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SAFETY PERFORMANCE INDICATORS FOR MARITIME SAFETY MANAGEMENT

Literature review

Risto Jalonen, Kim Salmi

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ABSTRACT

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Title
SAFETY PERFORMANCE INDICATORS FOR MARITIME SAFETY MANAGEMENT

Abstract
Statistical measurements of maritime safety

In this literature study safety measurement and evaluation methods used in safety management are scrutinized. Emphasis of this study lies on indicators which influence and usefulness in safety management and as tool for safety measurement and development are evaluated.

Indicators used in other domains, especially in other forms of transport are also being studied. These indicators already found useful in other domains are not only considered to be implemented as they are to maritime environment, but their possibilities as base for developing indicators with maritime particularities is also considered. A good example of use of indicators in safety management can be found from aviation, which have some important similarities as its international nature with maritime transport. This culture which leaves no room for negligence in different processes of aviation should be used as example for maritime domain.

The general safety level of seafaring should be raised to the level of domains of comparison with highest safety outcome. The first problem showing up when effort on development of safety is started is the evaluation of current safety level. Indicators used for this evaluation in maritime domain are partially insufficient and the scope of problems can be hard to evaluate as a whole. Accident driven risk evaluation, where estimation of safety is based purely to the information gained from realized incidents is not considered sufficient. The maritime domain needs a set of indicators that can measure actual and future level of safety. In road transport these leading indicators, example. frequencies of speeding or driving under influence of alcohol, are in constant use.

The intention of this work packet 1 of the METKU-project is to evaluate the use and usefulness of safety indicators in maritime and other domains to be able to give recommendations to safety development. In this research the aim is to find safety indicators, existing or newly developed, that can be used successfully as tools in safety management.

Keywords (and classification)
Safety, Maritime safety, Performance indicators, Accident models, Risk, Risk control, Safety management

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SAFETY PERFORMANCE INDICATORS FOR MARITIME SAFETY MANAGEMENT

Tiivistelmä
Merenkulun turvallisuuden tunnusluvut

Tässä tutkimuksessa tarkastellaan merenkulun turvallisuusjohtamisessa käytettäviä turvallisuuden mittaus- ja arviointimenetelmiä. Pääpaino tutkimuksessa kohdistetaan indikaattoreihin, eli tunnuslukuihin, joiden käyttökelpoisuutta meriliikenteen turvallisuusjohtamisessa, turvallisuuden arvioinnin ja sen kehittämisen työkaluna pyritään selvittämään.

Tutkimuksessa selvitetään myös muilla toimialoilla (lähinnä liikenne ja eräät teollisuuden alat) käytössä olevia tunnuslukuja, jotta jo olemassa olevien hyviä käytäntöjen käyttökelpoisuutta merenkulussa voitaisiin arvioida ja mahdollisesti hyödyntää, joko soveltuvin osin tai niitä edelleen kehittäen. Eräänä malliesimerkkejä turvallisuuden tunnuslukujen käytössä turvallisuusjohtamisessa voidaan pitää lentoliikennettä, jonka järjestelmissä ei turvallisuuteen kohdistuvalle välinpitämättömyydelle ole varaa, ja minkä toiminta on yhtä kansainvälistä ja laaja-alaista kuin meriliikennekin.

Merenkulun yleinen turvallisuus tulisi nostaa parhaiden vertailualojen tasolle.. Ongelmaksi nousee helposti turvallisuustason määrittämisen vaikeudet. Käytössä olevat merenkulun turvallisuuden tunnusluvut ovat osin puutteellisia, mutta koko ongelmakentän laajuuttakin voi olla vaikea hahmottaa. Turvallisuuden arviointi jälkijättöisesti ei riitä. Merenkulkuakin varten tarvitaan nykyhetken turvallisuustasoa ja sen tulevia trendejä mahdollisimman hyvin kuvaavia mittareita. (Ajoneuvoliikenteessä tällaisina työkaluina, muiden joukossa, toimivat esimerkiksi havainnot rikkomuksista, kuten ylinopeus- ja rattijuopumustapausten esiintymistaajuuksista, ja niiden muutoksista.)

Tämän, METKU-hankkeen työpaketti 1:n tarkoituksena on kartoittaa tunnuslukujen käyttöä merenkulussa ja eräillä muilla toimialoilla sekä tuottaa tuloksenaan merenkulkualan turvallisuuden kehittämistyötä koskevia suosituksia. Tutkimuksessa pyritään löytämään ja tuottamaan hyviä ehdotuksia merenkulun turvallisuuden tunnusluvuiksi, joita turvallisuusjohtamisen eräänä työkaluna apuna käyttäen voidaan elinkeinoalan toimintaa ohjata entistä tehokkaammin ja tarkoituksenmukaisemmin sen toimijoiden tahoilla.

Avainsanat - asiasanat (ja luokat)
Turvallisuus, Meriturvallisuus, Tunnusluvut, Onnettomuusmallit, Riski, Riskinhallinta, Turvallisuuden hallinta

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DEFINITIONS

ACCIDENT	An unplanned sequence of events leading to a certain consequence in terms of damage to humans, environment or assets.
BARRIER	Barrier is something that can prevent harm from being caused.
DEVIATION	An act, event, condition or interaction, when the system does not function as planned, being outside a norm. These norms can be: legal, rules or regulations, in a form of a standard, something that is adequate or acceptable, normal or usual, planned and intended [Harms-Ringdahl, 1993]. All deviations do not necessarily have a negative effect [Harms-Ringdahl, 1993].
HAZARD	Something that can cause significant harm. A condition or physical situation with a potential for an undesirable consequence, such as harm to life (or limb), environment or property.
INCIDENT	An unplanned sequence of events with potentially important safety-related effects, which, in the end, are prevented from developing into actual adverse consequences (i.e. an accident) [van der Schaaf, 1992].
RELIABILITY	The probability that an item will perform a required function without failure under stated conditions for a stated period of time. [O'Connor, 2002]
RISK	Risk is the chance of harm in terms of probability and severity of the consequences.
SAFETY	Safety is the state in which the risk of harm to persons or property damage is reduced to, and maintained at, or below, an acceptable level through a continuing process of hazard identification and risk management.
SAFETY CULTURE	The safety culture of an organisation is the product of individual and group values, attitudes, perceptions, competencies, and patterns of behaviour that determine the commitment to, and the style and proficiency of, an organisation's health and safety management [Glendon et McKenna, 1995].
SAFETY PERFORMANCE	Measured outcome of safety efforts, that indicate frequency and severity of incidents in time or in other scale
SAFETY PERFORMANCE INDICATOR	Any measurement that is causally related to the accidents or the risks, used in order to indicate safety performance in prevention, preparedness and/or response, or to understand the process that leads to accidents.
SYSTEM	Entirety of chosen limited scope of interacting factors

ABBREVIATIONS

AIS	Automatic Identification System
ALARP	As Low As Reasonably Practicable
ATM	Air Traffic Management
BA	Barrier Analysis
COLREG	Convention on the International Regulations for Preventing Collisions at Sea
DNV	Det Norske Veritas, a classification society
ETA	Event Tree Analysis
FMA	Finnish Maritime Administration
FMEA	Failure Mode and Effects Analysis
FMECA	Failure Mode, Effects and Criticality Analysis
FSA	Formal Safety Assessment
FSC	Flag State Control
FTA	Fault Tree Analysis
GBS	Goal Based Standards
HOFs	Human and Organisational Factors
HSC	High Speed Craft
IACS	International Association of Classification Societies
IMO	International Maritime Organisation
ISM	International Safety Management (Code)
LL	International Convention on Load Lines
MSA	Marine Safety Agency (in UK)
MTS	Maritime Transport System
PMOU	Paris Memorandum of Understanding
PSC	Port State Control
SMS	Safety Management System
SOLAS	Convention for the Safety of Life at Sea
SPI	Safety Performance Indicator
STCW	Convention on Standards of Training, Certification and Watchkeeping for Seafarers
TKK	Teknillinen korkeakoulu (ex. Helsinki University of Technology)
UK	United Kingdom
VTS	Vessel Traffic Service

PREFACE

This literature study is the first deliverable of the METKU/WP1.

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In Otaniemi, 28.5.2009

1 INTRODUCTION

Safety has often been considered as a critical feature in almost all marine operations. The hostile environment set many challenges not only to the ship itself, as a technical artefact, and the people onboard, but also to the higher levels of safety management. The management of an organization should be arranged to be able to keep sufficient control of the safety and make plans to overcome the hazards, i.e. be prepared for all foreseeable situations that can be encountered and that may possibly cause harm to the organization, to its customers and other stakeholders. The risk should be below the limits set by the regulators and concurrently as low as reasonably acceptable, taking into account the relevant stakeholders.

In order to manage safety in a proper way the top management needs salient information to support the process of decision-making. Sufficient information is needed to identify the problems (if any) in time and planning the actions required and giving orders and allocating premises for the enforcement of them. An efficient safety management system gives sufficient support for the operators to be aware of the state and variations of safety margins. If necessary, the safety management system should be able to react to warning signals to change an adverse development of safety towards the desired direction in a confused variety of different constant and dynamic parameters and more or less easily identifiable trends. In its entirety, safety is a complex concept. The many features of safety, e.g. dynamics, latent errors, human and organizational errors etc., claim for a vigilant, skillful and agile safety management system. To keep all risks in good control is a challenging task for the safety management.

“You can't manage it, if you can't measure it”, is a widely cited slogan (in its different versions). It can be applied also to safety management. Managers may sometimes need to base their decisions on intuition, which helps them to make the required decisions quickly. Time can be critical, so if there aren’t any better groundings, even this basis seems to be acceptable. However, it can also be claimed that pure intuition is not necessarily the best basis for decision-making, if reliable indicators for decision support are available. Good indicators give information of the safety level and of the trends having influence on it or can be developed. “Measurement is an absolute prerequisite for control, whether this be the control of production quality, accidents, or any other component of an industrial system” claims [Rouhiainen, 1990], who refers in this statement to [Johnson, 1980] and [Tarrants, 1963]. Safety management will probably reach its goals more easily, if good safety performance indicators (SPIs) are available and properly used for control and guidance. Therefore, it seems beneficial to develop such indicators in good time.

Every master knows that the navigation of a ship requires observations regarding the sea area ahead of the vessel. The use of lookouts is familiar to most masters and mates. On the other hand, a chief engineer may sometimes need to take a look at the wake of his vessel. Similarly, the use of leading and lagging indicators as a tool of the safety management system onboard, in a shipping company or the maritime administration should not be a totally new idea within this context. These concepts will be discussed later in this paper.

This text presents the ideas behind the use of various safety performance indicators and examples of them that have been developed for use in different modes of transportation and in other industries, e.g. in the offshore industry. One goal of this paper is to start discussion about the applicability of various safety performance indicators for maritime transportation and the possibilities to develop them further in this respect. Most aspects are presented from the standpoint of the administrator. However, as the different stakeholders have different viewpoints, other approaches, e.g. the shipping company’s points of view, have also been included.

2 BACKGROUND

The sea is a very demanding environment exposing a considerable physical risk on ships, their cargo and people onboard. All hazards related to the marine environment are not always easy to keep in mind or to be detected on a calm and sunny day. Experienced and well educated sailors are aware of that the conditions can be quite different e.g. during a winter storm, in a dense fog, in the vicinity of unmarked underwater rocks or in compressive ice. These hazards, and a vast number of other hazards, related to the development and operation of the socio-technical system, must be taken into account in the shipping operations. Risks related to collision, contact and grounding, fire and explosion, capsize and sinking as well as the damage in the categories of cargo, hull and engine are not unknown to the people involved.

All the countermeasures to avoid the risk seem to have created a positive trend in the accident statistics during the last decenniums. The descending trend in accident statistics has been a general phenomenon in the context of various industries as identified by [Duffey et Saull, 2003]. The accident statistics in the years 1968-2007, compiled by the Finnish Maritime Administration [FMA, 2008a], see Figure 1, has a much similar, decreasing nature.

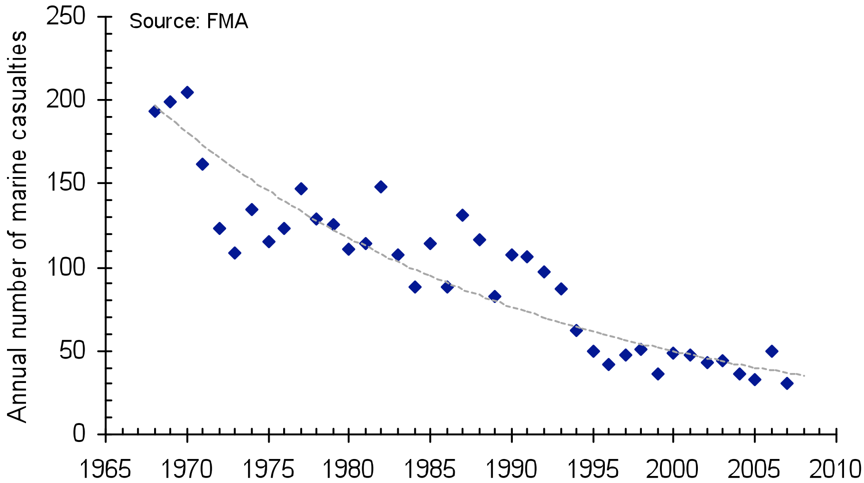


Figure 1 The annual number of marine accidents registered by the Finnish Maritime Administration (FMA)

However, although the trend in national accident statistics above gives a very positive impression of the achievements in safety management, it may not tell the whole truth of the maritime safety in the Finnish waters and their vicinity. Safety is a concept which may easily get endangered. Safety cannot genuinely be improved only by looking to the past and taking precautions against the accidents that have happened [Hollnagel, 2008]. The dynamics and pressures in the system cause changes, which may result in a sudden and unfavorable change in the risks. Such a surprising change to an increase in the number of marine accidents (worldwide) has been reported recently e.g. by [DNV, 2008]. Thus, vigilance and continuous efforts, preferably proactive and sometimes also reactive actions of the safety management are required in order to keep the situation under control.

Maritime safety is governed by the combination of international rules and regulations, national regulations of the flag states and port states, port regulations, rules of the classification societies and insurance companies. International conventions like SOLAS, STCW, MARPOL, LL and COLREG have a very important role in this framework. This regulatory system, which is supported by the Safety Management Systems of the shipping companies, is very complicated due to the many players (and stakeholders) involved, see Figure 2. The line between the actual ship owner, operator or technical manager of the vessel is not completely clear in shipping and therefore complicates enforcement of the legal instruments [Knapp, 2006].

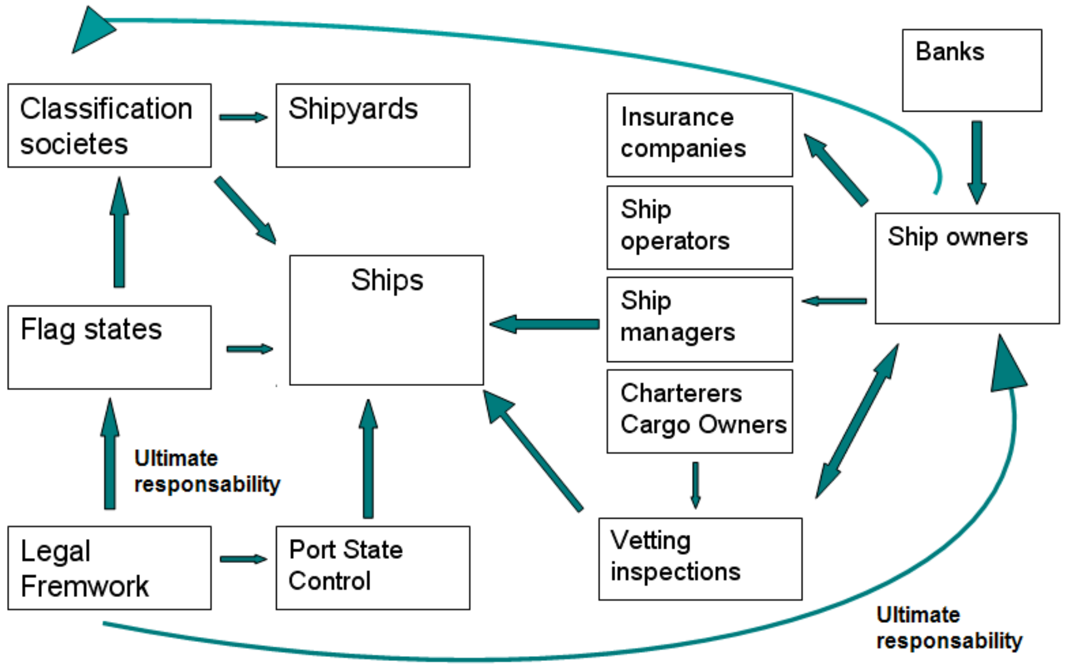


Figure 2 The players of the maritime safety regime in general according to [Knapp, 2006]

Bigger improvements or any modifications to the maritime regulatory system, most often to the specific rules, are most easily carried out after a major accident. Due to this reason some critics claim that the system is "disaster-driven". However, if there would not be any changes in the regulatory system after a major accident, the whole system would be too stable. The accident investigation usually reveals a number of problems in the system so it is natural to react on them. However, a proactive way to proceed would be more fruitful. Fortunately, some development of the regulatory system is going on all the time and there is an emergent trend to apply risk assessments in the safety management. The process of making improvements in international or even national legislation is slow, but it should be remembered that the safety standards are usually just minimum standards. The shipping companies may set their own higher standards, too.

Due to the nature of the international maritime system the safety requirements have been hard to be enforced [Perrow, 1984]. Due to its wide scope and variety the maritime transportation system has always included some loopholes for the so-called sub-standard vessels, the safety records of which have not in general been favorable enough. In many cases economical issues like the manning costs have been named as the most important reason for flagging the vessels out of the owners flag, see e.g. figure 3 [Bergantino et Marlow, 1998].

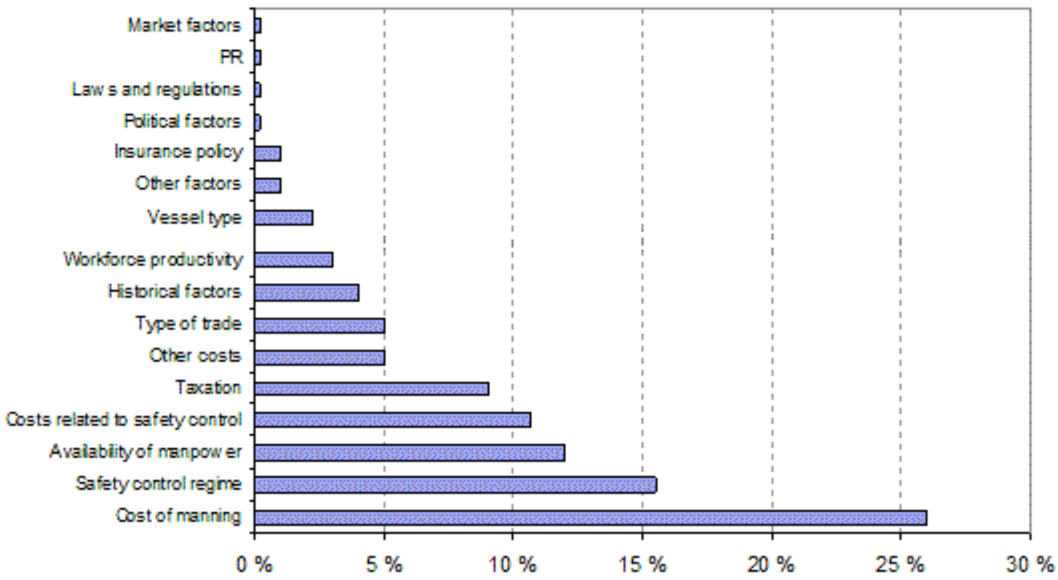


Figure 3 Reasons for flagging out, distribution of answers from questionnaire study (results adopted from [Bergantino et Marlow, 1998]).

Some of the flag states that have been benefitting (and still are making profit) of this phenomenon may not have as strict, well resourced and experienced regulatory system as some other flag states, to fulfill their role to ensure the full accomplishment of internationally agreed standards onboard the ships (and their management) under their flag. The Port State Control is a rather new regulatory system that has been established to handle this problem. Inspectors in one Port State inspect a certain portion of the ships visiting the port(s) of that state, as well as the certificates, the crew onboard, the safety management system, i.e. the conformity to all necessary rules and regulations. If the deficiencies onboard are too gross, the ship may be detained. This system creates lots of useful information related to ship safety, including statistics, see e.g. [PMOU, 2007]. The effects of the Port State Control inspections have been recently discussed e.g. by [Knapp et Frances 2007 and 2008] and [Cariou et al. 2008].

In addition to the inspections of the Port State Control -system, there has been some market for vetting inspections which are performed by private vetting organizations. Vetting inspections have been carried out on oil tankers, chemical tankers and bulk carriers. The vetting inspections create a strong commercial incentive for the ship owner to comply with the vetting inspection requirements since the outcome of these inspections will determine if the ship gets cargo or not [Knapp et Frances, 2007].

The organizations within the maritime transportation sector need to attain a certain minimum level of safety in their operations. In minimum this level is set by the rules of the regulators. However, some pioneering shipping companies have clearly acted for and manifested in their goals and policy to e.g. give a higher priority to the environmental issues with an attempt to exceed the general standards.

E.g. in the case of the car/passenger ferry Estonia the vessel operated around 14 years before the major catastrophe occurred [JAIC, 1997]. Means to reveal the latent factors contributing to this accident were available already in the late 1970's, when the ship was designed and built. Unfortunately, the large area of the car deck susceptible to the danger of free water surface effects was not better protected against flooding.

It is not known if any effective safety performance indicators that could have warned or made an alarm to the top management of the company, when buying the ship and when setting it to operate on the new, more susceptible route, were used. Consequently, the operators of the ship, when navigating the vessel with a major structural weakness, in the environmental conditions that could cause critical damage to it, were probably not well enough aware of the risk involved.

3 SAFETY THEORY – ACCIDENT MODELS AND RISK MODELS

Safety can be described as a state in which the risks are at an acceptable level (or below the limit between acceptable and unacceptable). Thus, in order to be able to give a definition for safety it is useful to define first its counterpoint, risk. Risk is a word that can have many meanings. In this paper we can use the definition adopted from [Manuele, 1997]: Risk is defined as a measure of the probability of a hazards-related incident occurring, and the severity of harm or damage that could result. This harm can be directed to persons (crew/passengers/ others), environment (nature) and/or property (ships/port facilities/other). In some cases the harm may even affect the reputation. According to [Hollnagel, 2008] in practice it is impossible to completely prevent unwanted events completely, so the two approaches (risk and safety) are best used together.

There are several difficulties to observe safety, due to the fact that safety is not an easily observed a directly measurable state. Therefore, indirect measurements, risk assessments, are required for this purpose. Risk fundamentally involves uncertainty [Manuele, 1997]. Thus, it seems to be inevitable that some uncertainty is always involved with safety.

Concept of safety

> *Failures will occur, in spite of the most accomplished prevention efforts. No human endeavour or human-made system can be free from risk and error. Controlled risk and error is acceptable in an inherently safe system. The elimination of accidents (and serious incidents) is unachievable. Failures will occur, in spite of the most accomplished prevention*

Risk and safety analysis/assessments are widely used in hazardous industries. The main targets are usually in preventing (and/or mitigating) unwanted events, such as occupational accidents, major accidents and disasters. These industries (and services) comprise e.g. nuclear power production, chemical industry, offshore industry and the various modes of transport. A typical feature of all these (and some other) industries is that they have an inherent potential to cause large losses.

In order to have the risks under control all hazards should be identified, the risks involved should be assessed and effective risk control options against most remarkable risks developed and also taken into operation. In the FSA-process, which has been applied already in several areas of the maritime industry, cost-benefit analysis has also been included in the phases to ascertain the feasibility of the selected risk control measures. Reliable risk models enabling (quantitative) risk assessments are in the core of this process. However, a premise for the development of such models is that the mechanisms leading to accidents are known.

3.1 Accident models

In order to better understand the opportunities that the safety performance indicators can offer to proactive safety management it is useful to present first a short review of the development of the theory of accidents – accident models. Some accident models can be easily used or are on purpose designed to characterize the nature of the risk that is subjected to the system or to the operation under scrutiny. Thus, accident models can also be used as a basement, when more comprehensive risk models are developed.

Accident model, like any model, is always a simplified representation of reality. It should highlight the most essential characteristics of the phenomenon and reveal its most relevant functions. However, the deficiencies of each model should always be considered and the benefits of a multitude of different approaches are warmly recommended. Therefore, there is a need for several accident models.

The causal relationships in accidents have raised common interest for a long period and e.g. accident statistics with nominated main cause(s) of each accident have been gathered. On the other hand it has turned out that the multitude of contributing factors and the dynamics of the chain of events leading to the accident make it very difficult to disentangle the causal relationships from statistics [Häkkinen et Luoma, 1991].

There is a wide range of different accident models, but a universally-applicable, uniform theory is still lacking [Harms-Ringdahl, 1993], [Manuele, 1997]. Several models have been developed serving different purposes in different frameworks. The extremes of the thinking in the various accident causation models in the papers of a safety-related symposium in the mid-1990s have been outlined by [Manuele, 1997] in the following statements:

- "90 % of accidents are caused by unsafe acts, and the proper solution for them is to modify employee behavior

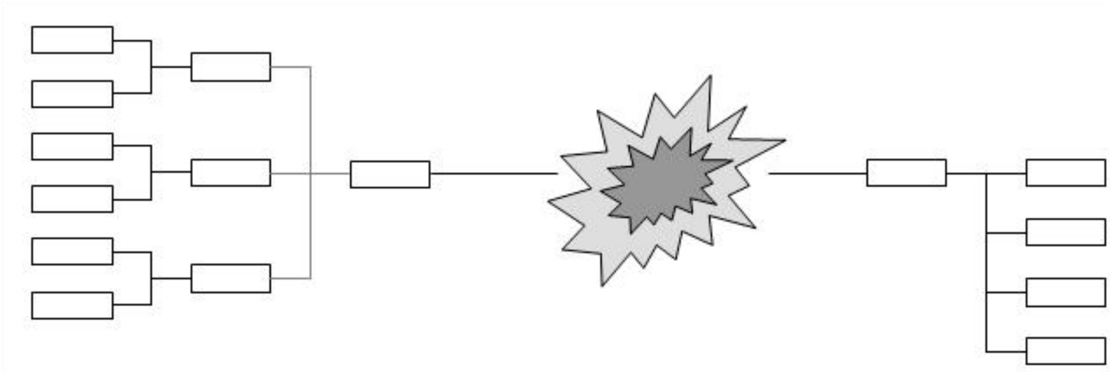
- causal factor for 90 % of accidents are systemic and the proper solution for them is to modify the work system"

The earliest accident "theory" may be represented by the belief that fate, mere chance, or the act of some supernatural force or spirit, is the major causal explanatory factor for accidents. There seems to be nothing to do by the safety management, if these fatalistic theories would be valid. The "Accident-proneness" of the victim was another commonly accepted theory during the early years of the past century.

Three different types of accident models can be distinguished today: a) the *sequential accident model*s, b) *epidemiological accident model*s and c) *systemic accident model*s. The "Domino theory", which is clearly a sequential model, has preceded many current accident models. In the modern versions of this classical model the early part of the causal chain has been stretched from the unsafe act of the "victim" to organizational factors, see e.g. [Kjellen, 2000]. During the development of modern accident models the prevalent victimization of the "accident-prone" persons has been gradually decreased.

Domino theory: One of the earliest accident models of modern times was the "Domino theory" presented by Heinrich already in the 1930's [Heinrich, 1950]. Its core is the chain of multiple events, the Domino-effect which is characterized by the sequence of events following each other. This chain of multiple events ends up to the accident and finally its consequence, e.g. an injury. The early “Domino theory” has been criticized because it does not account for multiple causality [Kjellen, 2000].

Fault tree models were started to be developed in the 1960s. Descriptions of the method are presented e.g. in [Vesely et al, 1981] and [Kumamoto & Henley, 1996]. The fault tree model, see Figure 4a), can be often utilized even for a quantitative risk analysis of the accident probability a complicated technical system if the probabilities of the “failure events” are known. This method, based on the use of AND- and OR-gates [Vesely et al, 1981], is well known and widely applied, but it has been criticized for being difficult to use, see e.g. [Harms-Ringdahl, 1993]. It may not be a suitable model for the analysis of man-machine interaction or for the analysis of the organization [Harms-Ringdahl, 1993].



a) b)

Figure 4a) Fault tree model and b) Event tree model

It has been claimed that more unusual accidents cannot be captured by a fault tree, because there are usually too many conjunctive conditions [EEC, 2006].

Event tree models: A fault tree can often be supplemented by an event tree, which can be described as being the opposite of a fault tree. An introduction to event trees is given e.g. by [Suokas et Rouhiainen, 1993]. An event tree, see Figure 4b), starts from the initiating event and then describes all the possible outcomes of this. It offers possibilities to for carrying out probabilistic estimates of the consequences [Harms -Ringdahl, 1990].

Bowtie models can be built of the combination of a fault tree model and an event tree (or consequence) model, thus it integrates the elements and options affecting on the probability/ frequency of an accident with its outcome. A bowtie model, see Figure 5, demonstrates clearly how a critical event may have several precursors as well as several consequences [Delvosalle et al, 2005]. Thus, it accounts for multiple causality, which can be considered as important feature.

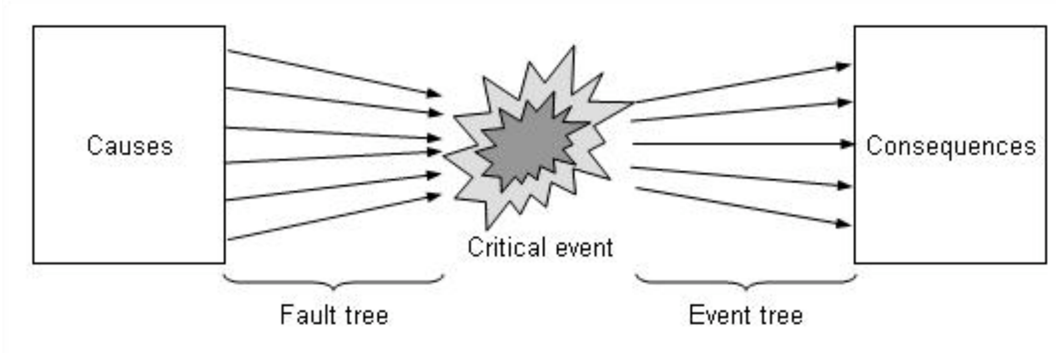


Figure 5 The bowtie model (adopted from [Hollnagel, 2008]).

Energy model can be classified as being an *epidemiological accident model*. It is rooted in epidemiology, representing an effort by the medical discipline to systematize the analysis of accident causes in a way that is similar to the way the causes of diseases are analyzed [Kjellen, 2000]. The core of energy model lies in the fact that the consequences of an accident are always based on the transfer of energy (in one or another form: mechanical, chemical, thermal, electrical, etc.), which is affected by a barrier. The pioneering work with energy model was based on [Gibson, 1961] and this model was developed by [Haddon, 1980].

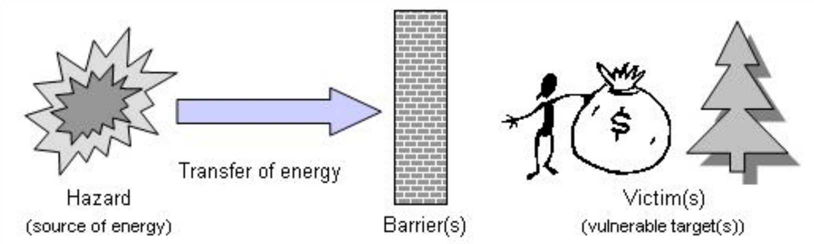


Figure 6 Energy model

The widely used concept of a *barrier*, which protects the target (or victim, usually human life or limb) from the hazardous effects of energy, see Figure 6, is another key concept in the energy model, and has had an important effect on many other accident models too. Different types of strategies that can be applied in the framework of energy models are [Haddon, 1980]: prevention from build-up of the energy, modifying the qualities, limiting the amount, preventing the release, modifying the rate and spatial distribution, separating in time and space, separating by barriers, making the victim more resistant, using counter measures and rehabilitation. A description of different types of barrier systems has been recently presented by [Hollnagel, 2008], who divides them in physical barriers, functional barriers, symbolic barriers and incorporeal barriers. The barrier functions can often be divided in active barrier functions (e.g. a sprinkler system) and passive barrier functions (e.g. a wall), but the classification is not always as simple as these examples picked up by [Hollnagel, 2008].

Bayesian belief network (BBN) is a method that has been developed to improve the understanding of the effects of different causes on the risk [Netjasov et Janic, 2008]. Applications of the use of Bayesian networks as a modeling tool in maritime applications have recently been demonstrated widely, e.g. [Friis-Hansen, 2000] and [Trucco et al. 2008]. The basic idea of establishing dependency of events in a diagram has been naturally used already earlier, see e.g. by [Tuovinen et al. 1983, Appendix 3] and by [Moore, 1994, figures 2-6], but quantitative models of this kind were not as common about 15-25 years ago as today. According to [Friis-Hansen, 2000] one of the main strength of Bayesian networks regarding risk analysis is that they add consistency and transparency to risk models. [Trucco et al. 2008] demonstrated that that the BBN modeling of Human and Organizational Factors (HOFs) can be used in risk analysis to identify further opportunities of risk mitigation acting at the organizational and regulatory level of the Maritime Transportation System (MTS).

In a rather recent document (7 February 2006), submitted to the IMO Maritime Safety Committee [MSC 81/18/1, 2006] by the Japan body of maritime safety, the use of Bayesian Belief Network (BBN) modeling in Formal Safety Assessment (FSA) was suggested as a risk analysis tool, since the complexity of the system cannot be correctly modeled only by a Risk Contribution Tree (i.e. the joint use of FTs and Event Trees).

Other modern accident models: Understanding of the causal factors of an accident with the linkage to human error was greatly improved with the structural division of the human performance on: the skill-based level, the rule-based level and the knowledge-based level [Rasmussen et Jensen, 1974], [Rasmussen, 1980]. Still, modern models also often include the violations, too. A violation can be categorized as a further type of human error, provided that the intention was not to damage the system. The socio-technical approaches developed during the last 20 years do take into account the background of human and organizational errors, see e.g. [Reason, 1990]. The “Swiss-cheese” model used by [Reason, 1990], and adopted in various forms as in Figure 7, has become a classical representation of deficiencies in the safety barriers.

According to the present trend in relevant legislation and regulation the general aim seems to get away from prescriptive rules to performance-centered objectives [Rasmussen, 1997]. This kind of development is in favor of the use of more process-oriented accident models.

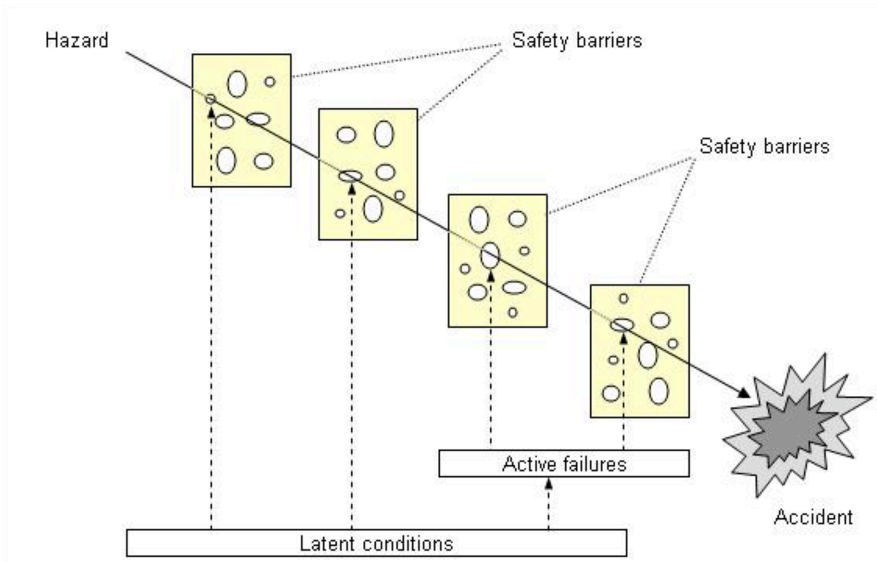


Figure 7 “Swiss-cheese”-accident-causation model adopted from [Reason, 1990].

In a two year old study [EEC, 2006] the background and philosophy of the “Swiss-cheese” –model were discussed in order to describe the suitability and limitations of the model with a reply to some of its critics. The model has been further developed from its origin [Reason, 1990] and the current Mark 3 version of it, see Figure 8, has a changed the appearance of the model significantly. Most of the accident models presented in this chapter, including the two depicted in Figure 7 and Figure 8, are good examples of generic and descriptive models. According to [Reason, 1997] the defects in the safety barriers, the holes in the “Swiss cheese” are not static. Thus, they can either expand or shrink, move, come and go, depending on the local conditions, as a response to operator actions and local demands.

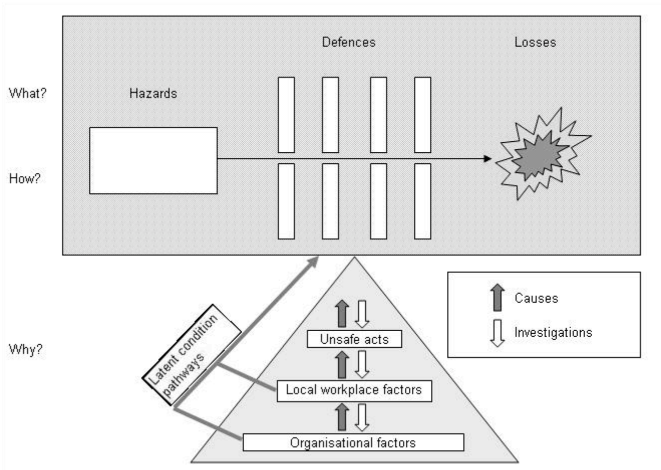


Figure 8 Mark 3 version of the Reason’s accident causation model adopted from [EEC, 2006].

Process models: The process models use time as a basic factor, but, in contrast to causal-sequence models, they make a clear distinction between the accident sequence and the underlying causal or contributing factors [Kjellen, 2000]. A good example of an accident process model, with all its basic elements (hazard, exposure, consequences), is presented in Figure 9. It is noteworthy that the starting point of this model is composed of the deviations and/or the determining factor(s) in the system.

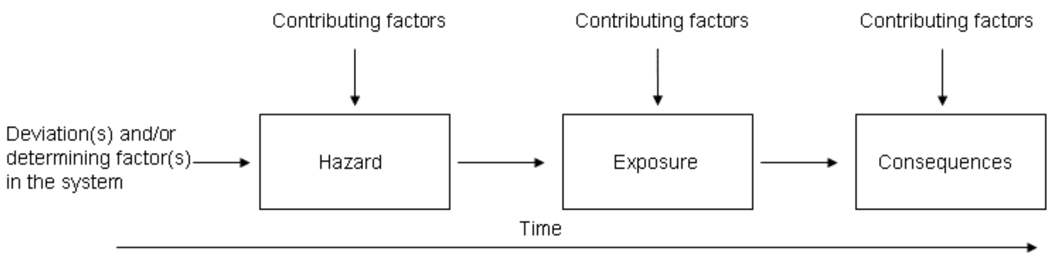


Figure 9 A model of the accident process, adopted from [Rouhiainen, 1990].

Systemic models: One of the latest developments in accident modeling based on this approach is STAMP, the Systems-Theoretic Accident Model and Processes, presented by [Leveson, 2004]. This approach, presented in Figure 10, considers an accident as arising from the interactions between system components and do not look after a single accident cause. The challenge in the use of classic system safety models is to find out what went wrong with the systems operation or the organization when it allowed the accident to take place [Leveson, 2004]. Thus, in the new model the focus is put on the constraints, control loops, process models and levels of control.

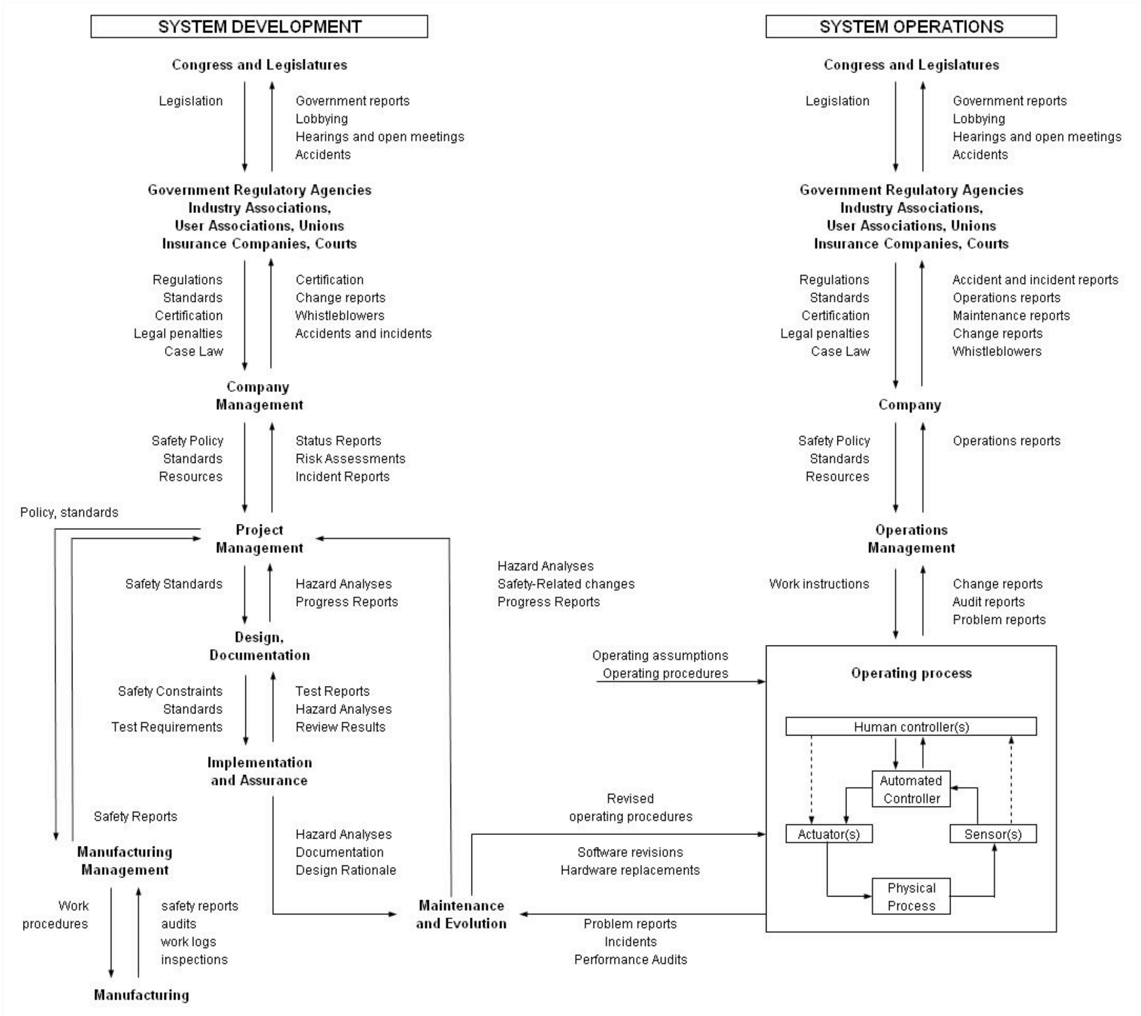


Figure 10 General form of a model of Socio-Technical Control, adopted from [Leveson, 2004].

Most of the accident models presented above serve the generic purpose of offering a means of communication. Some of them can be used for serving as a basis for accident investigation, but only a few accident models may have predictive capability. Predictive models are well suited for proactive safety management.

3.2 Risk models

Risks can be modeled using accident models as a basis, but a sufficient risk model is usually much more comprehensive than a pure accident model. The risk models can be either descriptive, qualitative or quantitative models. Descriptive risk models can in some cases be used to facilitate better understanding of the risk mechanisms and the information needed for more sophisticated qualitative and quantitative risk models. It is important that the risk model includes at least the most important parameters and contributing factors.

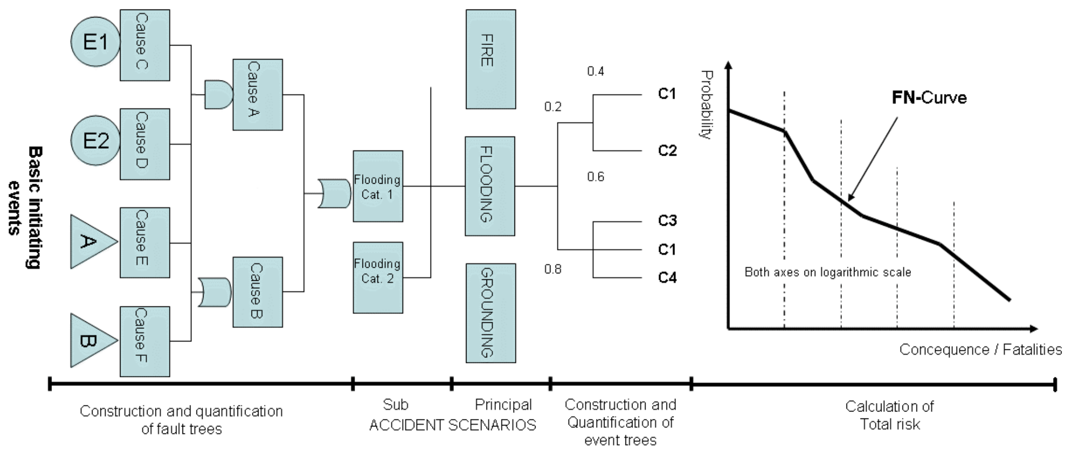


Figure 11 An example of a Risk Contribution Tree, including all types of marine accidents with type specific fault tree and event tree, adopted from [Kristiansen, 2001].

A risk contribution tree can be formed by collecting all relevant risk models together, see figure 11. This kind of tree can be developed either as a qualitative model or as a quantitative model. The latter option is possible if the fault trees and event trees can be equipped with quantitative data related to the risk contributors. Then, the risk contribution tree may be used e.g. for focusing the risk control options to areas, where their impact is greatest and do it in a cost-effective way. The possibilities to improve the outcome, i.e. decrease the probability and or the consequences depend on the stakeholder. A crew member, ship designer, owner of the ship and the administrator do not have similar alternatives available for risk reduction. However, by the use of proper risk models it will be easier to select the best alternative(s) in each case.

Quantitative modeling of the risks requires reliable risk models, preferably based on physical, first-principle modeling, thus producing good numerical estimates for the probability of the accident and also for the consequences. However, if it takes too much effort and a too long time to develop a physical model, expert judgments and statistical data are often used, as shown e.g. by [Rosqvist et al. 1998] and [Vanem et al. 2008]. When quantitative input data for a quantitative risk model is available (or can be obtained) then it is also possible to get quantitative output data, i.e. a numerical assessment of the risk, as a result. The sensitivity of the risk model should be assessed too, and the model should be validated in order to confirm that it is a reliable tool.

Various physical risk models with their background in the modeling of the physical accident process, requiring understanding of the applied methods in engineering sciences, applications of e.g. Finite Element Method (FEM) and Monte Carlo simulations, have been presented during the last five-ten years, see e.g. [Jalonen, 2003] and [Jalonen, 2007]. The results of a risk assessment are often presented in a form of a risk matrix, where both measures (the probability and the consequences) of the risk are easily perceivable.

The consequences, the various types of consequences and the various classes of their severity, are very important when safety (or the risk) is considered. They have also been often taken into account in some safety indicators by utilizing some relevant measure of the consequence. The number of victims, injured persons or lives lost, as well as the number of days out of work (e.g. more than three days) are just some examples. Environmental damage is more difficult to assess, but of course the number of victims is naturally one valid option. The number of endangered species and the area of contaminated soil or even the length of polluted shoreline can be used when assessing the environmental damage. In some cases nonreversible changes to the ecosystem may take place. Fortunately the populations of various species may often able to recover after some time, but the whole ecosystem may change, if some important part of it does not recover. The spoiled opportunities for e.g. fishing or other coastal activities may be assessed in monetary units.

Money is in many cases a well-known measure and the total amount of costs involved are often used when capital or property losses due to accidents are assessed. The material damage may vary from a total loss (or even more) to zero. Explosion in a ship has caused, not only the loss of the ship itself, but significant devastation in the surroundings e.g. in the accident starting from a fire onboard of a ship loaded with dangerous cargo in Texas City in 1947 [Perrow, 1984].

3.3 Formal Safety Assessment

Risk models are in an important role in the process of Formal Safety Assessment (FSA). In order to replace the less rational methodologies in the traditional approach of disaster-driven rule-making, a new, more systematic methodology in rule-making process was introduced to the maritime regulators in IMO by the United Kingdom in 1993 [MSC62/24/3, 1993].

FSA was developed by the UK Marine Safety Agency (MSA) as a response to Lord Carver's report [HoL, 1992]. This report recommended applying a scientific approach safety regulation, based on quantified assessment of risk, on analysis of costs and benefits and on international agreement as to what level of risk is acceptable. In essence, the report recommended a performance based approach to safety aspects in ship design and technology. It also presented a vision of a long term move to a so-called "safety case", which is a widely applied approach to safety in other industries, e.g. the chemical, nuclear and offshore industries. The apparent problems of creating an internationally governed, but still uniform concept of a "safety case" lead MSA to develop the idea further and to apply the same analytical processes to rule-making.

The FSA-concept has been suggested to be evaluated by the Member States. Interim guidelines for performing an FSA application have been published in [MEPC 40/16/Circ. 355, 1997]. Several applications of FSA have been performed, some of which are shortly referred to in the end of this chapter. The guide-lines regarding the FSA-procedure were updated in 2002, when IMO published "Guidelines for Formal Safety Assessment (FSA) for use in the IMO rule-making process" in MSC /Circ.1023-MEPC/ Circ.392 [IMO, 2002]. The latest version of the FSA guidelines [IMO, 2006] includes risk evaluation criteria and an agreed process for reviewing FSAs [Bitner-Gregersen et Skjong, 2009].

Formal Safety Assessment is a risk-based, systematic and sturdy approach to safety management. It is a rather new methodology for rule-making, which applies a scientific approach of thinking. If correctly applied, FSA applications are transparent, traceable and repeatable. Recommendations for rule-making prepared by independent FSA-teams on some area of interest should therefore not be contradictory. FSA acts in a pro-active way: it should put emphasis not only on risks which have lead to accidents, but also on risks which may have severe consequences.

An ideal FSA has been characterized with the following attributes [Skjong, 1998]:

* Well structured, systematic, comprehensive
* Objective, rational
* Auditable, repeatable, well documented
* Defensible, reliable, robust

FSA consists of the following five steps (see Figure 12):

1. Identification of hazards
2. Assessment of risks
3. Generation of risk control options
4. Cost benefit assessment of the risk control options
5. Decision making recommendations concerning the options available

All relevant grounds and arguments, models and data applied by the FSA-team leading to recommendations for decision making in regulatory work should be documented in a systematic way. Thus they can be discussed and, if necessary, revised later, if essential changes in the shipping or its environment take place. The application of FSA should lead to cost-efficiency in rule-making, which probably leads to a better balance in the development of safety even if the funds available for this purpose are limited.

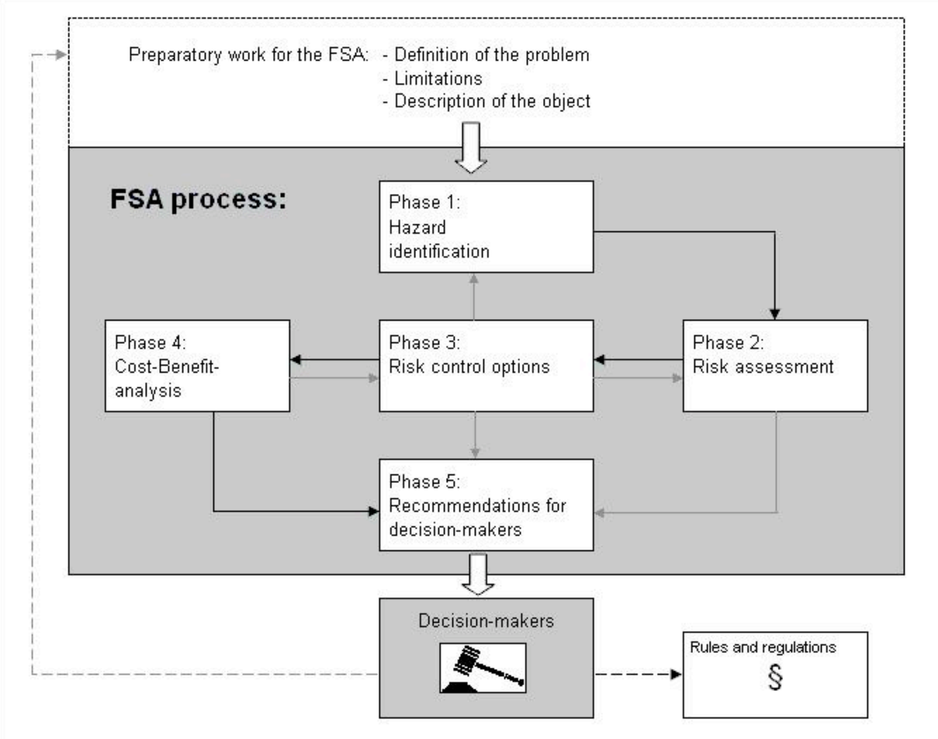


Figure 12 The structure of the Formal Safety Assessment -process. The paths of information flow between various phases are described by arrows. Note! Iterative feedback loops (between phases 1-4) included in this descriptive structural model are an important feature of the FSA-process.

Passenger RoRo ships have been under scrutiny in a FSA-study carried out in a North West European project on Ro-Ro-Safety [NWPERS, 1996] and quite recently in a FSA for ROPAX-ships, which was submitted by Denmark [IMO, 2008a]. In the end of nineties, two trial applications of FSA were performed concerning High-Speed Craft. The first one was submitted by MSA (UK) [IMO, 1997] and the other by Sweden [JNP/HSCO, 1998]. The former concentrated on catamarans, whereas the latter, which was the result of the work of the Joint Nordic Project [JNP/HSCO, 1998] had a wider scope, including monohulls.

The very specific topic of Helicopter Landing Area (HLA) on Passenger Ships was the target of two other FSA-studies [DNV, 1997] and [ICGHLA, 1998]. Bulk carriers have also been studied in many FSA-studies, see e.g. [Lee et al. 2001]. A Formal Safety Assessment for containerships was presented by [Wang et Foinikis, 2001]. Generic AFRAMAX-class oil tankers have been under examination in a FSA-study carried out in the EU-project SAFEDOR [IMO, 2008b] and e.g. in the risk assessments presented by [Cross et Ballesio, 2003].

The guidelines regarding the FSA-procedure were updated in 2002, when IMO published "Guidelines for Formal Safety Assessment (FSA) for use in the IMO rule-making process" in MSC /Circ.1023-MEPC/ Circ.392 [IMO, 2002]. Based on all the other realized Formal Safety Assessments it can be claimed now that the FSA-methodology has been accepted into wide use by the maritime safety researchers and safety practitioners.

Due to the generic nature of FSA it should be clear for everyone that when assessing the safety or risk of a ship on a certain route, or ships in a certain sea area, the local conditions should be taken into account. When applied by this way, the process of carrying out a quantitative risk assessment and the results of it may produce very useful safety performance indicators (SPIs). The reliability of these SPIs depends on the validity of the risk models and the validity data, input parameters and constant values.

It can be stated that those parameters that have the biggest effect on the outcomes are probably the most important safety (performance) indicators. The most important indicators can be found by the use of sensitivity analysis. Any change in these parameters will have either a favorable or unfavorable effect on the risk and safety (unless there is no effect at all). Thus, if there are not any changes present that would necessitate a change of the risk model, the most important input parameters of valid risk models should be used as the safety performance indicators.

4 SAFETY PERFORMANCE INDICATORS

4.1 General

Safety performance indicators (SPIs) are widely used within some safety-critical industries, e.g. nuclear power production. The purpose of using such indicators is to keep track on the trends and developments of safety. Safety performance indicators can be used by the industry itself but also by the authorities, whose responsibility it is to look after that the operation of a plant is safe enough. In these two cases the indicators may be the same, but this may not always be necessarily so. At its best the use of safety performance indicators can give useful support for decision-making regarding risk management and in directing resources aimed for improvements in some specific areas where proactive development is needed.

One of the most easily observed indicators of (deficient) safety today is the number of accidents. Trends in the development of the statistical data based e.g. on the annual number of accidents may in some cases (but not always!) be used as an indicator of the development of the safety. A persuasive example of such a trend was presented in Figure 1. Examples of output indicators (in a nuclear power plant) are: collective radiation exposure to the personnel, number of force power reductions and outages due to internal causes, the frequency of number of events or near misses, number of failures in safety systems, number of scrams [Sandén, 2006].

The general descending trend in the accident statistics within most sectors of transportation and other industries, too, has been clearly demonstrated to follow the mathematical formulation presented e.g. by [Duffey et Saull, 2003]. This general decrease in the number of accidents is based on the lessons learned from the previous accidents, the efficiency and distribution range of the dissemination of this new knowledge. Other important factors affecting the trend are technological changes and changes in the legislation, the latter belonging to a wider framework of sociological changes. If a sociological change, e.g. a new rule is efficiently taken into worldwide use at a time, it may lead to an abrupt change of the accident statistics. A widely reported disaster may have similar effects, but perhaps not on an as sustaining base as in the case of new rules and legislation.

In some cases the indicators cannot be based on statistics. The withdrawal of water from the beaches of Phuket on Boxing day in 2005 was clearly a leading indicator, or a precursor of the tsunami that shortly afterwards hit the people and buildings at the waterfront with full fierce. In this case the earthquake was another, even earlier, single indicator of a tsunami, although generally not as reliable indicator as the other. However, application of both seismology as well as technology has made it possible to build dedicated warning systems against tsunamis. They may not predict a tsunami with a reliability of 100 %, but are still very useful when being able to give an early warning of a significant hazard.

Accidents can often be classified according to their sub-type and on the basis of their consequences. The number of accidents (per time unit) is the simplest type of safety performance indicator. New indicators can be derived from the number of registered accidents, e.g. the number of accidents per some time unit, e.g. one year. Thus, it is possible to obtain the annual frequency of accident occurrence. Other derivatives may include the number of accidents divided by some other characteristic quantity. Such quantities can be e.g. in transport safety the cumulative distance travelled, the number of voyages or the size of the fleet. The exposure (time or some other characteristic parameter) per unit should be somehow included in the derivative (SPI) in order to make them more comparable to similar SPIs elsewhere. In some other industries, the specific type and amount of production defines the quantity by which the number of accidents is divided, e.g. energy in power production. In occupational safety one relevant quantity is the number of individuals and e.g. their time of exposure (to the hazards).

A clear distinction should be made between personal safety indicators (related to occupational safety) and process safety indicators (related to major hazards). The reasonable accentuation between the different types of safety indicators is an important question, due to the difference between various industries, processes, sites, structural arrangements, operations, operators, environments and conditions. An unbalanced portfolio of indicators with too much emphasis on personal (occupational) safety performance indicators may have negative effect on the industry, especially, if this is the case at the expense of process safety in an installation running under the risk of a major accident.

The purpose, effectiveness and reliability should always be considered when selecting the safety indicators. According to [Grabowski et al. 2007] a primary purpose in measuring safety is to develop intervention strategies to avoid future accidents.

The selection of safety performance indicators should be soundly based on an underlying model of safety and the precursor forces that lead to the failures of concern [Wreathall, 2008]. To develop effective interventions (to promote safety), indicators are needed to identify where to direct the limited resources [Körvers et Sonnemans, 2008]. Several indicators are always needed, because focusing just on a single aspect can often be inefficient or even misleading [Mengolini et Debarberis, 2008].

4.2 Leading and Lagging Indicators

According to [Allford, 2008] the development of safety performance indicators is currently a hot topic within the process safety community. A wide compilation of the views of several researchers and practitioners[1] of process safety has been published quite recently with various views regarding the taxonomy [Hale, 2008a]. This interesting debate, consisting of short presentations of individual views on the issue, was initially inspired by an article by [Hopkins, 2008a], discussing the dimensions of leading and lagging indicators.

In the reply to the comments regarding his article [Hopkins, 2008b] highlights the diversity of understandings of leading and lagging indicators. One example concerns the sufficient number of events to make it possible to measure an increase or decrease. According to [Hopkins, 2008b] a single event cannot be counted as an indicator on the selected basis. However, several of his respondents have taken the opposite view by claiming that even **a single warning event** can be described as an indicator. Hopkins admits the possible importance of such weak signals, giving even an example of a single warning event, but keeps strictly to his selected principle: "***indicators are based on a sufficient number of instances to be able to identify change over time***". Thus, [Hopkins, 2008b] defines an indicator as a slope of a trend in time. A partition of leading and lacking indicators as before and after accident indicators, illustrated to Reasons "Swiss-cheese" model, see figure 13, is one of the approaches to simplify and fasilitate understanding of differentials between leading and lacking indicators.

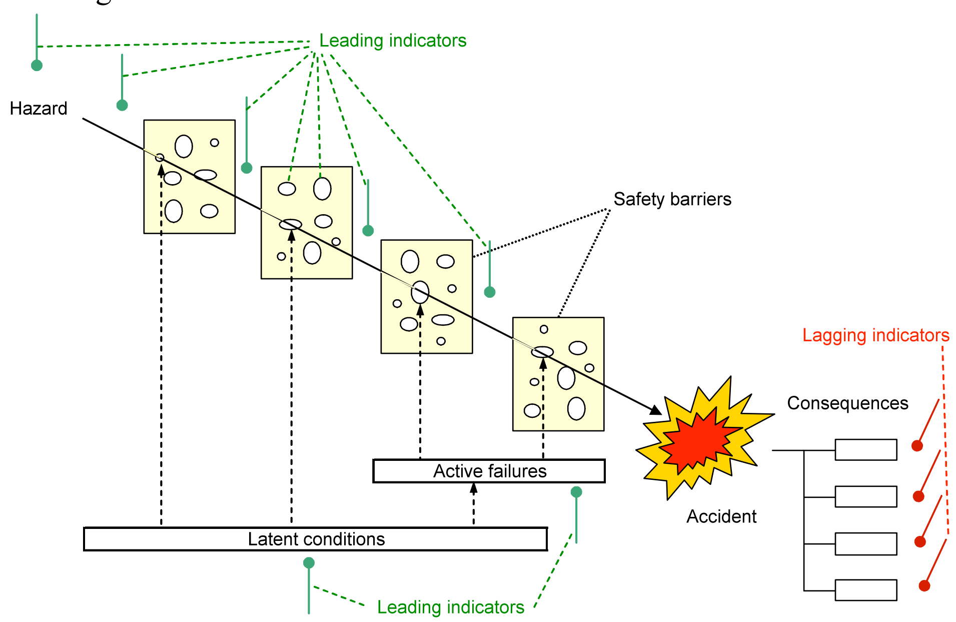


Figure 13 Leading and lagging safety performance indicators in the context of the "Swiss-cheese" accident model of Reason.

[1] This debate was organised by the Safety Science [Hale, 2008a] when comments and views regarding the issues presented in the paper by [Hopkins, 2008a] were asked from several researchers and practitioners of process safety. Short or long replies were presented (in alphabetical order) by: [Ale, 2008], [Allford, 2008], [Bellamy, 2008], [Chaplin, 2008], [Dyreborg, 2008], [Erikson, 2008], [Glendon, 2008], [Grote, 2008], [Hale, 2008b], [Harms-Ringdahl, 2008], [Hodgkinson, 2008], [Hudson, 2008], [Kjellén, 2008], [Le Coze, 2008], [Mearns, 2008], [Webb, 2008], [Woods, 2008], [Wreathall, 2008] and [Zwetsloot, 2008] . A short summary of the diversity in the views was finally presented by [Hopkins, 2008b].

[Hopkins, 2008b] states that the main point of his earlier article [Hopkins, 2008a] was that "*the distinction between leading and lagging indicators is not clear*" and "*it may not be important to make this particular distinction*". However, most of his respondents consider that the distinction is important. [Hopkins, 2008b] states also that it is not helpful to call performance measures, like number of component failures, rates of PPE (Personal Protective Equipment) usage and frequency of walk-arounds, lead indicators or even indicators. He continues by explaining that this is because each one measures how well the particular risk control is performing.

Leading and lagging safety performance indicators have been the topic also in many other recent papers, see e.g.: [Sudgen et al. 2007], [Grabowski et al. 2007], [Körvers et Sonnemans, 2008] and [Mengolini et Debarberis, 2008].

Although the shift of the main focus of some safety authorities from mainly technical aspects to human error and later to safety management and safety culture, i.e. organizational aspects as a whole, can be clearly seen and referred to [Mengolini et Debarberis, 2008], none of the different sectors and levels should be grossly neglected. Due to the many ubiquitous changes in our environment, in society, in technology, and in their interactions, there will always be a need for frequent updates of the information and data of safety critical parameters and indicators. Thus, older models like the one presented by [Tuovinen et al. 1983], see figure 14, may still be valid today. As the potential number of causal factors and their combinations associated in marine accidents is high [Tuovinen et al. 1983], there might still be use for new approaches in marine accident modeling.

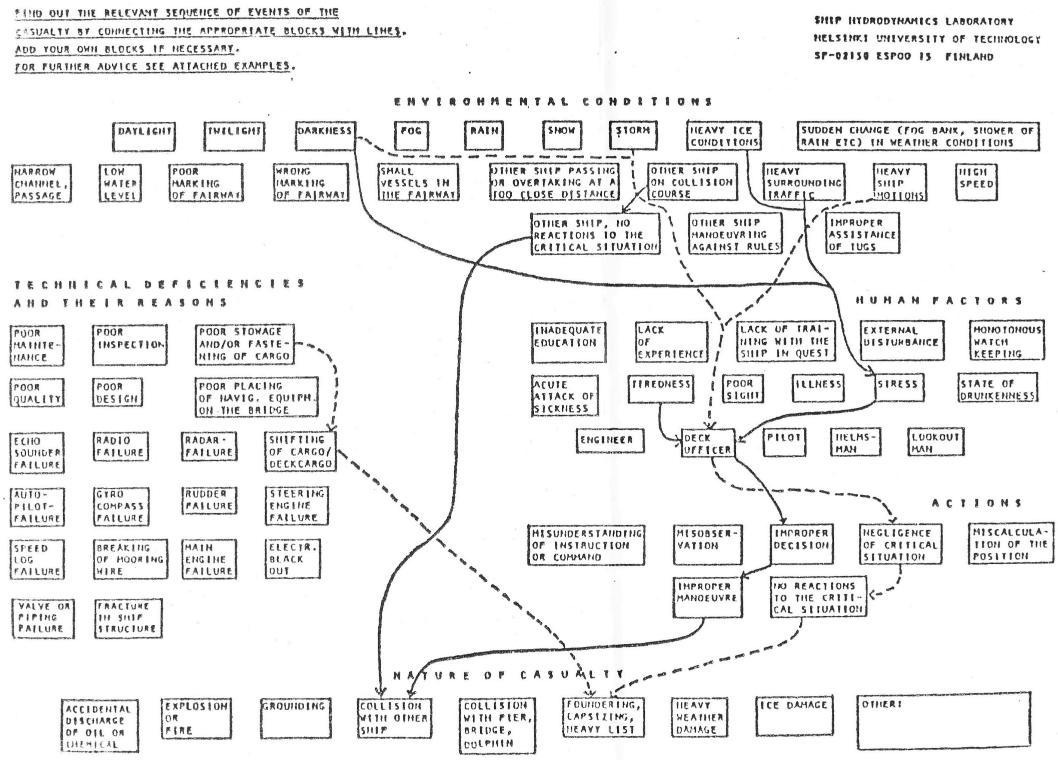


Figure 14 Causal factors associated with marine casualties according to [Tuovinen et al. 1983]. Two examples of causal paths, the sequences of the events leading to a collision and a capsize are presented.

As it has been pointed out e.g. by [Sandén, 2006], both regulators and licensees (in the nuclear energy sector) understand that the use of safety performance indicators, as a tool for evaluating safety at a plant, is only one tool among several others. In safety management there will always be call for various methods for safety assessment. Thus, it can be concluded that both leading and lagging safety performance indicators are needed, but safety management should not be solely based on their use.

Risk contributing factors included in the marine accident database DAMA are presented in the following table 1. Multiple/frequent/concurrent occurrences of these factors in relation to a ship may indicate an increased risk related to its operation.

Table 1 Contributing factors to maritime accidents (adopted from DAMA)

A)	**External factors, not directly related to ship**
A01	Heavy storm, natural catastrophe
A02	Drift or other ship handling difficulties due to wind, current etc.
A03	Collision to a floating object that could not be observed or avoided in time
A04	Failure in external aids to navigation
A05	Failure in sea chart or publication
A06	Technical failure in other vessel (including tugs)
A07	Operational error of other vessel
A08	Technical failure in external cargo loading, unloading or bunkering equipment. A failure in quay, channel lock, or bridge structures
A09	Operational error in operation of cargo loading, unloading or bunkering equipment. An operational error in using port equipment or channel locks.
A10	"Blow-up" or other external conditions in connection to oil drilling.
A11	Difficult ice conditions
A12	Icing on deck structures or deck cargo
B)	**Ship structures and the location of equipment onboard**
B01	Insufficient structural strength of ship
B02	Deteriorated structural strength of ship due to repair welding or other welding work, or due to corrosion
B03	Deteriorated stability of the ship due to the construction
B04	Poor maneuvering characteristics of the ship
B05	Engine room lay-out / location of the equipment has caused a danger of leakage or fire
B06	Poor location or arrangement of the cargo space or store
B07	Poor location or arrangement of other space, not bridge
B08	A difficult space to enter for cleaning, maintenance or inspection
B09	Other conditions connected to ship construction or maintenance
C)	**Technical failures in ship equipment**
C01	Technical failure in navigation equipment
C02	Technical failure in maneuvering equipment
C03	Technical failure in propulsion machinery
C04	Technical failure in auxiliary machinery
C05	Technical failure in anchoring equipment / deck equipment
C06	Technical failure in control devices / remote control devices / automatic control devices / warning systems
C07	Technical failure in cargo handling equipment
C08	Technical failure in redundant systems / safety devices / inert gas system / fire extinguishing system
C09	Technical failure in drilling equipment
C10	Other technical failure
D)	**Issues related to the operation and placement of equipment onboard**
D01	Unpractical design of the bridge, missing or wrongly located devices
D02	Wrong or illogical design or location of controls

D03 Device not located in a suitable place for use
D04 Device unfit / bad / weared / difficult to use
D05 Other factors related to the design / operation of the device. Man-machine interaction problems.

E) Issues related to the cargo / fuel and cargo / fuel handling equipment

E01 Self-ignition of the cargo / fuel
E02 Missing inert gas system / or other fire / explosion prevention system
E03 Stability contrary to the rules (wrong location of cargo, missing ballast etc.)
E04 Defective securing of cargo
E05 Leakage of liquid cargo (barrels, containers, tanks, etc.)
E06 Leakages in cargo or fuel pipes / hoses
E07 Other factor related to cargo or fuel

F) Issues related to communication, organisation, operational instructions and routines

F01 General instructions missing / deficient
F02 General methods of operation unknown / not practiced sufficiently
F03 Safety instructions missing / deficient
F04 Safety instructions known, but not followed
F05 Safety instructions not followed in connection with welding
F06 Welding work lead to fire although safety instructions were followed
F07 Lifesaving equipment testing and exercising instructions not followed
F08 Protective equipment not used
F09 Organisational / instruction / knowledge level too low
F10 Instructions for inspection / maintenance not followed
F11 State of stability not known / ship without accepted stability calculations
F12 Unsuitable methods of leadership, personal problems etc.
F13 Ship or bridge not sufficiently manned (missing helmsman, lookout etc.)
F14 Areas of responsibility or task assignment unclear
F15 Bridge routines non-existing or deficient
F16 Bridge routines not followed
F17 Sea charts / publications not updated
F18 Errors in co-operation / procedures with tugs, shore organisation etc.
F19 Other factors related to organisation, safety regulation, routines or communication

G) Human factors, awareness & assessment of situation, etc.

G01 Insufficient formal competence for duty (training, certifications etc.)
G02 Insufficient practical competence for duty (experience, local knowledge of waters, use of devices etc.)
G03 Task / operation poorly designed (cargo, night navigation, route planning, anchoring etc.)
G04 Available means of getting warning not sufficiently used
G05 Alternative systems for navigation not used. Wrong assessments of navigational lights, lighthouses etc.
G06 Available aids for navigation or publications not sufficiently used
G07 deficient positioning of own vessel, not marked in sea chart
G08 Wrong assessment of other vessel's movements / intentions
G09 Wrong assessment of own vessel's movements (current, wind etc.)
G10 Aim to perform task / operation under non-favourable conditions
G11 Right side of the waterway / channel not used
G12 Excessive situational speed
G13 Sickness, fatigue, overstrain etc.
G14 Falling asleep on the watch
G15 Alcohol or other intoxicating substance
G16 Other cause related to persons

Other factors

ANN Other known reason
UKJ Reason unknown (not announced, impossible to determine etc.)..

4.3 Air Transport Safety and Performance Indicators

Aircraft and aviation differ in many ways from ships and maritime traffic. Long series of aircraft are typically manufactured after type approval, whereas uniqueness is more common in the case of ships. A prototype must be built, tested in trials and accepted before mass production of a new aircraft can be started. However, in the case of a new ship, it is quite often a prototype. Some ship series have been built, but the number of ships is usually much lower than in the case of aircraft. Due to this difference it is much more difficult to apply similar standards on ships. It is normally sufficient for the owner, if the plans, drawings and the final construction can be accepted by the maritime authorities. Ship trials are often arranged, but not necessarily in the same extent as the trials of the prototype of an aircraft. The number of aircraft manufacturers is limited, but the number of shipyards is much larger.

The duration of flights are typically just some hours, whereas the duration of passages across the sea(s) can take days or even weeks. Therefore, the work onboard a ship is in most cases different from the nature of work of other transport modes.

Commercial aviation exercised by big airlines can nowadays be considered as a very safe mode of transportation. Unfortunately, this has not been the case in the beginning of the flights with passengers. Some branches of technology have almost disappeared after a single major accident (e.g. zeppelins after the fire of “Hindenburg” in 6.5.1937 in Lakehurst, USA). Achievement of the current level of safety in aviation has not been cheap, it has required considerable efforts. The developments of the technology and its reliability have been conclusive steps in the improvement of safety.

Another important cornerstone to the favorable development regarding safety in air transportation have been the establishment of good, standardized operational procedures. One example of such a new procedure was the anonymous incident reporting system, established by FAA in May 1975, after a serious accident of TWA flight 514, in December 1974, with a “near miss” event of a UA flight barely escaping a similar accident just six weeks prior to the TWA-case, see e.g. [Ödegård, 2000]. The principles of voluntary and confidential **incident reporting system** with no fear of sanctions made it possible to start a new era of successful safety management, with much better opportunities to acquire more detailed information of human errors.

“Experience has shown that often before an accident occurs, a number of incidents and numerous other deficiencies have shown the existence of safety hazards” [2003/42/EC]. Therefore, “the improvement of the safety of civil aviation requires a better knowledge of these occurrences” [2003/42/EC].

The following list in Table 2 presents the main titles adopted from the Directive of the European Parliament and of the Council on a mandatory system for occurrence reporting in civil aviation [2003/42/EC]. The occurrences to be reported are described in more detail under the titles and subtitles (and sub-subtitles) of Table 2, but even these upper level titles make it more easy to understand the potential benefits of such an information system.

Table 2 Occurrences in civil aviation to be reported according to [2003/42/EC]

A AIRCRAFT FLIGHT OPERATIONS

- i) Operation of the aircraft (28 subtitles)
- ii) Emergencies (9 subtitles)
- iii) Crew incapacitation (2 subtitles)
- iv) Injury
- v) Meteorology (5 subtitles)
- vi) Security (3 subtitles)
- vii) Other occurrences (4 subtitles)

B AIRCRAFT TECHNICAL

- i) Structural (6 subtitles)
- ii) Systems (15 subtitles and 58 sub-subtitles)
- iii) Propulsion (including engines, propellers and rotor systems, and auxiliary power units (16 subtitles)
- iv) Human factors
- v) Other occurrences (6 subtitles)

C AIRCRAFT MAINTENANCE AND REPAIR

- i) Incorrect assembly of parts or components of the aircraft found during an inspection or test procedure not intended for that specific purpose
- ii) Hot bleed air leak resulting in structural damage
- iii) Any defect found in a life-controlled part causing retirement before completion of its full life
- iv) Any damage or deterioration (e.g. fractures, cracks, corrosion, delamination, disponding etc.) resulting from any cause (e.g. as flutter, loss of stiffness or structural failure (3 subtitles)
- v) Any failure, malfunction or defect of any system or equipment, or damage or deterioration thereof found as a result of compliance with an airworthiness directive or other mandatory instruction issued by a regulatory authority (2 subtitles)
- vi) Failure of an emergency system or equipment, including all exit doors and lighting, to perform satisfactorily, including when being used for maintenance or test purposes (2 subtitles)
- vii) Non-compliance or significant errors in compliance with required maintenance procedures
- viii) Products, parts, appliances and materials of unknown or suspect origin
- ix) Misleading, incorrect or insufficient maintenance data or procedures that could lead to maintenance errors
- x) Any failure, malfunction or defect of ground equipment used for testing or checking of aircraft systems and equipment when the required routine inspection and test procedures did not clearly identify the problem, where this results to a hazardous situation

D AIR NAVIGATION SERVICES, FACILITIES AND GROUND SERVICES

- i) Air navigation services (ANS)
- ii) Aerodrome and aerodrome facilities (2 subtitles)
- iii) Handling of passengers, baggage and cargo (5 subtitles)
- iv) Aircraft ground handling and servicing (3 subtitles)

All the titles and subtitles, and the sub-sub-titles not shown, in Table 2 above could be applied as safety performance indicators in the case of civil aviation. However, it should be taken into account that although the list in the ANNEX I of [2003/42/EC] covers the majority of all reportable occurrences, it will not be completely comprehensive.

It can be easily understood that the benefits of the indicators or any near-miss-reporting system depends on the users of the system. If there will be reports, there will be information to be shared and used for further analysis. Otherwise the system will be more or less useless.

In an interesting example from the branch of Air Traffic Management (ATM) Safety Performance [Eurocontrol, 2007], the following issues were considered themselves as indicators of safety performance:
- Level of Reporting
- Under-Reporting

The assessment of these figures may not be easy, but comparisons to well managed organizations can possibly reveal some deficiencies, if the organizations compared operate within the same branch, in comparable environmental conditions and use similar technology.

ECAC ATM Safety Performance Indicators for 2006 [Eurocontrol, 2007] were:

- Accidents -Overall Numbers
- Accident Categories
- Incidents
- General Trends
- Separation Minima Infringements
- Near Controlled Flight into Terrain (Near CFIT)
- Runway Incursions
- Unauthorized Penetration of Airspace
- Aircraft Deviation from ATC Clearance
- Aircraft Deviation from Applicable ATM Regulation
- ATM Specific Occurrences
- Total ATM Specific Occurrences
- Occurrences Related to ATM Support functions
- Achieved Level of ATM Safety in ECAC

The Key Safety Issues were as follows:

Operational Risk Areas
- Runway Incursions
- Unauthorized Penetration of Airspace
- Level Busts
- Near CFIT
- Level of ATS at Aerodromes

Institutional Risk Areas
- National Safety Regulatory Resources

The Finnish Civil Aviation Authority collects data from reported announcements that are collected for analysis, if necessary. In year 2007 it got an announcement of about 1400 hazardous occasions and deviations. Information received is used for clarifying the causes and for looking after solutions in order to avoid such occurrences.

In aviation the use of safety performance indicators based on accident and incident reporting seems to work well. It might be very useful to find out the prerequisites that have been crucial for this favorable state. It is natural that any well operating reporting system and standardized good procedures do not form spontaneously and automatically. They have to be fit for the user needs, both for them who write the reports and for them who use them.

A blame free culture makes it easier to those involved to write reports even of their own mistakes and errors. A well functioning incident reporting system linked with procedures to analyze and discuss the incidents and to find the most feasible ways to cope with them and possibly to seek and find the ways to avoid or eliminate the root causes should be the target also in other means of transportation.

Aviation has been in a lucky position to have a structure and set of stakeholders, standardized elements and operative partners as well as co-operation between them that have all been favorable for the development of such a culture. The variance in operating environments of aviation and maritime transportation differ a lot, but this should not be seen as an obstacle to avoid adopting the best practices of well operating systems, like the incident reporting system, and the basic elements behind it, to areas where their benefits may be even bigger.

4.4 Rail Transport Safety Performance Indicators

In EU an objective has been raised to harmonize the railway sector's safety management systems e.g. by the use of the following Common Safety Indicators (CSI). Based on the EU Directive 2004/49/EC [EU, 2004] the following information shall be reported by the safety authorities:

Table 3 Safety Performance Indicators of Railway Sector adopted from [EU, 2004]

1. Indicators relating to accidents

1. Total and relative (to train kilometers)number of accidents and a breakdown according to those responsible for accidents and according to the following types of accidents:
   - collisions of trains, including collisions with obstacles within the clearance gauge;
   - derailments of trains;
   - level-crossing accidents, including accidents involving pedestrians at level-crossings;
   - accidents to persons caused by rolling stock in motion, with the exception of suicides;
   - fires in rolling stock.

   Only the primary accident shall be accounted for, even if the consequences of the secondary accident are more severe, e.g. a fire following a derailment.

2. Total and relative (to train kilometers) number of persons seriously injured and killed by type of accident ,with a breakdown according to those responsible for accidents and divided into the following categories:
   - passengers (also in relation to total number of passenger-kilometers);
   - employees including the staff of contractors;
   - level-crossing users;
   - unauthorized persons on railway premises;
   - others.

2. Indicators relating to incidents and near-misses

1. Total and relative (to train kilometers) number of broken rails, track buckles and wrong-side signaling failures.
2. Total and relative (to train kilometers) number of signals passed at danger.
3. Total and relative (to train kilometers) number of broken wheels and axles on rolling stock in service.

3. Indicators relating to consequences of accidents

1. Total and relative (to train kilometers) costs in Euro of all accidents where, if possible, the following costs should be calculated and included:
   - deaths and injuries;
   - compensation for loss of or damages to property of passengers, staff or third parties, including damages caused to the environment;

- replacement or repair of damaged rolling stock and railway installations;
- delays, disturbances and re-routing of traffic, including extra costs for staff and loss of good will.

From the costs shall be deducted indemnity or compensation recovered from third parties such as motor vehicle owners involved in level crossing accidents. Compensation recovered by insurance policies held by railway undertakings or infrastructure managers shall not be deducted.

2. Total and relative (to number of hours worked) number of working hours of staff and contractors lost as a consequence of accidents.

4. Indicators related to technical safety of infrastructure

1. Percentage of tracks with Automatic Train Protection (ATP)(1) in operation and percentage of train kilometers on ATP-equipped tracks.
2. Number of level crossings (total and per line kilometer). Percentage of level crossings with automatic or manual protection.

5. Indicators relating to the management of safety

Accomplished internal audits by infrastructure managers and railway undertakings as set out in the documentation of the safety management system. Total number of completed audits and the number as a percentage of required (and/or planned) audits.

6. Definitions

The reporting authorities may use nationally applied definitions of the indicators and methods for calculation of costs when data according to this Annex are submitted. All definitions and calculation methods in use shall be explained in an Annex to the annual report described in Article 18.

As can be seen from the listed items above quite many of them are related to accidents, thus being of lagging character. However, it can be also seen that under the titles 2, 4 and 5 the main emphasis is put on more proactive issues, thus enabling their possible use as leading indicators.

In the early days of railways it was required that a man with a red flag warned all people ahead of the train as an indication of the approaching danger. Today, analogous information is delivered by warning lights and a boom that prevents unsuspecting people to enter into the zone of danger at wrong time. The number of violations, to not take these signals into account is a typical safety indicator of this sector of transportation, where the motion of the conveyance is generally limited to a single degree of freedom.

4.5 Road Transport Safety Performance Indicators

The use of motorized road transport have been under safety regulations practically from the birth of first the automobile. A well known “red flag”-law was passed through in 1865 in Britain to save animals and pedestrians from possible harms of these noisy, unreliable steam-vehicles. The law stated that a man blowing horn and waving a red flag should walk in front of the vehicle to warn of its coming.
Due to the general familiarity of the road traffic to everyone the benefits of the road transport safety performance indicators can be easily understood. The ETSC-report [ETSC, 2001] listed the following four main categories of the Best Practice Road Safety Performance Indicators:

- Behavior (speed, alcohol, seat belts)
- Vehicles (passive safety)
- Road (road design and quality, road network quality)
- Trauma management (arrival time, quality of medical treatment)

The raise of safety awareness in general have not left road transport or traffic uninfluenced. There are many methods that have been used for evaluating road safety as [Dhillon, 2007] points out in his publication. In effect Dhillon shows that as in other fields of safety also in road transport methods like fault tree analysis, Markov method, failure modes and effect analysis etc. have been and are still in use. The problem as pointed also by [Hakkert et al. 2007] is that this multiplicity of different type of indicators causes difficulties in comparing results.

As in many other fields the EU has influenced a lot on latest developments in field of road transport safety. Its 2001 White Paper: “European Transport policy for 2010: time to decide”, EU declared an ambitious plan of halving annual deaths in its member states. One of the leading ideas of this white paper was to harmonize legislations and standards in its member states in able to compare and measure correctly safety development. One of the fruits of this plan is the “Road Safety Performance Indicators”-rapport [Hakkert et al. 2007], which clarifies the SPIs and their use on chosen seven most important activities (table 4) concerning safety on road transport.

Table 4 Road Safety Performance Indicators

Alcohol and drugs
Speed
Protective systems
Daytime running lights
Passive vehicle safety
Roads
Trauma management

These seven activities were chosen by two main reasons: their obvious influence in death toll and because these activities were already been examined by practically all member states, which mean that existing information was comparable. By comparing individual member state records and existing SPIs, Hakkert & al. have been able to construct seemingly efficacy SPI-system for the use of road traffic evaluations. The key point of developing these SPI according to Hakkert & al. is to make them <<more general than direct outputs of specific safety intervention>> and this way to get them more adaptable for future development.

Sweden that is being thought as one of the leaders in safety field adopted 1997 a "Vision Zero" approach to road traffic risks. This vision accepts the fact that accidents happen but, is targeted to minimize death toll and serious injures. Actual improvements in the spirit of "Vision Zero" are for example better separation of lanes heading opposite direction (this way even if the control of the vehicle is lost it will not end up head to head against other vehicle) and reduction in speed limits (hitting a pedestrian 50km/h causes death by more than 80% surety where as with the speed of 30km/h the fatality is less than 10%). This approach apparently has influenced on death toll as Johansson [Johansson, 2008] in his research concludes. Unfortunately the overall cost of this Swedish vision is not been presented, so that efficacy comparison in base of economical view could be discussed.

When comparing road traffic and sea traffic we have to remember few fundamental differences that exist:

In road accident the Trauma management, which is also mentioned as one of the seven important activities by [Hakkert et al. 2007] can make important impact in death toll because the help is normally relatively close i.e. Ambulances, fire department and police are able to arrive to accident scene with in minutes. As for the sea traffic in case of an accident due the distance it may take hours for first help to arrive. In road accidents the average number of people in danger per accident is relatively small while an accident of a Cruiser or ROPAX puts in danger thousands. Which causes the fact that rather than focusing on consequences like "Vision Zero" in maritime safety the diminishing of probability should be the factor of main focus.

One important difference is also the fact that in road traffic majority of movement happens on roads and passages that are well materialized as in sea clear and stable "lane" marking doesn't exist everywhere and even where marked passages exists the nature (wind/storms/currents) may force vessels out of these lanes.

In land it is possible to use indicators gathered by police or other inspecting authorities as in the sea vessel is practically never stopped for surprise inspection to check if voyage is going by the rules (rules of which country is also a open question) , and this generates the lack of information compared to road activity. The importance of this gained information is pointed out by [Hermans E. & al. 2008a/2008b] by two articles concerning the choosing and weighting of chosen SPIs in order to develop a working models of safety issues.

4.6 Maritime Transport Safety Performance Indicators

In maritime environment various hazards and risks have been prevalent for many centuries. Ships and their crews have been lost during storms, sometimes during good weather, too. Experience that has been gathered during the past centuries and the new knowledge, closely related to the results of scientific research have both been utilized in developing today's internationally regulated maritime safety management system.

Best practices of good seamanship have thus developed as a process of evolution. They have now been included in the ISM code, which gives general framework for guidelines related to operational practices. The education of seamen and officers has been based on practical and theoretical education. Long intervals for gathering work experience between promotions has ensured the existence of sufficient experience among the higher ratings, officers and masters. Today, the educational requirements for the crew are included and described in STCW-code. The educational level and experience of the crew might be possible to be described as numerical indicators, but the measurement of real skills and capabilities is a bit more difficult task.

Technical ship safety issues have been handled by improving the regulations related to design in small steps until the ships became safe enough to be able to sail back and forth along the selected routes. In the good old days of sailing ship era the ship systems were seldom, if ever, as complicated as today and extra hands were always available just in case some sailors would have been lost during the long journeys. Although the navigational aids were much simpler and had more limitations than the current integrated systems, they were more easily understood and used, once their principles of operation were learned.

Even though the principle of international shipping, based on the *United Nations Convention on the Law of the Sea (UNCLOS)* is *the freedom of the seas,* some legislation actually reduce it by form of authorized inspections. Due the observed lack of proper inspection by some flag states a *Memorandum of Understanding on Port State Control (MoU)* was signed in 1982 by 19 European states and Canada. This first Memorandum was named Paris MOU and it has been followed by others. [Kristiansen, 2001]

Currently there are ten safety regimes, which cover most of the coastal states, imposing *Port State Controls* (*PSC*). These regimes are [Knapp, 2006] :

- Europe and North Atlantic (Paris MoU)
- Asia and the Pacific (Tokyo MoU)
- Latin America (Acuerdo de Viña del Mar)
- Caribbean (Caribbean MoU)
- West and Central Africa (Abuja MoU)
- Black Sea (Black Sea MoU)
- Mediterranean (Mediterranean MoU)
- Indian Ocean (Indian Ocean MoU)
- Arab States of the Gulf (Riyadh MoU)
- US (US Coast Guard)

All above regimes divide inspection following way [Knapp, 2006]:

- Priority inspections
- Initial inspections
- More detailed inspections in case of "clear grounds", if the inspector feels it is necessary:

Clear grounds are defined by the IMO [Knapp, 2006] as follows:

1. the absence of principal equipment or arrangements,
2. ship's certificates are clearly invalid,
3. certificates are incomplete, not maintained or falsely maintained,
4. evidence from general impression and observation reveals serious hull or structural deterioration that may place at risk the structural, watertight or weather tight integrity,
5. evidence from general impression and observation reveals serious deficiencies in the area of safety, pollution prevention or navigational equipment,
6. master or crew is not familiar with essential shipboard operations relating to the safety of ships or the prevention of pollution,
7. key members cannot communicate with each other,
8. emission of false distress alerts followed by proper cancellation procedures,
9. receipt of a report of complaint containing information that the ship is substandard

Inspection may result in [Kristiansen, 2001]:

- Deficiency: a non –conformity, technical failure or lack of function. A deadline for correction will be given.
- Detention: a serious deficiency or multitude of deficiencies that must be corrected before the vessel is allowed to leave the port.
- Banning: ship having a multitude of detentions or lacking an ISM certificate may be banned from particular waters.

Paris MoU have introduced deficiency codes, see table 5, which have been more or less followed by other regimes, with the exception of US Coast Guard [Knapp, 2006]. This coding system facilitates in finding of critical and repeating lacks, thus the system can be used as a source of performance indicators.

Table 5 Description of Main Deficiency Codes, Adopted from [Knapp, 2006]

Code	Deficiency code description	Code	Deficiency code description
100	Ship's certificates and documents	1600	Radio communications
200	Crew certificates	1700	MARPOL Annex I (Oil pollution)
300	Accommodation	1800	Gas and chemical carriers
400	Food and catering	1900	MARPOL Annex II (Noxius liquids)
500	Working places and accident prev.	2000	SOLAS Operational deficiencies
600	Lfe saving appliances	2100	MARPOL related oper. deficiencies
700	Fire safety measures	2200	MARPOL Annex III (Pack.Harmf.Sub.)
800	Accident prevention (ILO 147)	2300	MARPOL Annex V (Garbage)
900	Structural safety	2500	ISM related deficiencies
1000	Alarm signals	2600	Bulk carriers
1100	Cargo	2700	Security (ISPS code)
1200	Load lines	2900	MARPOL Annex IV (sewage)
1300	Mooring arrangement (ILO 147)	9800	Other def. clearly hazardous safety
1400	Propulsion and auxiliary engine	9900	Other def. not clearly hazardous safety
1500	Safety of navigation		

[Knapp, 2006] shows that Port State Control finds deficiencies on high risk vessels and that vessels with higher number of deficiencies have higher probability of casualty, see figure 15. From the figure 15 it can also be noted that when the number of deficiencies is higher than 10, the casualty probability slightly decreases. This result can be explained by the higher possibility of detention for the sake of multiple deficiencies, and that way more thorough inspection [Knapp, 2006].

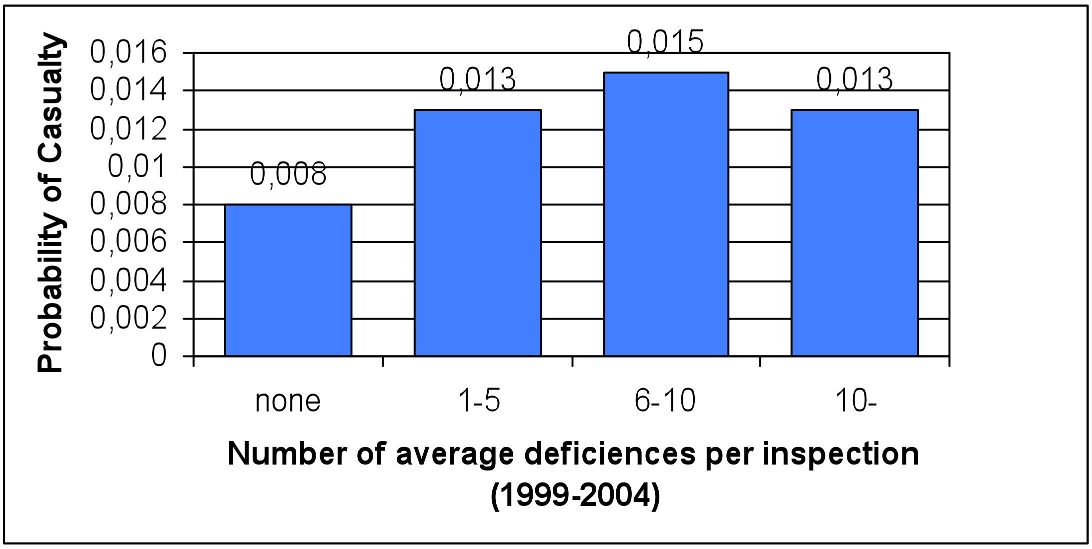


Figure 15 Probability of casualty and number of deficiencies. This figure is based on average estimated probabilities (of approximately 25800 inspected ships) presented by [Knapp, 2006].

According to [Knapp, 2006] 4.9% of PSC eligible vessels that have been inspected with in last 6 moths have an accident. From this, two observations can be made:

- enforcement of corrective actions need to be improved
- correct implementation of safety management should be assured

One of the concerns pointed out by [Knapp, 2006] is that approximately 32% of PSC relevant casualties have the accident first event in engine related areas and in the same time only 9% (Paris MoU, others the same or less) of detentions are made because of engine related areas. This concern may indicate that the efficiency of PSC-system might call for some development in this area. One problem here is that the inspections are normally carried out only when the ships are moored or anchored.

The correlation between the detention percentage (in 1992-1998) in the PMOU inspections and the total loss ratio of various major flag states with more than 50 lost ships can be also found in figure 16. Based on this figure may be estimated that a flag state with zero detention percentage might attain a total loss ratio of about 1-2 total losses per 1000 shipyears, but if the general quality of the ships deteriorates and the detention rate increases, this trend may lead to a considerable increase in the number of total losses.

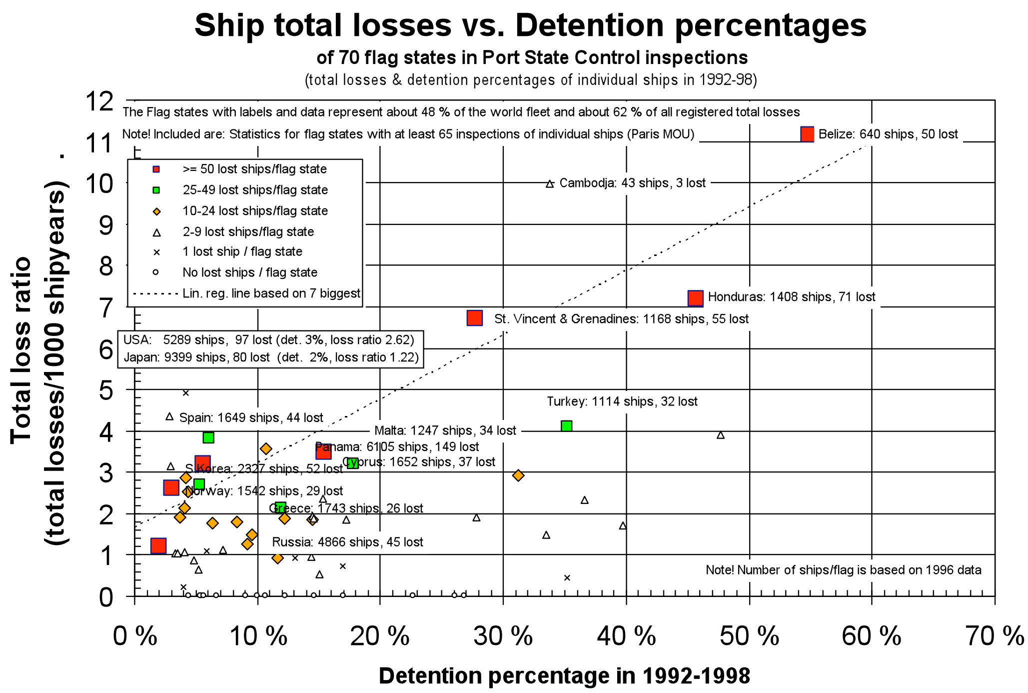


Figure 16 The total loss ratio as a function of detention percentage in PMOU inspections in 1992-1998.

The development of international rules and regulations regarding ship safety has reached a stage where the number of various requirements in the rule books is very high. Requirements for e.g. minimum values for freeboard, intact stability and damage stability have formed a SOLAS-based design envelope within which the design is limited. A good example can be selected from the concept of attained index (A) as well as the required index (R).

The rules often include some features that may set certain restrictions to the design itself or to its performance. Rather recently, new approaches, such as Goal Based Standards (GBS), may give new opportunities for the designers, if it can be approved that a sufficient level of safety can be attained, see e.g. [Papanikolaou, 2009].

4.7 Safety Performance Indicators in Offshore Industry

Offshore industry is often imagined by public as rough and hazardous lottery, where by risking their lives these roughnecks literally pump by their bare hands the oil out of the storming sea. But on contrary of these believes offshore industry have made huge investments to safety and is actually developing better and more safe procedures all the time.

Even though the offshore technology was first used in GOM the safety approach started when Europeans, mainly British, started to develop their own offshore industry in North-Sea during sixties and seventies. The declaration of the Continental Shelf Act 1964 by UK [Gee, 2000] can be considered as the beginning of safety culture in offshore industry. As in many other fields of industry the main developments of acts and rules have followed some severe accidents. Mineral Workings (Offshore Installations) Act 1971, which was the first fully comprehensive statutory instrument for installations on high seas, followed the Sea Gem accident which killed 13 out of 32 persons onboard.

The next step was when the influence of classification societies in offshore business truly started, the UK legislation in 1974 demanded that all installations in UK waters should posses a Certificate of Fitness issued by one of the five authorized Certifying Authorities. [Gee, 2000]

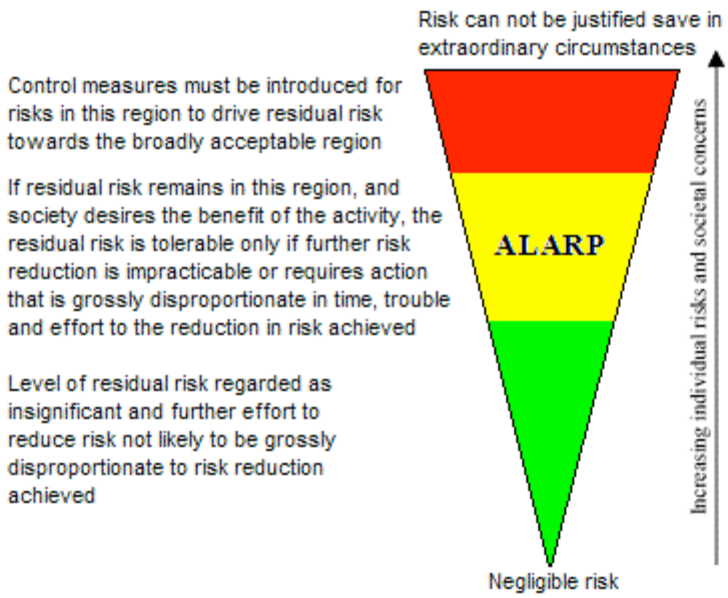


Figure 17 Tolerability of risk framework adopted from [HSE, 2001]

Due the obvious affinity between marine and offshore vessels and installations the beginning of classification in offshore was based largely on existing marine rules. During last three decades national legislations, IMO rules and propositions and classification society's rules have developed from simple "Certification of fitness" regime towards a continuous verification and development regime [Gee, 2000].

Currently all three elements behind safety development (e.g. IMO, Governmental agencies and classification society's) are encouraging the offshore industry towards risk based decision making. HSE[2] Tolerability of Risk (TOR) approach (Figure 17) has been adopted by most of the offshore operators [HSE, 2001].

TOR approach does not how ever force in the use of some particular risk reduction or assessment method. [HSE, 2001] presents a wide but non comprehensive list of methods for risk assessment:

- Hazard identification (HAZID) tools
  - Judgment
  - FMEA-Failure Modes and Effects Analysis
  - SWIFT-Structured What-If Checklist Technique
  - HAZOP-Hazard and Operability Study

- Risk Assessment approach
  - Rules based approaches: regulations, approved codes of practice, Class-Rules
  - Engineering judgment
  - Qualitative risk assessment
  - Semi-quantitative risk assessment
  - Quantitative risk assessment
  - Value-based approaches

- Risk Assessment techniques
  - Qualitative (risk matrix)
  - Semi-Qualitative use of structured tools (fault trees, events trees) – Bow-Tie approach
  - Quantitative risk assessment (coarse and detailed levels)
  - Stakeholder consultations

- Hierarchy of Options approaches for risk reduction
  - Eliminate the hazard
  - Prevent the occurrence
  - Escape, Evacuation, Rescue and Recover

- Decision making
  - Level within organization and tools (design team, senior management, judgment, CBA-Cost Benefit Analysis)

OGP[3] in its workshop report [OGP, 2008] shows that their Lost Time Injury Frequency (LTIF) and Total Recordable Incident Rate (TRIR) have improved (Figure 18.) during the 10 year period of 1996-2005. But they also conclude that even though their collected safety performance data shows improvements in occupational safety and small accidents it does not necessarily prove that any reduction of major incident risk has been made. To get information from which E & P industry could evaluate risks of major incidents and efficiency of different actions on their reducing, OGP report points out the need of agreed Key Performance Indicator (KPI) within E & P.
With in UK sector 3 high level KPI's presenting major incident potential have been adopted:

[2] Health and Safety Executive, UK regulatory body of offshore safety
[3] OGP, International Association of Oil & Gas Producers

- KPI 1: Loss of containment (number of reportable hydrocarbon releases)
- KPI 2: Number of significant non-compliances (uncorrected deficiencies with function, performance or management of defined Safety Critical Elements)
- KPI 3: Production impact from integrity failures

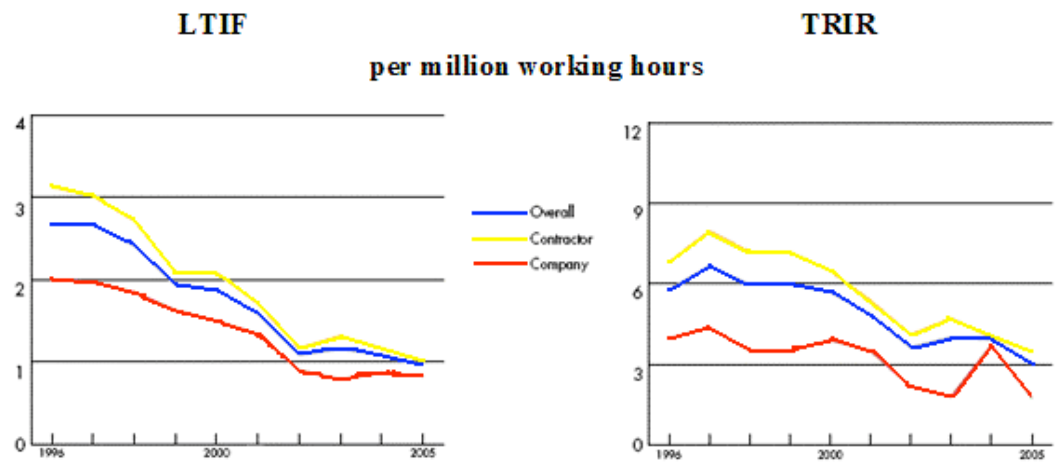


Figure 18 LTIF and TRIR of the E & P industry 1996-2005 adopted from [OGP 2008]

In the same workshop report Statoil presented their own list of performance standards (Table 6.) that could be used for producing limited number of high level performance indicators. [OGP, 2008]

Table 6 Statoil, technical performance standards, adopted from [OGP 2008]

PS1	Containment
PS2	Natural ventilation and HVAC
PS3	Gas detection system
PS4	Emergency shutdown
PS5	Open drain
PS6	Ignition sources control
PS7	Fire detection system
PS8	Blowdown and flare
PS9	Active firefighting
PS10	Passive fire protection
PS11	Emergency power and lighting
PS12	Process safety
PS13	PA, alarm, emergency communication
PS14	Escape and evacuation
PS15	Explosion barriers
PS16	Offshore deck cranes
PS17	Drilling and well intervention
PS18	Ballast system and positioning
PS19	Ship collision barriers
PS20	Structural integrity

E & P industry have already proved that by collecting safety date together it is possible to build a database which can be profited by the hole industry in the common target of a safer working environment. Maritime transport community should take an advantage of adopting same kind of joint data bank as E & P. Of course to do this, a set of common indicators should be developed on the base of maritime transport particularities by the industry.

4.8 Safety Performance Indicators in Nuclear Power Plants

Nuclear Power Plants (NPP) are somewhat in different level of safety expectance than any other branch of industry. Public knowledge and believes concerning possible harms of this particular industry have put it in position of constant surveillance. This situation have made possible that inside the industry it self, a culture of safety have grown. This culture can be seen in Nuclear Energy Agency's (NEA) declaration that: Nuclear safety is <<freedom from physical harm, unreasonable risk and environmental damage due to the operation of nuclear facilities>> [NEA, 2008].

As in other industries the beginning of third millennium have been a period of safety development for the nuclear industry. The Probabilistic Safety Analysis (PSA) which is only just coming in use in most of the other industries is already one of the basis of nuclear safety. The importance of PSA can be seen in Figure 19. PSA exigency in NPP licensing [STUK, 2003].

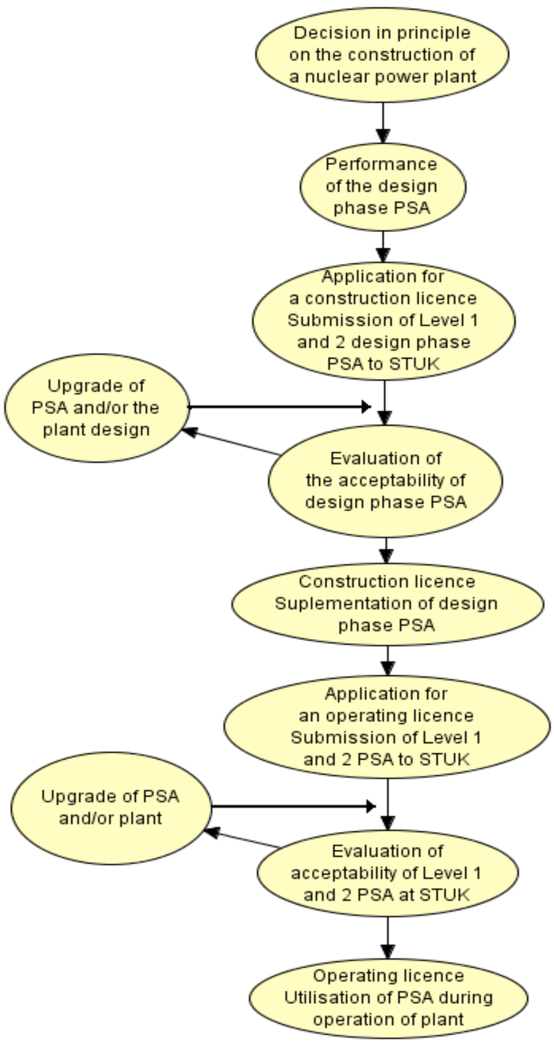


Figure 19 PSA in a licensing of nuclear power plant. Adopted from [STUK, 2003]

SMiRT 17[4] [Chakraborty et al. 2003] in their report criticize that in existing PSAs, generally accepted approach of Management, Organization and Safety Culture (MOSC) effects to safety analysis have not been agreed. In 2007 annual report [STUK, 2008] Finish authorities present their view of indicators concerning safety and quality culture:

"Safety and quality culture is assessed on the basic of information concerning the radiation protection and maintenance of the plant. The operation and maintenance of the plant is monitored using the failure and maintenance data for the components with an effect on the safe operation of the plant, as well as by monitoring compliance with the Technical Specifications. The success of radiation protection is monitored on the basis of the employees radiation doses and radioactive releases into the environment. When assessing the safety and quality culture, attention is also paid to investments to improve the plant and to the currency of the plant documentation."

Indicators used in Finnish NPPs are divided in three sectors, see Table 7 [STUK, 2008]:

Table 7 Safety sectors and indicators of Finnish NPPs. Presented by [STUK, 2008].

A.I Safety and quality culture
1. Failures and their repairs
2. Exemptions and deviations from the Technical Specifications
3. Unavailability of safety systems
4. Occupational radiation doses
5. Radioactive releases
6. Keeping plant documentation current
7. Investments in facilities

A.II Operational events
1. Number of events
2. Direct causes of events
3. Risk-significance of events
4. Accident risk of nuclear facilities
5. Number of fire alarms

A.III Structural integrity
1. Fuel integrity
2. Primary and secondary circuits integrity
3. Containment integrity

One important developer of SPIs in nuclear industry is World Association of Nuclear Operators (WANO) whose indicators [WANO, 2007] (table 8) complemented by other indicators are used worldwide [Chakraborty et al. 2003].

[4] SMiRT, Transaction of the 17th International Conference on Structural Mechanics in Reactor Technology

Table 8 SPIs according to WANO [WANO, 2007].

WANO SPIs 2007
Safety System Performance
Chemistry Performance
Fuel Reliability
Grid-Related Loss Factor
Contract Industrial Safety Accident Rate
Unit Capability Factor
Unplanned Capability Loss Factor
Forced Loss Rate
Collective Radiation Exposure
Unplanned Automatic Scrams per 7,000 Hours Critical
Industrial Safety Accident Rate

The safety in nuclear industry is very much self regulating and self developing which would be a good goal also for maritime transport community. Even though safety indicators are in constant development to be able to recognize new actual threats, certain primary indicators like quantity of technical failures, number of alarms and different kind of accident statistics seem to have stabilized their positions. By observing Finish NPP indicators (table5.) a note could be made that by excluding direct indications to nuclear particularities, one could easily see the same table in use in maritime transport industry. This observation shows that apparently a very general indicator system seems to be also very efficacy: No major NPP accidents have happened since Tšernobyl accident 1986. And last nuclear related death was in 1999 in Tokaimura fuel conversion plant where 2 workers out of 119 exposed of an experiment gone bad, died. In this accident procedures and actions were not developed and used as expected for nuclear activity [IAEA, 1999].

4.9 Safety Performance Indicators in Chemical Industry

In principle it is easy to understand that the features of chemical industry, nuclear energy sector as well as process industry are in general very similar. Thus, many safety performance indicators in chemical industry may have same type of indicators in use as those that are in use e.g. in nuclear power plants. Releases of poisonous substances and exposure to them may have common features with releases of radiation and their consequences in the surrounding population.

Therefore, the safety performance indicators in chemical industry are not discussed here in more detail. Interested readers may get more information on the subject e.g. from references [OECD, 2008a] and [OECD, 2008b].

5 DISCUSSION

It is often useful to make comparisons between some alternatives. Safety indicators in different modes of transportation can be compared with each other but also to the indicators in some other sectors of industry. In some cases the best practices may be easily transferred or modified to serve the needs of another field.

What is important when safety performance indicators are selected in the toolbox of maritime safety management? The indicators should be able to indicate relevant changes in all different areas of maritime transportation having influence on safety. Elements of ship safety should also be included in the portfolio of such indicators.

The traffic intensity, e.g. the frequency of port calls could be one of the indicators. Similarly, the number of passengers and the type and amount of cargo onboard should have some effect on the safety. The proportion of sub-standard ships is for certain an indicator of safety, but it must be remembered that although the age of the ship may have a general diminishing effect on the safety level of ships, there are exceptions, vessels that are kept in good condition regardless of the age. Therefore, some general trends may be more difficult to assess what one would at first glance assume.

History has taught us that many accidents may have had a long series of similar type of incidents before the disaster. Some stakeholders may have reacted to the incident data realizing its significance and carrying out the required actions to avoid the danger, or reduced the probability or the consequences. Unfortunately, in maritime sector the flow of the safety critical information and the execution of required countermeasures has not been ideal [Hänninen, 2007].

The use of technical equipment for measuring traffic density, used routes and nearby accidents should not be overlooked as a possible indicator donor. The Finnish Maritime Administration [FMA, 2008b] has currently underway several research projects evaluating different ways of gathering and using of electronic information given by for example AIS.

It is beneficial to identify safety threats before they realize themselves in an accident. In aviation this led, already several decades ago, to the establishment of well organized systems for collecting and disseminating the information related to incidents and accidents. Similar type of incident reporting systems [INSJÖ] have already been taken into use in Swedish maritime sector, too. If such systems are considered worth of while to be established, as they are, it is utmost important that these systems do not only act as data storages, but an element of a well working system of incident data analysis and synthesis refining the most important information to the levels where the decisions concerning the use of sufficient resources to the required countermeasures can be made.

6 CONCLUSIONS AND RECOMMENDATIONS

In the maritime sector the most widely used safety performance indicators seem to be lagging indicators. Such indicators are most often related to the number of accidents, accident frequencies and the consequences, measured by the loss of life, persons injured, total losses, material damage in terms of costs and environmental damage.

The problem with lagging safety performance indicators is the fact that the approach is reactive. Thus, something bad must first happen to make a change in the indicator. Efficient accident investigations provide us with information regarding the cause(s) and contributing factors related to the accident under scrutiny. This is important to make it possible to avoid similar accidents in the future. However, the problem with accidental losses might be avoided if an efficient information system based on efficient development and use of risk models with significant leading and lagging indicators would be available. Therefore, the development of such a proactive system for the maritime sector should be started.

An ideal safety information system would facilitate analysis and synthesis of data taking into account accident investigation reports, accident statistics, incident reports, developments in science and trends in society, technology and traffic on several levels:
- Global level (internationally)
- EU (PMOU)
- Sea area (Baltic Sea)
- Fleet (of a shipping company)
- Ship type
- Ship
- Stakeholder

It is believed that a solution to the problems might be in systems based on risk models facilitating a less viscous flow of information.

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