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Decision Performance and Safety Performance: A Value-Focused Thinking Study in the Oil Industry

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Abstract

Considerable research has been performed to develop leading indicators of safety performance. We use value-focused thinking to understand the objectives and evaluation measures that frame a particular safety-related decision within an organization. These decisions are part of the safety culture. Our research partners were two oil shipping companies; we surveyed crewmembers on their tankers to evaluate performance in each decision objective on their vessel. We demonstrate that measurements of the achievement of these objectives are related to future safety performance and so provide leading indicators of safety.

Key words: Value-Focused Thinking, Risk Analysis, Applications: Transportation, Organizational studies: Decision making

1. Introduction

The Exxon Valdez ran aground on Bligh Reef on March 24th, 1989 spilling an estimated 11 million gallons of crude oil into the Prince William Sound, Alaska. The clean-up costs ran to $2.2 billion. The accident occurred when the third mate was left in charge of the bridge and lost track of his location while steering out of the traffic lanes to avoid icebergs. On June 8th, 1990, the Mega Borg released 5.1 million gallons of oil 60 nautical miles from Galveston, Texas when there was an explosion and a subsequent fire in the engine room. On November 28th, 2000, the Westchester lost power and ran aground, dumping 567,000 gallons of crude oil into the Lower Mississippi. A major storm pushed the Selendang Ayu onto a rocky shore on December 7th, 2004 in the Aleutian Islands spilling 337,000 gallons of oil. On July 25th, 2008 a barge collided with a tanker in the Mississippi river spilling hundreds of thousands of gallons of fuel oil.

Several large studies have been performed in Prince William Sound and San Francisco Bay after such accidents, aimed at estimating the changes in risk caused by proposed risk intervention measures (Merrick et al., 2000; Merrick et al., 2002; Merrick et al., 2003). It is human nature to wonder whether there were signs warning of the impending catastrophe. What happened in these organizations that allowed these accidents to happen? What series of decisions were made?

Value-focused thinking (Keeney 1992) and multiple objective decision analysis have been used in strategic decision making (Keeney & McDaniels 1992, Parnell et al. 1998, Phillips and Bana e Costa 2007, Simon et al. 2013) and structuring complex decisions with many stakeholders (Phillips and Phillips 1993, Arvai et al. 2001, Gregory et al. 2001, Keller et al. 2009, Keeney 2012). Merrick et al. (2005) used value focused

thinking to examine safety-related decisions at three different levels of the organizational hierarchy in the oil transportation industry. Figure 1 includes a means-ends objectives network (Keeney 1992) across the top that mirrors the accident event chain (Harrald et al. 1998). The fundamental objectives that comprise the crewmember, vessel, and organization decision frames are then shown below their overall objective. Thus, the network relates the objectives of the three safety-related decision contexts from Merrick et al. (2005) in means-ends relationships. The three decision contexts are then linked to the strategic objectives from the accident event chain; minimizing triggering incidents is a means to minimizing near losses, which is a means to minimizing accidents, which is a means to minimizing consequences.

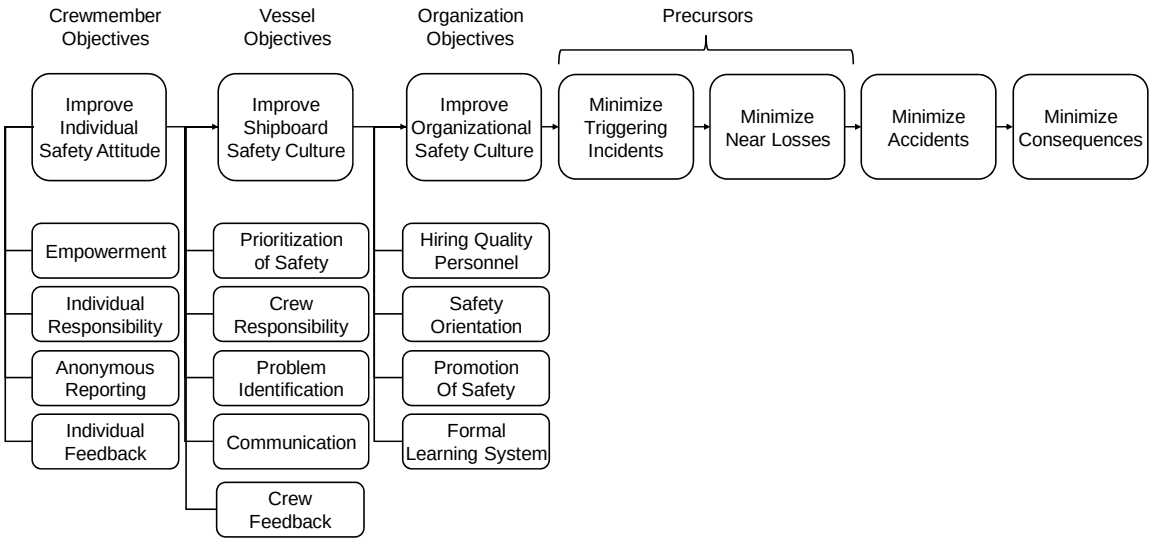

Figure 1. A means-ends objective network that relates our three decision contexts to the accident event chain, along with the fundamental objectives for these decision contexts.

In this paper, we test whether performance on the objectives from the three decision contexts (decision performance) is related to the strategic objective of minimizing the number of accidents (safety performance). We use data from two industry partners, a privately held energy transportation subsidiary of a large multinational organization and a global energy transportation service provider, transporting crude oil, petroleum products, and dry bulk commodities throughout the world.

We start in Section 2 with a review of the results of the value-focused thinking sessions with one of the research partners described in Merrick et al. (2005) and the later confirmation from the other research partner. In Section 3, we describe the hypotheses we wish to test. Section 4 describes the surveys we administered with the crewmembers of our two research partners. Sections 5 and 6 discuss the results of relating the decision performance to safety performance. Conclusions are drawn in Section 7.

2. Examining Safety Decisions with Value Focused Thinking

Flinn et al. (2000) review 18 studies examining safety culture and looking for leading indicators of high levels of safety from the energy, chemical, transportation, and construction industries. The 18 studies used a variety of techniques to search for leading indicators, including literature review, focus groups, management discussions, brainstorming sessions, and analysis of accident statistics. When the process involved decision makers or experts in the industry, value focused thinking was not used to improve the brainstorming (Keeney 2012).

Shafai-Sahrai (1971) examined 11 matched pairs of low and high injury rate companies to identify common factors in low injury rate companies. Since this early work, 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 et al., 1996; Shannon et al., 1997; Mearns et al., 2001a; Mearns et al., 2001b; 2003; DeJoy et al., 2004). Hopkins (2009) notes that many examples of safety indicators are "failures of one kind or another." These include failures that are close to the end of the accident event chain in Figure 1, also known as precursors. They occur more frequently, but are less harmful, than the events that they indicate (Corcoran 2004, Tamuz 2003). Our focus is not precursor events. We evaluate the decisions made in day-to-day operations. We test whether the level of achievement of various objectives guiding these decisions is related to safety performance. This approach is proactive as problems can be diagnosed before any failures occur and improving the achievement of objectives is a more positive frame for including the indicators in a continuous safety improvement process (Mearns 2009). Specifically, it is clear which areas need improvement when the level of achievement of objectives drops (Hale 2009).

A decision frame is the set of alternatives from which the decision maker is choosing and objectives that govern that choice (Keeney 1992). There are three types of objectives: means, fundamental, and strategic. A *means objective* is a means to achieve another objective. A *strategic objective* is a long-term objective whose outcome can be influenced by factors outside this decision frame. A *fundamental objective* is an objective whose outcome is not influenced by factors outside this decision frame, but it is also not a means to an end; it is the end objective for this decision frame. The terms means, fundamental, and strategic apply to an objective within a decision frame. For example, an objective may be a means objective within one decision frame and fundamental to another decision frame. Similarly, an objective may be fundamental to one decision

frame and strategic to another. Figure 1 shows the means-ends relationships across the top of the diagram, but then shows the objectives that are fundamental for the three different decision frames below their overall objective. Let us examine the process that led to the development of these three decision frames and their fundamental objectives.

Merrick et al. (2005) discuss the results of a series of interviews with our first Industry Partner using value-focused thinking. In 2005, Industry Partner 1 had approximately 500 employees and operated 7 U.S. flag oil tankers and 2 tug escorts in coastal U.S. waters. We held interviews with the senior leadership team, the health and safety office, and a group of active crewmembers, including captains, engineers, mates, and deck crew. Through the initial discussions, we identified the decision frames for each of the interview groups. In 2006, Industry Partner 2 owned and operated an international flag and U.S. flag fleet of 156 vessels, 117 of which were operating vessels and 39 of which were under construction, aggregating 15.5 million deadweight tons. In 2008, it was amongst the top five largest publicly traded oil tanker companies in the world, measured by the size of its fleet. The company has nearly 4000 employees. We performed objectives generation sessions with the same types of groups from Industry Partner 2 and found the same decision frames.

The leadership team makes decisions that seek to make the whole organization as safe as it can be. In this interview, we sought attributes of an organization with an effective organizational safety culture. We considered an ideal organization and what made it ideal from a safety perspective and then an organization that does everything wrong with respect to safety. We considered various real organizations and discussed what they do well, and what they do badly. We also considered regulations on an

organization (or constraints), and what they told us about the minimal level of performance in various attributes that are required by law.

The bridge crew interview concerned the attributes of an ideal vessel. We asked them to consider that they were starting a rotation on a new vessel and what would give them an impression of good safety performance. We considered what an ideal vessel would look like and a crew and vessel that would lead the individual to ask immediately for reassignment. We considered the good and bad vessels that they had served on and crews that they had worked with. We considered regulations that make requirements both on the vessel and on the crew as a whole.

The health and safety office makes decisions about training and certification of individual crewmembers. In this interview, we sought attributes of an effective system for preparing crew. We considered an ideal crewmember and a crewmember that you would not keep on your crew. We considered actual cases where crewmembers were given safety awards and others that were fired (but not by name). We also considered regulated certification requirements for crewmembers and what these regulations say about the minimal level of performance in various objectives that are required by law.

Thus from these three interviews groups, we identified three decision frames, which can be thought of in simplistic terms as choosing the ideal organization, choosing the ideal vessel, and choosing the ideal crewmember. The final set of fundamental objectives for each of the three decision frames were found to be identical across our two Industry Partners. In the organizational interviews, we identified four fundamental objectives for the ideal organization decision frame:

- O1 Hire Quality Personnel: Hire the highest quality personnel;

- O2 Safety Orientation: Ensure that new hires are fully oriented in the organization's safety expectations;
- O3 Promotion of Safety: Ensure that safety is promoted at every opportunity (and that the management team leads by example);
- O4 Formal Learning System: Ensure that the organization has a highly effective formal learning system.

In the bridge crew interviews, we developed five fundamental objectives for the ideal vessel decision frame:

- V1 Prioritization of Safety: Ensure that the crew prioritizes safety in all they do;
- V2 Crew Responsibility: Ensure that the crew feels a personal responsibility for safety;
- V3 Problem Identification: Ensure that the crew identifies potential safety problems;
- V4 Communication: Ensure that the crew communicates well about safety issues;
- V5 Crew Feedback: Ensure feedback to the whole crew about resolution of safety problems.

In the safety management interviews, we identified four fundamental objectives for the ideal crewmember decision frame:

- C1 Empowerment: Ensure that each crewmember feels empowered to act on safety concerns
- C2 Individual Responsibility: Ensure that each crewmember feels responsible for the resolution of safety problems

- C3 Anonymous Reporting: Engender a no-blame culture so each crewmember will anonymously report all safety problems
- C4 Individual Feedback: Ensure that feedback is provided to all reported problems.

Evidently, there are other possible objectives that are not fundamental to one of the decision frames that we studied. Each of the decision makers makes a number of more limited scope decisions in their daily work that are pieces of the wider decision frame that we considered, but we sought to develop the broadest scope decision frame for each group interviewed. This generated the most general fundamental objectives within each decision frame.

3. Does Decision Performance Lead to Safety Performance?

Safety performance refers to the strategic objective to minimize accidents and other unwanted events. For the purposes of this study, we define safety performance in terms of minimizing the number of accidents on board each vessel in our research partners' fleets. An accident is "an undesired event that results in personal injury, damage or loss. Accidents include loss of life or major injury to any person on board, the actual or presumed loss of a ship, her abandonment or material damage to her; collision or grounding, disablement, and also material damage caused by a ship. An accident can also be an occurrence such as the collapse of lifting gear or a loss of cargo overboard, if the occurrence could have caused serious injury or damage to the health of any person" (U.K. Marine Accident Investigation Branch, 2005).

Decision performance refers to the performance on the objectives that decision makers across an organization are attempting to achieve in the choices they make. In this

study, we define decision performance as the level of performance on the fundamental objectives for the three decision contexts described in Section 2. This gives thirteen fundamental objectives. We measure decision performance in our two research partners' fleets.

We wish to test the relationship for each decision frame to find if any one decision frame is sufficient as a leading indicator of safety performance and at what level of organizational unit we should seek the strongest relationship.

- *H_O: The performance on the four fundamental objectives for the organizational decision frame (O1-O4) is related to safety performance on the vessels of our two research partners.*
- *H_V: The performance on the five fundamental objectives for the vessel decision frame (V1-V5) is related to safety performance on the vessels of our two research partners.*
- *H_C: The performance on the four fundamental objectives for the crew decision frame (C1-C4) is related to safety performance on the vessels of our two research partners.*

Our general hypothesis is that decision performance is related to safety performance. We test this on our research partners, thus the hypothesis that we test herein is specific to our partners' vessels.

- *H_{VFT}: The performance on the thirteen fundamental objectives is related to safety performance on the vessels of our two research partners.*

As a comparison to traditional precursor approaches, we also include a hypothesis about precursor events.

- *H_P: The occurrence of precursor events is related to safety performance on the vessels of our two research partners*.

4. Survey Design and Response

We developed questionnaires that our industry partners sent to employees of their organizations to assess the performance on each objective. In this manner we could verify the efficacy of the fundamental objectives and thus justify the effort to maintain the data collection in the long-term for these attributes. To develop the survey questions, we reviewed the research literature on safety culture, leading indicators, and general organization theory. We determined multiple survey questions from the literature for each fundamental objective. Each of the survey questions was termed as a statement and responses were requested on a five-level Likert scale (Likert 1932) from 1. Strongly Disagree to 5. Strongly Agree. In each case, the assertion was phrased so that agreeing meant good performance on the objective. Tables 1, 2 and 3 show the list of assertions for each fundamental objective in the organizational decision frame, the vessel decision frame, and the crewmember decision frame respectively. Each of the assertions in Tables 1 to 3 provides a slightly different interpretation of what it means to achieve the corresponding objective. For instance, in Table 1 the objective "Ensure that the organization has a highly effective formal learning system" has the following three assertions:

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.

As crewmembers rotate across different vessels in a fleet, e) and f) represent organization-wide assertions. In the aviation industry, reporting accidents and near losses (or near misses) are required by law. However, the maritime industry is only strictly required to report accidents, so some near losses go unreported. Thus, f) is a higher level of performance than e). Assertion d) is different again as it refers to learning from the events rather than simply reporting them. As the different assertions imply a different meaning to the objective, we do not want to follow the usual statistical analysis of survey data by aggregating all assertions for a given objective using principal components analysis. Instead, we keep each assertion as a potential definition of the objective.

Table 1. Survey Assertions for the Fundamental Objectives in the Organizational Decision Frame.

Objective		Survey Assertion	
O1	Hire 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.
O2	Safety Orientation	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.
O3	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 meet 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.
O4	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.

Table 2. Survey Assertions for the Fundamental Objectives in the Vessel Decision Frame.

Objective		Survey Assertion	
V1	Prioritization of Safety	a)	Officers on this vessel would stop us from working due to safety concerns, even if it meant losing money.
		b)	A consistent message that work pressures must not compromise safety is communicated by the vessel management to the workforce.
		c)	Safety is the top priority when work is scheduled on this vessel.
V2	Crew Responsibility	a)	The crew perceives safety as a top priority while performing their duties.
		b)	The crew is involved in informing management of important safety issues.
		c)	The crew feels involved when health and safety procedures, instructions or rules are developed or reviewed on this vessel.
		d)	The crew is accountable for reporting safety violations - actual or potential - on this vessel.
V3	Problem Identification	a)	I am encouraged to conduct job safety analyses and report unsafe conditions.
		b)	All jobs have safety procedures, instructions or rules on my vessel.
		c)	Whenever I see safety regulations being broken, I point it out.
		d)	Vessel rules make it easy for me to identify procedures that are not safe.
V4	Communication	a)	I am satisfied with the way I am kept informed about what takes place on my ship.
		b)	There is good communication on this vessel about safety issues.
		c)	I am always informed about the outcome of shipboard meetings that address health and safety.
		d)	The crew is kept informed about the company's safety policies, safety goals and safety performance assessments.
		e)	The crew is always given feedback on accidents and near losses that occur on this ship.
		f)	There is good communication at watch handover.
		g)	The vessel crew is very effective in communicating safety information.
V5	Crew Feedback	a)	The crew is always given feedback on accidents, near losses or injuries that occur on board this vessel.
		b)	I am very satisfied with regard to follow-up and measures taken after accidents, injuries, and near losses have taken place on this vessel.

Table 3. Survey Assertions for the Fundamental Objectives in the Crewmember Decision Frame.

Objective		Survey Assertion
C1	Empowerment	a) I can influence health and safety performance on my vessel.
		b) I have a good control over the safety outcomes of my job.
		c) I am very satisfied with my involvement in safety on my vessel.
		d) I feel involved when health and safety procedures, instructions or rules are developed or reviewed.
		e) I have fair opportunity to influence the decisions being made by my superiors.
C2	Individual Responsibility	a) I perceive safety as a top priority while performing my duties.
		b) Whenever I see safety regulations being broken on this vessel, I point it out.
		c) I am involved in informing management of important safety issues.
		d) I am accountable for reporting safety violations - actual or potential - on this vessel.
C3	Anonymous Reporting	a) An effective anonymous reporting system exists in our organization.
		b) My organization has a `no-blame culture'.
		c) Mistakes are corrected without punishment and are treated as a learning opportunity on my vessel.
		d) Employees are not reluctant to report a co-worker's failure.
C4	Individual Feedback	a) I am always given feedback on accidents, near losses, and injuries that occur on board this vessel.
		b) I am very satisfied with regard to follow-up and measures taken after accidents, near losses and injuries have taken place.

With these two industry partners, 2170 individual shipboard safety factor surveys were administered to the 89 tankers in the two research partners' fleets between 2005 and the beginning of 2006. From those, 915 individual shipboard responses were received, a 42.2% response rate. Note that each individual responded to the statements in Tables 1, 2, and 3. Thus, they assessed their vessel's performance on organizational, safety management, and vessel objectives.

We received responses from personnel on 56 of the 89 tankers in the study, for a 61.25% coverage rate of tankers across the two industry partners. We received responses

from 10 of 11 tankers in the fleet of Industry Partner 1, and 46 of the 56 tankers with responses were from Industry Partner 2. The response rates for the surveys are comparable to response rates reported by similar studies: 45% (Sexton et al. 2000), 10% to 80% (Mearns et al., 2001b), and 48% to 100% (Havold 2005). Response rates for each individual tanker varied from 27% to 100% of the crew, which corresponded to at least six responses from each tanker for which we had responses. Table 4 shows the age and experience of the responders to the surveys that provided this information. These averages are not significantly different from the averages provided by each organization at a 5% significance level. Thus we conclude that the survey responses provide a representative sample.

Table 4. Demographics of the Survey Participants.

Variable	N	Min	Mean (Std Dev)	Max
Age	885	20	37.53 (9.27)	69
Experience in current employer	857	0	5.35 (5.74)	37
Experience in Industry	875	0	12.85 (8.57)	41

6. Safety Performance Models for Each Decision Frame

We will test the hypotheses H_O, H_V, and H_C separately using a model that relates a set of survey responses for a given decision frame at time t to a given strategic safety attribute at time $t+\Delta$, where $\Delta > 0$, or

$$Y_i^{t+\Delta} = f\left(X_{i,1}^t, X_{i,2}^t, \ldots, X_{i,n_i}^t\right) + \varepsilon_i^{t+\Delta},$$

where f is a n-dimensional function and $\varepsilon_i^{t+\Delta}$ is an error term. In this case, Y_i^t is the number of accidents for the i-th tanker in the year for which data was provided. The numbers of accidents are not normally distributed, so a $\ln(y+1)$ transformation was used to ensure that the residuals were normally distributed. The attributes $\left(X_{i,1}^t, X_{i,2}^t, \ldots, X_{i,n_i}^t\right)$ are the median responses on a survey question for the i-th tanker to aggregate the opinion of each responding crewmember. Thus, we seek to determine whether the median response on a vessel is related to safety performance.

In the timeline of data collection, the accident counts for each tanker were for the calendar year 2006. However, the surveys were collected during mid-2005 for Industry Partner 1 and at the end of 2005 and delivered at the beginning of 2006 for Industry Partner 2. Thus while $\Delta > 0$, its exact value for each person responding varied. Thus significant results here show that the attributes are in fact leading indicators, but the precise length of that lead is not known. We received accident data for 32 of the 56 tankers with survey responses, including 9 tankers from Industry Partner 1 and 23 tankers from Industry Partner 2. To test hypothesis H_P, we obtained the number of near losses for each vessel and include a model relating the number of near losses to the number of accidents.

The form of $f\left(X_{i,1}^t, X_{i,2}^t, \ldots, X_{i,n_i}^t\right)$ is not known, thus we use stepwise regression to determine the model for each decision frame. We included each first-order term as well as all two-way interactions between terms in the stepwise procedure. We use a forward stepwise regression maximizing the Bayesian Information Criterion as the objective function. We then used a backwards stepwise regression starting with the model

obtained in the forwards stepwise regression. The analysis was performed with JMP™ Pro version 10.0.2.

Table 5 compares the overall model statistics for each of the three decision frame models and shows that the decision frame with the most significant model is the organizational decision frame. However, each model of our indicator models are significant, confirming hypotheses H_O, H_V, and H_C. The precursor model is not significant which does not confirm hypothesis H_P and near losses only explain 4% of the variation in accidents. Performance on the objectives of each decision frame is related to safety performance on the vessels of our two research partners and each is more significant than near losses. It is interesting to see which of the objectives led to significant explanatory variables in each model.

Table 5. Stepped Model Results for each Decision Frame.

Model	Adjusted R^2	Root Mean Square Error	F Ratio	ANOVA p-value	N
H_O	0.7208	0.278	11.0051	<0.0001	32
H_V	0.2789	0.447	4.9960	0.0067	32
H_C	0.2679	0.450	4.7810	0.0082	32
H_P	0.0391	0.5204	2.2220	0.1469	32

Let us now look in more detail at the relationships found in the model for each decision frame. Tables 6, 7, and 8 show the effects tests for the explanatory variables (objectives) for the three models. We show all interactions in bold in each table, along with the main effects that are not included in an interaction term. Main effects that are

included in an interaction term are not bold because they do not have a direct interpretation separate to the interaction.

Table 6 shows two interactions and six main effects. Four of the main effects are included because they are included in the interaction terms. The two main effects that are not included in an interaction are two questions from the O3 Promotion of Safety objective and each has a significant negative slope, showing that an improvement in these responses leads to a decrease in the number of accidents. The parameters of the four main effects that are part of the interaction terms can be misleading as some are positive. This would indicate that an improvement in the responses leads to an increase in the number of accidents. However, such main effects should only be considered as part of the interaction.

Table 6. Effects tests for the explanatory variables in the organizational decision frame model.

Objective	Question		Estimate	t Ratio	p-value
O1	HQP b)	The hiring process in my organization is effective in identifying the right people for jobs	0.7338	4.77	<.0001
O1	HQP e)	The individuals that are hired in this company are the best qualified individuals for the job	0.0144	0.11	0.9155
O4	FLS d)	This organization is very concerned about learning from accidents and near losses	-3.1742	-4.72	<.0001
O4	FLS f)	My colleagues are willing to report near losses	-0.2858	-2.05	0.0523
O3	**PromS b)**	**People can always get the equipment that is needed meet my organization's health and safety procedures, instructions, or rules**	**-0.5762**	**-5**	**<.0001**
O3	**PromS e)**	**The company really cares about the health and safety of the people who work here**	**-1.0954**	**-3.18**	**0.0041**
O1 * O4	**HQP b) * FLS d)**	**The hiring process in my organization is effective in identifying the right people for jobs * This organization is very concerned about learning from accidents and near losses**	**-2.7315**	**-4.32**	**0.0003**
O1 * O4	**HQP e) * FLS f)**	**The individuals that are hired in this company are the best qualified individuals for the job * My colleagues are willing to report near losses**	**-0.8165**	**-4.18**	**0.0004**

The two interactions in Table 6 are between questions for the O1 Hiring Quality Personnel objective and questions for the O4 Formal Learning System objective. For each interaction, if the O1 Hiring Quality Personnel objective scores low, then improving the O4 Formal Learning System responses can increase the number of accidents. However, if the O1 Hiring Quality Personnel scores high, then improving the O4 Formal Learning System responses has the desired effect and decreases the number of accidents. Thus, from this model, we learn that a good formal learning system is only effective if the organization hires quality personnel, but promotion of safety is effective on its own. O2 Safety Orientation is not found to be significant.

Table 7 shows that the stepped model for the vessel decision frame is one interaction with its two included main effects. Again, interpreting the parameters for the main effects is not as important as interpreting the parameters for the interaction, namely that V5 vessel-level feedback is more effective if there is V4 good communication about safety on the vessel. V1-V3 are not found to be significant.

Table 7. Effects tests for the explanatory variables in the vessel decision frame model.

Objective	Question		Estimate	t Ratio	p-value
V4	Comm b)	There is good communication on this vessel about safety issues	-1.676991	-2.33	0.0273
V5	Feed b)	I am very satisfied with regard to follow-up and measures taken after accidents, injuries, and near losses have taken place on this vessel	-0.5311	-2.4	0.0233
V4 * V5	**Comm b) * Feed b)**	**There is good communication on this vessel about safety issues * I am very satisfied with regard to follow-up and measures taken after accidents, injuries, and near losses have taken place on this vessel**	**-3.26624**	**-3.14**	**0.0039**

Table 8 shows that the stepped model for the crewmember decision frame is again one interaction with its two included main effects. The interaction shows that C4 individual feedback is only effective if there is a good C3 anonymous reporting system on the vessel. C1 and C2 are not found to be significant.

Table 8. Effects tests for the explanatory variables in the crewmember decision frame model.

Objective	Question		Estimate	t Ratio	p-value
C3	Anon a)	An effective anonymous reporting system exists in our organization	0.4258	3.23	0.0032
C4	Ind Feed b)	I am very satisfied with regard to follow-up and measures taken after accidents, near losses and injuries have taken place	-0.5173	-2.76	0.0101
C3 * C4	**Anon a) * Ind Feed b)**	**An effective anonymous reporting system exists in our organization * I am very satisfied with regard to follow-up and measures taken after accidents, near losses and injuries have taken place**	**-0.7718**	**-2.26**	**0.0321**

In this section, we have examined the models and predictions for each decision frame. The organizational decision frame provided the highest adjusted R^2. However, each of the decision frames provided significant models and factors. Thus, we should examine each decision frame when developing objectives with value focused thinking. None is enough on its own and none should be ignored. In each model, some objectives within the decision frame were not found to be significant. This could be due to the sample size and corresponding power of the significance tests, but this will not be known without more data.

7. An overall model for safety performance

To develop an overall indicator set, we used stepwise regression to find an appropriate model including all thirteen objectives. We again used stepwise regression, following the

same procedures as for the decision frame models. The final model includes eight of the thirteen objectives and four interactions. The model is statistically significant with an ANOVA F ratio of 13.1058 and p-value of less than 0.0001. This confirms our overall research hypothesis H_{VFT}. The adjusted R^2 for the model is 0.8111. The root mean square error is 0.2286. Each of these model results are significantly better than any of those obtained for a single decision frame. The residuals of the model are normally distributed and did not show any indications of dependence.

Table 9 shows the parameter tests for each of the terms in the final model. Each of the main effect terms in the organizational decision frame model is included in this overall model, although only one of the two interactions appear here and one new interaction is now included.

Table 9. Effects tests for the explanatory variables in overall model.

Objective	Question		Estimate	t Ratio	p-value
O1	**HQP b)**	**The hiring process in my organization is effective in identifying the right people for jobs**	**0.5949**	**4.85**	**<.0001**
O1	HQP e)	The individuals that are hired in this company are the best qualified individuals for the job	-0.0512	-0.45	0.6559
O4	FLS d)	This organization is very concerned about learning from accidents and near losses	-2.8665	-6.04	<.0001
O4	FLS f)	My colleagues are willing to report near losses	0.2277	1.34	0.1937
V1	**PromOS b)**	**People can always get the equipment that is needed to meet my organization's health and safety procedures, instructions, or rules**	**-0.7184**	**-7.03**	**<.0001**
V1	**PromOS e)**	**The company really cares about the health and safety of the people who work here**	**-1.2459**	**-3.83**	**0.001**
C1	**Emp d)**	**I feel involved when health and safety procedures, instructions or rules are developed or reviewed**	**-0.6678**	**-2.83**	**0.0104**
C2	**Ind Resp b)**	**Whenever I see safety regulations being broken on this vessel, I point it out**	**1.3242**	**3.13**	**0.0053**
C3	**Anon d)**	**Employees are not reluctant to report a co-worker's failure**	**0.1482**	**1.68**	**0.1089**
O1 * O4	**HQP e) * FLS f)**	**The individuals that are hired in this company are the best qualified individuals for the job * My colleagues are willing to report near losses**	**-1.2692**	**-5.3**	**<.0001**
O4 * O4	**FLS d) * FLS f)**	**This organization is very concerned about learning from accidents and near losses * My colleagues are willing to report near losses**	**-2.7213**	**-5.03**	**<.0001**

The interaction between Hiring Quality Personnel and Formal Learning System is still included. The new interaction is between two assertions for the Formal Learning System objective. Specifically, this interaction shows that reporting near losses is only effective if the organization learns from the events.

Interestingly, the terms for the model for the vessel decision frame and the terms for the model for the crewmember decision frame are not the same here. In the vessel decision frame model, there was an interaction between communication and crew-level feedback. In the crewmember decision frame model, there was an interaction between anonymous reporting and individual feedback. These effects appear to be explained in the overall model by stronger interactions between hiring quality personnel and a formal learning system. With these larger effects explained, smaller effects from the vessel and crew decision frames become significant, namely empowerment, anonymous reporting, and individual responsibility. Empowerment reduces the number of accidents as expected. However, the significant anonymous reporting question is “Employees are not reluctant to report a co-worker's failure” and the significant individual reporting question is “Whenever I see safety regulations being broken on this vessel, I point it out”, both of which increase the number of accidents, or at least the number of reported accidents.

8. Conclusions

We have demonstrated that value focused thinking can be used to find indicators of safety performance using interviews, data collection, and surveys with our two research partner organizations. Our demonstration involved 56 tankers and surveys completed by 915 crewmembers. Our final model related the survey responses in 2005 and the beginning of

2006 to the number of accidents on board 32 tankers during 2006. We showed that each decision frame provided a significant model, but organizational level objectives provided the most significant model by a significant margin with an adjusted R^2 of 0.7208 compared to the other decision frames with adjusted R^2 of less than 0.3. However, each of the decision frames is more effective than the traditional precursor approach, where near losses alone were not a significant predictor of accidents and had an adjusted R^2 of 0.0391. The best model comes when all three decision frames are included. The model had a p-value of less than 0.0001 and an adjusted R^2 of 0.8111.

As can be seen from Table 9, it is not as simple as attempting to improve just one objective at a time. Considering the set of responses that would minimize the number of accidents, hiring quality personnel and a formal learning system work together, but are not as effective separately, so minimizing accidents was related to the following assertions:

- The individuals that are hired in this company are the best qualified individuals for the job
- My colleagues are willing to report near losses
- This organization is very concerned about learning from accidents and near losses

Promotion of safety and empowerment are effective on their own, so we need positive responses to

- People can always get the equipment that is needed to meet my organization's health and safety procedures, instructions or rules
- The company really cares about the health and safety of the people who work here

- I feel involved when health and safety procedures, instructions or rules are developed or reviewed

Two more questions were effective in predicting the number of accidents, so they are leading indicators. However, positive responses on these two questions actually increases the number of reported accidents:

- Employees are not reluctant to report a co-worker's failure
- Whenever I see safety regulations being broken on this vessel, I point it out

We should recognize here, that our true strategic objective is to minimize the number of accidents, not just the reported accidents. So having all accidents reported is a critical part of achieving the organizations' strategic objectives.

It is important to note that the objectives developed are specific to these organizations. This approach is not designed to generate leading indicators that are generalizable, although we did find that the decision frames and objectives were consistent across two oil shipping organizations. Our contribution is the approach, not the specific product in our studies. Our results do show that value focused thinking provides an effective framework for developing leading indicators. While an increased number of precursor events, like near losses, are warnings of safety problems, we did not find them to provide a statistically significant indicator in our data. Instead we examine operational decision performance on a day-to-day basis and the leading indicators provide specific directions for improvement to avoid future accidents.

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