the literature review, the two indicators are discussed in some of the same articles. Another indication of the way leading and lagging indicators are related to each other refers to their mutual purpose, which is inclined towards promoting health and safety at the workplace. The first study conducted by Lingard et al. sought to determine the relationship
between the leading and lagging indicators (Lingard et al., 2011). The study indicated that they were closely related but served different purposes. The authors suggested that future studies should classify indicators as positive and negative, rather than employing the leading-lagging approach. Even though some differences exist, the positive aspects are numerous, and are therefore ideal to help maintain safety in construction company projects.

With the focus on the construction industry, the literature mentions that positive improvements exist. Arkoush (2017) states in his study that he presents “a database of all safety practices, strategies, and management techniques that experts believe would serve as dynamic predictors of future safety hazards” (123). Within the collection of fatal and damaging incidents the rate of these cases remained high. The analysis of lagging indicators supports the potential to improve safety management (Mills et al., n.d.). Nevertheless, it cannot totally solve all the existing issues and eliminate incidents in the future. Numerous researchers claim that lagging indicators may not provide enough insights “for taking corrective action to avoid future accidents” (Hinze et al., 2013). A safety management system serves to predict accidents and eliminate or avoid them. Meanwhile, worker engagement levels are directly correlated with accident rates. “When organizations invest in a safety a management system approach to preventing accidents […] they should be concerned about overtly winning over the minds and hearts of their workers through a system of workers’ engagement” (Wachter & Yorio, 2014).

Furthermore, an examination of past results and predicts future results, was applicable in the marine industry when conducting safety climate assessment. The scholars intended to “define the appropriate time period for studying incidents relative to
a safety climate assessment” (Bergman et al., 2014). To reach this target, they established leading indicators. They then identified gaps in the current environment to assist in improving the forthcoming performances (Grabowski et al., 2007). However, several industries faced a problem. No established ratio of leading indicators to lagging indicators to measure safety exists. It varied in accordance with indices set in the particular industry. Thus, companies have to define and implement the most appropriate indicators for their industry-leading indicator (“Reduce incidents with universal metrics for leading indicators | 2018-02-01 | ISHN,” n.d.). Operations-related leading indicators are used to assess the functioning of operations, machinery, and other items of infrastructure. System-based leading indicators refer to the management of the system, rolling up “from a facility level to a region/ business unit or cooperative level” (Mills et al., n.d.). Behavior-based leading indicators measure the actions of an individual or a group in the workplace. Eventually, the predictive analysis uses data from the inspection process and a robust safety checklist to differentiate between operations-based, system-based, and behavior-based leading indicators.

2.5 Critical Analysis

In their study, Liang, Zhang, & Su identified Toolbox talk & Safety Training, Management Commitment, Employee Awareness/ participation, Risk Management, and Safety Management System as the most effective leading indicators (Liang et al., 2018). According to the authors, construction companies should use these leading indicators at the prequalification stage of construction projects to choose contractors. Evidently, the authors preferred a more managerial approach to enhance construction safety instead of tactical methods. After testing these leading indicators, a significant effect on lagging
indicators was evident, particularly the poor climate and occupational hazard. With support from their findings, the authors suggested that the chances of accidents and incidents were considerably reduced if the four leading indicators are taken into consideration. Pawłowska proposed the adoption of both tactical and managerial leading indicators to improve safety levels at construction sites (Pawłowska, 2015). Site Inspection and Safety Audit, Toolbox talk and Safety Training, and Risk Assessment represent the tactical measures, while Management Commitment, Employee Awareness/participation, Risk Management, and Safety Management System provide managerial solutions. While not tested, the authors recommended Recordable Injury and Safety Performance to be most likely lagging indicators to be affected by the proposed measures. The proposed leading indicators overlap with regard to reducing the two lagging indicators, with fewer reports of injuries and better performance expected after the implementation of the proposed leading indicators.

In another study, Rajendran assessed both technical and managerial solutions that were used to improve the safety of workers at the construction site. This study sought to assess the chosen leading indicators under real project conditions and develop recommendations for their use by construction contractors. Site inspection and safety audit, management commitment, employee awareness/participation, and risk management were selected for assessment. After the evaluation, risk management and management commitment, employee awareness/participation were found to be effective in reducing first aid injury and recordable injury. Hence, as the authors explain, these two indicators can help construction firms formulate intervention techniques that can fix any weaknesses identified before an injury or incident occurs (Rajendran, 2013). However,
the study concluded that Site Inspection and Safety Audit do not have a significant impact on First Aid Injury, Recordable Injury, or near-miss cases.

After peer-review of work done by previous researchers, ten leading and five lagging indicators were derived by combining similar leading and lagging variables. The leading indicators comprise of tactical and strategic proactive measures that seek to enhance the safety levels on the work environment. These leading indicators provide the relevant authorities with the early warnings of danger and enable them to enforce measures to avoid incidents and accidents. Summary of the analysis of the 20 articles and the finding is in Table 4 below.

Table 4. Summary of the relationship between leading and lagging indicators

<table>
<thead>
<tr>
<th>Leading Indicators</th>
<th>Lagging Indicators</th>
<th>First Aid Injury</th>
<th>Recordable Injury</th>
<th>Near Miss</th>
<th>Environmental Impact incidents &amp; Property damage</th>
<th>Poor Climate &amp; Occupational Hazard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site Inspection &amp; Safety Audit</td>
<td>Site Inspection &amp;</td>
<td>1</td>
<td>5</td>
<td>1</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Safety Audit</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Toolbox talk &amp; Safety Training</td>
<td>Toolbox talk &amp;</td>
<td>1</td>
<td>2</td>
<td></td>
<td>5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Safety Training</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Notice of Offenses &amp; Disciplinary Action</td>
<td>Notice of Offenses &amp; Disciplinary Action</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Management Commitment, Employee Awareness/ participation</td>
<td>Management Commitment, Employee Awareness/ participation</td>
<td>1</td>
<td>7</td>
<td>1</td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td>Work History/ Record Keeping</td>
<td>Work History/ Record Keeping</td>
<td>1</td>
<td>1</td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Safety Professional</td>
<td>Safety Professional</td>
<td>3</td>
<td>1</td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Recognition / Incentive</td>
<td>Recognition / Incentive</td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Risk Management</td>
<td>Risk Management</td>
<td>2</td>
<td>8</td>
<td>3</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Good routine Housekeeping &amp; Safety Climate</td>
<td>Good routine Housekeeping &amp; Safety Climate</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>Safety Management System</td>
<td>Safety Management System</td>
<td>5</td>
<td>1</td>
<td></td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>
In conclusion, the analysis of sources on the safety management system shows the importance of its implementation in the functioning of the organization. It does not reduce the level of incidents and accidents in the workplace. It establishes the set of leading indicators to increase workers’ awareness and eliminate hazardous situations.

Failure to effectively utilizing leading indicators results in data that is used as lagging indicators. These include incidents and accident statistics, which assess the effectiveness of the safety program in place. However, the peer-review revealed that lagging indicators were much less commonly used, as compared to the leading indicators. Worker compensation, first aid and recordable injury, near misses, environmental impact incidents, and property damage, as well as poor climate and occupational hazard, are the most common lagging indicators. Indeed, the use of both lagging and leading indicators is valuable in the evaluation of occupational safety and health performance across different industries.
Chapter Three: Research Methodology

3.1 Method Overview
The research methodology chapter provides background, evidence, and structure to the research methods used in this study. It describes the hypotheses sought to answer, sampling method, data collection, and method of collection, post-data collection analysis, findings, and limitations of the research. Moreover, this chapter describes how the data provided was used to show that construction sites with higher leading indicators predict fewer incidents/accidents. To effectively answer the relationship between the leading indicators used in a construction site, and the number of incidents predicted, data from thirty-three Royal Commission construction site projects from the Saudi NTP were collected.

A quantitative data collection method was used. All data in the study were secondary data from the RC construction sites, from both the RCSG engineers and the contractors, was gathered and used in the analysis. The data for all the sites was collected over approximately two years, from early 2017 to mid-2019. Fifteen key performance indicators (KPI) were used as the indicators in the selected RC construction sites, which were used by both the RC engineers and the contractors.

3.2 Research Question, Design framework, and Hypotheses to Test

3.2.1 Research Question
Do construction sites with higher leading indicators predict fewer incidents/accidents? This research was conducted to determine if a construction site with
higher leading indicators predicts fewer incidents compared to sites with lower safety indicators.

3.2.2 Design Framework

Besides determining if there was a relationship between the number of indicators used in a site and the incidents predicted, this study also aimed at investigating other recommended indicators that the RC could adopt to reduce the accidents reported on their construction site. A research design framework (see Figure 6) was developed to answer the research question as well as meet the other objectives of this study. The research model used in this study was divided into four primary steps.

a) Data collection- the KPIs provided by the RCSG was used to collect monthly records from the RCSG site engineers and the contractors. The indicators had both leading and lagging indicators, which would help answer the research question.

b) Data analysis- once the data had been collected, it was analyzed using different methods, as indicated in the model framework shown in Figure 6.

c) Environmental application- after analyzing the data and determining how the KPIs given by the RC contributed to the promotion of safety in their construction sites, several suggestions were made on how the KPIs would be applied in other sites to improve safety.

d) Recommendations- recommendations on other indicators that the RC should include in their activities as well as the contractors were made since one of the primary objectives of this study was to find if the RCSG needed to include other indicators to improve safety performance on their construction sites.
3.2.3 Data Collection

The data used for this project were secondary data since it was not collected directly from the sites by the researcher. Secondary data is usually obtained from other sources, by researchers, to get information and data about their research topic (Nardi,
2003). The data used was provided by the RCSG. The data set was presented in two worksheets. One of the worksheets had the safety performance monthly statistics data submitted to the RCSG by the (33) contractors for each construction site. While the other worksheet had the activities, which the RCSG conducted on each construction site to monitor and enhance safety performance on these sites.

The contractors provided the data for each site, in the form given to them by the RCSG and submitted the forms at the end of every month back to the RCSG. The data required to be filled by the contractors included Lost Time Injuries, Lost Workdays, First Aid Minor Medical, Work Illness, Recordable work injuries, Stop Work Order (SWO) report, and all the leading indicators that were used as the KPI by the RCSG engineers. The leading indicators recorded by RCSG engineers included the safety RFI they attended, the number of inspections they conducted, the toolbox talks they gave, the number of SWO issued, and any other training and workshops they gave to the contractor's workers. This data was also recorded monthly and was submitted at the end of each month.

The KPI monthly statistics data submitted by the contractors were then audited randomly by the RCSG engineers who are assigned to the different sites to verify the accuracy of data and determine the overall contractor safety performance. The overall contractor's safety performance and the percentage contractor compliance to RC safety were then discussed internally in the RCSG to determine if the indicators recorded by the safety engineers and the contractors helped in reducing the violation, incidents reported, and improving the contractor safety performance. A monthly meeting was scheduled between the contractors and the RC management to discuss the recorded data and
contractor safety performance. The issued SWO was also analyzed and discussed in these meetings to identify high-risk activities and reported immediate danger to life or health (IDLH) that needed contractor management attention. Other issues addressed in these meetings included identifying risk on each site based on planned activities on all sites. The RCSG made recommendations on topics and activities that needed to be addressed during the training sessions conducted by RCSG as well as recommend internal training sessions by the contractor for contractor employee, based on the recorded repetitive violation or risk base audit assessment. Besides, these meetings also enhanced the contractor toolbox talk before commencing any construction activity on the site.

3.2.4 Hypotheses to Test

The hypothesis generated for this study tested the relationship between the activities shown in the conceptual model and the research question. The derived hypotheses are listed below:

H1: Leading indicators are associated with the rate of incidents (I)

H2: Leading indicators are associated with the rate of incidents plus near misses (I+M)

H3: Leading indicators are associated with rate of stop work orders (SWO)

3.2.5 Data Definitions

The first data set gives the leading indicators used by the RCSG engineers on their respective sites to reduce the number of incidents recorded in the sites.
- Safety Request for Inspection (RFI) attended by RCSG Engineer - this column indicates the number of times the RCSG engineer attended safety RFI as per the contractor’s request.

- Number of RCSG Engineer's Inspections – this data shows the number of times the RCSG engineer conducted a safety inspection on the construction site without the contractors requesting for it.

- Toolbox Talks (Conducted by RCSG Engineer) - a toolbox talk is a safety meeting that is conducted to focus on the safety topics related to any (Parmenter, n.d.). This column shows the number of times the RCSG engineers conducted toolbox talks based on contractor request or based on the repetitive violation or SWO issued for that site and the training performed by RCSG for the contractor employees on that site.

- Other Training/Workshops by RCSG - shows the data for training workshops given to contractor employees by the RCSG engineers.

The RCSG data record also had one lagging indicator, the Stop-Work Order (SWO), that was also included in the datasheet provided in this study.

- Number of Stop Work Notices issued by RCSG - SWO report showed the number of times SWO was issued due to an existing immediate danger to life or health (IDLH) or when safety violations were reported on a site.

The second data set contained the contractors’ monthly report on both leading and lagging indicators. The leading indicators are explained below:

- Safety Request for Inspection (RFI) – this column indicates the number of RFI that the contractors requested.
- Self-inspections – this column indicated the number of safety inspections that the contractors conducted on-site by themselves.

- Job Hazard Analysis (JHA), and Activity Hazard Analysis (AHA) - a job hazard analysis is used to identify hazards related to any job task before they occur. JHA mainly focuses on the relationship between the worker, the task, the tool, and the surrounding work environment (Tremblay & Badri, 2018). AHA, on the other hand, deals with identifying any hazards related to the activity that the worker undertakes (Tremblay & Badri, 2018). The column with Both JHA and AHA indicates the number of times this analysis was conducted by the contractor.

- Toolbox Talks– these were records of the number of times the contractor conducted safety talks for their workers.

- Safety Orientation Conducted on Sites – Safety orientation is conducted on sites to enlighten the workers on how they should keep themselves safe during work. For example, by wearing protective gear all the time, operating machines when sober, etc. (Kao, Spitzmueller, Cigularov, & Wu, 2016). This column indicates the number of times the contractor conducted safety orientation.

- Safety Training and Workshops – the data entered in this column showed how often the contractor conducted safety workshops and training in a month.

- Disciplinary Action (DA) – DA reports indicate any reports of Internal Safety Violations (ISV) taken on a worker that deliberately deviated from the safety regulations provided by the employer. In this column, the data for any safety violation recorded within the month was entered.
The other indicators in the 33 NTP projects safety KPI file were lagging indicators. They are explained below:

- Near Miss Incidents- a near-miss incident is an unplanned event that had the potential to cause harm but did not result in injury, damage, illness, or loss (Salas & Hallowell, 2016). The data for any near-miss incident was recorded in this column.

- Lost Time Injuries (LTI) - LTI is any work-related injury that results in a contractor’s or company's employee not being able to return to work for the next scheduled shift (Shea, De Cieri, Donohue, Cooper, & Sheehan, 2016). The data in this column indicated the number of times LTI was recorded on the construction site.

- Lost Workdays (LWDs) - is the count of the total number of workdays that a worker is not on-site due to work-related injury or illness (Shea et al., 2016). The contractors entered the number of times the LWD incident was reported.

- First Aid Offered Due to Minor Injuries on Site – this includes the number of times that workers received First aid due to minor injuries and incidents on site. The contractors filled the number of times they had to offer first on-site in this column.

- Work Illness Recorded During the Construction Period- these are records of illnesses that the workers suffered due to unsafe exposure during work hours, such as prolonged exposure to dust (Sheehan et al., 2016).

- Recordable Work Injuries- these are injuries that needed more attention besides first aid. They are categorized as injuries recorded in a workplace that resulted in the workers being away from their workstation for a given schedule or a day or more days (Salas & Hallowell, 2016).
• Number of Accidents and Incidents Recorded During the Construction Period – this column indicated the number of accidents and incidents that were recorded in the construction site during the month.

• Stop Work Orders (SWO) – the data entered in this column indicated the number of times the contractors had to shut down a construction site due to IDHL or near miss.

The measures taken by the RCSG and Contractors were categorized as independent variables. They can be referred to as the leading indicators used in the construction sites. These were activities that the RCSG and Contractors undertook to reduce the number of accidents/incidents reported on any of the projects. These variables include Safety RFI attended by the construction workers, Number of inspections conducted by RCSG Engineer, Job Hazard Analysis (JHA), and Activity Hazard Analysis (AHA), Toolbox talks conducted by RCSG engineer per site – these were records of the talks conducted by the RCSG Engineer on how to handle toolboxes in the field, Safety orientation conducted on sites, Safety training and workshops attended by the workers and Risk Base Audit (RBA).

The dependent variables used were the lagging indicators in the RC construction sites. These are classified as lagging indicators since they were recorded as outcomes of what transpired during the construction works, with respect to safety. They include: Lost time injuries (LTI), Lost workdays as a result of injuries, First aid offered due to minor injuries on-site, Work illness recorded during the construction period, Recordable work injuries, Number of accidents and incidents recorded during the construction period, Near
miss, and Number of stop-work notices issued. Effect modifiers are the classification of projects and Man Hours for individual construction sites.

3.2.6 Data Analysis

As illustrated in Figure 6 above, the collected data was analyzed through hypothesis testing. JMP and SPSS Statistics were used to test the three research hypotheses. The data fields were converted into dependent and independent variables and tested using bivariate correlation. The three hypotheses compare two sets of different variables, i.e., RCSG leading indicators and contractor safety performance (1), contractor leading indicators and overall safety performance of the site (2), contractor leading indicators and lagging indicators (3), and RCSG leading indicators, and safety outcomes on the site. Thus, the bivariate correlation helped to determine if two variables are linearly related to each other. A scatter plot was performed before conducting the correlation to determine if the assumptions have been met. Correlation coefficients varied from a perfect positive correlation (represented by 1.0) to a perfect negative correlation (represented by -1.0). The descriptive statistics section provided the mean, standard deviation, and the number of observations (N) for each of the specified variables. After computing the correlation coefficient, the likelihood that recorded correlation occurred by chance was ascertained using a significance test. A significance level of .05 was assumed and used to either reject or accept the hypothesis. In cases where the hypothesis was rejected, an alternative hypothesis was derived.

3.2.7 Study Validity and Reliability

It is important to ensure the research data, methods, and findings are valid and reliable. Subsequently, this provides assurance to the citizens and leaders of the Kingdom
of Saudi Arabia that they can implement recommendations based on conclusions from this study. Several measures were used to ensure that the study results were valid and reliable. First, the data used in the study was thoroughly scrutinized before being analyzed to ensure its relevance and validity. Given that secondary data was used in the study, the data was subjected to an evaluation process to vet their inclusion. The following factors were assessed during the assessment process.

- The individual/company providing the data
- The aim of the data provider
- Techniques used to collect the data
- When the data was gathered
- Type of data collected
- The relation of this data to other respondents

The data used for the study was relatively current (collected between 2017 and 2019). Since the construction and safety sectors are extremely volatile, this helped to avoid using obsolete data, which could lead to misleading interpretations. Finally, after collecting reliable and valid data, it was critical to use an accurate analysis technique. Hypothesis testing in JMP and SPSS proved to be remarkably accurate, and only qualified personnel can perform the analysis.

3.2.8 Confidentiality of the Data Source

The data used in the study was collected from the RCSG sites and the (33) contractors. Since the contractors were a major data source, it was vital to ensure that they provide honest and reliable data. Thus, the identity of the contractors was de-identified to avoid victimization. Certainly, construction safety is a sensitive issue, which
can affect a contractor's future competitive position in the market. During the data collection process, the contractors were assured that their identities would be kept confidential.

3.2.9 Generalizability of Findings

Although this research is based on data from the Royal Commission (RC), it can be generalized to the construction sector in the Kingdom of Saudi Arabia, as well as other regions in the world. The relevant construction management and oversight agencies can use conclusions from this research to formulate and enact policies to ensure construction safety among the contractors, and the site owners. Indeed, construction practices and concerns around the world are similar. As Yilmaz and Celebi explain, the construction industry is a critical element of the economies among all nations, providing employment opportunities to a large population. It is also considered to be among the most hazardous sectors globally. The main safety hazards witnessed on construction sites include working in excavations, tunnels, at heights, in confined spaces, and on highways, operating construction machinery, exposure to electricity, among others (Yilmaz et al 2015). Thus, recommendations from this study can be adopted by similar construction firms and contractors to improve construction safety.

3.2.10 Application of Literature Review to Data Analysis

The hypotheses were derived from determinations made in the literature review section. Ten leading and five lagging indicators were constructed from the 20 identified articles, combining similar leading and lagging variables. After testing the hypothesis and finding them to be true, it will be cleared whether data analysis connects to the reviewed literature.
3.2.11 Strengths and Weaknesses of the Study

Several strengths and weaknesses characterize this study. The first strength arises from the use of secondary sources which provide a variety of expert perspectives and insights, ensure high-quality research through scholarly articles, and enabled a faster and more efficient study. The techniques used for this study were also cost-effective. However, contractors and the existing safety culture presented the biggest weakness of the study. The study heavily relied on an accurate and reliable response from the contractors. Yet, there was minimal incentive, apart from protecting their identities, to encourage them to provide accurate information.
Chapter Four: Results

This study sought to determine the impact of leading and lagging indicators for the safety of construction sites. In particular, the study intended to determine whether higher leading indicators predicted fewer safety incidents and accidents. Based on this view, a quantitative approach was adopted, and the data obtained from the Royal Commission construction site records and collected over a timeframe of two years between 2017 and 2019 were used for this analysis. The record set was subjected to various statistical analyses to test the presented hypotheses. This chapter presents the results of this investigation. It begins with the presentation of descriptive statistics and then the testing of the rational hypotheses. The chapter concludes with an overall summation of the findings of the study. The IBM Statistical Package for Social Sciences (IBM SPSS version 27.0.1.0, Chicago, IL) software was employed in descriptive data analysis, in which the mean and standard deviation of the measures were determined. As noted in the methodology, regression analysis was performed on the collected data to determine associations between the leading and lagging indicators. Specifically, JMP software (version 16, Cary NC) was used to perform Poisson, Logistic, and GLM regressions. The findings of the statistical analyses are presented using scatter plots and tables.

4.1 Descriptive Statistics

Data were obtained from 33 different construction sites that were undertaking different construction projects across Yanbu. These project classifications included housing,
infrastructure and utilities, facilities & services, power and substations, and schools and colleges. The projects were valued between $1.9M and $117.25M. Projects were classified by size into two groups for better recognition and analysis. Notably, nine (9) projects were valued below $8M and twenty-four (24) were valued above $8M. Overall, infrastructure and utilities accounted for the largest number of projects (17) followed by housing (6), facilities & services (4), power and electricity (4), and schools and colleges (2). Six leading indicators were reported including Safety Request for Inspection (RFI), Self-Inspections (Self-Ins), Hazard Analysis (HA), Risk Assessment Inspection (RAI), Disciplinary Action (DA), and Training. Three lagging indicators were identified including the number of incidents (Inc), number of incidents plus near misses (I+M), and stop work orders (SWO). These indicators were recorded in relation to the five major construction sites.

An overview of the data shows that the number of workers and number of incidents were related to the size of the project. For instance, projects that were valued below $8M had a total number of workers ranging from 500 to 2000 people, whereas those construction projects valued above $8M had employees ranging between 700 and 4000. Notably, projects valued below $8M recorded zero incidents and only 10 incidents plus near misses. For projects valued above $8M, the number of incidents and incidents plus near misses is relatively higher, numbering 33 and 159 respectively. A similar trend was also observed with regard to the value and size of the construction projects and the stop work order.

Tables 5 and 6 present the overall descriptive statistics of the leading and lagging indicators. Because there were large differences in the number of workers in each of the
sites, the data were normalized by dividing the counts by 100 FTE (full-time equivalents). RAI was the leading indicator with the lowest mean and standard deviation with values of 0.51 and 1.48 respectively. Conversely, training had the highest mean and standard deviation recording 152.85 and 95.96 respectively. Among the lagging indicators, Incidents had the lowest mean ± standard deviation of 0.36 ± 0.76 and stop work orders had the highest mean of 2.29 ± 2.34 as shown below:

Table 5. Descriptive statistics of leading indicators

<table>
<thead>
<tr>
<th>Leading Indicators</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>RFI /100FTE</td>
<td>20.0</td>
<td>27.64</td>
<td>33</td>
</tr>
<tr>
<td>Self Insp /100FTE</td>
<td>110.3</td>
<td>73.76</td>
<td>33</td>
</tr>
<tr>
<td>HA / 100 FTE</td>
<td>1.11</td>
<td>2.76</td>
<td>33</td>
</tr>
<tr>
<td>RAI / 100FTE</td>
<td>0.51</td>
<td>1.48</td>
<td>33</td>
</tr>
<tr>
<td>Disc Action / 100 FTE</td>
<td>8.09</td>
<td>13.74</td>
<td>33</td>
</tr>
<tr>
<td>Training / 100FTE</td>
<td>152.85</td>
<td>95.96</td>
<td>33</td>
</tr>
</tbody>
</table>

Table 6. Descriptive statistics of lagging indicators

<table>
<thead>
<tr>
<th>Lagging Indicators</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inc / 100FTE</td>
<td>0.35</td>
<td>0.75</td>
<td>33</td>
</tr>
<tr>
<td>I+M / 100FTE</td>
<td>1.9</td>
<td>2.39</td>
<td>33</td>
</tr>
<tr>
<td>SWO / 100FTE</td>
<td>2.29</td>
<td>2.34</td>
<td>33</td>
</tr>
</tbody>
</table>

The training was the most recorded leading indicator in all the 33 construction sites (9043). It was followed by self-inspection (6429), RFI (1014), disciplinary action (514), HA (58), and RAI (23). Similarly, the number of incidents plus near misses was the most recorded lagging indicator (174) followed by stop work orders (134) and the number of incidents (33). Table 7 below details the mean and standard deviation of the leading and lagging indicators in each of the five types of projects under the National Transformational Projects.
Table 7. Detailed leading and lagging descriptive statistics

<table>
<thead>
<tr>
<th>Type</th>
<th>Mean</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Housing</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inc / 100FTE</td>
<td>0.04</td>
<td>0.11</td>
</tr>
<tr>
<td>i+M / 100FTE</td>
<td>2.13</td>
<td>3.0</td>
</tr>
<tr>
<td>SWO / 100FTE</td>
<td>2.83</td>
<td>1.31</td>
</tr>
<tr>
<td>RFI /100FTE</td>
<td>24.97</td>
<td>15.61</td>
</tr>
<tr>
<td>Self Insp /100FTE</td>
<td>101.55</td>
<td>32.95</td>
</tr>
<tr>
<td>iHA / 100 FTE</td>
<td>0.50</td>
<td>0.43</td>
</tr>
<tr>
<td>RAI / 100FTE</td>
<td>0.08</td>
<td>0.2</td>
</tr>
<tr>
<td>Disc Action / 100 FTE</td>
<td>8.73</td>
<td>15.24</td>
</tr>
<tr>
<td>Training / 100FTE</td>
<td>87.56</td>
<td>49.26</td>
</tr>
<tr>
<td><strong>Facilities</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inc / 100FTE</td>
<td>0.48</td>
<td>0.98</td>
</tr>
<tr>
<td>i+M / 100FTE</td>
<td>1.65</td>
<td>3.07</td>
</tr>
<tr>
<td>SWO / 100FTE</td>
<td>3.40</td>
<td>2.09</td>
</tr>
<tr>
<td>RFI /100FTE</td>
<td>15.59</td>
<td>7.91</td>
</tr>
<tr>
<td>Self Insp /100FTE</td>
<td>55.43</td>
<td>20.68</td>
</tr>
<tr>
<td>HA / 100 FTE</td>
<td>0.35</td>
<td>.49</td>
</tr>
<tr>
<td>RAI / 100FTE</td>
<td>0.08</td>
<td>0.17</td>
</tr>
<tr>
<td>Disc Action / 100 FTE</td>
<td>1.58</td>
<td>1.92</td>
</tr>
<tr>
<td>Training / 100FTE</td>
<td>133.96</td>
<td>71.82</td>
</tr>
<tr>
<td><strong>Infrastructure</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inc / 100FTE</td>
<td>0.47</td>
<td>0.88</td>
</tr>
<tr>
<td>i+M / 100FTE</td>
<td>0.98</td>
<td>1.21</td>
</tr>
<tr>
<td>SWO / 100FTE</td>
<td>2.41</td>
<td>2.75</td>
</tr>
<tr>
<td>RFI /100FTE</td>
<td>17.01</td>
<td>29.91</td>
</tr>
<tr>
<td>Self Insp /100FTE</td>
<td>133.19</td>
<td>88.25</td>
</tr>
<tr>
<td>HA / 100 FTE</td>
<td>1.62</td>
<td>3.76</td>
</tr>
<tr>
<td>RAI / 100FTE</td>
<td>0.82</td>
<td>1.98</td>
</tr>
<tr>
<td>Disc Action / 100 FTE</td>
<td>9.17</td>
<td>15.35</td>
</tr>
<tr>
<td>Training / 100FTE</td>
<td>166.99</td>
<td>109.41</td>
</tr>
<tr>
<td><strong>Electric</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inc / 100FTE</td>
<td>0.38</td>
<td>0.76</td>
</tr>
<tr>
<td>i+M / 100FTE</td>
<td>5.89</td>
<td>1.08</td>
</tr>
<tr>
<td>SWO / 100FTE</td>
<td>0.11</td>
<td>0.23</td>
</tr>
<tr>
<td>RFI /100FTE</td>
<td>35.73</td>
<td>48.61</td>
</tr>
<tr>
<td>Self Insp /100FTE</td>
<td>68.70</td>
<td>62.06</td>
</tr>
<tr>
<td>HA / 100 FTE</td>
<td>0.17</td>
<td>0.34</td>
</tr>
<tr>
<td>RAI / 100FTE</td>
<td>0.50</td>
<td>1.01</td>
</tr>
<tr>
<td>Disc Action / 100 FTE</td>
<td>0.05</td>
<td>0.11</td>
</tr>
<tr>
<td>Training / 100FTE</td>
<td>180.33</td>
<td>98.27</td>
</tr>
<tr>
<td><strong>Schools</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inc / 100FTE</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>i+M / 100FTE</td>
<td>1.50</td>
<td>2.12</td>
</tr>
<tr>
<td>SWO / 100FTE</td>
<td>1.75</td>
<td>2.480</td>
</tr>
<tr>
<td>RFI /100FTE</td>
<td>8.22</td>
<td>1.12</td>
</tr>
<tr>
<td>Self Insp /100FTE</td>
<td>135.58</td>
<td>39.97</td>
</tr>
<tr>
<td>HA / 100 FTE</td>
<td>1.91</td>
<td>1.54</td>
</tr>
<tr>
<td>RAI / 100FTE</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Disc Action / 100 FTE</td>
<td>26.07</td>
<td>0.68</td>
</tr>
<tr>
<td>Training / 100FTE</td>
<td>211.39</td>
<td>79.27</td>
</tr>
</tbody>
</table>
Scatter plots between the leading and lagging indicators were reviewed before subjecting the data to further statistical analysis. Scatter plots were useful to visualize any association. Each of the leading indicators was plotted against each lagging indicator as shown below:

Figure 7. RFI vs I+M

Figure 8. RFI vs Inc

Figure 9. RFI vs SWO
Figure 10. Self Insp vs Inc

Figure 11. Self Insp vs I+M

Figure 12. Self Insp vs SWO
Figure 13. HA vs Inc

Figure 14. HA vs I+M

Figure 15. HA vs SWO
Figure 16. RAI vs Inc

Figure 17. RAI vs I+M

Figure 18. RAI vs SWO
Figure 19. Disc Action vs Inc

Figure 20. Disc Action vs I+M

Figure 21. Disc Action vs SWO
Figure 22. Training vs Inc

Figure 23. Training vs I+M

Figure 24. Training vs SWO
4.2 Statistical Analysis

A statistical analysis was conducted to test the three primary hypotheses. Poisson and GLM regressions were undertaken to evaluate the existing relationship or effect between leading and lagging indicators, and logistic regression was conducted to test the presence of events. The working hypotheses were:

H1: Leading indicators were associated with the rate of incidents (Inc)

H2: Leading indicators were associated with the rate of incidents plus near misses (I+M)

H3: Leading indicators were associated with rate of stop work orders (SWO)

The result of the statistical analysis using Poisson, Logistic regression and GLM are provided in Tables 8, 9 and 10.

Table 8. Poisson Analysis (Lagging rate /100FTE)

<table>
<thead>
<tr>
<th>Leading Rates</th>
<th>Inc</th>
<th>I + M</th>
<th>SWO</th>
</tr>
</thead>
<tbody>
<tr>
<td>RFI</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Self Insp</td>
<td>ns</td>
<td>- at p = 0.08</td>
<td>+ at p &lt; 0.001</td>
</tr>
<tr>
<td>HA</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>RAI</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Disc Action</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Training</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
</tbody>
</table>

Table 9. Logistic Regression Analysis (Lagging Dichotomous)

<table>
<thead>
<tr>
<th>Leading Rates</th>
<th>Inc</th>
<th>I + M</th>
<th>SWO</th>
</tr>
</thead>
<tbody>
<tr>
<td>RFI</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Self Insp</td>
<td>ns</td>
<td>ns</td>
<td>+ at p = 0.04</td>
</tr>
<tr>
<td>HA</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>RAI</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Disc Action</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Training</td>
<td>ns</td>
<td>ns</td>
<td>- at p = 0.098</td>
</tr>
</tbody>
</table>
Table 10. GLM Analysis (Lagging rate /100FTE)

<table>
<thead>
<tr>
<th>Leading Rates</th>
<th>Inc</th>
<th>I + M</th>
<th>SWO</th>
</tr>
</thead>
<tbody>
<tr>
<td>RFI</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Self Insp</td>
<td>ns</td>
<td>ns</td>
<td>+ at p &lt; 0.001</td>
</tr>
<tr>
<td>HA</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>RAI</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Disc Action</td>
<td>- at p = 0.0345</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Training</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
</tbody>
</table>

4.2.1 Leading indicators and incidents

H1o: The rate of leading indicators was not associated with the incident rate

H1a: The rate of leading indicators was associated with the incident rate

The findings from the Poisson regression revealed that there is no statistically significant association between the independent and dependent variable among the 18 comparison pairs. In particular, all leading factors did not have a statistically significant association with the rate of incidents. Similarly, a GLM regression analysis showed that there was no association between the rates of leading indicators and incidence except for disciplinary action. There was a statistically significant negative association between disciplinary action and incident rate at p=0.035.

H4o: The rate of leading indicators was not associated with the presence of incidents

H4a: The rate of leading indicators was associated with the presence of incidents

A logistics regression was used to test this hypothesis. Findings showed that there was no statistically significant relationship between the leading indicators and incidents.
4.2.2 Leading indicators and incidences plus near misses

\( H2_0 \): The rate of leading indicators was not associated with incidences plus near misses

\( H2_a \): The rate of leading indicators was associated with incidences plus near misses

The Poisson regression revealed that there was a negative association between the rate of self-inspection and rate of incidents plus near misses. Even though the other leading indicators did not show a statistically significant relationship, self-inspection was negatively associated with incidences and near misses at \( p=0.08 \). A GLM analysis did not yield any statistically significant relationship between these variables.

\( H5_0 \): The rate of leading indicators was not associated with the presence of incidences plus near misses

\( H5_a \): The rate of leading indicators was associated with the presence of incidences plus near misses

Logistic regression did not yield any statistically significant relationship between all the leading indicators and incidents plus near misses.

4.2.3 Leading indicators and stop work order

\( H3_0 \): The rate of leading indicators was not associated with stop work order

\( H3_a \): The rate of leading indicators was associated with stop work order

A Poisson regression showed that self-inspection was positively associated with stop work orders at \( p<0.001 \). All other leading indicators did not have a statistically significant relationship with SWO. A GLM analysis also confirmed a positive association with stop work order.
**H6a:** The rate of leading indicators was not associated with the presence of a stop work order

**H6b:** The rate of leading indicators was associated with the presence of a stop work order.

Logistic regression revealed that there was a statistically significant positive relationship between self-inspection and the presence of stop work orders at $p=0.04$. There was also a negative association between training and stop work orders at $p=0.10$.

### 4.3 Summary of results

This chapter presented the findings of the study, which sought to determine whether there exists a relationship between the leading and lagging indicators pertaining to the safety of construction sites. The identified leading indicators used in this analysis included safety requests for inspection, self-inspection, hazard analysis, risk assessment inspection, disciplinary action, and training. The identified lagging indicators included the number of incidents, the number of incidents and near misses, and the stop work orders. Descriptive statistics described the data, and different statistical tests were performed. Essentially, the Poisson regression and GLM were used to assess the effect of the rate of leading indicators on the lagging indicators, and the logistic regression was used to determine if leading indicators were predictive of the presence of lagging indicators. Findings show that some of the leading indicators had a statistically significant relationship with the lagging indicators. Nevertheless, the logistic analyses revealed that the leading indicators were only predictive of the presence of the stop work order and not the incidents or incidents plus near misses.
Overall, there was one clear finding and three other significant findings (see Tables 8, 9, 10). The most confident finding was that SWOs and Self-Inspection were clearly related with a positive association. That is, Self-Inspections increased with Stop Work Orders. There was some evidence for a negative association between (1) Self-Inspection and I+M, (2) training and SWO, and (3) DA and Inc.
Chapter Five: Discussion and Conclusion

5.1 Interpretation of Results
As noted in the literature, one of the expected results is that there would be an indirect relationship between the leading and lagging indicators, such that an increase in the leading indicators would lead to a decrease in the lagging indicators. However, all the three models used in this analysis established a positive association between Self-Inspections and Stop Work Orders. In essence, self-inspections increased with stop work orders, contrary to expectations. Based on this finding, it is arguable that an increase in self-inspection was a likely response to stop work orders. This development highlights the issues associated with cross-sectional study designs given that the direction of association cannot be ascertained.

A critical analysis also reveals that Self-Inspection was negatively associated with incidences plus near misses. Even though this association was only established in the Poisson analysis, the negative association was in the expected direction. Consistent with the available literature, this model establishes that an increase in self-inspection is associated with a decrease in incidents plus near misses in construction sites. This development may arise from the fact that Self-Insp can lead to the early detection of defects and safety hazards, prompting appropriate interventions to eliminate threats. Such an association has a significant implication for safety management in the construction industry.
It is also fundamental to note that the logistics regression established a negative association between training and stop work orders. As expected, this association predicted that an increase in training would lead to a reduction in SWOs. This development is highly desirable in the management of safety in construction sites. Since training can enhance awareness and improve individuals’ abilities to handle safety issues, it is desirable for the management to consider this indicator in establishing safe construction sites.

The GLM analysis also reveals a negative association between disciplinary action and the rate of incidents. Fundamentally, stronger disciplinary actions led to a subsequent decline in incident cases. This aspect shows that the management’s implementation of stronger direct actions that discourage workers from neglecting safety guidelines can result in fewer incidents, thus reinforcing safety at the construction sites.

Given that prior studies have shown the association between leading and lagging indicators in the safety management of construction sites, it was expected that a statistically significant relationship would be established between the variables of interest. However, this study did not find a systematic association between all the leading and lagging indicators. This discrepancy may have been a consequence of the size of the data set used in the study. Insufficient power complicates the quality and generalizability of research findings.

5.2 Analysis
The safety of construction sites is one of the critical aspects that determines not only the overall well-being of workers but also the successful completion of projects. Studies have shown that unsafe construction sites and unsafe workers’ behaviors are detrimental to
the expected outcomes, with an increase in construction accidents and casualties (Guo et al., 2019; Li et al., 2021). They may also be associated with increasing costs of completing a given project. In this regard, contractors and other stakeholders seek to establish safe construction sites to minimize the occurrence of undesirable events. As such, this study sought to determine some of the approaches that contractors in Yanbu have implemented to enhance the safety of construction projects in the region. In particular, it sought to determine whether higher safety performance leading indicators translated to fewer accidents and incidents, thus reflecting improved safety on a construction site.

Leading indicators are indispensable in construction site safety management given that they can be used to scrutinize the safety measures and engage in actions to help prevent accidents from occurring in the future. In particular, these leading indicators are used to control risk and prevent accidents, unlike the lagging indicators. Based on this view, one would expect higher leading indicators in a construction site to lead to lower lagging indicators or fewer accidents and incidents. This aspect formed the basis for the analysis of the study’s findings.

Leading and lagging indicators were recorded in most construction sites across Yanbu. All the leading indicators, except risk assessment inspection in schools, were recorded in various counts across all projects. Similarly, all lagging indicators, except the number of incidents in schools, were recorded in various degrees across construction sites in the region. Infrastructure and utilities, which accounted for the largest and more expensive construction projects in Yanbu, recorded the highest number of both leading and lagging indicators. There were also fewer incidents and near misses in school
projects than in other fields, thus denoting contractors’ commitment to improving the overall safety performance of construction sites across learning institutions.

A critical analysis of the findings with respect to the set of hypothesis shows that some leading indicators had a significant effect on a couple of lagging indicators. In essence, these leading indicators were associated with decreasing lagging indicators. For instance, self-inspection was negatively associated with incidents and near misses, training was negatively associated with stop work orders, and disciplinary action was negatively associated with incidents. Additionally, these leading indicators could predict the presence and occurrence of the lagging indicators. Nevertheless, it was clear from the findings that self-inspection had a positive association with stop-work orders. This is due to several SWO issuance by RC which required contractors to perform several self-inspections prior request RC to agree on the corrective action. Therefore, the stop work orders were an ideal approach to initiating self-inspection among construction sites. Although this relationship may not be ideal for a safety management system, it is valuable when used by the Royal Commission to improve safety in construction sites across the region. In general, these findings show that some leading indicators, including disciplinary action and self-inspection, were important in mitigating the prevalence of lagging indicators. As noted in the literature, there is no standardized or established relationship between leading and lagging indicators to considerably assess safety. Given that these indicators vary according to industry standards and indices, companies need to adopt and implement the most appropriate ones.

It was also important to assess whether the leading indicators would predict the presence or absence of the respective lagging indicators. As such, the logistic regression
revealed that the rate of all the leading indicators did not predict or affect the presence of incidents and incidences plus near misses on a construction site. However, some of the leading indicators, particularly self-inspection and training, predicted the probability of the occurrence of stop work orders. In essence, a high rate of SWO increased the self-inspection and a higher level of training reduced the rate of SWO. As such, these leading indicators can be incorporated into the safety management of construction sites across Yanbu to improve safety and mitigate the occurrence of undesirable events.

5.3 Limitations of the Study
The study design was cross-sectional, which allowed only for the determination of association. That is, the design did not allow for the determination of cause and effect. This limitation was most clearly seen in the positive association between self-inspections and stop work orders.

Another critical limitation was associated with this analysis is that the use of contractors’ data in the research may affect the accuracy and subsequent validity of the findings. Fundamentally, there was no standardized reporting or documenting procedures for the stated leading indicators in construction sites. Unlike the lagging indicators that are easier to document, leading indicators are difficult to track by other organization like the RC. There are also challenges and disparities associated with the measurement of the safety performance indicators by various contractors. These differences may have an ultimate effect on the quality and completeness of the data used in the research, thus potentially impacting the overall outcome.

Another important limitation is that the accuracy of the findings may be influenced by the biases of those in power. Essentially, the performance indicators are reported by
individual contractors to the Royal Commission, thus anchoring the control of the information on contractors’ perspectives. Additionally, some of the international contractors may not demonstrate their willingness to track and report some of the leading indicators. Such aspects may have an effect on the representativeness and unbiased nature of the reported data.

5.4 Implication for Practice
Even though contractors continue to improve the safety of construction sites, they remain hazardous and pose considerable danger to both workers and the general public. Fundamentally, construction sites continue to account for significant accidents, injuries, and even fatalities not only in Yanbu but also across the world. As such, there is a need for stakeholders in this industry to establish strategies and mechanisms intended to enhance construction site safety management and performance. As noted in the literature review, leading indicators can play a significant role in promoting construction site safety compared with lagging indicators. As such, there is a need for contractors and other stakeholders in the construction industry to establish standardized measures and incorporate some of these leading indicators as metrics to assess the safety performance of construction sites. In particular, there is a need to emphasize the role of self-inspection, disciplinary action, and training in managing the occurrence of undesirable events and improving the safety of construction sites.

5.5 Implication for Research
The goal of this research was to determine whether some of the leading indicators have an effect or can predict the occurrence of the lagging indicators on a construction site. However, the list of explored leading indicators is not exhaustive. Therefore, there is a
need for further research to determine whether other leading indicators, such as recognition and incentives, site inspection, and safety management systems, have an impact on lagging indicators. Researchers may also need to devise appropriate primary data collection approaches for these metrics to establish the relationship. Moreover, there is a need for additional quantitative primary research to determine whether a correlation exists between the leading and lagging indicators to improve decision-making with regard to the safety and performance of construction sites.

5.6 Recommendations for the Royal Commission
The Royal Commission plays a significant role in not only setting policies but also supervising strategic programs and plans. As such, it occupies a central role in protecting the interests of workers by making construction sites across Yanbu safer. The commission also provided the data used in this study, depicting its contributions to research and development. Based on the findings of this research, it is important to reevaluate Royal Commission’s occupational health and safety data management. Even though collecting relevant information and measuring the leading and lagging indicators is important, the usefulness of this data is anchored in its quality. Therefore, the following recommendations can play a pivotal role in facilitating this process.

One of the recommendations is for the commission to establish and schedule peer reviews with individuals involved in the collection and reporting of safety performance metrics to maintain the quality and consistency of data. This process can address cases of underreporting of indicators perceived as insignificant, such as near misses or minor incidents, and portray the true state of safety management in various construction sites. Moreover, consistent peer reviews can lead to the development of more standard tools
and procedures that can be used to comprehensively measure the leading indicators, thus addressing any current inconsistencies in data collection and documentation. These measurement tools can also help future researchers to evaluate the indicators on a scale rather than using counts. If the Royal Commission adopts this approach, it can provide quality data for research that can lead to more accurate findings.

The second recommendation for the Royal Commission is to improve its reporting procedures. Given that global trends are moving towards a technology-based ecosystem, there is a need for the Royal Commission to deploy advanced technologies to track safety performance and facilitate the reporting process. As noted in this paper, the quality of the reported data may be undermined by administrators’ biases or contractors’ unwillingness to submit the required safety performance data. Therefore, the Royal Commission may consider adopting modern technology to synchronize the reporting process and eliminate any barriers that may impact the process.

5.7 Conclusion
Construction remains one of the critical aspects characterizing the country’s socioeconomic development. As such, safety performance in the construction industry, especially in the Yanbu area, is paramount. This paper sought to determine the impact of leading and lagging indicators on the safety of construction sites. In particular, the study intended to determine whether higher leading indicators predicted fewer safety incidents and accidents. An analysis of the data obtained from the Royal Commission shows that some of these leading indicators, such as disciplinary action, self-inspection, and training had a significant association with some of the lagging indicators. This provided support for the importance of leading indicators.
The findings of this study have considerable implications for both practice and research. Even though the study may be limited in terms of the quantity and quality of data, the findings can be incorporated into the current practice to enhance construction site safety performance. Some of the leading indicators that have an association with the lagging indicators, albeit weak, can contribute to the overall safety management of construction sites. In terms of research, there is a need for scholars to investigate whether other leading indicators that were not explored in this study, have an effect on lagging indicators. There is also a need to devise and develop standard tools to measure leading indicators to improve the quality of data and ultimate findings. On the part of the Royal Commission, the findings imply that there is a need to address the commission’s safety data management to not only reinforce and contribute to quality research but also improve policy implementation.
References


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