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TRACEr-MAR: Technique for the retrospective & predictive analysis of cognitive errors adapted to the maritime domain

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TRACEr-MAR

Technique for the Retrospective & Predictive
Analysis of Cognitive Errors Adapted to the
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Foreword to the first issue of the WMU Papers on Maritime and Ocean Affairs

World Maritime University (WMU) was founded almost 35 years ago in an effort of the International Maritime Organization (IMO) to establish an institution for further education of future maritime and ocean leaders as well as a centre of excellence in research dedicated to maritime and ocean matters. A major task for WMU has been capacity building, primarily for developing countries. However, we have also seen a growing interest in sharing maritime and ocean-related knowledge and experience for developed countries. This is the reason for WMU's academic Journal and Book Series, which is a means to facilitate discussions on contemporary issues in the maritime and ocean-related fields. At the same time, we have taken cognizance, during the many missions that WMU has carried out over the years, of the need for practical guidance and the sharing good practice among IMO member States. This experience gave birth to the idea of a technical paper series.

I am delighted to present the first paper in this new series about the TRACER methodology adapted in the maritime context. This is a guidebook for interested parties involved in maritime accident investigations and technical risk assessments who may be interested in making use of this methodology. With this guidebook, we have tried to facilitate the work of our parent organization, the International Maritime Organization (IMO) and support the considerable efforts it has made and continues to make to raise the profile of accident investigation as a core responsibility for member States. This would also help to improve the outcome of such investigations for the benefit of the wider maritime and ocean community at large.

By making the new paper series of WMU available in electronic format that can be downloaded free of charge and easily distributed, we hope to facilitate the efforts of IMO in areas related to technical cooperation. At the same time, it is intended to be a small contribution from WMU in support of the UN Sustainability Goals 4 and 14, by promoting life-long learning, increased maritime safety and contribute to the sustainability of life below water.

I hope the new paper series is well received by our global community of stakeholders and look forward to many more papers that will address vital maritime and ocean issues.

Dr. Cleopatra Doumbia-Henry

President

World Maritime University

About this guidebook:

This guidebook is the first of a series of WMU Papers in Maritime and Ocean Affairs. It introduces the Human Error Identification technique TRACEr-Mar (**T**echnique for the **R**etrospective and predictive **A**nalysis of **C**ognitive **E**rrors adapted to the **M**aritime Domain).

Modern socio-technical systems had witnessed a complex co-evolution and interaction of both social and technical aspects in the day-to-day reality. However, when an accident occurs in such complex systems, accident causation models always have to simplify the reality and may therefore be limited for fully understanding all the aspects involved in the failing of the maritime socio-technical system involved in that accident. In order to carry out an accident investigation that covers the needs of a particular investigator, different tools exist. A systematic accident analysis requires a full methodological framework consisting of a model to support the focus of the investigation, a related data taxonomy, a methodology for the application of the taxonomy and an outline of the analysis of the findings. This guidebook provides the necessary information for such a framework, TRACEr-Mar, as adapted to the Maritime domain. This framework focusses on human machine interfaces and the related decision making during maritime operations.

The guidebook is addressed to practitioners and researchers determined to apply the TRACEr-Mar technique to maritime accident investigations.

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Gesa Praetorius and **Aditi Kataria** are former members of the Maritime Risk and System Safety (MaRiSa) Group at WMU and have worked in this capacity on this guidebook as part of their involvement in the EU sponsored project CyClaDes – a project focussing on user centred design in the maritime sector.

The authors of this guidebook wish to acknowledge the work and effort of former group member Sarah Hofmann on an earlier version of the book and of current group member Raza Mehdi, who designed the graphs in this guidebook.

About World Maritime University:

The World Maritime University (WMU) in Malmö, Sweden is a postgraduate maritime university founded by the International Maritime Organization (IMO), a specialized agency of the United Nations. Established by an IMO Assembly Resolution in 1983, the aim of WMU is to further enhance the objectives and goals of IMO and IMO member States around the world through education, research, and capacity building to ensure safe, secure, and efficient shipping on clean oceans. WMU is truly an organization by and for the international maritime community.

Find out more at **www.wmu.se**

About the Maritime Risk and System Safety (MaRiSa) Research Group:

The Maritime Risk and System Safety (MaRiSa) Group is a research group at WMU established in 2009. The main focus of the group is risk and safety in maritime socio-technical systems. The main objective for MaRiSa activities is to improve maritime safety by enhancing resilience in maritime operations as well as to inform and support policy makers, stakeholders and end-users in their efforts for safer maritime transportation domain.

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About the WMU Papers in Maritime and Ocean Affairs:

WMU Papers in Maritime and Ocean Affairs is a technical paper series published by WMU. The intention is to include technical reports, guidebooks and discussion papers on contemporary issues in the maritime and ocean domain. In addition to the WMU Papers in Maritime and Ocean Affairs, WMU publishes the WMU Journal of Maritime Affairs (JoMA) and a book series, the WMU Studies in Maritime Affairs. As part of the WMU mission, the WMU Papers in Maritime and Ocean Affairs are published electronically only and made available free download and distribution.

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Guidebook

TRACEr-Mar

*Technique for the **R**etrospective and predictive **A**nalysis of Cognitive **E**rrors
adapted to the **M**aritime Domain*

FOREWORD

Core tasks of maritime administrations relate to the implementation and enforcement of maritime safety standards on board ships and in shipping companies. In this respect, accidents could be an indicator for insufficient regulations or ineffective enforcement provisions. Thorough accident investigation is therefore an important mandate for maritime administrations in order to identify ways to improve the overall safety performance of the fleet in an International Maritime Organization (IMO) member state.

The Maritime Risk and System Safety (MaRiSa) Group at World Maritime University (WMU) has applied a number of accident causation models and models used for the analysis of single aspects of system performance during different studies in recent years. As part of this new WMU series of reports, the MaRiSa group will introduce some of these models, taxonomies and methodologies to demonstrate the potential that systematic application of an analytical framework for accident analysis offers for accident investigation bodies and ultimately increased maritime safety.

This first paper is dedicated to the analytical framework of the **T**echnique for the **R**etrospective and predictive **A**nalysis of Cognitive **E**rrors (TRACer). TRACer was developed with a specific focus on air traffic control as a retrospective incident analysis technique and as a predictive human error identification tool (Shorrock & Kirwan 2002). TRACer focusses on the human-machine interface (HMI) and suggests that incidents are often triggered by underlying cognitive and psychological processes that affect the performance of an operator. TRACer consists of a modular structure comprising eight inter-related taxonomies. The core of the TRACer methodology is the operator's cognitive process and the environment in which the operator carries out a task. The TRACer taxonomy could be used to categorise the findings of the analysis of individual incident and accident reports as well as questionnaires, interviews and other observations. In order to be used in the maritime context, TRACer needed to be adapted accordingly. This adaptation was called TRACer-Mar and developed and used in the EU financed CyClaDes project.

This guidebook introduces the TRACer-Mar framework and will aid the practitioner in applying TRACer-Mar for the retrospective analysis of maritime accidents.

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LIST OF ABBREVIATIONS

AB	Able Seaman
AIS	Automatic Information System
ATC	Air Traffic Control
BNWAS	Bridge Navigational Watch Alarm System
ECDIS	Electronic Chart Display and Information System
ECS	Electronic Chart System
EEM	External Error Mode
HEI	Human Error Identification
HMI	Human Machine Interaction
HRA	Human Reliability Analysis
IEM	Internal Error Mode
IMO	International Maritime Organization
OS	Ordinary Seaman
PEM	Psychological Error Mode
SMoC	Simple Model of Cognition
SHERPA.....	Systematic Human Error Reduction and Prediction Approach
TRACER.....	Technique for the Retrospective and predictive Analysis of Cognitive Errors
VHF	Very High Frequency

1. BACKGROUND TO TRACER-MAR

Core tasks of maritime administrations relate to the implementation and enforcement of maritime safety standards on board ships and in shipping companies. In this respect, accidents could be an indicator for insufficient regulations or ineffective enforcement provisions. Thorough accident investigation is therefore an important mandate for maritime administrations in order to identify ways to improve the overall safety performance of the fleet in an International Maritime Organization (IMO) member state.

In its specific guidelines the IMO highlights the safety aspects in accident investigations. This means that safety investigations carried out by maritime administrations should not have the objective of establishing individual liability. Instead, such investigations are supposed to identify factors that systematically may lead to accidents. In order to deliver on this task, a high degree of harmonization in accident investigation procedures is a pre-requisite. Without guidelines individual investigators may randomly highlight different factors that culminate in the accident. This could lead to a situation where the results of such investigations cannot be used for statistics and trend analysis. Therefore, a tool is needed to set a baseline or standard in investigations that would allow different investigators to focus on similar issues and harmonise the focus and outcome of these investigations.

Modern socio-technical systems, which witness the co-evolution and interaction of both social and technical aspects (Geels, 2004), are highly complex, no less in the maritime sector. However, accident causation models always simplify the reality to a certain extent and may be inadequate for fully understanding the complexity of maritime socio-technical systems. While many accident causation models cannot be used for modelling and analysing an entire socio-technical system, they may be able to focus on single aspects of the overall system performance. This is the reason why, over the years, so many different accident causation models and models of single aspects in socio-technical systems were developed.

A systematic accident analysis requires a full methodological framework consisting of a model to support the focus of the investigation, a related data taxonomy, a methodology for the application of the taxonomy and an outline of the analysis of the findings (Figure 1). This guidebook provides the necessary information for such a framework, TRACer-Mar, the **T**echnique for the **R**etrospective and predictive **A**nalysis of **C**ognitive **E**rrors (TRACer) as adapted to the **M**aritime domain.

The first part of this guidebook sets out the background of TRACer-Mar and includes a discussion of its strengths and weaknesses. The second part introduces the methodology for using TRACer-Mar and includes comments on the validity and reliability of the method. In the third part, the full taxonomy is provided, which in combination with the methodology, allows the coding of accidents using TRACer-Mar.

The guidebook concludes with a commented application example, where an accident was analysed and relevant events were coded. This example will help an inexperienced user to become more familiar with the application of the TRACer-Mar framework.

Figure 1: Framework for casualty investigation (Schröder-Hinrichs, 2003 on the basis of Hollnagel, 1998)

1.1 WHAT IS TRACER ABOUT?

In the past, human error has been held accountable for a large percentage of accidents, including in the maritime domain (Donaldson, 1994). The reduction of human error is a key end goal of human reliability analysis (HRA) as it enables practitioners to assess and enhance the reliability of human operators by reducing the likelihood of errors that can occur (Kirwan, 1994). HRA has three main steps: human error identification (HEI), in which the errors that can occur are identified; human error quantification, in which the probability/likelihood of the errors is quantified; and human error reduction, in which the likelihood of the errors is reduced by taking appropriate measures (Kirwan, 1994).

The Technique for the Retrospective and predictive Analysis of Cognitive Errors (TRACER) is a methodology that facilitates the identification and classification of human errors in relation to human-machine interaction (HMI). TRACER is an HEI method and the premise of HEI is that if one has an understanding of the task and the technology with which it is to be performed (the HMI), one can identify the probable errors that can occur (Stanton, Salmon, & Rafferty, 2013). TRACER was primarily developed for air traffic control (ATC) by Shorrock and Kirwan (2002) as a domain specific tool for HEI. The need for a classification system, specific to ATC had been identified earlier in a feasibility study (Evans et al., 1998), and TRACER fulfilled this vital need. For the developers of TRACER, error analysis is essential for safety management, and a meaningful classification of errors is required to detect trends in incidents and to identify the probable ways a system could fail (Shorrock and Kirwan, 2002). Therefore, TRACER was developed as a comprehensive technique for error classification specific to ATC.

TRACER embodies the Janus' perspective (Shorrock and Kirwan, 2002). The Roman deity Janus presides over beginnings and transitions and is depicted with two faces, looking forward into the future and looking back at the bygone past. In a similar vein, TRACER allows for the identification of errors in a predictive as well as retrospective capacity. For the forward looking predictive application of TRACER, the reader is referred to Shorrock and Kirwan (2002). Their paper focuses on the retrospective application of TRACER for the purpose of incident analysis to classify operator errors and to identify patterns in incidents that contribute to error reduction and/or mitigation.

TRACER was developed iteratively and was based on expert interviews, accident analysis and a review of HEI literature, among others (Shorrock and Kirwan, 2002). TRACER focuses on HMI and a comprehensive analysis of errors by operators in accidents. TRACER adds to the knowledge about errors and their context and provides empirical evidence to nuance human error. TRACER focusses on operator-machine interaction and suggests that incidents are often triggered by cognitive and psychological errors by the operator. External and internal factors also influence the operator's performance.

TRACer consists of a modular structure comprising eight inter-related taxonomies. These taxonomies can be divided into those that describe the context of the incident, those that describe the cognitive background of the production of an error and those relating to incident recovery. The context of the error is captured by the *Task Error, Information and Performance Shaping Factors* (PSF) taxonomies. Error production is classified within TRACer utilising external error modes (EEMs), cognitive framework, internal error modes (IEMs), psychological error mechanisms (PEMs) and error detection and correction (Shorrock and Kirwan, 2002). These taxonomies are discussed in-depth in chapter 3.

1.2 COGNITIVE MODELS UNDERLYING TRACER

A model or framework to support and inform accurate error classification with the help of a taxonomy is extremely important (Figure 1). Shorrock and Kirwan (2002) considered several cognitive frameworks and models of task performance and human error in the development of TRACer. The simple model of cognition (SMoC) by Hollnagel (1998) (Figure 2) and Wickens' (as cited by Liebl et al., 2011) framework (Figure 3) were found to be the most suitable for developing the cognitive framework for TRACer.

SMoC emphasises the cyclical nature of cognition (Figure 2). Wickens' framework (Figure 3) shows that the stimulus need not necessarily start the information flow and that the working memory can internally trigger operator decisions and/or responses. Furthermore, the flow of information need not necessarily progress sequentially through the perception, cognition and action stages. Instead, the long-term memory can directly trigger cognition and (re)action, thereby shortening the flow of information, if required. Together these two models highlight the internal mental processes that shape cognitive errors and formed the basis of the cognitive framework which helps to organise IEMs and PEMs in TRACer (Shorrock and Kirwan, 2002).

Figure 2: Simple model of cognition (adapted from Hollnagel, 1998)

Figure 3: Approach to information processing (adapted from Wickens as cited by Liebl, et al., 2011)

1.3 THE TRACER-MAR FRAMEWORK

Since TRACER was originally developed for the application in aviation with a focus on ATC, it could not directly be applied in the maritime domain and needed to be adapted to the maritime context. The resulting domain specific application was called TRACER-Mar. Figure 4 sets out the applied TRACER framework as adapted to the maritime domain.

In principle, two types of adaptations were made in TRACER-Mar (Schröder-Hinrichs et al., 2016). The first adaptation relates to bringing the ship-system into the coding structure in order to enable coders to portray its complex operations, locations and personnel. The second adaptation mainly relates to the production of the error. Changes made within this aspect were deemed necessary to enrich the outcome of further analyses.

1.3.1 INTRODUCING THE SHIP AS A SOCIO-TECHNICAL SYSTEM

The most significant variation to TRACER was made in relation to the coding of the task errors and to portraying the social and technical complexity of the vessel. TRACER-Mar had to consider multiple operators in various locations involved in different operational tasks. TRACER-Mar categorizes four different locations (bridge, deck, engine (control) room and others) and adds contextual information to the erroneous task (error information). The additional error information relates to the technical equipment used by an operator (e.g., radar, ECDIS, VHF, etc.) and enhances the focus on HMI. In addition, an option to specify subtasks to add clarity, where appropriate, is given. This provides a more substantial description of the task error.

1.3.2 ENHANCING THE OUTCOME OF FURTHER ANALYSES

In order to support databases and analyses, a table containing fixed information (such as size, dimension, etc.) and variable information (such as draught, trim, etc.) about the ship under consideration was added. In addition, a table with a causality level was included. The determination of the causality level (causal, contributory, compounding, or non-contributory) of a task error should enhance the analytical strength of TRACer-Mar.

Another adaptation pertains to the error recovery. A table was added specifying barriers (physical, functional, symbolic, or incorporeal) that were intended to prevent the task error. The main aim of physical or material barriers is to protect personnel and the vessel by blocking or mitigating the effects of the task error (e.g., walls, doors, helmets, etc.). Functional barrier systems (e.g., locks, passwords, distance, sprinklers, firefighting, etc.), in most cases, only work if they are combined with physical barrier systems. They only come into operation when a specific condition exists. A symbolic barrier system (e.g., sign, signals, instructions, procedures, demarcations, etc.) works indirectly through its meaning and hence requires an act of interpretation by someone. An incorporeal barrier system (e.g., informal guidance, formal guidance, rules, restrictions, etc.) lacks material form or substance in the situations where it is applied and instead depends on the user to apply it in order to achieve its purpose.

Although the original TRACer taxonomy considered error recovery, it did not define a coding structure for this element of the technique. The barrier concept for error recovery is also intended to add analytical strength to the technique.

Figure 4: Applied TRACer framework adapted to the maritime domain (adapted from Shorrock and Kirwan, 2002)

2. TRACER-MAR METHODOLOGY

This chapter provides an overview of the TRACer-Mar application methodology and discusses the issue of inter-rater reliability. The chapter concludes with an assessment of the advantages and disadvantages of TRACer-Mar.

2.1 STEPS FOR THE CODING AND ANALYSIS OF MARITIME ACCIDENTS WITH TRACER-MAR

The TRACer-Mar application process has three main aspects – data collection, coding with TRACer-Mar and data analysis (adapted from Walker et al., 2012).

- Data collection
 - Detailed data should be collected with respect to the incident(s) to be analysed. This can include investigation reports, video recordings of incident, and interviews with involved personnel. When more than once incident has to be analysed, databases can be mined and, if required, data sets can be combined.
- Data coding
 - General information: Details of the ship (name, IMO number, type, size and age of vessel), details of incident (where, when, type and severity of incident) and where on the vessel the error was performed that led to the incident.
 - Task error: Who performed the erroneous action? What task was performed wrongly?
 - Error information: Which equipment was involved in the error? Which specific task was performed wrongly? What information concerning the vessel was not taken into account?
 - Causality level: Was the operator performance causal, contributory, compounding or non-contributory to the incident?
 - External error mode: What was the observable manifestation of the task error?
 - Cognitive domain: Was it a perception, memory, and decision-making or action error, or was the error an intended violation?
 - Internal error mode: What specific internal error occurred?
 - Psychological error mechanism: Which psychological mechanisms led to the error?
 - Performance shaping factor: Which internal and external factors had a negative influence on operator performance?
 - Error recovery: Which barriers were in place that prevented the incident from developing into a catastrophe/total loss?
 - Calculation of inter-rater reliability.
- Data analysis
 - Frequency counts obtained from the coding can be utilised to analyse data. An overview of the data analysis of multiple accident cases can be obtained from frequencies and their distribution.

Figure 5 depicts the process of coding incidents using TRACer-Mar. The process commences with filling in the narrative and generic information of the incident and continues in a cyclical manner until all of the identified task errors have been classified according to the relevant TRACer-Mar taxonomies (see Chapter 3 for the detailed TRACer-Mar taxonomy tables).

Figure 5: TRACer-Mar process application (adapted from Shorrock and Kirwan, 2002)

2.2 TRACER AND INTER-RATER RELIABILITY

TRACer-Mar, as adapted to maritime operations based on the original TRACer methodology (Shorrock & Kirwan, 2002), focuses on error classification and coding of those errors involved in individual accidents. Although TRACer has been used for human error (retrospective) analysis and prediction, there is still a lack of validation procedures that are generally applicable across domains (Walker et al., 2012). The scope of this guidebook encompasses the application of the taxonomy in the context of maritime accidents. Further research studies utilising the taxonomy could contribute to its validation in the maritime context.

In order to enhance the TRACer-Mar framework, some comments about inter-rater reliability should be given. Inter-rater reliability is a measure of the consistency of the rating/coding in a study. It is applied if more than one person has been involved in the coding and is a measure to determine the degree to which the “raters” (i.e., coders) agree to and are consistent in scoring/rating. Differences in rating are the result of variability among the “raters”; no humans are alike and most ratings rely on a certain degree of interpretation and therefore subjectivity. This variability should be considered carefully and counterbalanced in the design phase. The measure of inter-rater reliability provides a score for the homogeneity of the rating and indicates if a further refinement of scales might be required (Heiman, 2001). One technique to determine the inter-rater reliability is the application of reliability testing instruments such as Cohen’s Kappa (Walker et al., 2012), which measures agreement between categorical variables. It is recommended to consider this method when applying TRACer-Mar.

As TRACer-Mar is based on the coding being conducted by “raters”, it is important to ensure that the raters show consistency across their coding. Several researchers, among others Stanton et al. (2013), point out that the original TRACer has been prone to misinterpretations and inconsistencies in its application by analysts. This was considered during the adaptation of TRACer to the maritime domain and it is hoped that issues that have been criticized previously have been dealt with by the adaptation.

2.3 ADVANTAGES AND DISADVANTAGES OF TRACER

Advantages and disadvantages of the TRACer framework are as follows:

Advantages

- TRACer is a comprehensive HEI method.
- It can be used predictively to identify probable errors that may occur in a specific scenario.
- It can be used retrospectively to classify and analyse errors in incidents.
- TRACer was primarily developed for ATC, however due to most of its generic taxonomies, it has been applied in other domains such as rail transport (Baysari, Caponecchia, McIntosh, & Wilson, 2009) and now even in the maritime domain (Graziano et al., 2016; Schröder-Hinrichs et al. 2016).
- Even though it heavily focuses on errors performed by the individual operator, it considers PSFs, which are system-wide.
- Can be undertaken with a pen and paper and related taxonomies.

Disadvantages

- May appear overcomplicated due to its comprehensiveness.
- Training and application time may be high due to its exhaustive nature.
- It can be difficult to find data to support TRACer analyses without access to personnel involved in the incident.
- Even though there is encouraging usability data for the method, there is a lack of validation of the method in the academic literature.
- Other error classification approaches such as the Systematic Human Error Reduction and Prediction Approach (SHERPA) could be quicker and simpler to use.
- Exclusive focus on errors detracts from considering the wider organisational system in detail.
- As TRACer was developed for ATC, some of its taxonomies cannot be applied to other domains.

A key strength of TRACer is that it can help a practitioner to comprehensively identify and classify operator errors in operator-machine interaction. The fact that it can be used both predictively and retrospectively enhances its utility. Most of the TRACer taxonomies are generic in nature, which allow the method to be seamlessly adapted to other domains. TRACer considers system-wide PSFs and this adds depth to the taxonomy, which primarily focuses on human error. TRACer only requires copies of the pertinent taxonomies and pen and paper for its application, making it easy to use.

On the flip side, its comprehensiveness may make the method seem overly complicated and it may require a long training and application time. At times it can be difficult to access involved personnel and obtain data to support TRACer analysis. This can be overcome and balanced with comprehensive data collection. The usability data for the method is encouraging; however there is a lack of validation of the methodology, suggesting that more studies are required to validate the method. A focus on errors does detract from the wider organisational system, however this can be balanced by addressing PSFs. Some of the TRACer taxonomies are specific to ATC so other domains will need to develop their own domain specific taxonomies (Walker et al., 2012). This was one of the motivations to develop TRACer-Mar for the maritime domain.

3. TRACer-MAR TAXONOMY

The TRACer-Mar taxonomy has a modular architecture that includes nine coding steps or classification schemes that can be divided into three main groups which describe (i) the context of the incident, (ii) the production of the error (operator context) and (iii) the recovery from the incident. The taxonomy includes the description of the error, the psychological explanation of the error, measures of error recovery as well as explanations pertaining to performance shaping factors and the causality level of the error. Table 1 provides an overview of the nine inter-related TRACer steps. In subsequent sections of this chapter, each of these steps is described in detail.

Table 1: Description of TRACer-Mar steps

TRACER 1 st level	TRACER 2 nd level	Description
Context of incident	1. Task errors	Describe human error in term of task that was not performed satisfactorily
	2. Error information	Describe the subject matter or the topic of the error, i.e., the human-machine interface
	3. Causality level	Human error is classified as being causal, contributory, compounding or non-contributory to an accident
Operator context	4. External error mode	External and observable manifestation of the actual error
	5. Cognitive domain	Describe the process within which the error occurs (perception, memory, decision, or action)
	6. IEM	Describe what cognitive function failed or could fail and in what way
	7. PEM	Describe the psychological nature of the IEMs, the cognitive biases that are known to affect performance
	8. PSF	Classify factors that have influenced or could influence performance, aggravated the occurrence of errors or assisted error recovery
Error recovery	9. Error recovery	Classify how the driver was recovered and what factors influenced the recovery of the error

Before analysing any data, some general information is required about the vessel involved in the accident/incident or near-miss to make sure that no event is double-coded (table 2). This information will also provide insight about what factors correlate with maritime occurrences. This step is conducted prior to the identification of any task error.

Table 2: Generic vessel information

IMO vessel number/call sign	Note the IMO vessel number, when indicated. Otherwise please note the call sign of the vessel for identification
Name of vessel	Name of the vessel at the time of the occurrence as indicated in the report
Date of occurrence	The date of the occurrence as indicated in the report
Geographical position	Insert the GPS location of the vessel when the incident occurred
Severity of occurrence	Near-miss, on-board injury/fatality, mitigated loss, severe loss, total loss
Type of occurrence	Fire, explosion, grounding, foundering, stranding, capsized, listed, flooded, collision, hull, machinery, other
Flag state	The flag state of the vessel at the time of the occurrence (when indicated in the report)
Type of vessel	Tanker, combined carrier, product carrier, gas carrier, chemical carrier, bulk carrier, Ro-Ro, tween decker, container carrier, reefer, cruise ship, ferry
Deadweight or GRT	The deadweight or GRT of the vessel as indicated in the report
Age of vessel	The age of the vessel at the time of occurrence, in years, should be noted
Station on the vessel	The location on the vessel where the incident was triggered should be identified

3.1 CONTEXT OF THE INCIDENT

As shown in Table 1, the Context of the Incident comprise three level of information. In the first level, the Task Error, the context of the error is analysed; In the second level, the coder or analyst shall identify what equipment was involved at the time of the error, if any; In the third and last level, the causality level is determined. The three levels are described in more details in the following sections.

3.1.1 TASK ERROR

The first step of TRACer-Mar tries to capture the context of the error. During the performance of which task did the error occur? To capture the context of the accident/incident, a narrative should be drafted and a chronological order of the events should be developed by the coder. The text of the conclusion of the report can be very useful for the narrative and summarize what happened. During this step, it is thus relevant to identify the location where (e.g., bridge, deck, engine control room) the task was performed and who performed it (e.g., captain, pilot, first officer, bosun, able bodied seaman AB) (table 3). The task error is therefore chosen according to the identified location and for each one a list of possible tasks and subtasks is available for codification. It is important to bear in mind that the taxonomy architecture was designed such that for each task error only one location, one operator and one user material (technical equipment) should be entered in the system. For example, if the operator makes an error that involves two piece of equipment (e.g., Radar and AIS), two task errors must be created. Once a task error has been identified, the coder shall choose from a list the subtask associated with the particular task error. This increased granularity is particularly relevant when it associates the task error with the technical equipment involved and for in-depth statistical analyses. Part of the taxonomy has been adapted following the suggestions made by Graziano, Teixeira, and Guedes Soares (2016).

Table 3: Operator

Operator performing the task error	
Bridge	Indicate the operator (master, chief officer, second officer, helmsman, deck cadet officer, etc.)
Deck	Indicate the operator (bosun, AB, oiler, etc.)
Engine (Control) Room	Indicate the operator (chief engineer, second engineer, third engineer, etc.)
Other	Please indicate in writing

Tables 4, 5 and 6 outline the task errors created for each location on board: bridge, deck and engine (control) room. After having identified the operator and the location, the coder must identify the nature of the task the operator was performing at the time the error occurred.

Table 4: Task errors attributed to location bridge

Bridge	
Internal communication	Communication between crew members both on the bridge or between the bridge and the engine control room or the bridge and the deck
External communication	Communication between a crew member and a third party on another vessel or ashore
Hand-over/take-over	Some relevant information was not passed on during the hand-over process. This information was crucial and led to or contributed to the accident
Safety drills	The safety drills were not performed according to the regulations. This led to a situation where an emergency could not be brought under control
Supervision	Supervision was not performed with care. A mistake was not noticed and led to the incident. This also involves the control exercised over another crew member tasked to do a specific job
Navigation	A navigational error occurred and led to an emergency situation (e.g., manoeuvring errors, course change)
Traffic monitoring and Watchkeeping	The traffic was not monitored with enough attention; critical information was not perceived and this led to an incident. Watchkeeping was not conducted with care. Errors belonging in this category deal with the general control of the surroundings of the vessel and/or position of the vessel. This category should not be confused with navigation
Voyage planning including preparation	An error occurred during voyage planning. The error was not discovered and led to a risky situation. It is important to specify the equipment, if any, used when the error was performed
Other tasks	Any other task related to the bridge personnel that was not performed properly and had serious consequences. Free text category

Table 5: Task errors attributed to location deck

Deck	
Internal communication	Communication between crew members
External communication	Communication between a crew member and a third party on another vessel or ashore
Hand-over/take-over	Some relevant information was not passed on during the hand-over process. This information was crucial and led to or contributed to the accident
Safety drills	The safety drills were not performed according to the regulations. This led to a situation where an emergency could not be controlled
Supervision	Supervision was not performed with care. A mistake was not noticed and led to an incident. It also involves the oversight of another crew member tasked to do a specific job
Mooring operations	During mooring operations a mistake was made that had negative consequences
Cargo-work	During cargo-handling work a mistake led to an emergency situation
Maintenance work	During maintenance work an error led to a risky situation
Other tasks	Any other task that was performed by the deck personnel and which was performed faultily and led to an incident

Table 6: Task errors attributed to location engine (control) room

Engine (Control) Room	
Internal communication	Communication between crew members
Hand-over/take-over	Some relevant information was not passed on during the hand-over process. This information was crucial and led to or contributed to the accident
Safety drills	The safety drills were not performed according to the regulations. This led to a situation where an emergency could not be controlled
Supervision	Supervision was not performed with care. A mistake was not noticed and led to the incident. It also involves the oversight of another crew member tasked to do a specific job
Monitoring of engine room control panel	The monitoring of the engine room control panel was not performed with enough care and this action led to an emergency. It also involves the engine room panel in the cabin of the engineer on watch during night hours
Maintenance of equipment	During maintenance work an error led to a risky situation
Other tasks	Any other task that was performed by the engine room personnel and which was performed faultily and led to an incident

3.1.2 ERROR INFORMATION

The category ‘error information’ helps the researcher to look more closely at the context of an accident. It deals with the equipment involved in the error, denoted as ‘user material’ in the taxonomy (e.g., radar, GPS, ECDIS, AIS, alarm panels), and which information concerning the vessel, if any, was not taken into account and represents a contributory factor to the accident (e.g., size and dimension, stability of the vessel, condition of navigational aids). The coder should be aware that the technical equipment is directly related to the location and that for each task error identified in tables 4, 5 and 6, a subtask must be chosen; this additional step gives more granularity to understanding the error.

3.1.2.1 USER MATERIAL (TECHNICAL EQUIPMENT)

The user material relates to the technical and non-technical equipment that is used on a vessel. It is separated into the three locations for more detailed analysis (tables 7, 8 and 9). Once the bridge, deck or engine (control) room has been chosen as the location where the task error happened, the available technical equipment that was not working properly or from which some information was deducted or misinterpreted can be identified.

Table 7: User material for location bridge

Bridge	
Radar	Information from the radar was read out or interpreted wrongly or not taken into account
GPS	Information from the GPS was read out or interpreted wrongly or not taken into account
BNWAS	The BNWAS was switched off or the alarm was not audible
ECDIS	Information from the ECDIS was read out or interpreted wrongly or not taken into account
ECS	Information from the ECS was read out or interpreted wrongly or not taken into account
AIS	Information from the AIS was read out or interpreted wrongly or not taken into account
Echo sounder	Information from the echo sounder was read out or interpreted wrongly or not taken into account
Autopilot	Faulty interaction with the autopilot led to the incident
Steering panel	Faulty interaction with the steering panel led to the incident
External equipment	Faulty interaction with the external equipment led to the incident
Sea chart	Information from the sea chart was read out or interpreted wrongly or not taken into account
VHF	Problems with the VHF led to the occurrence of an error
Other communication devices	Problems with the other communication devices led to the occurrence of an error
Alarm panels	Information from alarm panels was read out or interpreted wrongly or not taken into account
Engine room controls	Information from engine room controls was read out or interpreted wrongly or not taken into account
Checklists & forms	Checklists or forms were not filled out as required leading to an incident
Handbooks	Information from handbooks was read out or interpreted wrongly or not taken into account
Decision support system (paper, electronic)	Faulty interaction with the decision support system led to the incident
Stairs & ladders	An error occurred while the operator was using the stairs or a ladder
Other material	Other material was used when the error occurred
No technical equipment involved	The task error did not involve a human-machine/tool-interface

Table 8: User material for location deck

Deck	
Communication devices	Problems with communication devices led to the occurrence of an error
Monitoring devices	Problems with monitoring devices led to the occurrence of an error
Loading devices (cranes, pumps)	Problems with loading devices led to the occurrence of an error
Mooring equipment	Problems with mooring equipment led to the occurrence of an error
Forms, checklists	Checklists or forms were not filled out as required leading to an incident
Other working tools	Other working tools were in use when the error occurred
Stairs & ladders	An error occurred while the operator was using the stairs or a ladder
Emergency response equipment	Problems with emergency response equipment led to the occurrence of an error
Other material	Other material was used when the error occurred
No technical equipment involved	The task error did not involve a human-machine/tool-interface

Table 9: User material for location engine (control) room

Engine (Control) Room	
Main engine	Problems with the main engine led to the occurrence of an error
Auxiliary engine	Problems with an auxiliary engine led to the occurrence of an error
Engine control room panel	Information from the engine control room panel was read out or interpreted wrongly or not taken into account
Fuel pumps	Problems with fuel pumps led to the occurrence of an error
Boilers	Problems with boilers led to the occurrence of an error
Turbo chargers	Problems with turbo chargers led to the occurrence of an error
Separators	Problems with separators led to the occurrence of an error
Ballast water pumps	Problems with ballast water pumps led to the occurrence of an error
Communication equipment	Problems with communication equipment led to the occurrence of an error
Forms, checklists	Checklists or forms were not filled out as required leading to an incident
Handbooks	Information from handbooks was read out or interpreted wrongly or not taken into account
Generators	Problems with generators led to the occurrence of an error
Electricity control panel	Problems with an electricity control panel led to the occurrence of an error
Stairs & ladders	An error occurred while the operator was using the stairs or a ladder
Steering system	Problems with the steering system led to the occurrence of an error
Other material	Other material was used when the error occurred
No technical equipment involved	The task error did not involve a human-machine/tool-interface

3.1.2.2 USER ACTIVITIES

For every task error identified above (tables 4, 5 and 6) a subtask or user activity is added in order to give a better understanding of the activity performed by the operator. For each task error, it is possible to choose between several subtasks, which are set out in tables 10, 11 and 12 for bridge, deck and engine (control) room respectively.

Table 10: User activities for location Bridge

Bridge	
Internal communication	Communication between bridge officers, between officers and the captain, between bridge and deck, between bridge and engine room, between bridge officers and helmsman
External communication	Communication between bridge and pilot, bridge and port employees, bridge and tug boat
Hand-over/take-over	Hand-over between captain and officers, between officers
Safety drills	Safety drills not performed with care
Supervision	Supervision of deck work, bridge tasks, engine room work
Navigation	Dead reckoning, radar navigation, satellite navigation, pilotage, manoeuvring, emergency manoeuvring
Traffic monitoring & watchkeeping	Watchkeeping (maintaining a proper lookout), monitoring equipment regarding traffic, anchorage, monitoring of sea chart

Table 10 (cont.): User activities for location Bridge

Voyage planning including preparation	Appraisal, planning, monitoring
Other tasks	Other tasks were performed unsatisfactorily leading to the error. Please indicate in writing

Table 11: User activities for location deck

Deck	
Internal communication	Communication between, e.g., ABs/OSs, between bosun and AB/OS, between bridge and deck, between deck and engine room
External communication	Communication between deck personnel and pilot, port employees, tug boat
Hand-over/take-over	Hand-over of tasks between AB/OS, between bosun and AB/OS
Safety drills	Safety drills not performed with care
Supervision	Supervision of deck work
Mooring operations	Mooring in harbour, anchoring
Cargo work	In harbour, en route, loading, unloading
Maintenance work	Painting, rust removal, maintenance of machinery, maintenance deck
Other tasks	Other tasks were performed unsatisfactorily leading to the error. Please indicate in writing

Table 12: User activities for location engine (control) room

Engine (Control) Room	
Internal communication	Communication between engineers, between AB/OS, between AB/OS and engineers, between engine room and deck, between bridge and engine room
Hand-over/take-over	Hand-over tasks between engineers, between AB/OS, between engineers and ABs/OSs
Safety drills	Safety drills not performed with care
Supervision	Supervision of engine room work
Monitoring of engine room control panel	The engine room control panel was not monitored at all or not monitored with care so that information was not registered, information was wrongly interpreted
Maintenance work	Painting, rust removal, maintenance of machinery
Other tasks	Other tasks were performed unsatisfactorily leading to the error. Please indicate in writing

3.1.2.3 SHIP FIXED INFORMATION

Coding must also capture ship fixed information mentioned in the accident report that was not taken into account or underestimated as it could be a contributory factor to the incident (table 13).

Table 13: Ship fixed information

Ship fixed information	
Size and dimensions	Fixed information about the build of the ship was not taken into account leading to an incident
Manoeuvring characteristics	Fixed information concerning the reaction of the ship to manoeuvres and its movement characteristics in water was not taken into account leading to an incident
Main engine specifics, propulsion	Fixed information concerning the performance of a vessel's machinery was not taken into account leading to an incident
Stability of the vessel	Information on how stable a ship is in a certain situation and how she reacts was not taken into account leading to an incident

3.1.2.4 SHIP VARIABLE INFORMATION

As for ship fixed information, information varies between vessels that must also be considered during coding as it could be a contributory factor to the incident (table 14).

Table 14: Ship variable information

Ship variable information	
Draught, trim, list, current stability	Specific information for the ship concerning the draught, list, trim or current stability issues were not taken into account and lead to an incident
Current propulsion, machinery deficiencies	Specific information concerning the propulsion, machinery deficiencies or other similar issues were not taken into account and lead to an incident
Condition of navigational aids	Specific information concerning the condition of navigational aids, i.e., problems or deficiencies, were not taken into account and lead to an incident. Error margins or variations in the display of information were not taken into account

3.1.3 CAUSALITY LEVEL

To complete the analysis, it is essential to classify the errors by their causality level, i.e., their significance in contributing to the error. Table 15 sets out four levels of causality.

Table 15: Error causality level

Type	Description
Causal	The operator's action was the ultimate cause without which the incident would not have happened
Contributory	An error that contributed to the incident and occurred in addition to the causal error but the error would probably still have occurred
Compounding	An error that made the situation worse and that occurred after the person realised that the situation was going to occur
Non-contributory	Other errors that occurred but had no bearing on the situation

3.2 CONTEXT OF THE OPERATOR

The main strength of the TRACer-Mar taxonomy is represented by the operator's cognitive process and the context in which the operator is operating while performing an erroneous task. The focus on the cognitive context is in line with the need to analyse the performance variability of an operator where performance variability is defined as "the way in which individual and collective performances are adjusted to match current demands and resources, in order to ensure that things go right" (EUROCONTROL, 2009). Understanding how crew members adjust or not their performance during both expected and unexpected conditions may help further studies on how to enhance system response. In this regard, TRACer-Mar considers additional five steps: the external error mode (EEM); cognitive domain; internal error mode (IEM); psychological error mechanism (PEM); and performance shaping factor (PSF). The focus at this point of the coding is to emphasise the error production and to analyse in detail which external and internal factors may have had an influence on the crew member.

3.2.1 EXTERNAL ERROR MODE

One of the first challenges is the coding of the different error modes (EEM). The EEM, according to Shorrock and Kirwan (2002), is the external and observable manifestation of an error based on the logical outcome of an erroneous action in term of timing sequence, selection, quality, etc. EEMs are generally context free and independent from any cognitive process. EEMs are classified in three main areas: selection and quality, timing and sequence, and communication (table 16). This category is often used only for error prediction due to its limited descriptive nature. A full overview is given below.

Table 16: Overview of external error mode

Selection and quality	Timing and Sequence	Communication
Omission	Action too long	Unclear information transmitted
Action too much	Action too short	Unclear information recorded
Action too little	Action too early	Information not sought/obtained
Action in wrong direction	Action too late	Information not transmitted
Wrong action on right object	Action repeated	Information not recorded
Right action on wrong object	Mis-ordering	Incomplete information transmitted
Wrong action on wrong object		Incomplete information recorded
Extraneous act		Incorrect information transmitted
		Incorrect information recorded

3.2.2 COGNITIVE DOMAIN

The cognitive domain represent the taxonomy level that potentially applies to the error under consideration, i.e., perception, memory, decision-making and action. These four categories deal with errors that are non-intentional. The final category, violation, indicates a voluntary breach of the rules.

- *Perception* deals with the input of information and the question of whether or not the user received the necessary information in order to be able to process it.
- *Memory* means that the user did perceive the information, but did not deal with the perceived critical situation or the crucial information in the way the he or she should have due to not remembering correctly or to not knowing what to do.
- *Decision-making* means that the user received the crucial information and processed it correctly, but came to a wrong conclusion and therefore took a wrong decision.

- *Action* means that the user perceived and processed the information correctly, made a correct decision, but then made a mistake in the implementation of the action.
- *Violation* means an intended violation of rules and regulations that finally led to the incident. This category is added based on Reasons (1990) model summarizing the principal error types.

The categories IEM and PEM are strictly related to the cognitive domain chosen (table 17). Both represent a better explanation of the cognitive domain by providing a description of what cognitive function failed, or could fail, and in what way (Shorrock & Kirwan 2002). IEMs describe the internal taxonomy of the seafarer's error within each cognitive domain, i.e., what error did the user commit. PEMs describe the psychological reason(s) that can be attributed to the occurrence of the error. Tables 18, 19, 20 and 21 describe these taxonomies in detail.

Table 17: List of IEMs and PEMs

Internal Error Mode	Psychology Error Mechanism
Perception	
Mishear	Expectation
Mis-see	Confusion
No detection (audio or visual)	Discrimination failure
Late auditory recognition	Tunnel vision
Late detection (visual)	Overloaded
Repeat error	Vigilance
Misread	Distraction/ preoccupation
Visual misperception	
Memory	
Forget to monitor	Memory confusion
Omitted or late action	Memory overloaded
Forget temporary information	Insufficient familiarisation /learning
Forget store information	Mental block
Mis-recall information or action	Distraction/ preoccupation
Prospective memory failure	Similarity interference
Forget to ask/share information	
Decision-making	
Mis-projection	Misinterpretation
Poor decision and poor planning	Failure to consider side or long term effects
Late decision or late planning	Mind set
No decision or no planning	Knowledge / competency problem
	Decision freeze or overloaded
	Risk recognition failure
Action	
Information or data entry error	Manual variability
Selection error	Confusion
Unclear information	Habit intrusion
Incorrect information	Distraction/ preoccupation
Non – performed action	Other slip
Timing error	
Unclear information recorded	
Information not transmit	

3.2.2.1 INTERNAL ERROR MODE

After selecting the cognitive domain, the first step is to choose the most likely IEM for the identified cognitive domain. The single most appropriate IEM should be selected from the identified domains and recorded. Tables 18 and 19 set out details for each IEM by cognitive domain.

Table 18: IEM: Perception and memory

Perception	
Mishear	The signal(s) of technical equipment were not heard accurately
Mis-see	The signal of technical equipment was not seen properly. This aspect focusses on the ergonomic or physical part of human perception
No detection (audio/visual)	The signal of technical equipment was not seen or heard
Late detection	The signal of technical equipment was only detected when it was too late to correct the situation
Repeated error	Repeating a mistake leading to a worsening of the situation
Misread	The information from the technical equipment was misread
Visual misperception	The visual signal was inaccurately perceived/ misperceived by the operator
Memory	
Forget to monitor	The operator forgot to monitor the technical equipment
Omitted or late action	The error leading to the accident can be traced back to an operator who omitted to act or reacted late to a warning signal
Forget temporary information	The error can be traced back to a user who temporarily forgot relevant information
Forget to store information	The error can be traced back to a failure in storing relevant information
Mis-recall information/action	The user recalls inaccurate information and provides an inaccurate account of his or her actions post incident
Prospective memory failure	Post-incident failure in recalling the event as it happened
Forget to ask / share information	The operator suffered from a lack of information as he or she forgot to ask for relevant information/ share relevant information with other crew members

Table 19: IEM: Decision-making and action

Decision-making	
Mis-projection	Faulty interpretation of information
Poor decision/planning	A wrong decision taken that led to or could not prevent the incident
Late decision/planning	The decision was taken too late to prevent the incident
No decision/planning	No decision was taken to prevent the incident
Action	
Information/data entry error	The wrong information was entered into technical equipment

Table 19 (cont.): IEM: Decision-making and action

Selection error	The wrong technical equipment was selected for performing a certain task
Unclear information	The information transferred to another party via technical equipment was not clear
Incorrect information	The information transferred to another involved party via technical equipment was not correct
Non-performed action	No action was taken in order to prevent the incident
Timing error	The action taken was not faulty itself, but occurred at the wrong moment
Unclear information recorded	The information that was recorded was not clear
Information not transmitted	Necessary information was not transmitted / transferred to the involved parties
Violation	
Routine violation	On the vessel informal work practises were followed instead of complying with formal rules. The formal rule was routinely disobeyed
Exceptional violation	The formal rule was not followed only in this one scenario, which led to the incident
Sabotage	The official rule was not followed with the intention to cause harm

3.2.2.2 PSYCHOLOGICAL ERROR MECHANISM

After the IEM is identified, the next step is choosing the most likely PEM. The PEM needs to correspond to the same domain as the IEM (tables 20 and 21). For instance, if the IEM is selected from the memory domain, then the PEM is also selected from the memory domain. More than one PEM can be selected for each error. PEMs are fundamental to describing the psychological reason(s) that determine why the error occurred.

Table 20: PEM: Perception and memory

Perception	
Expectation	Information was not perceived properly as the operator was influenced by an expectation bias, i.e., the operator only perceived the information that was expected and supported his or her view of the situation
Confusion	The operator confused information with something else
Discrimination failure	The operator received the information, but did not process it as it was perceived to be irrelevant
Tunnel vision	The operator focused on one single technical equipment or piece of information, ignoring all the others and not perceiving the relevant information
Overloaded	The operator was overloaded with other information and therefore did not perceive the new information
Vigilance	The operator did not perceive the necessary information due to lack of vigilance
Distraction	The operator was distracted and therefore did not perceive the information
Memory	
Memory confusion	The operator got confused and used the wrong information for the given situation

Table 20 (cont.): PEM: Perception and memory

Memory overload	The operator's memory was overloaded as he or she was simultaneously processing other information
Insufficient familiarisation	The operator was not familiar with the kind of information that should be processed and therefore erred in processing it
Mental block	Operator could not access the relevant information
Distraction	The operator was processing other information and therefore did not realize the relevance of the new information and failed to process it
Similarity interference	Due to the similarity of the character of the information the operator processed the information based on wrong assumptions

Table 21: PEM: Decision-making and action

Decision-making	
Misinterpretation	The data were misinterpreted leading to a wrong decision
Failure to consider side or long-term effects	The operator did not consider the long-term or side effects of the situation
Mind set	The mind set and world view of the operator had an important influence on decision-making and eventually led to a wrong decision
Knowledge/competency problems	The operator did not have the necessary competency or knowledge to make the right decision
Decision freeze or overload	The operator was overloaded with information or tasks and was therefore unable to make a decision
Risk cognition failure	The operator failed to recognize the risk in a given situation or the decision taken
Action	
Manual variability	The risky situation occurred due to a mistake in the manual handling of technical equipment
Confusion	The operator got confused and used the wrong technical equipment for the action he or she wanted to perform
Habit intrusion	Out of habit the operator handled the technical equipment in a certain way. However, this action led to a mistake in the given situation
Distraction/preoccupation	The operator was distracted or preoccupied with something else and therefore did not perform the necessary action
Other slip	Any other slip that occurred in connection with the handling of technical equipment
(Intended) Violation	
Stress/pressure	Stress and pressure to perform lead to risky actions that consciously violated existing rules
Fatigue	Body and cognitive fatigue leading to risk taking behaviour/risky decisions being taken consciously
Intoxication	The operator is intoxicated due to alcohol, drugs or medicine and consciously makes a risky decision
Lack of knowledge	The operator takes a risk knowing the rules that are being violated, but not being aware of/not knowing the potential consequences
Emotional condition	The operator is dissatisfied or emotionally unstable leading him or her to willingly not follow the procedures and rules in place

3.2.3 PERFORMANCE SHAPING FACTORS

The final category of the operator context level is the PSF. PSFs help to classify all factors that could have influenced the performance of the crew member: personal factors, aspects of communication/information, internal/external environment, organisational factors and other. Tables 22 set out the details of the PSFs.

Table 22: Performance Shaping Factors I

Personal factors	
Cognitive fatigue	Cognitive fatigue influenced a person's performance in an emergency situation
Body fatigue	Body fatigue influenced a person's performance in an emergency situation
Stress	A person being qualitatively or quantitatively overloaded or under challenged which influenced his or her performance
Intoxication	A person was intoxicated either by alcohol, drugs, medicine or by engine fumes. This led to a limitation in their performance
Emotional condition	The person was preoccupied with some personal matters and did not perform at their usual level
Aspects of communication/information	
Ambiguous information	The information received from technical equipment or other persons was ambiguous and the person did not know which information to rely on
Lack of information	The person did not have the crucial information at hand to come to a good conclusion in a certain situation
Wrong information	The received information for decision-making was wrong
Language problems	Misunderstandings occurred due to language barriers
Miscommunication	Miscommunication occurred for various reasons
Training/competence	
Lack of experience	The person lacked experience and could not perform to expected standards
Lack of orientation	The person did not have the necessary orientation in a certain situation and this decreased his or her performance level
Inadequate training/instruction	The person had inadequate instruction and training on how to react/what to do in a certain situation and therefore could not perform to the expected standards
No training	The person had no training and could not perform to the expected standards
Internal/external environment	
Weather	Weather/climate and related issues had an influence on the operator or the technical equipment and influenced his/her/its performance
Time of day	Sunshine or darkness influenced the operator's performance
Atmosphere on the vessel	The onboard workplace environment influenced the individual behaviour of the operator leading to worse performance
Business climate	The business operations of the shipping company influenced the performance on board the vessel, e.g., budget restrictions
Organisational factors	
Organisational culture	The overall organisational culture of the shipping company had an influence on the performance on the ship (e.g. safety culture)
Organisational structure	The organisational structure of the shipping company had an influence on the performance on the ship
Organisational policies	The organisational policies of the shipping company had an influence on the performance on the ship

Table 22: cont.

Operations	The organisational operations of the shipping company had an influence on the performance on the ship
Procedures	The organisational procedures of the shipping company had an influence on the performance on the ship
Supervision	A lack of supervision had a negative influence on shipboard operations
Manning/staffing characteristics	Manning policies, i.e., international crewing, had an influence on the performance of the individual operators on board the vessel
Time pressure	Pressure to meet a deadline set by the shipping company led to decreased performance by the operator
Other	
Other factors	Any other factor that had a negative influence on the performance of the operator

3.3 ERROR RECOVERY

Looking at accident models it becomes clear that at some point a barrier should arise to prevent the incident from happening. If a barrier is efficient and effective, the accident can be prevented and it will cause a near-miss. If the barriers however do not work properly, an accident will ensue. Hollnagel (2004) differentiates between physical, functional, symbolic and incorporeal barriers (tables 23, 24, 25 and 26).

3.3.1 PHYSICAL BARRIERS

Physical barriers are passive barriers that fulfil their purpose by themselves (table 23). The aim of physical or material barriers is to protect by blocking or mitigating the effects of an action.

Table 23: Physical barriers

Physical barrier	
Wall, doors, fences, containers...	Prevents penetration of people into unsafe areas
Helmets, safety clothes, gas masks...	Prevents penetration of dangerous material into the human body
Safety glass, fire safe rooms, fire doors...	Prevents penetration of dangerous material into a place/space

3.3.2 FUNCTIONAL BARRIERS

Functional barrier systems in most cases only work if they are combined with physical barrier systems (table 24). These barriers need to be active or ready in order to work. They only start to function when a specific condition exists.

Table 24: Functional barriers

Functional barrier	
Locks, physically interlocking...	Preventing movement or action concerning “hardware”
Passwords, entry codes, action sequences, pre-conditions...	Preventing movement or action concerning “software”
Distance (too far away for being touched by mistake), persistence (dead-man button) ...	Hindering or impeding actions in a spatio-temporal sense
Sprinklers, air bags, fire extinguisher...	Dissipating energy, quenching, or extinguishing

3.3.3 SYMBOLIC BARRIERS

A symbolic barrier system works indirectly through its meaning and hence requires an act of interpretation by someone (table 25).

Table 25: Symbolic barriers

Symbolic barrier	
Demarcations, labels, warnings...	Countering, preventing or thwarting actions
Instructions, procedures, precautions, conditions, dialogues	Regulating actions
Signs, signals, warnings, alarms...	Indicating system status or conditions
Clearance, approval...	Communication and interpersonal dependency

3.3.4 INCORPOREAL BARRIERS

An incorporeal barrier system lacks material form or substance in the situations where it is applied and instead depends on the user in order to achieve its purpose (table 26).

Table 26: Incorporeal barriers

Incorporeal barrier	
Informal guidance: self-restraint, ethical norms, morals, social or group pressure...	Complying with or conforming to these rules will help to recover from an accident
Formal guidance: Rules, restrictions, laws, guidelines, prohibitions, training...	Complying with or conforming to these rules will help to recover from an accident

4. TRACer-MAR COMMENTED APPLICATION EXAMPLE

In this section the TRACer-MAR taxonomy is applied to an accident reported by the Maritime Accident Investigation Body (MAIB) of the UK. In the summary an overall sequence of the accident is presented. In section 4.2 a comprehensive list of the identified task errors is given to the reader. However, for the purpose of this Chapter, the TRACer-MAR taxonomy is thoroughly applied only to the first two task errors, respectively in section 4.2.1 and 4.2.2. Tables 28 and 29 condensate the various coding in accordance to the taxonomy structure. For each code, a reference to the original taxonomy is made on the extreme right column. A brief explanation of the coding rationale is given.

4.1 SUMMARY

At 0308 UTC on 12 December 2012, the dry cargo vessel Beaumont ran aground on Cabo Negro on the north Spanish coast while on passage from la Coruna to Avilés. At the time of the grounding she was proceeding at full speed, and the officer of the watch (OOW) was asleep. An inspection of the vessel's internal compartment quickly established that, despite being driven hard aground on a rocky ledge, there was no breach of the hull. The MAIB investigation identified that the OOW had fallen asleep soon after sending his night lookout off the bridge. Available bridge resources that could have alerted the crew and/or awoken a sleeping OOW were not used resulting in Beaumont steaming at 11.5 knots with no-one in control on the bridge for over an hour.

Table 27 : Identified task errors

Report Number	14/2014
Accident Investigation Body	Marine Accident Investigation Body (MAIB)
Date of the accident	12 December 2012
Ship Name	Beaumont
Ship IMO number	9319416
Flag	UK
Ship Type	General cargo
Port of Departure	La Coruna
Port of Arrival	Avilés
Manning	6
Type of accident	Grounding

4.2 IDENTIFIED TASK ERRORS

Following a thorough analysis of the investigation report, the coder identified seven main tasks error which are set out in table 27.

Table 28 : Identified task errors

Task Error	Task error description	Who?	Where?
1	The lookout was sent away	1st/Chief Officer	Bridge
2	1st Officer fell asleep on the bridge	1st/Chief Officer	Bridge
3	ECS volume decreased	1st/Chief Officer	Bridge
4	BNWAS switched off	1st/Chief Officer	Bridge
5	Radar guard zone absent	1st/Chief Officer	Bridge
6	Echo sounder switched off	1st/Chief Officer	Bridge
7	The master did not insist on having a lookout on the bridge during night hours	Captain	Bridge

4.2.1 TASK ERROR 1 – THE LOOKOUT WAS SENT AWAY BY THE 1ST OFFICER

As mentioned in the introduction of this chapter, only the first two task errors will be coded following the TRACer-Mar taxonomy (tables 28 and 29).

Table 29: Task Error 1

1st Level of Information	2nd Level of Information	Coding	Reference
Task error	Task error	Supervision	Table 1
Error Information	Subtask	Of bridge tasks	Table 10
	User material	No technical equipment involved	Table 7
	Ship fixed info	N/A	Table 13
	Ship variable info	N/A	Table 14
Causality level	Causality	Contributory	Table 15
Context of the operator	External error mode	Selection and quality	Table 16
	External error mode	Wrong action on right object	Table 16
	Cognitive domain	Decision-making	Section 3.2.2
	Internal error mode	Poor decision – poor planning	Table 19
	Psychological error mechanism	Failure to consider long-term or side effects	Table 21
Performance shaping factor	Personal factor	Body fatigue	Table 22
	Aspects of communication/information	N/A	Table 22
	Training/competence/experience	N/A	Table 22
	Internal/external environment	Time of day (dark, light)	Table 23
	Organisational factor	N/A	Table 23
	Other	N/A	Table 23
Error recovery	Physical barrier not successful	N/A	Table 24
	Functional barrier not successful	N/A	Table 25
	Symbolic barrier not successful	Instructions, procedures, precautions, dialogues	Table 26
	Incorporeal barrier not successful	Formal guidance, informal guidance	Table 27

The action of sending away the lookout from the bridge during night hours was in contrast with international regulations, however could not be considered a full violation since it was not required by the company's safety management system. The coder decided to assign the task error 'supervision' and the subtask of 'bridge tasks' for this particular action. No user material or ship fixed or variable information were involved in this particular task error. Following the guidelines in table 16, the EEM coded is 'selection and quality' and specifically 'wrong action on right object' since the first officer dealt with the lookout (right 'object') but unfortunately decided on an erroneous action (sending him away from the bridge). Taking into account the internal cognitive process of the first officer, 'decision-making' was chosen as the main cognitive domain for this particular task error because following the guidelines set out in section 3.2.2 above, 'the user received the crucial information and processed it correctly, but came to a wrong conclusion and therefore took a wrong decision'. By following this train of thought, the IEM was identified as 'poor decision – poor planning' and the PEM as 'failure to consider long-term or side effects'. The main PSF

identified was the time of the day (dark), while error recovery was neither instructions, procedures, precaution nor dialogues, but and ‘formal Guidance, informal Guidance’ were deemed relevant.

4.2.2 TASK ERROR 2 – 1ST OFFICER FELL ASLEEP ON THE BRIDGE

Table 30: Task error 2

1st Level of Information	2nd Level of Information	Coding	Reference
Task error	Task error	Traffic monitoring & watchkeeping	Table 1
Error information	Subtask	Watchkeeping	Table 10
	User material	ECS	Table 7
	Ship fixed info	N/A	Table 13
	Ship variable info	N/A	Table 14
Causality level	Causality	Causal	Table 15
Context of the operator	External error mode	Selection and quality	Table 16
	External error mode	Omission	Table 16
	Cognitive domain	Perception	Section 3.2.2
	Internal error mode	No detection	Table 18
	Psychological error mechanism	Vigilance	Table 20
Performance shaping factor	Personal factor	Body fatigue	Table 22
	Aspects of communication/information	N/A	Table 22
	Training/competence/experience	N/A	Table 22
	Internal/external environment	Time of day (dark, light)	Table 23
	Organisational factor	Manning	Table 23
	Other	N/A	Table 23
Error Recovery	Physical barrier not successful	N/A	Table 24
	Functional barrier not successful	Distance, persistence, dead-man button, alarms	Table 25
	Symbolic barrier not successful	- Instructions, procedures, precautions, dialogues - Signs, signals, warnings, alarms	Table 26
	Incorporeal barrier not successful	Formal guidance, informal guidance	Table 27

The first officer fell asleep while on watchkeeping duties. In this sense the task error coded is ‘traffic monitoring & watchkeeping’ and the subtask ‘watchkeeping’. The equipment in use was the electronic chart system for which the alarm was barely audible. Following the taxonomy, the EEM chosen was ‘omission’ since the operator did not perform any action. Since the ECS alarm was not heard, the cognitive domain identified was ‘perception’, and the IEM as ‘no detection’ and the PEM as ‘vigilance’. The manning level and the time of the day (dark) with a very warm environment on the bridge were considered by the coder the main PSFs. Further, in the error recovery category, neither functional, symbolic nor incorporeal barriers such as alarms, instructions, warnings, signs, dead-man button, distance, and formal and informal guidance managed to prevent the accident.

REFERENCES

- Baysari, M. T., Caponecchia, C., McIntosh, A. S., & Wilson, J. R. (2009). Classification of errors contributing to rail incidents and accidents: A comparison of two human error identification techniques. *Safety Science*, 47(7), 948-957. doi:<http://dx.doi.org/10.1016/j.ssci.2008.09.012>
- Donaldson, J. F. (1994). *Safer Ships, Cleaner Seas: Report of Lord Donaldson's Inquiry into the Prevention of Pollution from Merchant Shipping*. HMSO: London.
- EUROCONTROL. (2009). *A White Paper on Resilience Engineering for ATM*. Retrieved from <http://www.eurocontrol.int/sites/default/files/article/content/documents/nm/safety/safety-a-white-paper-resilience-engineering-for-atm.pdf>
- Evans, A. E., Basra, G., & Megaw, E. (1998). *Generation of Human Error Probability Data for Air Traffic Control: A Feasibility Study*. NATS R&D Report 9846. National Air Traffic Services: London.
- Geels, F. W. (2004). From sectoral systems of innovation to socio-technical systems: Insights about dynamics and change from sociology and institutional theory. *Research Policy*, 33(6-7), 897-920. doi:<http://dx.doi.org/10.1016/j.respol.2004.01.015>
- Graziano, A., Teixeira, A. P., & Guedes Soares, C. (2016). Classification of human errors in grounding and collision accidents using the TRACer taxonomy. *Safety Science*, 86, 245-257. doi: <http://dx.doi.org/10.1016/j.ssci.2016.02.026>
- Heiman, G. W. (2001). *Understanding Research Methods and Statistics: An Integrated Introduction for Psychology*. Houghton Mifflin: Boston.
- Hollnagel, E. (2004). *Barriers and Accident Prevention*. Ashgate Publishing Limited: Farnham.
- Liebl, A., Haller, J., Jödicke, B., Baumgartner, H., Schlittmeier, S., & Hellbrück, J. (2012). Combined effects of acoustic and visual distraction on cognitive performance and well-being. *Applied Ergonomics*, 43(424-434).
- Schröder-Hinrichs, J.-U. (2003). The Human Element (HE) in marine casualties – are we prepared to address the real issues? In: *Risk and Safety Management in Industry, Logistics, Transport and Military Service: New Solutions for the 21st Century*. Tallinn: Technical University.
- Schröder-Hinrichs, J.-U., Graziano, A., Praetorius, G. & Kataria, A. (2016). TRACer-MAR – Applying TRACer in a maritime context. In: Walls, L., Revie, M., & Bedford T. (eds.). *Risk, Reliability and Safety: Innovating Theory and Practice: Proceedings of ESREL 2016 (Glasgow, Scotland, 25-29 September 2016)*. Leiden: CRC Press, pp. 120-126.
- Shorrock, S. T., & Kirwan, B. (2002). Development and application of a human error identification tool for air traffic control. *Applied Ergonomics*, 33, 319-336. doi: [http://dx.doi.org/10.1016/S0003-6870\(02\)00010-8](http://dx.doi.org/10.1016/S0003-6870(02)00010-8)
- Stanton, N., Salmon, P. M., & Rafferty, L. A. (2013). *Human Factors Methods: A Practical Guide for Engineering and Design*. Ashgate Publishing Limited: Farnham.
- Walker, G. H., Jenkins, D. P., Rafferty, L. A., Lenné, M. G., Stanton, P. N. A., & Salmon, P. P. M. (2012). *Human Factors Methods and Accident Analysis: Practical Guidance and Case Study Applications*. Ashgate Publishing Limited: Farnham.