Systematic Analysis of Multi-Source Inspection Database via Ship Smart Audit System

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This study proposes a methodology to deeply analyze the multi-source inspection/audit findings gathered from a ship fleet to promote and implement proactive measures systematically. In addition to the ship audit reports of Company-A operating 16 bulk carriers in the Black Sea and the Mediterranean, the multi-source inspection database also consists of benchmarking datasets of different fleets. The Ship Smart Audit System (SSAS), including data collection, causation, analysis and prioritization, and implementation phases, is developed to strengthen the maritime regulatory compliance. Particularly, the Marine Systematic Cause Analysis Technique (M-SCAT), Cognitive Mapping (CM), and Pareto analysis are integrated into methodological background of the study. The SSAS is demonstrated with 5,000 findings from the benchmarking dataset and, subsequently, over 1,900 findings from the Company-A. Then, cause priorities, root cause trends, preventive actions, and audit item preferences are identified as an interconnected process of the ship management company. Consequently, the study encourages maritime executives to increase the effectiveness of pre-inspection and internal audit implementations.

KEY WORDS

~ Ship inspection
~ Smart audit
~ Cognitive mapping
~ Statistical analysis
~ M-SCAT

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e-mail: cptonder@yahoo.com
doi: 10.7225/toms.v11.n02.w01
Received: Jan 12, 2022 / Revised: May 10, 2022 / Accepted: May 17, 2022 / Published online: May 20, 2022

1. INTRODUCTION

In recent years, ship management companies following traditional methods have been experiencing difficulties in achieving and maintaining regulatory compliance. This creates barriers for shipowners to fully implement the maritime regulations. (Chauvin et al., 2013). Between 1980 and 1990, the investigation of several accidents (Batalden and Sydnes, 2014), categorized into fire, collision, grounding, have addressed the loss of lives, environmental pollutions, and economic losses. In these circumstances, the human element has been identified as a predominant factor. Nevertheless, there are also various links among the human errors and the key subfactors such as design, maintenance, training, manning levels, working hours, etc. The increasing level of competition has forced shipowners to reduce operating costs, employ less-skilled labor, and reflag the vessels. (Bhattacharya, 2009). Rather than human element and management strategies, it is another viewpoint to pinpoint the role of construction and equipment in safety and environmental aspects (Anderson, 2003). Indeed, the extensive changes in maritime regulations have been considered as one of critical aspects (Power, 2000). For instance, measuring the effectiveness of safety management system implementations on board ships is a good practice of regulatory change management (Akyuz and Celik, 2014). The increasing numbers of studies on the strengthening of maritime regulations supported with audit practices (Hale, 2003; Tzannatos, 2010; Baldwin, Cave, and Lodge, 2010; Gilad, 2010; Kristiansen, 2013; Reason, 2016) are found in the literature. Besides the ongoing efforts of flag state control (FSC) and port state control (PSC) specific to accident prevention (Fan, Luo, and Yin, 2014), the effects of open register flags (Li and Wonham, 2010) at this point are also argued. Hence, the efficiency of inspections to reinforce the regulations is studied in the literature as the core topic, especially after recognition of New Inspection Regime (NIR) (Chung et al. 2019; Xiao et al., 2020; Yang, Yang, and Teixeira, 2020). The mentioned studies identify the association rules between the encountered defects and different ship characteristics in detail.

At this insight, the limited studies mainly address the analysis of accidents, deficiencies, and various findings using advanced algorithms. One of the most remarkable contributions by researches (Fu et al., 2020; Yang, Yang, and Teixeira, 2020) is to adapt Apriori algorithm to ship deficiency investigation problem. Moreover, a novel algorithm based on Bayesian network (BN) combined with Greedy Thick Thinning (GTT) was proposed to determine the relationships between ship characteristics and accident cases (Fan et al., 2018; Knapp and Franses, 2010). The study claims that the probability of accidents is greatly reduced by good inspections. Hänninen and Kujala (2014) developed a safety management model, supported with BN-NPC, which links the encountered deficiencies to accident data to identify opportunities for safety improvement (Hänninen and Kujala, 2014). In the literature, there are also more advanced studies (Zhang and Thai, 2016; Ventikos, Sotiralis, and Drakakis, 2018; Demirci and Cicek, 2022) on the use of the inspection findings in prediction. The studies (Celik and Cebi, 2009; Akyuz and Celik, 2014; Soner et al., 2015), investigating accidents and deficiency reports, recommend solutions from the human factor perspective.

Nevertheless, the lack of studies on smart inspection solutions draws attention. Broadly, auditing is recognized as a systematic, independent, and documented process (ISO 2011). The audits can be organized in the form of first-party inspection, second-party inspection, third-party inspection (ISO 2011). Particular to maritime industry, internal audit, charter inspection, and flag state inspection can be exemplified. In ship management companies, the Safety Management System (SMS) is being audited in accordance with the policies, procedures, practices, etc. (Saunders, 1992). It duly covers the potentials of shore-based management activities, shipboard shore-based communication and the ship operational performance. A systematic approach is still needed for the ship audit mechanism to work effectively.

This study develops a Ship Smart Audit System (SSAS) to strengthen the maritime compliance. The first section reviews the existing studies on ship inspection analysis and explains the critical points open for development. The next section provides the methodological background. Then, a case study on a multi-source database is conducted. Finally, the concluding remarks and future research agenda are given.

2. METHODOLOGICAL BACKGROUND

2.1. M-SCAT

Root cause analysis methods are used in all industries as well as in specific areas. Specific to maritime industry, Marine Systematic Cause Analysis Technique (M-SCAT) was introduced by DNV-GL (DNV-GL, 2015). M-SCAT is a systematic structure to conduct the analysis of accidents, deficiencies, and hazardous occurrences on board ships. It has been used as a useful and comprehensive tool to perform the step-by-step analysis in order to identify the probable causes leading to an event. The M-SCAT framework covers substandard acts, substandard conditions, personal factors, and job/system factors. This study adapts the M-SCAT into multi-source inspection database to initially identify the causes of deficiency findings.

2.2. Cognitive Mapping (CM)

Cognitive mapping (CM) is used to determine the critical sub-elements that affect the main elements of a problem. The technique visualizes a meaningful map. It ensures that certain problem areas remain within meaningful concepts (Swan, 1997). The CM approach has many advantages, such as focusing on the problem, highlighting priorities and key factors, and providing and filling in missing information (Poppe, Termeer & Slingerland, 2009).

The basic elements of CM are generally simple. While the concepts used by individuals in the system are determined by dots, the causal relationships between concepts are indicated by arrows between the dots. The system represented by a dot and arrow diagram, which is referred to as a cognitive map, represents all strategic alternatives, various causes and consequences, goals, and the ultimate utility of the decision maker, all of which can be viewed as concept variables and represented as dots in the causal map. Causal relationships can take the basic values of + / (1) (promotes, develops, helps, benefits, etc.), - / (1) (delays, harms, prevents, is harmful, etc.), and 0 (e.g., no effect). With this representation, it is relatively easy to see the general causal relationships of one concept to others, and how concepts and causal relationships relate to each other. The relationships can be represented in the matrix called the *valency matrix,* when the cognitive map is converted into a matrix format. Where n is the total number of concepts in the corresponding cognitive map of the valency matrix C is a square matrix of nxn. C is a signed matrix composed of the values (vij) representing the strength of the relations between the variables in the map: $vij = 0$ if the variables are unrelated; $vij = 1$ if a positive relationship from i to j is present in the cognitive map; $vij = -1$ if a negative relationship from i to j is present. The crosswise elements in the map are assumed to be 0. A number of useful specifications are available in the valency matrix. The outdegree (od) of concept i is obtained from the sum of the absolute values of the elements of row i, i.e., the number of concepts perceived to be directly affected by concept i. Correspondingly, the in-degree (id) of concept i is obtained from the column sum of the absolute values of the elements of column i, where the number of perceived concepts directly affects concept i. The total degree of the concept i is obtained via the sum of the indegree and outdegree, which is the useful operational measure of the concept's cognitive centrality in the decision maker's belief structure. In applying the CM approach, the centrality of a concept is a measure. Centrality is a reference point that indicates the importance of a concept in a map. Basically, the row/column sums of the absolute values of the existing relations are used to determine the centrality value (CV) (Chaib-Draa & Desharnais, 1998).

The CM technique was applied in various fields such as network systems (Zhang, Wang & King, 2009), business process redesign (Kwahk & Kim, 1999), plant control (Gotoh et al., 1989), and electrical circuits (Styblinski and Meyer, 1988). In the maritime field, the CM was used by (Celik & Topcu, 2010) to analyze the reported deficiencies of the ISPS Code implementations. In addition, environmental management in the Black Sea was successfully built using the CM technique (Kontogianni et al., 2012). In this study, the CM technique is utilized to prioritize the selected causes through the M-SCAT framework.

2.3. Pareto Analysis

The Pareto analysis is based on the principle that a large part of the result, usually expressed as 80%, is created by a small number of reasons that are assumed to be only 20% (Andersen et al., 2010). In order to solve the main problem, determining the relative frequencies of the problem in a decreasing order, determining which reason will be taken, the greatest benefit is provided by this technique and helps the analysis team (Ziarati, 2006). Looking at the available data in different ways is an important requirement to make the best decision when doing a Pareto Analysis. All factors are grouped together for similar reasons and categorized. Since the priority values to be obtained will change as a result of breaking down these categories or combining some of them, it is essential to pay utmost attention when creating categories for which factor to be included in which group (Okes, 2009).

2.4. Proposed Approach

Integrating the M-SCAT, CM, and Pareto Analysis, a SSAS is proposed. Figure 1 illustrates the conceptual flow diagram of the SSAS. It includes data collection, causation, analysis and prioritization, and implementation phases. The SSAS aims at promoting the maritime regulatory compliance via the analysis of multi-source inspection database.

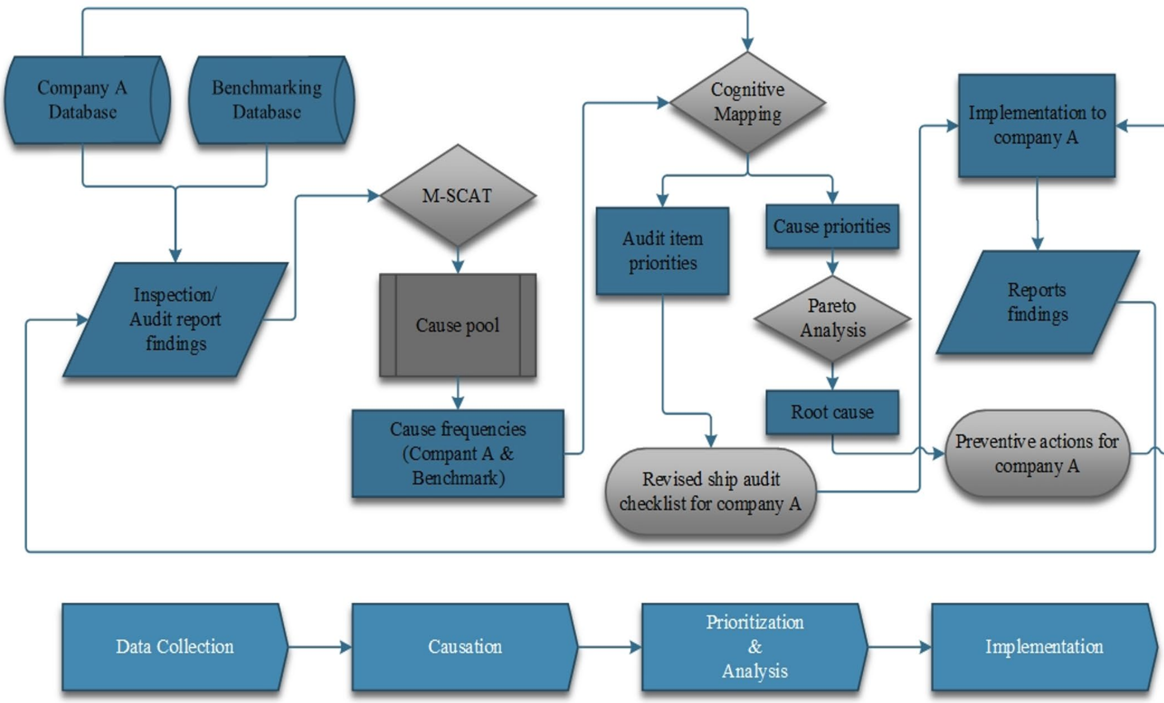

Figure 1. SSAS conceptual flow diagram

The first step is the collection of data. The audit reports of Company A and the benchmarking dataset are merged. The second step is the cause investigation. In this step, the causation of the findings is identified. The third step is priority setting. In this step, the CM matrix is created. This phase is the most important step of the process, where the order of the root causes and the audit checklist is redefined. The final step is implementation, in which the shipboard audit was conducted in accordance with the revised form. The analysis of the collected data was carried out with a group consensus of both maritime executives and researchers. The group includes DPA, technical managers, operation managers, human resources managers, engine superintendent, deck superintendent, shipmasters, chief engineers, experienced surveyors, and maritime academicians.

3. CASE STUDY

To conduct a case study, multi-source inspection database including various findings such as deficiencies, nonconformities, accidents, near miss reports, risk assessments are examined. To identify potential causes, an M-SCAT analysis was first performed. After identifying the most common causes, a CM analysis was performed to identify the relationship between the causes and the audit control mechanisms. In the prioritization and analysis phase, Pareto analysis was then conducted to find out the root cause. Finally, the revised shipboard audit checklist was implemented.

3.1. Data Collection Phase

In this study, multi-source inspection database includes two different datasets: i) Benchmarking dataset, and ii) Company-A dataset. Benchmarking dataset globally covers 5,000 findings from different types of ships (e.g., bulk carriers, LPG, LNG, oil-tankers, ro-ro ships, etc.) inspected in 46 countries. Company-A dataset involves more than 1,900 findings from 5-year (2016-2021) reports of 16 multipurpose dry cargo, general cargo, and bulk-carrier type, varying between 5,000 dwt and 53,000 dwt.

3.2. Causation Phase

The initial review of the existing records underlined that the most frequently faulty sections are lifeboats, lights, shapes, sound signals, and auxiliary engines, followed by the ISM, fire doors/openings in fire-resistant compartments, other machinery, and other fire protection. Considering the M-SCAT framework, the causes of findings were investigated based on 4 main categories, such as the ICSA (Immediate Causes - Substandard Acts), ICSC (Immediate Causes - Substandard Conditions), BCPF (Basic Causes - Personal Factors), BCJSF (Basic Causes - Job/System Factors). The comprehensive analysis was conducted to benchmarking dataset and Company-A dataset respectively.

	Num. Item	Item Ratio	Cumulative	Cum. Ratio	Cause Num.	Cause Ratio
Immediate Causes - Substandard Acts						
ICSA - 16.	1,506	31.99%	1,506	31.99%	1	4.76%
ICSA - 2.	1,238	26.30%	2,744	58.30%	2	9.52%
ICSA - 19.5.	637	13.53%	3,381	71.83%	3	14.29%
ICSA - 15.	570	12.11%	3,951	83.94%	4	19.05%
ICSA - 3.	226	4.80%	4,177	88.74%	5	23.81%
ICSA - 17.	178	3.78%	4,355	92.52%	6	28.57%
Immediate Causes - Substandard Conditions						
ICSC - 25.	578	30.57%	578	30.57%	1	5.56%
ICSC - 41.	428	22.63%	1,006	53.20%	2	11.11%
ICSC - 42.	327	17.29%	1,333	70.49%	3	16.67%
ICSC - 40.	274	14.49%	1,607	84.98%	4	22.22%
ICSC - 39.	116	6.13%	1,723	91.12%	5	27.78%
Basic Causes - Personal Factors						
BCPF - 5.6.	2,376	56.94%	2,376	56.94%	1	3.70%
BCPF - 5.1.	478	11.45%	2,854	68.39%	2	7.41%
BCPF - 5.2.	281	6.73%	3,135	75.13%	3	11.11%
BCPF - 5.8.	265	6.35%	3,400	81.48%	4	14.81%
BCPF - 5.3.	236	5.66%	3,636	87.13%	5	18.52%
BCPF - 5.9.	165	3.95%	3,801	91.09%	6	22.22%
BCPF - 5.11.	116	2.78%	3,917	93.87%	7	25.93%

Basic Causes - Job/System Factors						
BCJSF - 12.6.	1,177	26.71%	1,177	26.71%	1	1.37%
BCJSF - 14.6.	617	14.00%	1,794	40.72%	2	2.74%
BCJSF - 12.9.	420	9.53%	2,214	50.25%	3	4.11%
BCJSF - 8.5.	413	9.37%	2,627	59.62%	4	5.48%
BCJSF - 16.13.	307	6.97%	2,934	66.59%	5	6.85%
BCJSF - 17.1.	295	6.70%	3,229	73.29%	6	8.22%
BCJSF - 17.	192	4.36%	3,421	77.64%	7	9.59%
BCJSF - 14.5.	117	2.66%	3,538	80.30%	8	10.96%

Table 1. Cause distributions of benchmarking dataset

According to the results, inadequate organizational processes, poor performance of shipboard personnel, and inadequate inspections are noted under the ICSA category. While the ICSC category underlines the inadequate equipment, outdated charts and publications as the results of inadequate inspections, the BCPF highlights the unqualified personnel and the human error rates. The BCJSF category addressed the inadequate PMS, lack of repair/maintenance arrangements, poor inspection procedures.

Table 2 illustrates the cause distributions of Company-A dataset. Failure to follow procedure and instruction, and failure to inform about remarkable causes found in the ICSA category. While the ICSC indicates the defective tool/equipment and inadequate conditions of floor/surface, the BCPF emphasizes the routine tasks not conducted properly and a serious lack of situational awareness. The BCJSF category coped with the inadequate preventing cleaning/resurfacing and inadequate assessment of repair needs. Meanwhile, the BCJSF - 7 and BCJSF - 12.10 remain hidden causes as they were not detected due to analysis method.

	Num. Item	**Item Ratio**	**Cumulative**	**Cum. Ratio**	**Cause Num.**	**Cause Ratio**
Immediate Causes - Substandard Acts						
ICSA - 2.	269	43.88%	269	43.88%	1	11.11%
ICSA - 5.	216	35.24%	485	79.12%	2	22.22%
ICSA - 4.	36	5.87%	521	84.99%	3	33.33%
ICSA - 11.	33	5.38%	554	90.38%	4	44.44%
ICSA - 8.	23	3.75%	577	94.13%	5	55.56%
ICSA - 14.	18	2.94%	595	97.06%	6	66.67%
Immediate Causes - Substandard Conditions						
ICSC - 25.	670	35.71%	670	35.71%	1	7.69%
ICSC - 43.	446	23.77%	1,116	59.49%	2	15.38%
ICSC - 41.	248	13.22%	1,364	72.71%	3	23.08%
ICSC - 39.	214	11.41%	1,578	84.12%	4	30.77%
ICSC - 37.	78	4.16%	1,656	88.27%	5	38.46%
ICSC - 42.	73	3.89%	1,729	92.16%	6	46.15%
Basic Causes - Personal Factors						
BCPF - 4.4.	236	44.44%	236	44.44%	1	6.67%
BCPF - 5.6.	83	15.63%	319	60.08%	2	13.33%
BCPF - 5.4.	71	13.37%	390	73.45%	3	20.00%
BCPF - 5.2.	43	8.10%	433	81.54%	4	26.67%
BCPF - 3.1.	35	6.59%	468	88.14%	5	33.33%
BCPF - 6.11.	18	3.39%	486	91.53%	6	40.00%
BCPF - 5.11.	17	3.20%	503	94.73%	7	46.67%

Basic Causes - Job/System Factors						
BCJSF - 12.4.	419	24.94%	419	24.94%	1	3.33%
BCJSF - 12.7.	405	24.11%	824	49.05%	2	6.67%
BCJSF - 9.4.	205	12.20%	1,029	61.25%	3	10.00%
BCJSF - 12.8.	196	11.67%	1,225	72.92%	4	13.33%
BCJSF - 12.2.	95	5.65%	1,320	78.57%	5	16.67%
BCJSF - 12.1.	89	5.30%	1,409	83.87%	6	20.00%
BCJSF - 12.5.	50	2.98%	1,459	86.85%	7	23.33%

Table 2. Cause distributions of Company A dataset

3.3. Prioritization and Analysis

In this phase, a comprehensive analysis of multi-source database was conducted. Initially, the combination of causes derived from the benchmarking dataset and Company-A dataset was taken. The numbers of 31 causes were distributed as follows: 7 causes in the ICSA category, 6 causes in the ICSC category, 7 causes in the BCPF category, and 11 causes in the BCJSF category. Then, the audit elements were combined and associated with the determined causes in order to structure the valency matrix provided in **Appendix 1**. In the matrix, the causal relationships are identified. Finally, the CV was calculated by summing the row and column values for each cause provided in **Table 3**.

Categories	Row	Column	Cv. Ttl.	Mix. Ratio	Cum.	Cum. Ratio
BCPF - 5.9	23	33	56	8.06%	56	8.06%
ICSA - 17	22	19	41	5.90%	97	13.96%
ICSA - 2	12	26	38	5.47%	135	19.42%
BCJSF - 16.13	15	22	37	5.32%	172	24.75%
BCJSF - 17	5	31	36	5.18%	208	29.93%
BCPF - 5.6	19	14	33	4.75%	241	34.68%
ICSC - 39	11	12	23	3.31%	264	37.99%
ICSA - 15	12	10	22	3.17%	286	41.15%
BCPF - 5.3	11	11	22	3.17%	308	44.32%
BCJSF - 14.6	11	11	22	3.17%	330	47.48%
ICSA - 16	8	13	21	3.02%	351	50.50%
BCPF - 5.1	3	18	21	3.02%	372	53.53%
BCJSF - 12.7	10	11	21	3.02%	393	56.55%
ICSA - 5	9	11	20	2.88%	413	59.42%
ICSC - 41	11	9	20	2.88%	433	62.30%
BCJSF - 12.4	11	9	20	2.88%	453	65.18%
ICSC - 43	12	6	18	2.59%	471	67.77%
ICSA - 19.5	5	12	17	2.45%	488	70.22%
ICSC - 40	7	10	17	2.45%	505	72.66%
BCPF - 4.4	7	10	17	2.45%	522	75.11%
BCJSF - 12.9	3	14	17	2.45%	539	77.55%
BCJSF - 9.4	4	13	17	2.45%	556	80.00%
ICSC - 25	8	8	16	2.30%	572	82.30%
BCPF - 5.2	3	13	16	2.30%	588	84.60%
BCPF - 5.8	5	11	16	2.30%	604	86.91%

BCJSF - 17.1	3	13	16	2.30%	620	89.21%
BCJSF - 12.8	7	9	16	2.30%	636	91.51%
BCJSF - 12.6	6	10	16	2.30%	652	93.81%
ICSA - 3	5	10	15	2.16%	667	95.97%
ICSC - 42	3	12	15	2.16%	682	98.13%
BCJSF - 8.5	4	9	13	1.87%	695	100.00%

Table 3. Centrality values of causes

According to the calculated CV(s), **Figure 2** depicts the priorities of ship audit elements, which gives a preference order in implementation.

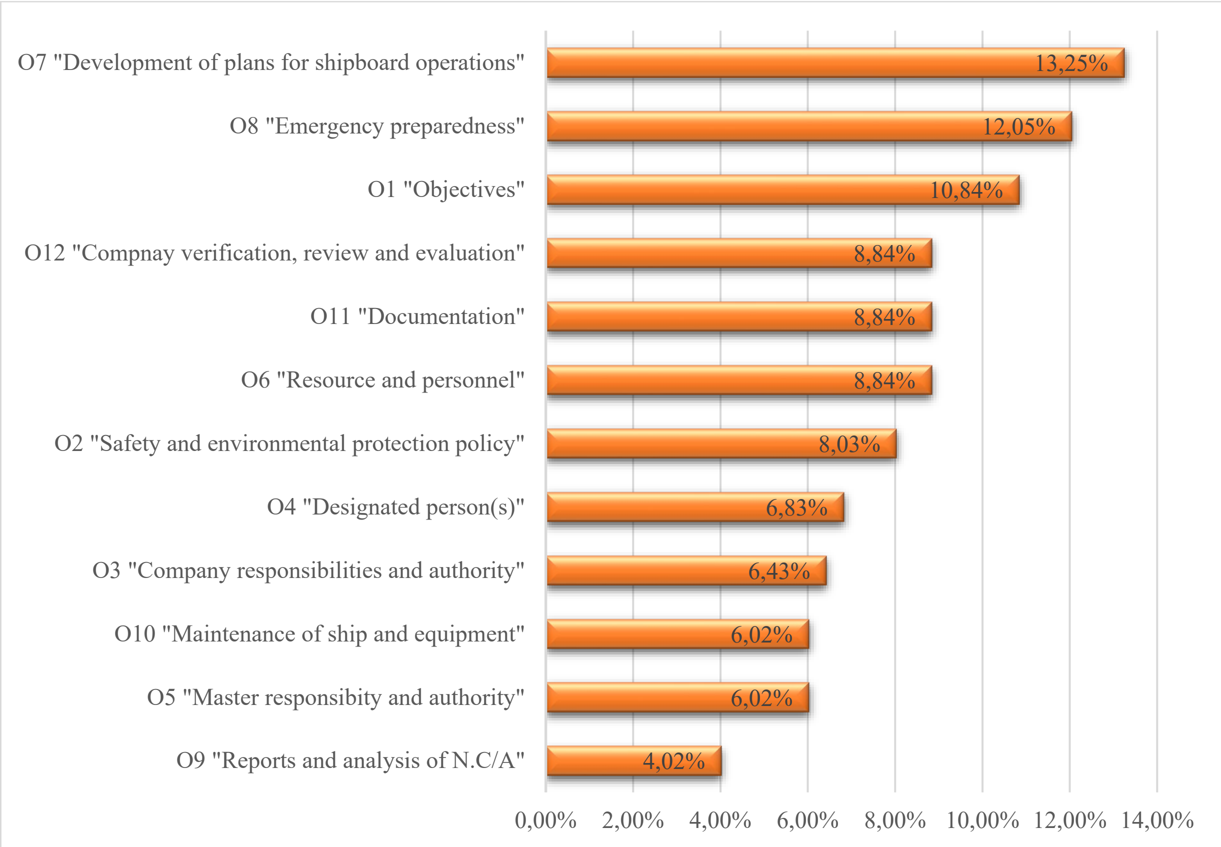

Figure 2. Priorities of ship audit elements

Considering the priorities of ship audit elements, the Company-A internal audit checklist was revised to arrange the sequence and timeline of the inspection elements. The existing checklist begins with *Objectives* and continues with *Safety and Environmental Protection Policy*, *Company Responsibilities and Authority*, *Designated Person(s)*, etc. However, the sequence of items in the revised checklist is given as follows: *Development of Plans for Shipboard Operations*, *Emergency Preparedness*, *Objectives*, *Company Verification*, *Review and Evaluation*, etc. **Table 4** provides the comparison of the priorities and the timeline of the existing and revised audit checklists.

Audit Items	Existing Order	Revised Order	Time (Min)
Objectives	O1	O7	24
Safety and environmental protection policy	O2	O8	22
Company responsibilities and authority	O3	O1	20
Designated person(s)	O4	O6	16
Master’s responsibility and authority	O5	O11	16
Resource and personnel	O6	O12	16
Development of plans for shipboard operations	O7	O2	14
Emergency preparedness	O8	O4	12
Reports and analysis of N.C/A	O9	O3	12
Maintenance of ship and equipment	O10	O5	11
Documentation	O11	O10	11
Company verification, review and evaluation	O12	O9	7

Table 4. Priorities and timeline of existing and revised audit checklist

The final step of prioritization & analysis is to identify the root causes using a Pareto statistical analysis. In this case, this method can be used after the main causes have been identified. Pareto rule assumes that in all situations 20% of the causes are responsible for 80% of the problems. This ratio is merely a convenient rule of thumb and should not be considered an immutable law. Pareto analysis identified 7 out of 31 causes (BCPF-5.9, ICSA-17, ICSA-2, BCJSF-16.13, BCJSF-17, BCPF-5.6., ICSC-39), i.e., root causes, schematized in **Figure 3**.

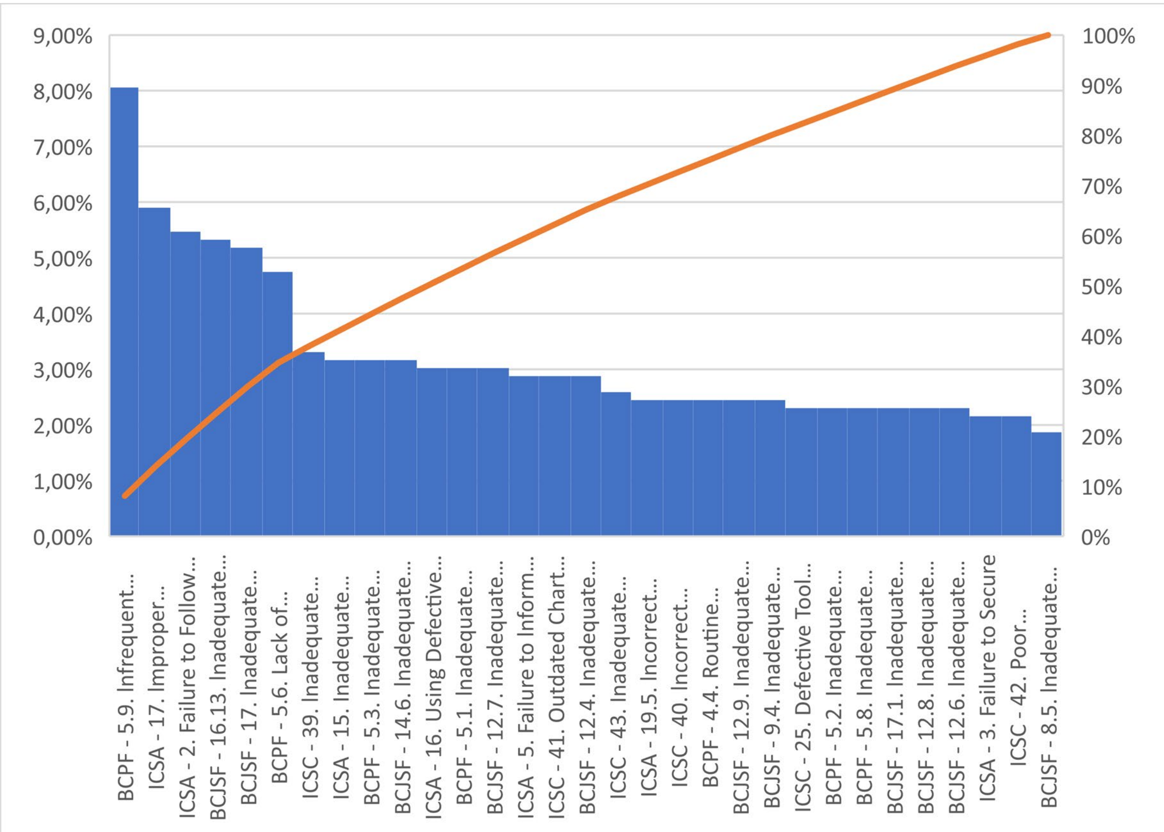

Figure 3. Pareto analysis of main causes

3.4. Implementation

In the implementation phase, preventive actions and revised audit checklist are applied. To eliminate the root causes, appropriate preventive measures should be taken. **Table 5** provides the preventive action recommendations against the identified root causes.

Code	Root Causes	Preventive action
BCPF - 5.9	Infrequent performance	Plan training to identify and develop solutions to vulnerabilities through regular performance measurements and assessments.
ICSA - 17	Improper operation of tool, equipment, machinery device	It should be determined which equipment / tools / machines is/are needed to perform important operations, and they should always be kept well-maintained and ready for use.
ICSA - 2	Failure to follow procedure/instruction	Adding the relevant procedure as a reference to remind the operation instructions as a topic for each relevant department to follow the company SMS, Standing Orders and circulars.
BCJSF - 16.13	Inadequate monitoring of standard compliance	Establish a department to oversee the enactment of ordinances and ensure implementation before they take effect.
BCJSF - 17	Inadequate communication / information	Disseminate written instructions and procedures and take them as a basis to prevent misinformation and information pollution. Regular meetings should also be held more frequently to improve communication both within and between ships.
BCPF - 5.6	Lack of situational awareness/risk perception/risk awareness	Training should be provided to improve situational awareness and risk perception, and in particular, shipboard personnel responsible for management should be trained in this regard by more experienced personnel.
ICSC - 39	Inadequate warning systems	The development of warning systems is possible by defining possible accidents and risks in advance, and it was decided to create near miss and risk assessments for more scenarios. In addition, the alarms of the safety and automation systems should be checked more frequently.

Table 5. Preventive action recommendations

Considering the preventive action recommendations, the revised audit checklist was applied to a general cargo ship and a bulk carrier ship. **Table 6** provides internal audit findings with the revised checklist.

New Findings with Revised Audit Checklist			Root Causes						
No	Topic	Remark	SA2	SA17	SC39	PF5.6	PF5.9	JSF16.13	JSF17
1	O8	Abandon ship drill for lifeboat maneuver on the water never conducted. (ISM)	x			x	x	x	
2	O8	MOB fix not proper.		x		x		x	
3	O8	Ship staff unable to demonstrate rescue-boat launching-davit electrical and manual operation. (ISM)	x	x		x	x	x	
4	O1	Crew unable to demonstrate correct operation of OWS. Crew maintained flushing FW on OCM during operation. On second opportunity, crew closed OCM sample.	x				x	x	x
5	O7	ER bilges - dirty, oil + water accumulated.	x		x	x	x	x	
6	O8	IMO symbols for fire doors need to be posted.			x	x		x	
7	O7	All electronic charts used in previous and intended voyage not up-to-date. (ISM)	x			x		x	
8	O7	Night order book (Master) compulsory entries.	x			x	x		x
9	O12	IMSBC Code and IMDG Code are of old edition. (ISM)				x	x	x	
10	O8	Bridge-wing life-buoys have less than 4 kg.		x		x		x	
11	O12	Stern whistle inoperative. (ISM)		x			x	x	
12	O1	Upper solenoid v/v or discharge sludge oil of OWS malfunction. (ISM)				x		x	
13	O8	Emergency transfer pump (wilden pump) responding to oil-spill on deck not ready to use.		x			x	x	
14	O10	Handhold for both side embarkation ladder - made corrosion hole						x	
15	O7	Hatch cover opening mechanism, hydraulic piping found leaking on main deck port side in way of No.2 and No.4 Holds.		x			x	x	
16	O1	At well, excess garbage was being kept in the Bosun store blocking the life-saving equipment.	x				x	x	
17	O8	Heat detector in E/R tested by open fire, not safe.	x			x	x		
18	O8	Rescue-boat switch-panel with cracks.		x		x		x	
19	O7	Passage plan is not berth to berth, charts out of date. (ISM)	x			x		x	x
20	O10	M/E rpm-indicator located portside wing bridge unreadable.		x				x	x
21	O2	The lifebuoys nearby both side gangways, light not fitted.	x			x			
22	O2	One (1) piece lifebuoy in bad condition, need to replace. (Starboard-side lifeboat-deck)				x	x	x	
23	O7	Ballast-pump leak through shaft seal.		x		x			
24	O7	Voyage or passage plan/incomplete information available - UKC and SQUAD.	x			x	x	x	x
25	O8	Portable VHF is not working.		x		x		x	x
26	O8	Limit switch for lifeboat (S-side) - stuck.		x		x		x	

Table 6. Internal audit findings with revised checklist

4. CONCLUSIONS

Maritime regulatory compliance is a core value for ship management companies. The effective implementation of ship audit mechanism contributes to execute proactive measures accurately. In this insight, a systematic analysis of inspection records derived from different sources is a complex managerial responsibility. Despite the growing interest in the maritime industry, the literature review addressed a lack of studies on smart inspection solutions. This study proposed a systematic analysis of multi-source inspection database via SSAS. The methodology behind the SSAS covers the M-SCAT, CM, and Pareto analysis. The case study conducted data collection, causation, analysis and prioritization, and implementation phases, derived root causes, preventive actions and revised shipboard audit checklist. The implementation of the revised checklist has a great potential to report deficiencies, quick response to deficiency analysis, and effective time management. Consequently, the study provides reasonable contributions to identify findings more precisely, recommend accurate preventive actions, and increase safety and environmental performance at sea. Further studies might conduct a systematic analysis of the records of third-party inspection regimes, such as TMSA, SIRE, CDI, etc.

ACKNOWLEDGEMENT

This paper has been produced following the PhD dissertation entitled “Development of A Methodology on A Ship Smart Internal Audit System (SSAS)”, which has been written in the Maritime Transportation Engineering Program of Piri Reis University Institute of Graduate Studies.

CONFLICT OF INTEREST

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

REFERENCES

Anderson, P., 2003. Cracking the Code: The Relevance of the ISM Code and Its Impact on Shipping Practices. Nautical Institute.

Baldwin, R., Cave, M. & Lodge, M., 2010. “The Oxford Handbook of Regulation.” The Oxford Handbook of Regulation, September. Oxford University Press, 1–680. doi:10.1093/OXFORDHB/9780199560219.001.0001.

Batalden, B.M. & Sydnes, A.K., 2014. “Maritime Safety and the ISM Code: A Study of Investigated Casualties and Incidents.” WMU Journal of Maritime Affairs 13 (1). Springer Verlag: 3–25. doi:10.1007/S13437-013-0051-8/TABLES/9.

Bhattacharya, S., 2009. Impact of the ISM Code on the Management of Occupational Health and Safety in the Maritime Industry. Cardiff University (United Kingdom).

Andersen, B., Fagerhaug, T. & Beltz, M., 2010. “Root Cause Analysis and Improvement in the Healthcare Sector : a Step-By-Step Guide.”, Quality Press.

Chaib-Draa, B. & Desharnais, J. (Received 3 December 1997 and accepted in revised form 20 April 1998), De& département d'informatique, Faculte des Sciences, Universite Laval, Sainte-Foy, QC, Canada G1K 7P4. email: chaib@ift.ulaval.ca

Celik, Metin, and Y Ilker Topcu. 2010. “Assessment of ISPS Code Compliance at Ports Using Cognitive Maps.” TransNav, International Journal on Marine Navigation and Safety Od Sea Transportation 4 (3).

Chauvin, Christine, Salim Lardjane, Gaël Morel, Jean Pierre Clostermann, and Benoît Langard. 2013. “Human and Organisational Factors in Maritime Accidents: Analysis of Collisions at Sea Using the HFACS.” Accident Analysis & Prevention 59 (October). Pergamon: 26–37. doi:10.1016/J.AAP.2013.05.006.

Chung, Wu Hsun, Sheng Long Kao, Chun Min Chang, and Chien Chung Yuan. 2019. “Association Rule Learning to Improve Deficiency Inspection in Port State Control.” Https://Doi.Org/10.1080/03088839.2019.1688877 47 (3). Routledge: 332–351. doi:10.1080/03088839.2019.1688877.

D. Okes, 2009, “Root Cause Analysis. The Core of Problem Solving and Corrective Action.”, Quality Press,

E Akyuz, M Celik, 2014, “Utilisation of cognitive map in modelling human error in marine accident analysis and prevention”, Safety science 70, 19-28,

E Akyuz, M Celik, 2014, “A hybrid decision-making approach to measure effectiveness of safety management system implementations on-board ships”, Safety Science 68, 169-179

Fan, Lixian, Meifeng Luo, and Jinbo Yin. 2014. “Flag Choice and Port State Control Inspections—Empirical Evidence Using a Simultaneous Model.” Transport Policy 35 (September). Pergamon: 350–357. doi:10.1016/J.TRANPOL.2014.04.008.

Fan, Lixian, Zimeng Zhang, Jingbo Yin, and Xingyuan Wang. 2018. “The Efficiency Improvement of Port State Control Based on Ship Accident Bayesian Networks:” Https://Doi.Org/10.1177/1748006X18811199 233 (1). SAGE PublicationsSage UK: London, England: 71–83. doi:10.1177/1748006X18811199.

Fu, Junjie, Xinqiang Chen, Shubo Wu, Chaojian Shi, Huafeng Wu, Jiansen Zhao, and Pengwen Xiong. 2020. "Mining Ship Deficiency Correlations from Historical Port State Control (PSC) Inspection Data." PLOS ONE 15 (2). Public Library of Science: e0229211. doi:10.1371/JOURNAL.PONE.0229211.

Gilad, Sharon. 2010. "It Runs in the Family: Meta-Regulation and Its Siblings." Regulation & Governance 4 (4). John Wiley & Sons, Ltd: 485–506. doi:10.1111/J.1748-5991.2010.01090.X.

Gotoh, K, J Murakami, T Yamaguchi, and Y Yamanaka. 1989. "Application of Fuzzy Cognitive Maps to Supporting for Plant Control." In SICE Joint Symposium of 15th System Symposium and 10th Knowledge Engineering Symposium, 99–104.

Hale, A. R. 2003. "Safety Management in Production." Human Factors and Ergonomics in Manufacturing & Service Industries 13 (3). John Wiley & Sons, Ltd: 185–201. doi:10.1002/HFM.10040.

Hänninen, Maria, and Pentti Kujala. 2014. "Bayesian Network Modeling of Port State Control Inspection Findings and Ship Accident Involvement." Expert Systems with Applications 41 (4). Pergamon: 1632–1646. doi:10.1016/J.ESWA.2013.08.060.

International Organization for Standardization, ISO. 2011. Guidelines for Auditing Management Systems. na.

Knapp, Sabine, and Philip Hans Franses. 2010. "A Global View on Port State Control: Econometric Analysis of the Differences across Port State Control Regimes." Http://Dx.Doi.Org/10.1080/03088830701585217 34 (5). Routledge : 453–482. doi:10.1080/03088830701585217.

Kontogianni, A, E Papageorgiou, L Salomatina, M Skourtos, and B Zanou. 2012. "Risks for the Black Sea Marine Environment as Perceived by Ukrainian Stakeholders: A Fuzzy Cognitive Mapping Application." Ocean & Coastal Management 62. Elsevier: 34–42.

Kristiansen, Svein. 2013. "Maritime Transportation: Safety Management and Risk Analysis." Maritime Transportation: Safety Management and Risk Analysis, September. Taylor and Francis, 1–503. doi:10.4324/978080473369/MARITIME-TRANSPORTATION-SAFETY-MANAGEMENT-RISK-ANALYSIS-SVEIN-KRISTIANSEN.

Kwahk, Kee Young, and Young Gul Kim. 1999. "Supporting Business Process Redesign Using Cognitive Maps." Decision Support Systems 25 (2). North-Holland: 155–178. doi:10.1016/S0167-9236(99)00003-2.

Li, K. X., and J. Wonham. 2010. "Who Is Safe and Who Is at Risk: A Study of 20-Year-Record on Accident Total Loss in Different Flags." Http://Dx.Doi.Org/10.1080/030888399286961 26 (2). Taylor & Francis Group : 137–144. doi:10.1080/030888399286961.

M Celik and S Cebi 2009, "Analytical HFACS for investigating human errors in shipping accidents", Accident Analysis & Prevention 41 (1), 66-75,

O Soner, U Asan, M Celik, 2015, "Use of HFACS–FCM in fire prevention modelling on board ships", Safety Science 77, 25-41

Poppe, Krijn J, Katrien Termeer, and Maja Slingerland. 2009. Transitions towards Sustainable Agriculture and Food Chains in Peri-Urban Areas. Wageningen academic publishers.

Power, Michael. 2000. “The Audit Society — Second Thoughts.” International Journal of Auditing 4 (1). John Wiley & Sons, Ltd: 111–119. doi:10.1111/1099-1123.00306.

Reason, James. 2016. “Managing the Risks of Organizational Accidents.” Managing the Risks of Organizational Accidents, January. Taylor and Francis, 1–252. doi:10.4324/9781315543543/MANAGING-RISKS-ORGANIZATIONAL-ACCIDENTS-JAMES-REASON.

R. Ziarati, 2006 “Safety at sea–applying Pareto analysis,” in Proceedings of World Maritime Technology Conference (WMTC 06), Queen Elizabeth Conference Centre, vol. 94, no. September, [Online]. Available: http://www.marifuture.org/Publications/Papers/safety_at_sea_applying_pareto_analysis.pdf.

Saunders, Roger. 1992. The Safety Audit: Designing Effective Strategies.

SME Demirci, K Cicek 2022. “Deficiency analysis identified in PSC inspections using event tree analysis”, Journal of Marine Technology and Environment 1, 40-46

Styblinski, M A, and B D Meyer. 1988. “Fuzzy Cognitive Maps, Signal Flow Graphs, and Qualitative Circuit Analysis.” In ICNN, 549–556.

Swan, Jacky. 1997. “Using Cognitive Mapping in Management Research: Decisions about Technical Innovation.” British Journal of Management 8 (2). John Wiley & Sons, Ltd: 183–198. doi:10.1111/1467-8551.0050.

Tzannatos, Ernestos. 2010. “Human Element and Accidents in Greek Shipping.” The Journal of Navigation 63 (1). Cambridge University Press: 119–127. doi:10.1017/S0373463309990312.

Ventikos, N. P., P. Sotiralis, and M. Drakakis. 2018. “A Dynamic Model for the Hull Inspection of Ships: The Analysis and Results.” Ocean Engineering 151 (March). Pergamon: 355–365. doi:10.1016/J.OCEANENG.2017.11.020.

Xiao, Yi, Grace Wang, Kun Chin Lin, Guanqiu Qi, and Kevin X. Li. 2020. “The Effectiveness of the New Inspection Regime for Port State Control: Application of the Tokyo MoU.” Marine Policy 115 (May). Pergamon: 103857. doi:10.1016/J.MARPOL.2020.103857.

Yang, Zhisen, Zaili Yang, and Angelo Palos Teixeira. 2020. “Comparative Analysis of the Impact of New Inspection Regime on Port State Control Inspection.” Transport Policy 92 (June). Pergamon: 65–80. doi:10.1016/J.TRANPOL.2020.04.009.

Zhang, Wen-Ran, Wenhua Wang, and Ronald S. King. 2009. “A-pool: An Agent-oriented Open System Shell for Distributed Decision Process Modeling.” Http://Dx.Doi.Org/10.1080/10919399409540220 4 (2). Taylor & Francis Group : 127–154. doi:10.1080/10919399409540220.