Leading Indicators of Safety in Virtual Organizations

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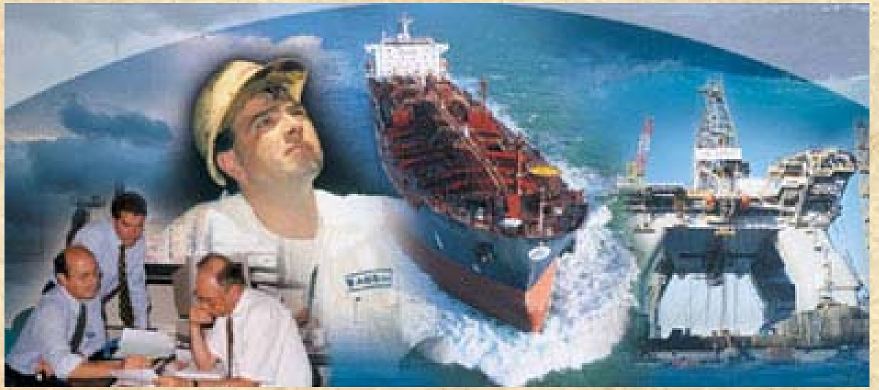
Leading Indicators of Safety

"In the aftermath of catastrophes, it is common to find prior indicators, missed signals, and dismissed alerts, that, had they been recognized and appropriately managed before the event, might have averted the undesired event.

Indeed, the accident literature is replete with examples, including the space shuttles Columbia (Columbia Accident Investigation Board, 2003) and Challenger (Vaughan, 1996), Three Mile Island (Chiles, 2002), The Concorde crash (BEA, 2004), the London Paddington train crash (Cullen, 2000), and American Airlines flight 587 to Santo Domingo (USA Today, May 25, 2003), among many others (Kletz, 1994; Marcus & Nichols, 1999; Turner & Pidgeon, 1997).

Phimister, J.R., Bier, V.M., & Kunreuther, H. (editors). *Accident Precursor Anlaysis and Management: Reducing Technological Risk through Diligence.* Washington, D.C.: National Academy Press, 2003.

Virtual Organizations



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- Organizations comprised of multiple, distributed members

- Temporarily linked together for competitive advantage

- Share a common value chain and business processes via distributed information technology

Virtual Organizations

Health maintenance systems
of distributed physicians,
medical societies,
managed care systems

Fire and emergency medical
service units

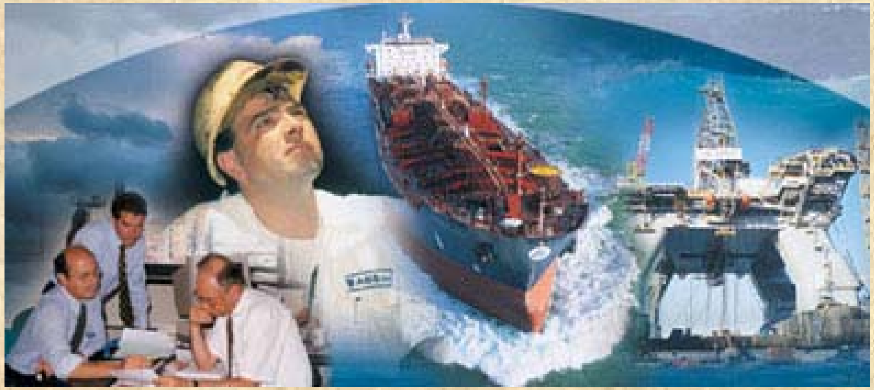
Danish wind farm consortia

Global telecommunications alliances
providing 99% of the world's
secure interbank transactions

International offshore
oil and gas consortia

Oil spill response teams

Characteristics of Virtual Organizations



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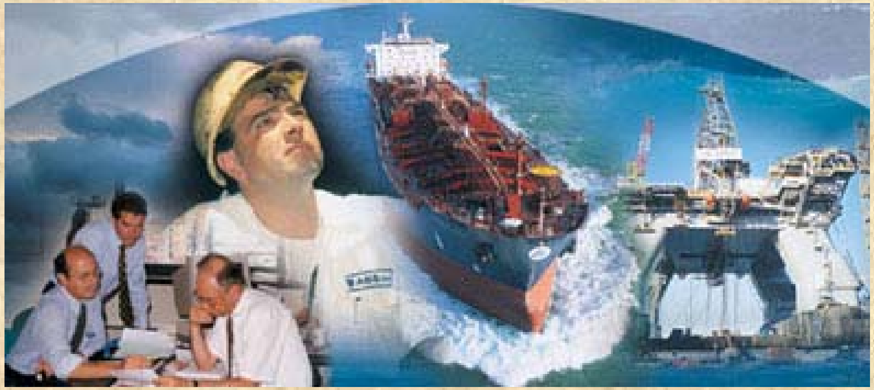
- **Members are not co-located**
- **May occasionally meet face-to-face as well as electronically**
- **Success depends on shared, interdependent business processes to achieve shared objectives**

Characteristics of Virtual Organizations



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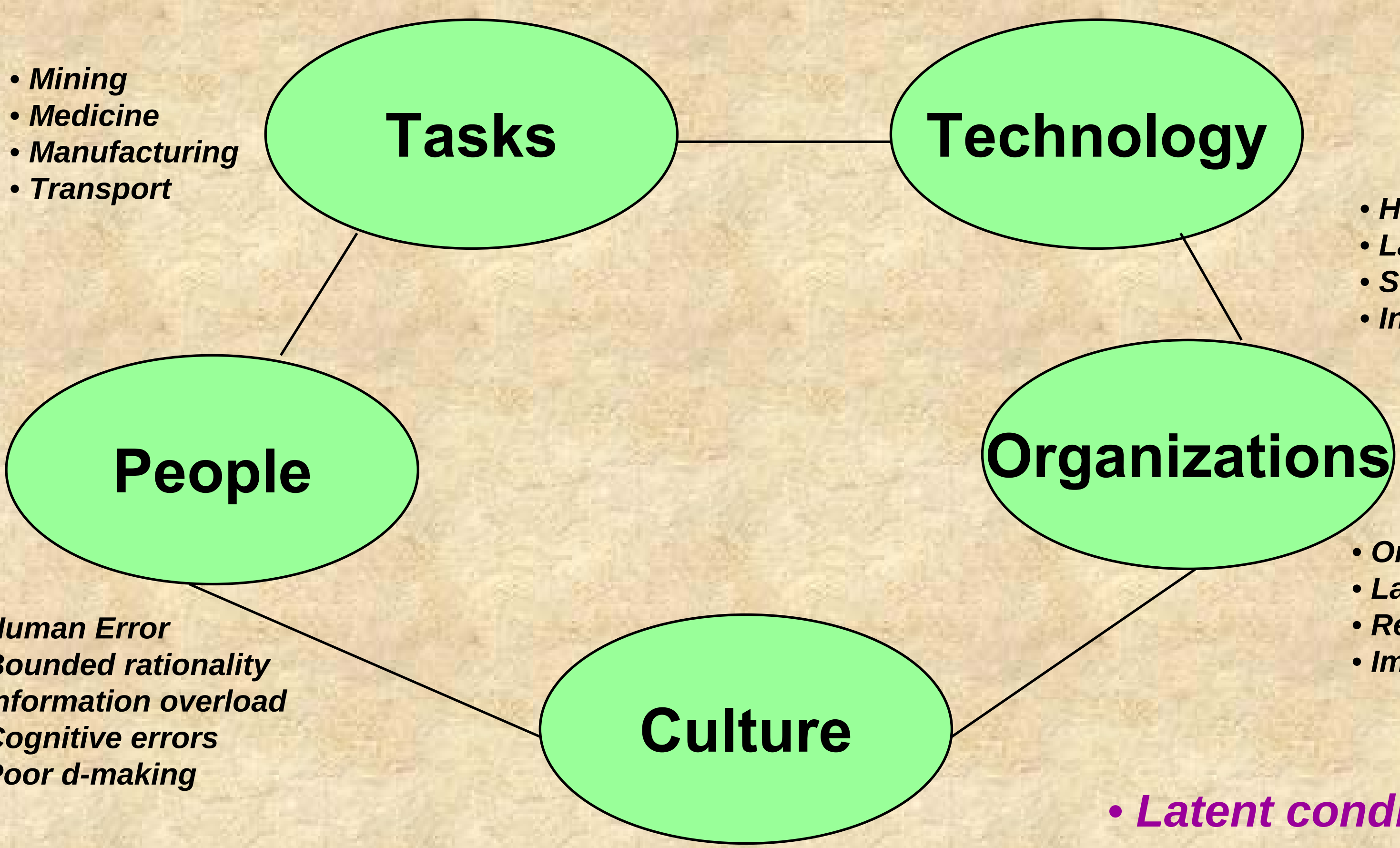
Several common features….

- **Creation of a common value chain among the members**

- **Temporary linkages between members**

- **Business processes supported by distributed information technology**

Risk Propensity in Large-Scale Systems



- Mining
- Medicine
- Manufacturing
- Transport

- Heavy Equipment
- Lasers, Chemicals
- Sensor Systems
- Information Technology

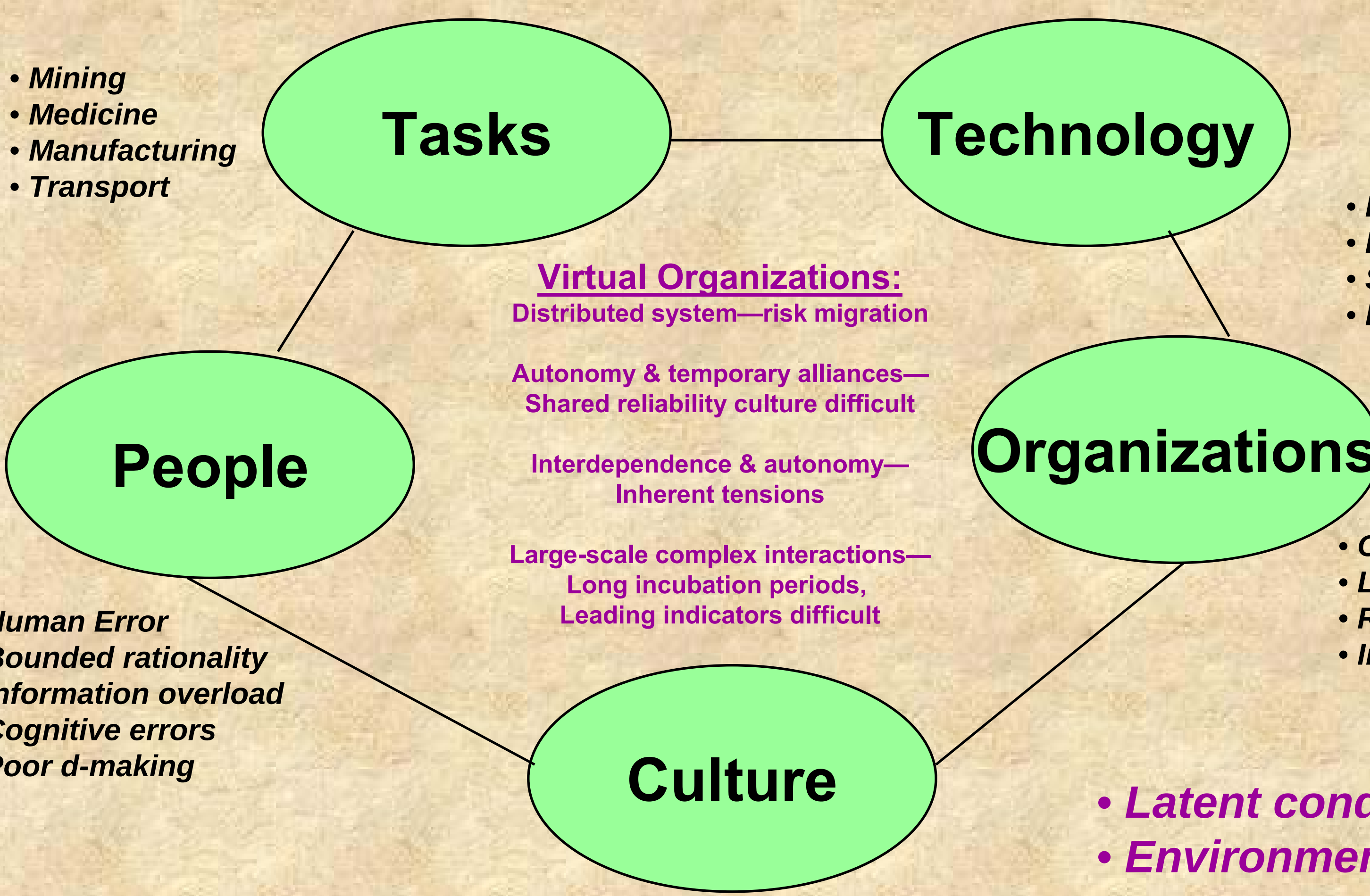
- Human Error
- Bounded rationality
- Information overload
- Cognitive errors
- Poor d-making

- Organizational Errors
- Lack of safety systems
- Reporting structures
- Impossible standards

- Risk Taking Cultures

- Latent conditions
- Environmental factors

Risk Propensity in Virtual Organizations



- *Mining*
- *Medicine*
- *Manufacturing*
- *Transport*

- *Heavy Equipment*
- *Lasers, Chemicals*
- *Sensor Systems*
- *Information Technology*

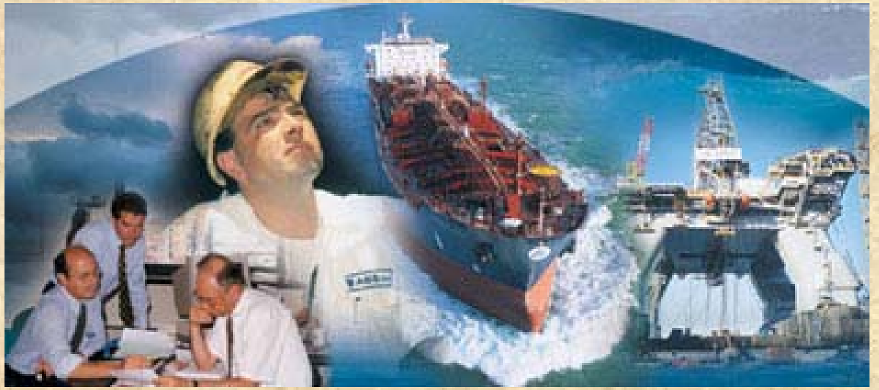
- *Human Error*
- *Bounded rationality*
- *Information overload*
- *Cognitive errors*
- *Poor d-making*

- *Organizational Errors*
- *Lack of safety systems*
- *Reporting structures*
- *Impossible standards*

- *Risk Taking Cultures*

- ***Latent conditions***
- ***Environmental factors***

Leading Indicators



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- **Conditions, events or measures that precede an undesirable event** ***and have some value in predicting the arrival of the event***

- **Associated with proactive activities that identify hazards and assess, eliminate, minimize or control risk**

Leading Indicators of Safety

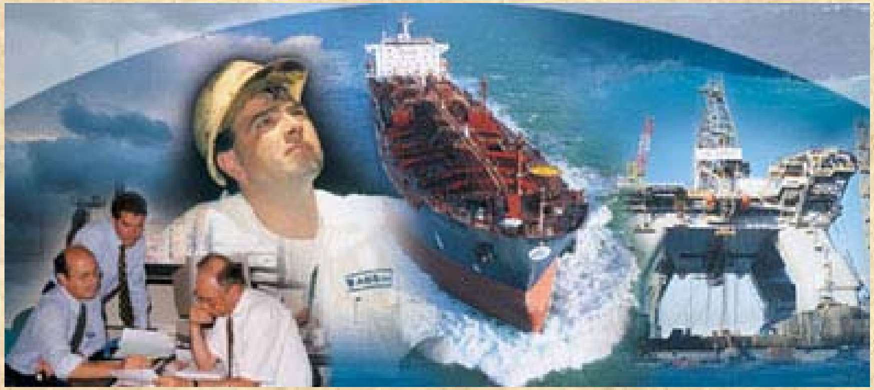
"In high reliability industries, where significant hazards are present and rarely realized, organizations and their regulators pay considerable attention to safety assessment and risk mitigation.

In recent years, there has been a movement away from safety measures based purely on retrospective data or 'lagging indicators' such as fatalities, lost time accident rates and incidents, towards so called 'leading indicators' such as safety audits or measurements of safety climate…

It has been argued that these are predictive measures enabling safety condition monitoring (Flin, 1998) which may reduce the need to wait for the system to fail in order to identify weaknesses and to take remedial action. This can also be conceived as a switch from 'feedback' to 'feedforward' control (Falbruch & Wilpert, 1999; Flin, Mearns, O'Connor & Bryden, 2000, p. 177)."

Falbruch, B. & Wilpert, B. System Safety—an Emerging Field for I/O Psychology. In Cooper, C. & Roberston, I. (editors). *International Review of Industrial and Organizational Psychology*. Chichester, UK: Wiley Publishing, 1999; Flin, R. Mearns, K., O'Connor, P. & Bryden, R. Measuring the Safety Climate: Identifying the Common Features. *Safety Science*, 34: 2000, 177-192.

Leading Indicators--Examples



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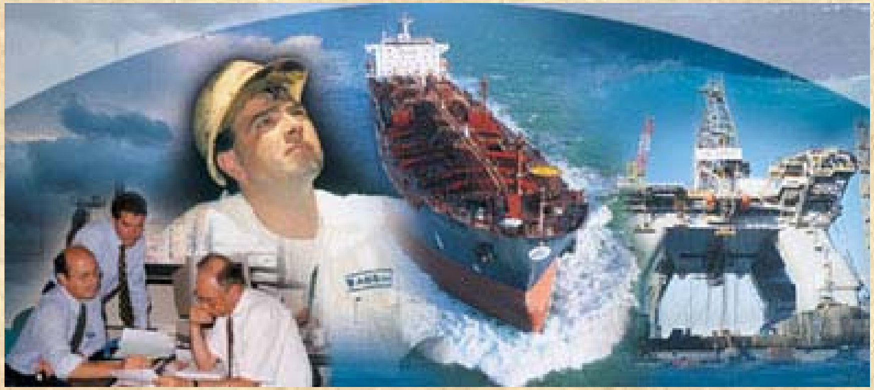
- **Economic leading, lagging and coincident indicators**
- **Health systems**
- **Electric power industry**
- **Near hit reporting in anesthesia management**
- **Nuclear safety precursor management**
- **Offshore oil & gas hazard analyses**

Lagging Indicators--Examples



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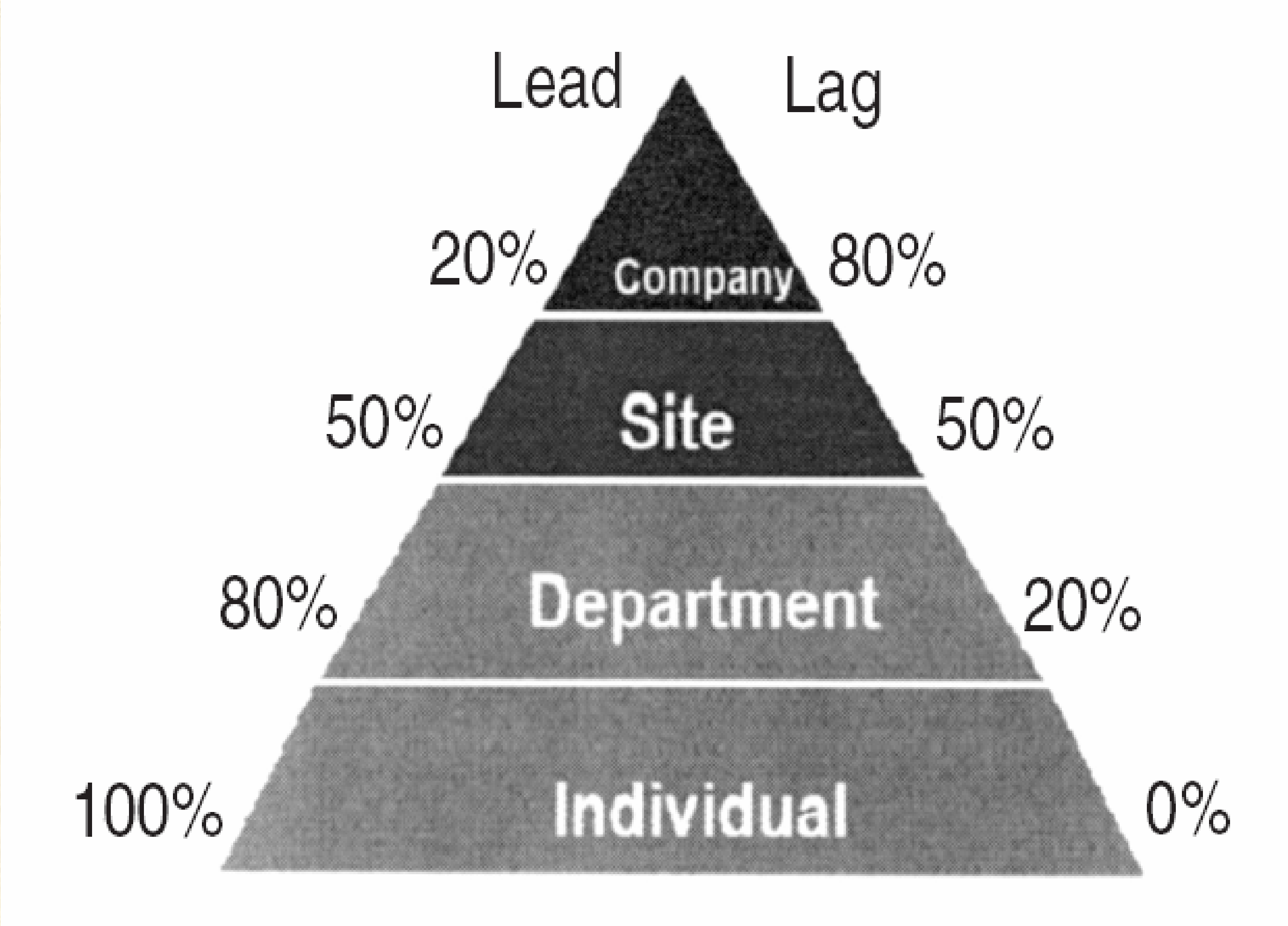
- **Measures of a system taken after an event**
- **Measure outcomes and occurrences**

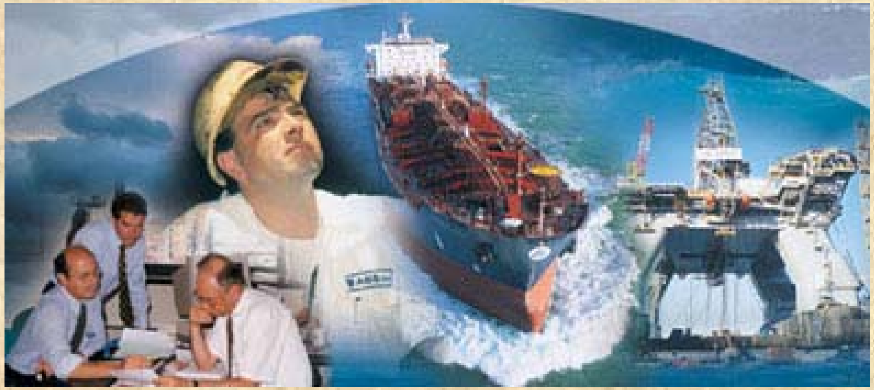
- **Recordable injury frequencies**
- **Lost time frequencies**
- **Lost time severity**
- **Vehicle accident frequencies**
- **Workers' compensation losses**
- **Property damage costs**
- **Numbers & frequency of accident investigations**

Leading and Lagging Indicators



[Bergh, V. Leading and Trailing Indicators: Occupational Safety. Presented at the ISSA/Chamber of Mines Conference 2003. Mines and Quarries—Prevention of Occupational Injury and Disease. Sandton, South Africa, 2003]

Types of Indicators



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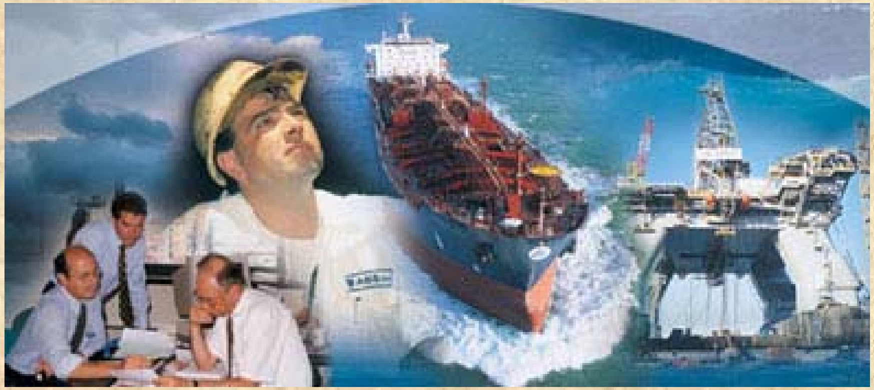
- Indicators with <u>direct links</u> between signals and adverse events

  --causal link (presence of an individual)

- Indicators with <u>correlations</u> between signals (or clusters) and adverse events

- <u>Proxy</u> or surrogate indicators

Criteria for Selecting Indicators



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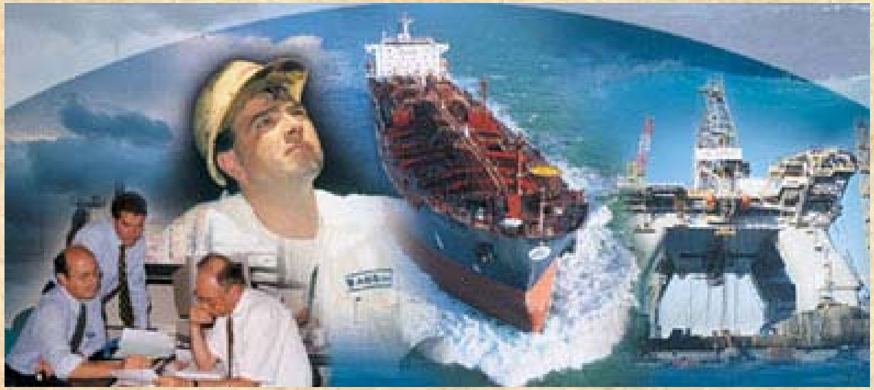
[Chrvala & Bulger, 1999]

Chrvala, C.A. & Bulger, R.J. (editors). *Leading Health Indicators for Healthy People 2010: Final Report.* Washington, D.C.: National Academy Press, 1999. http://books.nap.edu/html/healthy3/.

• Indicators should be worth measuring,
• Indicators can be measured for diverse populations,
• Indicators can be understood by people who need to act,
• Information will galvanize action,
• Actions that can lead to improvement are known and feasible, and
•Measurement over time will reflect the results of action.

Pilot Study



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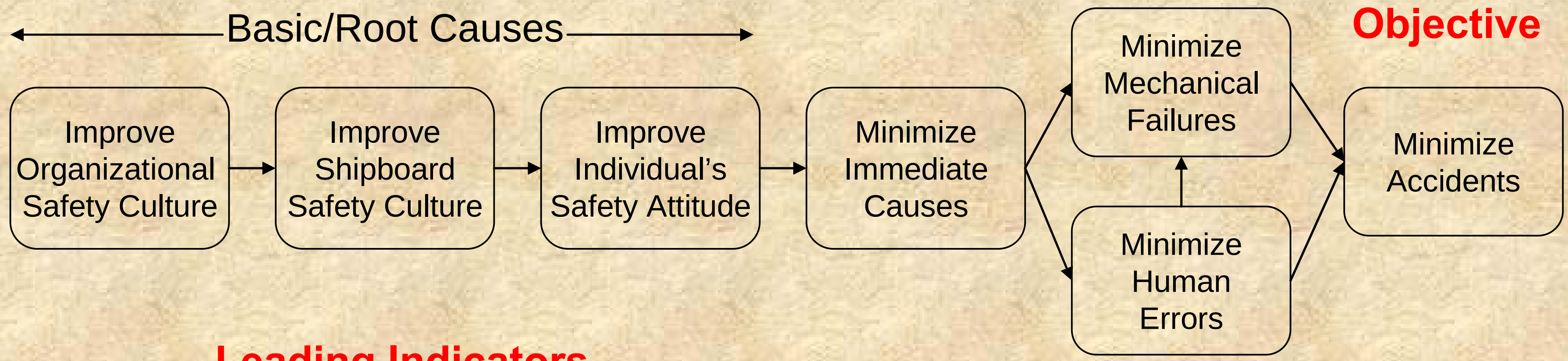
- Identify, analyze & evaluate a set of leading safety indicators in marine transportation
- Initially, domestic tankers (2004-2006)
- Data analysis & structuring
- Partnerships with industry

Value-Focused Thinking

Fundamental Objectives

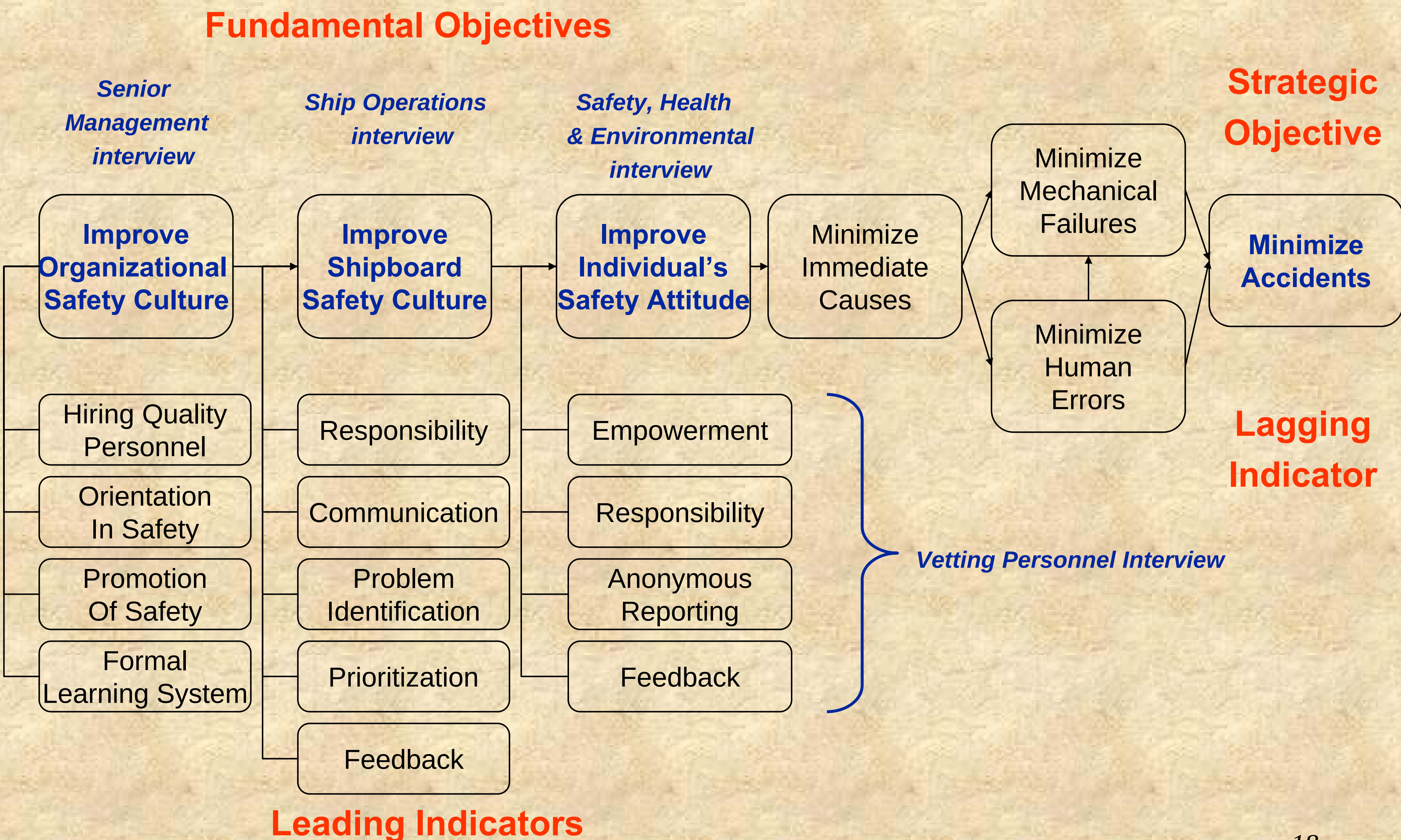
Strategic Objective



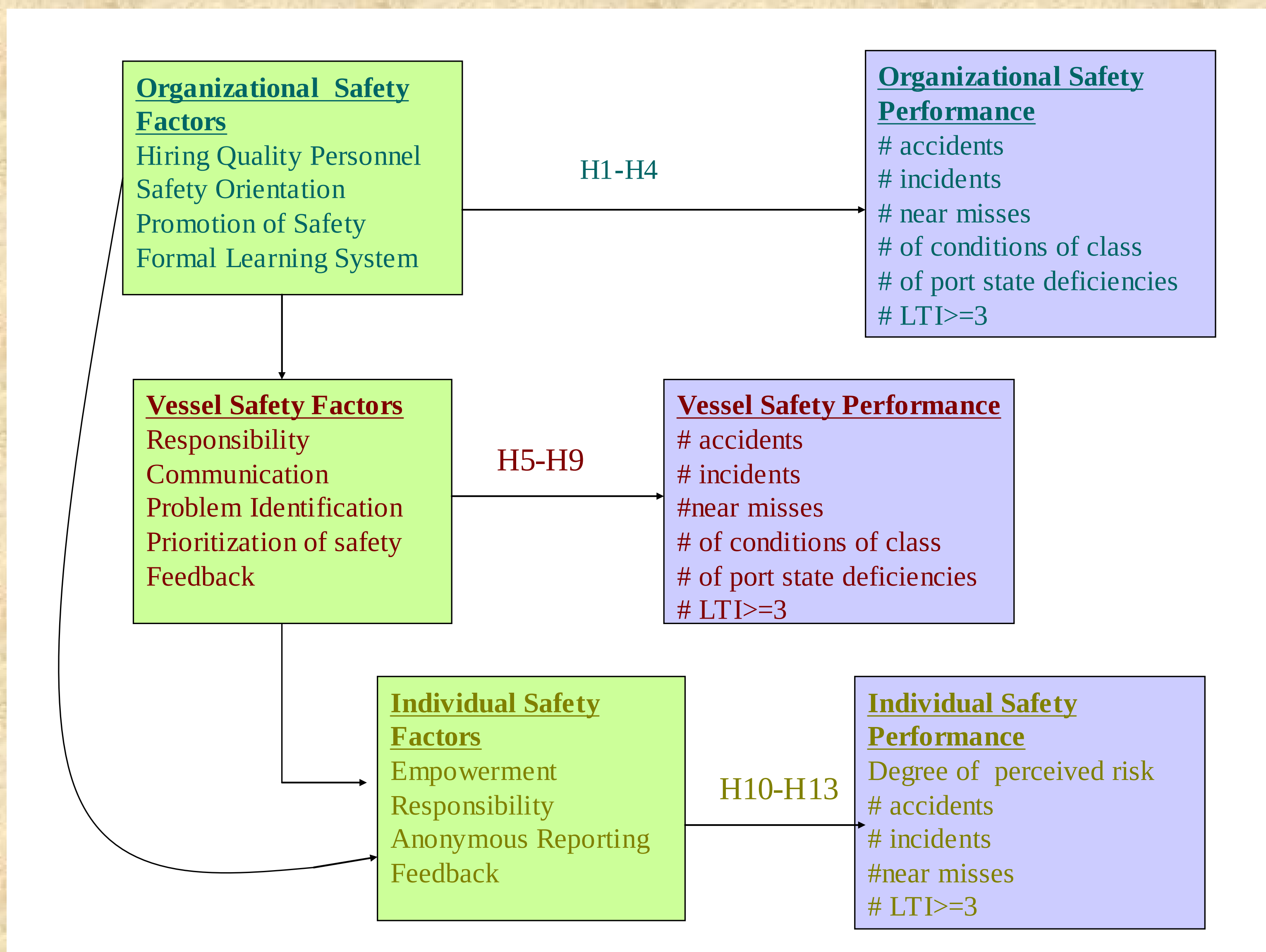
Leading Indicators

Lagging Indicator

Initial Safety Factor Structure



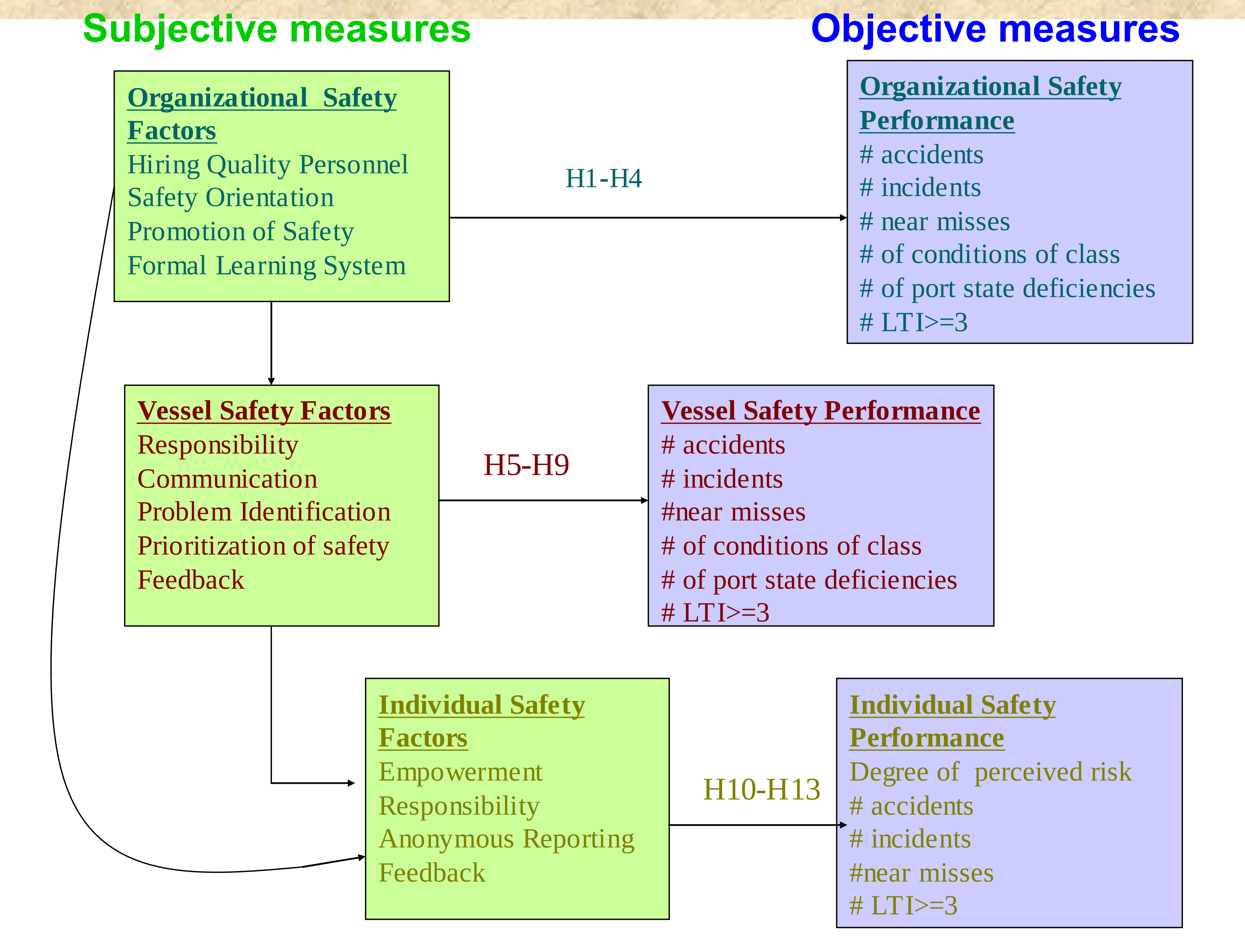
Research Model



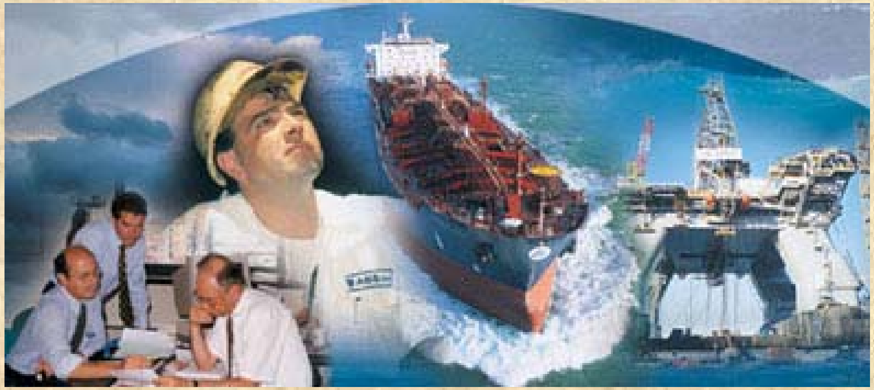
Hypotheses

Organizational Hypotheses	
H1	**Hiring Quality People will lead to an improvement in organizational safety performance.**
H2	**Safety Orientation will lead to an improvement in organizational safety performance.**
H3	**An Effective Formal Learning System will lead to an improvement in organizational safety performance.**
H4	**Promotion of Safety at the organizational level will lead to an improvement in organizational safety performance.**
Shipboard Hypotheses	
H5	**Prioritization of Safety at the shipboard level will improve shipboard safety performance.**
H6	**Effective Communication at the shipboard level will improve shipboard safety performance.**
H7	**Effective Problem Identification at the shipboard level will improve shipboard safety performance.**
H8	**Effective Feedback at the shipboard level will lead to improved shipboard safety performance.**
H9	**Responsibility at the shipboard level will lead to improved shipboard safety performance.**
Individual Hypotheses	
H10	**Employee empowerment will improve individual safety performance.**
H11	**Anonymous Reporting will improve individual safety performance.**
H12	**Effective Individual Feedback will improve individual safety performance.**
H13	**Individual Responsibility will improve individual safety performance.**

Method


Subjective measures
Objective measures
Organizational Safety Factors
Hiring Quality Personnel
Safety Orientation
Promotion of Safety
Formal Learning System
H1-H4
Organizational Safety Performance
accidents
incidents
near misses
of conditions of class
# of port state deficiencies
LTI>=3
Vessel Safety Factors
Responsibility
Communication
Problem Identification
Prioritization of safety
Feedback
H5-H9
Vessel Safety Performance
accidents
incidents
#near misses
# of conditions of class
# of port state deficiencies
LTI>=3
Individual Safety Factors
Empowerment
Responsibility
Anonymous Reporting
Feedback
H10-H13
Individual Safety Performance
Degree of perceived risk
accidents
incidents
#near misses
LTI>=3

Method



http://www.eagle.org/default.html

- Subjective measures
- Objective measures

- Subjective measures—safety factor surveys
  (Flin, Mearns & O'Connor 2000, 2001)
  - *--5 point Likert scale*
  - *--Strongly agree to Strongly disagree*
  - *--Employee perceptions of the importance of safety factors in safety performance*
- Objective measures—safety performance data

Individual Survey

http://surveymonkey.com/s.asp?u=863991467514

Individual Safety Factor Questionnaire

Department of Decision Sciences and Engineering Systems
Rensselaer Polytechnic Institute
Troy, New York, 12180

Your organization is participating in a research project, sponsored by American Bureau Shipping and being conducted by Rensselaer Polytechnic Institute, that is examining employee perceptions of factors responsible for safety performance in the U.S. marine transportation system. This survey is being administered as part of this research project. The researchers will not collect any identifying information from the survey (e.g., IP addresses).

Individual Survey

http://surveymonkey.com/s.asp?u=863991467514

Hiring Quality People

	Strongly disagree	Slightly disagree	Neutral	Slightly agree	Strongly agree
a) My colleagues consider safety issues seriously while performing job duties.					
b) The hiring process in my organization is effective in identifying the right people for jobs.					

Vessel Survey

http://surveymonkey.com/s.asp?u=675411524477

Vessel Safety Performance Questionnaire

TO BE FILLED OUT BY THE CHIEF SAFETY OFFICER OF EACH VESSEL

Department of Decision Sciences and Engineering Systems
Rensselaer Polytechnic Institute
Troy, New York, 12180

Your organization is participating in a research project identifying the factors responsible for safety performance in the U.S. marine transportation system. The attached questionnaire is being administered as part of this research project. It is recommended that the chief safety officer of the vessel or someone who has access to the safety performance data of the vessel answer this questionnaire.

Organizational Survey

http://surveymonkey.com/s.asp?u=597531527497

Organizational Safety Performance Questionnaire

TO BE FILLED OUT BY THE CHIEF SAFETY OFFICER OF THE ORGANIZATION

Department of Decision Sciences and Engineering Systems

Rensselaer Polytechnic Institute

Troy, New York, 12180

Your organization is participating in a research project identifying the factors responsible for safety performance in the U.S. marine transportation system. The attached questionnaire is being administered as part of this research project. It is recommended that the safety officer of the organization or someone who has access to the safety performance data of the organization complete this questionnaire.

Safety Performance Data

Organizational Safety Performance

#accidents per vessel
#incidents per vessel
#near-misses per vessel
conditions of class per vessel
port state deficiencies per vessel
LTI>=3 per vessel

Vessel Safety Performance

#accidents per employee
#incidents per employee
#near-misses per employee
conditions of class per employee
port state deficiencies per employee
LTI>=3 per employee

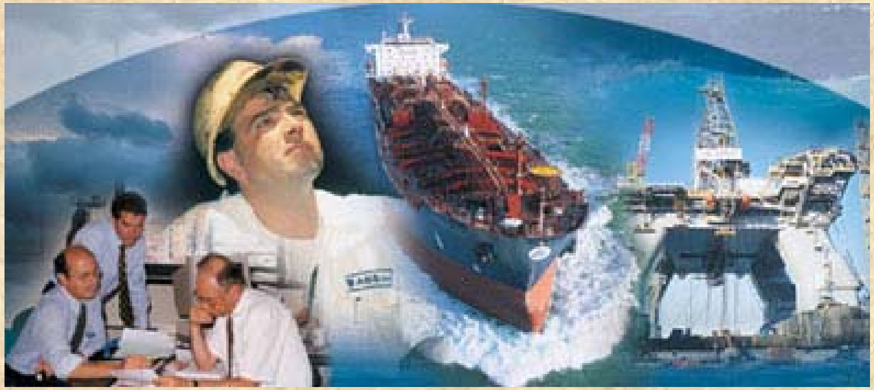
Individual Safety Performance

#accidents
#incidents
#near-misses
LTI>=3
Perceived risk

Participants

No.	Organization	Operation	Trade	Fleet
1	**Sea River Maritime Inc.**	**Oil tanker**	**Domestic US**	**7, 2 tugs**
2	Alaska Tanker Company	Oil tanker	Domestic US, Intern.	8
3	Bouchard Transportation Inc.	Tug-barge	Domestic US, Great Lakes, Intern.	26 B, 19T
4	Keystone Shipping Company	Oil tanker	Domestic US, TAPS	6
5	Crowley Maritime Corp	Tug-barge, Oil tanker	Inland	6+
6	SeaBulk International	Petro. & Chem. tankers	Inland, Intern	10, 26T
7	Chevron Shipping Company	Oil and LNG	Domestic US, Intern	30
8	Cononco Philips Polar Tankers	Oil tankers	Domestic US, TAPS	6
9	**Overseas Shipholding group**	**Oil tankers**	**International**	**86+**
10	Shell Shipping	Oil tanker, LNG	Domestic US, Intern	10
11	AHL Shipping Company	Oil tanker	Domestic US, Gulf Tr.	7
12	EL Paso Marine	LNG	International	6
13	American Steamship Comp.	Dry Bulk	Great Lakes	11
14	Odjfell USA Inc.	Chemical tankers	International	32

Statistical Analysis



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- **Correlation analysis between**
  - --indicators and safety factors
  - --indicators and safety performance
  - --Pearson product moment correlation
  - --t-test to test significance of correlation

Statistical Analysis

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- **Regression analysis to determine predictive power of leading indicators**

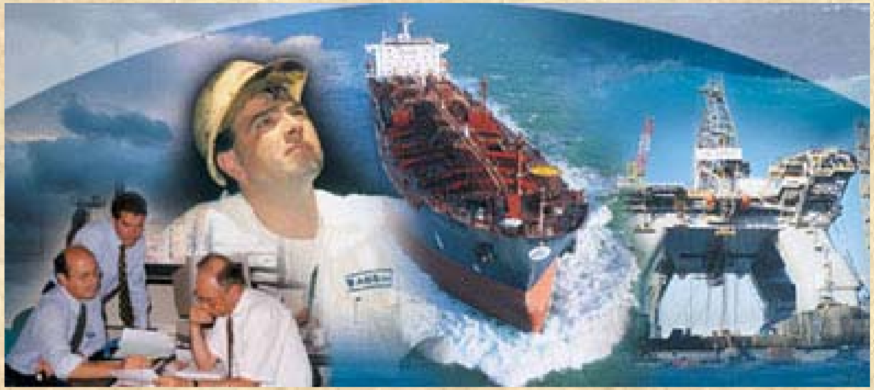
  --Safety factors with safety performance

  --Leading indicators with safety performance

  --Distribution of mean errors to validate predictive power of leading indicators

  --Kolmogrov-Smirnoff statistic

Statistical Analysis



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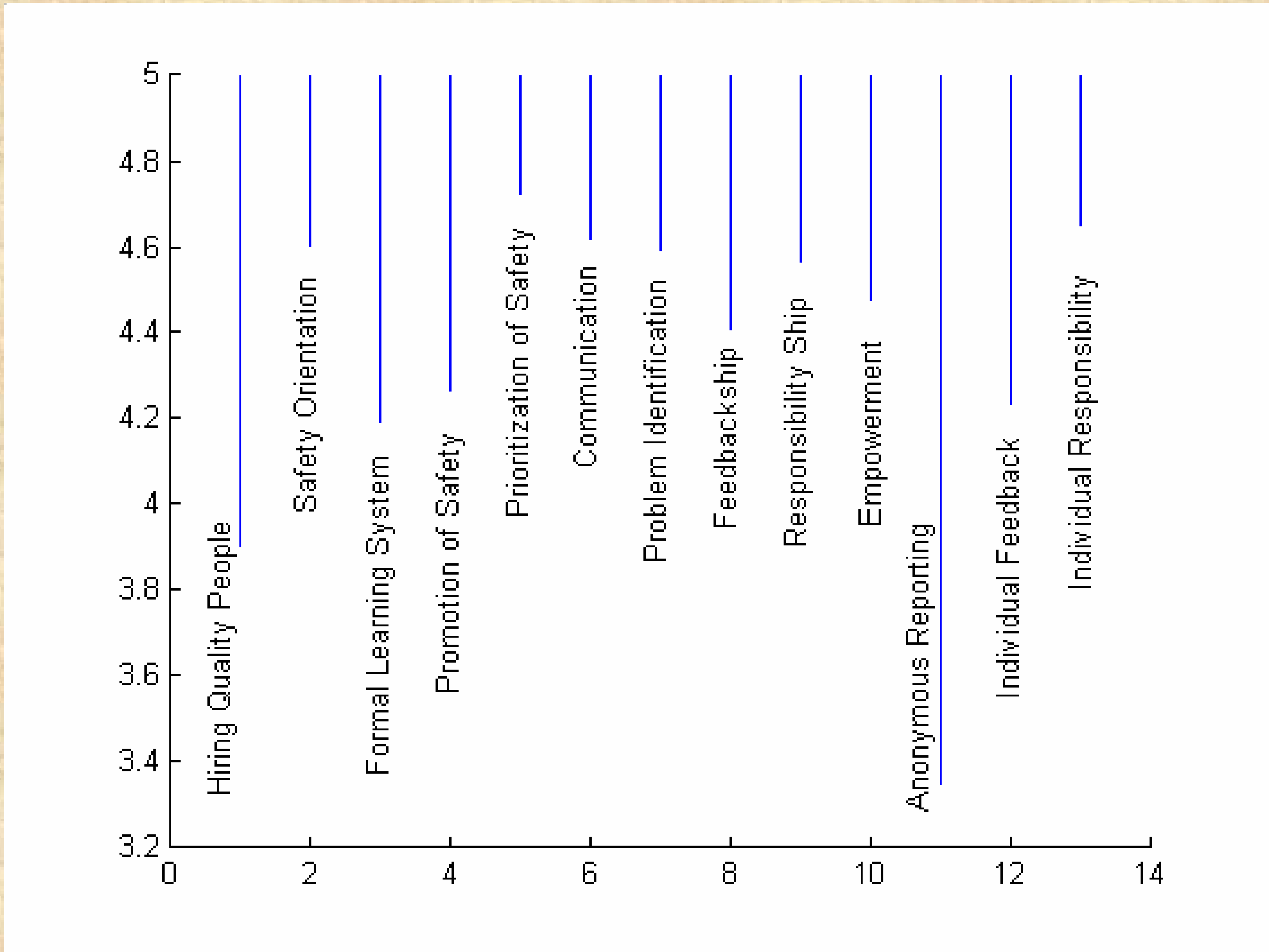
Factor analysis of safety climate data
--orthogonal and oblique rotations
--is there a common factor structure in all operator organizations?

- **Questionnaire reliability**

- **Logical analysis of data**

Safety Factor Results

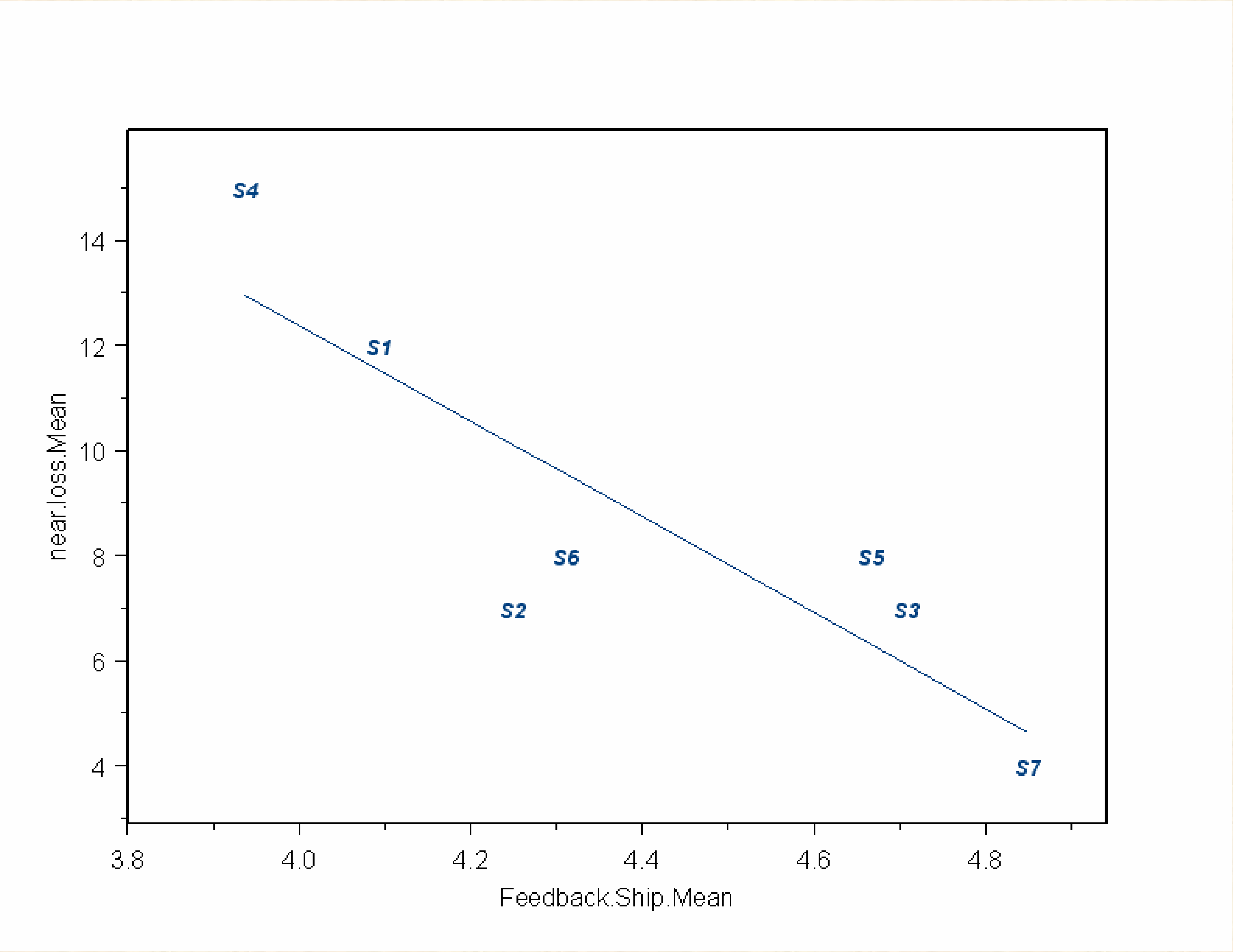


Principal Component Factor Analysis followed by orthogonal varimax rotation. The factors are chosen on the basis of minimum eigen value criterion.

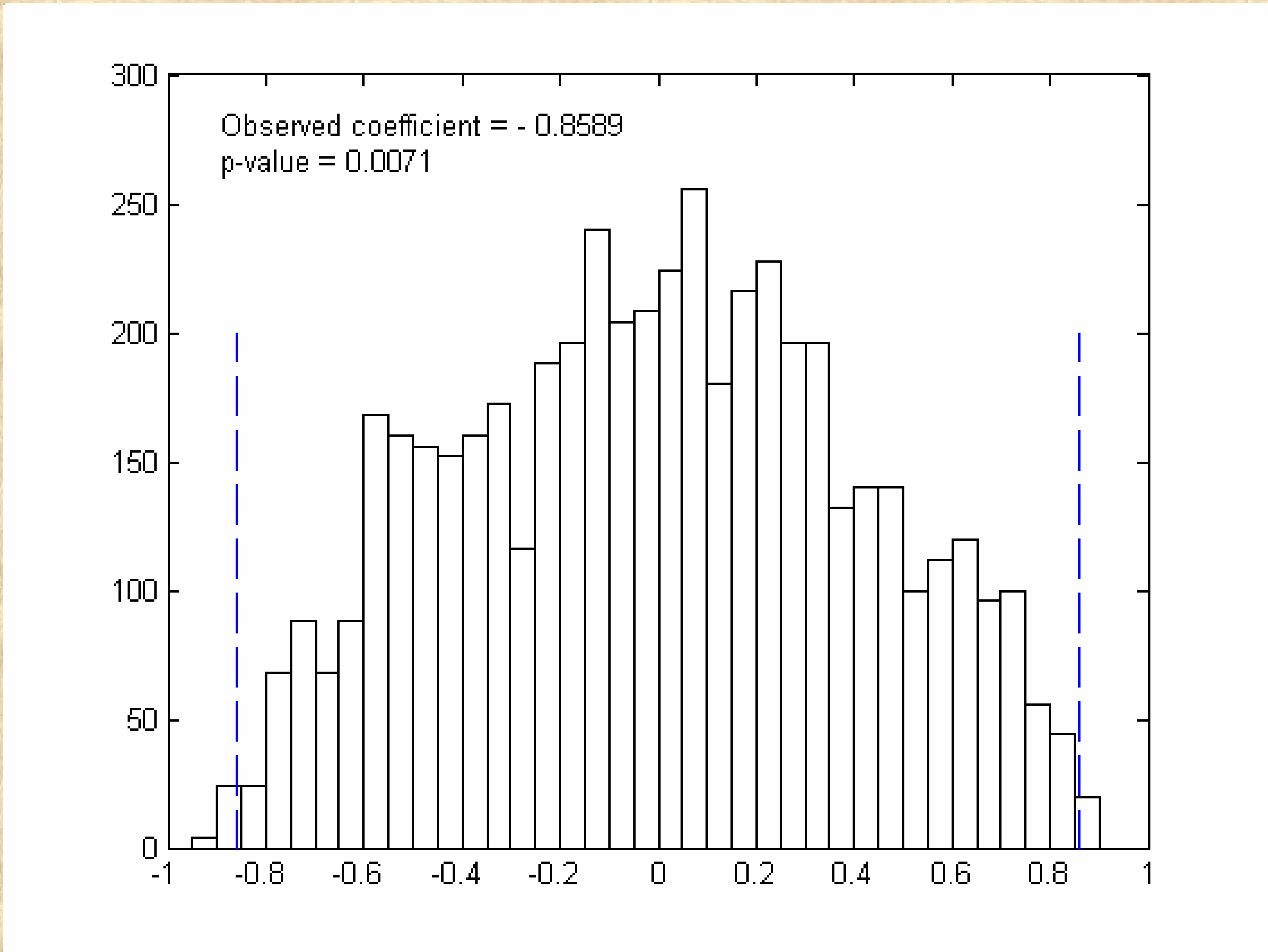
Factor Analysis:

- **Anonymous Reporting**
- **Hiring Quality People**
- **Feedback (Individual, Ship)**
- **Formal Learning System**
- **Empowerment**
- **Communication**

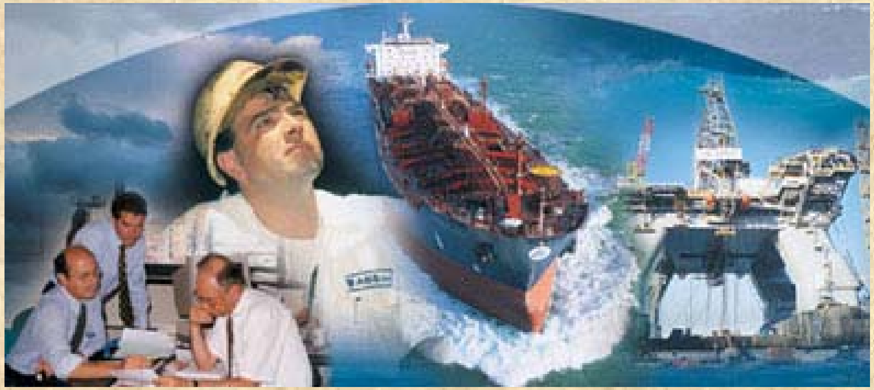
Feedback vs. Near Losses



Permutation test--Feedback_Ship



Safety Index



$$Safety\ Index = w_i * SafetyFactor_i$$

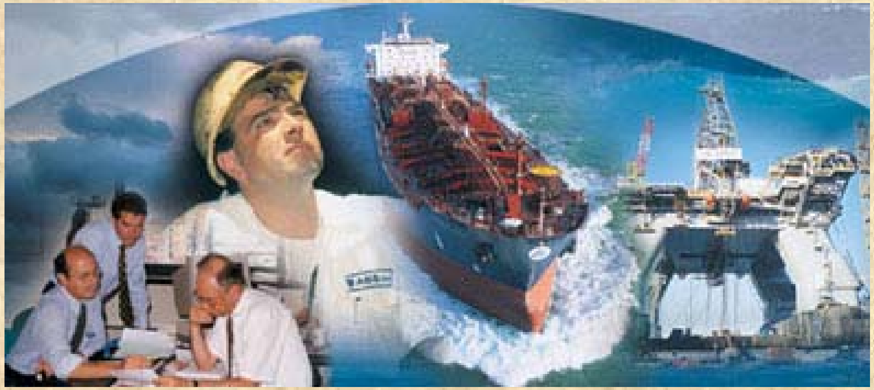
Weights provided by solution to the following optimization problem

$$\underset{w}{Min}\ Corr(Safety\,index, Near\ Loss)$$

$$\sum w_i = 1$$

$$w_i \geq 0$$

Ship Safety Index

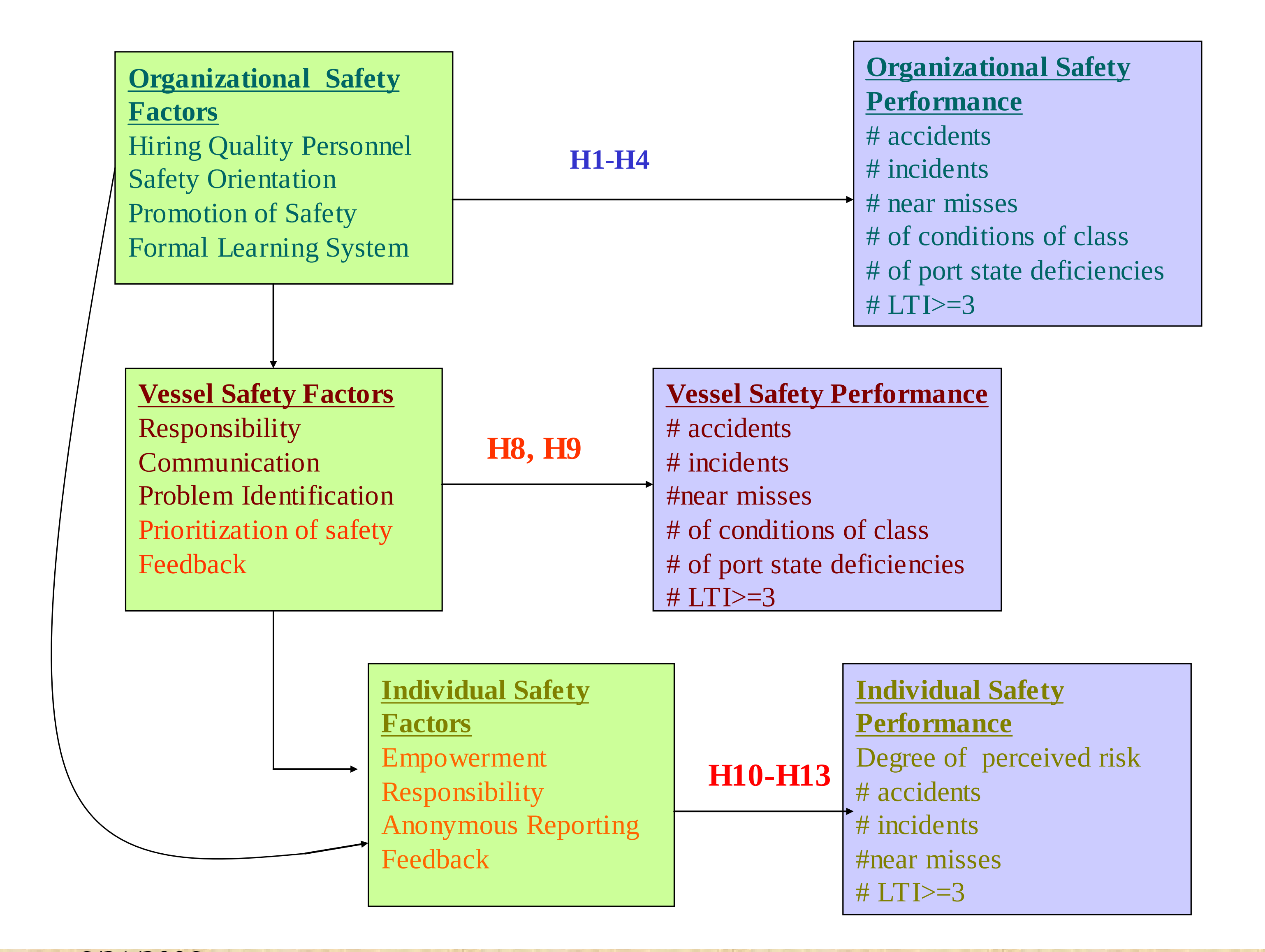


$$Safety\ Index = w_i * SafetyFactor_i$$

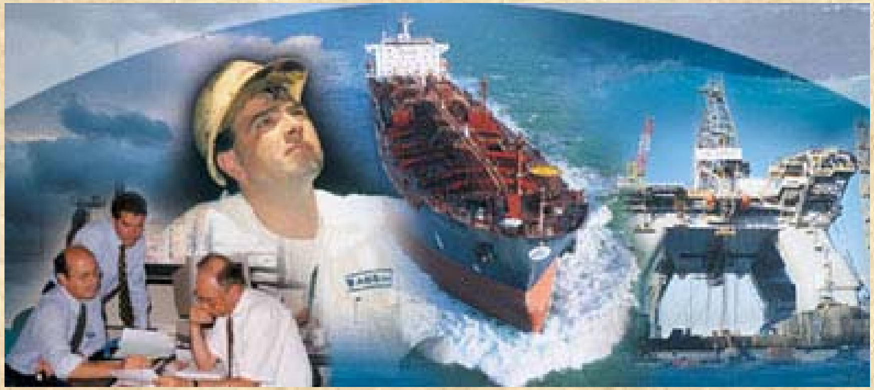
$$\begin{aligned} SafetyIndex = {} & 0.326 * prioritization\ of\ safety + \\ & 0.0 * communication + \\ & 0.036 * problem\ identification + \\ & 0.637 * feedback\ ship + \\ & 0.0 * responsibility \end{aligned}$$

$$Mean\ NearLoss = 59.40 - 11.23 * SafetyIndex$$

Pilot Study Significant Results --



Leading Indicators in Virtual Organizations



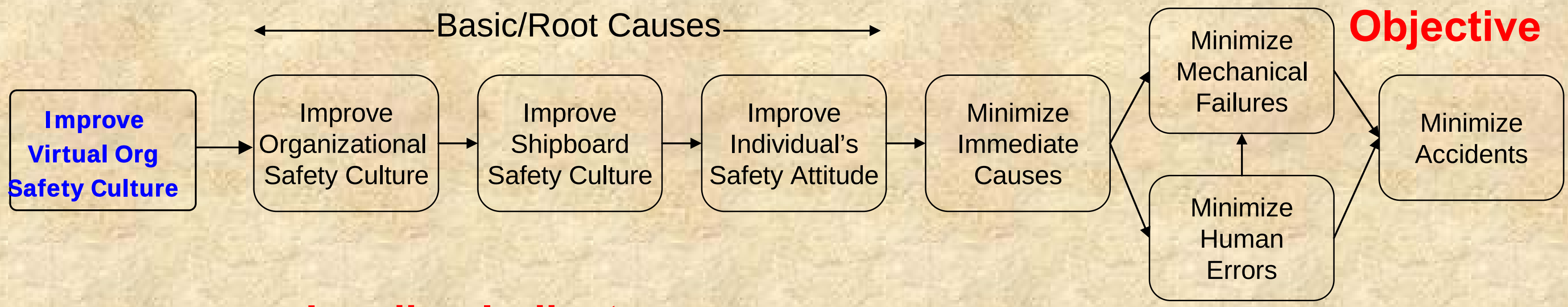
- High reliability organization research
- Network, virtual organizations

- **Prioritization of safety and reliability as goals**
- **Organizational structuring and design**
- **Shared organizational culture of reliability**
- **Communication at the organization's interfaces**
- **Trust**

Virtual Organization Safety Factors

Fundamental Objectives

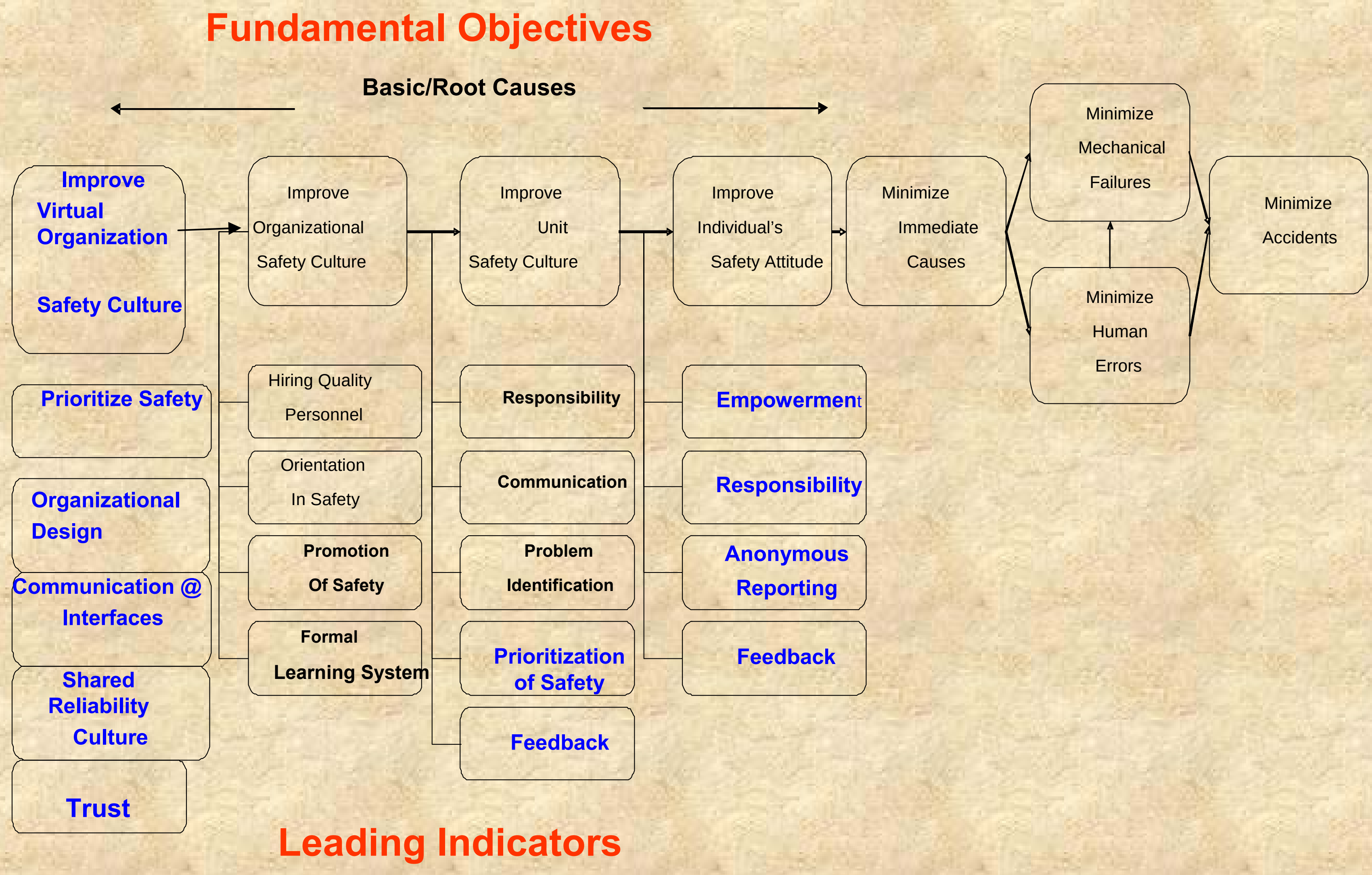
Strategic Objective



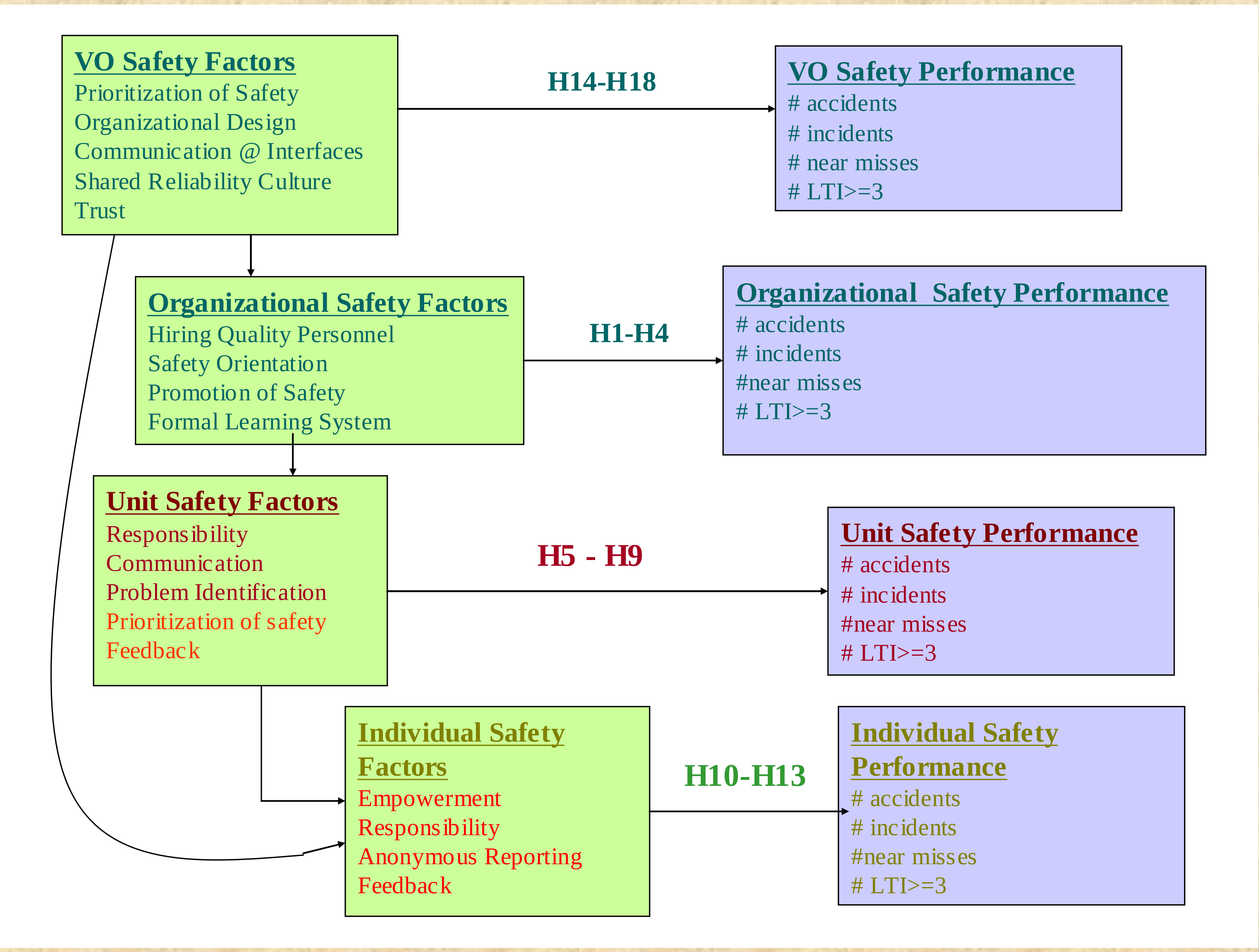
Leading Indicators

Lagging Indicator

Virtual Organization Safety Factor Structure



Revised Virtual Organization Model



Candidate Leading Indicators

Soma Neural Nets, 2004

- *#ILO conventions adopted by vessel flag*
- *Propulsion system availability*
- *Primary fleet flag*
- *Co-ownership?*
- *Country of registry*
- *Non-IACS class?*
- *Mean fleet age*
- *Ship type*
- *Vessel flag*

→ R^2 = .43 - .61

Safety Performance

ADAC score

deficiencies per PSC inspection

Accidents

Immaculate PSC inspections

(Soma, Chapter 4, Figure 5, p 72)

Soma PCA, 2004

- *Safety rehearse*
- *Commitment*
- *Communication*
- *Job satisfaction*
- *Acknowledgement of personal limitations*
- *Work integrity*
- *Social integration*
- *Power & dignity*

Principal Components

(Soma, Ch. 7, p. 126)

UK HSE, 2000

- *Productivity vs. safety*
- *Learning organization*
- *Safety resources*
- *Participation*
- *Shared perceptions about safety*
- *Trust*
- *Training*

- *Management commitment & visibility*
- *Communication*
- *Job satisfaction and industrial relations*

Mearns, et al., 2003

- *Involvement*
- *Perceived supervisor competence*
- *General safety behavior*
- *Safety behavior under incentive*
- *Rules & implementation of safety measures*
- *Propensity to report incidents/ accidents*

- *Perceived management commitment*
- *Communication*
- *Satisfaction with safety*
- *Job satisfaction*

Candidate Leading Indicators

ABS, 2004

- *Safety management*
- *Maintenance systems*
- *Incident investigations*
- *Safety system evaluat'n & improvement*
- *Work integrity*
- *Safety training/orientat'n*
- *Mgmt commitment*
- *Communication*
- *Job satisfaction*
- *Emeg preparedness*
- *Management of change*

Soma Neural Nets, 2004

- *#ILO conventions adopted by vessel flag*
- *Propulsion system availability*
- *Primary fleet flag*
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- *Vessel flag*

(Soma, Chapter 4, Figure 5, p 72)

OCIMF TMSA, 2004

- *Mgmt, Leadership, Accountability*
- *Recruitment/mgmt of personnel*
- Reliability & maintenance
- *Navigational safety*
- *Cargo, ballast & mooring ops*
- *Management of change*
- *Incident investigation & analysis*
- *Safety management*
- *Environmental management*
- *Emergency preparedness*
- *Measurement, analysis & improvmt*

Soma PCA, 2004

- *Safety rehearse*
- *Commitment*
- *Communication*
- *Job satisfaction*
- *Acknowledgement of personal limitations*
- *Work integrity*
- *Social integration*
- *Power & dignity*

Principal Components

(Soma, Ch. 7, p. 126)

UK HSE, 2000

- *Productivity vs. safety*
- *Learning organization*
- *Safety resources*
- *Participation*
- *Shared perceptions about safety*
- *Trust*
- *Training*

- *Safety training & rehearsal*
- *Management commitment & visibility*
- *Communication*
- *Job satisfaction and industrial relations*

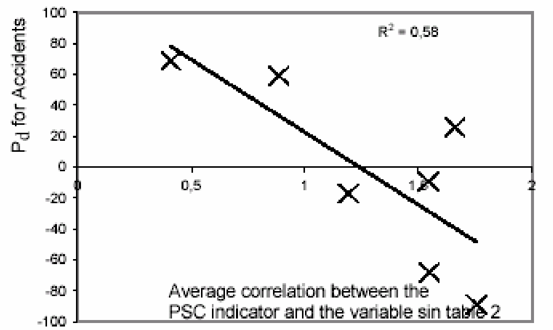
Mearns, et al., 2003

- *Involvement*
- *Perceived supervisor competence*
- *General safety behavior*
- *Safety behavior under incentive*
- *Rules & implementation of safety measures*
- *Propensity to report incidents/ accidents*

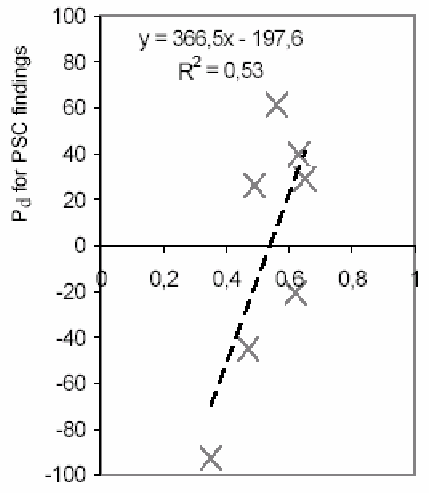
- *Safety training & rehearsal*
- *Perceived management commitment*
- *Communication*
- *Satisfaction with safety*
- *Job satisfaction*

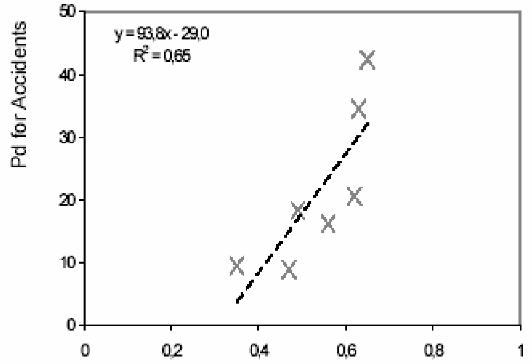
Statistical Significance

Figure 5: Relationship between the sum of



absolute correlation values and the PSC indicator.





Correlation between ship characteristics and PSC indicator
R^2 = .58

Correlation between safety culture correlation measure and PSC indicator
R^2 = .53

Correlation between safety culture correlation measure and accidents
R^2 = .65

(Soma, Chapter 6, p 104)

Statistical Significance

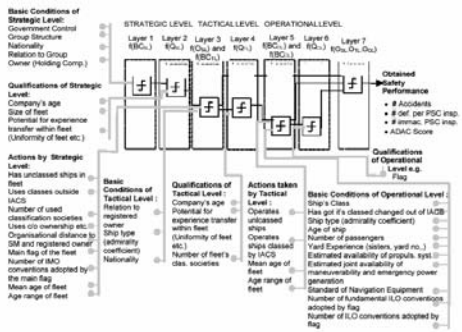


Figure 5. Neural network of organizational influence on safety performance

	# Accidents (M = 100)	# PSC DEF (M = 51)	# IMMAC PSC (M = 51)
ADAC Score	P = 0.15	P = 0.10	P= 0.15
# Accidents		P = 0.36	P = -0.08
# PSC Deficiencies			P = -0.63

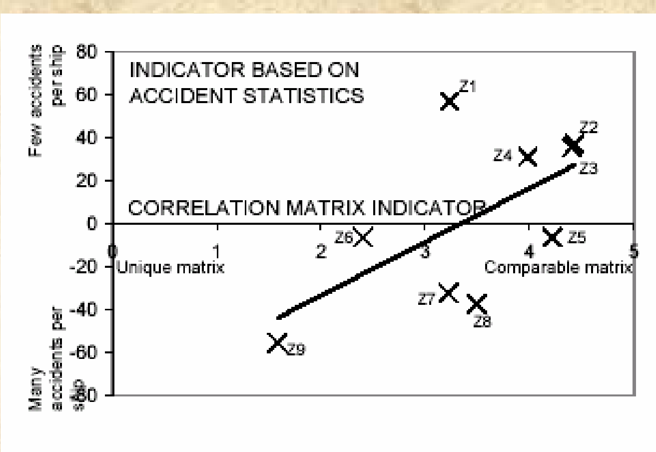
(Soma, Chapter 4, p 104)

Neural Net, Ch. 4

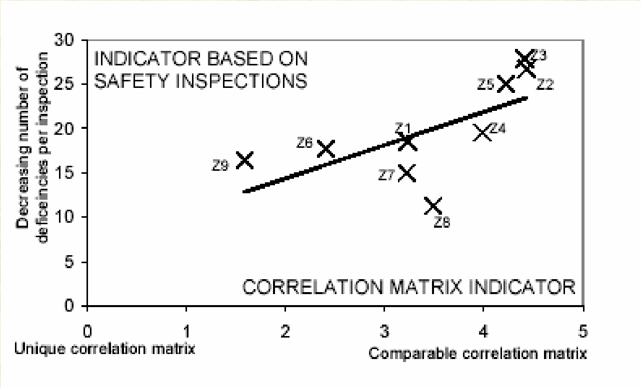
Correlation between NN results and ADAC score
R^2 = .43

Correlation between NN results and accidents
R^2 = .61

Statistical Significance



Correlation between correlation matrix indicator and accident indicator $R^2 = .61$



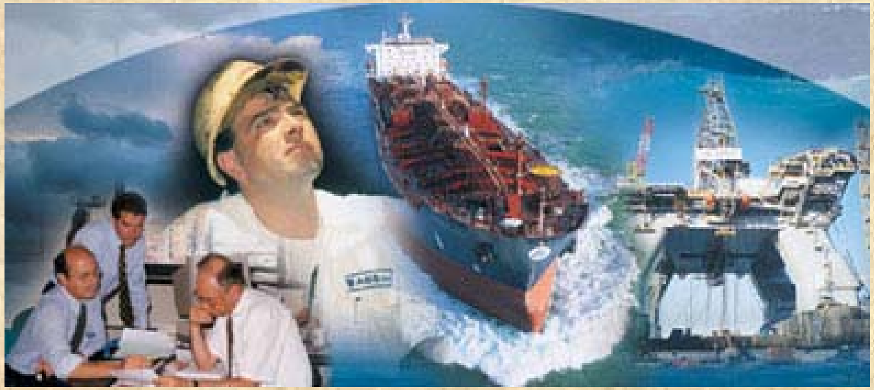
Correlation between correlation matrix indicator and PSC indicator $R^2 = .65$

(Soma, Chapter 7, Figure 7)

- **'It is now assumed that having the cultural pattern that is most similar to the others have the most mature pattern.'**
- **The correlation coefficient between the correlation matrix indicator and the accident indicator was 0.61, and the same figure for the safety inspection indicator was 0.65.**
- **Even though the values isolated are not statistically significant, it is unlikely that 2 independent analyses [would] produce spurious correlations of this high value."**

(Soma, Chapter 7, p 122)

Validating Leading Indicators



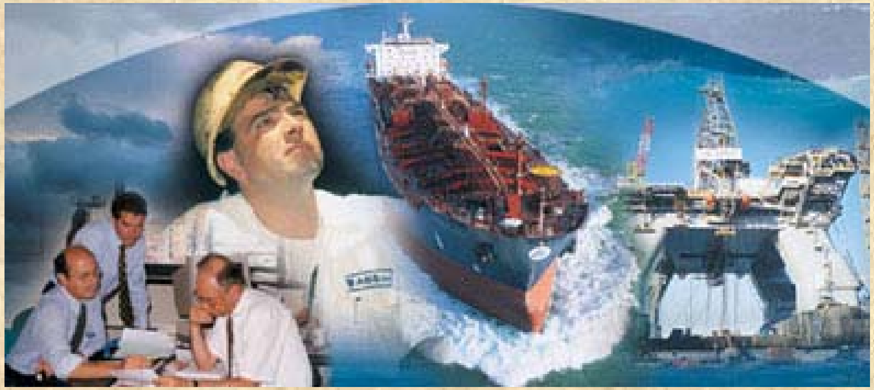
http://www.eagle.org/default.html

Once candidate leading indicators have been identified….

- **Scatter plot analysis**
- **Multiple regression analysis**
- **Validation against additional data sets**
- **Principal components analysis**
- **Neural nets**
- **Artificial (hybrid) neural nets**
- **Logical analysis of data (LAD) [data mining]**

… to determine predictiveness of indicators

Cautions



http://www.eagle.org/default.html

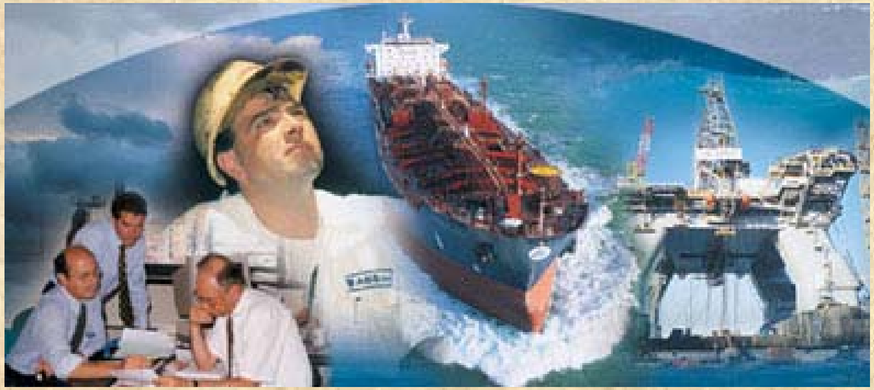
Several cautions associated with leading indicators…

- **Safety plateaus—mishap rates stabilize**

  --suggests a mix of system- and individual-level leading indicators

- **Heedfulness important to identify indicators**
- **Shared understanding of normal and abnormal**

Cautions



http://www.eagle.org/default.html

Several cautions associated with leading indicators…

- **Learning from accident precursors and leading indicators is difficult for organizations**
  --root cause analyses, incident investigations

- **Different subsystems within a large system may have their own cultures**
  --different vessels may have different leading indicators

Event Chain for Maritime Accidents

Causal Chain