Improving ship safety by integrating risk management into the SMS framework and tracking new key performance indicators

Stuart Williams

Maritime Safety Research Centre (MSRC)

University of Strathclyde

Stuart.Williams@Strath.ac.uk

ABSTRACT

Recent well publicized cruise and ferry ship accidents have been a wake-up call to the ship operating industry. These events raise the question of better integration of risk and safety, and using more advanced risk and safety key performance indicators by ship owners. This paper presents the current findings of research underway at the University of Strathclyde's Maritime Safety Research Centre (MSRC) from the author's PhD program. The paper summarizes the development of the current International Maritime Organization (IMO) approach to implementing a Safety Management System (SMS), looks at rail and airline industry's approaches to SMSs and then proposes a new framework for maritime implementation. The focus is on integrating a more holistic (Enterprise) risk management process into the SMS and generating a new set of performance indicators. SMS modelling is accomplished via application of Dr. Nancy Leveson's (MIT) System-Theoretic Process Analysis (STPA) on cruise and ferry operators. The preliminary results from two ship operators are presented. The current state of the art in maritime performance indicators is reviewed. The author proposes an extension of Pareto's 80/20 Rule and Parmenter's 10/80/10 Rule to generate a new set of generic key performance indicators that can be implemented and tracked by ship operators to guide the improvement in safety gained over time.

OVERVIEW

Over the past two and a half years the author has been part of the newly established Maritime Safety Research Centre (MSRC), part of the Naval Architecture Department at the University of Strathclyde. The initial approach was to look at a fairly broad spectrum of cruise and ferry operators and see how mature their holistic or Enterprise Risk Management (ERM) approaches were, and determine whether the companies with a more mature approach to risk management exhibited a corresponding improvement in their safety records. While conceptually this was straightforward, after gathering information from approximately 10 companies, it became clear that their focus was on meeting the requirements in the International Safety Management (ISM) Code and not employing holistic risk.

The ISM Code became mandatory for tankers, bulk carriers and passenger ship operators in 1998. (1) All other ship types had to meet the Code by 2002. Figure 1 summarizes the headings of the various sections in the ISM Code, which has had only fairly minor revisions since its development by the Maritime Safety Committee in the late 1980's and early 1990's.

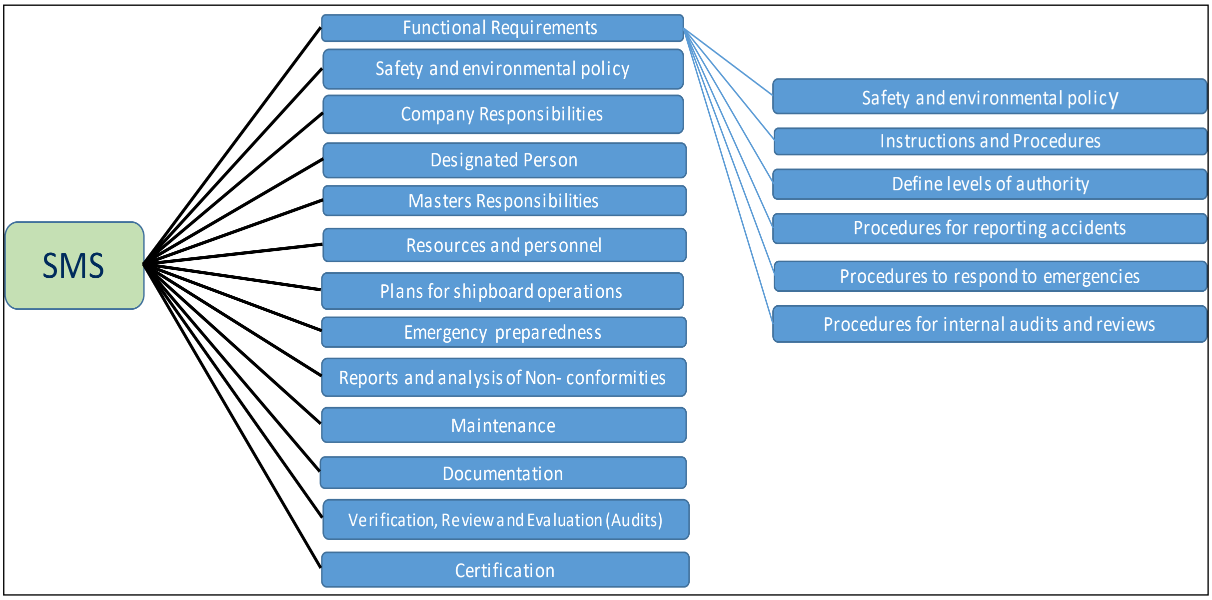

Fig. 1: ISM Code SMS required

Risk management is only mentioned in the Objective Section of the ISM Code, and is not integrated into the requirements set for the SMS implementation.

With this realization, the author's research evolved by studying the implementation of Safety Management Systems (SMSs) in other safety critical transportation industries. Rail and airline approaches were reviewed. In Europe, the European Union (EU) started requiring railroads to implement the use of SMS in 2004. (2) The International Civil Aviation Organization (ICAO), part of the United Nations, began requiring the use of a SMS in 2006. (3) Both the EU railroad requirements and the ICAO airline requirements benefited from the pioneering work done by the IMO. Both include a much more defined integration of hazard and risk procedures into their SMSs. After a review of the required components of the rail and airlines, an extension of the current maritime SMS was developed and used as the template for modelling. This template then served as the framework for assessing the first two ferry and cruise ship company's SMS implementations.

In order to study the functioning of each ship operator's SMS, research was conducted to determine what modelling technique should be implemented to study the performance of the existing systems. Since 2004, Professor Nancy Leveson at the Massachusetts Institute of Technology (MIT) has developed the System-Theoretic Accident Model and Process (STAMP) (4). Basically, this process looks at safety as an emergent property of the complex social-technical control system that ship operations represent.

STAMP assessments via the System Theoretic-Process Analysis (STPA) of each of the cruise and ferry companies were conducted to determine how effective the management barriers, trying to prevent hazardous conditions from accruing, are operating. The controllers, their control actions and the corresponding unsafe control actions are modelled based on each company's SMS implementation. An example of a controller would be the shore side safety managers providing safety alerts and guidance on safety audits to the ships in their control.

Besides defining the requirements that the SMS must address, the ultimate outcome of the STPA process is to generate a set of indicators for each company. These indicators provide insight into measuring the performance of the company in general and the SMS in particular. By analysing several companies a generic set of performance indicators can be created that are useful for any ship operating company.

The concept of Key Performance Indicators was assessed. Recent work by David Parmenter extended the work of the Italian economist Pareto's 80-20 Rule, by creating his 10/80/10 Rule. (5) Parmenter's argument is that the set of indicators should have 10% as Key Performance Indicators (KPIs) and 10% as Key Results Indicators (KRIs). The KRIs have a financial focus. For safety-critical transportation industries like ships, airlines and railroads, the author proposes the creation of key risk and safety indicators.

METHODOLOGY

A review of maritime SMS implementation

The ISM Code provides an outline of what ship operating company's Safety Management System (SMS) must address. (1) Figure 1 contains the outline of the information required. It can be noticed that the maritime implementation of the requirements for a SMS is not organized by functional areas, and certain key elements like hazard analysis and risk management are not directly addressed. General guidance on risk is provided in the Objectives section of the ISM Code. In Section 1.2.2, the following guidance is provided:

> "*Safety management objectives of the company should, inter alia;*
>
> *(1) Provide for safe practices in ship operations and safe working environment;*
> *(2) <u>Assess all identified risks to its ship, personnel, and the environment, and establish appropriate safeguards</u>; and*
> *(3) Continuously improve safety management skills of personnel ashore and aboard ships."*

Part (2) underlined above is the only specific mention of risk management in the regulation, which therefore gives a very broad avenue for interpretation by each ship operator.

Review of the airline and railroad SMS implementation

Figure 2 contains European Union (EU) guidance for implementing safety on rail systems. To see how one country interpreted this guidance, the United Kingdom's Network Rail system's approach to creating its SMS was reviewed.(6) The UK used the EU guidance, with their implementation having an almost identical framework for its SMS. The UK did create a small change by adding a set of Common Safety Methods (CSMs), which provides more specific guidance on risk and monitoring. One of the required areas is risk evaluation and the implementation of risk controls. As reported by the Enterprise Risk Manager (ERM) at Network Rail, Network Rail has a very mature ERM approach and seeking to achieve the highest level (7).

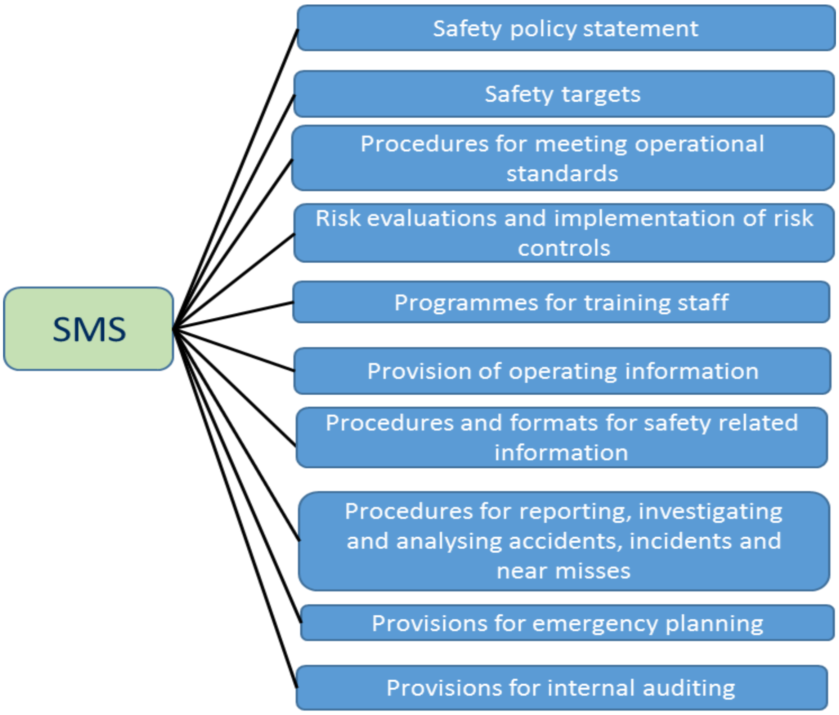

Fig. 2: European Union Railroad safety guidance

In a similar manner, the airline SMS guidance was reviewed. The International Civil Aviation Organization (ICAO) created the first requirement for airline use of a SMS in 2006, eight years later then the maritime implementation requiring the use of a SMS. ICAO's initial implementation benefited from the maritime work, but was much more comprehensive in its guidance. The first issue of the Safety Management Manual (1) provided general guidance in each area with a recommended 10 Steps to follow to implement a SMS. It was not until the 2nd edition in 2009 that the characteristic outline shown in Figure 3 emerged, with the four building blocks for creating a SMS implemented. (8) The second edition was a major re-write, focusing on how to implement and track the usage of airline SMSs. The manual was further improved with updates in 2013 and 2018.

The strength of the guidance in Figure 3 is that it organizes the various functions required for a strong safety management system. Each airline must establish clear safety polices, establish a visible integrated risk approach, measure how well the safety system is working and then train and communicate safety and risk information throughout the company. These high-level functional categories provide a critical and firm foundation to guide the long-term implementation of airline SMSs.

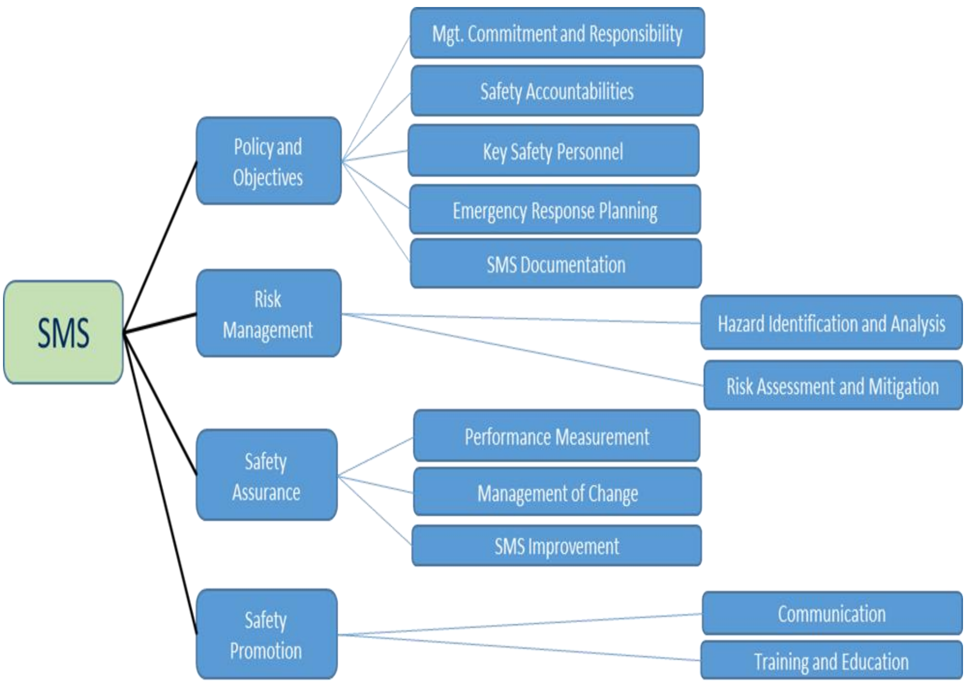

Fig. 3: ICAO SMS

Using the ICAO framework as a guide, a proposed generic SMS for ship operations was developed (Figure 4) which integrates the requirements contained in the marine ISM Code with the functional areas from the airline industry. A crucial aspect is the integration of risk management, hazard analysis and safety assurance as part of the requirements that the SMS must contain.

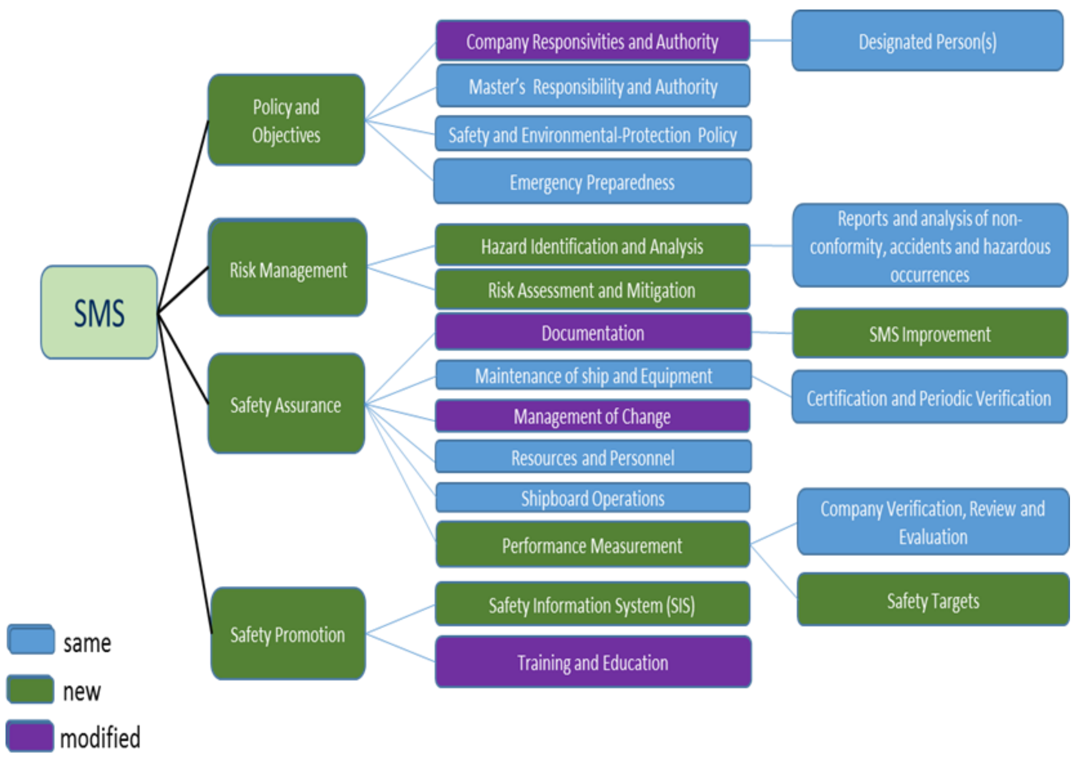

Fig. 4: Proposed Generic SMS for Ship Operators

System-Theoretic Process Analysis (STPA)

The System-Theoretic Process Analysis (STPA) applied is a systems tool, based on STAMP that can be used to analyse organizational structures, like safety management. (9) The process identifies loss scenarios that might cause potential accidents, then generates a set of requirements for safe operations and ultimately a corresponding set of performance indicators. The recent past accident, incident and near miss statistics are then analysed to establish baseline performance. To date, one ferry operator and one cruise ship operator have been analysed.

In STAMP the controllers are the various individuals throughout the structure that implement various safety barriers. For example, at a high level the Chief Executive Officer is responsible for providing the high-level Safety Policy that the company should follow. The Safety Policy is a control action. At a lower level in the organization the shore based ship management team the safety manager insures prompt release of Safety Alerts, another control action.

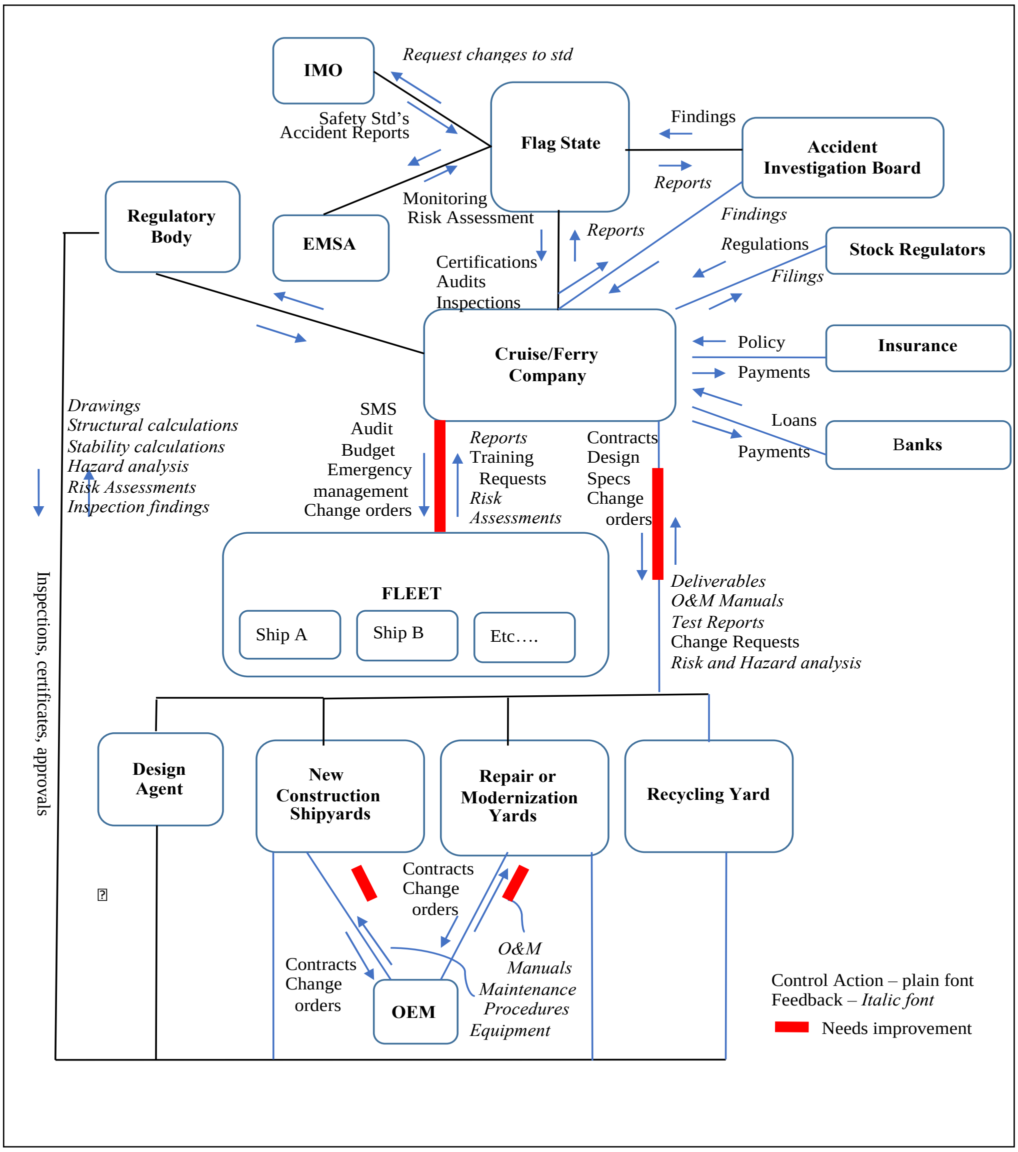

Figure 5: STPA Multi-Layer Control Structure

An example of an Unsafe Control Action (UCA) would be the safety manager failing to issue a Safety Alert, or issuing it late so that a similar problem occurs on another ship in the fleet.

The first step in the process was to create an overarching control diagram that places the ship operator within the entire system that ultimately influences the safe operation of their fleet of ships. Figure 5 captures this environment on one of the companies studied.

In this diagram the Stock Regulators, for publically traded companies, require that the company identify the risks to the company's performance. These risks provide insight in to the health of the company on a yearly basis and should be generated as part of the risk process being used at each company.

In the case of this company, the framework showed missing reports, or feedback documentation that was created to just pass an audit, but did not provide strong control of risks or hazards. The areas highlighted in Red were uncovered as a result of the STPA implementation.

The diagram models the controllers, the controlled processes and the control flows between them (as control actions and feedback). The safety and risk control actions and feedback typically manifest in the form of documents such as standards, manuals, reports, etc. Each of these Control Actions (CAs) creates a set of Unsafe Control Actions (UCAs). The STPA model then analyses these UCAs to determine the loss scenarios, system requirements and corresponding system indicators. STPA assess the functioning of the SMS and generates a set of requirements and indicators that the system should meet and produce, if it is working in accordance with regulations and the company's management approaches. This diagram represents a compilation of the barriers created to prevent unsafe conditions from developing. Since the amount of data generated is fairly large, an Access data base was created to track the information.

Key Performance Indicators (KPIs)

There is a rather large body of research and fair number of commercial products that address the development and use of indicators to try and track performance and improve the safe operation of ships. A search of the literature identified the following providers of systems based on developing indicators to track:

- Baltic and International Maritime Council (BIMCO) (10)
- Tanker Management Self-Assessment (TMSA) (11)
- American Bureau of shipping) as well as other commercial vendors have products that provide a set of KPIs for ship operators to implement (12)

Each of these are based on collecting data on operations and then using some process to filter that data to create meaningful information to manage ship operations. The underlying issue that each of these systems has to grapple with is that each of these processes can generate a large number of KPIs. The term "Key" becomes diminished when hundreds of "key performance indicators" are created and tracked.

ANALYSIS

STPA results

Table 1 summarizes the first two company's STPA findings. With the exception of the number of Controllers, there are similarities exhibited for the number of Control Actions and corresponding Unsafe Control Actions. This probably reflects the fact that each of the company's SMS implementations is patterned after the required number of items that must be included based on the ISM Code.

To understand the type of information generated by the STPA process, Table 2, an excerpt from the STPA Access database, gives an example of the shore based audit team executing an audit of one of the ships in the fleet. Working step wise down through the table shows that even if the Control Action is accomplished, there can be one or more Unsafe Control Actions created. In this case UCA C6-8-1-8 notes that if the audit is conducted, the analysis could be a superficial "check the box" approach which fails to uncover hazards or repeat findings. Based on this a loss scenario was created with a corresponding requirement that when audits are performed they must be of high quality uncovering new hazards and repeat findings.

Table 1 STPA Findings

Function	# Company A	# Company B
Controllers	26	37
Control Actions (CAs)	103	101
Unsafe Control Actions (UCAs)	358	314
Loss scenarios (LSs)	358	314
Safety System Requirements (SSRs)	358	314
Safety System Indicators (SSIs)	274	275

The final step in the STPA process is to generate an indicator that tracks this particular loss scenario. In this case, the number of repeat findings is the indicator that gives a very good assessment of the performance of the complete audit process. In all, as Table 1 shows, there were slightly more than 100 control actions that were generated for each company. The total number of safety system indicators was 274 and 275 for the two companies respectfully. Table 2 has the loss scenario, system requirement and indicator for one Unsafe Control Action. Due to the large number of these factors, each controller was asked to prioritize each loss scenario, system requirement and indicator on a scale of 1 to 3, with 1 being very important, two less and three lesser still. Using this process 61 level 1 indicators were created for Company A and 101 for Company B. The use of subject matter experts helped to focus which factors are most important. This is currently an area of research, especially in the analysing the output of STPA assessments of airline safety management systems. There is recent work trying to address this issue by Karanikas & Chatzimichalidou (13). Their paper proposes the use of continuous values for the behaviour of system components along with a weighing of each component relative to its hierarchical level in the organization

The prioritization process used here is just a first attempt to determine which of the UCAs and their corresponding factors are most important. Additional work is needed in this area.

Table 2 Steps in the STPA process

Control Actions (CA) By Controller – Fleet Operations		
Locator	**Control Action Name**	**Description**
C6-8	Audit	Support of audit analysis

Step 1

Unsafe Control Action (UCA)	
Unsafe Control Action Locator	**Unsafe Control Action Description**
C6-8-1	The audit is conducted, but is a superficial check the box approach that fails to uncover hazards, or repeat findings. [SSH5]

Step 2

List Loss Scenario				
List20	**Locator**	**Priority**	**Loss Scenario Name**	**Description**
C6-8-1	C6-8-1-LS1	1	Audit	Audit is superficial and therefore fails to uncover existing hazards or repeat findings.

Step 3

List Safety System Requirement				
Combo20	**Locator**	**Priority**	**Safety System Requirement Name**	**Description**
C6-8-1	C6-8-1-SSR1	1	Audit	Quality of audits shall be monitored periodically to insure that the breadth and depth of the audit coverage consistently uncovers new and repeat findings.

Step 4

System Indicator					
System Indicator Locator	**Controller Name**	**Priority**	**System Indicator Name**	**Description**	**Unsafe Control Action Locator**
C6-8-1-SI1	Audit Team	1	Audit	Number of repeat findings each review cycle shall be tracked and reviewed monthly.	C6-8-1

Step 5

Stu's (4x5)x80 Rule

The Italian economist Vilfredo Pareto in 1897 hypothesized that there is an 80/20 rule that roughly 80% of an effect comes from 20% of the causes. In his case, he was looking at the fact that 80% of the land in Italy was owned by 20% of the people. Richard Koch (15) extended this approach to the broader concept that worthwhile results come from a small minority of the effort. Using this thought, David Parmenter postulated (5) that of the range of performance indicators, roughly 80% should be tracked and reported lower in the organization, while another 20% are key and should be reported to senior management and the board of directors. For a traditional corporation (non-safety critical) he recommended using 10% Key Results Indicators and 10% for Key Performance Indicators, therefore his 10-80-10 rule. A majority of the result indicators are financial.

Table 3 shows the four key areas that need to be tracked: safety, risk, performance and financial. The initial work at the first two companies in the financial area focused on the safety related aspects of financial indicators. One example was to track the size of the budgets for safety training. Each company had different ideas as to tracking financial indicators and due to just two data points, more work is needed in this area.

Appendix A contains a summary of the characteristics, frequency of measurement and number of measures for each area. In each of the key areas up to a maximum of five parameters could be developed. From the STPA models of the initial two companies researched, this table shows an initial set of generic key metrics developed by combining overlapping results from both companies. These appear to provide real insight into the operation of the company's ships. Over time the number of key indicators in each area will grow and change, but the idea would be to keep each key area to five or less parameters. A much larger number of lower level indicators can be tracked in each category.

Table 3 Example of Stu's (4x5)x80 Rule

a	Metric
Key Safety Indicator (KSI)	Crew retention rate reported weekly
	Number of safety meetings held onboard reported weekly
Key Risk Indicator (KRI)	Percentage of company covered by holistic (enterprise) risk management, reported quarterly.
	Number of new high risks in the risk register reported weekly.
	Total number of incomplete risk assessments should be reported monthly
Key Performance Indicator (KPI)	Percentage of preventative maintenance items completed versus planned reported monthly
	Number of environmental violations reported weekly
	Number of repeat audit findings reported monthly

Key Financial Indicator (KFI)	Passenger advanced booking trend reported daily
	Average monthly vessel cost change per ship, reported monthly
	Percentage change in safety budgets for ship training, reported monthly

Each of these generic indicators captures in one parameter the functioning of a whole set of procedures or processes. For example, the audit indicator tracks the overall performance of the audit system by capturing the number of repeat items found during follow-on audits. If this number starts to increase, it is a very telling flag that the health of the whole audit process is starting to deteriorate.

CONCLUSIONS

Use of STAMP/STPA provides a structured framework to generate a set of indicators that assess how well a current ship operator's SMS is functioning. Using STPA on the first two company's safety and risk management systems provided a system's approach to generating a detailed set of loss scenarios, system requirements and indicators for each companies to use. By utilizing these requirements and indicators, that are linked to known hazards, the effectiveness of the current set of policies and safety management procedures can be tracked over time. Clearly the number of company's modelled needs to be increased validate the benefits of better integration of risk.

The author proposes the creation of a limited number of key indicators, Stu's (4x5)x80 Rule to sharpen the focus on the truly critical key indicators for a safety critical industry like ship operations. While a large number of indicators can be tracked, the key indicators for safety, risk, performance and financial are the ones that will provide the necessary information for the various control layers within the ship operating company to use to improve safety.

WAY FORWARD

This paper raises the prospect of incorporating more aggressive risk and hazard analysis in to the safety management approach used by ship operators. The author spent several weeks as an Intern at the IMO. During this period the 100th Maritime Safety Committee (MSC) meeting took place. The concepts describe here were presented to the Maritime Safety Division and Legal Affairs Divisions at the IMO. A paper is in preparation by one of the member nations to recommend starting work on an update to the ISM Code and will be submitted for consideration at MSC 102. This paper recommends starting work on assessing what changes are needed to the ISM Code. Assuming a working group is established a wide range of changes will be assessed. The recently approved International Standards Organization (ISO) standard on Occupational Health and Safety (14) should provide an excellent source of guidance for the MSC to use in the update of the ISM Code.

In order to assess the impact of better integration of risk management into ship operations, the path forward is to implement the recommended changes at a larger number of ship operators. The first two companies studied are starting the implementation of more aggressive risk and hazard analysis. The results of these implementations will be instrumental in generating the data needed to support the next evolution in maritime safety management.

REFERENCES

(1) International Maritime Organization [IMO]. (2018). International Safety Management (ISM) Code, (5th ed.,p.16), ISBN: 978-92-801-1696-0.

(2) L 220/16, Official Journal of the European Union, 21.16.04, Directive 2004/49/EC

(3) International Civil Aviation Organization [ICAO] Safety Management Manual. (2018). 4th Edition DOC 9859-AN/474), Retrieved from https://rise.articulate.com/share/v5Sm_0DJQvKI51ZQb6HJmBy7bOrhQfTE#/lessons/_5KUx8747VkDIz_znAbNxw_pCdPBQguw.

(4) Leveson, N. (2004). A New Accident Model for Engineering Safer Systems, *Safety Science, Vol. 42, No. 4.* April 2004. Pp. 237-270

(5) Parmenter, D. (2015). Key Performance Indicators, 3rd Edition, ISBN 978-1-119-01984-8

(6) Office of Rail and Road (ORR) The Railways and Other Guided Transport Systems (Safety) Regulations 2006 (as amended) A Guide to ROGS, April 2018

(7) Hunter-Jones, H., (2016). ERM as a Change Initiative at Network Rail, *Enterprise Risk*, Autumn 2016, p.10-13. Retrieved from https://enterpriseriskmag.com/enterprise-risk-magazine/

(8) International Civil Aviation Organization [ICAO] Safety Management Manual. (2018). 4th Edition
(DOC 9859-AN/474), Retrieved from https://rise.articulate.com/share/v5Sm_0DJQvKI51ZQb6HJmBy7bOrhQfTE#/lessons/_5KUx8747VkDIz_znAbNxw_pCdPBQguw

(9) Leveson, N. & Thomas, J. (2018). *System Theroetic Process and Analysis Handbook*, p.133.

(10) BIMCO, (2018). The Shipping KPI Standard, Released 1st January 2018

(11) Tanker Management Self-Assessment (TMSA) Version 3. (2019) Retrieved from https://OCIMF.org

(12) ABS launches new software for vessel efficiency. (2016, Jun 07). *Progressive Digital Media Transportation (Incl Airports, Roadways, Railways, Shipping, Automotive & Logistics) News.* Retrieved from https://search.proquest.com/docview/1794545159?accountid=14116

(13) Karanikas, N. & Chatzimichaidou, M. (2018). The COSYCO Concept: an indicator for Comparing System Configurations, *International Cross-industy Safety Conference (ICSC) 2017*, (*ADV 1*(1) p. 154-174), DOI: 10.5117/adv2018.1.011 Kara.

(14) Nisonger, T. (2008) The “80/20 Rule” and Core Journals, The Serials Librarian, 55:1-2, 62-84, DOI: 10.1080/03615260801970774

(15) International Standards Organization [ISO] Occupational Health and Safety Management Standard, 45001, March 2018, https://www.iso.org/iso-45001-occupational-health-and-safety.html

Appendix A: Summary of indicators

Types of Performance Indicators (PIs)	**Characteristics**	**Frequency of Measurement**	**Number of Measures**
Key Performance Indicators (KPIs) tell staff and management what to do to increase performance across the whole organization	Tells how well the various parts of the organization are performing	Monthly, Quarterly	Up to 5
Performance Indicators (PIs) are targeted measures that track preventative maintenance, environmental releases etc…		24/7, daily, Weekly, Monthly, Quarterly	No more than 20
Key Risk Indicators (KRIs) are based on an enterprise risk process that captures areas that may cause significant problems to the viability of the organization	Risk indicators guide where to focus mitigation efforts to reduce risk	Monthly, Quarterly	Up to 5
Risk Indicators (RIs) are more focused on potential areas that will impact operational safety, environmental issues or financial performance.		Weekly	No more than 20
Key Safety Indicators (KSIs) give a summary of the collective efforts of the various teams in meeting the goal of delivering safe operations	Safety indicators guide where potential unsafe actions may occur	Monthly, Quarterly	Up to 5
Safety Indicators (SIs) provide a sense of how the safety culture is performing		Weekly	No more than 20
Key Financial Indicators (KFIs) give an overview on the company's financial performance	Financial measures provide guidance on the overall performance of the company	Weekly, Monthly, Quarterly	Up to 5
Financial Indicators (FIs) are working level metrics that help guide day to day decision making		Daily, Weekly	No more than 20