Balancing Safety I and Safety II: Learning to Manage Performance Variability at Sea Using Simulator-Based Training

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Abstract: The article explores how simulator-based training of professional maritime deck officers can improve the management of performance variability and safety during critical operations at sea. The research has a qualitative design and is based on observational data from two different training programmes and interviews with simulator instructors and experienced mariners attending these programmes. Learning and performance variability in this specific context is explored through the lenses of Resilience Engineering. The study aims to provide guidance to practitioners and researchers on how to achieve resilient performance. The data illustrates three key aspects in learning to manage variability: the ability to prevent adverse events by recognising anomalies and solve problems in a flexible manner, the ability to define limits of action through shared knowledge and the ability to operate the system with confidence. The results indicate that the simulator offers a necessary backdrop for realistic tasks that forms the basis for experiential learning and joint reflection among professionals. The study demonstrates that history of failure works as a repository for highlighting and improving the skills and confidence needed to deal with situational complexity and to maintain operational variability.

Keywords: experiential learning; maritime officers; reflective practices; Resilience Engineering, simulator-based training; system variability

Highlights:

- The work explores simulator-based training of deck officers
- It aims to discover how resilient performance can be achieved in practice
- Performance variability is studied through the lenses of Resilience Engineering
- Experiential learning and reflective practice are essential training tools
- Effective training rests on balancing Safety I and Safety II

1 INTRODUCTION

The maritime industry is still associated with high risk. In 2017, there were 2,712 registered casualties and 94 total losses of ships worldwide [1]. Despite a steady decline in the number of reported accidents, there is a general concern in the industry that human error may continue to be a major driver of incidents in a situation where the vessels become larger and the commercial pressure is increasing [1,2]. The grounding of the cruise ship *Costa Concordia* in January 2012 where 33 people perished [3], the fire onboard the oil tanker *Sanchi* in January 2018 with 32 fatalities [1] and the recent capsizing of the frigate *KNM Helge Ingstad* at the west coast of Norway [4] exemplify the potential severity of accidents at sea.

Operational safety is influenced by a variety of factors, such as other maritime traffic, weather conditions and technical equipment. Although much navigation is routine for long periods of time, contextual factors might align and create unexpected situations that must be handled promptly. Thus, maritime deck officers must be able to handle variable conditions and be prepared for both the known and unknown. This resonates with one of the predominant perspectives in safety research, Resilience Engineering (RE). In RE, *performance variability* is considered a key concept for ensuring safety in complex sociotechnical systems [5,6,7,8]. Performance variability involves adjustment of performance to meet changing conditions [9]. While not always successful, such adjustments can sometimes 'save the day' and ensure that things go well and as planned.

Performance variability can be studied both on the organisation and the individual level, even if organisational variability according to Hollnagel [9, p.92] analytically is the result of individual variability. The focus of this article is on the individual and team level. In line with this, performance variability is associated with *resilience skills,* defined as 'individual or team skills of any type necessary to adjust performance, in order to maintain safe and efficient operations during both expected and unexpected situations' [10, p. 30]. Thus, resilience skills are skills that support performance variability [9].

Practical guidance on how to develop such skills has to a limited extent been explored in RE literature [5,11,12]. The development of this perspective has to a large degree been theory-driven and has been criticised for little empirical knowledge and a lack of practical and operational implications [5,12]. This article aims to explore how resilient performance can be achieved in practice. More concretely, we will investigate how simulator-based training can be applied to maintain safety by managing performance variability and develop resilience skills. Empirically, it is based on a study of training of deck officers who operate a specific computerised system at shuttle tankers. Simulator-based training allows deck officers to safely test a ship's operational limits through trial and error in a safe environment as close to reality as possible.

The simulated technical system and the related work processes are presented in the next subchapter. The theoretical framework of the study is given in section 2. The ability to discover and manage unexpected events is described through the lenses of RE with an emphasis on variability and organisational learning. A detailed description of the methodological approach, the qualitative research design and the sampled training programmes is given in section 3. The results are presented in section 4 and illustrate three key aspects in learning to manage performance variability: the ability to prevent adverse events by recognising errors and anomalies and solve problems in a flexible manner, the ability to define limits of action through shared knowledge, and the ability to operate the system with confidence. The results are discussed in section 5. The article concludes by highlighting a set of training principles that may enhance learning of safety critical performance and suggests areas for further research.

1.1 DYNAMIC POSITIONING AT SHUTTLE TANKERS

Dynamic positioning (DP) is a computerised system for automatic positioning and heading control of a vessel controlled from the bridge. DP technology is used in operations when mooring or anchoring is not feasible, when the work requires the ship to follow a moving target or when navigational precision is of prime importance. The work process is characterised by an active interaction between human and computer, where the operator enforces supervisory control and can select different modes and forms of control [13,14,15]. As such, the DP system can be considered a 'joint cognitive system' [16], involving the operator and the technology. The officers operating the DP system must attend system specific training and be certified as DPOs (dynamic position operators) in accordance to industry requirements [17].

A shuttle tanker is a ship designed to offload oil from an offshore oil field and transport and discharge it either to an oil terminal or to another tanker for further transport. Offloading operations require a high degree of accuracy, and the DP system is used to keep the ship within specified position and heading limits, counteracting forces such as wind, waves and ocean currents, as well as forces generated by the propulsion system of the vessel. Input from different sensors (e.g., wind, motion and vertical reference), gyrocompasses, and position reference systems are used to build mathematical models in the advanced computer system. Based on this information, the system calculates the necessary force to be exerted by the thrusters and propellers for the vessel to remain in position.

Deviations from the desired heading or position are automatically detected, and appropriate adjustments are made by the system [18].

Once the DP is activated, the operator's main tasks are to monitor the system and the environment, enter commands (e.g., to change heading or position), take precautionary actions if something is amiss and be prepared to take manual control of the vessel if the DP is malfunctioning. This study looks at how DPOs are trained to handle the system during offloading operations and the stepwise work process that enables the shuttle tanker to be connected to an offloading unit. Figure 2 shows how a tanker approaches a floating production, storage and offloading unit (FPSO). The process follows a very strict oil field–specific procedure. Table 1 gives an overview of the typical phases and steps performed before, during and after connection to an offloading unit. From 10 nautical miles to connect, the procedure usually takes three to four hours depending on factors such as wind, waves and current. An offloading may take from a few hours to several days, influenced by factors such as hose dimension, pump capacity, amount of oil to be offloaded, disruptions and weather.

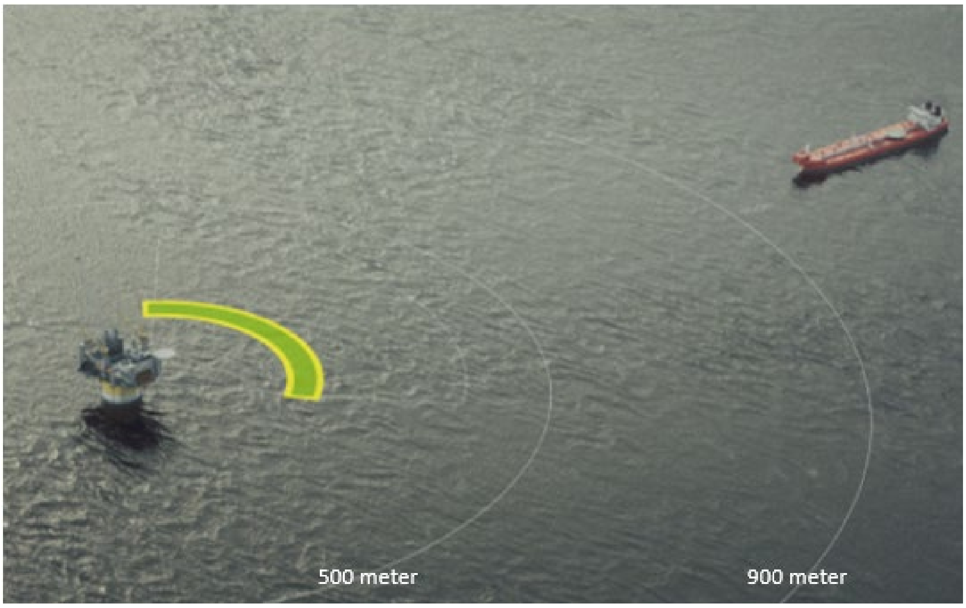

Figure 1 An overview of the stepwise sequence where a shuttle tanker approaches an offloading unit to start offloading oil to the ship (copyright: Kongsberg Group).

In an offloading position, the bow of the ship is to stay in the green section (visualised in Figure 1), with the stern away from the installation. The ship will rotate in the sector according to wind direction (weather vane) to stay in an optimal position with respect to weather conditions and hose integrity. During the offloading operation, the ship is very close to the offloading unit. An average shuttle tanker is 250 meters long, which means that there is little room for error when staying at a distance at approximately 300 meters. If the bow enters the yellow section, mitigating actions need to be taken to get the bow back into the green section (Figure 1). Risk during offloading relates to changes in weather and wind current, DP system failures (e.g., loss of navigation aids or sensors) or power supply failures. If there are critical system faults, the DP can be disengaged, and the vessel can be controlled manually by the deck officers. In such a case, the operation will be aborted, the hose disconnected, and the vessel steered to a safe distance from the offloading unit outside the installation’s 500-meter safety zone. The worst-case scenario is a total loss of engine power where the ship drifts uncontrollably and collide with the installation. In addition to material and environmental damages and potential production downtime, such a scenario involves a substantial risk for personnel injuries.

Table 1. An overview of the typical phases and steps performed before, during and after connection to an offloading unit. Distance to the offloading unit with reference to nautical mile (nm) zone or meter (m).

PHASE	**STEP *(distance to offloading unit)***	**DESCRIPTION (*time used*)**
Prearrival	Approaching 10 nm	Prepare to enter field and activate DP
Arrival	At 10 nm 10–3 nm 3000 m–900 m	Continue preparations in accordance to distance specific checklists (*1.5–2 hrs.*)
	At 900 m	Activating the DP system (*5–10 mins.*)
	900–500 m	Continue approach (*30 mins.*)
	500 m	DP system test (*10–15 mins.*)
	500 m to connection position	Move into position to connect (*30 mins.*)
Connection	Connection position Hawser/hose pick up Hawser/hose connected Step vessel back to loading position	Stepwise connection of hose from offloading unit to ship (*10–60 mins.*) Start offloading oil
Offloading	At 300 m*	Monitor operation (*20 hrs. average***)
Disconnect	At 300 m	Hose/hawser disconnection (*60 mins.*)
Departure	At 500 m	Deactivate DP system
	500 m–10 nm	Leave field following voyage instructions

** The proximity to the offloading unit will vary.*
*** An offloading may take from a few hours to several days.*

2 THEORETICAL FRAMEWORK

The focus of Resilience Engineering is to develop ‘principles and practices that are necessary to enable systems to function in a resilient manner’ [7, p.183]. The perspective embraces organisations, teams and individuals [10,19] who are considered successful when they can ‘recognise, adapt to and absorb variations, changes, disturbances, disruptions, and surprises’ [19, p.3]. Four main abilities are highlighted as constituting a resilient system [20,21]: the ability to *respond* to regular and irregular threats in a robust yet flexible manner; the ability to *monitor* what is going on, including its own performance; the ability to *anticipate* disruptions, as well as the consequences of adverse events; and the ability to *learn* from experienced successes and failures. Learning can be seen as a basis for the other abilities; the ability to respond, monitor and to anticipate. Learning from experience can be related to both the individual (knowledge, skills, attitudes) and the institutional level (for example rules, procedures and policies). Thus, a resilient system must be able to improve both individual and institutional knowledge [22, p. 133]. According to Praetorius et al. [23] the four abilities are mutually dependent, each representing one facet of a system's functioning. They describe anticipation, responding and monitoring as core tasks in maritime traffic management and demonstrate how learning affects these and the ability to operate under a variety of conditions without major performance drops. This implies that analysing DPO training through the lenses of these abilities gives an opportunity to identify aspects of learning that enhances system operating skills of deck officers.

The RE safety perspective differs from more design- and rule-based approaches that aim to build safety through planning in advance rather than by increasing the ability to deal with surprises. Hollnagel [7] uses the terms *Safety I* and *Safety II* to distinguish between these two views on safety. The Safety I perspective is associated with a preoccupation of things that go wrong. Adverse events are analysed in hindsight to understand what went wrong and to define measures to avoid similar outcomes in the future [7,9,21,24]. As a supplementary perspective, it is suggested to include knowledge on how and why things go right. This perspective has been labelled Safety II (ibid.) and is described as 'a condition where the number of successful outcomes is as high as possible. It is the ability to succeed under varying conditions. It is achieved by trying to make sure that things go right, rather than preventing them from going wrong' [7, p.183]. The complexity of many sociotechnical systems means that accident causation can be complex and difficult to predict. Learning from things that have gone wrong in the past (in line with the Safety I perspective) has thus some clear limitations in such systems, where there are many possible configurations of factors that can produce accidents.

Safety II represents a perspective that addresses the handling of unexpected events. Hollnagel [7] underlines that proactive safety management requires an understanding of how a system works and that this knowledge is established by observing patterns and relationships across events rather than simply looking at causes of single events. Despite Safety I and Safety II being described as two fundamentally different ways of viewing and achieving safety, the two are not mutually exclusive. The safety of the maritime operations in our study displays obvious components of both. On one hand, a shuttle tanker's approach to an FPSO is strictly regulated by detailed operational rules as illustrated by the sequence in table 1. On the other hand, the situational complexity in terms of wind and currents can be high at the same time as the operational margins are quite narrow. This means that the navigators' situational adaptation will be a key ingredient in making sure that things go right, and that safety will depend on an interplay between compliance and resilience. Thus, Safety II plays out within a context of Safety I [25].

Table 2 Overview of the main differences between a Safety-I and a Safety II perspective. Based on Peñaloza et al. [26, p.3] and Hollnagel [24, p.13]

	SAFETY-I	**SAFETY- II**
Understanding of safety	Reducing what goes wrong	Increasing what goes right
Safety management principle	Reactive, respond when something happens	Proactive, try to anticipate developments and events
View of human operators	A liability (to err is human)	A resource (manage and control technological systems)
Knowledge basis	Understanding unwanted events, failures and accidents	Understanding successes and surprises in everyday work
Performance variability strategy	Prevent harm (e.g. by barriers, standardized processes/ procedures)	Monitor and manage variability

Table 2 gives an overview of the main difference between a Safety-I and a Safety-II perspective. As defined by Hollnagel, Wears and Braithwaite [27, p.1] Safety I 'presumes that things go wrong because of identifiable failures or malfunctions of specific components: technology, procedures, the human workers and the organisations in which they are embedded'. The safety I perspective thus involves identifying or imagining what can go wrong and put measures in place (e.g. training toward identified scenarios) to prevent unwanted consequences. Safety II is defined as the ability to succeed under varying conditions. Few advocates of safety II would disagree that it is important to keep trying to identify predictable ways a system can fail. The main argument is, however, that this will not be enough when faced with complexity and variability. Thus, there is a close relationship between the two tales of safety.

2.1 VARIABILITY

A key issue in RE, and specifically the Safety II perspective, is the importance put on performance variability and the ability of individuals and organisations to continuously adapt their everyday work to situational changes to ensure that 'everything goes right' [7, p.137]. This view on variability is quite different from the view in, for example, quality control of production processes, where variability is seen as deviations from a quality norm and where the reduction of variability is a goal [28]. In RE, variability represents necessary adjustments and a basis for safety and productivity [7]. Resilience is achieved by controlling variability rather than by constraining it.

Most seafarers, regardless of rank, would recognise that their work is characterised by variability. Earlier studies demonstrate that maritime operations to a high degree are intractable with complicated descriptions and frequent, irregular operational changes and often incompletely understood [29]. This indicates that everyday performance can be understood as flexible and inherently variable. The situational context, for example, weather, work operations and traffic complexity, is constantly changing and can be the source of small and big surprises. The ability to discover and respond to such unexpected events is important for safe maritime operations. This is not to say that performance adjustments might lead to unacceptable outcomes also. The Safety II view involves seeing performance adjustments as a precursor for both success and failure [7].

Other safety perspectives have addressed how variability on the system level can lead to catastrophes. The normal accidents theory [30] describes how tight couplings and non-linear interactions of components enhance complexity in a sociotechnical system and may lead to errors spreading in unexpected ways, eventually causing accidents. This is a form of variability that is not immediately comprehensible and thus difficult to control. Functional resonance [31] is a concept parallel to complex interactions, where performance variability of components in complex systems can add up and lead to systemic accidents. Patriarca and Bergstrøm [29] used the functional resonance analysis method (FRAM) to show how mooring operations are highly interacting and coupled with several other activities. Their study demonstrated how bridge crew adapt their work practices to the task a hand handling the complex interaction between cognitive tasks and technical, organisational and external factors.

In the earlier safety theory, performance variability has also been associated with human error and noncompliance, but this has been considerably nuanced in later years. How operators and decision-makers make sense of changes in the situational context of operations and adapt accordingly has been subject of much research attention [32,33]. Performance variability has, in many instances, been found to be a human asset that has averted accidents and catastrophes. The Snorre A accident in the petroleum industry in 2004 is one example, where a gas blowout eventually came under control by the efforts of a small group of people performing under circumstances not described by any procedures [34]. In other words, work as imagined in procedures might be different from work as done, and variability can in some circumstances be necessary [21]. This is consistent with ‘Model 2’ thinking about rules and procedures [35], involving three basic ideas: (1) rules are underspecified and can never cover all eventualities; (2) variations and adaption of human performance is valuable and necessary; and (3) experience-based, professional judgment is fundamental for safety. This shows the value of a RE perspective emphasising the ability to adjust performance to match the needs of operating scenarios and to balance the incompleteness of procedures and instructions [36].

2.2 LEARNING

The fundamental goal of simulator training is learning. Learning is one of the four cornerstones in RE and is regarded as crucial for resilient performance [5,11,12,21]. Hollnagel [21, p.36] defines learning as 'the ways in which an organization modifies or acquires new knowledge, competencies and skills'. He emphasises that learning is incremental, shaped by previous knowledge and to be understood as an active process of development rather than as a passive collection of facts and knowledge. According to Hollnagel [21], a basic prerequisite for learning on the organisational level is a competent staff. Thus, organisational learning depends on individual learning, that can be deposited on the organisational level, and influence on the ability to anticipate, monitor and respond [21]. It is common to base safety training programmes on lessons learned from accidents or incidents in accordance with a Safety I perspective and with an emphasis on preventing similar errors in the future [21]. Many RE studies place the capacity to maintain system resilience with activities or skills of sharp-end operators such as deck officers and say this capacity is enhanced by planning or training [11].

Argyris and Schön [37] claimed that all human action is based on theories of action and differentiated between *espoused theories-of-action* and *theories-in-use*. They explained that espoused theories of action are self-reported by people as a basis for their behaviour, while theories-in-use are construed based on observations of how people actually behave. To alter theories-in-use, people must question the framework of theories that form their actions, described as *double-loop learning* (ibid.). They emphasised that most organisations are characterised by *single-loop learning* where changes only happen at an espoused level. Leadership at sea may be particularly exposed to single-loop thinking since a crew is organised following a strict hierarchy, where the people work together over long periods and where the ship organisation is loosely coupled to the onshore shipping company. Leaders tend to receive little feedback on their behaviour, and followers tend not to question or break their governing norms [38]. Simulator training offers a way to counterweight this, as an important aspect of simulator-based training is to give officers an opportunity to observe each other's actions and reflect on their practice with peers.

Rudolph et al. [39] indicated that the goal of simulator training is to allow trainees to explain, analyse and synthesise information and emotional states to improve performance in similar situations in the future. This kind of training follows the four-stage learning cycle proposed by Kolb [40]: Professionals learn by doing (*having a concrete experience*), by thinking about what they are doing (*reflective observation*), by using lessons learned to modify work practice (*abstract conceptualisation*) and by applying what is learned (*active experimentation*). A learning process cannot take place without rigorous reflection from learners and Kolb described learning as 'the process whereby knowledge is created through the transformation of experience' [40, p.38].

Schön [41] focused on professionals and their capacity to self-reflect on their actions in a continuous process of learning and improvement. He coined the term 'reflective practice', demonstrating that experience alone does not necessarily lead to learning; deliberate reflection on what drives one's own professional practice is essential. Professional practitioners get their experience from repetitive action and then build up their *knowing-in-action* through subsequent development of a repertoire of expectations, images and techniques. Over time, the practitioners' knowledge tends to become increasingly tacit, individual, intuitive and automatic and develops as a *reflection-in-action* that will benefit the situation at the time of an event. To change work practice requires *reflection-on-action* where the practitioner revisits an event, think back on what happened and adjust future actions based on this knowledge. We will explore how simulator-based training supports reflective practices and eventually learning.

3 RESEARCH DESIGN

This study uses simulator-based training of professional DPOs at shuttle tankers to explore performance variability and safety at sea. The research aims to generate rich data [42] from several sources to get an in-depth understanding of this specific training in relation to the research question. The material used in this article is collected over a six-month period. Observations of two specific DP training programmes, interviews with 12 DP instructors and seven course participants are the main data sources. Secondary sources include written documents describing the relevant training programmes, scenario scripts for the simulator exercises, presentation materials used in the classroom and pertinent training requirements for DP operators. The next section gives an overview of the methodological approach and the empirical material. It is followed by a detailed description of the research context.

3.1 METHODS

The data is from a Norwegian global company providing a broad range of simulator-based training for mariners. Two different DP training programmes were observed, and relevant information captured in field notes. Both DP instructors and course participants were interviewed. The training and the informants were purposively sampled with the research question in mind. The data gathering followed the principle of saturation [42] and was concluded when no new insights or patterns were uncovered and when the material was judged as robust.

The 12 interviewed DP instructors worked at four different geographic locations, with a majority (seven) teaching at the same centre in Norway. All instructors held valid deck officer certificates at the time of the interviews, and their experience as instructors ranged from two to twenty years. The interviews focused on what characterises good simulator-based training and what the instructors emphasised in the debriefing session. The interview guide was sent to the informants prior to the interviews. The conversations were done face-to-face or on Skype, and notes were taken during the talks. Some of the informants provided written answers on e-mail before the interview session. These answers were then discussed and clarified during the talk. The interviews lasted between 30 and 60 minutes. Three of the informants were instructors at the observed training programmes and provided information through informal conversations as well.

Three group interviews, with a total of seven course participants attending three different courses, were carried out. The informants were professional officers, in which two were masters, three were chief officers and two were second officers. All had a valid DP certificate at the time of the interview, with an experience on the system ranging from two to fifteen years. The course participants were asked to describe what characterised simulator-based training that best enabled them to handle errors in the DP system or incidents during DP operations. One interview was with three people. This was audio recorded and later transcribed ad verbatim. The other two interviews were with groups of two, and notes were taken during the talks. These interviews lasted 15–20 minutes. Two of the groups attended training that was also observed, and this allowed for informal talks and some additional data besides what was discussed in the interviews.

The analysis was performed as an iterative process moving back and forth between empirical material and theoretical perspectives in an ongoing construction of meaning following abductive reasoning [43]. The data was coded and organised first at a general level, giving an overview of the material, and then more detail codes were used to expand and add new levels of interpretation [44].

3.2 DP TRAINING OF DECK OFFICERS AT SHUTTLE TANKERS

Simulator-based training of deck officers operating the DP system on shuttle tankers is investigated in this study. Two different DPO training programmes described as offshore loading phase 3 and phase 4 were sampled. The entry requirements and the training were in accordance to the certification scheme recommended by DNV-GL [45]. The participants were all certified navigators with the rank of either junior officer, chief officer or master at the tanker where they work. All had completed advanced DP training and worked as DPOs at their vessel at the time of the training. The course participants were thus skilled seafarers, and many had worked as DPOs for several years. The number of participants in a course was two or three persons. The instructors were experienced mariners who had worked at sea for several years and had in-depth knowledge not only about the technology to be taught but also about the work context. The expressed scope of the programmes was basic knowledge of offloading procedures at specific oil fields and in-depth competence of DP specific equipment and software at the bridge in combination with a general understanding of vessel and environmental factors. Offshore loading phase 3 is a repetition course with retraining every two years, where many of the trainees have participated in similar courses earlier. This is a three-day course (20 hours) intended to refresh knowledge focusing on the proper use of procedures relating to different oil fields and knowledge sharing.

The participants are updated on the latest development of DP technology as well as DP incidents and are urged to share their own hands-on experience with the DP system. Non-technical skills such as communication, risk awareness, and decision-making are implicit aspects of the training. Offshore loading phase 4 courses are training programmes developed on request by customers. They have many similarities with phase 3 programmes but offer training on specific offloading systems and belonging field procedures.

The observed programme lasted two days (15 hours) and focused on offloading operations at a new FPSO in the North Sea. The course highlighted understanding and familiarisation of the DP software, safety barriers and limiting factors in the system during normal approach procedures.

Figure 2 Layout of a bridge simulator (copyright: Kongsberg Group).

Both programmes combined classroom lectures and practical exercises. The length of the lectures and the simulator sessions varied with the course participants' level of experience. Since the trainees usually have different rank, their years as sea varies and work at ships operating at different fields, the instructor adapt the training to the specific needs of the attending participants to reach the training objectives. This was enabled by having a flexible curriculum and exercise scripts that allowed for adjustments along the way. The bulk of the training was performed in full-mission ship bridge simulators (Figure 2). Here, the physical layout of an actual bridge is combined with hydrodynamic forces and digital projections providing up to a 360-degree virtual view of the ship's surroundings (e.g., other vessels, harbours and weather conditions). A simulator session typically started with a briefing, followed by a simulator exercise, and ended with a debrief. Figure 3 gives an overview of the main elements in the training.

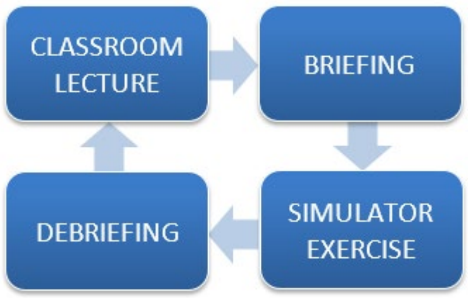

Figure 3 Overview of the main phases in simulator-based training for professional maritime officers.

The classroom lectures were intended to give in-depth knowledge of the DP system and prepare the attendants for the simulator exercises. The length of the lectures depended on the course participants' prior knowledge and were generally longer in the phase 4 training since this was a new field where none of the participants had sailed before. In the briefing, the instructor reviewed the tasks to be performed in the simulator and explained to the course participants what is expected of them and the purpose of the simulation with respect to learning objectives. The simulator exercises in the phase 3 programmes typically went on nonstop for one and a half to two hours, with a minimum of one simulator session in the morning and one in the afternoon of each course day. The phase 4 programme had longer simulator sessions with several breaks, allowing for one session each day. The debriefing usually followed immediately after the simulation and was characterised by discussions in which the attendants revisited and explained actions that took place during the exercises. The debriefing lasted from a few minutes to an hour. It usually lasts longer if the lack of knowledge or skills were uncovered in the exercise. Sometimes, parts of the classroom lectures were repeated or explained in more detail during the debriefing to cover knowledge gaps.

4 RESULTS

The simulator training programmes emphasised routine offloading operations, and the main goal was to learn to handle unforeseen events or errors before they develop into an uncontrollable situation. The simulator exercises, the debriefings and the instructor are all instrumental in this training process. The analysis identified three key aspects in learning to manage performance variability: the ability to prevent adverse events by recognising errors and anomalies and solve problems in a flexible manner, the ability to expand limits of action through shared knowledge and the ability to operate the system with confidence.

4.1 RECOGNISING ANOMALIES AND SOLVING PROBLEMS IN A FLEXIBLE MANNER

The DP training was designed to mirror real work tasks performed at the bridge during offshore loading. This made the training lifelike and gave the instructors an opportunity to introduce errors and anomalies in the system that the DPOs should detect and mitigate. The informants stressed the importance of realistic errors in this kind of training. According to the informants, the worst-case scenario is a total loss of power and a ship drifting uncontrollably. The deck officers are obliged to learn to handle such a scenario adequately, even if the chance that it happens in real life is small. It is more likely to have minor errors that can cause big problems if left undetected. One of the DPOs put it like this: 'It is often minor errors that triggers a large accident or a serious incident.' Another DPO emphasised that it is important to learn to recognise nuances in the system to detect anomalies as early as possible. This may not only prevent things from going wrong but also buys time to consider mitigating actions. One DPO said, 'It is important not to act on impulse, but to take one step back, take a few breaths and think'.

The simulator exercises were based on known, frequent errors or adverse events that may happen while operating a DP system. An instructor explained how he uses 'incident reports to link what is done in the simulator to the real world, demonstrating the worst possible outcome of actions'. In this case, the scenario intends to replicate a chain of events described in the report, and the goal is to enable the participants to identify problems at an early stage and take actions that will lead to a different trajectory than the actual accident. Although this was regarded as valuable input to the learning process, the instructors explained that it is more common to address known typical minor system weaknesses or frequent errors in the simulator sessions (e.g., problems with reference systems, sensors or gyros). The instructors described these errors as minor fluctuations or variations in the system that an operator should be able to detect and contain to maintain safe operations. The DPOs valued the focus on system deviations rather than emergency situations. One of them explained, 'It is only so much you can learn from practising total loss of engine power, then there is only one solution. You also need to learn to recognise minor deviations and how to handle these, for example what to do if you lose one of the wind sensors. The simulator was regarded as a unique opportunity to identify limitations of the DP system and to find solutions to problems that the DPOs may encounter on board. The DPOs broadened their understanding and repertoire of actions by testing different solutions to the simulator tasks in a learning-by-doing manner to the effect of 'if I do like this, what happens then?'

Several of the instructors used the term 'hot debrief' to describe how they sometimes take a time-out or stop the exercise momentarily to guide the course participants during a scenario. It is a short break, lasting a few minutes, where the instructor joins the officers at the bridge to clarify or correct something. The instructors explained that this may be done when trainees are unfamiliar with procedures or equipment available in the bridge simulator. This hands-on adjustment of the technical knowledge or skills needed to perform the tasks was frequently used. The instructors also highlighted the importance of a time-out to get the trainees back on track if they fail to use the procedures correctly or make mistakes that may reduce the realism in the scenario. This is done to ensure that training objectives are met in the limited available time. It requires the instructors to understand when to interfere and when to let the trainees experiences the outcome of theirs actions 'the hard way'. According to the instructors, the officers' ability to correct errors and handle the system may become better if you stop the exercise and explain what is about to happen, allow for some time to reflect and maybe redo actions instead of letting the ship to run aground or the engine room fire to get out of control. This opportunity to freeze a scenario and reflect on different actions while still in the situation was regarded a strength.

The instructors emphasised that the learning outcome benefits from discussing rationales behind what went well and what went wrong during the exercise during the debriefing. An instructor sums it up like this: 'Recognise what they did good, which errors were identified. Were there any minor deviations that could have been could have corrected early on or did they allow them to escalate? Could the task have been handled differently?' Several of the instructors highlight that the tasks resolved in a manner both below and above standards may have had a different outcome if the conditions had been slightly altered. Thus, a key aspect in the debriefing is to discuss if there could have been different possible options and actions even if the exercise was successful.

4.2 DEFINING LIMITS OF ACTION THROUGH SHARED KNOWLEDGE

The observed simulator sessions focused on exercises specific to offshore loading and emphasised operator compliance to industry guidelines and requirements. The exercises typically contained a set of tasks to be solved by the course participants in which the goal was to perform the job within the limits set by procedures and checklists. This line of work is strictly governed by detailed work descriptions as shown in the introduction, and the main purpose of the training is to learn to follow the procedures applicable to a certain oil field or part of an operation. Still, the procedures are regarded as a flexible frame of action. One of the instructors explained that 'there are many ways to solve the tasks satisfactory – despite checklist and procedures'. Both instructors and course participants expressed that they were sometimes surprised by the actions of others and how they choose to solve a problem. This indicated that there is room and need for operator discretion even in this rule governed trade.

The debriefing is designed to give the trainees an opportunity to reflect and actively take part in evaluating different ways to approach a solution. One of the instructors said that 'the debrief period can often be half of the learning experience even though it typically only takes about 10% of the time spent on an entire simulator session'. The core of the debriefing is to explore frames of action that influence team and individual performance during the simulator tasks and to bridge what is learned during simulator scenarios with actual work. It is described as an important element in the training of all informants. It revisits key events in the simulator exercise and is used to explore and discuss the outcome of chosen actions. An instructor reported that 'during the debriefing I mention my perception of the student's actions, or lack thereof, then I ask the students to show me their point of view, saying why they took that action – whether this action is correct or not – and what led them to interpret the fault in that way. After that I try to explain to them what the fault caused to the system and why their action was or was not the best one'.

One of the instructors explained that he 'coaches participants to actively reflect or ask questions', and even if his role is to instruct, 'students can in many cases learn better from fellow participants'. Another upheld that 'sharing experiences among the participants is just as important as the opinions of the instructor'. The instructors jointly described their role as a facilitator or mentor rather than a teacher during the training programmes. Many of the trainees were considered highly knowledgeable officers, and according to the instructors, they could learn a lot from each other if this was facilitated. If they actively shared their knowledge and experiences from real work situations, it could expand the action repertoire and skills of the entire group and clarify the boundaries of safe performance, in addition to reinforcing already-existing good practices. The instructors emphasised that they themselves often learned from the course participants. The trainees are experienced professional officers, and their knowledge about how work is performed onboard helps translate theory to real work situations. Their descriptions of technology or systems in use at their vessel and the strengths and weaknesses of the system during normal or critical operations indicate topics that need to be addressed and included in the training not only in the course they are attending themselves but also in future programmes.

An aspect of the training highlighted by the instructor and evident in the observations was the intention to develop the course participants' ability to self-assess not only during training but also in work settings. To evaluate oneself, the decisions made, and the actions taken are highlighted as important skills at sea by the instructors, as well as understanding frames of actions and uncovering errors at an early stage and containing them before they evolve into an uncontrollable situation.

4.3 OPERATING THE SYSTEM WITH CONFIDENCE

The observations and the interviews made it evident that building confidence as a system operator was an inherent part of the training. Several mentioned that to perform well as a DPO, you must feel safe in unusual contexts. This is partly accomplished by detailed knowledge of the DP system and the vessel so that a DPO can trust the system to perform in accordance to supervisory control. This feeling, however, also comes from a DPO's level of assertiveness and trust in one's ability to control the system. An instructor explained that 'the goal is that they should feel more confident and not be nervous while operating the DP'. It was interesting to note that disengaging the DP and manually handling the vessel was one of the learning objectives in the training aimed at reducing possible uneasiness. One of the participants described it like this: 'We get to test and do things that you usually do not do onboard, for example manual manoeuvring. The simulator gives you an impression of how it will work, then you don't have to worry about something going wrong when back on board.' One of the pitfalls in being used to and becoming confident with the DP system is that a DPO gets less experience with 'hands on' control of the ship. The instructors explained that it is essential that a DPO can handle the vessel manually. In a worst-case scenario where the best option is to disengage the DP, the DPO must do so without hesitation. Lack of confidence or doubting one's own abilities can cost valuable seconds in an emergency and cause the ship to collide with the installation.

The phase 4 programme exemplified how the training is designed to build a DPO's level of confidence with the step-by-step offloading operation. The training started with a classroom lecture on the characteristics of the new field emphasising similarities and differences with other familiar fields. The stepwise sequence from 10 nm to connection and the options for staying in position during the offloading were described in detail by the instructor. The course participants were encouraged to ask questions and raise concerns during the entire lecture. This session usually lasted two to three hours, and it served as a preparation for the simulator training that started after lunch. The first simulator session lasted the rest of the day (three to three and a half hours), allowing for a short debriefing at the end to wrap up the first day. The simulation was frequently stopped during this period, not only for the DPOs to take breaks but also to ask questions or discuss actions, test the equipment or clarify system warning or alarms. On the second day of training, the DPOs were asked to request scenarios or tasks they would like to practice. This flexible schedule was emphasised by the instructor as vital to close knowledge gaps and to reduce uncertainties about the field or the DP system in general.

The programmes also allowed for requests from the participants to tailor the training to their needs, either to go more detailed into specific parts of the theory or to train certain skills or aspects of the DP operation in the simulator. The simulation scenarios in both programmes were designed to allow for adjustments given trainees needs and wishes while still meeting training objectives. This flexibility was appreciated and expected by the trainees. One of the DPOs explained, ‘I like to bring some questions with me to the phase 3 training. If I have noticed something while onboard that I want to check with the instructors or in the simulator, I make a note of it and raise the question or test it during training’. The instructor emphasised the importance of having a flexible schedule with ample room for the participants to ask questions and raise concerns to expand their knowledge and build confidence.

The instructors emphasised the importance of establishing a sense of achievement throughout the training. As explained earlier the instructors need to understand when to stop a scenario and do a hot debrief, and when to let the actions play out allowing the trainees to experience the consequences of their mistakes or lack of knowledge hands on. One instructor said, ‘It is wrong to watch people do mistakes that they will be ashamed of after the training.’ Thus, several of the instructors used the hot debrief to avoid that the trainees making a fool of themselves. It was considered better for the learning process to give some guidance and help during the exercises than to wait until the debriefing to point out weaknesses and poor decisions, with one exception: if a course participant had a cocky attitude or displayed overconfidence that caused unnecessary risk, it was regarded as ‘OK to give them difficult tasks where they would fail’. Overconfidence was regarded just as dangerous as lack of technical understanding by the informants. Several of the instructors mentioned that technical-brilliant but complacent DPOs can be difficult to teach. It may be difficult to address their weaknesses during training, particularly if the person is a senior captain and the instructor is more of a junior: ‘Depending on level of rank or age they may take it personal, a captain will not listen to critique from a junior.’

The training was characterised by joint discussions and reflection among the course participants during simulations and in the debriefing sessions. Peer feedback was highlighted as an effective method to correct unwanted actions or attitudes, especially if the participants held the same rank or if seniors corrected junior officers. What was observed to be more problematic was if the most senior participant was defensive or indifferent to others' feedback. Most instructors had experienced a course participant pulling rank and not being open to the input of others and described how this would have a negative effect on the training outcome for all participants. One of the instructors explained, 'For me a good debrief establishes confidence in each delegate, makes them feel like they are heard and promotes their desire to learn more and pay attention to the details'.

5 DISCUSSION

The aim of this study is to explore how simulator-based training of professional maritime deck officers can be applied to manage performance variability and maintain safety during critical operations at sea. Learning is regarded as crucial for resilient performance and is one of the four cornerstones in RE [20-22]. The theoretical framework presented in Chapter 2 indicates that the practical guidance on how to develop these skills has been little explored in RE literature [5,11,12]. In the following discussion, we want to examine performance variability in a Safety II perspective [7] and provide guidance to practitioners and researchers on how to achieve resilient performance based on the results in this study.

5.1 MANAGING VARIABILITY THROUGH EXPERIENTIAL LEARNING AND REFLECTION

The handling of variability is an important safety issue in RE. Under complex and changing conditions at sea, it is essential that navigators can respond and adapt adequately to expected and unexpected situations. This is what performance variability is about; it involves the adaptation of work performance to situational changes. As a theoretical concept, it builds on the law of requisite variety from cybernetics, stating that 'variety can destroy variety' [46, p.207]. In other words, the regulation of external variability can be achieved by a matching internal (performance) variability. Performance variability can be regarded as an operator's ability to regulate performance to maintain safe and efficient operations during both expected and unexpected situations and has been described as resilience skills [10]. It is widely recognised that the development of skills requires training. Simulator-based programmes seem to have several features that make them suitable for training the skills needed to manage performance variability.

Simulators can generate a realistic and safe training environment to practice hazardous work, creating an important link between the development of skills and the operational context in which the skills are to be applied. Earlier studies have pointed out the importance of simulator-based training to reduce risk in the maritime domain [47-50]. Technological development has made it possible to create advanced computer-generated training environments that replicate the real world at a very detailed level [51,52]. Wahl [53] coined the term ‘social fidelity’, indicating that an exact replication between the simulated and the actual physical entities of a bridge is not always necessary to realise training goals; rather, it emerges in the interaction among the simulator, the course participants and the instructor. The data material indicates that the simulator exercises alone will not provide learning of resilience skills. The simulator offers a necessary backdrop for lifelike tasks but is not a sufficient condition for learning. Learning among professional officers also requires reflection and feedback from others.

The social aspect of the simulator training enhances reflection and strengthens learning. By joint discussions involving peers and instructors, new solutions and practices can be made available, as well as considerations of current, individual practices. The collaborative setting of simulator training is well suited for reflective practice [39,41]. Our analysis illustrates that learning occurs when the trainer and the trainees jointly explore the frames of action that leads to the actual performance in the simulator and develop new frames for action together. The deck officers did not only learn about the DP technology but also learned skills in handling the sociotechnical system from each other. Thus, it is valuable that experienced, professional officers from different ships or companies train together. The training gives the DPOs an opportunity to develop a repertoire of actions for handling variations in the DP system. Testing the system limitations in the simulator and reflecting on their actions with peers expanded their understanding and strengthened their ability to adapt to novel situations with the right level of confidence.

Different opportunities for reflection were provided during the training. It is interesting to note that the use of a simulator provides the opportunity to ‘freeze time’ either during a training session or by reviewing recordings of certain decisions made after a session. The hot debrief was applied in our case as a time-out for reflection during exercises, in addition to conventional debriefs after sessions. The hot debrief can be regarded as both a *reflection in action* and *reflection on action* [41]. The time-out allows reflection on what is happening in the simulated situation, and at the same time, it involves reflecting on how practice can be changed in future operations on board. Reflection was also described as the main rationale for the debriefing. The instructors emphasised the importance of dialog during debriefing and described their role more as facilitators than teachers. Facilitation involves bringing the participants’ experiences and knowledge to the forefront and integrating the different views of the participants [54]. The data material revealed that the instructors encouraged asking questions and active reflection during debriefing and that sharing of experiences was important.

The opportunity to observe other DPOs' actions and later discuss what was observed may also be valuable for *double loop learning* [37]. Theories-in-use can be derived from observing actual behaviour in the simulator and used to nuance or counteract espoused theories verbalised in the briefings or debriefings. Thus, the training may challenge established theories of action and give the officers direct feedback on actual behaviour. The simulator training also provides an opportunity for experiential learning [40]. The design of the training programmes lets the course participants think about what they are doing, modify their practice and to apply what was learned in the next simulator exercise. This rigorous reflection and immediate try-out of the lessons learned allows knowledge to be created through the transformation of experience.

Simulators provide an opportunity to enact events that rarely happen in real life. They give the chance to test actions and decision-making during the exercises, as well as set focus or aid discussions in the debriefing sessions. Even if it is not likely that the deck officers will encounter the exact same scenario in real life, they train their overall ability to anticipate, monitor and respond. Training for events with low probability but high consequence can add to a general repertoire of responses that can be useful across different situations. Here, learning does not only mean learning to respond to specific system errors; rather, the DPOs train their ability to recognise and respond to system errors in general and to apply this knowledge in different situations.

5.2 BALANCING SAFETY I AND SAFETY II

We do not view Safety I and Safety II as a question of choosing one over the other. This was underlined early by Hollnagel [7, p.178] who emphasised that Safety II is 'intended as a complement to Safety I rather than a replacement of it'. The contrast between them is a pedagogical way of highlighting different capabilities needed to maintain safety under different operational conditions. In empirical accounts of safety practices, the boundaries between the two concepts become far more blurred. In our data, three examples of this may be highlighted.

First, the simulator training is based on scenarios constructed from previous errors and accidents that belong to the Safety I paradigm. However, they are used to improve skills related to Safety II. When the participants play out the accident scenarios, they are experimenting with different ways of handling situational complexity in a flexible way. There is no single, right way to solve the situation which draws more on Safety II than Safety I. In this way, the history of failure works as a repository for highlighting and improving the skills and confidence needed to deal with situational complexity.

Second, the need for balancing between Safety I and Safety II is apparent in the way the level of situational complexity can change rapidly when a shuttle tanker approaches a FPSO. Wind, waves, ocean currents or technical failure in the DP system may change the operational limits during off-loading. If we accept the premise that the level of situational complexity is not a static property of a system or an activity, the implication is that the need for Safety I and Safety II strategies may vary accordingly. If the situational complexity is low, a Safety I–based approach would be sufficient to maintain control over the hazards involved, although small adaptations will occur also in these conditions. The operational complexity may, however, increase in an instance, calling for a more resilience-based Safety II approach[1]. As Safety II has to do with the ability to succeed under varying conditions, the 'varying conditions' include both the conditions where situational complexity is high and calls for flexible adaptation *and* the conditions where rule-based approaches would be enough to remain in control over the situation. The key point in this respect is the ability to recognise the level of complexity and the need for adaptation and the actual skills needed to make these adaptations. This can be pivotal mode-switching moments[2] where the difference between success and failure can be marginal. More importantly, this is not an elusive system property; it requires both technical and non-technical skills among the operators involved in the operation. This skill must come from somewhere, and we argue that simulator training can be a way of increasing the operator's repertoire for dealing with such situations.

The third, and on a related point, is that simulator training needs to be tailored towards the balancing between Safety I and Safety II to have the desired effect (Table 3). In our data, the instructors emphasise the importance of a dual focus on the participants' errors and increasing their ability to recognise and reflect on the conditions contributing to success. The hot debrief approach allows for taking time-outs as the training proceeds to highlight pivotal moments in which complexity and the corresponding need for performance variability to deal with unexpected situations are both increasing. The debriefing sessions provide additional opportunities to explicate and generalise such lessons. These sessions are also unique opportunities to shed light on the relationship between work as imagined and work as actually done [21], providing an occasion to consider practical drift [57], increasing awareness of the limitations of safe operation and reveal needs for adjustment in work procedures.

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[1] The way sudden increases in situational complexity influences safety has been previously described in Weick's analysis of the Tenerife aviation disaster [55].

[2] This way of reconfiguring the operational approach to deal with increases in complexity has been previously described by several HRO researchers [e.g. 56].

A key element in training of DP operators is to enable them to handle known failures and respond to expected threats while at the same time ensure that they have the confidence and knowledge needed to discover and react to surprises before they evolve into serious incidents or accidents. This can only be achieved through a training process that include all the elements described in Table 3. This demonstrates the value of balancing Safety-I and Safety-II in DPO training.

Table 3 Balancing Safety-I and Safety-II in DPO training.

	TRAINING FOCUS	**TRAINING PROCESS**
Safety-I	Prevent things from going wrong in the future by looking at accidents and adverse events in the past.	Rigorous training focusing on standardized processes and compliance with procedures to handle known system failures.
Safety-II	Increase things that go right in the future by looking at experienced successes in normal and non-normal operations.	Flexible training based on joint reflection and operator experience to increase the ability to handle unknown system failures.

6 CONCLUSION

The data material demonstrates how simulator-based training of professional deck officers can be used to manage performance variability and develop resilience skills. The result sections indicate three resilience skills that are essential to DPOs, and that can be trained in simulators; (1) the ability to recognise anomalies and solve problems in a flexible manner, (2) the ability to define limits of action through shared knowledge with peers, and (3) the ability to operate the system with confidence. These are to be understood as a set of overarching categories and as a basis for developing training scenarios. It should be kept in mind that an operators' knowledge and skills for managing and controlling the technological system at hand depend on several operation specific variables for example ship type, hardware and software technology, degree of complexity and numbers of involved actors. Future studies need to address this and continue developing a catalogue of skills needed to operate ships safe and efficiently.

It is important to note that these skills are not automatic results of simulator training. They are the possible effects of a training philosophy that is designed to address the balancing between Safety I and Safety II. Our advice would not only be to do more simulator training but also to use the opportunity better by recognising it as fertile ground to increase the skills and capabilities needed. The practical implications of our work may be summarised in the following recommendations for simulator-based training:

- Ensure realistic training by combining unexpected events and normal operations in the exercises
- Focus on learning processes that support joint reflection and experiential learning
- Persistent use of hot debriefings and post simulation debriefings as tools in the learning process

The DPOs' capability to control variability depend on their ability to anticipate, monitor and respond to system errors. These abilities are at the core of resilience skills. The results indicate that deck officers learn these skills through joint reflection and experiential learning triggered by realistic simulator exercises. It is important to note that realistic training is not limited to a focus on accident scenarios and emergency handling but must include normal operations and minor errors so that operators can learn to catch and contain minor errors before they evolve into uncontrollable situations. The study shows that available simulator technology to a large degree is adequate for the ongoing training of DPOs. This implies that the design of the training and learning processes needs to be given attention, not only the design of the hardware and software used in the simulations.

The data indicates that simulator training allows for reflection both *in* and *on* practice and gives a unique opportunity to discover discrepancies between *work-as-imagined* and *work-as-done*. The debriefings let the trainees and their trainer jointly reflect on what went well and what went wrong during the simulator sessions. The reflections do not only draw on what happened during training but also rest on each participant's level of experience and his or her successes or failures at sea. This demonstrates the importance of debriefing as a learning tool. It may be valuable to study this aspect of simulator-based training further, for example, how to structure and facilitate these sessions to support the needed reflection and sharing of experience among professionals.

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