We are Lagging behind on Safety:
Leaders Should Measure Leading Indicators

Organizations involved in safety-critical activities measure their performance using the number of problems, accidents, or events that they have experienced in a given period of time. Recently some organizations have focused on near misses to examine what could go wrong, but this still means the organization was close to experiencing a potentially tragic or dangerous event. This paper describes a framework for developing leading indicators of safety. Considerable research has been performed to develop leading indicators for economics, health care, and safety, and many managers are seeking a dashboard to warn of upcoming problems in their organizations. Our approach is drawn from Value Focused Thinking, which helps to understand the objectives and evaluation measures that frame a particular decision context within an organization and to relate the objectives for different decision contexts with mean-ends relationships. The hypothesis that we explore in this article is that measures that are fundamental to the units within an organization are leading indicators of performance for the whole organization. We find that for better leading indicators of an organization's performance, one must drill down further in to the organization. The domain for our initial research is maritime transportation, a critical factor in the performance of a maritime organization. We test our hypothesis with surveys and safety data drawn from the maritime transportation divisions of two Fortune 100 companies.

Key words: leading indicators; value focused thinking; safety

1. Introduction

An indicator is a metric that reflects an organization's performance in a given area. When given the choice of an indicator that tells you how you have performed to date, a lagging indicator, and one that tells you how you will perform in the future, a leading indicator, most managers would choose the latter; they seek a crystal ball to warn of future catastrophes or an executive dashboard that warns when the corporate oil pressure is getting too low. However, most indicators used by organizations are lagging indicators. For instance, most financial indicators are based on data from the previous year. In this research, we aim to provide a framework for developing leading indicators and demonstrate its effectiveness in a real-world case study. While the focus of our research has been safety, we believe this approach is equally applicable to provide leading indicators for other strategic objectives of an organization.

Our approach seeks to understand the decisions made within an organization through the objectives that decision makers at various levels of the organization are attempting to achieve; we inter-relate the objectives of decision makers at different levels of the organization, determine how to measure these objectives, and test the performance for different sets of objectives as leading indicators of the organization's overall strategic objectives. Keeney (1992) uses the concept of a *decision frame* to explain the decisions that people make. A decision frame consists of a decision maker's set of alternatives and the objectives that the decision maker is attempting to achieve when choosing between these alternatives. The objectives can be categorized as means, fundamental, and strategic objectives. A *means objective* is one way to achieve another objective. A *fundamental objective* is an objective that governs a decision maker's choice in a particular decision context and is not controlled by factors beyond the current decision at hand. A *strategic objective* is one that reflects the long-term goals of a decision maker's organizational setting; a strategic objective may be affected by many decisions in an organization. Our research hypothesis is that measures of the fundamental objectives of decision makers within an organization are indicators of the organization's future performance, or leading indicators. Leading indicators have been studied in many types of systems, with widely varying results. The usual approach is data mining relationships be-

tween the variables of interest and any indicator data that is already gathered. Currently no formal approach to determining indicators, irrespective of whether data is already collected on them, exists.

Many economic systems, including the U.S. economy, use composite indexes and economic series with leading, coincident, and lagging indicators of economic performance (Conference Board, 1997; 2004). In economic systems, leading indicators are those indicators that tend to shift direction in advance of a business cycle. Coincident economic indicators, such as employment and production, are broad series that measure aggregate economic activity, and thus define the business cycle. Lagging indicators tend to change direction after the coincident series. In economic systems, lagging indicators are used to confirm turning points and to warn of structural imbalances in the economy.

Over the past thirty years, the medical community has developed increasingly sophisticated leading indicators of health 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).

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 (1971), 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).

Our approach differs from this previous work by not aiming to examine the organizational culture or mine the data that is already collected by the organization, but rather to first understand the decisions made within the organization and then to develop indicators to measure the attainment of these objectives. Furthermore, unlike previous research in leading indicators, value focused thinking provides a sound methodological framework for our research. In Section 2, we use the tools of value focused thinking to understand the relationships between the objectives of decision makers at various levels of the organizational structure. Section 3 provides a more formalized research hypothesis using these objectives. In Section 4, we discuss the development of the survey instruments used to test our research hypothesis. Section 5 discusses the results of the surveys and answers three basic questions associated with our research: 1) Does value focused thinking identify good leading indicators? 2) What type of survey questions provides the strongest leading indicators? 3) At what level of the organization chart should we seek decision makers to find the best leading indicators? Final conclusions and future research directions are identified in Section 6.

2. Relating Objectives within an Organization

Consider the objectives that the chief executive officer or the board of an organization might consider in making decisions: maximize profit, maximize revenue, minimize costs, and maximize dividend return to investors. Now maximize revenue and minimize costs are means to maximizing profit. Moreover, maximize profit is a means to maximizing dividends. These relationships are shown in Figure 1, which is re-

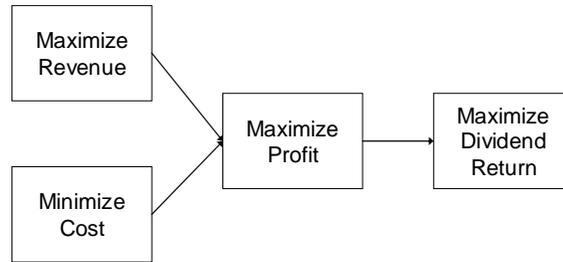ferred to as a means-objectives network, with arrows connecting each means objectives to its end objective.

Figure 1. A partial means objectives network for the head of an organization.

Now let us consider the head of sales for an organization. One obvious fundamental objective in this role is to maximize sales volume; maximize sales volume is a means to maximizing revenue. Consider the head of production and their fundamental objectives: minimize production costs and maximize quality. Minimizing production costs is one means to minimizing total costs and maximizing quality is a means to both minimizing costs (of returns and lost future business) and maximizing units sold (through maintaining good brand image). Figure 2 shows these relationships as a means objectives network. Thus the objectives within an organization are inter-related and the fundamental objectives for the decisions that the head of sales and the head of production are means to achieving the fundamental objectives for the CEO or board. Further down the organization, an individual salesperson is attempting to maximize his or her personal sales volume which is a means to maximizing the organization's sales volume. An individual attempting to maximize their own efficiency and quality on production line is in turn helping achieve the head of production's objectives.
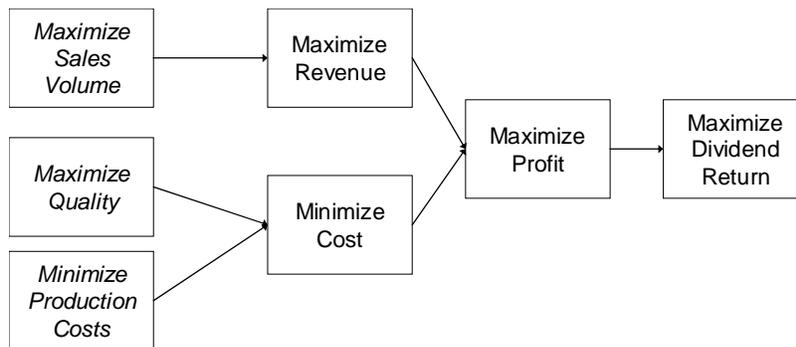

Figure 2. Connecting the fundamental objectives across the executive team.

The objectives we have discussed thus far provide well known indicators of organizational performance, but these are lagging indicators. Once a problem presents itself through these indicators, the effects have happened and the organization is attempting to recover. We assert that this is because they are objectives for decision makers at the top of the organizational structure. Let us turn now to consider our initial domain for this research, namely safety in shipping companies, and seek to understand the objectives for decision makers further down the organizational structure.

Through interviews with mariners and managers in a major shipping company, we developed the means objective network shown in Figure 3. The strategic objective of safety initiatives in a shipping company is to minimize the consequences of accidents involving their vessels; a means to obtaining this objective is minimizing the frequency of accidents involving their vessels; this may be achieved through reducing the frequency of mechanical failures and minimizing human errors that cause accidents. This part of the means objective network in Figure 3 mirrors the accident event chain used in many maritime risk studies (Merrick et al. 2000, 2002, 2003; Grabowski et al 2000). However, such reductions can only be achieved by having each individual involved in operating the vessels take the correct actions, thus the organization must improve each individual's safety attitude. Most programs or initiatives to achieve this objective are carried out at the crew level, seeking to improve the overall shipboard safety culture on each vessel operated by the organization. To obtain this objective, the organization seeks to instill an organization-wide identity centered on safety.
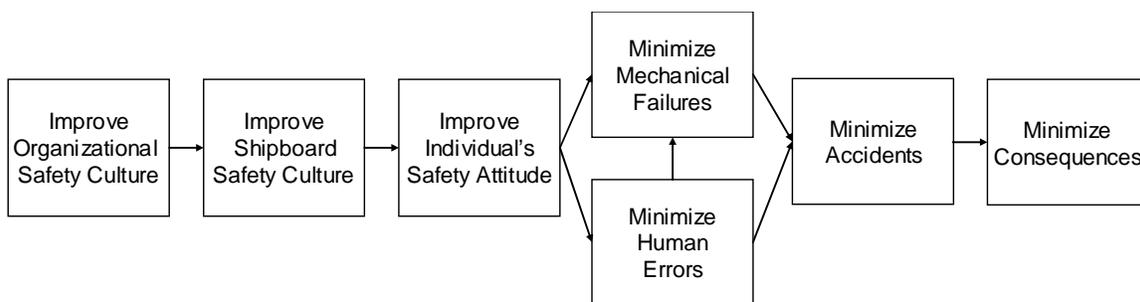

Figure 3. The means objective network for improving safety in a major shipping company.

Merrick et al. (2005) use this framework to link the fundamental objectives of three types of decision makers within a major shipping company. The organizational safety culture is the purview of the senior management team of the organization; the shipboard safety culture is the responsibility of the captain and his vessel management team; the individual safety attitude is interestingly enough the main target of the safety, health and environmental (SHE) team. Figure 4 extends Figure 3 by including the fundamental objectives for these three types of decision makers within the organization, as developed in Merrick et al. (2005). The leaves that drop down from "improve organizational safety culture", "improve shipboard safety culture", and "improve individual safety attitudes" are the fundamental objectives that define what is meant by each of these more general objectives.
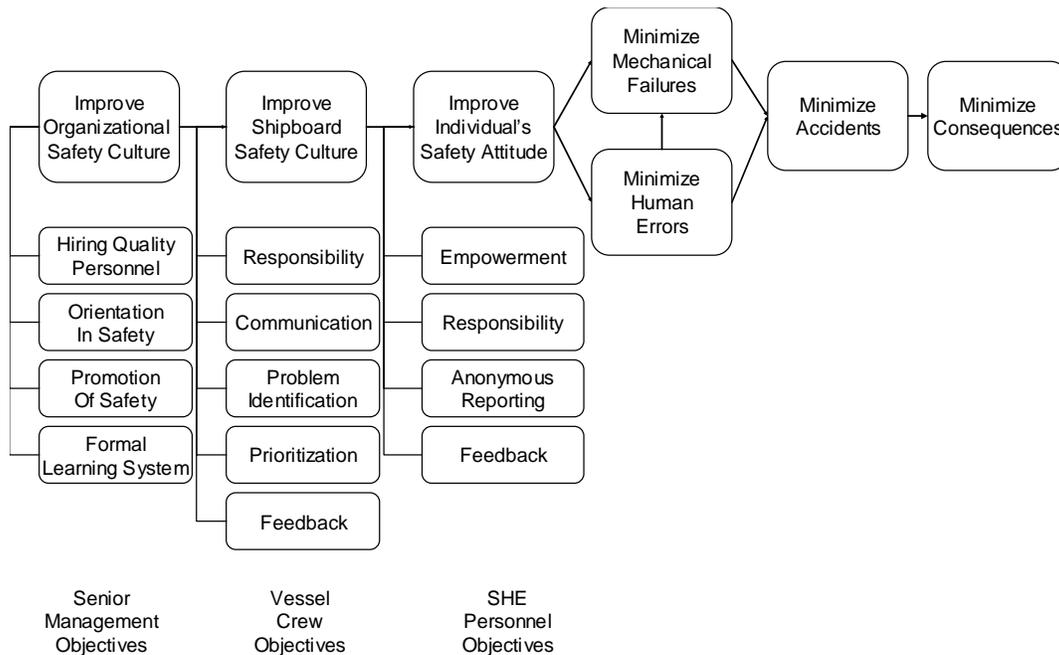
Figure 4. Adding different decision makers' fundamental objectives to the means objective network for improving safety in a major shipping company.

Figure 4 shows the relationships between the decision makers with primary responsibilities for safety within a shipping company. While this framework was developed in Merrick et al. (2005) through interviews with one major shipping company, it has since been verified through interviews with two other

organizations involved in worldwide shipping. This framework provides the basis for the testing of our research hypothesis.

3. Research Hypothesis

As stated in the introduction, our research hypothesis is that measures of the fundamental objectives of decision makers within an organization are indicators of the organization's future performance, or leading indicators. However, this statement is too general to test. Thus we seek to test our assertion through a more specific hypothesis. We claim that the fundamental objectives for the three different decision contexts in Figure 4 provide indicators that are highly correlated with both accident frequencies and precursor events, such as near misses or near losses. Furthermore, we claim that such indicators current values are indicators of safety performance in the future.

However, at the current stage of the research we have data from two organizations on their current levels of indicators of the fundamental objectives in Figure 4 and current safety performance. The organizations for which we have data have long-standing, stable safety programs, thus we assume that their performance on these indicators is the same as it was five years ago and we can test the relationship between these indicators and their overall safety performance. However, we will seek to verify this assumption over the next five years by continuing to collect safety performance data on these organizations as well as data on other partner organizations. Also, the level of safety in our partner organizations is high, meaning that they have very few, if any, accidents. Thus we use the number of near losses per year as our measure of safety performance and seek to correlate this to the indicators we develop from the objectives in Figure 4.

Recall that we have three primary research questions: 1) Does value focused thinking identify good leading indicators? 2) What type of survey questions provides the strongest leading indicators? 3) At what level of the organization chart should we seek decision makers to find the best leading indicators? The first question is answered by testing the strength of the relationship between the achievement of the fundamental objectives in Figure 4 and the number of near losses. The second question will be tested by using different metrics to measure the achievement of the fundamental objectives in Figure 4 and analyz-

ing which provide the strongest relationships with the number of near losses. The third question seeks to compare the three sets of fundamental objectives; the senior management team is at the top of the organizational chart, then each vessel's management, and then the individual crew members. Should we look for leading indicators at the top of the organization or the bottom?

4. Safety Surveys

While the partner organizations in this research are in the process of setting up the data-collection processes necessary to track the leading indicators developed, for the purposes of testing our hypothesis we used a survey instrument based on agreement/disagreement questions with various assertions about the fundamental objectives in Figure 4. Each respondent could then make an evaluation on a standard 5-point Likehart scale (1 – Strongly Disagree, 2 – Somewhat Disagree, 3 – Neutral, 4 – Somewhat Agree, 5 – Strongly Agree). This provided ordinal factors that could be regressed against the number of near losses encountered on each vessel in the organization's fleet.
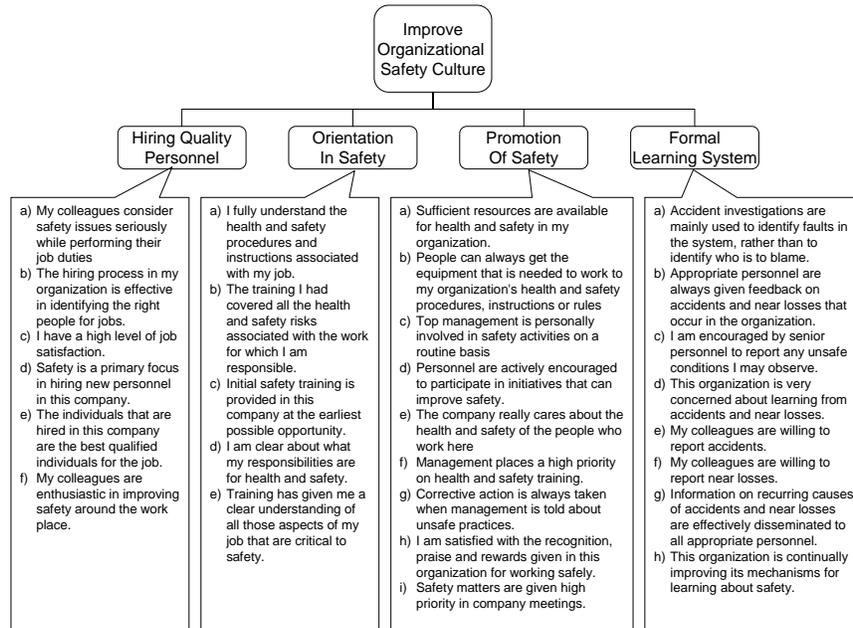


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                        Improve
                     Organizational
                     Safety Culture

    Hiring Quality      Orientation       Promotion         Formal
     Personnel           In Safety        Of Safety     Learning System
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Hiring Quality Personnel
a) My colleagues consider safety issues seriously while performing their job duties
b) The hiring process in my organization is effective in identifying the right people for jobs.
c) I have a high level of job satisfaction.
d) Safety is a primary focus in hiring new personnel in this company.
e) The individuals that are hired in this company are the best qualified individuals for the job.
f) My colleagues are enthusiastic in improving safety around the work place.

Orientation In Safety
a) I fully understand the health and safety procedures and instructions associated with my job.
b) The training I had covered all the health and safety risks associated with the work for which I am responsible.
c) Initial safety training is provided in this company at the earliest possible opportunity.
d) I am clear about what my responsibilities are for health and safety.
e) Training has given me a clear understanding of all those aspects of my job that are critical to safety.

Promotion Of Safety
a) Sufficient resources are available for health and safety in my organization.
b) People can always get the equipment that is needed to work to my organization's health and safety procedures, instructions or rules
c) Top management is personally involved in safety activities on a routine basis
d) Personnel are actively encouraged to participate in initiatives that can improve safety.
e) The company really cares about the health and safety of the people who work here
f) Management places a high priority on health and safety training.
g) Corrective action is always taken when management is told about unsafe practices.
h) I am satisfied with the recognition, praise and rewards given in this organization for working safely.
i) Safety matters are given high priority in company meetings.

Formal Learning System
a) Accident investigations are mainly used to identify faults in the system, rather than to identify who is to blame.
b) Appropriate personnel are always given feedback on accidents and near losses that occur in the organization.
c) I am encouraged by senior personnel to report any unsafe conditions I may observe.
d) This organization is very concerned about learning from accidents and near losses.
e) My colleagues are willing to report accidents.
f) My colleagues are willing to report near losses.
g) Information on recurring causes of accidents and near losses are effectively disseminated to all appropriate personnel.
h) This organization is continually improving its mechanisms for learning about safety.

Figure 5. Survey indicators developed for the fundamental objectives of senior management.

To develop the assertions or questions for each fundamental objective, we surveyed the literature for each domain across various industries, including maritime transportation, offshore drilling, aviation, mining, manufacturing, nuclear energy, and medicine, as well as general occupational safety literature.

Figures 5, 6, and 7 show the relevant assertions that were found for each fundamental objective, with Figure 5 showing those under "improve organizational safety culture", Figure 6 showing those under "improve shipboard safety culture", and Figure 7 showing those under "improve individual safety attitude".
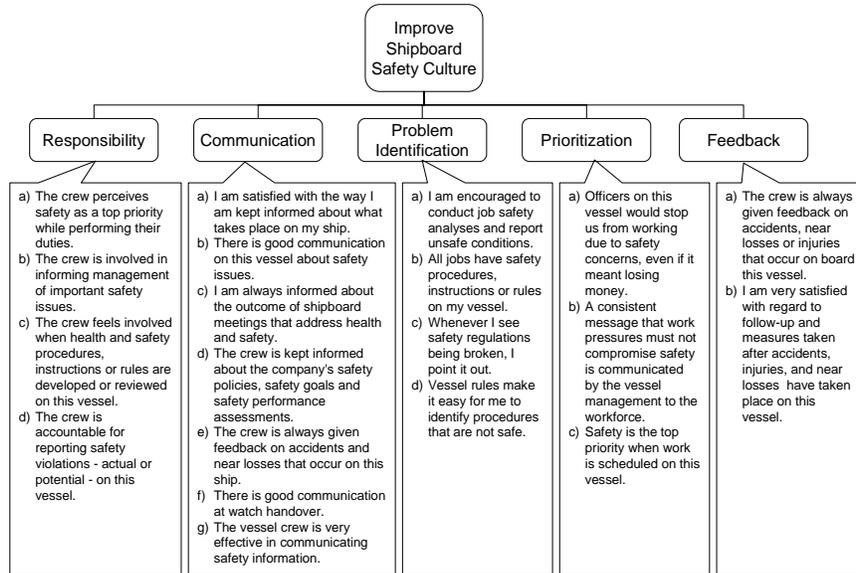

Figure 6. Survey indicators developed for the fundamental objectives of vessel management.
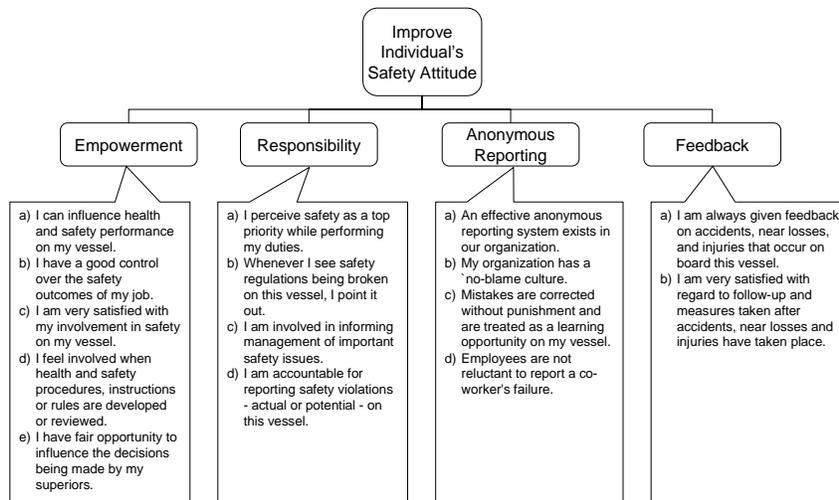

Figure 7. Survey indicators developed for the fundamental objectives of individual crew members.

Each of these assertions, and a corresponding Likehart scale, was included in the leading indicator survey that went out to all employees in the organization. We also collected data on the number of near losses and number of accidents on each vessel operated by our partner organizations in the previous year. We should note that for one of our partner organizations, there were not enough accidents to provide

a meaningful response variable, so we use near losses. For the other partner organization, we could use the number of accidents per year as the response variable, but their near losses were insufficient as they did not have as reliable a near loss reporting system. In the results that follow we remove the scale to maintain confidentiality for our partner organizations.

5. Results

The first step in our analysis of the leading indicator survey and near loss data is to assess which indicators have the strongest relationship with the response variable, near losses. If we assume that each unit increase on our 1-5 scale is equivalent, then we may treat the responses on the Likehart scale as continuous factors and calculate their correlation with the near loss response variable. This provides an easily interpretable assessment of the strength of the relationship, namely that we are seeking moderately strong, negative values that would indicate that the stronger the achievement of the fundamental objective the fewer near misses the organization experiences. Although we would like correlations showing strong and very strong negative relationships, we point out that there is no silver bullet in predicting safety performance as even the safest organization cannot avoid all problems caused by other users of the waterways that they traverse or even rogue employees within their own organization. Table 1 shows all the indicators for "improve organizational safety culture" and their corresponding correlations with near losses for each partner organization. The strongest negative relationships are shown in bold for each organization. (Note that to check our assumption of equivalent unit increases, we also regressed the ordinal factors against the response variable and the p-values of the analysis of variance on the model agreed with the rankings for the correlations, but did not provide an indication of direction, so we felt that the interpretation of the correlations was better). Tables 2 and 3 show the correlations for the shipboard safety indicators and for the individual safety indicators respectively. Our first observation is that there are many moderately strong, negative correlations in Tables 1, 2, and 3. Thus we have answered our first research question: the level of achievement of the fundamental objectives of our partner organization is a leading indicator of their safety performance.

Table 1. The correlations of each indicator with the number of near misses for organizational safety indicators.

Organizational Safety Factors	Questions	Organization A	Organization B
Hiring Quality Personnel	a) My colleagues consider safety issues seriously while performing their job duties	0.22	-0.14
	b) The hiring process in my organization is effective in identifying the right people for jobs.	-0.07	-0.11
	c) I have a high level of job satisfaction.	-0.10	-0.06
	d) Safety is a primary focus in hiring new personnel in this company.	**-0.20**	**-0.23**
	e) The individuals that are hired in this company are the best qualified individuals for the job.	-0.19	-0.11
	f) My colleagues are enthusiastic in improving safety around the work place.	0.02	-0.07
Orientation in Safety	a) I fully understand the health and safety procedures and instructions associated with my job.	-0.36	-0.06
	b) The training I had covered all the health and safety risks associated with the work for which I am responsible.	-0.31	-0.11
	c) Initial safety training is provided in this company at the earliest possible opportunity.	-0.38	0.05
	d) I am clear about what my responsibilities are for health and safety.	**-0.40**	-0.05
	e) Training has given me a clear understanding of all those aspects of my job that are critical to safety.	-0.23	**-0.13**
Promotion of Safety	a) Sufficient resources are available for health and safety in my organization.	-0.07	-0.09
	b) People can always get the equipment that is needed to work to my organization's health and safety procedures, instructions or rules	0.02	-0.12
	c) Top management is personally involved in safety activities on a routine basis	-0.23	-0.09
	d) Personnel are actively encouraged to participate in initiatives that can improve safety.	-0.09	-0.17
	e) The company really cares about the health and safety of the people who work here	**-0.31**	-0.19
	f) Management places a high priority on health and safety training.	-0.26	**-0.22**
	g) Corrective action is always taken when management is told about unsafe practices.	-0.15	-0.20
	h) I am satisfied with the recognition, praise and rewards given in this organization for working safely.	-0.02	-0.15
	i) Safety matters are given high priority in company meetings.	-0.09	-0.21
Formal Learning System	a) Accident investigations are mainly used to identify faults in the system, rather than to identify who is to blame.	-0.23	**-0.24**
	b) Appropriate personnel are always given feedback on accidents and near losses that occur in the organization.	-0.19	-0.14
	c) I am encouraged by senior personnel to report any unsafe conditions I may observe.	-0.05	-0.06
	d) This organization is very concerned about learning from accidents and near losses.	-0.24	-0.20
	e) My colleagues are willing to report accidents.	-0.14	-0.08
	f) My colleagues are willing to report near losses.	-0.16	-0.12
	g) Information on recurring causes of accidents and near losses are effectively disseminated to all appropriate personnel.	**-0.28**	-0.11
	h) This organization is continually improving its mechanisms for learning about safety.	-0.24	**-0.24**

Table 2. The correlations of each indicator with the number of near misses for shipboard safety indicators.

Crew Safety Factors	Questions	Organization A	Organization B
Responsibility - Shipboard	a) The crew perceives safety as a top priority while performing their duties.	-0.04	-0.10
	b) The crew is involved in informing management of important safety issues.	-0.01	-0.10
	c) The crew feels involved when health and safety procedures, instructions or rules are developed or reviewed on this vessel.	0.05	**-0.19**
	d) The crew is accountable for reporting safety violations - actual or potential - on this vessel.	**-0.34**	-0.09
Communication	a) I am satisfied with the way I am kept informed about what takes place on my ship.	0.03	-0.13
	b) There is good communication on this vessel about safety issues.	-0.05	-0.14
	c) I am always informed about the outcome of shipboard meetings that address health and safety.	-0.11	-0.17
	d) The crew is kept informed about the company's safety policies, safety goals and safety performance assessments.	**-0.13**	-0.19
	e) The crew is always given feedback on accidents and near losses that occur on this ship.	0.01	**-0.23**
	f) There is good communication at watch handover.	-0.03	-0.13
	g) The vessel crew is very effective in communicating safety information.	-0.03	-0.13
Problem Identification	a) I am encouraged to conduct job safety analyses and report unsafe conditions.	-0.01	-0.10
	b) All jobs have safety procedures, instructions or rules on my vessel.	**-0.16**	**-0.29**
	c) Whenever I see safety regulations being broken, I point it out.	-0.02	-0.07
	d) Vessel rules make it easy for me to identify procedures that are not safe.	0.03	-0.11
Prioritization	a) Officers on this vessel would stop us from working due to safety concerns, even if it meant losing money.	0.17	0.06
	b) A consistent message that work pressures must not compromise safety is communicated by the vessel management to the workforce.	0.11	-0.02
	c) Safety is the top priority when work is scheduled on this vessel.	**-0.03**	**-0.20**
Feedback - Shipboard	**a) The crew is always given feedback on accidents, near losses or injuries that occur on board this vessel.**	-0.02	**-0.24**
	b) I am very satisfied with regard to follow-up and measures taken after accidents, injuries, and near losses have taken place	**-0.06**	-0.22

Table 3. The correlations of each indicator with the number of near misses for individual

safety indicators.

Individual Safety Factors	Questions	Organization A	Organization B
Empowerment	a) I can influence health and safety performance on my vessel.	0.03	-0.09
	b) I have a good control over the safety outcomes of my job.	**-0.10**	-0.06
	c) I am very satisfied with my involvement in safety on my vessel.	-0.06	**-0.21**
	d) I feel involved when health and safety procedures, instructions or rules are developed or reviewed.	0.06	-0.19
	e) I have fair opportunity to influence the decisions being made by my superiors.	-0.04	-0.16
Responsibility - Individual	**a) I perceive safety as a top priority while performing my duties.**	0.17	**-0.14**
	b) Whenever I see safety regulations being broken on this vessel, I point it out.	-0.01	-0.10
	c) I am involved in informing management of important safety issues.	-0.12	-0.06
	d) I am accountable for reporting safety violations - actual or potential - on this vessel.	**-0.15**	-0.06
Anonymous Problem Reporting	**a) An effective anonymous reporting system exists in our organization.**	**-0.32**	0.02
	b) My organization has a `no-blame culture.	-0.23	**-0.23**
	c) Mistakes are corrected without punishment and are treated as a learning opportunity on my vessel.	-0.06	-0.12
	d) Employees are not reluctant to report a co-worker's failure.	-0.07	-0.10
Feedback - Individual	**a) I am always given feedback on accidents, near losses, and injuries that occur on board this vessel.**	**-0.03**	-0.27
	b) I am very satisfied with regard to follow-up and measures taken after accidents, near losses and injuries have taken place.	0.00	**-0.29**

Table 1 not only shows the best leading indicators from our survey instrument, but closer examination reveals the types of questions that make good indicators. In each case, the best indicators for each organization are either the same or very similar in their assertion. Some of the assertions like "My colleagues are enthusiastic in improving safety around the work place." for hiring quality personnel, are too long-winded. Others, like "I have a high level of job satisfaction" are too indirectly related to the fundamental objective. Each of these types of indicators has low, negative or positive correlations. Each of the "best" leading indicators in bold are directly related to the corresponding fundamental objective and they are succinct statements that can be readily assessed by the respondent. Thus we answer our second re-

search questions: succinct survey statements that are directly related to the fundamental objective provide the best leading indicators. The same observations hold true in Tables 2 and 3.

With the "best" leading indicator questions identified, and indeed the best approach for determining assertions in the survey instrument, we may now ask our third research question. What is the best level of the organizational chart at which to seek leading indicators? Should we assess the achievement of the objectives discussed in the board room or on deck of the vessel? To answer this question, we performed a regression of the "best" indicators in each group coded as ordinal variables against the number of near misses. When we say coded as ordinal variables, the parameters for each indicator reflected the improvement from level 1 to level 2, from level 2 to level 3, etc. Thus we fitted three regression models to the survey and near loss data from our partner organizations, one each for "improve organizational safety culture", "improve shipboard safety culture", and "improve individual safety attitude". If the best fitting model was for the four indicators under "improve organizational safety culture" then we may conclude that we should seek leading indicators in the board room, or at the highest level of the organizational structure. If the best fitting model was for the indicators under "improve individual safety attitude" then we may conclude that we should seek leading indicators on deck, or at the lowest level of the organizational structure.

Table 4 shows the adjusted R^2 and whole model p-value for each of the three models and for both partner organizations. The adjusted R^2 value accounts for the different number of parameters in each model and higher numbers indicate that the model explains a larger percentage of the variability in the near loss response variable. The whole model p-value indicates the statistical significance of each model and lower values indicate that the relationship between the model's predictions and the observed values of the near loss response variable are more statistically significant. In Table 4, the adjusted R^2 values increase the further down we get in the organizational structure and the p-values decrease for both organizations. Thus, we may conclude that the further down the organizational structure we search for leading indicators, the better the leading indicators will be.

Table 4. Model fit criteria for regression models including all indicators at each level.

Level	Organization A (n=77)		Organization B (n=846)	
	Rsquare Adj.	p-value	Rsquare Adj.	p-value
Organizational Safety Factors	18.00%	0.03370	9.95%	0.00006845
Crew Safety Factors	27.83%	0.00210	15.51%	0.00000059
Individual Safety Factors	28.58%	0.00220	15.98%	0.00000001

Figure 7 shows the least square means of the parameters for the indicators under "improve individual safety factors" along with their corresponding confidence intervals. These estimates are for partner organization A; as the results were similar for organization B, the figures were omitted to conserve space. We may see moderate to strong decreases in the predicted number of near losses as the agreement with each assertion increases for all but one factor. The decreases for an effective anonymous reporting system and feedback to the individual crew member were the strongest; empowerment of the crew member to improve safety shows a decrease, but not a statistically significant one.
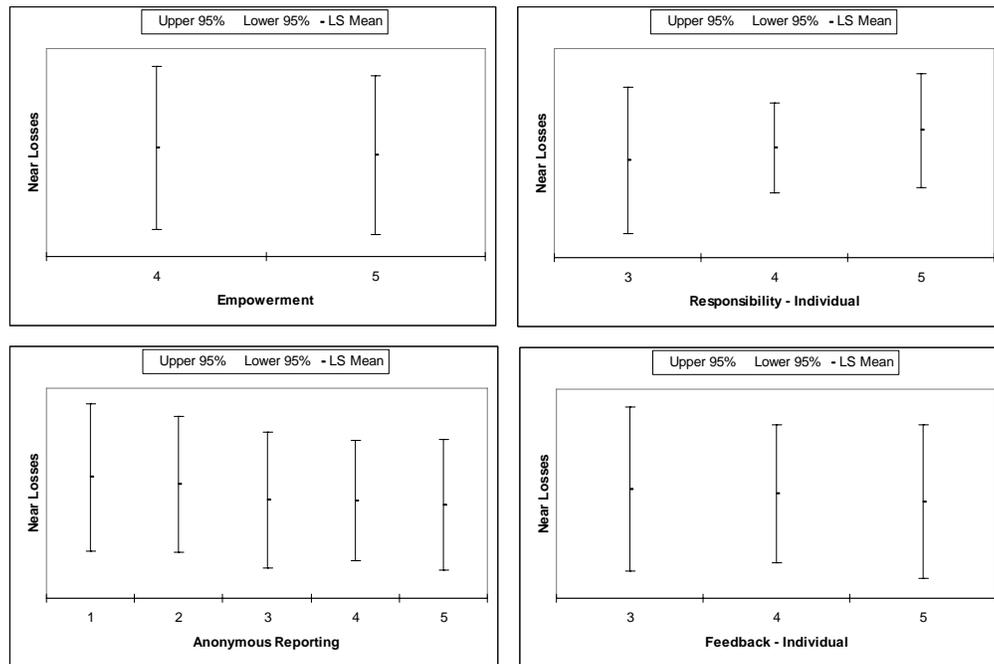

Figure 7. The lest square means estimates for the survey response variables for the indicators at the lowest level of the organizational structure.

However, once the effect of these three indicators on the near loss response variable is removed (by fitting the model with all four indicators) the final indicator, improve responsibility, shows a positive trend. This is at first glance unexpected as that indicator showed a correlation of -0.15 on its own, before the effect of the three other indicators on the response variable was filtered out. However, if we examine the language used in the "best" indicator we find a possible answer. The "best" indicator came from the statement "I am accountable for reporting safety violations - actual or potential - on this vessel." It is interesting to note that agreement with this statement means that the responder to the survey will report all unsafe events on the vessel, meaning that there will be higher number of near losses reported than for a vessel where the crew were less willing to report unsafe events, even though the willing reporter's vessel may actually experience fewer unsafe events. This is the same effect we have observed in previous maritime risk assessments where safer organizations actually voluntarily report more unsafe events, even though the less safe organizations turn out to experience more (Merrick et al. 2000; Grabowski et al. 2000). It will be interesting to see whether this effect continues as additional data is collected as the project continues.

6. Conclusions

We have demonstrated an approach for finding leading indicators based on value focused thinking. We tested our approach working with our research partner organizations in the domain for our research, maritime safety. Through interviews with decision makers at various levels of the organizational structure, we develop the fundamental objectives for each level of decision maker and relate the objectives of each level through a means objective network. We developed a survey instrument to assess the levels of achievement of each fundamental objective that went out to employees of our research partner organizations. The responses to this survey made up the indicators tested in our research; we analyzed the relationship between these indicators and the number of near losses experienced on each vessel. We found that the strongest leading indicators were found from the interviews with decision makers at the lowest level of the organization. We also found that the surveys were best if the statements were straightforward and

directly related to the fundamental objectives. These findings held true for each of our research partner

organizations, two extremely respected companies in the realm of maritime transportation.

The formal approach provided by value focused thinking has provided strong leading indicators

of safety in the maritime domain. While some decision analysts may note that these results are somewhat

obvious (employees are attempting to achieve what their bosses want), we note that previous leading indi-

cator work has not taken this approach, preferring to mine whatever data already exists. Our approach is

equally applicable to other domains and we provide our results in the hope that it may spawn similar re-

search in economics, health, organizational performance, and other problem domains.

Acknowledgments

References

Ayres, T.J., M.M. Gross. 2002. Exploring Power Plant Data Resources for Organizational Epidemiology.
Proceedings of the 7th IEEE Conference on Human Factors and Power Plants 2002. Scottsdale,
Arizona: 15-19 September 2002, 10.1-10.16.

Chew, D.C.E. 1988. Effective Occupational Safety Activities: Findings in Three Asian Developing Coun-
tries. *International Labor Review*. **127** 111-124.

Chrvala, C. A., R. J. Bulger. 1999. Leading Health Indicators for Healthy People 2010: Final Report.
Washington D.C., National Academies Press.

Cohen, A. 1977. Factors in successful ocuupational safety programs. *Journal of Safety Research* **9** 168-
178.

Cohen, A., R.J. Cleveland. 1983. Safety Practices in Record-Holding Plant. *Professional Safety* **9** 26-33.

Conference Board. 2004. Business Cycle Indicator Project. Retrieved 18 October 2004http://www.tcb-
indicators.org/GeneralInfo/bciproject.cfm.

DeJoy, D.M., B.S. Schaffer, M.G. Wilson, R.J. Vandenberg, M.M. Butts. 2004. Creating Safer Work-places: Assesing the Determinants and Role of Safety Climate. *Journal of Safety Research* **35** 81-90.

Grabowski, M., J. R. W. Merrick, J. Harrald, T. Mazzuchi and J. R. van Dorp. Risk Modeling in Distrib-uted, Large Scale Systems. 2000. *IEEE Systems, Man & Cybernetics, Series A* **30**(6) 651-660.

Gross, M.M., T.J. Ayres, J. Wreathall, A. Merritt, D. Moloi. 2001. Predicting Human Performance Trends. *Proceedings of the 7th Annual Human Performance/Root Cause/Trending Workshop*, Baltimore, Maryland, 4-7 June, retrieved 13 February 2004. http://www.epri.com/attachments/266888_BaltHPmtext.pdf.

Keeney, R. L. 1992. *Value Focused Thinking*. Cambridge, Mass: Harvard University Press.

Lehtinen, E., B. Wahlstrom. 2002. Safety Performance Measurement in Process Industries. *Proceedings of the 3rd International Conference on Performance Measurement and Management,* Boston, Massachusetts: 17-19 July.

Levitt, B., J.G. March. 1988. Organizational Learning. *Annual Review of Sociology* **14** 319-340.

March, J.G., L.S. Sproull, M. Tamuz. 1991. Learning from Samples of One or Fewer. *Organization Science* **2**(1) 1-14.

Mearns, K., R. Flin, R. Gordon, M. Fleming. 2001. Human and Organizational Factors in Offshore Safety. *Work and Stress* **15**(2) 144-160.

Mearns, K., S. M. Whitaker, R. Flin. 2001. Benchmarking Safety Climate in Hazardous Environments: A Longitudinal, Interorganizational Approach. *Risk Analysis* **21**(4) 771-786.

Mearns, K., S. M. Whitaker, R. Flin. 2003. Safety Climate, Safety Management Practice and Safety Per-formance in Offshore Environments. *Safety Science* **41** 641-680.

Merrick, J. R. W., J. R. van Dorp, J. Spahn, J. Harrald, T. Mazzuchi and M. Grabowski. 2000. A Systems Approach to Managing Oil Transportation Risk in Prince William Sound. *Systems Engineering* **3**(3) 128-142.

Merrick, J. R. W., J. R. van Dorp, T. Mazzuchi, J. Harrald, J. Spahn and M. Grabowski. 2002. The Prince William Sound Risk Assessment. *Interfaces* **32**(6) 25-40.

Merrick, J. R. W., J. R. van Dorp, J. P. Blackford, G. L. Shaw, J. Harrald and T. Mazzuchi. 2003. A Traffic Density Analysis of Proposed Ferry Service Expansion in San Francisco Bay Using a Maritime Simulation Model. *Reliability Engineering and System Safety* **81**(2) 119-132.

Merrick, J. R. W., M. Grabowski, P. Ayyalasomayajula, J. R Harrald. 2005. Understanding Organizational Safety Using Value Focused Thinking. *Risk Analysis* **25**(4) 1029-1041.

Shafai-Sahrai, Y. 1971. *An Inquiry into Factors that Might Explain Differences in Occupational Accident Experience of Similar Size Firms in the Same Industry*. Division of Research, Graduate School of Business Administration, Michigan State University. East Lansing, Michigan.

Shannon, H.S., J. Mayr, T. Haines. 1997. Overview of the Relationship between Organizational and Workplace Factors and Injury Rates. *Safety Science* **26** 210-217.

Shannon, H.S., V. Walters, W. Lewchuk, J. Richardson, L.A. Moran, T.A. Haines, D. Verma. 1996. Workplace Organizational Correlates of Lost Time Accident Rates in Manufacturing. *American Journal of Industrial Medicine* **29** 258-268.

Tamuz, M. 2003. Understanding Accident Precursors. In Phimister, J.R., V.M. Bier, H. Kunreuther (editors), *Accident Precursor Analysis and Management: Reducing Technological Risk through Diligence*. Washington, D.C., National Academy Press, 63-78.

Woods, D.D., E. Hollnagel. 2006. Prologue: Resilience Engineering Concepts. In E. Hollnagel, D.D. Woods, N. Leveson (editors). *Resilience Engineering: Concepts and Precepts*. Burlington, Vermont, Ashgate Publishing.