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Application of Human Factors Analysis and Classification System (HFACS-MA) vs Root Cause Analysis (RCA) in Investigation of Maritime Incident within Marine Ports

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المستخلص

تستعرض هذه الدراسة مقارنة بين نظام تحليل وتصنيف العوامل البشرية (HFACS) وتحليل السبب الجذري (RCA) في سياق تحقيقات الحوادث البحرية ضمن الموانئ البحرية. يركز نظام تحليل وتصنيف العوامل البشرية على الأخطاء البشرية والتأثيرات التنظيمية التي قد تسهم في الحوادث، بينما يهدف تحليل السبب الجذري إلى تحديد الأسباب الكامنة وراء الحوادث من خلال نهج دقيق. تُظهر المقارنة كيف أن نظام تحليل وتصنيف العوامل البشرية يتناول بشكل شامل العوامل التفصيلية النظامية والبشرية، في حين أن تحليل السبب الجذري يبرز كأداة فعّالة لتحديد الأسباب المباشرة للحوادث. تشير النتائج إلى أن كلًا من النظامين يتمتعان بخصائص قوية تُسهم في تعزيز فهمنا للمخاطر، وعند استخدامهما معًا، يمكن تشكيل إطار شامل يعزز السلامة البحرية ويُحسن إدارة المخاطر في عمليات الموانئ.

Abstract:

This study compares the Human Factors Analysis and Classification System (HFACS) and Root Cause Analysis (RCA) in the context of marine incident investigations within the Marine Port. HFACS focuses on human error and organizational influences, while RCA identifies the underlying causes of incidents through a systematic process. The comparison highlights HFACS's detailed approach to human and systemic factors and RCA's efficiency in pinpointing direct causes. The findings suggest that both methods have unique strengths and, when used together, can provide a more comprehensive framework for improving safety and risk management in port operations.

Keywords: Human Factors, Root Cause Analysis, Incident Investigation, Maritime Safety, Port Department.

1- Introduction

The marine operations sector is a cornerstone of Ports, driving both economic growth and energy production for the nation. Given the high-stakes nature of these operations, safety and operational efficiency are paramount. Each year, the Marine Port Department manages myriad activities involving complex interactions among personnel, technology, and the marine environment. These factors can lead to incidents that disrupt operations and pose significant risks to personnel and the environment.

Traditionally, Root Cause Analysis (RCA) has been employed as the primary methodology for investigating incidents within most port departments. RCA focuses on identifying the underlying causes of failures, often through a linear approach that examines what went wrong and why. While effective in many contexts, RCA can be limited in its capacity to capture the multifaceted nature of human interactions, decision-making processes, and organizational influences that often contribute to incidents in marine operations. (Fahlbruch, B., & Gohl, M. , 2021)

Human errors are frequently implicated in marine incidents, ranging from miscommunication among team members to lapses in judgment under pressure. These errors are not merely the result of individual negligence; human factors influence them, including organizational culture, work environment, training, and fatigue. Traditional RCA methods may overlook these complexities, leading to recommendations that fail to address the root causes of human error and, consequently, do not sufficiently enhance safety protocols. (Hollnagel, E., & Wears, R. L., 2020)

Incident investigation in the maritime sector, particularly within the marine port department, is critical for identifying hazards, preventing accidents, and improving safety standards. Among the various frameworks used in these investigations, two prominent methodologies are the **Human Factors Analysis and Classification System (HFACS)** and **Root Cause Analysis (RCA).** Each offers a unique approach to understanding and addressing the causes of incidents.

This research aims to explore which is more robust the application of the Human Factors Analysis and Classification System (HFACS) or Root Cause Analysis (RCA) for analyzing marine field incidents at Ports.

The following objectives present a clear and structured approach, utilizing HFACS to address key human factors in marine operations, thereby enhancing safety and operational efficiency compared to RCA.

- To evaluate the effectiveness and limitations of existing incident investigation methods, specifically RCA, in capturing human factors within the Port Department in marine operations.
- Enhance understanding of human factors and analyze the specific human factors identified through HFACS to understand their role in marine incidents, including organizational influences, and unsafe supervision
- To compare the analytical outcomes of HFACS analyses with those from previous RCA investigations to highlight differences in insights regarding incident causation and contributing factors.

- Develop and create actionable recommendations for the Port Department based on HFACS findings, focusing on improving training programs, safety protocols, and organizational practices to mitigate human error.
- Develop metrics to evaluate the effectiveness of HFACS in incident investigations and its impact on safety performance and incident reduction at the Port Department.

In marine incident investigation, particularly within Marine Port Departments, the Human Factors Analysis and Classification System (HFACS) and Root Cause Analysis (RCA) methods aim to improve safety and prevent future incidents; comparison focusing on how each can be applied in investigating incidents within a marine port department.

This research addresses the need for an accident analysis technique to analyze the marine field incident and identify the underlying human and organizational factors contributing to the catastrophe.

This analysis will help to:

- Identify specific unsafe acts and errors made during the incident.
- Understand preconditions that may have contributed to these unsafe acts.
- Assess the role of supervision and oversight in the incident.
- Evaluate the influence of organizational factors on the occurrence of the incident

2- List of the most important techniques (tree) used for the analysis of human errors

Table 1 shows the most important models used in the analysis of human errors were showed, and they counted (86) models, divided into (32) Human Reliability Assessment models (HRA), (25) Human Error Identification models (HEI), (29) Accident Analysis models.

This table helps risk analysts, or human factors experts to determine which models are appropriate for various industry accidents or risk scenarios. The table also underscores certain models' limitations and specific applicability, guiding experts on which methods are best suited to their needs, depending on the industry and accident type (e.g., nuclear, maritime, generic systems)

Table 1: The Most Important Models Used in The Analysis of Human Errors

<table>
<tr><th>Num</th><th>Human Reliability Assessment</th><th>Human Error Identification</th><th colspan="3">Accident Analysis</th></tr>
<tr><td>1</td><td>AcciMap</td><td>ATHEANA</td><td>AcciMap</td><td rowspan="4">Generic</td><td rowspan="5">Not applicable on maritime accident</td></tr>
<tr><td>2</td><td>AIPA</td><td>CADA</td><td>AEB</td></tr>
<tr><td>3</td><td>APJ</td><td>CBDTM</td><td>ANP</td></tr>
<tr><td>4</td><td>ASEP</td><td>CES</td><td>BA</td></tr>
<tr><td>5</td><td>ATHEANA</td><td>CREAM</td><td>CA</td><td>Nuclear</td></tr>
</table>

6	CAHR	FMEA	Critical Path	Generic	
7	CARA	GEMS	CREAM		Applicable
8	CES	HAZOP	Drift into Failure Model	Undefined	
9	CESA	HEART	Domino Model	Generic	Applicable
10	CODA	HEIST	ECFC	Nuclear with wider application	Not applicable on maritime accident
11	COGENT	HERA	ECFCA	Nuclear with wider application	
12	CREAM	HET	ETA	Nuclear with wider application	Applicable
13	FRAM	HFACS	Five Whys	Generic	Applicable
14	HCR	HRMS	FRAM	Generic	Applicable
15	HEART	IMAS	FTA	Generic	Applicable
16	HRMS	K-HRA	HERA	Generic	Not applicable on maritime accident
17	IDAC	NARA	HFACS	Generic	Applicable
18	IDHEAS	PHECA	HFIT	Generic	Applicable
19	INTENT	SHERPA	HPES	Nuclear	Not applicable on maritime accident
20	JHEDI	SLIM	MTO	Nuclear	Not applicable on maritime accident
21	MERMOS	SLIM-MAUD	Normal Accident Theory	Generic	Applicable
22	NARA	SPAR-H	PEAT	Generic	Not applicable on maritime accident
23	OATS	SRK	RCA	Nuclear with wider application	Applicable
24	PC	THERP	Risk Management Framework	Generic	Applicable

25	RARA	TRACEr	SCAT - M-SCAT	Generic	Applicable
26	SLIM		STAMP	Generic	Applicable
27	SLIM-MAUD		STEP	Nuclear	Not applicable on maritime accident
28	SMoC		Swiss Cheese Model	Generic	Applicable
29	SPAR-H		TRACEr	Generic	Applicable
30	STAMP				
31	TESEO				
32	THERP				

3- Human Factors Analysis and Classification System (HFACS)

HFACS is a human-centric framework developed by (Wiegmann & Shappell, 2003), categorizing human error into four levels: **unsafe acts**, **preconditions for unsafe acts**, **unsafe supervision**, and **organizational influences**. HFACS has been widely adopted in aviation and maritime industries to analyze human error and identify organizational factors contributing to incidents (Shappell, S. A., & Wiegmann, D. A., 2007) In marine field incidents, HFACS is particularly useful for uncovering latent conditions such as poor safety culture, inadequate training, and ineffective communication (Neal, A., & Griffin, M. A. , 2006).

HFACS provides a structured framework for identifying and categorizing human factors contributing to errors, offering deeper insights into the interplay between human behavior and operational systems. HFACS can help Ports to develop more effective strategies for risk mitigation, training, and operational improvements by focusing on the systemic issues that lead to human error.

Adopting HFACS will enrich the understanding of incidents and foster a proactive safety culture prioritizing human factors. This study seeks to provide the Port Investigations Department with a comprehensive approach to incident analysis that aligns with the complexities of marine operations, ultimately enhancing safety and efficiency in the organization's critical maritime activities.

Several studies suggest that HFACS provides a comprehensive framework for understanding the multi-dimensional aspects of maritime accidents. For example, in a study on ship collisions, researchers found that HFACS helped to identify not only the immediate human errors involved but also the organizational and environmental factors that played a significant role (de Vries, J. , 2011). However, a common analysis of HFACS is its complexity and the subjective nature of classifying errors, making it time-consuming and potentially inconsistent if not applied rigorously (Salas, E., Tannenbaum, S. I., Kraiger, K., & Smith-Jentsch, K. A., 2006)

3.1 The HFACS Framework

HFACS was developed to provide a structured approach to analyzing human errors across various industries, including aviation and healthcare. It categorizes errors into four main levels: unsafe acts, preconditions for unsafe acts, supervisory factors, and organizational influences (Shappell, S. A., & Wiegmann, D. A., 2000). This hierarchical classification enables a deeper understanding of the underlying causes of incidents, making it particularly suitable for complex environments like marine operations.

3.2 HFACS Hierarchical Structure

Table 2 shows the framework categorizes and analyzes human errors and organizational factors contributing to incidents. It is divided into four hierarchical levels, each addressing a different aspect of human performance and organizational influence:

Table (2): HFACS Hierarchical Structure

Level	Category	Description
1. Unsafe Acts	- Errors	Unintentional mistakes (e.g., misjudgment).
	- Violations	Intentional deviations from rules (e.g., skipping safety checks).
2. Preconditions for Unsafe Acts	- Environmental Factors	Conditions affecting performance (e.g., poor visibility).
	- Personnel Factors	Issues related to individual capabilities (e.g., fatigue, lack of training).
3. Supervisory Factors	- Inadequate Supervision	Lack of oversight or guidance.
	- Poor Safety Culture	Insufficient emphasis on safety practices.
4. Organizational Influences	- Resource Management	Allocation of resources impacting safety (e.g., staffing, funding).
	- Organizational Culture	Values and beliefs that shape safety practices.

4- Root Cause Analysis (RCA)

RCA (Root Cause Analysis) is a problem-solving method that identifies the fundamental causes of incidents by repeatedly asking “why.” It is widely used in healthcare, engineering, and maritime safety for its simplicity and focus on corrective actions (Smith, J., & Robert, K. , 2007). In the marine sector, RCA is applied to incidents like vessel groundings, collisions, and equipment failures (Fleming, M., & Lardner, S. , 2013). Its linear approach allows for quick identification of technical flaws and actionable recommendations. However, RCA has been criticized for oversimplifying complex accidents by not fully considering human factors or organizational influences (Dekker, S., 2006). This can lead to repeated incidents if systemic issues are overlooked (Rodrigues, H., & Lussier, M., 2016).

4.1 Root Cause Analysis (RCA) frameworks:

RCA frameworks provide different methodologies for investigating issues, ranging from simple techniques like the **5 Whys** to more complex tools such as the **Fishbone Diagram**, **Failure Mode and Effects Analysis (FMEA)**, and **Fault Tree Analysis (FTA)** (Anderson, R. D., & Fagerhaug, T., 2006). Each framework offers a unique approach to breaking down problems and identifying their root causes, making it easier to implement corrective and preventive measures.

Using these frameworks, organizations can systematically identify root causes, prioritize corrective actions, and prevent similar issues from occurring in the future, leading to more efficient, reliable, and safe operations. (Stamatis, D. H., 2003)

Table (3): RCA Frameworks

Framework	Description	Best Use Case	Example
5 Whys	Asking "Why?" repeatedly to uncover the root cause.	Simple problems with clear cause-effect relationships.	Why did the ship collide? (Miscommunication → Lack of training → Inadequate procedures)
Fishbone Diagram (Ishikawa)	Visual tool to categorize causes into major groups (People, Process, etc.).	Complex problems with multiple potential causes.	Vessel collision causes: People (crew fatigue), Process (outdated procedures), Machines (faulty radar), Environment (weather conditions)
FMEA (Failure Mode and Effects Analysis)	Identifying potential failure modes and assessing their impact.	Risk assessment and prioritization in complex systems.	Engine failure mode: Risk of loss of power → Severity 9, Occurrence 4, Detection 2, RPN = 72 (high priority)
Fault Tree Analysis (FTA)	Top-down, deductive approach to analyze failures.	Analyzing system-level issues with multiple interrelated causes.	Ship collision: Miscommunication or Navigation error and Equipment malfunction → Root cause is communication breakdown and faulty system
Event and Causal Factor Charting	Visualizes the sequence of events leading to an incident.	Complex incidents with a clear timeline of events.	Sequence: Bad weather → Poor maintenance → Equipment failure → Collision

Barrier Analysis	Examining barriers and their failures to prevent incidents.	Analyzing safety system failures and risk controls.	Hazardous spill: Failed barrier - Improper containment equipment use → Root cause: Lack of proper training on equipment

4.2 Hierarchical Structure of Root Cause Analysis (RCA)

Root Cause Analysis (RCA) is a systematic approach to identifying the fundamental causes of problems or incidents, rather than merely addressing the symptoms. In complex operations, such as marine operations, it is essential to understand the various layers of contributing factors that lead to an issue. The Hierarchical Structure of RCA provides a structured framework to trace the problem from its immediate causes to its root causes, ensuring that organizations can implement effective solutions to prevent recurrence. (Ishikawa, K., 1986)

The hierarchical structure organizes the RCA process into distinct levels, starting with the identification of the problem, followed by data collection, analysis of causes, and development of corrective and preventive actions. Through breaking down the problem into smaller, manageable categories and systematically analyzing each one, organizations can accurately pinpoint the root cause and address it effectively.

The above structured approach helps prioritize resources, optimize safety, and improve operational efficiency, particularly in high-risk industries like maritime operations.

The following section table (4) outlines the various levels in the Hierarchical Structure of RCA, detailing each stage of the process and its significance in uncovering and addressing underlying causes.

Table (4): Hierarchical Structure of Root Cause Analysis (RCA)

Level	Description	Examples
1. Problem Identification	Define the problem clearly and assess the impact.	Vessel collision, equipment failure, environmental spill, operational delays
2. Data Collection	Gather relevant data, such as logs, records, weather data, and interview stakeholders involved.	Vessel logs, weather conditions, crew reports, maintenance records
3. Cause Identification	Identify direct causes, contributing factors, and root causes.	Immediate Causes: Navigation error, mechanical failure, miscommunication Contributing Factors: Poor weather, lack of training Root Causes: Inadequate SOPs, outdated systems, ineffective communication

4. Cause Analysis (Tools)	Use RCA tools to analyze causes.	Fishbone Diagram, 5 Whys, FMEA, Fault Tree Analysis, Event and Causal Factor Charting
5. Root Cause Validation	Cross-check the identified root causes with historical data, incident comparison, and expert opinions to confirm accuracy.	Comparing with previous incidents, expert review, historical data analysis
6. Solution Development	Develop corrective and preventive actions based on the root causes identified.	Corrective Actions: New training programs, updated SOPs, equipment upgrades Preventive Actions: Improved safety measures, updated technology, regular audits
7. Implementation & Follow-Up	Implement solutions and monitor their effectiveness.	Apply corrective actions, track progress, conduct post-implementation reviews, document lessons learned

5- Comparison of HFACS and RCA in Marine Incident Investigation

Numerous studies have compared HFACS and RCA in maritime safety, noting the strengths and weaknesses of each method. HFACS excels at capturing the complexity of human error, including individual actions, organizational culture, and environmental factors (Van de Merwe, S., & Dyk, H., 2014). It is particularly useful for incidents with multiple contributing factors, such as crew behavior and communication breakdowns (Neal, A., & Griffin, M. A., 2006). However, its detailed categorization may not always lead to immediate corrective actions (Shappell, S. A., & Wiegmann, D. A., 2007).

With its focus on identifying the immediate cause, RCA allows quicker decision-making and corrective actions, making it useful for incidents requiring rapid resolution (Smith & Robert, 2007). However, it has been criticized for overlooking broader systemic issues, such as organizational culture and safety management practices (Dekker, 2006)

Some suggest a hybrid approach combining HFACS and RCA for a more comprehensive analysis. For example, using HFACS for human and organizational factors and RCA for immediate corrective actions could improve incident analysis and risk management in port operations (Fleming & Lardner, 2013). This combined approach has been successfully applied in aviation safety (Reason, 2008).

5.1 Application of Human Factors Analysis and Classification System (HFACS-MA) vs Root Cause Analysis (RCA) in Port Incidents

Port presents unique challenges for incident investigation, given the complexity of maritime logistics, the variety of stakeholders involved, and the high level of coordination required between different departments. HFACS has proven valuable in identifying the human and organizational factors that influence port incidents, such as communication lapses or safety protocol failures. For instance, in analyzing port vessel accidents, HFACS identified errors and issues related to training, equipment maintenance, and supervisory practices.

RCA, meanwhile, is often employed in port incident investigations to quickly pinpoint and rectify specific causes, such as equipment failure, procedural errors, or environmental factors. RCA was used to investigate a ship collision at a port and successfully identified a malfunctioning radar system as the root cause, leading to swift corrective actions. However, the study also pointed out that a more in-depth analysis of human factors and systemic issues could have further reduced the likelihood of future incidents.

5.2 The Advantages and Disadvantages of Human Factors Analysis and Classification System (HFACS) vs Root Cause Analysis (RCA)

Table 5 shows the advantages and dis-advantage of (HFACS) vs (RCA)

Table 5: Advantages and Dis-advantage of (HFACS) vs (RCA)

Aspect	**HFACS**		**RCA**	
	Advantages	Disadvantages	Advantages	Disadvantages
Complexity Handling	Handles multifaceted incidents effectively, capturing complex interactions.	It can be complex to implement, requiring thorough training.	It is simpler and more straightforward to apply in many cases.	Oversimplifies complex incidents, missing nuanced factors.
Human Factors Focus	Systematically identifies and categorizes human errors and influences.	Requires significant qualitative data collection, which can be resource-intensive.	Effective at identifying technical failures and immediate causes.	Neglects critical human factors in incident analysis.

Proactive Approach	Encourages continuous improvement and proactive safety measures.	It may not yield immediate results, requiring a long-term commitment.	A reactive approach can lead to quick fixes for immediate issues.	Fosters a reactive safety culture, potentially overlooking future risks.
Non-punitive Culture	Promotes open communication and a learning culture around errors.	Changing organizational culture can be challenging and slow.	It can be seen as straightforward and familiar by staff.	Often fosters a blame culture, discouraging open reporting.
Comprehensive Insights	Provides deeper insights into systemic issues and root causes.	It may require extensive time and effort to analyze incidents thoroughly.	A focused approach can lead to quick identification of specific failures.	Limited in scope; often misses underlying systemic problems.
Data Collection	Utilizes both qualitative and quantitative data for a holistic view.	Qualitative data collection can complicate analysis processes.	Primarily relies on quantitative data, making it straightforward.	Lacks depth; may miss critical qualitative insights.
Training Requirements	Enhances training programs by identifying key human factors.	Initial training investment can strain resources.	Familiarity with RCA can reduce the need for extensive training.	It may not effectively address training needs related to human factors.
Implementation Challenges	Supports the development of targeted interventions based on findings.	Requires commitment to ongoing evaluation and adaptation of practices.	Easy to implement in organizations accustomed to traditional methods.	An implementation may not address systemic vulnerabilities effectively.

6- Summary of HFACS's Success in Ports and other industries

HFACS has been effectively utilized by various organizations in the marine sector to enhance safety, reduce incidents, and improve operational effectiveness.

Key implementations and successes of each organization's included in table 6:

Table (6): Summary of HFACS's Success in Ports and other industries (HFACS's year implemented)

Organization	Year Implemented	Key Successes
Maersk	Late 2000s	Reduced operational incidents and increased crew awareness.
Royal Caribbean	Late 2000s	Enhanced safety protocols and reduced incident frequency.
U.S. Coast Guard	Early 2000s	Improved understanding of human error, better training.
International Maritime Organization (IMO)	Early 2000s	Improved safety management and reduced accident rates.
Shell	Early 2010s	Informed training programs and enhanced safety measures.
Norwegian Maritime Authority	Early 2010s	Enhanced regulatory frameworks and improved safety standards.

6.1 Outcomes of HFACS in Other Countries (Marine Operations)

- **Reduced Incident Rates**: Decline in accidents and near-misses.
- **Enhanced Safety Culture**: Encourages open discussion about human factors.
- **Improved Training Programs**: More targeted training initiatives.
- **Better Decision-Making**: Refined operational procedures and decision-making processes.

HFACS has driven significant improvements in safety and operations, proving valuable for marine organizations.

6.2 The Port Department needs to use the HFACs over RCA

Transitioning to HFACS offers Port Department a more all-encompassing and effective framework for enhancing safety and operational effectiveness, ultimately leading to better incident prevention and a stronger safety culture.

Table (7): The table below summarizes the advantages of transitioning from a traditional root cause analysis system to the HFACS system within the Port Department.

Aspect	Traditional Root Cause Analysis	HFACS
Focus	Primarily on technical failures and individual mistakes	Comprehensive analysis of human factors and systemic issues

Structure	Linear approach to identifying causes	Hierarchical structure for deeper insights (unsafe acts, preconditions, supervisory factors, organizational influences)
Safety Culture	Reactive approach to incidents	Proactive safety culture, encouraging open discussions about errors
Training and Prevention	General training based on identified causes	Targeted training programs addressing specific human factors and risks
Flexibility	Limited adaptability to various contexts	Adaptable to different operational contexts, especially in marine environments
Industry Alignment	May not align with best practices	Endorsed by industry leaders and regulatory bodies as a best practice for safety management

6.3 The Benefits of Implementing HFACS at the Port Department

- HFACS provides a multifaceted view of incidents, considering human behavior and organizational influences, which can lead to more effective safety measures at the Port Department.
- **Enhanced training programs, identifying specific human factors contributing to incidents, allow the Port Department to** develop targeted training initiatives that address identified gaps in knowledge and skills.
- **Proactive Safety Culture and** implementation of HFACS encourages a culture that prioritizes understanding human error, fostering an environment where safety is a shared responsibility among all personnel.
- **Data-driven decision-making for** HFACS offers a structured framework for data analysis, allowing the Port Department to make informed decisions based on empirical evidence regarding safety and operational practices.

7- Conclusion:

In conclusion, both HFACS and Root Cause Analysis (RCA) are valuable methodologies for marine incident investigation, but their applicability depends on the nature of the incident being analyzed. In the Port Department, where human error, communication breakdowns, and organizational factors often play a significant role in accidents, HFACS offers a more targeted and comprehensive approach.

In comparison with RCA is a more general tool that is effective in identifying root causes across a wide range of incidents, but it may not fully address the human and organizational aspects unless specifically examined.

Therefore, HFACS is better suited for port operations, where the focus is on understanding and mitigating human and systemic factors to improve safety, while RCA remains valuable for more straightforward technical or procedural investigations. Combining both approaches could offer a more holistic view, but for complex, human-centered issues typical in port environments, HFACS is the preferred methodology.

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