Identification of Leading Objective Indicators of Safety in Shipping

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Report 5426, Lund 2013

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Lund 2013

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Report 5426

ISSN: 1402-3504

ISRN: LUTVDG/TVBB--5426--SE

Number of pages: 60

Keywords
Leading indicators, safety management, shipping, safety culture, metrics, safety performance, incident reporting, near miss, objectivity, the ISM Code, concepts, expressions.

Abstract
This study investigated the possibilities of identifying leading objective indicators of safety across shipping organisations. Leading objective indicators of safety are safety culture related metrics that are statistically correlated with safety performance data which enables a more proactive approach to safety management. The conclusion was that no indicators could be identified, at least not across a wide range of different shipping companies from different sectors due to major differences in safety monitoring and perception of terms and expressions related to safety. It was therefore concluded that there is a need for a more common understanding of terms and expressions used within the shipping sector. It is also concluded that a well-functioning reporting system is essential for enabling an effective safety monitoring. We believe that leading objective indicators can be a useful supplementary tool in safety management if it is further developed and used within one organisation.

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Summary

Maritime accidents have a high potential of causing catastrophic consequences for both humans and the environment and the need of a more proactive approach to safety management in shipping to prevent these accidents is becoming increasingly recognized. One way to measure safety, which is a concept that is difficult to measure directly, is by using indicators. Leading indicators of safety, which are safety metrics that are statistically significantly correlated with safety performance data, can be used to discover weaknesses in advance of adverse events and aid safety management.

The metrics in this study were based on three key fundamentals of safety culture; management commitment, personnel empowerment and continuous improvement. The main objective was to identify leading objective indicators of safety in shipping by collecting data across organisations.

The main research questions in this thesis were:

- Can common leading objective indicators of safety be identified across organisations in the shipping industry?
- If any leading indicators are found, how are they correlated with safety performance?

A method presented in a report by the American Bureau of Shipping, "Guidance notes on safety culture and leading indicators of safety", formed the foundation of the study. However, the method presented in the guidelines was thoroughly revised to suit the question at issue. The project was performed in several steps. First, a datasheet for collection of data was created through a literature study and expertise consulting. Then data was collected from ten shipping companies and finally a statistical analysis of the data was executed.

After performing this project, our opinion is that leading objective indicators of safety in shipping cannot be identified, at least not across different sectors of shipping companies. The indicators that were found cannot be said to be valid since they are largely based on data of poor comparability and are far from objective.

Most of the problems that we encountered can be traced back to the aim to find common indicators by involving several different sectors of shipping companies, as the definitions of concepts used in their safety work vary considerably. Hence we draw the conclusion that in order to facilitate safety research, collaboration and comparison between different shipping companies there is a need to reduce the diversity of definitions that are used within the shipping industry.

One of the main disadvantages of objective indicators is their inability to capture the quality of the metrics, which might lead to a misdirected focus on numbers. Also the problems that occur when correlating the metrics to safety performance, where the reporting rate is a large source of uncertainties, are difficult to overcome. If leading objective indicators of safety are used in safety management, it is of great importance that the safety managers are aware of these problems, and that the indicators are used mainly as a more proactive complement to other ways of monitoring and managing safety.

Sammanfattning

Olyckor till sjöss har en hög potential att orsaka katastrofala följder för både människor och miljö och behovet av ett mer proaktivt angreppssätt gällande säkerhetshantering inom sjöfarten för att förebygga dessa olyckor blir allt mer erkänt. Ett sätt att mäta säkerhet, som är ett begrepp som är svårt att mäta direkt, är genom att använda säkerhetsindikatorer. Ledande indikatorer för säkerhet, som är mätetal som är statistiskt signifikant korrelerade med säkerhetsutfall, kan användas för att upptäcka svagheter innan incidenter inträffar och stödja företagets säkerhetshantering.

Mätetalen i denna studie bygger på tre viktiga grunder i säkerhetskultur; ledningens engagemang, personalens delaktighet och ständig förbättring. Huvudsyftet var att identifiera ledande objektiva indikatorer för säkerhet inom sjöfarten genom att samla in data från flera olika organisationer.

De huvudsakliga frågeställningarna i denna avhandling var:

• Kan gemensamma ledande objektiva indikatorer för säkerhet identifieras för olika organisationer inom sjöfartsbranschen?
• Om några ledande indikatorer identifieras, hur är de då korrelerade med säkerhet?

En metod som presenteras i en rapport från American Bureau of Shipping, "Guidance notes on safety culture and leading indicators of safety ", har legat till grund för studien. Metoden som presenteras i dessa riktlinjer har emellertid grundligt reviderats för att passa den aktuella frågeställningen. Projektet utfördes i flera steg. Först formulerades ett datablad för insamlingen av data genom en litteraturstudie och konsultation med experter inom området. Data samlades in från tio rederier och slutligen gjordes en statistisk analys av den insamlade datan.

Efter att ha utfört detta projekt är vår uppfattning att ledande objektiva indikatorer för säkerhet inom sjöfarten inte kan identifieras, åtminstone inte över olika sektorer av rederier. De indikatorer som hittades kan inte sägas vara giltiga eftersom de till stor del bygger på data med dålig jämförbarhet och är långt ifrån objektiva.

De flesta problem som vi stött på kan spåras till syftet att hitta gemensamma indikatorer genom att involvera flera olika sektorer av rederier, eftersom definitionerna av begrepp som används i säkerhetsarbetet varierar avsevärt. Därför drar vi slutsatsen att det finns ett behov av att minska den mångfald av definitioner som används inom sjöfarten för att underlätta säkerhetsforskning, samarbete och jämförelser mellan olika rederier.

En av de största nackdelarna med objektiva indikatorer är deras oförmåga att mäta kvaliteten av mätetalen, vilket kan leda till ett missriktat fokus på siffror. Även de problem som uppstår när mätetalen korreleras med säkerhetsutfall, så som att rapporteringsgraden är en stor källa till osäkerhet, är svåra att övervinna. Om ledande objektiva indikatorer för säkerhet ska användas i säkerhetshantering är det av stor vikt att de ansvariga är medvetna om dessa problem och att indikatorerna främst används som ett mer proaktivt komplement till andra sätt att övervaka och hantera säkerhet.

Acknowledgements

This master thesis project has been performed during the spring and summer of 2013 under the supervision of Johannes Hüffmeier, project manager at the department of maritime operations at SSPA Sweden AB and Johan Bergström, teacher and researcher at the Department of Fire Safety Engineering and Systems Safety, Lund University. The project has been performed at SSPA Sweden AB and has also been a part of the EU project CyClaDes with the purpose to investigate the influence of safety culture on human factors in incidents and accidents in shipping.

First of all we would like to thank the employees at SSPA Sweden AB for giving us the possibility to perform this thesis project and introducing us to the exciting field of safety in shipping. Also, thank you for being helpful in providing us with contact information and valuable input. Big thanks to our supervisors Johan Bergström and Johannes Hüffmeier for being absolutely amazing in supporting this study and guiding us in the right direction in the huge field of safety culture where it otherwise would have been easy to get lost. Thanks to Tryggve Ahlman at the Swedish Shipowners' Association, Martin Hernqvist at The Swedish Club and Magnus Gustafsson at Codan for your expertise and valuable input in the initial phase of the project. Also, thanks to the American Bureau of Shipping for providing the guidelines on which this thesis is based upon and to Olle Bråfelt at ICC for your expertise on incident reporting in shipping. And finally, a big thank you to all the safety managers at the participating companies who so generously took time and interest in helping us and let us collect the data that was needed. Without you, this study would not have been possible.

Table of Contents

Glossary

Accident or Incident: An event that has occurred and received an unwanted consequence.

Conditions of Class: The number of deficiencies identified, or recommendations made, by the classification society's surveyor on a vessel which should be carried out within a limited time in order to retain class.

Designated person (DP): The person who is responsible for monitoring the safety and pollution-prevention aspects of each ship. He/she provides a link between the company and those on board and has direct access to the highest level of management.

KPI: Key Performance Indicator. A commonly used way to monitor the organisational performance and may or may not be safety-related.

ISM Code: The International Safety Management Code, which provides an international standard for the safe management and operation of ships and for pollution prevention.

Leading objective indicators of safety: Metrics significantly correlated with safety performance data that are quantitative measures of proactive safety activities.

Lost Time Incident (LTI): Any work-related injury other than a fatal injury that results in a person being unfit for work for a period of 24 continuous hours immediately after the occurrence of the incident.

Medical Treatment Case (MTC): Work-related injuries that are not severe enough to be reported as fatalities, Lost Time Incident, or Restricted Work Accident cases but are more severe than requiring simple first aid treatment; however the injured person is able to carry out all his duties after treatment.

Near Miss (NM): An event, or a chain of events, that under slightly different circumstances could have resulted in an accident, injury, damage, or loss of personnel, equipment, or the vessel.

Non-conformity: An observed situation where objective evidence indicates the non-fulfillment of a specified requirement.

Port State Deficiencies: The number of deficiencies on a vessel identified by Port State Control.

Restricted Work Accident (RWA): Any work-related injury (other than a fatality or lost time incident) that results in a person being unfit to perform all of his/her regular job after the accident.

Total Recordable Cases (TRC): The sum of all work-related fatalities, lost time incidents, restricted work accidents and medical treatment cases. TRCs = LTIs + RWAs + MTCs.

1. Introduction

This introductory chapter contains a short background to the project. The objectives in this study are presented and the questions at issue are defined. Finally, the limitations and delimitations of this study are discussed.

1.1 Background

Shipping is the oldest global industry and it still plays a vital role in the world economy, as shipping covers approximately 90 % of the world trade (Mansell, 2009). The International Maritime Organization states that “Shipping is still perhaps the most international of all the world´s great industries and one of the most dangerous” (as cited in Hetherington, Flin, & Mearns, 2006, p. 401). This is mainly because maritime accidents have a high potential of causing catastrophic consequences for both humans and the environment (Hetherington et al., 2006). The shipping industry is special in the sense that both cargo and crew are exposed to a considerable physical risk (Jalonen & Salmi, 2009) and seafarers are exposed to a demanding worksite, e.g. due to inability to leave their workplace, extreme weather conditions and long periods away from home (Hetherington et al., 2006).

The shipping companies play a vital role in maritime safety. The Swedish Shipowners´ Association states in their safety policy that the most important link in the maritime safety chain is the shipping company and that within this safety chain, the shipping company link must be of the highest quality (The Swedish Shipowners´ Association, 2003). Therefore, the shipping companies are the players in maritime safety that are in main focus of this study.

Due to technological advances which has led to increased automation and decreased manning, the shipping industry has developed rapidly. These advances have reduced the frequency and severity of incidents, but also changed the role of the seafarer as automation creates new attentional demands (Hetherington et al., 2006). According to The Swedish Shipowners´ Association the crew can be considered the key to a high safety level on board a ship and a good maritime safety culture is the foundation of all maritime safety work (The Swedish Shipowners´ Association, 2003).

Tools that are used in the maritime industry, such as the International Safety Management Code and safety management systems, help compliance with regulations, but they do not necessarily improve safety culture. It is recognised in the maritime industry that to improve maritime safety a better understanding of organisational factors is needed rather than more regulations (American Bureau of Shipping [ABS], 2012). Hence, in this master thesis, the influences of safety culture on accidents in the maritime industry are considered.

Safety is often defined as the freedom of unacceptable risk, which would mean that the purpose of a safety management system is to avoid something. According to this definition, an increase in safety leads to lower numbers of measured negative output. This may lead to complications as this lack of information can be misinterpreted as a state of control. It would thus be more logical if the output increases when the safety level in the organisation increases, i.e. output measured as something positive. The goal of safety management should not be to avoid something, but to get closer to something (Hollnagel, 2008).

One way to measure and monitor safety, which is a concept that is difficult to measure directly, are by using indicators of safety (the Organisation for Economic Co-operation and Development [OECD], 2008). Traditionally safety measures are based on something that has already gone wrong, for example economic losses or the number of accidents that have occurred within an organisation. However, the need for more proactive ways of managing safety in shipping is becoming increasingly recognised. This project is focused on a more proactive approach to maritime safety work as metrics based on safety culture factors are used to identify leading objective indicators of safety.

1.2 Objectives

The main objective of this thesis is to identify leading objective indicators of safety in shipping by collecting data across organisations. These indicators may aid safety management by facilitating the revealing of areas of weakness in advance of adverse events. They may thereby enable a more proactive approach for safety management in shipping companies.

The long term objective is to enable the use of leading objective indicators of safety as a tool to help decision makers to make better prioritisations of resources in their preventive safety work by providing information about which organisational activities that are strongest correlated with safety performance.

1.3 Questions at Issue

The main research questions in this thesis are:

- Can common leading objective indicators of safety be identified across organisations in the shipping industry?
- If any leading indicators are found, how are they correlated with safety performance?

1.4 Limitations and Delimitations

The study is delimited to involve shipping companies which comply with the International Maritime Organization's (IMO) definition presented in the International Safety Management Code (the ISM Code) section 1.1.2: "*Company* means the owner of the ship or any other organisation or person such as the manager, or the bareboat charterer, who has assumed the responsibility for operation of the ship from the owner of the ship and who on assuming such responsibility has agreed to take over all duties and responsibilities imposed by the International Safety Management Code" (International Maritime Organization [IMO], 2010). This means that no shipping companies with outsourced management is included in the study.

The aim has been to include ten shipping companies with a varying range of size, nationality and type of cargo. The number of studied shipping companies is limited both to fit the timeframe of the thesis project and the availability of shipping companies having the willingness to participate. The latter reason also affects the range of different types of shipping companies. This means that if any indicators are found, they cannot be applied generally to the entire shipping industry, but they may still give a valuable indication and inspiration for future studies.

There might be a limited access to statistical data of safety metrics and safety performance due to confidentiality or simply because the company has not collected this data.

There might be delayed effects in safety performance and therefore metrics from 2011 was correlated to safety performance data from 2011 and 2012. It was decided in this study to delimit the collection of safety performance data to two years. However, in a more comprehensive study the correlation should have been done over several years to ensure that all delayed effects were captured.

The terminology used in this study complies with what is commonly used in the field of leading indicators. However, it is argued in this report that objective indicators are actually not very objective at all.

In theory, there could be a very large number of potential indicators but this thesis is limited to studying 40 metrics which are objective, leading and related to safety culture factors. There are of course other indicators (e.g. for technical safety) that are not included in this study which are also important to include in a decision making process regarding how to allocate resources for safety improvement in shipping companies.

2. Method

This chapter presents the method used to perform this study. It describes the main three steps in the working process; formulation of the datasheet, collection of data and finally a statistical analysis of the data. In the end of this chapter the sources of errors and biases in this study is discussed.

After conducting an introductory literature study in the area of safety culture, it was decided to focus the project on finding indicators of safety related to safety culture factors in shipping companies.

A method presented in a report by American Bureau of Shipping (ABS) from 2012, "Guidance notes on safety culture and leading indicators of safety" became the foundation of the study. However, the method presented in these guidelines was thoroughly revised to suit the question at issue.

2.1 Formulation of the Datasheet

Leading indicators of safety are safety metrics that are statistically significantly correlated with safety performance data (ABS, 2012). In order to perform the study, a datasheet for collection of safety metrics and safety performance data from shipping companies was formulated. To decide which metrics and safety performance data to collect and to ensure that the terminology used would be easily understood by the shipping companies, a literature study was performed and a number of experts were consulted.

Literature Study

The base for designing the list of metrics and safety performance data was taken from the foundational report by the American Bureau of Shipping about guidelines on how to implement a leading indicators programme related to safety culture in shipping companies (ABS, 2012). Also several other studies regarding safety performance indicators from other high risk industries, such as chemical industries and nuclear industries were used.

ABS (2012) states that identification of leading objective indicators can be done at three different levels:

- At the organisational level
- Across business units
- Across the fleet

In this study, a fourth level is tested:

- Across organisations

The choice of this forth level was based on the aim of this project to find common denominators for safety in shipping that can be generalised across organisations. Furthermore, by doing this the awareness of leading objective indicators as a potential tool for safety improvement was raised in a wide selection of shipping companies.

In the guidelines (ABS, 2012), the list of suggested safety metrics had been divided into eight different categories of safety factors. Safety factors are important dimensions of safety culture e.g. communication, feedback and personnel empowerment (ABS, 2012). After the literature study it was concluded that there is a large number of ways to categorise safety culture factors. In this study, safety culture is categorised into three different safety factors; personnel empowerment, management commitment and continuous improvement. These are based on the fundamentals of the ISM Code which are the same as for the quality, safety and environmental management standards (Lappalainen, 2008). Some of the metrics could be placed in more than one of the categories, in which case it has been placed where found most suitable. More about the three chosen safety factors can be read in chapter 3.2 about safety culture.

Expertise Counselling

In the process of developing the datasheet meetings were held with experts within the area of merchant shipping safety parallel to the literature study. Apart from experts at SSPA Sweden AB, where this project was carried out, experts from three major actors in the maritime insurance sector and from the Swedish Shipowners' Association were also consulted about the content of the datasheet. They all have extensive experience from working with safety-related issues in the shipping industry and hence had a good knowledge of which metrics that would be understandable and reasonably easy for the shipping companies to provide. Many changes were made in the original list of metrics after these meetings. Some metrics were removed, a lot of them were rewritten in order to ease the collection of data and a number of suggested additional metrics were added to the datasheet.

During one of these meetings, the idea of complementing the data collection with safety manager interviews originated. The purpose of these interviews was to capture a sense of the attitudes towards safety of the managers responsible for safety in the companies and how suitable the companies are for partaking in a leading indicators program. The interviews may also give an indication of how accurate the provided numbers of incidents, near misses, non-conformities etc. are.

The datasheet was continuously revised as more safety manager meetings were held, to be adjusted for best possible quality of data and increase the comparability of the answers from the different companies. Some clarifications of expressions and concepts were made and some of the metrics were erased as it became clear that they were too difficult for the shipping companies to answer.

The Datasheet

The metrics and safety performance data presented in Table 1 and Table 2 are from the final version of the datasheet. The entire datasheet can be found in Appendix A and the interview in Appendix B.

The final version of the datasheet contained 40 metrics and eight safety performance data and the safety manager interview in Table 4 contained 11 questions and four statements. In order to capture any potential delayed effects, metrics from year 2011 were collected and correlated to safety performance data from year 2011 and 2012.

All safety performance data had to be normalised and converted to frequencies before it could be used in the statistical test. The number of exposure hours was used to normalise all health and safety data and also the number of near misses. The rest of the operations data was normalised using number of port calls. This was necessary in order to make the data from different shipping companies comparable to each other. The normalisation data can be found in Table 3.

Table 1 Metrics

Metrics
Management commitment
Audits, inspections and meetings
Number of safety audits completed per year (by company management) per vessel
Number of safety inspections per year (by onboard management) per vessel
Number of completed safety inspection/monitor/audit/review activities vs. planned in the past year (%)
Number of safety management meetings onboard per vessel
Percentage of safety meetings onboard attended by ashore management
Number of officer (from different vessels within the company) safety meetings ashore
Supplementary
Number of employees onboard/ashore in full time safety positions (DP, Safety Manager(s), Risk Manager(s), Safety Officers etc.)
Percentage of tasks (all onboard activities) that have safety checklists
Number of job hazard analyses conducted per vessel
Percentage of times a Management of Change was conducted when there were changes to jobs, tasks, or equipment
Percentage of safety budget that is separated from the operational and technical budget
Personnel empowerment and motivation
Training
Percentage of employees attending a Bridge Resource Management (BRM) course or similar safety training
Percentage of safety training that includes competency testing
Average number of safety training sessions logged per employee
Percentage of new employees put through a formal induction process (on board or in-service training)
Feedback
Percentage of crew receiving feedback on safety audits, issues, and concerns
Percentage of employees who have their performance appraised annually
Number of fleet-bulletins
Percentage of employees with access to fleet-bulletins
Supplementary
Average percentage of shipboard personnel attending at onboard safety meetings
Average retention rate of ratings (%)
Average retention rate of officers (%)
Continuous improvement
Reporting
Number of safety suggestions submitted per vessel
Number of near misses reported per vessel
Number of non-conformities reported per vessel
Percentage of the above reports that are reported by officers
Responsiveness
Percentage of safety reports on which relevant feedback was provided
Percentage of safety suggestions on which relevant feedback was provided
Percentage of incident reports on which causal analysis was undertaken
Number of corrective action reports (CARs) originating from audits per vessel
Percentage of corrective action reports (CARs) closed out within 9 months
Percentage of safety audit recommendations closed out in time
Percentage of Planned Maintenance System (PMS) items completed on time
Percentage of safety concerns (accidents, near misses and non-conformities) that are addressed within 3 months
Communication
Number of safety meetings onboard per vessel
Number of toolbox talks per vessel
Supplementary
Average update frequency of safety checklists
Average update frequency of standard operating procedures
Number of key performance indicators utilised in safety management
Frequency of revision of the company´s Safety Management System

Table 2 Safety performance data

Safety performance data
Operations Data for the Organisation
Incidents and accidents
Near misses
Conditions of class
Port state deficiencies
Health and Safety Data
Total recordable cases
Lost time incidents
Medical treatment case
Restricted work accidents

Table 3 Data for normalisation

Data for normalisation
Total number of exposure (working) hours
Number of port calls

Table 4 Safety manager interview questions

Safety manager/DP interview

1. How long have you worked for your present company? What is your position and how long have you had this position?
2. Do you believe your Company operates a 'no blame' culture where accidents, hazardous occurrences and near misses can be reported without fear of punishment or reprisal?
3. Do you believe you work within a 'safety culture' - where safety has been raised to the highest priority?
4. Do you think that <u>your seafarers</u> believe they work within a 'safety culture' - where safety has been raised to the highest priority?
5. If you think (in questions 3 and 4) that there is a difference, then why do you think that is?
6. From your own experience, how many per cent of the <u>accidents and incidents</u> which occur onboard are reported to the Company ashore?
7. If there is reluctance to report <u>accidents and incidents</u> to the Company, why do you think that is?
8. From your own experience, how many <u>near misses</u> which occur onboard are reported to the Company ashore?
9. If there is reluctance to report <u>near misses</u>, why do you think that is?
10. From your own experience, how many <u>non - conformities</u> which come to light onboard are reported to the Company ashore?
11. If there is reluctance to report <u>non-conformities</u>, why do you think that is?

To what extent do you agree with the following statements?

Disagree strongly……….Disagree…...Neither agree nor disagree……….Agree…………Agree strongly

12. The organisation is compliant with all relevant regulations.
13. Human error or organisational factors are causing the majority of operational incidents or personal injuries.
14. The organisation has a genuine desire to prevent operational incidents and personal injuries and is not solely driven by the avoidance of prosecution.
15. The organisation is relatively stable, not in the middle of mergers, acquisitions or significant reorganisations.

Most of the interview questions in table 4 were retrieved from a questionnaire developed by Phil Anderson in his doctoral thesis on the ISM Code, “Managing Safety at Sea” (Anderson, n.d.). The purpose of the first question is to confirm that the person answering the questions has the experience to be fully informed with the questions that he or she is answering. Questions two to five are to get an understanding of how the senior safety manager perceives the safety culture of the company. Since it is commonly known that the incident reporting is not very well functioning in the shipping industry, question six to eleven is asked to get a sense of what percentage of events that are reported to management. This gives an indication of how certain the values for the metrics and safety performance data as incidents, near misses, accidents and non-conformities really are. These questions also give us an insight to how familiar the safety manager is with this problem. The last four questions, or rather statements, are taken from ABS’ method where they are presented as criteria for undertaking a leading indicators program. If the criteria are not met, then the organisation is not considered ready for a leading indicators program (ABS, 2012).

2.2 Data Collection

Once the first version of the datasheet was finalised, the next step was to decide which selection of shipping companies to include in the study. The aim has been to include at least ten shipping companies with a varying range of size, nationality and type of cargo. The more participants, the higher significance of the results but the number of studied shipping companies is limited both to fit the timeframe of the thesis project and the availability of shipping companies having the willingness to participate. The availability also affects the range of different types of shipping companies. This means that any found indicators cannot be applied generally to the entire shipping industry, but give a valuable indication and inspiration for future studies.

At first the limitation was set to get participating shipping companies that are based in Sweden and are known for having a strong commitment to safety, increasing the likelihood that they had collected the requested metrics. Several shipping companies that fulfil these criteria were suggested by employees at SSPA Sweden AB during an introductory meeting. Contacts were made particularly through phone calls to the designated person or safety manager of the company. When possible a personal meeting was scheduled. In order to receive as much data as possible, all participants were granted anonymity. Hence, the selection of companies and the results of this study are presented in such a way that precludes any company to be identified.

Further into the project it was decided that the selection needed to be broadened in order to get enough participants. Contacts were made with companies that where suggested from employees at SSPA and through the Swedish Shipowners’ Association. These companies were mostly large international shipping companies and they were contacted by email. The final selection consists of ten participants ranging from Swedish companies with only a few vessels to companies that are based in other countries with up to around eighty vessels. The type of vessels included range from tankers to Ro-Ro, Ro-Pax, bulkers and container vessels etc.

When possible, the data has been collected during a personal meeting at the offices of the shipping companies where any questions and concerns have been discussed and sorted out. These meetings have also included the short interview regarding the safety manager’s perception of the safety culture of the company. A total of seven interviews have been held. In a few cases the same meeting has been held over phone and some companies have replied without any discussion by sending the filled out datasheet by email or post. Several companies have promised or been asked to complement their answers, some of which were never received. If the shipping companies were unable to provide any of the metrics required since they did not collect this information they were asked to make an approximation.

The received data was transferred into an Excel document awaiting the analysis. Before the statistical analysis was performed, some values that were wrongly approximated compared to reasonable range were removed to certify that they would not affect the result.

2.3 Data Analysis

In order to find leading indicators of safety, it needs to be examined if there are any statistically significant correlations between any safety metrics and any safety performance data. In order to do this the Spearman's rank test (ABS, 2012; Sheskin, 2000; Rees, 2001) is used. The purpose of the test is to see if any metric covaries with any of the safety performance data, i.e. if one tends to increase or decrease when the other increases or decreases – a so called monotonic relationship.

Spearman's rank test is a commonly used method for investigating correlation between two measurable variables which in this case are the metrics and the safety performance data, respectively. There is also a variable called the nominal variable which places the measurements from the other two variables together in pairs. According to the method suggested by ABS (2012) where correlation is studied within an organisation over past years, the nominal variable would be which year the data was collected from. However in this study, examining correlations across organisations, the nominal variable is which shipping company the data was received from. This means that the data from one year only is enough to identify leading objective indicators in this study, as opposed to doing the same identification within one company which would require data from at least five years back in time.

Unlike other common correlation tests, like for instance Pearson's correlation, the Spearman approach can be performed without the assumptions of normality, linearity or homogeneity of variance. This is due to the fact that it is a non-parametric test that compares ranks instead of values.

In order to perform the test, the two variables must first be converted to ranks. The lowest value gets rank 1, the second lowest rank 2 etc. If two or more values are equal, the average rank is calculated. If for instance the two second highest ranks are equal, they get the rank 2.5 (the average of 2 and 3). When the metrics and safety performance data have been transformed into two columns of ranks the Spearman's correlation coefficient, also called Spearman's rho, can be calculated with the following equation.

$$\rho = 1 - \frac{6 \sum d_i^2}{n(n^2 - 1)}$$

Spearman's correlation coefficient is denoted by ρ, n is the sample size and $\sum d_i^2$ is the sum of the squared differences from subtracting the ranks from one metric and one safety performance data at the time. When calculating manually, the test is repeated over and over until all metrics have been correlated with all safety performance data. In this study however, all calculations are performed through one Matlab simulation. See Appendix C for the code used in the simulation.

The null hypothesis is that the two variables do not covary, i.e. that the correlation coefficient is not significantly separated from zero. The closer to -1 or 1 the correlation coefficient becomes, the stronger the correlation. -1 indicates a perfect inverse correlation and 1 indicates a perfect positive correlation, i.e. that one variable is a perfect monotonic function of the other. In this study we are mostly looking for inverse correlations as a positive action denoted by an increased metric should be beneficial on the safety outcome, i.e. decrease the number of adverse events. ABS suggests the following guidelines, in Table 5, on the strength of the correlation, as a mean to decide which results that are most relevant to follow up (ABS, 2012).

Table 5 Strength of relationship

Strength of relationship	Value of r (positive)	Value of r (inverse)
Strong	0.5 to 1.0	-1.0 to -0.5
Moderate	0.3 to 0.5	-0.5 to -0.3
Weak	0.1 to 0.3	-0.3 to -0.1
None	0 to 0.1	-0.1 to 0

Once the correlation coefficient is calculated, it must be determined whether the correlation is statistically significant or not. The simulation in Matlab generates matrixes for the correlation coefficient and the corresponding p-value so no manual calculations are needed. A significance level of 95 % is chosen which means that the null hypothesis can be rejected if the p-value is less than 0.05. The simulation uses all rows regardless of missing values. Since no shipping companies were able to provide answers for all metrics and safety performance data, some values are missing and the number of data included varies. Missing data will decrease the significance of the test.

2.4 Sources of Errors and Biases

When dealing with statistical correlation it is important to remember that correlation does not imply causation. If two variables covary it does not necessarily mean that one causes the other, and if it does it might be difficult to determine which one that causes which. There may be other factors involved that are not measured which cause both variables to increase or decrease simultaneously. For the purpose of monitoring safety the indicators do not need to be causally linked to safety performance as long as the correlation is strong enough. However, for the purpose of using indicators as a mean to decide where and how to take action the indicator needs by definition to be before the event and in a causal pathway leading to it (Hale, 2009).

Another bias is the widely disparate understandings of the concepts near misses, incidents and accidents. It was not possible within the limitations of this study to calculate the exact numbers of events and categorise them according to set definitions. Instead data was collected as they had been categorised and collected by the shipping companies, even if this meant that for instance the category of incidents included different types of event for different companies and thereby where not optimal for comparison. Furthermore, the same definition problems apply to many more of the metrics and safety performance data.

The degree to which adverse events are reported is widely varying between different shipping companies and even different vessels within the same company. Generally the number of reported events is quite low compared to how many events that could be expected to have occurred. Hence, the result may be biased because it is impossible to say if a high number of reported events means that more events have occurred or that the safety awareness is high and that the reporting system is well functioning.

3. Theoretical Foundation

This chapter presents the theoretical foundation of this study. The first part, Safety in Shipping, deals with the external demands and regulations that shipping companies need to comply with regarding their safety work. It also contains an introduction to incident reporting in the shipping industry. The second part of this chapter, Safety Culture, contains an introduction to the terms safety culture and safety climate. It also argues for the value of having a safety culture in risk prone industries. This is followed by an explanation of why the three safety factors management commitment, personnel empowerment and continuous improvement are fundamental in a safety culture. In the third part of this chapter, Indicators of Safety, the concept of indicators is introduced and the differences between leading and lagging as well as subjective and objective indicators are explained.

3.1 Safety in Shipping

Maritime safety is governed by several international regulations, the national regulations of flag states and port states, port regulations and by the demands from classification societies, insurance companies and costumers (Jalonen & Salmi, 2009). In this chapter these concepts will be briefly described to provide the reader with an understanding of the external demands that shipping companies need to comply with regarding safety. It is important to have a notion of which regulations and external demands that exists in the industry, since these regulations control the safety level in shipping. Figure 1 shows an overview of the external influences on the safety work of a shipping company.

Figure 1 External influences on the safety work of a shipping company

Shipping companies have to comply with safety regulations and rules from a range of different stakeholders. Some requirements apply to all shipping companies but ships carrying different kinds of cargo obey to different regulations and thus do some safety requirements vary between different types of vessels. The requirements from customers also put various pressure on the safety work of shipping companies. There are for instance strict rules from oil companies regarding tanker ships which the shipping companies must comply with to retain their customers. Below follows a short presentation of the major players and regulations which governs maritime safety.

IMO, SOLAS and the ISM Code

The International Maritime Organization (IMO) is an agency within the UN which deals with maritime safety and protection of the marine environment. It was founded in 1948 and was the first international agency for coordination of work for maritime safety (Svensk Sjöfarts Tidning, 2011). The most important conventions of IMO are the Convention for the Safety of Life at Sea (SOLAS), the International Convention for the Prevention of Pollution from Ships (MARPOL) and the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW) (IMO, n.d.). The fundamentals of SOLAS were formed already in 1914 during a conference held after the Titanic accident. SOLAS covers regulations regarding subjects such as lifeboats and other life-saving equipment, fire protection measures, safe navigation and transportation of dangerous goods.

In 1994, The International Safety Management code, commonly referred to as the ISM Code, was enacted (Svensk Sjöfarts Tidning, 2011). The purpose of the code is to provide an international standard for the safe management and operation of ships and for pollution prevention (IMO, 2010). The code is a part of SOLAS and became effective in 1997 (Svensk Sjöfarts Tidning, 2011). It has been compulsory for passenger vessels, bulk carriers and tankers since 1998 and for all ships since 2002 (Gold, 2006). Among other things, the ISM Code requires that the shipping companies have a functioning safety management system and that the company should designate a person, who provides a link between the company and those on board, that has direct access to the highest level of management. The Designated Person (commonly referred to as the DP) is responsible for monitoring the safety and pollution-prevention aspects of each ship. He or she should also ensure that adequate resources and shore-based support are applied (IMO, 2010). The DP commonly also carries the title safety manager.

While conducting this study, the main contact with the included shipping companies was with the designated person (in the interview also referred to as the safety manager), since he or she is the link between the vessels and the company ashore and is responsible for safety management and incident reporting within the company.

Flag States, Port State Control and Classification Societies

The two major systems for controlling vessel compliance with regulations and laws are flag state control and port state control (United States Coast Guard, 2002).

A ship must sail under a flag state and follow the jurisdiction of that state. The flag state should exercise its jurisdiction and control over those ships in administrative, technical and social matters (Mansell, 2009) and it is the flag state that is primary responsible for the ship´s standard (IMO, 2013). In Sweden, it is the Swedish Transport Agency that is the supervisory agency for safety regulations in shipping (The Swedish Transport Agency, 2010).

Port state controls are inspections of foreign ships carried out in the national ports to ensure that the condition, manning and operation of ships comply with international regulations (IMO, 2013). In Sweden the port state controls are carried out by The Swedish Transport Agency (The Swedish Transport Agency, 2011). Port state controls have evolved as port and coastal states tried to ensure that visiting vessels would not cause problems in their waters (Gold, 2006). The Paris Memorandum of Understanding (Paris MOU) on port state control is an agreement between states (originally in Europe) which sets out guidelines for an improved and synchronised system of port state control and enhanced co-operation in the exchange of information. Today it is also closely connected to similar systems in other regions, e.g. The Caribbean MOU and The Indian Ocean MOU (Gold, 2006). The number of port state deficiencies was one of the safety performance data that was collected from shipping companies and correlated to metrics to find leading indicators in this study.

The purpose of ship classification is to verify the technical safety of a ship, i.e. the structural strength of essential parts of the hull, the function of propulsion and steering systems and other systems which are required to maintain essential services on board. A vessel either meets the requirements of the classification society or it doesn't, and consequently it is either "in" or "out" of class. When a defect or damage is identified during a survey, conditions of class are specified. These are requirements that repairs or other measures should be carried out within a limited time in order to retain class (International Association of Classification Societies, 2011). The classification societies also perform inspections on the behalf of the flag states (The Swedish Transport Agency, 2012). In the statistical analysis of this study, the number of condition of class is another safety performance data that is correlated with metrics.

Vetting

When a serious accident occurs, focus is not only on the ship owner but also on those owning the cargo. In the late sixties the oil industry decided to ensure the safety standards of the ships transporting their products to avoid oil spills and accidents. This started the formation of ship vetting departments within the oil companies and the initiative was also taken up by the chemical industry (The European Chemical Industry Council, 2011).

The vetting is a comprehensive investigation during which a large range of safety and quality matters are examined. Among other things, the certificates and documents are checked, the mooring and navigation system are controlled and the safety management, pollution prevention work and communication system of the ship owner is evaluated (Oil Companies International Marine Forum, 2012).

Since the vetting process only applies to tankers carrying oil, chemicals or gas the safety requirements are higher on these kinds of ships than on vessels carrying other kinds of cargo.

Incident Reporting in Shipping

Incident reporting is an essential part of safety management in a number of industries. The ISM Code requires that shipping companies establish an internal system for reporting accidents, near misses and non-conformities. Incident reporting systems can be implemented in two levels:

1) An internal reporting system, which is mandatory according to the ISM Code.

2) A national or international shared reporting system, which is voluntary.

In Sweden there is a national system for incident reporting called INSJÖ. The system was initiated by the Swedish Maritime Administration and the Swedish Shipowners´ Association. It is voluntary to report to INSJÖ and the shipping companies decide which incident reports they want to send to the system. The incident reports are entered anonymously by the designated person at the shipping company (Storgård, Erdogan, & Tapaninen, 2012). The INSJÖ data base can be used to search for incident reports and may help the shipping companies to learn from each other´s experiences (INSJÖ, 2001).

In the shipping industry, numerous different definitions of the terms accidents, incidents, near misses are used. Some even use other expressions like for instance near accidents. There are also various ways to categorise work related injuries in e.g. medical treatment cases and restricted work accidents. These differences in the used terminology may complicate comparison, and communication, between different shipping companies.

The statistics regarding incidents used in the statistical analysis in this study was collected from the internal incident reporting systems of the shipping companies that participated in this study. The fundamental theory behind incident reporting is the iceberg theory which is further explained in chapter 3.2.

3.2 Safety Culture

Definition of Safety Culture

Historically, safety management has focused on technical issues and individual human errors (Health & Safety Laboratory, 2002). However, a series of large accidents during the last decades, such as the Chernobyl disaster, has contributed to an understanding of the significance of organisational policies and procedures in accidents (Health & Safety Laboratory, 2002). Human error was traditionally seen as the cause of incidents and accidents but today it is seen as a symptom of trouble deeper in the organisation. This means that according to this new view of human error, to do something about the incident, instead of doing something about the particular individual, one must analyse the system in which people work. Hence, one should for instance evaluate the production pressure, the existence of goal conflicts and the design of equipment and procedures (Dekker, 2007).

There are a variety of definitions of what a safety culture is. Though the definitions differ from each other, most of them are based on the concept of organisational culture which describes shared corporate values within an organisation which influences the attitudes and behaviours of its members (Health & Safety Laboratory, 2002). A safety culture is part of the overall organisational culture and influences the member's attitudes in terms of the health and safety performance of the organisation (Cooper, 2000). In the interview questions in this study, the definition of safety culture taken from Anderson's questionnaires (Anderson, n.d.) is a culture where safety has been raised to the highest priority.

One recognised definition of organisational culture is the one by Uttal (as cited in Reason, 1998, p. 294): "Shared values (what is important) and believes (how things work) that interact with an organisation's structures and control systems to produce behavioural norms (the way we do things around here)". One of the simplest definitions of safety culture is: "Safety culture reflects the attitudes, beliefs, perception and values that employees share in relation to safety" (Lappalainen, 2008). IMO made the following statement about safety culture (as cited in Lappalainen, 2008, p. 27): "An organisation with a "safety culture" is one that gives appropriate priority to safety and realises that safety has to be managed like other areas of business".

According to Reason (1998) there are two different ways of looking at safety culture: as something that an organisation is (the values and attitudes of its members) or something that an organisation has (structures and policies). Related to the definition by Uttal "…the way we do things around here" presented above, a safety culture can also be seen as something that an organisation does related to safety.

An organisational culture evolves gradually and is affected by past events and accidents, local conditions and the character of the leadership (Reason, 1998). It is continuously created and recreated as members of the culture behave in ways which seem natural and unquestionable to them. This repeated behaviour and communication will create a particular view of risk and safety within the company (Pidgeon, 1997).

One of many problems with the term safety culture is that organisations are rarely characterised by harmony. There are often differentiations and conflicts within a culture and even though a cultural approach to safety can be useful it is important to remember that this is a simplification of reality. However, having conflicting views on safety can also be a resource to the company. The most important thing is not to have a homogenous view on safety, but that the subject is discussed in a constructive manner which profits the learning of the company (Antonsen, 2009a).

Safety Climate

Safety culture and safety climate are two related concepts which are often used interchangeably and the difference between the terms is not very clear (Health & Safety Laboratory, 2002). However, safety culture can be seen as a more comprehensive expression. While safety climate refers to the attitudes towards safety in an organisation, the safety culture refers to the underlying beliefs of those attitudes (Guldenmund, 2010).

In research, safety culture is generally measured using questionnaires, where the behaviour of individuals is self-reported (Health & Safety Laboratory, 2002). In that case, it is in fact the safety climate that is measured. According to Cox and Flin, the safety climate can be seen as the indicator of the safety culture as perceived by the members at that specific time (as cited in Health & Safety Laboratory, 2000, p. 1). Safety climate measures have been widely used in this way and tend to be used as substitute measures of safety culture (Health & Safety Laboratory, 2002).

In this kind of safety culture surveys there is a risk that employees respond how they feel that they should behave rather than how they actually behave. Thus, this kind of surveys may not predict people's actual behaviour (Health & Safety Laboratory, 2002). It has also been shown that the satisfaction-dissatisfaction among employees regarding safety measures is dependent on whether they themselves have been injured while carrying out work duties. Thus, how employees answer in questionnaires is strongly affected by personal experiences (Rundmo, 1994).

The Value of Having a Safety Culture

In most hazardous industries it is considered good practise to have a safety management system (SMS). The relationship between the SMS and safety culture is strong, as the SMS should deal with factors that impact safety, including human and organisational, while the safety culture itself influences the way that the SMS in applied (ABS, 2012). The success of the safety management system is strongly dependent on the safety culture in the organisation (Lappalainen, 2008).

In the shipping industry, the competitive companies are those that provide qualitative transports at a better price than competitors. Cristina and Gheorghe (2009) argue that high professional seafarers, who are well trained and responsible with their work, are the key to success for competitiveness in maritime field. In order to be both competitive and responsible, maritime companies must implement a management of safety on board the ships. Commitment of leadership, continuous communication, crew´s involvement and responsible attitudes towards safety are the key elements for proper implementation of a safety management system (Cristina & Gheorghe, 2009).

Accidents can be costly for a company, not only because they decrease productivity, quality and cause delays, they might also ruin the company's image and internal climate. It has been shown that adopting a safety management system does not only improve safety performance by reducing accident rates, but it also increases the competitiveness and economic performance of a company since it can reduce worker's absenteeism and improve their motivation. A well-functioning safety management system can also increase customer satisfaction and the reputation of the company. Hence safety management should not be seen as an economic burden but as an opportunity to improve the competitiveness of the company (Fernández-Muñiz, Montes-Peón & Vázquez-Ordás, 2007).

A proactive safety work is extremely important in shipping since it is a large scale system in which the consequences of losses can be severe (ABS, 2012). A safety culture can be seen as "the engine which drives the system towards the goal of sustaining the maximum resistance towards its operational hazards" (Reason, 1998, p. 294). Thus, having a safety culture contributes to minimising the risk of accidents and incidents.

The importance of having a safety culture in shipping is recognised by the Swedish Shipowners´ Association. In their safety policy safety culture is considered the basis of all safety work and the personnel is considered the key to a high safety level. Also the important part that regulations and inspections play is emphasised. Below follows the maritime safety policy of The Swedish Shipowners´ Association in brief (The Swedish Shipowners´ Association, 2003).

The Swedish Shipowners' Association's maritime safety policy in brief

1. A good maritime safety culture is the basis of all maritime safety work.

2. Maintaining and developing a high maritime safety level are conditional on an effective organisation.

3. The personnel are the key to a high level of maritime safety.

4. Shipping should be a safe link in a safe transport system.

5. Continuous and preventive maintenance results in safe ships.

6. Uniform regulations are an important tool for achieving a high level of maritime safety worldwide.

7. External inspections should function as a safety valve so that substandard ships are removed from the market.

8. The shipping industry should participate actively in research and development in the field of maritime safety.

Key Fundamentals of Safety Culture

One of the objectives of this project was to identify leading indicators of safety, based on objective metrics for safety culture. Indicators should be categorised on the basis of the underlying phenomena they seek to measure (Reiman & Pietikäinen, 2010). There is a large number of ways to categorise the important aspects of a safety culture. The metrics for safety culture in the datasheet used to collect the statistics for this study was divided into the three categories presented in Figure 2; management commitment, personnel empowerment and continuous improvement. The reason for this division is that the ISM Code is mainly based on these key fundamentals of a safety culture and apart from reflecting safety culture these categories are also fundamental in safety management systems (Lappalainen, 2008). Below follows an explanation about why each of these categories is of great importance in a safety culture and in a safety management system.

Figure 2 The key fundamentals of a safety culture

Management Commitment

Management has one of the most important influences on safety culture (Health & Safety Laboratory, 2002). The commitment of the top management is essential to the culture in a company since it is responsible for setting up a company policy and providing adequate resources and tools to comply with this policy (Lappalainen, 2008). However, top management does not only influence the safety culture through direct decisions regarding safety budget and policies, but also through their attitudes. Individuals in higher positions have greater potential to influence the rest of the company. Decisions that are made at senior level affect the priorities and behaviours of employees lower down in the hierarchy. Therefore, it is of great importance for a company's safety culture that senior managers demonstrate a commitment to safety issues, and that their safety work is continuously visible to the rest of the company (Flin & Yule, 2004).

The importance of management commitment for safety management is also emphasised in the ISM Code preamble 6, as it is stated that "The cornerstone of good safety management is commitment from the top. In matters of safety and pollution prevention it is the commitment, competence, attitudes and motivation of individuals at all levels that determines the end result." (IMO, 2010).

One of the most important aspects of a safety culture is how punishment and blame is handled by management (Reason, 1998). The company management needs to work on achieving a no blame culture in which honest mistakes are not punished and this culture needs to characterise the entire organisation, both ashore and onboard each ship. This is important since a no blame culture is a prerequisite for an effective incident reporting and continuous improvement.

Personnel Empowerment and Motivation

According to Spreitzer (as cited in Ford & Tetrick, 2011, p. 49 and Dehkordi, Kamrani, Ardestani, & Abdolmanafi, 2011, p. 809) psychological empowerment is characterised by the following four elements:

- Meaningfulness (does the employee feel that his or her work is important?)
- Competence (is the employee confident that he or she is skilled enough to perform the assigned duty?)
- Self-determination (does the employee feel that he or she is in control and has the power to make decisions and act in various situations?)
- Impact (does the individual feel that he or she has control over important consequences in the company?)

The fulfilment of these four elements is perceived by the employees as an ability to shape their work context. Individuals feel empowered when they perceive that their organisation is concerned about their well-being and maintain a high-exchange relationship (Ford & Tetrick, 2011).

In order for a management system to work successfully, it is important that employees are provided with the opportunity to participate in the operation of the management system. This is in order to give them a sense of ownership in regard to the management system (Lappalainen, 2008). In a study by Hechanova-Alampay & Beehr (2001) it was shown that personnel empowerment was associated with both safety behaviours and safety record.

Continuous Improvement

In organisations with few accidents it is easy to take safety for granted. If no accidents occur, there is nothing to attract attention and it is easy to forget that something can go wrong (Reason, 1998). To achieve a safety culture, it is important to not be satisfied with the safety level within the company, but to continuously work on improving it. Continuous improvement is also fundamental in management systems (Lappalainen, 2008). Continuous improvement is stressed in the ISM Code section 1.2.2 as it is stated that the company should "Continuously improve safety management skills of personnel ashore and on board ships, including preparing for emergencies related both to safety and environmental protection" (IMO, 2010). Education of the staff is thus important both for personnel empowerment and continuous improvement.

One way of working for continuous improvement is by accident and near miss reporting. The main point of reporting is to contribute to organisational learning and help preventing recurrence of undesired events. This means that any event that may help increase safety is worth reporting (Dekker, 2007). According to The Heinrich Pyramid, also known as the iceberg theory, safety triangle or accident pyramid (Figure 3), the analysis of events that had the potential to cause harm, but never did, provides an opportunity to prevent future errors before they occur. Thus, according to this theory on which incident reporting systems are built, serious accidents can be avoided before they take place by studying near misses and take corrective action (Guffey, Szolnoki, Caldwell, & Polaner, 2011). Heinrich found that the exact ratio between near misses, minor injuries and major injuries varies and the ratio found in Figure 3 should be seen as the average value across different activities (Rosness et al., 2010). The words “injury” and “accident” are used interchangeably in literature about the iceberg theory and in this context they are interpreted to have the same meaning.

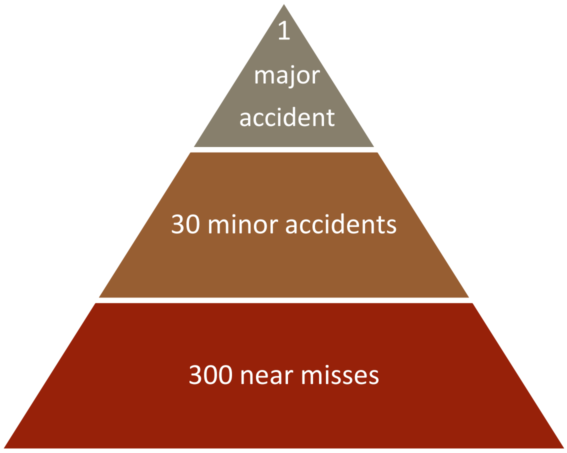

Figure 3 The Heinrich Safety Pyramid

A common perception of the iceberg theory is that near misses, minor accidents and major accidents have the same underlying causes and that the ratio is always constant, something which was not stated by Heinrich in the original theory (Rosness et al., 2010). The idea that the underlying reasons are the same is criticised by Hale (as cited in Rosness et al., 2010, p. 119) as he states that major and minor injuries differ in numerous ways, e.g. regarding amounts of energy released and the kinds of protection barriers that were bypassed in the event.

One potential problem in near miss reporting is that the quantity of reported near misses might be considered of highest importance, and thus analysis of the circumstances is easily forgotten. It is important not only to focus on implementing measures for a large number of near misses, but to focus on analysing the causes and implement measures where most useful in preventing possible accidents. It is thus important for organisational management to realise that even if incident reporting can contribute to organisational learning and safety awareness, the analysis and prevention of near misses and minor accidents are not enough to avoid major accidents. Hence, in order to prevent rare and severe events, additional methods for safety management are required.

To achieve a well-functioning reporting system it is important that the system is easily accessible and that the personnel do not feel anxiety about what will happen after they report (Dekker, 2007). Thus, in order to accomplish a high proportion of occurred near misses, incidents and accidents that are reported to ashore management, it is important that the shipping company has a no blame culture where the crew is not punished for reporting their mistakes. This is also argued in a study by Storgård, J., Erdogan, I., & Tapaninen, U. (2012) as they conclude that the factors that are important for a successful incident reporting are the existance of a no blame culture, management commitment, communication, feedback and a user-friendly system. They also state that the success of the reporting system is closely related to the safety management of the company and hence efforts for improving the incident reporting system do not only promote learning from incidents but also the overall safety management and safety awareness.

3.3 Indicators of Safety

Safety is a concept that is difficult to define, measure and manage (Reiman & Pietikäinen, 2010). This calls for a tool for handling these difficulties, for instance indicators of safety. The Organisation for Economic Co-operation and Development (OECD) explains indicators of safety, also referred to as safety indicators or safety performance indicators (SPIs), by saying that "The term "indicators" is used to mean observable measures that provide insights into a concept – safety – that is difficult to measure directly" (OECD, 2008, p. 5). Indicators of safety can be focused on safety in general or only on human factors or safety culture.

Indicators of safety can be used in different processes of an organisation's safety management system and the areas of use can be summarised in three points (Reiman & Pietikäinen, 2010; Hale, 2009):

1. *Monitoring the level of safety*.
   An organisation can use safety indicators to monitor the level of safety performance, often by collecting indicator data over a period of time to observe trends and thereby be able to identify deviations and check if the level of safety is good enough as it is or if more action is needed for improvement (Reiman & Pietikäinen, 2010; Hale, 2009). For this purpose, the indicators do not need to be causally linked with the safety performance data as long as it shows a strong correlation (Hale, 2009).

2. *Determining where and how safety needs to be managed.*
   If the monitoring of safety shows that further action is needed, indicators can be used to decide where and how to take that action. By using indicators which are causally linked to safety performance, action can be allocated where necessary and improvements in safety can be achieved (Hale, 2009).

3. *Motivating management and personnel to take action.*
   Both the indicators themselves and the process of utilising them can have an effect on the safety performance by putting an emphasis on organisational factors in human performance. The choice of indicators shows the managements' priorities and may affect the behaviour in the organisation by shaping the personnel's perception of what safety is (Reiman & Pietikäinen, 2010). It is important that the indicators give a sense of meaningfulness and as being influenceable within a foreseeable future (Reiman & Pietikäinen, 2010; Hale, 2009).

There are numerous ways to categorise safety indicators. Reiman & Pietikäinen (2010)presents six typologies of indicators:

- outcome versus activity based indicators
- leading versus lagging indicators
- input versus output indicators
- process versus personnel indicators
- positive versus negative indicators

- technical versus human factors indicators

The first three categories are very similar to each other and are more or less different expressions with the same meaning; see more about these types in the following paragraph. The categories overlap in some ways, a human factor indicator can for example also be a leading or lagging indicator (Reiman & Pietikäinen, 2010). Furthermore, safety indicators can also be categorised as subjective or objective (Grabowski, Ayyalasomayajula, Merrick, Harrald, & Roberts, 2007; ABS, 2012).

Leading versus Lagging Indicators

Safety performance has traditionally been measured by metrics of already occurred deviations from safety such as numbers of accidents, incidents and injuries. These lagging indicators, also called outcome or output indicators, are reactive metrics which gives indications of past performance (ABS, 2012; Reiman & Pietikäinen, 2010) and are therefore suitable for the purpose of monitoring the level of safety (Hale, 2009).

Lagging indicators have a long history of use and have become an accepted standard approach for assessing safety (ABS, 2012). Except their main purpose of monitoring safety, they can also be used to learn from past incidents to prevent recurrence. Under the assumption that serious accidents, incidents and near misses have the same causes, lessons learned from minor events can prevent more serious events in the future according to the iceberg theory.

However, several researchers have highlighted the weaknesses of lagging indicators. First of all, this approach requires by definition that incidents and other unwanted events do occur which opposes the objective of eliminating such events. Also, many accidents and incidents are very unlikely events which mean that the past absence of them is no guarantee for the absence of these events in the future (Grabowski et al., 2007). Finally, if the assumption that the iceberg theory is built on is not true i.e. incidents and near misses do not have the same causes, investigations of one cannot prevent future occurrences of the other.

A commonly used view of safety is “the absence of unacceptable risk” (Hollnagel, 2008). This is the view that is embedded in lagging indicators that by measuring the number of adverse events in other words actually measure the lack of safety. But in order to manage safety more proactively safety must be seen as not just the absence of risk, but the presence of something. Hence, there is a need for a different kind of indicators that enables organisations to take action before a negative event occurs; leading indicators (Hollnagel, 2008; Reiman & Pietikäinen, 2010; Hale, 2009).

In contrast to lagging indicators, leading indicators, also called activity or input indicators, are proactive metrics which can be used to discover weaknesses in advance of negative events. Hence, leading indicators can be used to prevent incidents by enabling the organisation to take corrective action before any losses occur (ABS, 2012; Reiman & Pietikäinen, 2010). ABS defines leading indicators as “safety metrics that correlate with safety performance for a given organisation” (ABS, 2012, p. 25). It is important to prove that the leading indicators are valid as indicators of safety performance by showing their correlation with lagging indicators (Hale, 2009).

OECD (2008, p. 5) summarises the different approaches by stating: “Thus, outcome indicators tell you *whether* you have achieved a desired result (or when a desired safety result has failed). But, unlike activities indicators, they do not tell you *why* the result was achieved or why it was not.”

Some indicators are hard to put in either one or the other category, for example number of near misses which may be seen as both a leading and lagging indicator. The number of near misses can be seen as a lagging indicator of safety performance in the sence that the near miss events have already occurred. Looking at it in a broader perspective though, the iceberg theory entails that the number of near misses can be a leading indicator of the number of more severe incidents and accidents.

Objective versus Subjective Indicators

Safety indicators can either be objective or subjective depending on how they are measured. Objective indicators are relatively straightforward to collect, to monitor and to analyse and therefore demand quite small resources to utilise (ABS, 2012; Grabowski et al., 2007). Because objective measures by definition already are quantified and hence does not rely on much interpretation, there is less risk of bias when using them as indicators.

Objective indicators are thus excellent for measuring quantities related to safety, but on the downside they may not be suitable for capturing the quality of the metrics (ABS, 2012; Grabowski et al., 2007). An objective indicator of safety might for instance be the number of safety training sessions per employee if it is correlated with the number of incidents, but it does not say anything about whether the quality and contents of the training sessions have any impact on the safety performance.

In contrast, subjective indicators are based on the values, attitudes and observation of employees, which are usually measured through a safety culture survey (ABS, 2012). The upmost advantage of subjective indicators is that they can capture the quality of the measures (Grabowski et al., 2007. Furthermore, the identification process can be conducted even if the organisation has not collected any metrics and may give rise to new metrics that has not previously been collected by the organisation (ABS, 2012).

On the other hand, the fact that subjective leading indicators require a safety culture assessment makes them more difficult and resource demanding to collect, monitor and analyse (ABS, 2012; Grabowski et al., 2007). Since they by definition are subjective measures, they are difficult to quantify (ABS, 2012).

Antonsen (2009b) and Guldenmund (2007) argue that the purpose of the results from assessments like these is their assumed influence on safety related behaviour and safety outcomes, and they present results that suggest that the correlation between safety culture assessments of an organisation and the actual safety conditions are actually quite weak. Hence, safety culture assessments can be a good method for evaluating general attitudes towards the safety culture of the organisation but their use as measurements of safety are questionable (Guldenmund, 2007). ABS (2012) also states that the preferred method is to identify objective leading indicators since the identification of subjective indicators is more speculative.

When reading these definitions it may seem that objective indicators are without any risk of biases or interference of subjective values. This however, is not the case. The objective indicators are probably more unbiased than subjective indicators, but still far from impartial. For example, the number of non-conformities is based on management's interpretation of what a non-conformity is and then further affected by onboard staff members who decide whether they think it is important enough to report. Also, in this study the safety manager or designated person of the company has made estimations where more exact numbers have been unavailable. This report hence uses the term objective indicators because it is the accepted terminology, but this does not mean that they are actually objective.

Utilisation of Performance Indicators in Shipping

Safety performance indicators should not be confused with key performance indicators (KPIs) which are more commonly used in the shipping companies' management systems. They monitor the organisational performance and may or may not be safety-related. Examples of KPIs are; reported incidents, retention rate, average number of port state control observations per inspection and loss time injuries. Many of the shipping companies that have been studied utilise KPIs for business purposes upmost but also because of demands from clients and in the vetting process. With the exception of number of near misses, which may be seen as a leading indicator, the studied shipping companies exclusively use lagging KPIs. There are generally goals set for every KPI, i.e. an upper boundary to limit the number of for instance incidents. However the KPI near misses may have a set goal for a minimum number of reports which should be exceeded, to overcome the problems with underreporting.

4. Results and Analysis

This chapter presents the results of the statistical analysis. The conclusion is drawn that the results are based on data of poor comparability. Hence, the focus of the analysis will not be on the found correlations but on explaining why the results cannot be said to be valid, intertwined with answers from the interviews.

All statistically significant findings (i.e. with a p-value less than 0.05) are presented in Table 6. A total of seventeen significant correlations were found, distributed over ten different metrics. This means that the result shows ten different leading objective indicators.

Table 6 Statistically significant correlations between metrics and safety performance data

Safety factor	Metric	Safety performance data	Spearman´s correlation coefficient (ρ)	Significance (p -value)
Management commitment	Number of safety inspections per year by onboard management per vessel	Total recordable cases frequency 2011	0.64	0.013
	Number of safety management meetings onboard per vessel	Restricted work accidents frequency 2012	0.86	0.029
	Percentage of safety meetings onboard attended by ashore management	Near miss frequency 2011 Near miss frequency 2012 Total recordable cases frequency 2011	1 0.9 0.85	0 0.037 0
	Number of employees in full time safety positions	Lost time incident frequency 2012	0.30	0.018
	Number of officer (from different vessels within the company) safety meetings ashore	Port state deficiencies frequency 2012 Total recordable cases frequency 2012	0.79 0.71	0.019 0.037
	Percentage of tasks (all onboard activities) that have safety checklists	Incidents and accidents frequency 2012	0.70	0.034
Personnel empowerment and motivation	Percentage of safety training that includes competency testing	Port state deficiencies frequency 2012 Total recordable cases frequency 2011 Total recordable cases frequency 2012	0.83 0.21 0.21	0.0057 0.0075 0.0075

Safety factor	Metric	Safety performance data	Spearman´s correlation coefficient (ρ)	Significance (p -value)
	Number of fleet-bulletins	Near miss frequency 2011 Medical treatment cases frequency 2012	-0.83 0.81	0.042 0.049
Continuous improvement	Number of safety suggestions submitted per vessel	Total recordable cases frequency 2011	-0.64	0.042
	Number of near misses reported per vessel	Near miss frequency 2011 Near miss frequency 2012	0.83 0.74	0.041 0.037
	Number of safety meetings onboard per vessel	Restricted work accidents frequency 2012	0.94	0.0048
	Number of key performance indicators utilised in safety management	Total recordable cases frequency 2011	-0.81	0.042

Thirteen of the seventeen correlations show a strong positive monotonic relationship, three show a weak positive relationship and three show a strong inverse relationship. In contradiction to the results we were mostly expecting inverse correlations as an increased metric should be beneficial on the safety outcome, i.e. decrease the number of adverse events. The reversed result suggests that there might be some underlying inaccuracies and biases. This suspicion is further supported by several difficulties in interpreting the meaning behind the correlations. For instance the result shows that *Percentage of tasks that have safety checklists* is correlated with *Incidents and accidents frequency* for 2012 with a correlation coefficient of 0.70 and a p-value of 0.034. As has been presented before, correlation does not necessarily imply causation and hence the meaning of the result is difficult to interpret. However we cannot find a plausible explanation for this relationship. Because the metric is collected from 2011 there is a time factor meaning that if there is causation it is that the metric causes the safety performance. Hence, the result indicates that a higher *Percentage of tasks that have safety checklists* leads to more incidents and accidents. The result can also be interpreted as an increase in reporting rate rather than an actual increase in incidents and accidents. Another example of a correlation is *Number of key performance indicators utilised in safety management* that is correlated with *Total recordable cases frequency 2011*. This correlation is inverse with a correlation coefficient of -0.81 and a p-value of 0.042. This could either be interpreted as that a larger number of KPIs leads to less working injuries or a lower reporting rate of these injuries. There can also be a third unknown variable causing the correlation. Hence, the meaning of the result is very difficult to interpret.

The main problem of this study has however been the inclusion of many different sectors in shipping with differing working conditions, which have led to poor comparability of the collected data. We believe that this has made the results biased and inaccurate. For instance *Percentage of tasks that have safety checklists* has very different meanings depending on whether it is a tanker vessel where all crew members are involved in high risk tasks or a passenger vessel with hundreds of employees working in service trades.

Because of the above reasons and more problems presented below we draw the conclusion that all results are based on data of poor quality and comparability and hence cannot be said to be accurate. Due to this, the meaning of the seventeen correlations will not be further investigated. This analysis will instead focus on why the results are distorted. There are several other explanations to why the result cannot be said to be valid, a few of which are presented below and further discussed in the next chapter.

4.1 Difficulties and Sources of Error

Diversity of Concepts

Regardless of the influence of shipping sectors the different companies have widely varying interpretations of the meaning of the metrics and safety performance data. For instance the concept incident seemed clear at first, especially since a set definition was provided in combination with the datasheet, but turned out to be everything but clear. First of all, neither we nor the companies had the time or resources to collect data according to our definitions. Instead, the data was provided as it had been collected by the company. Many of the companies had different definitions of which events that should be counted as an incident and even if they did have the same definition there is still an influence of the persons involved in the reporting process who decide in which category to report the event. This issue has affected most of the metrics and safety performance data. Furthermore, the shipping companies collect different types of data. Hence, there was a lot of missing data in our datasheets and different companies had different missing data. The safety managers were asked to provide approximated values of the metrics they did not collect. It is difficult to know how good these approximations are and they are undoubtedly a source of error.

Normalisation

One factor that influences all of the results is the normalisation data that is used to convert safety performance data into frequencies. First of all, some shipping companies could not provide either the number of exposure hours or the number of port calls in which case all other related data that was provided by the company became useless. Also, in many cases, the companies did not have exact numbers of port calls or exposure hours and hence much of the normalisation data comes from approximations. There are also a number of different ways to calculate exposure hours which leads to additional uncertainties. The used normalisation data has been carefully chosen by ABS to reach best possible comparability but that does not mean that it is perfect. See for instance *Number of near misses* correlated with *Near miss frequencies for 2011* in Table 6. In case of a perfect normalisation the correlation coefficient would have been equal to 1 and in the result it is 0.83. The number of working hours is problematic to use as normalisation data since the crew is a lot larger on passenger ferries than on other types of vessels. Passenger ferries have many employees working in low risk service professions and hence cannot be expected to have as many severe occupational injuries per employee. Furthermore, to use the number of port calls for normalisation may be problematic as passenger ferries go constantly back and forth while e.g. tanker ships make longer journeys. In this study the number of port calls per year and vessel differs from as little as 30 up to as much as 6000. It is simply not reasonable to expect passenger ferries to have 200 times as many accidents, incidents, conditions of class and port state deficiencies as for instance tanker ships. This indicates that the normalisation contributes to quite a bit of distortion. We performed a simplified sensitivity analysis where port calls where replaced by number of vessels and got considerably different results, indicating that the choice of normalisation data has a big impact on the result.

Underreporting

The interviews indicate big differences regarding to what extent adverse events and deficiencies that occur onboard are reported to management ashore. The safety managers estimate that between 30 and 80 per cent of near misses are reported, around the same numbers for non-conformities and between 40 and 100 per cent regarding accidents and incidents. It is generally believed amongst the safety managers that the more serious the events are the higher is the reporting degree. Because these estimations differ so much between different companies it is a big weakness of the collected data. Correlating metrics with safety performance data when it is unknown if that data is 100 or 30 per cent accurate can be a big source of distortion. There can be numerous reasons behind why there is a resistance to report and a few of them were mentioned in the interviews. For instance, all safety managers stated that they believe that they work within a no blame culture where accidents, hazardous occurrences and near misses can be reported without fear of punishment or reprisal. However, when answering the question as to why they believed there was a resistance to report several safety managers stated that they believe that employees feel ashamed and blame themselves for their mistakes. Whether the company then really has a no blame culture, or if that is just the intention of the management, is questionable. Other mentioned reasons for reluctance to report are for instance that employees don’t realise the importance of reporting, don’t think it is worth to take the time to do it or don’t know how to define near misses or non-conformities. Furthermore, it is impossible for us to know if the estimated differences in the different companies’ reporting rates are due to actual differences or due to diversity in the safety managers’ awareness and knowledge of the problem with reporting reluctance. It might also be that some of the safety managers were unwilling to admit that they have a problem with underreporting.

When it comes to the level of reporting it is impossible to say whether a high number means that there have been more adverse events and deficiencies or that the reporting system is well-functioning. Regarding near misses it is becoming generally recognised that one sees high numbers as something positive for safety, i.e. an indication of a better functioning reporting system. Hence, several companies which use the number of near misses as a KPI set a minimum level to be achieved. But when it comes to more severe events like incidents and accidents the KPI level is set to a maximum, i.e. one does not want many of them. But all other categories of events, deviations and different severities of injuries are also to some extent affected by shortcomings of reporting. So when is it reasonable to set a minimum level and when should a maximum level be set? It is far from clear where to draw that line. This makes it difficult to know how to interpret the correlations – does the metric indicate improved or impaired safety if it indicates a higher number of adverse events or injuries? The result shows that *Number of fleet-bulletins* is correlated with *Near miss frequency for 2011* with a correlation coefficient of -0.83 and a p-value of 0.042. It could for instance mean that an increased number of fleet-bulletins leads to less near misses, that an increased number of fleet-bulletins leads to a decreased reporting rate of near misses or that a third unknown factor causes the inverse correlation.

External Demands

The metrics collected in this study are based on safety culture factors, i.e. they are connected to either continuous improvement, management commitment or personnel empowerment. Hence, the initial thought was that high numbers in the collected metrics (many safety inspections, a large number of training sessions etc.) would reflect a good safety culture in the organisation. However, most of the metrics collected are somehow controlled by international or national regulations or customer demands and most companies state that they don't do much more for safety than what is required from these regulations. This means that most of the differences in metrics collected from different companies probably rather depend on the different external demands than on the safety culture of the companies. For instance, the vetting process puts high pressure on tank shipping companies. Another example of differences in demands is in the STCW regarding safety training, where the requirements are higher on passenger ferries. In other words this means that this study cannot be said to give any indication about the levels of safety culture at the different companies and sectors but rather reflect differences in legislations and customer demands. Because of this and the poor comparability of the data we cannot say anything about the influences of the three different safety factors management commitment, personnel empowerment and continuous improvement on safety performance either.

4.2 Additional Observations

Safety Culture

All of the safety managers that were interviewed in this study seemed to have a genuine interest to improve the safety within their shipping company and we think that the safety level in the participating companies is generally high compared to an international standard. We have experienced that our study has been met with interest from a large number of safety managers and that they are curious for new tools to help their safety management. All interviewed safety managers except one state that they believe that their company has a safety culture, where safety has been raised to the highest priority. After meeting with the safety managers we can conclude that there is no doubt that the ambition of the safety managers is to achieve a safety culture, the question is whether this is accomplished in the entire organisation on all levels. It has emerged during the personal meetings and interviews that most shipping companies do what is required of them to comply with safety regulations such as the ISM Code, but not much more due to lack of resources. Whether the companies then can be said to actually have a safety culture, at least according to the definition of an organisation where safety has been raised to the highest priority, is dubious. It is however important to remember that a shipping company is a profit making company with limited resources.

As has been presented in chapter 3.2 a commitment to safety management is essential for an effective shipping organisation and it can also have many economic advances such as an increased competitiveness, better reputation and lower staff absenteeism. This makes one wonder why the majority of the interviewed shipping companies do not seem to think that more investments in safety than a demanded minimum will increase their profitability. Two of the safety managers at the tanker companies however emphasised that profitability and safety go hand in hand since an accident may have severe economic consequences. This insight could possibly be an effect from the high demands of vetting. During the interviews with safety managers at the tanker companies, all of them expressed that they collect their metrics and KPIs mainly because the oil companies demand it.

One of the safety managers even said that everything they do is in order to receive a good result in the vetting inspections. An important element in a safety culture that has been highlighted in this report is a well-functioning incident reporting system. When it comes to tankers, the vetting process has both advantages and disadvantages on reporting. One positive effect is that the high requirements of measured data may increase the reporting and collection of KPIs related to safety but on the downside the vetting process may also work against a no blame culture. Some of the interviewed safety managers stated that they feel the pressure from vetting companies to dismiss employees that have made severe mistakes. This could lead to fear of reprisals and hence decrease the willingness to report.

Differences between Sectors

Even though the found correlations cannot be said to be valid due to the reasons presented above, there are a few things to be said about the collected data. First of all, the tanker shipping companies differed from the other shipping companies in a few aspects. Looking at the collected data, we could see a clear tendency that tanker shipping companies have a higher number of reported near misses per vessel than shipping companies from other sectors. We cannot make the statement that this is generally true for tanker shipping companies, but the tanker companies that participated in this study had consistently higher numbers of reported near misses than the other shipping companies. It is difficult to say if this is because more near misses occur in these shipping companies or if they have a better functioning reporting system. However, during the safety manager interviews we got the impression that the tanker companies have been working hard to increase their reporting rate and it seems like this has had an effect. On the contrary, it would be reasonable if the number of near misses per vessel would be higher on passenger ferries since they have a lot more employees than tanker ships (over ten times more employees per vessel). A larger crew should mean that more things can go wrong and hence there should be more near misses on a ship with a larger staff. This further strengthens the notion that the reporting system is better functioning in tanker shipping companies.

Another thing that stood out regarding the tanker shipping companies was that they use a larger number of KPIs in their safety work than shipping companies from other sectors. This could mean that tanker companies have come further in structuring their safety management and monitoring their safety performance. Also, the tanker companies could in general provide more of the metrics in exact numbers than shipping companies from other sectors, which made more estimations, which might indicate that tanker companies collect more statistics regarding their safety work. They were also more familiar with the definitions used in the datasheet. All of these things that separate the tanker companies from the other shipping companies could be because of the high demands from oil companies. The vetting process requires a more structured way of working with safety and that the tanker companies e.g. collect certain KPIs and reach a certain number of reported near misses. We thus consider it probable that it is mainly due to the vetting that the data collected from tanker companies are different in these ways.

Variation of Data

All correlations, except two, show strong relationships. This is probably not a coincidence. The weaker the correlations are the more data is needed to reach significance. Hence, it is difficult to use this method using a similar selection of participants. If data is equal between participants, all ranks will be the same and the test will not show significant results. This was the case in this study for instance for the metrics *Percentage of new employees put through a formal induction process* and *Percentage of employees with access to fleet-bulletins* in which cases all participants answered 100 per cent. In other words, if one wants to find all correlations regardless of their strength, the data needs to be collected from a bigger selection (i.e. more participating companies, business units, vessels or number of years depending on what the nominal variable is) to decrease the risk of getting equal ranks. The option is to exclude those metrics from the test which would be unfortunate since they may be potential indicators of safety.

Apart from the two examples presented in the paragraph above, there were several more metrics where the answers from all of the different shipping companies were very similar. The metrics that had the most similar answers, i.e. the metrics with the lowest coefficient of variation (standard deviation divided by mean value) were for example *Percentage of corrective action reports closed out within nine months*, *Percentage of safety concerns that are addressed within three months* and *Number of toolbox talks per vessel*. Regarding these metrics which had a low coefficient of variation the answers from many of the shipping companies were equal to “100 %” or “0” and hence the low variation. In order to gain some diversity in the results the metrics could have been expressed slightly differently, for instance *Percentage of corrective action reports closed out within nine months* could have been *Average closing time for corrective action reports* instead. The metrics that varied most in the answers provided by the shipping companies, i.e. the ones with the highest coefficient of variation were for instance *Percentage of safety meetings onboard attended by ashore management*, *Number of safety suggestions submitted per vessel*, *Number of near misses reported per vessel* and *Number of KPIs utilised in safety management*. The reason for these metrics to vary a lot between different shipping companies could be that they are not as controlled by legislations as many of the other metrics and hence it is more voluntary how much to work on these areas. It could also be because the demands are different on different kinds of shipping companies as was discussed above regarding near misses and KPIs for tanker shipping companies due to the vetting process.

5. Discussion

This chapter contains a discussion about whether the initial goals of the project were achieved. It also deals with the problems encountered while performing this study and the difficulties that are connected to identification of indicators across different organisations.

5.1 The Study in Hindsight

Data Collection

The main objective of this thesis was to identify leading objective indicators of safety in shipping by collecting data across organisations. The study involved data from ten different shipping companies which means that the goal to get at least ten participating shipping companies with a varying range of size, nationality and type of cargo was met. All companies also complied with the four criteria for undertaking a leading indicators program, i.e. they were considered ready for a leading indicators program according to ABS. Retrospectively, this wide selection has led to many complications. Even though we performed the feasibility study consulting both literature and experts in shipping safety, the data sheet turned out to have a lot of ambiguities. The anticipated problem of getting access to data due to confidentiality was never an issue though.

In hindsight it would have been better to collect data with the same method for all participants. Having had personal meetings with thorough discussions about how to interpret the metrics and safety performance data with most shipping companies, while others have just sent their answers by email has led to several uncertainties. If possible all data should have been collected through personal meetings. The companies that did not have the possibility to a personal meeting have not had the same opportunity to discuss and ask questions about the datasheet which means that they might have made misinterpretations that we do not know about. Furthermore we know nothing about their definitions of the concepts used like for instance near misses, incidents and fleet-bulletins. Having meetings with all participants would not have decreased differing definitions of the data, as for instance the number of safety training sessions would still include different things for different companies and sectors but at least we would have had better knowledge about the uncertainties of the data. We performed an analysis where the data from the three companies that had not been interviewed was excluded. It had a big impact on the results, especially since a lot of data was missing which meant that seven companies was not a big enough selection to receive significant results regarding several metrics.

Objective Indicators

The initial aim of this project was to find objective leading indicators of safety in shipping. Objective indicators seemed like a simple tool for achieving unbiased measures of safety without the interference of subjective opinions. Step Change in Safety (n.d., p. 14) even states that "The indicators selected should be objective and specific so that they are readily understood and easily monitored in an unambiguous way". However we soon realised that complete objectivity is difficult, or rather impossible, to maintain. Metrics that at first seemed to have clear and obvious definitions have been affected in multiple steps by subjective opinions and decisions. The so called objective indicators differ from subjective indicators in the way that they are based on metrics that are measured as numbers, but the use of the word objective in this case is definitely questionable. It is likely that the influence of subjectivity would have been smaller if the identification of leading indicators was performed as ABS suggested within one organisation where the definitions and perceptions of concepts perhaps are not identical but at least more similar than they are across different organisations.

Another downside with the so called objective indicators is their inability to capture the influence of the quality of the metrics. For instance concerning the indicator *Number of safety suggestions submitted per vessel*, it does not say anything about the importance of the substance of those suggestions. If an organisation for instance uses these indicators as a KPI to monitor safety performance by setting a goal of a minimum number of reports to be reached every year without any consideration to the quality of these suggestions, there is a risk of an ineffective allocation of resources in regards to safety management. It may be a struggle to find a balance where the pursuit of good numbers does not become a distraction from the actual target of safety improvement. It emerged during the interviews that some safety managers believe that their seafarers do not always embrace the increased focus on safety. Some for instance indicate that they see safety work as an oppressive extra workload and do not see the point of filling out checklists or think that there are too many drills. This resistance may cause employees to cheat and take shortcuts, for instance filling out checklist without actually fulfilling the tasks. Hence, more action and safety activities may not necessarily improve safety. Therefore it is highly important to include quality in the companies' safety management so that safety does not just appear to be good but actually is good. We believe that this indicates the importance of having a safety management system and a safety culture that is embedded at all levels throughout the organisation.

5.2 Future Use of Leading Objective Indicators

Across or within Organisations

The foundation of this study was the guidelines by ABS (2012) but unlike their suggestion of use we wanted to try if the method was possible to use across different companies. In hindsight, knowing all the difficulties that developed mainly due to the differences between companies' understanding and monitoring of safety it was not a very successful idea. Due to the biases and difficulties presented above, the results in this thesis are regarded to be too uncertain to be applicable. However, our opinion is that there is a need for a more proactive way to monitor and manage safety as it may provide opportunities to take corrective action before accidents occur. During this study, we have also experienced that there is an interest from the shipping companies concerning a development of more proactive ways to measure and manage safety. We agree with Hollnagel (2008) as he states that safety should not only be seen as the absence of something negative, but as the presence of something positive. To be able to achieve this there is a need for more proactive ways to measure safety and we therefore believe that the use of leading indicators may be a valuable tool if the methodology is further investigated and developed.

The three levels that ABS suggests the method for are: for the organisation, across business units and across vessels. Finding objective leading indicators for the organisation requires that metrics and safety performance data have been collected from at least five years back in time. We believe this approach would be very difficult due to that the shipping companies we studied have not collected data for that long, at least not yet. Identifying indicators across business units or across vessels within the same company however only demands collected data from one year even if it is preferable to collect safety performance data from several years in order to discover any delayed effects. It is our belief that this approach is the preferable method and probably the best way to fulfil the long term objective to enable the use of leading objective indicators of safety as a tool to help decision makers to make better prioritisations of resources in their preventive safety work. By using the datasheet and statistical analysis presented in this thesis the identification process could give valuable indicators of safety without being very resource demanding. If one however still wishes to identify leading indicators of safety across organisations we would recommend doing so with tanker companies only which are more comparable since they have similar and tough external demands to meet and hence collect similar data. This was however not possible in our study due to the limited number of participating companies which would have disabled the statistical analysis.

It is important to note that even if the influence of subjectivity can be decreased by studying a different selection, a lot of the discussed weaknesses of the method still remain. The inability of leading objective indicators to capture quality for instance is something that safety managers need to be aware of. It is important to incorporate the quality of the metrics when allocating resources so that focus is not only on the numbers but on actual safety improvement. Another problem that remains is that underreporting makes it impossible to know how accurate the safety performance data is. One of the major difficulties with this method regarding whether to interpret the number of reported events as the actual number of events or the quality of the reporting also persists.

A Well-Functioning Reporting System

An essential part of any safety measurement, regardless if they are leading or lagging, is a well-functioning reporting system. To be able to make corrective actions when something is not functioning in an optimal way it is obviously important that any weaknesses are brought to attention of the company management. We believe that three vital aspects must be fulfilled to achieve an efficient reporting system. First of all it is essential that the company has a no blame culture in which the crew feels encouraged to report if mistakes have been made, exercises have been missed due to lack of time etc. so that the management becomes aware of the problems that exist in the organisation. The crew also needs to have good knowledge about what to report, in what category to report which event and how to report. Furthermore they need to understand the importance and meaning of reporting. In other words, they need to be empowered to report.

A Need for Uniform Concepts

One thing that became clear to us during the execution of this project is that there is a need for more uniform concepts and definitions about safety in the shipping industry. This is necessary in order to enhance the possibility of comparative studies and safety communication across organisations. Enabling shipping companies to compare their safety performance to other companies could also ease benchmarking. More uniform definitions would also increase the applicability of the “lessons learnt” provided by shared incident reporting systems. In order for the industry to continuously improve its safety performance all shipping sectors can learn from the good influences the vetting process has had on tanker vessels´ ways of monitoring and managing safety.

6. Conclusions and Further Research

In this final chapter conclusions are drawn and the need for further research within the area is discussed.

So, can common leading objective indicators of safety be identified across organisations in the shipping industry? Our opinion based on this study is that they cannot, at least not to this extent, across different sectors of shipping companies and with the differing external demands and regulations that exist today. The indicators that were found cannot be said to be valid since they are largely based on data of poor comparability and far from objective.

Most of the problems that we encountered can be traced to the aim to find common indicators by involving several different sectors of shipping companies, as the definitions of concepts used in their safety work vary considerably. Hence we draw the conclusion that in order to enable safety research, collaboration and comparison between different shipping companies in the future there is a need to reduce the diversity of definitions that are used within the shipping industry. We have no answer on how to achieve this but hope that further research can find suitable incentives and means of control as a solution to this problem.

Even though the method used in this project proved to have a lot of weaknesses, our opinion is that there is a need for a future development towards a more proactive way to manage safety in shipping. As opposed to how safety is measured today, with lagging key performance indicators, we believe that there needs to be a development towards a measurement of safety as the presence of something positive. Our opinion is that the research community should continue to develop the usefulness of leading objective indicators and that organisations can contribute to this development by implementing them as a complementary tool in their safety management systems. However, as discussed above, there are several problems with leading objective indicators as a concept which are not easy to overcome. One of the main disadvantages of quantitative indicators is the inability to capture quality of the metrics, which might lead to a misdirected focus on an increase in numbers. Also the difficulties that arise when correlating the metrics to safety performance, where the reporting rate is a large source of uncertainties, are difficult to overcome. To have a well-functioning reporting system, including a no blame culture and empowered crew, is vital not only for monitoring safety with lagging indicators but also for enabling the identification of leading indicators.

If leading indicators of safety should be used in safety management, it is of great importance that the safety manager is aware of the above problems and that the indicators are used mainly as a more proactive complement to other ways of monitoring and managing safety.

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Appendix A – The Datasheet

Data for identification of leading objective indicators

This project is a master thesis at the M.Sc. programme in Risk Management and Safety Engineering at Lund University, Faculty of Engineering. The title of the project is "Leading objective indicators of safety culture in shipping" and is performed in collaboration with SSPA in Gothenburg. The project is also included in the EU project CyClaDes. The aim of our project is to identify objective leading indicators of safety within Swedish shipping companies, which are metrics statistically correlated with safety performance data. These indicators can be used in a more proactive safety work and reveal areas if weakness in advance of undesired events.

While answering the questions, please keep in mind that:

- *All data should be given as numbers per year and for the entire fleet unless otherwise is requested. The metrics should be from year 2011 and the safety performance data from years 2011 and 2012.*
- *If any answer is estimation, please make a note that so is the case. Though, remember that the result will be more accurate and useful if empirical data is provided.*
- *Your answers will be confidential and your company will not be named in the report.*

Thank you for your valuable contribution to our study!

Jessica Fälth & Mikaela Ljungqvist

If you have any questions, do not hesitate to contact us on 0730-72 91 25 or email Jessica.Falth@sspa.se or Mikaela.Ljungqvist@sspa.se.

Definitions

Accident or Incident: An event that has occurred and received an unwanted consequence.

Conditions of Class: The number of deficiencies identified, or recommendations made, by the classification society's surveyor on a vessel.

Leading Indicators: Conditions, events or measures that precede an undesirable event, and have some value in predicting the arrival of the event, whether it is an accident, incident, near miss, or undesirable safety state.

Lost Time Incident (LTI): Any work-related injury other than a fatal injury that results in a person being unfit for work for a period of 24 continuous hours immediately after the occurrence of the incident.

Medical Treatment Case (MTC): Work-related injuries that are not severe enough to be reported as fatalities, Lost Time Incident, or Restricted Work Accident cases but are more severe than requiring simple first aid treatment; however the injured person is able to carry out all his duties after treatment.

Metrics: A set of measurements that quantify or qualify aspects of a system (here, organisational safety performance).

Near Miss (NM): An event, or a chain of events, that under slightly different circumstances could have resulted in an accident, injury, damage, or loss of personnel, equipment, or the vessel.

Non-conformity: An observed situation where objective evidence indicates the non-fulfillment of a specified requirement.

Port State Deficiencies: The number of deficiencies on a vessel identified by Port State Control.

Restricted Work Accident (RWA): Any work-related injury (other than a fatality or lost time incident) that results in a person being unfit to perform all of his/her regular job after the accident.

Toolbox talk: A short safety talk (5-10 minutes), normally delivered at the workplace (not a training room) and on a specific subject matter and to the point with a specific safety message.

Total Recordable Cases (TRC): The sum of all work-related fatalities, lost time incidents, restricted work accidents and medical treatment cases. TRCs = LTIs + RWAs + MTCs.

Basic organisation information

- Type of cargo (dry-bulk/tanker/ro-pax/ro-ro/other) being transported……………………….
- Number of vessels……………………….
- Total market value of the fleet……………………….
- Flag states……………………….
- Number of employees within respective department (e.g. ashore, onboard)………………………
  …….
- Does the company manages all areas itself or are external companies involved? If so, for what area and to what extent? (e.g. technical management company) ……………………………
  …….

Metrics (for year 2011)

Management commitment

Audits, inspections and meetings

- Number of safety audits completed per year (by company management) per vessel……………………….
- Number of safety inspections per year (by onboard management) per vessel……………………….
- Number of completed safety inspection/monitor/audit/review activities vs. planned (%)……………
- Number of safety meetings onboard per vessel ……………………….
- Percentage of safety meetings onboard attended by ashore management ……………………….
- Number of officer (from different vessels within the company) safety meetings ashore……………..

Supplementary

- How many staff onboard/ashore employed in full time safety positions? (DP, Safety Manager(s), Risk Manager(s), Safety Officers etc.)……………………………………………………………………………………
- Percentage of tasks (all onboard activities) that have safety checklists……………………….
- Number of job hasard analyses conducted per vessel……………………….
- Percentage of times a Management of Change was conducted when there were changes to jobs, tasks, or equipment……………………….
- Percentage of safety budget that is separated from the operational and technical budget……………

Any additional comments?..

Personnel empowerment and motivation

Training

- Percentage of employees attending a Bridge Resource Management (BRM) course or similar safety training……………………….
- Percentage of safety training that includes competency testing……………………….
- Average number of safety training sessions logged per employee……………………
- Percentage of new employees put through a formal induction process (onboard or in-service training)……………………….

Feedback

- Percentage of crew receiving feedback on safety audits, issues, and concerns………………………
- Per cent of employees who have their performance appraised annually………………………
- Number of fleet-bulletins………………………
- Percentage of employees with access to fleet-bulletins………………………

Supplementary

- Average percentage of shipboard personnel attending at onboard safety meetings………………………
- Average retention rate of ratings (%)………………………
- Average retention rate of officers (%)………………………

Any additional comments?……………………………………………………………………………………………………

Continuous Improvement

Reporting

- Number of accidents and incidents reported per vessel (total number of reported accidents divided by the total number of vessels) ………………………
- Number of safety suggestions submitted per vessel ………………………
- Number of near misses reported per vessel………………………
- Number of non-conformities reported per vessel………………………
- Percentage of the above reports that are reported by officers ………………………

Responsiveness

- Percentage of safety reports on which relevant feedback was provided………………………
- Percentage of safety suggestions on which relevant feedback was provided………………………
- Percentage of incident reports on which causal analysis was undertaken………………………
- Number of corrective action reports (CARs) originating from internal audits per vessel………………
- Percentage of corrective action reports (CARs) closed out within 9 months………………………
- Percentage of safety audit recommendations closed out in time ………………………
- Percentage of Planned Maintenance System (PMS) items completed on time………………………
- Percentage of safety concerns (accidents, near misses and non-conformities) that are addressed within 3 months ………………………

Communication

- Number of safety meetings onboard per vessel………………………
- Number of toolbox talks per vessel ………………………

Supplementary

- Average update frequency of safety checklists………………………
- Average update frequency of standard operating procedures………………………
- Number of key performance indicators utilised in safety management………………………………
- Frequency of revision of the company´s Safety Management System…………………………………..

Safety Performance Data (for years 2011 and 2012)

Operations Data for the Organisation

- Incidents frequencies
  2011……………. 2012…………..
- Near miss frequencies
  2011……………. 2012…………..
- Conditions of class frequencies
  2011……………. 2012…………..
- Port state deficiencies frequencies
  2011……………. 2012…………..

Health and Safety Data for the Organisation

- Recordable cases frequency
  2011……………. 2012…………..
- Lost time incidents frequency
  2011……………. 2012…………..
- Medical treatment case frequency
  2011……………. 2012…………..
- Restricted work accidents frequency
  2011……………. 2012…………..

Data for normalisation

- The number of exposure (working) hours
  2011……………. 2012…………..
- The number of port calls
  2011……………. 2012…………..

Thank you for your cooperation!

Appendix B – Safety Manager Interview

1. How long have you worked for your present company? What is your position and how long have you had this position?

2. Do you believe your Company operates a 'no blame' culture where accidents, hazardous occurrences and near misses can be reported without fear of punishment or reprisal?

3. Do you believe you work within a 'safety culture' - where safety has been raised to the highest priority?

4. Do you think that <u>your seafarers</u> believe they work within a 'safety culture' - where safety has been raised to the highest priority?

5. If you think (in questions 3 and 4) that there is a difference, then why do you think that is?

6. From your own experience, how many per cent of the <u>accidents</u> which occur onboard are reported to the Company ashore?

7. If there is reluctance to report <u>accidents</u> to the Company, why do you think that is?

8. From your own experience, how many <u>near misses</u> which occur onboard are reported to the Company ashore?

9. If there is reluctance to report <u>near misses</u>, why do you think that is?

10. From your own experience, how many <u>non - conformities</u> which come to light onboard are reported to the Company ashore?

11. If there is reluctance to report <u>non-conformities</u>, why do you think that is?

To what extent do you agree with the following statements?

Disagree strongly……….Disagree…...Neither agree nor disagree……….Agree…………Agree strongly

12. The organisation is compliant with all relevant regulations.
13. Human error or organisational factors are causing the majority of operational incidents or personal injuries.
14. The organisation has a genuine desire to prevent operational incidents and personal injuries and is not solely driven by the avoidance of prosecution.
15. The organisation is relatively stable, not in the middle of mergers, acquisitions or significant reorganisations.

Appendix C – Matlab Code

The code written for this study

```
addpath \\sspa.local\gbg\exjobb\Säkerhetskultur\Spearman

% Inläsning
[data, text]=xlsread('Datasheet.xlsx','results');
metrics=data(1:41,:)';
safetyperfdata=data(42:57,:)';

[rho,p,ci1,ci2]=corrcoef(metrics,safetyperfdata,'Mode','Spearman','alpha',0
.05);
xlswrite('Spearmanresult',rho,'rho','B2:Q42')
xlswrite('Spearmanresult',p,'p','B2:Q42')

% Sourcecode http://pub.ist.ac.at/~schloegl/matlab/NaN/  NaN toolbox 2.5.7
% http://mathworld.wolfram.com/SpearmanRankCorrelationCoefficient.html
% http://mathworld.wolfram.com/CorrelationCoefficient.html

[data, text]=xlsread('Datasheet.xlsx','intervju -portcalls');
metrics=data(1:41,:)';
safetyperfdata=data(42:57,:)';

[rho,p,ci1,ci2]=corrcoef(metrics,safetyperfdata,'Mode','Spearman','alpha',0
.05);
xlswrite('Spearmanresultintervju_portcalls.xlsx',rho,'rho','B2:Q42')
xlswrite('Spearmanresultintervju_portcalls.xlsx',p,'p','B2:Q42')


[data, text]=xlsread('Datasheet.xlsx','bara intervjuade');
metrics=data(1:41,:)';
safetyperfdata=data(42:57,:)';

[rho,p,ci1,ci2]=corrcoef(metrics,safetyperfdata,'Mode','Spearman','alpha',0
.05);
xlswrite('Spearmanresultbaraintervjuade.xlsx',rho,'rho','B2:Q42')
xlswrite('Spearmanresultbaraintervjuade.xlsx',p,'p','B2:Q42')

[data, text]=xlsread('Datasheet.xlsx','utan port calls');
metrics=data(1:41,:)';
safetyperfdata=data(42:57,:)';

[rho,p,ci1,ci2]=corrcoef(metrics,safetyperfdata,'Mode','Spearman','alpha',0
.05);
xlswrite('Spearmanresultutanportcalls.xlsx',rho,'rho','B2:Q42')
xlswrite('Spearmanresultutanportcalls.xlsx',p,'p','B2:Q42')
```

The source code

```
% Spearman's 0rank correalation coefficient.
%
% r is the Spearman's rank correlation coefficient.
% t is the t-ratio of r.
% p is the corresponding p-value.
% x is the first data series (column).
% y is the second data series, a matrix which may contain one or multiple
%     columns.
```

```
%x=data(10:65,:)';
%y=data(69:81,:)';

%x=data(10:65,:)';
%y=data(69:81,:)';

%[R]=spearman(x,y) ???????????
%[R,p,ci1,ci2]=corrcoef(x,y,'Mode','Spearman','alpha',0.05);
% x = randn(30,4);
% y = randn(30,4);
% y(:,4) = sum(x,2);

%[data, text]=xlsread('The magic excelsheet 5 rederier.xlsx','Test');
%x=data(:,2);
%y=data(:,4);
%[R,p,ci1,ci2]=corrcoef(x,y,'Mode','Spearman','alpha',0.05);

function [R,sig,ci1,ci2,nan_sig] = corrcoef(X,Y,varargin)
% CORRCOEF calculates the correlation matrix from pairwise correlations.
%   The input data can contain missing values encoded with NaN.
%   Missing data (NaN's) are handled by pairwise deletion [15].
%   In order to avoid possible pitfalls, use case-wise deletion or
%   or check the correlation of NaN's with your data (see below).
%   A significance test for testing the Hypothesis
%   'correlation coefficient R is significantly different to zero'
%   is included.
%
% [...] = CORRCOEF(X);
%      calculates the (auto-)correlation matrix of X
% [...] = CORRCOEF(X,Y);
%      calculates the crosscorrelation between X and Y
%
% [...] = CORRCOEF(..., Mode);
%       Mode='Pearson' or 'parametric' [default]
%               gives the correlation coefficient
%               also known as the 'product-moment coefficient of
correlation'
%               or 'Pearson''s correlation' [1]
%       Mode='Spearman'     gives 'Spearman''s Rank Correlation
Coefficient'
%               This replaces SPEARMAN.M
%       Mode='Rank'         gives a nonparametric Rank Correlation
Coefficient
%               This is the "Spearman rank correlation with proper handling
of ties"
%               This replaces RANKCORR.M
%
% [...] = CORRCOEF(..., param1, value1, param2, value2, ... );
%   param       value
%   'Mode'      type of correlation
%       'Pearson','parametric'
%       'Spearman'
%       'rank'
%   'rows'      how do deal with missing values encoded as NaN's.
%       'complete': remove all rows with at least one NaN
%       'pairwise': [default]
%   'alpha'     0.01    : significance level to compute confidence interval
%
% [R,p,ci1,ci2,nansig] = CORRCOEF(...);
%   R is the correlation matrix
%   R(i,j) is the correlation coefficient r between X(:,i) and Y(:,j)
```

```
%  p    gives the significance of R
%   It tests the null hypothesis that the product moment correlation
coefficient is zero
%       using Student's t-test on the statistic t = r*sqrt(N-2)/sqrt(1-r^2)
%       where N is the number of samples (Statistics, M. Spiegel, Schaum
series).
%  p > alpha: do not reject the Null hypothesis: 'R is zero'.
%  p < alpha: The alternative hypothesis 'R is larger than zero' is true
with probability (1-alpha).
%  ci1  lower (1-alpha) confidence interval
%  ci2  upper (1-alpha) confidence interval
%   If no alpha is provided, the default alpha is 0.01. This can be changed
with function flag_implicit_significance.
%  nan_sig  p-value whether H0: 'NaN''s are not correlated' could be
correct
%       if nan_sig < alpha, H1 ('NaNs are correlated') is very likely.
%
% The result is only valid if the occurence of NaN's is uncorrelated. In
% order to avoid this pitfall, the correlation of NaN's should be checked
% or case-wise deletion should be applied.
%   Case-Wise deletion can be implemented
%    ix = ~any(isnan([X,Y]),2);
%    [...] = CORRCOEF(X(ix,:),Y(ix,:),...);
%
%  Correlation (non-random distribution) of NaN's can be checked with
%       [nan_R,nan_sig]=corrcoef(X,isnan(X))
%   or  [nan_R,nan_sig]=corrcoef([X,Y],isnan([X,Y]))
%   or  [R,p,ci1,ci2] = CORRCOEF(...);
%
% Further recommandation related to the correlation coefficient:
% + LOOK AT THE SCATTERPLOTS to make sure that the relationship is linear
% + Correlation is not causation because
%   it is not clear which parameter is 'cause' and which is 'effect' and
%       the observed correlation between two variables might be due to the
action of other, unobserved variables.
%
% see also: SUMSKIPNAN, COVM, COV, COR, SPEARMAN, RANKCORR, RANKS,
%       PARTCORRCOEF, flag_implicit_significance
%
% REFERENCES:
% on the correlation coefficient
% [ 1] http://mathworld.wolfram.com/CorrelationCoefficient.html
% [ 2] http://www.geography.btinternet.co.uk/spearman.htm
% [ 3] Hogg, R. V. and Craig, A. T. Introduction to Mathematical
Statistics, 5th ed.  New York: Macmillan, pp. 338 and 400, 1995.
% [ 4] Lehmann, E. L. and D'Abrera, H. J. M. Nonparametrics: Statistical
Methods Based on Ranks, rev. ed. Englewood Cliffs, NJ: Prentice-Hall, pp.
292, 300, and 323, 1998.
% [ 5] Press, W. H.; Flannery, B. P.; Teukolsky, S. A.; and Vetterling, W.
T. Numerical Recipes in FORTRAN: The Art of Scientific Computing, 2nd ed.
Cambridge, England: Cambridge University Press, pp. 634-637, 1992
% [ 6] http://mathworld.wolfram.com/SpearmanRankCorrelationCoefficient.html
% on the significance test of the correlation coefficient
% [11] http://www.met.rdg.ac.uk/cag/STATS/corr.html
% [12] http://www.janda.org/c10/Lectures/topic06/L24-significanceR.htm
% [13] http://faculty.vassar.edu/lowry/ch4apx.html
% [14] http://davidmlane.com/hyperstat/B134689.html
% [15] http://www.statsoft.com/textbook/stbasic.html%Correlations
% others
% [20] http://www.tufts.edu/~gdallal/corr.htm
```

```
% [21] Fisher transformation
http://en.wikipedia.org/wiki/Fisher_transformation

%       $Id: corrcoef.m 9387 2011-12-15 10:42:14Z schloegl $
%       Copyright (C) 2000-2004,2008,2009,2011 by Alois Schloegl
<alois.schloegl@gmail.com>
%       This function is part of the NaN-toolbox
%       http://pub.ist.ac.at/~schloegl/matlab/NaN/

%    This program is free software: you can redistribute it and/or modify
%    it under the terms of the GNU General Public License as published by
%    the Free Software Foundation, either version 3 of the License, or
%    (at your option) any later version.
%
%    This program is distributed in the hope that it will be useful,
%    but WITHOUT ANY WARRANTY; without even the implied warranty of
%    MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE.  See the
%    GNU General Public License for more details.
%
%    You should have received a copy of the GNU General Public License
%    along with this program.  If not, see <http://www.gnu.org/licenses/>.

% Features:
% + handles missing values (encoded as NaN's)
%       + pairwise deletion of missing data
%       + checks independence of missing values (NaNs)
% + parametric and non-parametric (rank) correlation
%       + Pearson's correlation
%       + Spearman's rank correlation
%       + Rank correlation (non-parametric, Spearman rank correlation with
proper handling of ties)
% + is fast, using an efficient algorithm O(n.log(n)) for calculating the
ranks
% + significance test for null-hypthesis: r=0
% + confidence interval included
% - rank correlation works for cell arrays, too (no check for missing
values).
% + compatible with Octave and Matlab

global FLAG_NANS_OCCURED;

NARG = nargout; % needed because nargout is not reentrant in Octave, and
corrcoef is recursive
mode = [];

if nargin==1
        Y = [];
        Mode='Pearson';
elseif nargin==0
        fprintf(2,'Error CORRCOEF: Missing argument(s)\n');
elseif nargin>1
        if ischar(Y)
                varg = [Y,varargin];
                Y=[];
        else
                varg = varargin;
        end;

        if length(varg)<1,
                Mode = 'Pearson';
```

```
        elseif length(varg)==1,
                Mode = varg{1};
        else
                for k = 2:2:length(varg),
                        mode = setfield(mode,lower(varg{k-1}),varg{k});
                end;
                if isfield(mode,'mode')
                        Mode = mode.mode;
                end;
        end;
end;
if isempty(Mode) Mode='pearson'; end;
Mode=[Mode,'         '];

FLAG_WARNING = warning;     % save warning status
warning('off');

[r1,c1]=size(X);
if ~isempty(Y)
        [r2,c2]=size(Y);
        if r1~=r2,
                fprintf(2,'Error CORRCOEF: X and Y must have the same
number of observations (rows).\n');
                return;
        end;
        NN = real(~isnan(X)')*real(~isnan(Y));
else
        [r2,c2]=size(X);
        NN = real(~isnan(X)')*real(~isnan(X));
end;

%%%%% generate combinations using indices for pairwise calculation of the
correlation
YESNAN = any(isnan(X(:))) | any(isnan(Y(:)));
if YESNAN,
    FLAG_NANS_OCCURED=(1==1);
    if isfield(mode,'rows')
        if strcmp(mode.rows,'complete')
            ix = ~any([X,Y],2);
            X = X(ix,:);
            if ~isempty(Y)
                Y = Y(ix,:);
            end;
            YESNAN = 0;
            NN = size(X,1);
        elseif strcmp(mode.rows,'all')
            fprintf(1,'Warning: data contains NaNs, rows=pairwise is
used.');
            %%NN(NN < size(X,1)) = NaN;
        elseif strcmp(mode.rows,'pairwise')
            %%% default
        end;
    end;
end;
if isempty(Y),
        IX = ones(c1)-diag(ones(c1,1));
        [jx, jy ] = find(IX);
        [jxo,jyo] = find(IX);
    R = eye(c1);
else
        IX = sparse([],[],[],c1+c2,c1+c2,c1*c2);
```

```
        IX(1:c1,c1+(1:c2)) = 1;
        [jx,jy] = find(IX);

        IX = ones(c1,c2);
        [jxo,jyo] = find(IX);
    R = zeros(c1,c2);
end;

if strcmp(lower(Mode(1:7)),'pearson');
        % see http://mathworld.wolfram.com/CorrelationCoefficient.html
    if ~YESNAN,
                [S,N,SSQ] = sumskipnan(X,1);
                if ~isempty(Y),
                    [S2,N2,SSQ2] = sumskipnan(Y,1);
                        CC = X'*Y;
                        M1 = S./N;
                        M2 = S2./N2;
                        cc = CC./NN - M1'*M2;
                        R  = cc./sqrt((SSQ./N-M1.*M1)'*(SSQ2./N2-M2.*M2));
                else
                        CC = X'*X;
                        M  = S./N;
                        cc = CC./NN - M'*M;
                        v  = SSQ./N - M.*M; %max(N-1,0);
                        R  = cc./sqrt(v'*v);
                end;
        else
                if ~isempty(Y),
                        X  = [X,Y];
                end;
                for k = 1:length(jx),
                        %ik = ~any(isnan(X(:,[jx(k),jy(k)])),2);
                        ik = ~isnan(X(:,jx(k))) & ~isnan(X(:,jy(k)));
                        [s,n,s2] = sumskipnan(X(ik,[jx(k),jy(k)]),1);
                        v  = (s2-s.*s./n)./n;
                        cc = X(ik,jx(k))'*X(ik,jy(k));
                        cc = cc/n(1) - prod(s./n);
                        %r(k) = cc./sqrt(prod(v));
                        R(jxo(k),jyo(k)) = cc./sqrt(prod(v));
                end;
    end

elseif strcmp(lower(Mode(1:4)),'rank');
        % see [ 6]
http://mathworld.wolfram.com/SpearmanRankCorrelationCoefficient.html
    if ~YESNAN,
                if isempty(Y)
                    R = corrcoef(ranks(X));
                else
                        R = corrcoef(ranks(X),ranks(Y));
                end;
        else
                if ~isempty(Y),
                        X = [X,Y];
                end;
                for k = 1:length(jx),
                        %ik = ~any(isnan(X(:,[jx(k),jy(k)])),2);
                        ik = ~isnan(X(:,jx(k))) & ~isnan(X(:,jy(k)));
                        il = ranks(X(ik,[jx(k),jy(k)]));
                        R(jxo(k),jyo(k)) = corrcoef(il(:,1),il(:,2));
                end;
```

```
        X = ranks(X);
    end;

elseif strcmp(lower(Mode(1:8)),'spearman');
        % see [ 6]
http://mathworld.wolfram.com/SpearmanRankCorrelationCoefficient.html
        if ~isempty(Y),
                X = [X,Y];
        end;

        n = repmat(nan,c1,c2);

        if ~YESNAN,
                iy = ranks(X);  %  calculates ranks;

                for k = 1:length(jx),
                        [R(jxo(k),jyo(k)),n(jxo(k),jyo(k))] =
sumskipnan((iy(:,jx(k)) - iy(:,jy(k))).^2);   % NN is the number of non-
missing values
                end;
        else
                for k = 1:length(jx),
                        %ik = ~any(isnan(X(:,[jx(k),jy(k)])),2);
                        ik = ~isnan(X(:,jx(k))) & ~isnan(X(:,jy(k)));
                        il = ranks(X(ik,[jx(k),jy(k)]));
                        % NN is the number of non-missing values
                        [R(jxo(k),jyo(k)),n(jxo(k),jyo(k))] =
sumskipnan((il(:,1) - il(:,2)).^2);
                end;
        X = ranks(X);
        end;
        R = 1 - 6 * R ./ (n.*(n.*n-1));

elseif strcmp(lower(Mode(1:7)),'partial');
        fprintf(2,'Error CORRCOEF: use PARTCORRCOEF \n',Mode);

        return;

elseif strcmp(lower(Mode(1:7)),'kendall');
        fprintf(2,'Error CORRCOEF: mode ''%s'' not implemented
yet.\n',Mode);

        return;
else
        fprintf(2,'Error CORRCOEF: unknown mode ''%s''\n',Mode);
end;

if (NARG<2),
        warning(FLAG_WARNING);  % restore warning status
        return;
end;


% CONFIDENCE INTERVAL
if isfield(mode,'alpha')
    alpha = mode.alpha;
elseif exist('flag_implicit_significance','file'),
        alpha = flag_implicit_significance;
else
    alpha = 0.01;
end;
```

```
% fprintf(1,'CORRCOEF: confidence interval is based on alpha=%f\n',alpha);


% SIGNIFICANCE TEST
R(isnan(R))=0;
tmp = 1 - R.*R;
tmp(tmp<0) = 0;      % prevent tmp<0 i.e. imag(t)~=0
t   = R.*sqrt(max(NN-2,0)./tmp);

if exist('t_cdf','file');
        sig = t_cdf(t,NN-2);
elseif exist('tcdf','file')>1;
        sig = tcdf(t,NN-2);
else
        fprintf('CORRCOEF: significance test not completed because of
missing TCDF-function\n')
        sig = repmat(nan,size(R));
end;
sig  = 2 * min(sig,1 - sig);

if NARG<3,
    warning(FLAG_WARNING);  % restore warning status
        return;
end;

tmp = R;
%tmp(ix1 | ix2) = nan;      % avoid division-by-zero warning
z   = log((1+tmp)./(1-tmp))/2;  % Fisher transformation [21]
%sz = 1./sqrt(NN-3);         % standard error of z
sz  = sqrt(2)*erfinv(1-alpha)./sqrt(NN-3);  % confidence interval for alpha
of z

ci1 = tanh(z-sz);
ci2 = tanh(z+sz);

%ci1(isnan(ci1))=R(isnan(ci1)); % in case of isnan(ci), the interval limits
are exactly the R value
%ci2(isnan(ci2))=R(isnan(ci2));

if (NARG<5) || ~YESNAN,
    nan_sig = repmat(NaN,size(R));
    warning(FLAG_WARNING);  % restore warning status
    return;
end;

%%%%% ----- check independence of NaNs (missing values) -----
[nan_R, nan_sig] = corrcoef(X,double(isnan(X)));

% remove diagonal elements, because these have not any meaning %
nan_sig(isnan(nan_R)) = nan;
% remove diagonal elements, because these have not any meaning %
nan_R(isnan(nan_R)) = 0;

if 0, any(nan_sig(:) < alpha),
        tmp = nan_sig(:);           % Hack to skip NaN's in MIN(X)
        min_sig = min(tmp(~isnan(tmp)));    % Necessary, because Octave
returns NaN rather than min(X) for min(NaN,X)
        fprintf(1,'CORRCOFF Warning: Missing Values (i.e. NaNs) are not
independent of data (p-value=%f)\n', min_sig);
```

```
        fprintf(1,'    Its recommended to remove all samples (i.e. rows) 
with any missing value (NaN).\n');
        fprintf(1,'    The null-hypotheses (NaNs are uncorrelated) is 
rejected for the following parameter pair(s).\n');
        [ix,iy] = find(nan_sig < alpha);
        disp([ix,iy])
end;

%%%%% ----- end of independence check ------

warning(FLAG_WARNING);  % restore warning status
return;
```