Crew resource management training in the maritime industry: a literature review

Aud M Wahl (corresponding author) and Trond Kongsvik
Department of Industrial Economics and Technology Management
Faculty of Economics and Management
Norwegian University of Science and Technology (NTNU)
7491 Trondheim, Norway

Abstract

The study is based on a literature review of recent empirical research on crew resource management (CRM) training in the maritime industry, organised around what non-technical skills to learn and how. The review indicates that existing work is dominated by individualistic theories of learning with less focus on learning as a social process. Five main categories of skills that need to be trained are identified: assertiveness, decision-making, communication, situation awareness and team coordination. We argue that it is necessary to operationalise these broad concepts further, emphasising the work context and crew specific needs. The review also shows that a combination of classroom lectures and simulator-based exercises is commonly used in maritime education and training in these skills. The learning effect seems to be suffering from training programmes that are exported 'as is' from aviation and not adjusted to the maritime domain or to operation-specific needs. This paper also examines maritime crew resource management training from a social learning perspective, involving the view that learning is a context bound, social process that might take place in communities of practice (CoP). A CoP is a group (e.g. a crew) wherein members share an activity and learn from each other. It is argued that CRM training programmes will benefit from including a social learning perspective. Factors that enable the assessment of teams are discussed, and it is argued that the training should be tailored to existing crews, emphasising a learning environment as close to reality as possible.

Keywords: crew resource management (CRM), non-technical skills, simulator-based training, communities of practice, social learning theory

1 INTRODUCTION

Crew resource management (CRM) was developed as a training concept by the aviation community in the 1970s as a response to the high number of fatal accidents in the industry caused by human error. The intention was to improve flight crews' skills in areas such as situation awareness, decision-making, teamwork and leadership (Kanki et al. 2010). These skills were later labelled non-technical skills and defined as "the cognitive, social and personal resource skills that complement technical skills, and contribute to safe and efficient task performance" (Flin et al. 2008: 1). CRM training can thus be understood as a risk reducing strategy, where increased understanding of non-technical skills among members in an organisation is regarded as a safety measure.

The maritime industry started to adopt the CRM training philosophy in the 1990s after several accidents in which human factors were identified as the main cause (Grech et al. 2008). Hetherington et al. (2006) conducted a literature review on human factors in shipping and found that this was a rather new area of research in the maritime domain. They identified several individual factors that were contributory causes in maritime accidents, such as fatigue, stress, health, situation awareness, teamwork, decision-making and communication. Later, the International Maritime Organization (IMO) changed the minimum standards of competence for seafarers (IMO 2011), now requiring all ship officers to undergo leadership and teamwork training and demonstrate knowledge of bridge and engine room resource management principles (BRM and ERM respectively) to be certified or to renew their certificates. This has led to an increased interest in non-technical skills in the maritime industry in general and among researchers. Still, there is no updated overview of studies in the field. This article will contribute in this respect, as it aims to review research from 2010 to 2017 that identifies applicable factors relevant to the non-technical training of maritime officers.

CRM training programmes have traditionally been based on psychological perspectives and team members' learning of social and cognitive skills (e.g. Helmreich et al. 1999; Flin et al. 2003; Kanki et al. 2010; Flin et al. 2016). A second contribution of this article is to introduce a sociocultural perspective to CRM training. This has largely been lacking in literature on CRM training and can supplement the psychological approach and contribute to a discussion on training methods. According to Gherardi (2017), safety is always rooted in a context of interaction, situated in a system of ongoing practices and learned through participation in a community of practice. She states that "…safety is emergent from the working practices of a community, it is a collective knowledgeable doing and is embedded in the practices that perform it" (Gherardi 2017: 12). In her view, safety knowledge is primarily tacit and taken for granted as well as deeply rooted in individual and collective identity. Thus, safety needs to

be considered as a social and collective accomplishment. We argue that a social view on learning can contribute to broadening the scope of CRM training in the maritime industry.

The International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW) published by IMO (2011) builds on competency-based training principles (Emad and Roth 2008). Individuals' overall level of competency can be understood as the result of the reciprocal interaction between a person's skills, knowledge and attitudes (Salas et al. 2006). The theoretical perspectives related to CRM training usually emphasise the skills element of competency, as the training is focused on improving team coordination and performance. (e.g. Salas et al. 2006; Kanki et al. 2010; Flin et al. 2016). This article follows the dominant tradition in the field and will discuss competency from a skills perspective.

In the following, we will give a short presentation of CRM as a concept before we introduce learning in the context of communities of practice. A description of how the literature review was carried out is followed by a results section highlighting the typical content and different learning processes in maritime CRM training. The discussion indicates a structure of non-technical skills for maritime officers and presents a sociocultural perspective on CRM training, highlighting the importance of training tailored to context and crew-specific needs.

1.1 CREW RESOURCE MANAGEMENT TRAINING

The first comprehensive CRM programme was developed by United Airlines in 1981 (Helmreich et al. 1999); the training became mandatory in the US for military flight crews in the early 1990s and for commercial flight crews in 1998 (Salas et al. 2006). Helmreich et al. (1999) described how the training initially started out as 'cockpit resource management', where the objective was to teach pilots about management styles. This usually took place in seminar/workshop settings. The training gradually evolved and was extended to other groups within airlines such as maintenance personnel, dispatchers and cabin attendants: hence the label 'crew resource management'. The training moved from standalone seminars on pilots' leadership skills to become fully integrated in all simulator-based training and in evaluations of crews during regular flights. According to Helmreich et al. (2010), airlines are now attempting to widen the scope of CRM even further to include non-operational departments in the training.

The maritime industry initially adopted both the name and the content of the CRM training used in aviation (Grech et al. 2008), but it has evolved over the years. Now the content is guided by the requirements in the latest STCW revision (IMO 2011) and the training is often referred to as BRM (bridge resource management), ERM (engine room resource management) or HELM (human element,

leadership and management). As in aviation, the training started out as classroom-based lectures on relevant subjects, but has evolved into simulator-based training. Grech et al. (2008) stated that these training programmes have helped raise awareness about human capabilities and limitations, but that the early programmes tended to focus on the sharp end practitioners only and on specific issues such as fatigue, situation awareness and communication. Grech et al. (2008) indicated that the work of James Reason was instrumental in changing the focus to a more holistic view on safety, widening the scope to organisational factors and technology design. The concept of safety culture exposed how attitudes in the entire organisation may influence safety behaviour at the sharp end, and managers and on-shore staff were invited to join the training. Still, Barnett et al. (2005) claimed that the bridge and engine room resource management courses offered today mostly are adopted directly from the aviation model. Thus, there seems to be a need for more tailoring to the maritime industry.

The aviation industry uses a non-technical skills taxonomy to structure the CRM training and assessment of pilots' CRM skills (Flin et al. 2003). The taxonomy is usually a three-level hierarchy with the skill categories at the highest level, each defined and divided into several distinct elements. These elements can be further split into several behavioural markers that exemplify both good and poor work practices (Flin et al. 2003; Yule and Smink 2016; Crichton 2017). Figure 1 depicts a common structure of a non-technical skills taxonomy.

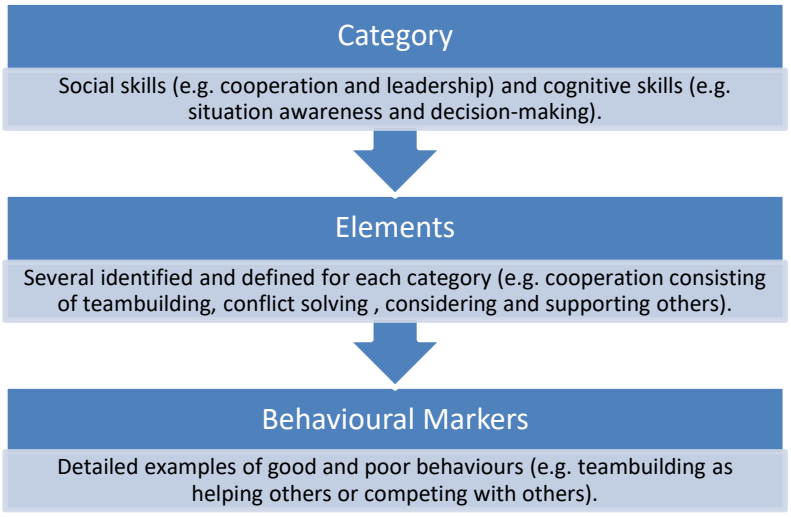

Figure 1. Non-technical skills taxonomy (Flin et al. 2003).

Flin et al. (2003) emphasised that all the described elements and behavioural markers must be directly observable. Framework designs vary across industries and training needs, but it is common to distinguish between a set of social skills and a set of cognitive skills (Thomas 2018). Individual factors such as health and ability to cope with stress and fatigue are usually regarded as behaviour-shaping

factors that are difficult to observe and measure objectively, and are often not included in behavioural frameworks (Flin et al. 2003; Flin et al. 2016). The framework provides a structured tool for evaluating performance and provides a common language for discussing non-technical skills. It can also be used to design learning programmes targeting categories in isolation or in combination (Yule and Smink 2016).

1.2 MARITIME TEAMS AS COMMUNITIES OF PRACTICE

Gherardi (2017) sees safety as a collective competence embedded in specific work practices. With this starting point, it is argued that safety training should be situated in the workplace, and, more specifically, within the communities of practice who interact socially in the performance of tasks.

Bridge and engine room teams perform common tasks and continually solve challenges together in their work. As a team, they can develop distinct work practices when the members interact (e.g. Bailey et al. 2006). This involves social learning, and will also include the social learning of non-technical skills. Community of practice (CoP) is a relevant theoretical concept in this respect (Lave and Wenger 1991; Wenger 1998, 2000). The concept builds on a social and cultural view on learning. A CoP involves a group of people that have a common interest in an activity or task, and that share information and learn from each other. CoPs can be understood as "...groups of people who share a concern or a passion for something they do and learn how to do it better as they interact regularly" (Wenger 2011: 1). CoPs can be regarded as vehicles of professional and situated learning (Lave and Wenger 1991), distinguished by a shared domain of interest and a shared competence. Members interact with each other and engage in joint activities and information sharing, thereby building relationships and learning. CoPs develop a shared practice and repertoire of resources, involving tools, common ways of addressing problems, experiences, stories, etc. (Lave and Wenger 1991: 1–2).

Learning seen from the perspective of a newcomer is regarded as a social process taking a person from legitimate peripheral participation to full participation (Lave and Wenger 1991). This process involves the competence already established in the community and the personal experience the members bring. According to Wenger (2000: 227), learning takes place at the intersection between social competence and personal experience: “Learning so defined is an interplay between social competence and personal experience. It is a dynamic, two-way relationship between people and the social learning systems in which they participate. It combines personal transformation with the evolution of social structures.” Learning can thus be seen as a negotiation process that takes place between the community and the individual member.

The concept of CoP involves seeing learning as both social and situated. In CoPs, learning takes place in a group or a team, where the team and the individual continuously influence each other. Learning is also seen as something that cannot be separated from the situation where the process takes place: it is context bound. These two aspects separate CoPs from many cognitive learning theories that seek to model individual learning processes and generalise across situations. As maritime officers are working in a social and situated setting, CoP is a relevant concept when discussing the learning of non-technical skills.

CoP as a theoretical concept has been applied in relation to safety training and in discussing the format and content of such training (Gherardi and Nicolini 2000; Gherardi 2017). A community of practitioners develops distinct safety knowledge related to its working practices. From such a situated view on safety, it follows that traditional training—which is often general, embracing participants from different teams and performed in classroom settings—could fall short. Abstract, scholastic training will seldom change actual collective practices, according to Gherardi and Nicolini (2000). Changes in practice involve participation and collective reflection.

Safety training should aim at collective reflection on common work practices to improve reliability (Gherardi 2017). Related to maritime education and training, it follows that training programmes should encompass the social group that is normally working together—e.g. the bridge team—and involve collective reflection on the situations to which it is exposed. This can support collective competence development, which is useful for handling real safety-related situations that the group might encounter at sea.

2 METHOD

We have completed a literature review of published research looking for different non-technical skills frameworks and training principles relevant for CRM training in the maritime industry. The information retrieval was limited to the period 2010–2017 and focused on research performed after the Manila Amendments to STCW (IMO 2011), highlighting new requirements in leadership and teamwork training.

The following terms were used in the search: non-technical skills, human factors, bridge resource management /BRM, bridge team management/BTM, engine-room resource management (ERM), crew resource management/CRM, simulator-based training and maritime. The word ‘maritime’ was included in all the searches in combination with at least one of the other terms. Different databases were used to identify relevant research in the field of interest. An initial search was performed using

the ORIA database available to researchers at the Norwegian University of Science and Technology (NTNU), which allows for a search of the university library's printed and electronic collections, including access to the most used scientific databases. This gave an overview of relevant databases, and those with the highest number of hits were chosen to broaden the search: Scopus, Web of Science, ScienceDirect (Elsevier) and ProQuest. Studies that met the following criteria were included: those in peer reviewed journals or conference papers; those with a quantitative or qualitative data set; those involving literature reviews or document studies; those with a sample of seafarers; and those published in English. A total of 31 studies were initially identified and the full-text papers reviewed; 16 of these met the inclusion criteria and are part of the literature review. The included articles were further analysed: broad topics were identified initially, and then the material was coded and categorised in an iterative process between the empirical data in the articles and the applicable theoretical perspectives (Bryman 2012; Charmaz 2014).

Table 1 gives a summary of the design, sample and purpose of the included studies. The majority of the identified research related to simulator-based training in the Navy and in merchant shipping. This review aims to present an overview of data applicable to the training of maritime officers and to point to areas where more research is needed. During the review of the articles, two topics became especially evident, which serve as a foundation for the analysis: the content of the CRM training and the CRM training process.

Table 1. Overview of studies included in the literature review

REFERENCE	DESIGN AND SAMPLE	PURPOSE
Baldauf et al. (2012)	Case study: Maritime university students	Explore maritime training using 3D training simulators
Chauvin et al. (2013)	Document study: UK and Canadian investigation reports of collisions	Identify human and organisational factors in maritime accidents
Conceição et al. (2017)	Document study: Portuguese Navy accident reports Questionnaire: Simulator instructors and students	Develop a behavioural marker system for rating cadets' non-technical skills
Cordon et al. (2017)	Expert group: Senior deck officers Questionnaire: Marine officers	Identify human factors in seafaring
Espevik et al. (2017)	Questionnaire: Norwegian deck officers	Evaluate a CRM training programme
Hontvedt and Arnseth (2013)	Video based study: Recordings of bridge simulator exercise with professional pilot and students	Analyse the social organisation of bridge simulator training
Håvold et al. (2015)	Questionnaire: Seafarers participating in anchor handling courses at Norwegian training centre	Evaluate training of anchor handling teams
O'Connor (2011)	Questionnaire: US Navy surface war officers and naval aviator officers	Assess the effectiveness of BRM training
O'Connor and Long (2011)	Focus groups and interviews: US Navy junior officers	Develop a prototype behavioural marker system for deck officers
Röttger et al. (2016)	Quasi-experiments: German Navy junior officers	Assess the effect of classroom-based BRM training
Röttger et al. (2013)	Questionnaire: Active seafarers Quasi-experiments: German Navy junior officers	Adapt CRM questionnaire to maritime domain and study correlation between attitude and behaviour
Saeed et al. (2017)	Interviews: Senior deck officers. Quasi-experiment: Chief mate students.	Propose a quantitative method to evaluate the effectiveness of HELM training

Sandhåland et al. (2015)	Document study: Norwegian continental shelf accident reports	Identify factors influencing bridge crews' abilities to achieve and maintain situation awareness (SA)
Sætrevik and Hystad (2017)	Questionnaire: Crews of offshore attendant vessels on hire to a major hydrocarbon company	Examine how SA and authentic leadership influence crew members' risk assessment and actions
Wahl and Kongsvik (2017)	Fieldwork and interviews: Seafarers in a merchant shipping company	Identify essential non-technical skills for maritime officers
Wu et al. (2015)	Questionnaire: Researchers Quasi- experiment: Naval engineering students	Develop a quantitative evaluation method for engine room resource management training

3 RESULTS

The literature is analysed and divided into two main sections. First we present literature considering the content of BRM training; then we present research related to the CRM training process.

3.1 WHAT TO LEARN? THE CONTENT OF MARITIME CRM TRAINING

Ten of the reviewed articles discuss or propose different factors of relevance to the content of CRM training. Four main topics that indicate subjects to be included in the training were predominant in the analysis: leadership, decision-making, situation awareness and team communication. These are elaborated and explained below. Based on the review, these topics may be regarded as important elements in CRM training. We emphasise that the topics are to some extent overlapping in content.

3.1.1 Leadership

Leadership is the most central topic in the literature reviewed, and all ten articles address leadership in a direct or indirect manner. Although not all studies discuss leadership explicitly, there is an underlying assumption that this is an important aspect of CRM, since maritime officers with leadership responsibilities or cadets training to become officers are the prominent research objects (e.g. O'Connor 2011; Röttger et al. 2013; Cordon et al. 2017; Espevik et al. 2017). Sætrevik and Hystad (2017) show the importance of leadership style in maritime safety and indicate how it has a direct effect on situation awareness (SA) and an indirect effect on crew members' unsafe actions and subjective risk assessments. They found that an increase in authentic leadership style caused a decline in unsafe acts and an increase in SA among crew members.

Wahl and Kongsvik (2017) base their set of performance criteria on what seafarers consider good leadership. Their study shows that followers expect the master to lay the foundation for harmony on board and regard him as a *pater familias* with distinct authority. Important abilities are maintaining professional expertise, planning and coordinating work, providing and maintaining standards, giving fair feedback and caring for the crew. Assertiveness in maritime leadership is discussed by Wu et al.

(2015), who underline the importance of being able to communicate sincerely and equally with others, to state decisions in a confident manner, and to notify any doubt about others' decisions. The authors state that good leadership is recognised as the ability to issue instructions and motivate team members appropriately. Saeed et al. (2017) describe how a proper amount of authority and assertiveness is characterised by a person's willingness to take full control if required by the situation, always to consider suggestions of team members, and to show initiative ensuring crew involvement and task completion. Providing and maintaining standards and a commitment to achieve top performance are key elements. The authors emphasise that officers should encourage the entire crew to participate in the planning and completion of tasks, ensuring that the plan is clearly stated and confirmed with team members, and that the goals and boundaries for task completion are clearly specified.

Workload management is highlighted by Saeed et al. (2017) and includes elements such as noticing signs of stress and fatigue, allowing sufficient time for task completion, demonstrating good task prioritisation and delegating all necessary tasks in a good manner. O'Connor and Long (2011) also point to the value of retaining a calm demeanour under pressure and demonstrating control, indicating the ability to cope with stress in oneself and other team members as an essential leadership skill. Setting and maintaining standards for the watch team in an effective manner is regarded as crucial by O'Connor and Long (2011). Taking the initiative, setting intentions and goals, and establishing a control standard are described as positive leadership skills by Conceição et al. (2017).

Leadership style seems to be a common denominator in these articles and officers are expected to behave in an assertive manner, to take the initiative, to set clear goals and to be concise when in command. Maritime officers are supposed to be role models that provide and maintain standards for the rest of the crew. According to the reviewed studies, CRM training should include elements that support such traits.

3.1.2 Decision-making

Decision-making is an important part of leadership and is discussed explicitly as a separate issue in six of the reviewed articles. Saeed et al. (2017) describe it as the process of reaching a judgement or choosing an option. Wu et al. (2015) underline the importance of decision-making in maintaining safe watch-keeping at the bridge or in the engine room, and highlight the importance of utilising available resources in this process. The authors claim that decision-making is affected by the prioritisation of tasks, where effective performance depends on the allocation and assignment of tasks to the crew. Considering crew experience and the ability to seek information from all available resources are regarded as influencing factors (Wu et al. (2015). Wahl and Kongsvik (2017) explain that taking

objections from the crew seriously, being open to suggestions and creating a climate where it is recognised as important to speak up are factors highlighted by their respondents. Deferring to expertise is a central factor in their model. Those with experience and technical knowledge are encouraged and expected to share their opinions. This makes it possible to identify and assess options and to make and share decisions. Reviewing the outcomes serves as an opportunity to learn, and is essential in building a reliable organisation. Checking outcomes against plans is also emphasised by Saeed et al. (2017), who further indicate the importance of involving other team members in identifying a wide range of options and discussing probable causal or limiting factors. This is crucial in problem definition and diagnosis, in order to generate alternative options, to make a risk assessment and to eventually select and clearly state the best option.

Chauvin et al. (2013) studied investigation reports and found that 85 per cent of collisions were caused by unsafe acts related to decision-making. A precursor of poor decisions was typically a lack of situation awareness and attention deficiencies, such as poor lookout. Preconditions to the accidents were often poor visibility and misuse or non-use of instruments such as the radar. According to O'Connor and Long (2011), decision-making contains three elements: analytical thinking, where an optimal solution is identified by generating and comparing multiple courses of action; following direct orders from superior officers or documented procedures; and making quick decisions based on prior experience in an intuitive manner. Conceição et al. (2017) use decision- making as one of the main categories in their behavioural marker system and include three behaviours: establishing alternative lines of action; assessing and verifying the consequences of the decision and actions; and considering and sharing with others the risks of different lines of action.

Sound decision-making emerges as an essential non-technical skill in allocating and utilising available resources in order to maintain safety. Central factors that, according to the reviewed articles, should be emphasised in CRM training are the ability to identify risk and assess options, to select options and plan action, and to review outcomes.

3.1.3 Situation awareness

A foundation for good decisions is awareness of the context where the operations take place. Five of the reviewed studies consider situation awareness (SA). The description of situation awareness at sea and the proposed analytical models in the reviewed articles refer to and are in line with the definition given by Endsley (1995: 36): "Situation awareness is the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future." She divides SA into three levels of information processing and hierarchical

phases: level 1 is the perception of elements in the environment; level 2 is comprehension of the current situation; and level 3 is the projection of future status (Endsley 1995). In line with this perspective, O'Connor and Long (2011) describe SA as a process that includes three cognitive skills: actively gathering information to keep up with a changing situation; achieving an understanding of what available information means; and forward planning to anticipate future events. We find the same division between three distinct skills in the work of Wu et al. (2015). They emphasise the perception of elements, picture formation and projection as relevant non-technical skills. Conceição et al. (2017) also highlight three aptitudes: the abilities to monitor and report changes in situations, to collect external information and to identify potential dangers or problems.

Cordon et al. (2017) describe SA as a key factor in navigation influencing officers' attention, spatial aptitude, organising, decisions and awareness. Sandhåland et al. (2015: 277) claim that "the bridge crew must be able to identify key aspects of the environment accurately, understanding the meaning of what they sense, and have a good sense of what can happen". They revealed that 18 of the 21 cases of collisions between attendant vessels and offshore facilities in the North Sea associated with human error involved loss of SA. Poor bridge design, failure to plan, communication failure, distracting elements and insufficient training are highlighted as significant contributing variables. Reduced vigilance and misconception of the technical automation system emerged as the primary antecedents of the collisions they studied, while inadequate planning was the most common contributing cause.

Saeed et al. (2017) point to awareness of bridge systems and the ability to monitor and report changes in system status as belonging to four SA skills: (1) awareness of external environment, including an ability to collect a full range of information about the environment—e.g. own ship position, traffic and weather; (2) sharing key information about the environment with team members; (3) awareness of time, where time constraints are discussed with other team members; and (4) the ability to assess changes in the situation. The importance of social awareness is highlighted by Wahl and Kongsvik (2017). They illustrate the importance of a master knowing his subordinates and discovering signals among the crew that may indicate a dysfunctional team. By combining this information with an understanding of the ship's systems and an awareness of external factors, the master may gain a more comprehensive understanding of the situation at hand and potential risks.

Situation awareness is indicated as an officer's ability to have a situational overview and to fit this knowledge into a mental model to trigger problem recognition. Being aware of the ship's systems and of external factors, collecting relevant information and identifying hazards are elements that are consistently highlighted as relevant for CRM training.

3.1.4 Team communication

Laying the foundation for good team communication is also an important skill for maritime leaders. Team communication is addressed in five of the reviewed articles. Communication is highlighted as a central skill in facilitating the coordination and collaboration of the crew members of a vessel. Wu et al. (2015) emphasise the importance of communication in efficient and safe operations at sea, particularly information sharing and discussion as part of problem-solving processes. Conceição et al. (2017) understand good communication skills to include the abilities to share information, to keep a continuous, clear and effective flow of information, and to promote a constructive environment for communications. The value of providing feedback and passing information to other watch stations or assets is also highlighted by O'Connor and Long (2011). They point to the importance of issuing effective orders to other members of the team as required, claiming that assertiveness and giving direct and explicit orders is an important non-technical skill that should be emphasised in the training of junior officers.

Wahl and Kongsvik (2017) underline the importance of officers who listen, ask questions and respond to concerns from their team. Communicating clear goals, being concise and emphasising a collective understanding are important factors. The authors claim that close cooperation within and between professions, and coordination in the performance of tasks, are necessary to get work done efficiently and safely on a vessel. Building and maintaining the team is crucial. Considering individuals' needs and delegating tasks when appropriate are emphasised as learning opportunities. Giving subordinates new challenges for them to experience personal growth and develop their professional knowhow is critical in maintaining a reliable organisation. Wahl and Kongsvik (2017) discuss how senior officers are instrumental in establishing team spirit and creating harmony on a vessel by setting high standards and clear goals, encouraging safe work practice, and addressing unwanted behaviour or conflicts in a direct and proactive manner. Teambuilding is highlighted by Saeed et al. (2017), together with the ability to encourage input and feedback from others. They also point to the ability to support and help others in demanding situations. Taking notice of suggestions from others, showing consideration for the condition of other team members, and providing personal feedback are all elements of an aptitude to consider others, according to Saeed et al. (2017).

When it comes to team communication, the review indicates that the ability to be aware of the condition of the team, to consider team experience, to coordinate and delegate tasks and to care for and support others are important factors. The officers' aptitude in asking questions, sharing information, giving feedback, and listening and responding to the concerns of the crew are important enablers and are relevant skills to include in CRM training.

3.2 How to learn? The process of maritime CRM training

Many of the articles identified in the literature search give examples of different ways to perform BRM training, from pure classroom lectures to a combination of classroom and simulator-based training to on the job training on vessels. An overview of factors related to the different training settings is given below.

3.2.1 Classroom training

Traditional classroom training still appears to be prevalent in relation to CRM. Several of the reviewed articles indicate a low effect of classroom lectures on the behaviour or safety attitudes of officers. Röttger et al. (2016) tested the effect of classroom-based bridge resource management training involving 117 junior naval officers. Approximately half of the officers belonged to an experimental group that received a five-day BRM classroom training course as an add-on to their leadership education. The other half were defined as a control group and only received the standard leadership training. Their work showed that the experimental group scored significantly better in a knowledge test on BRM topics than the control group, but no significant difference was identified between the two groups in observed attitude, behaviour or performance during real-world exercises following the training. Röttger et al. (2016) claimed that the reason for the low effectiveness of the BRM training on work practice was a too-strong emphasis on general principles in the BRM course and a lack of context-specific application of the theoretical principles. Saeed et al. (2017) evaluated a CRM programme mandatory in the UK called HELM (human element, leadership and management). They used a small sample of students who had completed a chief officer training programme. The participants were divided into two groups; one of the groups was given HELM training, the other was not. A comparison was made of the two groups in relation to the average performance as a bridge team during simulator exercises based on observations following a predefined non-technical skills taxonomy. Saeed et al. (2017) found no significant difference between the groups, stating that the HELM training course was an ineffective method for improving non-technical skills.

Many of the reviewed studies involved maritime CRM programmes that combined classroom lectures with simulator-based training. The objective of the classroom lectures was typically to give a theoretical review of central aspects related to the four main topics identified above: leadership, situation awareness, decision-making and team communication. Espevik et al. (2017) evaluated a four-hour CRM training programme aimed at enhancing team members' ability to speak up and their listening skills. The programme consisted of three modules, starting with a classroom task, followed by a simulator exercise and then a joint reflection module. The participants in each training session

were all officers from the same crew. The training arrangement received high scores in the participants' evaluation of learning effects. Espevik et al. (2017) claim that this indicates that the training was welcomed and that the ability to speak up is an important factor in maintaining safety at sea and should be included in CRM training of deck officers.

A study by O'Connor (2011) has some contradictory findings. In an evaluation of BRM training in the US Navy combining classroom lectures and simulator exercises, no significant effect on attitudes towards and knowledge of human factors in accidents was identified after the training. The author suggests that the main reason for the lack of learning was that the content of the training was not based on a systematic review of the needs of the specific community, but built solely on earlier research in aviation. O'Connor (2011) states that if BRM training is to become a valuable tool in preventing accidents in the maritime industry, it must be developed and adjusted to the needs of this domain rather than adopted 'as is' from another industry.

The literature review indicates that classroom training has some clear limitations but could have a better effect when it comes to learning non-technical skills when combined with simulator training and when the theoretical topics are relevant to specific operational needs. This needs to be considered when designing maritime CRM programmes.

3.2.2 Simulator-based training

The use of simulators is common in maritime education and training. There is a range of different types of simulator, with varying levels of physical fidelity. The more similar the simulated environment is to the actual work environment—e.g. the design of the bridge and the physical forces affecting a voyage—the higher the physical fidelity (Hontvedt and Arnseth 2013). Desktop simulators placed in a classroom have low physical fidelity and are often used to train very specific technical skills, such as the use of navigation equipment. Full mission simulators have a higher physical fidelity. Håvold et al. (2015) demonstrate how the use of full scale simulators is advantageous in creating a training environment as close to reality as possible and claim that it gives a unique opportunity to train in a risk-free environment where difficult scenarios or situations can be repeated and discussed in depth after the exercise is finished. The value of debriefing after simulator exercises is emphasised. The feedback and peer assessments after the simulator sessions in their study indicated that the participants got a better understanding of human factors and how these variables influenced anchor handling operations. That training should consist of opportunities for repetition and debriefing of the behavioural standards is highlighted by Röttger et al. (2016). How debriefing makes room for reflection and corrections is demonstrated by Hontvedt and Arnseth (2013), who indicate that sharing why

actions are taken among peers creates a joint understanding of communication practices and actions and a conceptual apprenticeship valuable for learning.

Baldauf et al. (2012) explore maritime safety and security training in a 3D training simulator and show the complexity of simulator-based training. They state that event-driven design of training scenarios needs to be combined with a focus on learning objectives established by formal requirements and the needs of the shipping company. This is also highlighted by Håvold et al. (2015), who point to the value of 'tailor-made' exercises for both critical and routine operations in accordance with ship owners' needs. They studied how a Norwegian simulator centre used bridge, deck and rig simulators in joint training of personnel involved in anchor handling operations. The learning objectives of the course were to improve teambuilding, leadership and communication, and were thus regarded as CRM training. Their research shows that the design of the course and the methods used for learning are promising when it comes to learning non-technical skills. According to Sandhåland et al. (2015), it is important that shipping companies ensure that sufficient on-board training is provided in addition to training on navigation simulators. Familiarisation with ship-specific equipment and systems may prevent collisions by improving the mental models used by bridge personnel to comprehend and assess critical situations.

Hontvedt and Arnseth (2013) stress the importance of role play and say that simulator fidelity is not necessarily crucial in creating real-life scenarios in an exercise. They discuss how simulated contexts are constructed collaboratively and point to the importance of social interactions for a fruitful learning outcome of the simulator training. The authors claim that the responses of the bridge personnel during training of ship handling skills are tied to jointly created activities, indicating that learning opportunities are closely related to the social construction of context. They state that a "rich understanding of how context is constructed and made use of in social interaction is key to examining learning as [a] situated activity" (Hontvedt and Arnseth 2013: 109).

An analysis of classroom and simulator-based training demonstrates the importance of CRM programmes that emphasise domain-specific challenges and that relate to the daily work situation of the course participants. Röttger et al. (2016) recommend that training targets specific behaviours in the given context of application, stating that a definition of best practices and behavioural standards is required to design the training and to achieve tangible improvements in non-technical skills. They claim that training should focus on teams instead of individual team members, and explain that new practices and procedures are more stable if they have been introduced to and exercised by each member of the team on board. The importance of training non-technical skills in a team context is

underlined by Conceição et al. (2017), particularly since the initial technical training of cadets in simulators is focused on individual achievements. They claim that a behavioural marker framework should be designed in accordance with the context in which it is applied. Röttger et al. (2016) emphasise the importance of tailoring training content to individual teams. They recommend that training needs are identified at the beginning of the training, allowing an opportunity to focus teaching on those non-technical skills and procedures that do not sufficiently comply with the defined behavioural standards. Röttger et al. (2016) conclude their study by saying that training in non-technical skills should not be limited to specific BRM courses, but should be encouraged in all simulator-based training, where it may influence technical performance.

The literature review shows the importance of context-specific training of crews, highlighting that CRM programmes needs to emphasise operation-specific needs in both classroom lectures and simulator training.

4 DISCUSSION

The discussion starts by summarising what maritime officers need to learn in accordance with applicable requirements and highlights some challenges in identifying a structure of non-technical skills that can support and guide CRM training. The results are then discussed in the light of social learning theory, indicating how best to train non-technical skills in order to maintain maritime safety. The conclusion addresses the main training principles and indicates areas of interest for future research.

4.1 A STRUCTURE OF NON-TECHNICAL SKILLS FOR MARITIME OFFICERS

Factors indicating what needs to be learned were analysed according to four broad topics: leadership, decision-making, situation awareness and team communication. Each category points to vast and different fields of knowledge and scientific research. Many of the studies present practitioners' views on what are important skills, building their findings on a bottom-up approach and identifying specifically wanted or unwanted behaviours that should be learned or changed in a training programme. The focus in many of the studies proposing non-technical skills taxonomies has been to identify tangible, observable behaviours that can be used to assess or validate training results (e.g. O'Connor and Long 2011; Wu et al. 2015; Conceição et al. 2017; Saeed et al. 2017). This applied approach may be the reason that many of the overarching topics in the material seem obvious and are often vaguely defined.

The analysis indicates that there is general agreement in the reviewed articles as to which non-technical skills are important. Many of the studies build on and refer to the work of Rhona Flin and colleagues. Their article about the development of the NOTECH (non-technical skills) system for assessing pilots' CRM skills (Flin et al. 2003) and the book *Safety at the sharp end: A guide to non-technical skills* (Flin et al. 2008) are cited in eight and five articles, respectively. Flin et al. (2003) suggested a taxonomy with four categories and fifteen elements in their NOTECH system, developed for pilots (see Figure 1). Several studies use this framework as a starting point in their work (O'Connor and Long 2011; Conceição et al. 2017; Saeed et al. 2017; Wahl and Kongsvik 2017).

Accordingly, we have applied the NOTECH framework illustrated in Figure 1 to our findings in Table 2, restricted to the two highest levels in the model: categories and elements. Behavioural markers are not included, as detailed examples of good or poor work practice are context-specific and difficult to generalise. We find that the categories identified in the material are to a large degree in accordance with the formal bridge and engine room resource management training requirements for maritime officers described by STCW. Here, non-technical knowledge is divided into five main categories (IMO 2011: 101, 143): allocation, assignment, and prioritisation of resources; effective communication; assertiveness and leadership; obtaining and maintaining situation awareness; and consideration of team experience. We have chosen to include the formal requirements in our taxonomy, but have made a few changes to the names of the categories based on the analysis.

We regard the entire framework as a representation of essential maritime leadership skills. Officers acting with confidence, standing up for themselves and stating their opinions are highlighted in the material, indicating that assertiveness should be one of the main categories in the model. The importance of leadership in maritime safety is shown by Sætrevik and Hystad (2017), who found that an authentic leadership style was linked to situation awareness and unsafe actions of crew members. Wahl and Kongsvik (2017) emphasise leadership style in their work and propose a non-technical skills taxonomy based on what seafarers consider good leadership. These articles indicate that all the categories in a non-technical skills framework should be seen as different aspects of leadership. Decision-making is highlighted as an essential skill by several of the researchers (O'Connor and Long 2011; Chauvin et al. 2013; Wu et al. 2015; Conceição et al. 2017; Saeed et al. 2017; Wahl and Kongsvik 2017) and the chosen name of the second category in the taxonomy. Allocation, assignment and prioritisation of resources is emphasised by Wu et al. (2015) as a part of the decision-making process. Actions and re-planning as a consequence of decisions are also regarded as part of this process by Conceição et al. (2017). Team communication is one of the topics highlighted in the analysis; we suggest splitting this into two categories in line with the knowledge requirements in STCW (IMO 2011).

Communication is suggested as the third category and team coordination as the fourth. Consideration of team experience is understood to encompass the ability to consider individuals and to support and help others, highlighted by Saeed et al. (2017) and Wahl and Kongsvik (2017) as essential skills when coordinating the crew. Situation awareness is one of the main topics in the analysis and thus maintained as the final category in Table 2.

Table 2. Overview of non-technical skills for maritime officers

CATEGORY	ELEMENT
ASSERTIVENESS	Provide and maintain standards Take initiative Set clear goals Be concise
DECISION-MAKING	Identify risk Assess options Select options and plan action Review outcomes
COMMUNICATION	Ask questions Share information Listen and respond to concerns Give feedback
TEAM COORDINATION	Be aware of team condition Consider team experience Coordinate and delegate tasks Care for and support others
SITUATION AWARENESS	Be aware of ship's systems Be aware of external factors Collect relevant information Identify dangers

The taxonomy gives an overview of what maritime officers need to learn according to the analysed material and indicates the magnitude of the concept of non-technical skills and the complexity of CRM training. Each category can be regarded as comprising different components in a training programme that can be adapted to different operation-specific needs. The importance or emphasis of each category may vary depending on the training needs identified. We suggest that these categories should be further developed, divided into different elements and detailed into behavioural markers. The behavioural markers should indicate important skills relevant to individual teams and their work situation. This is in line with the recommendations by Röttger et al. (2016), who highlight the importance of adjusting training to crew-specific needs, and O'Connor (2011), who emphasises domain-specific BRM programmes. We argue that the taxonomy should only be regarded as a tentative framework that needs to be translated and adjusted for the technical and social context that characterises the work environment of the officers undertaking the training.

4.2 A SOCIOCULTURAL PERSPECTIVE ON CRM TRAINING

A social and cultural view on learning involves looking at learning as context dependent. In their theory on communities of practice, Lave and Wenger (1991) see learning as a dynamic interplay between the individuals and the community of which they are a part. In this process, a shared repertoire of practices and common ways of problem-solving develop. This may also apply to safety and safety training. Gherardi (2017) sees safety as a kind of collective competence, and argues that safety training should take place in the context where the work is performed. The literature review indicates a need to adapt the training further to the maritime context. Related to how CRM training can be performed in a maritime setting, the theory of CoPs can represent an important supplement to psychological perspectives on learning.

The review of the literature shows that CRM training in the maritime industry is highly influenced by similar training in aviation (Barnett et al. 2005). This is no surprise, as the CRM concept was initially developed in aviation and efforts to develop a framework and content have been considerable over many years in this industry (Helmreich et al. 1999). Still, the maritime industry has some distinct hallmarks and is in some respects quite different from the aviation industry. Crew members spend long periods of time together, often weeks or even months, isolated from family and friends. In this respect, a ship has been described as a total institution (Aubert and Arner 1959). Furthermore, a bridge team and a crew often involve many people, in some cases several hundreds. This may represent different management challenges from in the aviation industry. The hazards and the context in which ships operate are also quite distinct. Groundings, collisions and allisions are common maritime accident types (Størkersen et al. 2017).

This implies that a careful tailoring of the CRM training for the maritime industry is appropriate. On a general level, the training should be directed at specific behaviours in the given context of application (Röttger et al. 2016). O'Connor (2011) points to the importance of developing and adjusting BRM training programmes according to the needs of the maritime domain and specific operational needs.

Furthermore, the review illustrates that CRM training is largely grounded on psychological theory. It involves a focus on human capabilities and limitations. This is evident in the non-technical skills taxonomy developed by Flin et al. (2003), dividing between cognitive and social skills. As illustrated above, this taxonomy has been highly influential in the maritime industry and is referred to in many of the reviewed articles. In the maritime industry, issues such as fatigue, situation awareness and communication have been important in CRM training, but in more recent years, safety culture and

organisational issues have gained an increased focus (Grech et al. 2008) and need to be further emphasised in future CRM programmes.

A possible consequence of the influence from psychological theory in CRM training concepts is that individual models of learning become dominant. The way both CRM classroom and simulator training are organised today may be a manifestation of this. In most cases, the targets for these courses are individual officers who participate without other members of their crew present and who are tested and evaluated as individuals. Although individual certification is a necessity and an important part of safety management at sea, it can also be regarded as a paradox that crew resource management training does not involve the crew itself as an entity. The work of Håvold et al. (2015) demonstrates the value of joint training of entire crews involved in offshore anchor handling operations and highlights the importance of tailoring exercises to team-specific needs.

One implication from the theory of CoPs is that existing bridge teams should train together, so that the members are enabled to collectively reflect on current work practices, and if and how these practices should be changed. Individual training does not facilitate collective reflection and it is reasonable to believe that the possibility of changed practices when one member returns from CRM training is not very high.

Another implication from the theory of CoPs is that CRM training should take place in a realistic working environment. Training simulators can resemble bridge teams' natural environment to some extent, although there are some clear challenges related to different bridge design layouts and lack of standardisation. In aviation, the cockpits are much more standardised (Haavik et al. 2017). Hontvedt and Arnseth (2013) argue that high physical fidelity of the simulator environment is not a prerequisite for successful training of mariners, but the ability to enact the social interactions that characterise the work situation is. Even large scale joint simulator exercises as described by Håvold et al. (2015) will have restricted selection of participants, which will most likely limit the opportunity to recreate the social factors of the work. A radical approach could be to go from a 'pull' to a 'push' strategy in CRM training. Instead of bringing CRM training participants to onshore facilities, instructors could perform the training in the bridge teams' ordinary working environment—on the ship. Although a push strategy would be more demanding of resources, the learning outcomes could be significantly improved.

A third implication is that the assessment of skills related to CRM should be related not only to individuals but also to the team. It can be fruitful to regard some of the non-technical skills (e.g. communication, situation awareness, decision-making) as group assets that can be trained and

facilitated, and thus assessed. This is in line with a holistic view on CRM, involving not only the individual members, but the team as an entity.

4.3 CONCLUSION

The literature review shows the complexity and magnitude of CRM training programmes in the maritime industry. There is a need to further operationalise the different categories that represent the content of the training and thus constitute CRM as a concept. The proposed taxonomy indicates essential non-technical skills for maritime officers. We argue that it should be understood as a tentative framework that cannot be adopted 'as is' to a specific context, but needs to be translated and adjusted to the sociotechnical system where the work takes place.

Much of the existing work in this field is characterised by applied research with a focus on end user needs, dominated by psychological theory and individual models of learning. It is important to maintain the applied focus, but the field would benefit from a more thorough use of theory, including social and cultural perspectives. Our study implies that CRM programmes should aim to train crews that usually work together, possibly in their natural environments, and consider giving assessments not only to individuals, but also at a team level to increase the learning effects. The increasing digitalisation in the industry has influenced the way mariners work, and so too their training tools. Future research should explore how this technological development may influence future CRM programmes, looking at both simulator fidelity and social aspects of the training.

5 REFERENCES

Aubert V, Arner O (1959) On the social structure of the ship. Acta Sociologica 3(4):200–219.

Bailey N, Housley W, Belcher P (2006) Navigation, interaction and bridge team work. Sociological Review 54(2):342–362.

Baldauf M, Schröder-Hinrichs JU, Benedict K, Tuschling G (2012) Simulation-based team training for maritime safety and security. Journal of Maritime Research 3:3–10.

Barnett ML, Pekcan CH, Gatfield DI (2005) Content and context: understanding the complexities of human behaviour in ship operation. In: Proceedings of the Human Factors in Ship Operations Conference, The Royal Institution of Naval Architects, London, pp 1–11.

Bryman A (2012) Social research methods. Oxford University Press, New York.

Charmaz K (2014) Construction grounded theory. SAGE Publications Ltd, London.

Chauvin C, Lardjan S, Morel G, Closterman JP, Langard B (2013) Human and organisational factors in maritime accidents: analysis of collisions at sea using the HFACS. Accident Analysis and Prevention 59:26–37.

Conceição VP, Basso JC, Lopes FC, Dahlman J (2017) Development of a behavioral marker system for rating cadets' non-technical skills. TransNav 2(2):255–262.

Cordon JR, Mestre JM, Walliser J (2017) Human factors in seafaring: the role of situation awareness. Safety Science 93:256–265.

Crichton MT (2017) From cockpit to operation theatre to drilling rig floor: five principles for improving safety using simulator-based exercises to enhance team cognition. Cognition, Technology and Work 19:73–84.

Emad G, Roth WM (2008) Contradictions in the practices of training for and assessment of competency. Education + Training 50(3):260–272.

Endsley M (1995) Toward a theory of situation awareness in dynamic systems. Human Factors 37(1):32–64.

Espevik R, Saus ER, Olsen OK (2017) Exploring the core of crew resource management course: speak up or stay silent. International Maritime Health 68(2):126–132.

Flin R, Martin L, Goeters K, Hörmann H, Amalberti R, Valot C, Nijhuis H (2003) Development of the NOTECHS (non-technical skills) system for assessing pilots' CRM skills. Human Factor and Aerospace Safety 3(2):95–117.

Flin R, O'Connor P, Chrichton M (2008) Safety at the sharp end. A guide to non-technical skills. Ashgate, Aldershot.

Flin R, Youngson GG, Yule S (2016) Enhancing surgical performance. A primer in non-technical skills. CRC Press, Boca Raton.

Gherardi S (2017) A practice-based approach to safety as an emergent competence. In: Bieder C, Gilbert C, Journé B, Laroch H (eds) Beyond safety training: embedding safety in professional skills. Springer Open, Cham, pp 11–22.

Gherardi S, Nicolini G (2000) The organisational learning of safety in communities of practice. Journal of Management Inquiry 9(1):7–18.

Grech MR, Horberry TJ, Koester T (2008) Human factors in the maritime domain. CRC Press, Boca Raton.

Haavik TK, Kongsvik T, Bye RJ, Røyrvik JOD, Almklov PG (2017) Johnny was here: from airmanship to airlineship. Applied Ergonomics 59:191–202.

Helmreich R, Anca J, Kanki BG (2010) The future of CRM. In: Kanki B, Helmreich R, Anca J (eds) Crew resource management. Academic Press, London, pp 493–500.

Helmreich RL, Merritt AC, Wilhelm JA (1999) The evolution of crew resource management training in commercial aviation. International Journal of Aviation Psychology 9(1):19–32.

Hetherington C, Flin R, Mearns K (2006) Safety in shipping: the human element. Journal of Safety Research 37:401–411.

Hontvedt M, Arnseth HC (2013) On the bridge to learn: analysing the social organisation of nautical instruction in a ship simulator. Computer-Supported Collaborative Learning 8:89–112.

Håvold JI, Nistad S, Skiri A, Ødegård A (2015) The human factor and simulator training for offshore anchor handling operators. Safety Science 75:136–145.

International Maritime Organization (2011) International Convention on Standards of Training, Certification and Watchkeeping for Seafarers. STCW. Including 2010 Manila Amendments. IMO, London.

Kanki B, Helmreich R, Anca J (2010) Crew resource management. Academic Press, London.

Lave H, Wenger E (1991) Situated learning. Legitimate peripheral participation. Cambridge University Press, Cambridge UK.

O'Connor P (2011) Assessing the effectiveness of the bridge resource management training. The International Journal of Aviation Psychology 21(4):357–374.

O'Connor P, Long MW (2011) The development of a prototype behavioral marker system for the US navy officers of the deck. Safety Science 49:1381–1387.

Röttger S, Vetter S, Kowalski JT (2016) Effects of a classroom-based bridge resource management training on knowledge, attitudes, behaviour and performance of junior naval officers. WMU Journal of Maritime Affairs 14:143–162.

Röttger S, Vetter S, Kowalski JT (2013) Ship management attitudes and their relation to behavior and performance. Human Factors 55(3):659–671.

Saeed F, Wall A, Roberts C, Riahi R, Bury A (2017) A proposed quantitative methodology for the evaluation of the effectiveness of human element, leadership and management (HELM) training. WMU Journal of Maritime Affairs 16:115–138.

Salas E, Wilson KA, Burke SC, Wightman DC (2006) Does crew resource management training work? An update, an extension, and some critical needs. Human Factors 48(2):392–412.

Sandhåland H, Oltedal H, Eid J (2015) Situation awareness in bridge operations. A study of collisions between attendant vessels and offshore facilities in the North Sea. Safety Science 79:277–285.

Størkersen KV, Antonsen S, Kongsvik T (2017) One size fits all? Safety management regulation of ship accidents and personal injuries. Journal of Risk Research 20(9):1154–1172.

Sætrevik B, Hystad SW (2017) Situation awareness as a determinant for unsafe actions and subjective risk assessment on offshore attendant vessels. Safety Science 93:214–221.

Thomas MJW (2018) Training and assessing non-technical skills. A practical guide. CRC Press, Boca Raton.

Wahl AM, Kongsvik T (2017) Leadership @ sea: Essential non-technical skills. In: Cepin M, Bris R (eds) Safety and reliability—theory and applications. Proceedings of the 27th European Safety and Reliability Conference (ESREL 2017), Portoroz, Slovenia, 18–22 June 2017. CRC Press, London.

Wenger E (1998) Communities of practice. Learning, meaning, and identity. Cambridge University Press, Cambridge UK.

Wenger E (2000) Communities of practice and social learning systems. Organisation 7(2):225–246.

Wenger E (2011) Communities of practice: a brief introduction. STEP Leadership Workshop, University of Oregon, October 2011. https://scholarsbank.uoregon.edu/xmlui/handle/1794/11736

Wu Y, Miwa T, Shimamoto K, Uchida M (2015) Development of quantitative team performance evaluation method for ERM. WMU Journal of Maritime Affairs 14:333–347.

Yule S, Smink DS (2016) Non-technical skills for surgeons: the NOTSS behaviour marker system. In: Flin R, Youngson GG, Yule S (eds) Enhancing surgical performance. A primer in non-technical skills. CRC Press, Boca Raton, pp 37–59.