

Maritime Resource Management: Current Training Approaches and Potential Improvements

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ABSTRACT: Shipping can be regarded as a high-risk domain with a large complexity in operations. Accidents and incidents may involve serious danger for seafarers and passengers, as well as for the environment and society at large. Education and training play a crucial role for the safe conduct of ships. While technical skills have been at the core of a mariner's skillset, non-technical skills (NTS) have become increasingly important for the safe conduct of merchant vessels. Therefore, knowledge in NTS has become a mandatory requirement for officers serving on board. This knowledge is normally taught in courses labelled Bridge Resource Management, Engine room Resource Management, or Maritime Resource Management. While the number of courses in the industry is steadily increasing, research focused on NTS training and its relation to safety in operation seems sparse. This review article aims to provide an overview of scientific literature focused on training NTS for maritime operations published between 2000 and 2018. Based on the reviewed literature the article identifies and discusses current research gaps, trends and potential future directions to improve maritime resource management training.

1 INTRODUCTION

The shipping industry can be identified as a high-risk domain with a significant complexity in operations (Perrow, 1999). As in many other high-risk domains, safety regulatory work follows in the aftermath of an incident or accident reflecting a reactive approach to safety with little to no guidance on how to implement proactive means and measures based on socio-technical system concepts (Chauvin, 2011). Consequently, safety improvements in the maritime domain are generally reactive, thus not explicitly aimed to avoid future incidents of new kinds, but mainly address the causes of what has already happened (Schröder-Hinrichs, Hollnagel, and Baldauf, 2012).

As a globalized industry, shipping is regulated at an international level by a specialized agency of the United Nations, the International Maritime Organization (IMO). IMO works to promote a safe, efficient and secure shipping industry with a limited impact on the environment. In practice, this is achieved by adopting regulations, technical standards and non-binding instruments (Harrison, 2011). Through the past 70 years, IMO has created an exhaustive framework including some of the most important conventions in international shipping, such as the International Convention for the Safety of Life at Sea (SOLAS) (IMO, 1974). International Convention for the Prevention of Pollution from Ships (MARPOL) (IMO, 2017a) and International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW) (IMO, 2017b).

Two important measures to promote proactive safety work are education and training. Since the grounding of the Torrey Canyon in 1967 (Liberian Board of Investigation, 1967), which initiated the MARPOL (1973) and the STCW Convention in 1978 (Schröder-Hinrichs, Hollnagel, Baldauf, Hofmann, & Kataria, 2013), it has been highlighted that there is a need for well-defined competence and training requirements to equip the crew onboard with all necessary skills and knowledge to work as safe as possible.

STCW addresses the requirements for training and certification of seafarers with a specific focus on the master and officers onboard. The aim of the convention is to establish the preconditions for comparable training standards world-wide (IMO, 2017b). This includes both technical skills, such as how various parts of the equipment onboard are to be operated and maintained, and non-technical skills, such as communication, teamwork and decision making. The latest revision of the STCW in 2010 increased the demands on non-technical skills (NTS) for officers onboard, i.e. the need to show proficiency in knowledge concerning the human element, leadership, management, and teamwork skills, which are normally trained as part of Bridge or Engine room Resource Management (STCW A- II/1, A-II/2, A-III/2, A-III/6) sometimes called Maritime Resource Management (MRM). However, while the number of MRM courses is steadily increasing, research focused on NTS training and its relation to safety in operation seems sparse.

The aim of this article is to explore and discuss resource management training in the maritime domain against the background of research from other high-risk domains. Based on a literature review, the article discusses current research gaps, trends and potential future directions to improve MRM training.

The following questions have guided this review:

- 1 What is the current state of Maritime Resource Management training?
- 2 How can Maritime Resource Management training be improved based on lessons learned in other high-risk domains?
- 3 How can resilience engineering help to create improved Maritime Resource Management through its complementary focus on systems, i.e. teams, in real life settings?

2 THEORETICAL FRAME OF REFERENCE

The following section provides the theoretical backdrop for this article. We will first introduce the concept of non-technical skills (NTS) and its relation to resource management training approaches. Secondly, we will provide an overview of resilience engineering (RE), which is a rather novel approach to safety in high-risk domains. In comparison to NTS which is focused on skills in individuals, RE has systems and teams in operations as its unit of analysis.

2.1 Non-technical skill training

Non-technical skills (NTS) can be defined as “the cognitive, social and personal resources skills that complement technical skills, and contribute to safe and efficient task performance” (Flin, O’Connor, & Crichton, 2008, p.1). The NTS concept has been applied to a large number of domains, such as healthcare, firefighting, mining, oil and gas and nuclear power (Flin, O’Connor, & Mearns, 2002; Helmreich, & Foushee, 2019; Thomas, 2018). These skills are normally split into seven areas; situation awareness, decision-making, communication, teamwork, leadership, as well as the ability to manage stress and cope with fatigue. These areas reflect skills normally trained in crew resource management (CRM) courses or their equivalent in other high-risk domains adopting this type of training (Thomas, 2018).

NTS training in the maritime domain gained recognition during the early 1990s after the aviation domain attributed increased operational safety to successful implementation of crew resource management. By the end of the 1970s several accidents had been associated to human error and investigations had identified deficiencies in the coordination of work, communication and decision making as causes for these adverse events. One of the prominent accidents often associated with the development of CRM is the collision of two aircraft on a runway at the Tenerife airport in 1977. Decision making, fatigue and leadership were among the identified causes for the accident that caused 583 fatalities (Flin, O’Connor, & Mearns, 2002). As a consequence of this and other incidents, the aviation industry started to investigate pilot error and to develop courses focused on how to prevent these errors in the end of the 1970s. By the beginning of the 1980s, NASA introduced its first CRM training as outcome of a human factors workshop (Helmreich, & Foushee, 2019).

NTS training has since been transferred to and adopted by several other high-risk domains (Hayward, Lowe, & Thomas, 2019). The courses normally encompass a mixture of classroom-based lectures and group discussions in combination with simulator training. The lectures generally address issues related to human performance in high risk systems, such as decision making, communication, leadership, teamwork, fatigue, stress and situation awareness. Further, courses often make use of a number of exercises, including discussions of incidents and accidents (Salas et al., 2006).

A first maritime version of the CRM course package focused on bridge operations was developed 1992 (Hayward, Lowe, & Thomas, 2019). In 1995, the IMO introduced the concept of Bridge Resource Management (BRM) - the effective use and allocation of all resources available on the bridge - into the STCW Code (Chauvin et al., 2013). Since then, the concept has been transferred to other departments onboard as the development of courses for ERM and MRM has continued. Through the latest amendments to the Code, NTS knowledge has become mandatory (IMO, 2017). Officers in different departments onboard need to provide proof of their knowledge of BRM/ERM/MRM principles; including the allocation,

assignment and prioritization of resources, effective communication between and within teams, assertiveness and leadership, teamwork and having situational awareness (IMO, 2017b).

As in many other settings, the shipping industry is currently undergoing substantial changes through an increased complexity in technology, which pushes seafarers farther away from the original core processes, such as navigating or operating machinery, towards a more supervisory role. Thus, technical and non-technical skills are increasingly becoming more critical for the safety of people and cargo onboard and for the assurance that resources (people and technology) are used and allocated in an efficient way. Since communication and teamwork are fundamental for a merchant vessel's safe operation (Grech, Horberry, & Koester, 2008), it is important to explore and understand how NTS are trained and maintained, as well as how the requirements for such knowledge can be demonstrated.

2.2 Resilience and safety in high-risk industries

Through the past decade, resilience engineering (RE) has received an amplified amount of attention from researchers and practitioners in high-risk domains. The theoretical framework of RE was developed in the early 2000s with the purpose to increase the understanding of human performance and its contribution to system safety, instead of focusing on the human operator as being the source of potential failure.

The concept of resilience has its origin within ecology in the early 1970s referring to an ecological system's ability to arrive at an equilibrium. The concept emphasizes that the equilibrium is achieved through adaptation to a dynamic and changing environment over time (Holling, 1973), i.e. it requires constant change in the system's behavior. Within the RE and in the context of socio-technical systems, resilience has been defined as the ability to sustain required functioning and attain to operational goals under a variety of operating conditions (Hollnagel, 2011). Thus, RE focuses on understanding systems', i.e. teams, everyday performance in changing operating environments with an emphasis on how safe performance is achieved. It highlights how systems successfully adapt their behavior to the shifting demands in the environment, hence to stay in control and produce a stable performance output (Hollnagel, 2011). System goals, such as efficiency and safety, often require trade-offs because they cannot always be attained to simultaneously. As a consequence, human operators in high-risk industries are often forced to improvise and discover workarounds to be able to cope with limited resources (Hollnagel, 2009). When this type of adaptation is successful, safety emerges as a property, as the system balances goals and demands in the current context (Woods, 2006).

The concept of resilience cornerstones, or abilities (respond, monitor, anticipate and learn) (Hollnagel, Woods & Levenson 2006) has been widely used to analyze everyday work in socio-technical systems. These four abilities are essential for a system to be able to recognize challenging conditions, respond to

them, evaluate the response and prepare for future events. The four abilities are mutually dependent, and each represents one facet of a system's functioning. By analyzing everyday operations with the aid of the abilities, ways in which the system's capacity for knowing what to do (respond), what to look for (monitor), what to expect (anticipate) and what has occurred (learn) can be strengthened may be identified (Hollnagel, 2011). Additionally, Woods (2015) has identified the following facets of resilience; capacity to recover from unanticipated events (rebound), the ability to cope with everyday complexity (robustness), and the ability to adapt to and cope with current and future operating conditions and events (gracefully extensibility and sustained adaptability).

RE approaches generally focus on work-as-done (WAD) rather than work-as-imagined (WAI) (Hollnagel, 2015). WAD is focused on the sharp-end of operations and explores how human operators in complex systems adapt their work to a variety of operating conditions, balancing limited resources and sometimes shifting organizational and operational goals. In contrast, WAI is often associated to guidelines, management systems and other formal descriptions of work. It does not take into concern that performance occurs in situ and is thus variable, i.e. requires adaptation to maintain the functioning. A RE approach based on WAD therefore has the potential to guide the development of safety measures and guidance that emphasize positive performance rather than risks and human error (Lay, Branlat, & Woods, 2015; Praetorius, Hollnagel & Dahlman, 2015; Sujana, Spurgeon, & Cooke, 2015; Woltjer, Pinska-Chauvin, Laursen, & Josefsson, 2015; Woods, 2015). While the RE framework has been applied across multiple domains, such as aviation (e.g. Studic, Majumdar, Schuster, & Ochieng, 2017; Woltjer, et al., 2015), healthcare (Wachs, Saurin, Righi, & Wears, 2016; Wachs, Weber Righi, & Saurin, 2012), and critical infrastructures (e.g. Labaka, Hernantes, & Sarriegi, 2015; Ouyang & Wang, 2015), this type of research has yet not been developed extensively in the maritime domain. There are only few studies, which mostly focus on learning from accident scenarios (Patriarca & Bergström, 2017) or understanding complexity of operations onboard (Praetorius & Lützhöft, 2011) or ashore (Praetorius & Hollnagel, 2014).

Despite the fact that resilience engineering has gained an increased popularity among practitioners and researcher in high-risk domains, there is little research on how to design team training to improve resilience (Righi, Saurin, & Wachs, 2015). Onboard operations are complex and need to take place in a large variety of conditions, i.e. an increased understanding for how to promote flexibility and adaptability is crucial. As resource management in the maritime context can be understood as the effective and efficient use of resource (people and technology), the resilience engineering framework may provide a viable lens to understand onboard operations and how different demands, opportunities and goals are attained to in everyday work. This in turn may generate knowledge on how to potentially identify essential skills for safety in everyday operations, as

well as means and measures to improve mandatory resource management training.

3 METHODS AND MATERIALS

3.1 Search strategy and inclusion criteria

To identify relevant articles for this review, the Scopus and ScienceDirect were used. Scopus (www.scopus.com) is one of the largest databases for research in humanities, science, engineering and medicine encompassing more than 21000 titles including scientific journals, as well as conference proceedings. ScienceDirect (www.sciencedirect.com) features around 2000 different journals within among others biology, medicine, engineering and economics. The scope of the literature search included peer reviewed work published over the 18-year period from 2000 and 2018. The literature search strategy and selection process are presented in Figure 1.

The review was initiated with a search for studies on MRM training in the maritime domain. The keywords (or a combination of keywords) used for the search were maritime resource management (MRM), crew resource management (CRM), maritime, bridge resource management (BRM) and engine room research management (ERM). The following search strategy was adopted; ("maritime resource management") OR ("crew resource management") AND TITLE-ABS-KEY (maritime) OR ("bridge resource management") OR ("engine room resource management").

Secondly, studies on NTS training using the resilience engineering framework in other domains than maritime were searched for. The keywords were non-technical skills, crew resource management and resilience. For this purpose, the following search strategy was adopted; TITLE-ABS-KEY (resilience) AND TITLE-ABS-KEY ("crew resource management"), followed by TITLE-ABS-KEY ("non-technical skills") AND TITLE-ABS-KEY (resilience). Finally, a complementary literature search using the same strings was conducted in the PubMed database (<https://www.ncbi.nlm.nih.gov/pubmed/>) to identify any additional relevant studies that could complement the dataset. However, this search did not return any new matches.

The inclusion criteria in the first phase of the review was defined as articles, which have undergone a peer review process and are published in scientific journals or conference proceedings. Only studies written in English were included. All identified matches were organized in a spreadsheet eliminating duplicates in the search results.

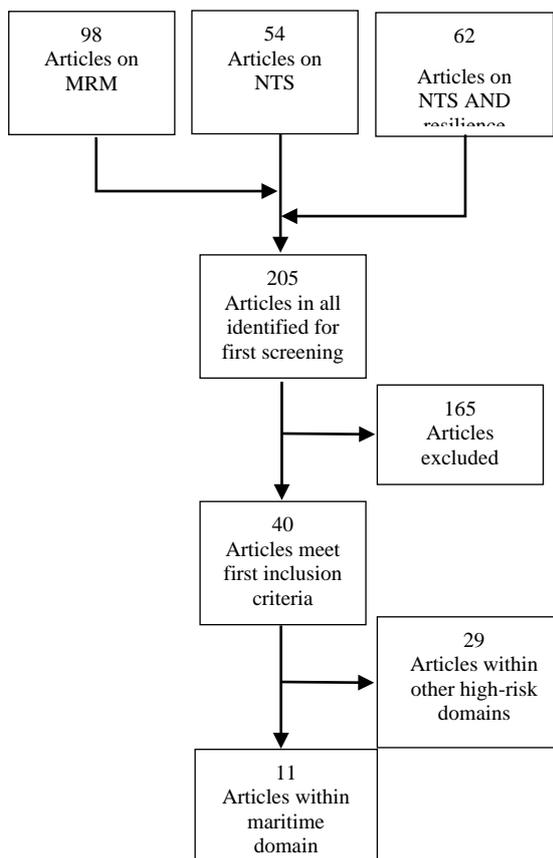


Figure 1. Overview of the article selection process

3.2 Selection process

The research questions were used to guide the selection process. In a first step, all abstracts were read by the authors to identify whether these addressed CRM, BRM, ERM, MRM, or non-technical skill training, and its contribution to safety or resilience in a high-risk domain. In a qualitative analysis, all abstracts were first independently judged by each of this article's authors and assigned one of the following values; include, exclude or maybe include. All articles assigned the value exclude by more than one of the authors were eliminated in this first step.

In a second step, all articles assigned include or maybe include were read in their entirety and screened for the following:

- Reports findings from studies on CRM, MRM, BRM or ERM
- Discusses MRM, BRM or ERM training
- Discusses the relationship between non-technical skill training and resilience, or safety, in a high-risk domain other than maritime
- Reviews of literature addressing CRM training or its adoptions in other domains

After reviewing all remaining articles in phase 2, 40 of the originally 205 matches were deemed relevant for this review. All included articles were categorized according to type of article (review, research study, other) and summarized in a spreadsheet using the following categories; domain, central concepts, method(s), results, conclusions, suggestions and future research.

4 RESULTS AND DISCUSSION

The following section will present the findings of the literature review and discuss these in line with the research questions. Firstly, the current state of MRM will be explored and research gaps presents in the published literature will be highlighted. In the second section, potential improvements to MRM based on lessons learned in other high-risk domains will be presented. Finally, we will discuss whether, and if so how, resilience engineering may present a complementary perspective to improve current MRM training approach to promote and increase safety in operations.

4.1 *What is the current state of Maritime Resource Management training?*

Despite the increased attention towards MRM training in the past decade, only 11 articles addressing this topic were identified. An overview of the identified literature is presented in the appendix of this article.

Seven articles report findings from empirical studies of training in various settings. Three of these address work coordination and communication on the bridge; two focus on anchor handling (Håvold, Nistad, Skiri, & Ødegård, 2015; Vederhus, Ødegård, Nistad, & Håvold, 2018), one on pilotage operations (Hontvedt, 2015), and one on the attitudes among navy surface warfare officers (SWOs) (O'Connor, 2011). The articles neither address any aspects of resource management and its impacts within the engine-room department, nor training across department borders. However, Vederhus, et al. (2018) and Wahl and Kongsvik (2018) advocate the joint training of crews as a result of their analyses.

Further, the training reported in the studies varied greatly in length, content, instructional methods, and focus. For example, Espevik, Saus, and Olsen (2017) provided a short 4-hour course focused on the ability to speak up, while other researchers studied courses that were several days long addressing NTS such as cooperation, communication, leadership, decision making, attitudes and motivation, performance under stress, and situation awareness (Håvold et al., 2015; O'Connor, 2011, Röttger, Vetter, & Kowalski, 2013; Röttger, Vetter, & Kowalski, 2016). Additionally, some studies, such as reported in Vederhus et al. (2018) and Hontvedt (2015), did not solely focus on NTS training, but on certain aspects, such as communication, coordination and demanding operations. In general, the instructional methods across the studies differed, but included a mixture of classroom-based lectures, group discussions, and simulator or real-life exercises.

Only five studies evaluated the effectiveness of the training (Espevik, Saus, & Olsen, 2017; Håvoldt et al., 2015; O'Connor, 2011, Röttger, Vetter, & Kowalski, 2013; Röttger et al, 2016) with regards to attitudes, perceived learning outcome, and knowledge. In those studies, all but Håvold et al. (2015), used questionnaires developed based on Kirkpatrick's taxonomy (Kirkpatrick & Kirkpatrick, 2006) level 1 "reaction" (participants' reaction towards a course) and level 2 "learning" (attitudinal changes and

knowledge gain) to evaluate the effectiveness of the course. Level 3 "behavior" (assessment of knowledge transfer from classroom to work environment) and level 4 "organization" (tangible effect, such as increased safety or productivity) were not addressed. Three of the studies utilized an adapted Flight Management Attitude Questionnaire for the evaluation of the course (O'Connor, 2011; Röttger et al., 2013, 2016). Röttger et al. (2016) distributed the questionnaire prior and after the course to determine changes in the participants' attitudes. In addition to attitudes, the participants' knowledge and skills with regards to non-technical aspects for maritime operations were assessed. O'Connor (2011) used a multiple-choice questionnaire to determine the surface warfare officers' CRM-knowledge, while Röttger et al. (2016) used a behavioral marker system based on Flin and Maran (2015) to determine performance during a real-life navigational exercise.

The reported findings in the studies do not provide an empirical proof of the effect of the training in real-life operations. Although several studies were able to show a change in attitudes and a knowledge gain, the only study including a field exercise and NTS behavioral markers did not identify positive effects on the participants' performance (task competition, decision making, situation awareness, leadership) in comparison to the study's control group (Röttger et al., 2016). Results from long-term studies addressing effectiveness in terms of transferability between training and work settings, or measuring effects on operational safety are currently missing and represent an important research gap to be addressed.

The results of this review also illustrate a general lack of training needs analyses in the development of courses. As guidance by the IMO on how to design courses that reflect the complexity of human behavior in ship operations are sparse (Pekcan et al., 2005), they are often built upon ready-made training packages developed for other domains, such as aviation, and are simply translated to the maritime domain (Wahl and Kongsvik, 2018). This may explain the limited training effects reported by O'Connor (2011) and Röttger et al. (2013, 2016). Further, through the lack of studies observing the long-term effect of training in real-life settings, it remains unclear what and how knowledge is translated into work practices

The published work shows a strong emphasis on simulators as training tools. Among others, Pekcan et al (2005), Hontvedt (2015), Håvold et al. (2015) and Nazir et al. (2015) discuss the potential of simulators to provide an environment for enhanced skill training in which technical skills and NTS can be improved. Especially safety-critical and demanding situations can be trained (Håvold et al., 2015, Vederhus et al., 2018), as well as professionals are provided with the opportunity to explore their work context in a safe setting (Hontvedt, 2015). However, simulated settings can also provide drawbacks when scenarios are not carefully matched to training objectives and the operational context in which the knowledge is supposed to be applied (Hontvedt, 2015; O'Connor, 2011). In addition, high fidelity simulation may draw the attention towards technical skills, i.e. how to navigate and use the equipment, rather than

emphasizing the need for task coordination, communication and decision making in teams.

Further, the assessment of NTS in the reported research largely focuses on a limited set of skills with the individual, not the team, in focus. Fjeld et al. (2018) explored generic NTS for bridge officers divided into two categories; cognitive skills (workload management, situation awareness, decision making) and interpersonal skills (leadership and communication). They found that studies have generally focused on one or a few skills, but neither developed nor explored a full taxonomy of NTS for bridge officers. Therefore, the authors (Fjeld et al., 2018) advocate the need to explore the relationship between work environment (technology, organization, context) and the bridge officers further. It is argued that a deeper understanding of how technical skills and NTS – both cognitive and interpersonal skills – complement each other in the work onboard.

Despite the increasing number of publications on NTS training in maritime operations, there are several research gaps that need to be addressed. They can be summarized as followed:

- There is a large ambiguity concerning the concepts NTS and MRM training which makes them appear to be labels, rather than thoroughly defined training approaches
- There is a lack of reported training needs analyses to underpin the development of training courses
- There is a need to develop assessment approaches that evaluate both training outcome and transferability of what is trained to real-world settings
- There is lack of exploring the transfer long-term effects of training in operational settings
- Training concepts need to address the interaction among departments to acknowledge the complexity of everyday work, which occurs across department borders
- Training approaches need to explore advantages and disadvantages of different instructional methods

4.2 *How can Maritime Resource Management training be improved based on lessons learned in other high-risk domains?*

A total of 24 articles addressing CRM and NTS training across the healthcare, oil and gas, and aviation domains, as well as operations research and driving research were identified in this review.

In these articles, NTS are referred to as being a generic skill set that is trained and enforced through CRM training (e.g. Burkhardt, Corneloup, Garbay, Bourrier, Jambon, Luengo, Job, Cabon, Benabbou, & Lourdeaux, 2016; Kontogiannis & Malakis, 2013; Malakis et al., 2010; Tawfik, Adair, Kaplan, & Profit, 2017; Youngson, 2016). CRM and NTS training are believed to increase safety through improving decision making, communication task coordination and leadership on a team level (Bennet, 2018; Cahill, Hurley, & Caughan, 2018; Kuy & Romano, 2017; Tawfik et al., 2017), as well as situation awareness,

problem recognition, workload management and problem-solving strategies when faced with complex operational settings (e.g. Malakis, Kontogiannis, & Kirwan, 2010; Kontogiannis & Malakis, 2013; Véronneau & Cimon, 2007). However, Havinga, de Boer, Rae, and Dekker (2017), Salas et al. (2006), and Jimenez, Kasper, Rivera, Talone, and Jentsch (2015) also observe that tools and practices related to CRM and NTS training may differ greatly between the various domains. Aviation and its CRM concepts have mostly been translated into other domains, but not necessarily based on domain-specific training needs and preconditions for work. Much of the research reported in scientific articles lacks an assessment of how the trained skills are transferred into operational settings, and to which extent participants use the training content once they return to the workplace (Havinga et al., 2017). Furthermore, it can be recognized in the reported studies that the definition and understanding of NTS differs greatly including both individual and team-level skills.

Despite the heterogeneity of the articles identified in the review, there are several important aspects that may help to improve MRM and NTS training in the maritime domain. These aspects can be clustered into the three main categories; organizational commitment and anchoring in work practices; simulation-based training and performance evaluation, and team training

4.2.1 *Improvements through commitment from the management and anchoring work practices*

The identified literature in this review shows a concern for the transferability of training into real life settings. A course may provide certain terminology, technique or practice, however, if not anchored properly in the operational context (Crichton, 2017), the learning outcome and long-term effects may decrease (O'Connor & Flin, 2003). An example is provided by Kuy and Romero (2017). The authors explored whether CRM training with focus on team-building and communication could potentially help to improve the safety climate perceptions among operating room staff. The study reports that briefly after the course the perception of the safety climate and teamwork had improved, but that the effect decreased over time (Kuy & Romero, 2017). Thus, successful CRM training only has an effect if values, norms and practices are reinforced as culture at a workplace. This requires organizational and individual engagement in the change. Similar findings were also obtained by Thorogood and Crichton (2014). Through interviews with management representatives they highlighted the need for leadership and organizational procedures to enable the integration of Threat and Error Management in workplace practices. If not supported and encouraged at all levels of the organization, CRM remains a single training intervention in the eye of operators, but will neither necessarily be transferred, nor integrated into the daily work. Consequently, anchoring and integrating NTS into workplace practices requires a continuous process throughout the education and professional life (Baker, Salas, King, Battles, & Barach, 2005; Youngson, 2016; Todd, 2017).

Commitment from the management is an important aspect for the successful transfer of training into practice. Therefore, MRM courses should not solely be directed at seafarers, i.e. the sharp end of operation, but also at the management level. As Tawfik et al. (2017) and Youngson (2016) emphasize, NTS need to be considered as a form of culture that involves a continuous learning within the organization. Thus, there is the potential to improve resource management in everyday operations only if it is defined as more than a skill-set or particular training unit. Training courses need to be provided regularly and should take place in simulated settings an in the workplace. Support and encouragement by the management are further of utmost importance for the transfer and adoption of trained practices. Only if integrated in the work settings, training benefits, such as increased operational safety, can be obtained. The management is responsible to provide the organizational frame and right precondition for this.

4.2.2 *Improved simulation-based training and performance evaluation*

Similar to the maritime domain, simulation-based training is one of the foremost instructional methods for NTS training across domains. The sampled literature reports the use of high-fidelity (e.g. Burkhardt et al., 2016; Moffat & Crichton, 2015; Crichton, 2017) and low-fidelity simulation (Guinea et al., 2018). These simulations offer an opportunity to train critical events safely in controlled settings allowing to evaluate operator behavior and performance throughout a scenario (e.g. Salehi et al., 2018). While simulation offers a valuable tool for NTS training, it needs to be considered that scenario design, performance evaluation and debriefing have to be carefully aligned (Crichton, 2017) to ensure that desired training outcomes are achieved.

Simulator exercises often present trainees with challenging scenarios. Hence, scenario design becomes central to create a learning environment which can help to achieve specific training goals. These goals should be developed in conjunction with clear objectives during the design phase and should be accompanied by the formulation of contextualized measures to evaluate trainee performance (Moffat & Crichton, 2015; Crichton, 2017, Burkhardt et al., 2016). Further, to increase the perceived meaningfulness of the NTS knowledge, domain experts should be involved in the design of training units and scenarios (O'Connor & Flin, 2003, Thorogood & Crichton, 2014). Additionally, current research in NTS training shows inconsistency among approaches, measures and concepts (Nicolaidis, Cardillo, Theodoulou, Hanrahan, Tsoulfas, Athanasiou, Papalois, & Sideris, 2018). This is important to consider when adopting training and evaluation methods across domains, as transferability may be limited.

Performance evaluation can build on quantitative measures and qualitative measures. Examples for the former are behavioral markers (e.g. Malakis, Kontogiannis & Kirwan, 2010, O'Connor & Flin, 2003, Moffat & Crichton, 2015) or human factors measurements such as eye-tracking, voice response rate and situation awareness ratings (e.g. Salehi et al.,

2018), while the latter concern criteria such as fostering shared understanding, reflection or interaction among participants (Guinea et al., 2018). Regardless which performance evaluation approach is used, it should be carefully matched to the context of work and training needs of the targeted group of participants (Crichton, 2017, Burkhardt et al. 2016). This can potentially be achieved through observing taskwork strategies in simulated or real-life settings (Malakis et al, 2010; Bennet, 2018), using incident and accident reports as case studies (Bove & Andersen, 2000), or developing domain-specific behavioral markers addressing team-level NTS (Moffat & Crichton, 2015). It is also important to note that measures based on observations, such as behavioral marker ratings, require repeated measurements and a well-grounded evaluation team to overcome reliability and validity issues of the measure (Baker et al., 2005).

MRM training has heavily relied on the use of high-fidelity simulation-based training (e.g. Espevik et al., 2017; Håvold et al., 2015, Hontvedt, 2015; Vederhus et al., 2018). While these types of simulation offer advantages, one major disadvantage is that they combine training technical and non-technical skills. This may make it hard to define concrete learning objectives and evaluation criteria for NTS in challenging and complex scenarios. If the line between technical skills and NTS is blurred, there is a risk that scenario design, learning objectives and evaluation criteria are not aligned. This may decrease the training outcome and make hard for participants to understand the importance of NTS in operations. It is therefore recommended to explore whether low-fidelity simulation approaches, such as demonstrated by Guinea et al (2018) may offer a valuable tool to activate participants and foster reflection on both team and individual level, as well as draw more attention to NTS.

Training design should also be based on thorough needs analysis to support the alignment of goals, instructional methods and performance measures (e.g. Crichton, 2017). While it is important to understand how courses are perceived by participants, there is a need to explore how to approach training effects on a team level, i.e. evaluating teamwork, task coordination and the overall distribution and use of resources in different operating settings. This knowledge is essential to be able to identify which practices should be explored as potentially viable approaches to feed operational data back into training to improve the overall training content and design. Further, if behavioral markers or other quantitative assessment methods based on observations are employed, it is necessary to ensure that the developed scales are reliable so that the evaluation does not suffer from validity issues (O'Connor & Flin, 2003; Baker et al, 2005). As also noted by Fjeld et al. (2018), there is a lack of a coherent behavioral marker taxonomy for the maritime domain. Therefore the complexity of the work tasks and settings need to be properly understood before measures are applied in the evaluation. Further, Salehi et al. (2018) suggest that advanced human factors measurements may provide a complementary set of assessment tools that can also provide input towards scenario design for different trainee groups

with regards to levels of expertise. This might be a valuable input for the design of performance measures in simulator-based training.

4.2.3 Stronger emphasis on team training

The reported findings in the maritime domain show a strong training focus on the individual level, which is exemplified by the training evaluation focusing questionnaires about attitudinal change, course reception and knowledge gain (e.g. Håvold et al, 2015; O'Connor, 2011, Röttger et al. 2013), as well as performance measurements through behavioral markers (Röttger et al. 2016).

In contrast to this, the literature from other high-risk domains has a stronger emphasis on the team as target level for training to foster NTS (Kuy & Romero, 2017, Guinea, Andersen, Reid-Searl, Levett-Jones, Dwyer, Heaton, Flenady, Applegarth, & Bickell, 2018, Murphy, McCloughen, & Curtis, 2018). Training should include a number of practices and exercises, such as standardized briefings, debriefing techniques, the establishment of a critical language, and assertiveness measures. Ideally, the entire team unit should be involved to foster both cultural change within the organization and within the team itself (Paige, 2010). As highlighted by Bennet (2018), CRM supports interaction among team members and provides a basis for communication, as well as behavioral norms in the work setting. Bennet (2018) observed that CRM practices were applied by the flight crew up to medium strain to cope with the variability of normal operations. This is also supported by Kontogiannis and Malakis (2013), who found that communication and coordination are part of the team factors that can offer support in the process of error detection, analysis and correction. Especially team communication may trigger reflection and become a valuable resource during the assessment of a situation. Further, addressing NTS on a team level has the potential to serve as a taxonomy providing a common language and concept which can be used to identify, teach and apply these skills in the context of everyday work (Youngson, 2016, Bennet, 2018). Domain-specific hierarchies, differences in expertise and seniority, or other factors embedded in the working context may play a significant role in the interaction, communication and task coordination among team members in highly complex environments. NTS potentially offers a way of making these factors visible (Youngson, 2016). This has also been emphasized in Moffat and Crichton (2015) who focused their study on team situational awareness, teamwork and communication, and team decision making, as well as team workload and stress management.

An increased focus on the team as unit of analysis can be of great benefit for current MRM approaches. Training should be provided, if possible, for those usually working together, i.e. are part of the same company or crew (e.g. Vederhus, et al., 2018, Wahl and Kongsvik, 2018). This may help to increase the mutual understanding within and across departments and create social norms and a behavioral baseline that can support the crew in their complex work settings. Factors positively and negatively affecting communication, coordination and cooperation within

and across departments could potentially be discovered and made visible as consequence of joint training. Additionally, a stronger team focus may also facilitate the overcoming of differences in hierarchy and culture among crewmembers that may otherwise create barriers in their successful cooperation.

4.3 How can resilience engineering help to create improved Maritime Resource Management through its complementary focus on systems, i.e. teams, in real life settings?

As highlighted above, the current approaches to MRM show a lack of team performance measure. Thus, it can be important to explore theoretical underpinnings that specifically address a systems perspective. As pointed out initially, resilience refers not only to the functioning of a team, but also to the performance of a socio-technical system as a whole (Hollnagel, 2011). This is emphasized in e.g. Tawfik et al (2017) who identify resilience as organizational or team capability essential to promote safety in operations. A more critical stance is presented by Morel, Amalberti, and Chauvin (2009) showing that resilience may include certain risk taking by operators and organizations. Their study reveals that safety measures are often used to increase the competitiveness and production rather than improving safety. Further, in this review only three articles that explicitly addressed NTS and training from a resilience engineering perspective could be identified (Wachs, Saurin, Righi, & Wears, 2016; Wachs, Weber Righi, & Saurin, 2012; Wahlström, Seppänen, Norros, Aaltonen, & Riikonen, 2018).

In a case study of electricians, Wachs et al. (2012) explored the relationship between NTS and procedural adaption. Based on interviews, documents and field observations, they defined an own set of NTS categories grounded in the workers' perspective. Through an analysis based on a RE lens, conflicting procedures and work goals, as well as input to the overall system design was identified. The authors thereby show that system design may influence the need for specific NTS in operations. Similar findings are presented in Wachs et al. (2016), who identified resilience skills in frontline staff in emergency departments in Brazil and the United States. According to the authors, resilience skills concern collaboration and cooperation, communication, anticipation of demands and managing trade-offs, as well as leadership, and matching capacity and demand in the department (Wachs et al., 2016). They found that the development of resilience skills is largely a spontaneous process influenced by the context of work, including work constraints, such as time, information or available resources.

As resilience skills are developed in the context and rather spontaneously, it might be difficult to identify exact training needs, as well as results may show limited generalizability across settings. This is discussed in Wahlström et al. (2018) who focused on resilience in robotic surgery for prostate removal. The authors conclude that teamwork becomes a social enabler and a source of system resilience defined through task-sharing, coordination and shared

understanding in a complex task environment with an inherently high degree of uncertainty.

Despite the sparse number of articles addressing the relation between NTS and resilience, the literature still indicates that resilience skills (Wachs et al., 2016) may become a fruitful approach for understanding teamwork and performance in highly complex work setting. This may include what resilience skills constitute in specific settings and how these are developed. As workers are forced to balance and adapt to workplace constraints (Wachs et al., 2016), understanding trade-offs in everyday work becomes an essential building block to be able to create resource management training that fits the operational settings and makes sense to those working at the frontline.

For the maritime domain, and MRM training in specific, this implies the need to consider skills beyond what is normally defined as NTS (e.g. situation awareness, decision making, leadership). Seafarers often have to work in settings characterized by limited resources (e.g. manning, time available for operations) and a high degree of uncertainty due many external factors, such as the weather, which require flexibility and the capability to adapt quickly. As maritime operations need to be conducted despite the large variety of operating conditions, it is essential to understand how required functioning of the crew can be sustained. As a first step, it is therefore essential to study work onboard in order to formulate training needs, goals and skill requirements for what is needed to cope with the large variety of operating conditions. Work-as-done (WAD) needs to be acknowledged and understood in situ with a specific focus on how the crewmembers onboard communicate, coordinate and distribute tasks, as well as how workload and operational trade-offs are handled within and across department borders. While the current organizational framework consisting of training requirements, guidelines and recommendations, as well as standard operation procedures provides a backdrop for maritime operations, it fails to acknowledge and uncover adaptive processes and behaviors of the crew (Hollnagel, 2015). Adaptive processes are essential for identifying training needs that promote the capacity of teams concerning functions such task coordination and communication in relation to resource limitations and other operational trade-offs (Woods, 2015). The results obtained by Wachs et al (2016) and Wahlström et al (2018) may provide a first guidance on how to approach WAD and the gain through the application of resilience, but to be able to transfer this into concrete training design a deeper understanding of task coordination, task and information sharing, as well as communication within and across teams in complex environments is needed.

With its focus on systems, flexibility and adaptive processes, resilience may offer a lens to gain a deeper understanding of the complexity mariners onboard face in everyday work. Making complexity visible and identifying needs, means and measures for training design will remain a challenge that requires more research.

5 CONCLUSIONS

This article has explored the current state of maritime resource management and discussed how non-technical skill training can potentially be improved. The review shows that research in the maritime domain has been sparse and that NTS training has mainly focused on adopting concepts from the aviation domain without any thorough training needs analyses. Evaluations and assessments of training effects have largely focused on attitudinal change and course perception, but long-term effects and the degree of transferability to work settings have not been explored further. It remains therefore unclear if MRM has a long-term effect on operational settings.

Further, training approaches have mostly focused on individual NTS trained in high-fidelity simulators without thoroughly defined training goals. This may explain the lack of reported results with regards to training outcomes. Based on literature from other high-risk domains, this review has identified three key areas (organizational commitment, team focus, simulation-based training and performance evaluation), which may guide improvements to current training and evaluation approaches. The potential improvements particularly address the need to enhance the training regime with a focus on team performance, as well as the importance of training being anchored in operational practices and being supported by the management.

While NTS training traditional draws attention to mishaps and accidents, and how to prevent those through effective resource management in various domains (Flin et al., 2008), there is little known on how positive performance can be integrated and exploited for the design of training. Thus, RE offers a novel perspective with the potential to update current MRM regimes and offer new knowledge on how adaptability, flexibility and safety in operations can be promoted through team training.

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