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Leading or lagging? Temporal analysis of safety indicators on a large infrastructure construction project

Helen Lingard, Professor [a,*], Dr. Matthew Hallowell, Associate Professor [b], Mr. Rico Salas [c], Mr. Payam Pirzadeh [a]

[a] School of Property, Construction and Project Management, RMIT University, Melbourne, GPO Box 2476, Victoria 3001, Australia
[b] Department of Civil, Environmental, and Architectural Engineering, University of Colorado at Boulder, USA
[c] Design & Facilities Information Engineering Management, Chevron, Bellaire, TX 77401, USA

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A B S T R A C T

Safety performance data collected over a five year period, at a large Australian infrastructure project was analysed. The analysis examined the temporal relationships between the safety performance indicators measured at the project, including traditional lagging indicators, as well as expected leading indicators. The purpose of the research was to uncover time dependent relationships and explore causal relationships between indicators. The analysis revealed complex interactions between safety indicators over time. Notably, the expected leading indicators behaved as both leading and lagging indicators in relation to the project total recordable injury frequency rate. This finding suggested a cyclical relationship between management actions relating to safety and the rate of safety incidents. This cyclical relationship is unlikely to produce long term sustained improvement in safety performance. The expected leading indicators of safety were also inter-related with one another in complex ways. The results indicate that assumptions underpinning the use of leading indicators should be reconsidered. In particular, the findings challenge the assumption that leading indicators measured at one point in time can predict safety outcomes at a subsequent point in time. The collection and use of different types of safety indicator data should be reconsidered.

1. Introduction

1.1. Workplace health and safety performance measurement

The management of safety relies on the "systematic anticipation, monitoring and development of organizational performance" (Reiman and Pietkäinen, 2012, p. 1993). Regular measurement of safety performance enables the detection and resolution of problems and provides the information needed to make proactive safety decisions and evaluate the effectiveness of safety initiatives. High reliability organizations, defined as those with hazardous work systems yet nearly accident free performance (La Porte, 1996), are pre-occupied with failure and maintain a constant mindfulness about safety (Weick and Sutcliffe, 2001). Cooke and Rohleder (2006) argue that effectively identifying and responding to changes in safety conditions as they occur can transform poor performing organizations into resilient, high-reliability organizations with exemplary safety performance. Using data to monitor and identify the early signs of escalating safety risk is critical to this transformation.

Most construction organizations engage in strategic, operational, and project planning processes, which include the establishment of corporate and project safety objectives. Robust safety performance measurement is also essential in order to understand whether objectives are being met, and if they are not, to identify opportunities to improve. Yet, how best to measure health and safety in industrial environments is a vexed question.

A variety of indicators are currently used to measure workplace safety performance in the construction industry. Kjellén (2009, p. 486) defines safety performance measures or indicators as "the metric[s] used to measure the organisation's ability to control the risk of accidents." Harms-Ringdal (2009) define safety indicators as "observable measures that provide insights into a concept – safety – that is difficult to measure directly" (p. 482). Traditionally incident or injury frequency rates have been used to measure safety performance. These are probably still the most widely used measures within the construction industry. However, problems

* Corresponding author.
E-mail addresses: helen.lingard@rmit.edu.au (H. Lingard), Matthew.Hallowell@colorado.edu (M. Hallowell), risalas@gmail.com (R. Salas), payam.pirzadeh@rmit.edu.au (P. Pirzadeh).

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inherent with the use of incident/injury rates are now well documented and, alternative measures of safety-related activity are increasingly favoured. At the same time, the terms "lagging" and "leading" have been applied to these safety indicators. These terms were coined from economic and financial modelling techniques and imply a distinction between proactive measures of the state of safety and retrospective measures of past safety outcomes. However, despite the widespread use of the terminology, the dependencies and temporal relationships among so-called leading and lagging indicators of safety are far from clear (Hopkins, 2009a). Thus, researchers call for a more robust analysis of the relationships and time dependencies between different safety performance indicators (Dyreborg, 2009).

1.2. Research objectives

Our primary goal in this research was to investigate the relationships and temporal interdependencies among safety indicators collected during the delivery of a large rail infrastructure project in Australia. In pursuit of this goal, we analysed data collected over a five-year period. This was a retrospective analysis of an existing dataset and we did not design the data collection approach or measures deployed. Notwithstanding this, the analysis provided an ideal opportunity to evaluate the longitudinal relationships between rates of injury/incidents (typically posited as lagging safety metrics) and management activity (typically posited as leading safety metrics) over the five year period.

The data was analysed to:

- uncover causal relationships among the different indicators over the five year period;
- quantify time dependencies among different indicators; and
- measure the magnitude and direction of relationships among indicators over time, i.e., whether a change in an indicator at one point in time was significantly associated with a change in another indicator at a subsequent time lag.

2. Background and theory

2.1. Problems inherent in the use of incident/injury rates

Traditionally, construction organizations have relied on measures of frequency with which undesirable safety outcomes have occurred as an objective indicator of performance. Thus, there are standardized ways to calculate lost time injury frequency rates (LTIFRs) and total recordable injury frequency rates (TRIFRs). Such indicators are useful because they are:

- relatively easy to collect;
- easily understood;
- easy to use in benchmarking or comparative analyses; and
- useful in the identification of trends over time (NOSHC, 1999).

However, these measures have been criticized on two grounds. First, because recordable incidents and injuries have a statistically low probability of occurrence over short time frames, they are usually neither valid, nor stable when measured at a single construction project (Hopkins, 2009a). Hopkins (2009b) terms this the "zoom" effect, referring to the fact that, even in very large construction projects, the frequency of accidents/injuries is insufficient to calculate a meaningful rate. Even a stable safety system will produce a variable number of injuries/incidents (Stricoff, 2000) and the absence of injuries/incidents does not necessarily mean that a workplace is safer than another workplace at which an injury/incident has occurred in the same period (Cadieux et al., 2006).

However, a more fundamental criticism of incident/injury rates is that are retrospective indicators capturing things that have already gone wrong. They measure the absence, rather than the presence of safety (Arezes and Miguel, 2003) and therefore cannot be regarded as a direct measure of the level of safety in a work system (Lofquist, 2010). Weick (1987) describes safety as a "dynamic non-event" and argues that, by definition, non-events cannot be counted. Consistent with this view, the preoccupation with measuring the absence of negative events has been criticized by researchers (Dekker and Pitzer, 2016).

The reliance on incident rates as the method of monitoring safety performance can have serious consequences. For example, Lofquist (2010) describes how relying on incidents as a safety indicator resulted in the failure to recognise a marked deterioration in safety that occurred in the Norwegian civil aviation industry during a period of organizational change. Pilots and air traffic controllers had observed a gradual decline in safety standards, but because no incident had occurred, decision-makers were not aware of the negative safety impact of the organizational change program. Thus, a low incident/injury rate does not guarantee that safety risks are being controlled or that incidents/injuries will not occur in the future (Mengolinim and Debarberis, 2008).

The use of injury/incident rates to underpin incentive schemes can also cause reporting problems. Tying incentives, such as management performance appraisals, bonus payments, or future tendering opportunities to injury/incident rates can encourage underreporting (Cadieux et al., 2006; Sparer and Dennerlein, 2013). For example Pedersen et al. (2012) describe how group-based rewards for periods of accident-free working encourages underreporting. Research also shows that workers who perceive that they have low levels of job security are less likely to report injuries and accidents (Probst et al., 2013). When underreporting occurs, data fidelity is compromised and erroneous conclusions can be drawn from analysis of performance. In fact, the greater the emphasis that is placed upon injury/incident rates in commercial incentive schemes, the less useful these measures are likely to be, because people learn how to manipulate them (Hopkins, 2009b). The extent of the problem is indicated by Daniels and Marlow (2005) who report that the actual level of reporting of non-fatal construction injuries in the UK construction industry is as low as 46%.

2.2. Alternative types of safety performance indicator

As a result of these limitations, there has been a move away from the exclusive use of retrospective injury or incident data for the measurement of safety performance (Sinelnikov et al., 2015). Different ways to quantify the state of safety, irrespective of the occurrence of injury or incidents, have been developed (see, for example, Lingard et al., 2011; Podgórski, 2015; Shea et al., 2016). These take various forms. For example, third party audits are sometimes used to measure the extent to which organizational safety management systems are compliant with pre-existing standards (see, for example, Teo and Ling, 2006). Other measurement approaches involve quantifying the direct causes of accidents, such as hardware failures or operational errors (Mohaghegh and Mosleh, 2009), or measuring the prevailing safety climate to predict safety behaviour and outcomes (Mearns et al., 2003; Neal and Griffin, 2006).

These methods have shown promise. Lingard et al. (2011, 2013) developed a composite measure combining positive performance indicators of management activity with safety climate scores, and more recently, Shea et al. (2016) developed an index to measure employees' perceptions of the quality of various aspects of safety-related activity in a workplace. Salas and Hallowell (2016) used leading indicators to develop a predictive model for providing