KEY WORDS: Safety; leading indicators; marine transportation; tanker operations; predictive indicators; lagging indicators; accident precursors; safety management; safety culture.

INTRODUCTION

Safety performance has traditionally been measured by ‘after the loss’ type of measurements such as accident and injury rates, incidents and dollar costs. However, there is a growing consensus among safety professionals and researchers that these “lagging” indicators, which means that an accident must occur or a person must get injured before a measure can be made, may not provide the necessary insights for avoiding future accidents. A low reported accident rate, even over a period of years, is no guarantee that risks are being effectively controlled, nor will it ensure the absence of injuries or accidents in the future (Lindsay, 1992). Moreover, in many safety-critical settings, the likelihood of catastrophic events or accidents is low; thus, the absence of unlikely events is not, of itself, an indicator of good management (Van Steen, 1996). Recognizing signals before an accident occurs offers the potential for improving safety, and many organizations have sought to develop programs to identify and benefit from alerts, signals and other types of prior indicators.

Leading indicators, one type of accident precursor, are conditions, events or measures that precede an undesirable event, and that have some value in predicting the arrival of the event, whether it is an accident, incident, near miss, or undesirable safety state. Leading indicators are associated with proactive activities that identify hazards and assess, eliminate, minimize and control risk. Lagging indicators, in contrast, are measures of a system that are taken after events and assess outcomes and occurrences. Examples of leading indicator measurement programs include near hit reporting in anesthesia management (Pate-Cornell, 2003), accident precursor assessment programs in nuclear safety (Sewell, Khatib-Rahbar & Erikson, 1999; Sattison, 2003), and hazard identification and analyses for offshore oil and gas in the United Kingdom (Step Change in Safety, 2004). Examples of lagging indicator measurements include recordable injury frequencies, lost time frequencies, lost time severity, vehicle accident frequencies, workers’ compensation losses, property damage costs, and numbers and frequency of accident investigations (Gross, Ayres, Wreathall, Merritt & Moloi, 2001).

This paper reports on the preliminary results of the American Bureau of Shipping (ABS) Leading Indicators of Safety project, undertaken for ABS by Rensselaer Polytechnic Institute, with assistance from Virginia Commonwealth University. This project, which began in 2003, focuses on identifying, analyzing and evaluating a set of leading safety indicators in marine transportation. Initially, two industry partners—one a domestic U.S. tanker organization, and one an international tanker organization—joined the project, and data were collected from those organizations in 2006. This report describes the results of the data analysis conducted with the domestic U.S. tanker organization. A third industry partner, a domestic U.S. container and government shipping organization, joined the project in 2006; data collection with the third industry partner is underway in 2007. Additional research partners in 2007 and 2008 include the international parent companies for the domestic U.S. tanker and container operators, as well as an international cruise ship line.

The ABS Leading Indicators of Safety project was initiated in response to the need for empirically validated guidance on safety management principles, indicators and measures. In this paper, we first discuss the concept of leading indicators and safety factors, followed by a description of the data analysis undertaken. The results of the analysis are then presented, followed by a discussion of the usefulness of the leading indicators. Implications of the analysis for future work conclude the report.

LEADING INDICATORS

Leading indicators have been studied in many types of systems, with widely varying results. Many economic systems, including the U.S. economy, use composite indexes and economic series with leading, coincident, and lagging indicators of economic growth as predictive tools. Leading indicators have been studied in many types of systems, including economic, industrial, health care, and organizational systems. Leading indicators are those that precede the occurrence of an event, while coincident indicators are those that occur simultaneously with the event, and lagging indicators are those that occur after the event. Leading indicators are often used to predict future outcomes, while coincident and lagging indicators are used to confirm or refute the predictions.

The ABS Leading Indicators of Safety project was initiated in response to the need for empirically validated guidance on safety management principles, indicators and measures. In this paper, we first discuss the concept of leading indicators and safety factors, followed by a description of the data analysis undertaken. The results of the analysis are then presented, followed by a discussion of the usefulness of the leading indicators. Implications of the analysis for future work conclude the report.
Some industries, such as aviation, have a relatively long history in the United States. Initially, these efforts focused on identifying predictors of individual mortality; recently, the focus has shifted to include broader leading indicators of the nation’s health (Chrvala & Bulger, 1999). The nuclear power industry has also evaluated the predictive validity of leading indicators of individual and group safety and performance in nuclear power plants (Gross, et al., 2001; Ayres & Gross, 2002; Lehtinen & Wahlstrom, 2002).

Some industries, such as aviation, have a relatively long history of seeking to identify leading indicators; others organizations, such as blood banks and hospitals, are relative newcomers to the field. Nevertheless, each field uses similar information-gathering processes and weighs common design choices (Tamuz, 2003). Some of these industries discovered accident precursors based on their common experiences, such as having to draw on small samples of accidents (March, Sproull & Tamuz, 1991), while other industries developed signal detection programs as a result of learning by imitation (Levitt & March, 1988), such as medicine’s Patient Safety Reporting System, which drew on aviation’s experience with its Aviation Safety Reporting System (Tamuz, 2003). Recent work in leading indicators has focused on the use of leading indicators in resilience engineering as a way to assist organizations in recognizing and adapting to change and surprise (Woods & Hollnagel, 2006).

Safety Factors and Leading Indicators

Research to identify leading indicators of safety has often begun with a search for safety factors, elements or conditions that can be linked to high levels of organizational safety performance. Beginning with Shafai-Sahrai’s 1971 dissertation, which examined 11 matched pairs of low- and high-injury rate companies in order to identify common factors in low injury rate companies, researchers have sought to identify factors in organizations that are associated with high levels of safety performance (Cohen, 1977; Cohen & Cleveland, 1983; Chew, 1988; Shannon, Walters, Lewchuk, Richardson, Moran, Haines & Verma, 1996; Shannon, Mayr & Haines, 1997; Mearns, Flin, Gordon, & Fleming, 2001; Mearns, Whitaker & Flin, 2001; 2003; DeJoy, Schaffer, Wilson, Vandenberg & Butts, 2004).

Review of the safety factors identified in several major studies undertaken over the past 30 years shows that there is general agreement about the factors that influence organizational safety (Dufort & Infante-Rivard, 1998; Zimolong & Elke, 2006):

- Communication about safety issues, including pervasive channels of formal and informal communication and regular communications between management, supervisors and the workforce, and
- Involvement of employees, including empowerment, delegation of responsibility for safety, and encouraging commitment to the organization (Zimolong & Elke, 2006, pp. 7-8).

One of the difficulties with previous work in leading indicators and safety factors, however, has been the lack of predictive validity in the safety factors and the leading indicators. Thus, one of the goals of the ABS Leading Indicators of Safety project is to develop a set of predictive, empirically-validated leading indicators of safety in marine transportation, and to benchmark the leading indicators over time. In the next section, we describe the steps taken to develop the leading indicators with the first industry partner.

LEADING INDICATORS OF SAFETY IN A DOMESTIC U.S. ENERGY TRANSPORTATION ORGANIZATION

The first industry partner was the domestic U.S. affiliate of a large international energy transportation company. A total of 77 shipboard and 22 shoreside individuals participated in the research project. Shipboard, the participants included all employees working on board the vessels, officers—captains, chief engineers, mates, and engineers—as well as crew members from all departments aboard the vessel. Shoreside, the participants included employees holding managerial positions as well as administrative and individual workers. The average age of the participants was 45.5 years, with a mean of 20 years’ experience in the maritime industry, and a mean of 16 years of employment with the industry partner.

As set forth by the ABS Guidance Note (2006), six steps were followed to identify and evaluate leading indicators of safety when working with the first industry partner:

- Identify the safety decisions in the organization,
- Identify the fundamental objectives for achieving safety in the organization,
- Identify safety factors to achieve the fundamental objectives,
- Measure the organization’s safety performance,
- Measure the safety factors, and
- Determine the candidate leading indicators.

Step 1: Identify Safety Decisions in the Organization

The first step in the Leading Indicators project was to identify the safety decisions in the industry partner organization. Central to the organization’s safety culture was a commitment to minimizing accidents. Thus,

Organization’s Strategic Objective = Minimize Accidents.

The members of the organization, including senior management; vessel managers; safety, health and environmental management; and vetting managers then worked to identify the decisions that were made about procedures and operations in the company that could either avoid accidents altogether or ensure that the correct actions were taken when
exposure occurred. Once the key safety decision in the organization—Minimize Accidents—was identified, the fundamental objectives of safety for the organization were identified.

**Step 2: Identify Fundamental Objectives for Achieving Safety**

In order to determine the fundamental objectives, interview sessions were arranged with experts with different decision contexts within the industry partner organization. Vessel crew management; safety, health and environmental personnel; senior management; and vetting personnel were identified as critical decision makers whose fundamental objectives were critical to the development of leading indicators.

The interviews began by defining the decisions to be analyzed and the alternatives that might be chosen in each decision. From these discussions, the fundamental safety objectives for the industry partner were identified, as shown in Figure 1. These fundamental safety objectives were:

- Improving the Organizational Safety Culture,
- Improving the Shipboard Safety Culture, and
- Improving Each Individual’s Safety Attitude.

**Step 3: Identify Safety Factors to Achieve the Fundamental Objectives**

The next phase of the project was to identify safety factors for each fundamental objective using the same group of experts. Four groups of 3-4 people comprised the expert groups. Participants represented the shipboard operations group; the safety, health and environmental group; the vetting group; and the senior management team. A total of thirteen personnel participated in four group exercises, which took place over a period of two days in the organization’s offices.

Figure 2 summarizes the safety factors identified in the sessions as subsets of the fundamental objectives of Figure 1. Review of previous safety factor studies showed the items to be common with safety factors identified in other studies (Shafai-Sahrai, 1971; Mearns, et al., 2001; 2003; Zimolong & Elke, 2006). Once the safety factors were identified, metrics to measure organizational safety and for the safety factors were determined.

**Step 4: Measure the Organization’s Safety Performance**

Official safety statistics and survey data from each of the participating vessels were utilized to develop the organization’s safety performance data. The safety performance metrics were traditional lagging indicator data—number of accidents per year, number of near losses per year, number of long term injuries requiring 3 or more days absence from work (LTI>=3) per year, number of port state deficiencies per year, and number of conditions of class per year. However, since data for each of the safety performance measures suffered from a small sample size, only near losses could be used as a safety performance variable to support statistically significant analyses.

Surveys were also administered between January and March 2006 to gather safety climate data from individuals and vessels. This data was utilized to evaluate the significance of the safety factors in the industry partner organization.

**Step 5: Measure the Safety Factors**

Metrics for the safety factors were then identified. Preference was given to metrics that were available, such as ones for which operating companies or government entities were already collecting data so as to facilitate future data gathering and leading indicator analysis. Figure 2 shows the number of metrics identified for each of the safety factors in parentheses. Figure 3 gives an example of the metrics identified for the organizational safety factors.
Figure 2 shows that for some safety factors, constructed or proxy indicators were required, such as for Improving Vessel Responsibility, Improving Vessel Communication, and Improving Individual Responsibility, as few metrics were identified for those safety factors. In addition, Figure 2 shows that more than twice as many organizational metrics were identified, compared to the vessel and individual metrics. This suggests that data collection and measurement systems in the industry partner organization focused on broad organizational measurements, rather than on individual metrics. This distribution of metrics may change in the future, as metrics are developed for some of the safety factors without metrics, and as measurement and control systems in the organization change over time.

Step 6: Determine the Candidate Leading Indicators

Significant safety factors were identified by identifying statistically significant correlations between the safety factor metrics and the organization’s safety performance data. Tables 1 and 2 present the correlations of the safety factors with the safety performance data (normalized near losses for the vessel safety factors; perceived safety for the individual safety factors). Near loss data was normalized by the number of vessels in the fleet to facilitate comparison with other companies. Caution is advised with the Table 1 vessel safety factor results, as the sample size is small (only 7 vessels). As a result, p-values within 0.10 are reported as significant in Table 1.

Once the significant safety factors were identified, the metrics corresponding to the safety factors were examined for correlation with the organizational safety data. The significant safety factors and metrics were then identified as candidate leading indicators, as shown in Table 3.

Table 1. Summary of Correlation Analysis of Shipboard Safety Factors (* = small sample size, n = 7 vessels)

<table>
<thead>
<tr>
<th>Vessel Safety Factor</th>
<th>Spearman Correlation with Normalized Near Losses</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prioritization of</td>
<td>-0.74 (n=7) *</td>
<td>0.07</td>
</tr>
<tr>
<td>Problem Identification</td>
<td>-0.85 (n=7) *</td>
<td>0.02</td>
</tr>
<tr>
<td>Vessel Feedback</td>
<td>-0.75 (n=7) *</td>
<td>0.07</td>
</tr>
</tbody>
</table>

Table 2. Summary of Correlation Analysis of Individual Safety Factors

<table>
<thead>
<tr>
<th>Individual Safety Factor</th>
<th>Correlation with Perceived Safety</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Individual Empowerment</td>
<td>0.52</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Anonymous Reporting</td>
<td>0.59</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Individual Feedback</td>
<td>0.67</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Individual Responsibility</td>
<td>0.60</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

Discussion

Seven categories of leading indicators were identified as significantly correlated with safety performance in the first industry partner organization. At the vessel level, Prioritization of Safety, Problem Identification and Vessel Feedback were significantly correlated with normalized near losses; at the individual level, Empowerment, Anonymous Reporting, Individual Feedback and Individual Responsibility were significantly correlated with perceived safety. Organizational level safety factors were not evaluated in this study, as there was only one research partner at the time. The number of leading indicators roughly corresponds to the number of leading indicators identified in other accident precursor and leading indicator studies (Chrvala & Bulger, 1999; Sattison, 2003; Step Change in Safety, 2004; Zimolong & Elke, 2006).

The distribution of leading vs. lagging indicator results is also consistent with earlier work. In general, leading and lagging indicators can be expected to differ by granularity and focus, as seen in Figure 4 (van den Bergh, 2003). Leading indicators are primarily focused at the individual and departmental levels. In contrast, lagging indicators are broader in scope and generally focus on organizational measures. The results of this study are consistent with van den Bergh, 2003, as leading indicators were found at the individual and department (vessel) level. No organizational leading indicators were able to be evaluated because there was only one industry partner participating at the time of this research.
Over the past twenty years, the leading energy transportation firms have developed a number of analytical tools to identify risk in operations, operators, and in vessels. Among these tools are the Oil Companies International Marine Forum’s (OCIMF’s) Tanker Management and Self Assessment program (TMSA) (OCIMF, 2004), which provides a tool to assess safety-management systems against key performance indicator categories, as shown in Table 4 (OCIMF, 2004), and OCIMF’s Ship Inspection Report (SIRE) program (OCIMF, 2007), which provides a data-based tanker risk assessment tool that assesses performance in the areas identified in Table 4 (OCIMF, 2007).

Table 4 shows that although there is some overlap between the TMSA, SIRE, and leading indicator categories, there are also some differences. For instance, the TMSA and SIRE program elements are primarily focused at the organizational level, assessing broad categories of organizational performance, while the leading indicators in Table 4 are focused at the individual and department (vessel) levels of the organization. Inspection of the three research instruments also reveals a qualitative difference between the information gathered with the TMSA and SIRE programs and in the leading indicator program: the TMSA and SIRE program elements determine whether the different systems identified in Table 4 are in place or not. In contrast, the leading indicator data verifies the effectiveness of the systems or their components. Thus, use of leading indicator data in concert with the TMSA and SIRE programs can provide insight as to the effectiveness of existing systems, as well as insight and warnings of impending events at the individual and department (vessel) level.

There are other differences in the leading indicators identified in this research. As can be seen from Table 3, the leading indicators are primarily subjective measures, in contrast to more traditional quantitative metrics of safety performance. Thus, the use of leading indicators, in conjunction with traditional safety and performance measuring systems, can provide a balance between quantitative, organizational, lagging metrics of safety performance and qualitative individual and vessel leading indicators. The subjective leading indicator data might serve as an effective complement to existing data collection and management systems in place in industry. However, new data gathering, analysis and monitoring processes may be required with a leading indicator program, since much safety data analysis is currently focused on quantitative, organizational lagging metrics, rather than qualitative, individual and departmental leading indicators.
Standardized metrics for measuring the leading indicators are provided in Table 3. Many of these metrics were derived from validated survey instruments developed by the aviation, railway, and marine transportation communities along with the aerospace and nuclear communities over the past 40 years. The root of these surveys is the Flight Management Attitudes Questionnaire (FMAQ), an aviation safety culture and safety climate survey (Sexton, Helmreich, Neillands, Bowen, Vella, Boyden, Roberts & Thomas, 2006; Helmreich, Merritt, Sherman, Gregorich & Weiner, 1993). The Table 3 metrics were also derived from validated safety climate surveys from the U.K. oil and gas industry, including the Health and Safety Climate Tool (HSCST), the Offshore Safety Climate Questionnaire (OSQ), the Computerized Safety Climate Questionnaire (CSCQ), the Loughborough Safety Climate Assessment Toolkit (LSCAT), the Quest Safety Climate Questionnaire (QSCQ), the Ship Management Attitudes Questionnaire (SMAQ), and the Safety Attitudes Questionnaire (Health & Safety Executive, 1997a; b; Mearns, Flin, Gordon, and Fleming, 1998; Flin, R., Mearns, O’Connor, and Bryden, 2000; Mearns, Whitaker, and Flin, 2003; Andersen, Garay, & Itoh, 1999; Sexton, Helmreich et al. (2006), Sexton & Thomas, 2003). The Table 3 metrics can be helpful in standardizing administration and data collection of qualitative leading indicator survey data across the marine transportation system.

The seven categories of leading indicators identified in Table 4 are preliminary in nature, and are in the process of review by the industry partner organizations. These results require assessment over time in order to establish their validity, particularly through a continuous improvement process that identifies and monitors leading indicators, to determine their predictive validity.

**USE OF LEADING INDICATORS**

The purpose of leading indicators is to identify gaps in the current environment and to guide actions for improving future performance. Thus, one of the important characteristics of leading indicators is that they should facilitate continuous improvement, and be seen as a part of a process for improving future performance (Chrvala & Bulger, 1999; Step Change in Safety, 2004).

Ship operators, owners and charterers can utilize leading indicators as part of their on-going screening, review, monitoring and control processes. Leading indicators can serve as a critical component of effective planning, monitoring and control systems, and of a continuous learning and improvement processes, within and between shipping organizations, owners and charterers. Following Table 4 and Figure 5, an extension of the Oil Companies International Marine Forum Vessel Inspection Questionnaire for bulk, oil, chemical and gas carriers (OCIMF, 2000) might be envisioned to incorporate leading indicator metrics, as might extensions to the Tanker Management Safety Assessment (TMSA) system.

Figure 5. TMSA, SIRE and Leading Indicators (following van der Bergh, 2003)

Regulatory organizations might utilize leading indicators as part of their oversight, compliance, and review responsibilities. Understanding which facets of an organization, culture, operation or vessel to monitor, observe or highlight as models for others in industry is an important benefit of an established and empirically validated leading indicator program. More importantly, understanding leading indicators of safety within different subcultures in an organization might significantly enhance regulatory oversight, understanding and compliance activities. Classification societies might also use leading indicator results as benchmarking metrics within and between class societies, as well as to provide services to clients. Thus, a common leading indicator framework used by industry, regulators, classification societies, and others, could provide the foundation for a strengthened safety culture and precursor measurement/management program.

Despite the promising nature of these findings, however, there are several cautions that should be heeded with these initial results. First, as described, the results reported in this paper are preliminary, the results of a cross-sectional study, and represent one data point in one organization, in what must be an on-going series of organizational measurements. No longitudinal data has been collected at this point from any of the research partners, although discussions about such data collection have begun. Analysis of safety culture and objective data from the industry partner over time can be helpful in understanding how safety culture perceptions fluctuate over time as well as how relationships between safety factors and safety performance metrics change over time. It will be important to establish the validity of any leading indicators over sufficiently long periods of time in order to determine their validity. In both industry and regulatory use, strong longitudinal correlations between the indicators and safety performance must be established in order to prove the indicators’ reliability.

Integration of diverse data sets from different operators will also be critical to developing a generalized leading indicator model that reaches across the marine transportation system. Longitudinal results that reflect many organizations’ performance and perceptions over time will be important in establishing effective and predictive leading indicators--for industry, for regulators, for different sectors of the marine transportation system, and for the marine transportation system itself.
There were a number of research design factors that limited the strength of these results. First, the results in this study relied on correlations, which is not causation, and only reveals bivariate associations between variables. Higher order models examining the causal relationships between safety factors and safety performance metrics (i.e., structural equation modeling (SEM)) will be considered in future research. In addition, the current study was limited by small sample sizes. In this research, data was collected in only one organization, with a small fleet (n = 7 vessels), which meant that the significance of any organizational level safety factors could not be evaluated, and the vessel safety factors were hampered by small sample sizes. Corroboration of the trends noted in the vessel results with larger and more diverse samples is an important next step in this research.

Finally, the data required to establish a leading indicators of safety program is a mix of existing quantitative safety performance data (already collected by industry, government, non-profit and environmental groups) as well as new qualitative safety perception data (not collected on a regular basis by any of the groups just noted). In order to establish an effective leading indicators program, new data collection and analysis methods, processes and requirements need to be developed, tested, promulgated and revised over time. The size and scope of this effort should not be underestimated. Industry might voluntarily agree to comply with new suggestions for data collection, reporting, and maintenance, and regulators might develop reporting, analysis and monitoring mechanisms for such precursor data, but the costs and infrastructure required to establish such a program industry-wide would be significant and warrant careful investigation (Chrvala & Bulger, 1999; Phimister, Bier & Kunreuther, 2003).

It will be important to analyze the effectiveness of leading indicators over time as safety efforts change, as goals are achieved, and as new areas of improvement are identified. Thus, in addition to initial validation of the leading indicators, a periodic analysis of leading indicators should be undertaken in order to reveal which indicators are not effective and need replacement. Analysis of the effectiveness of leading indicators can also be used to communicate the achievement of safety goals and to maintain momentum on safety efforts.

SUMMARY AND NEXT STEPS

Using the methodology described in this paper, seven categories of leading indicators for one domestic U.S. energy transportation company were identified. The methodology was described, safety performance and safety climate data were collected, and an analysis of the data was undertaken. Metrics operationalizing the leading indicator categories were presented, and the leading indicator results were compared to safety management concepts at use within the industry.

Data analysis from the first two industry partners in the ABS Leading Indicators of Safety project was completed in 2007. Data collection with the third industry partner, a domestic U.S. container and government shipping organization, began in April 2007; analysis of this data will also be completed in 2007. Additional research partners in 2007 and 2008 include the international parent companies for the domestic U.S. tanker and container operators. In addition, a second round of data collection with the original industry partners is anticipated in 2007 so as to provide early trend analyses. Following analysis of this data, a generalized model of leading indicators of safety in marine transportation will be proposed and empirically evaluated.

REFERENCES


