THE GRASSROOTS OF STRATEGICALLY PREPARING SPECIALISTS FOR SUBSEA OPERATIONS: USING A SIMULATOR AS A TOOL

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Many studies indicate that simulators could support human operators to anticipate potential risks in real operations. Simulation, for instance, suggests improved training efficiency in surgery, driving, medicine, and aviation. Hence, researchers and practitioners can benefit from simulator to develop virtual environments for complex and high-risk operations. Our study focuses on how simulator preparation supported a team to achieve a high level of competence prior to practicing skills and knowledge in a subsea operation. The central strategy for modern oil and gas industries is to prepare maritime operators. Therefore, we focus on risk, performance, procedures, familiarization, teamwork, and awareness as key factors in a subsea simulation set-up, with the purpose of probing how well virtual environments can service preparing subsea specialists as a team. A questionnaire was prepared for maritime operators who participated in subsea simulation from 2014–2015. We analyzed recently collected data from maritime operators in consort with prior interview results from the development group regarding their experience using the simulator. The results reveal that simulators can help in enhancing maritime operators' self-confidence in handling critical operations with high efficiency. However, simulators need to be customized for specific risk handling in demanding maritime operations, with more attention to areas of weakness in terms of end-users' perceptions.

I. INTRODUCTION

Simulation-based learning was first used more than 20 years ago in studies of aviation [1-3], medical and surgery [4], and driving [5-7] to increase confidence and reduce possible errors and risk operations. It is a new method for navigation training [8] in the maritime domain. To our knowledge, there have been few studies investigating how simulators can transcend the gap between preparing maritime experts from virtual reality to reality. Studies show that risk errors during scenario-based operations can be reduced to 31% [2] for helicopter training with simulators. Simulators also contribute to avoiding errors in commercial aviation and reduced 7.5% for general aviation [3]. In the field of transport, studies illustrate that the possibilities of risk and errors can also be reduced; for instance, investigations show that risk operations can be decreased to 24% for truck driver preparation in extreme conditions in simulators [9]. They have also helped to improve the Los Angeles fire service, with a 19% reduction of all driving errors [6]. In addition, medical and surgery simulators have also demonstrated a significant contribution, with a 10% reduction of errors in general [10].

In addition, simulators contribute to strengthen efficiency. Many studies have documented that simulators can increase the operation speed for truck drivers [9], commercial car drivers, and fire service car drivers [6] from 85% to 88%. Researchers in other domains have also reported that simulators have a considerable impact on increasing time and workload preparedness of human operators, such as surgery training (35%) and medicine (29%) [10], logistics transport (45%) [11], and flight training (77%) [12].

However, questions remain when applying simulators for the maritime domain. First, most studies focus on how simulators can contribute in preparing individual novice users. Simulators in such studies aim at enhancing individual users' confidence in known and pre-defined scenarios. For example, regarding studies of errors in truck driving [6], researchers imagine in what conditions simulators can be set up to exhibit those errors or risks. Compared to the maritime domain, some errors and risks are not possible to foretell. One particular example is error in teamwork-dependent actions with communication and coordination needs. Driving is a solo behavior. A driver only needs to interact with a car and the outside environment while driving. A few factors affect his/her driving and decision-making. On the other hand, maritime operations are team-based activities. One operator may not be able to make his/her own decision and operate machines independently. Rather, s/he needs to collaborate with other operators. Hence, it is necessary to understand how simulators can offer support to prepare cooperative group of operators for maritime operations. Secondly, some maritime operations are unique, in the sense of the procedure being in one-time or first-time performance event. These may be integrated from other general operational segments into unique operations, such as subsea installations. Even though we can assess characteristics of general maritime operations using simulators, we may unable to judge whether a simulator is useful for specific maritime operations. Studies of general operations may be of limited value for transfer to unique set-ups. Thus, the presents study might be meagerly useful for the next unique operation. A group entails both simulator and human operators. It may be unfair to assemble fragments of experiences from each human operator with a part of a simulator to portray a unique operation. Risk and challenge areas may arise during the course of cooperative work simulation, among human operations' interaction, and in coaction with their own mental demands, and so on.

We believe there are adequate reasons for assembling simulator set-ups to match the requirements of maritime operations. This is an advantage of simulators [13], but we need to demonstrate how simulators can contribute to real operations by analyzing the benefits in greater depth. Hence, it is important to consider how a group of operators is established. To what extent do human operators handle risk from individual to teamwork levels? How do they reproduce such simulation-based experience in real operations? This article aims to answer these questions, and is structured as follows: In the next section, we present the case we used for the study, offering a general background of subsea installations. Following this section, we present our research design and method. We then illustrate the results and discuss central issues in this study. We also point out the weakness of simulation preparations, and suggest possible ways to counter those weakness. In the last section, we conclude our study with recommendations for future work on simulation preparation for unique maritime operations.

I.I THE CASE

Subsea installation is a high technology-supported maritime operation and requires human beings to work cooperatively to accomplish each unique operation step during installation. The case included in this study was the preparation in a simulator by an oil company that wanted to execute an installation at sea but lacked some familiarity to accomplish this. There was insufficient information to ensure a group of operators could operate the procedure together successfully with low risk and without unsafe actions, although each different task could be done at the individual level. In addition, building a group for special operations, onboard offshore vessels, in which maritime experts, equipment, and coordinators can work together with simulators, may have other requirements than group trainings for standardized operations. Maritime operators have experience working with other colleagues. However, when a task is new for all, such previous experiences cannot guarantee a less risky operation.

Hence, the oil company had to investigate to what extent the company could build a team that could react quickly to unique subsea installation demands. For example, does the operator need a detailed procedure to follow to avoid risk? How can the company ensure that each individual maritime operator works in alignment with the technical equipment? How can the work procedures be coordinated during maritime operations where operators are located in different places? To what degree can an operator be aware of own and others' work? To answer such questions, the oil company engaged maritime operators in simulation preparation. Moreover, this urged the simulator to be developed specifically for subsea installations. Hence, the oil company cooperated with an engineering company and a simulator center to develop a unique simulation set-up.

Subsequently, skilled maritime operators recruited for this operation had to practice in the simulator before working in the actual environment. The preparation duration of maritime operators was in three effective weeks as well as refresher-session during autumn 2014 to spring 2015 in the simulator. After the preparation session, an investigation of how such subsea simulation could contribute in preparing maritime operators found that confidence and knowledge to handle potential risks resulted from two infrastructures [13]—a management development structure and a participant-operator structure, but only the developers were interviewed. In this article, a follow-up questionnaire study focusing on how participating operators perceived and experienced the simulation preparation is presented.

II. RESEARCH DESIGN AND METHODS

To understand how simulators can assist to prepare maritime operators, and to compare this experience with their self-reported efficiency, we administered a questionnaire to all participants. We used a questionnaire because of the number of participants, as it is inexpensive and as time-efficient compared to verbal data collection, and standardized questions make it simpler to compile data [14]. In addition, it may not accuracy for conducting interviewing due to participants may recall memories afterwards that might results in partial opinions on their on-site experiences and perceptions [15]. In addition, we have a strong interest in the statistical results because we believe they might help to illustrate the areas in which to concentrate for the future development of simulators, as well as preparing sessions. Five messages were undeliverable due to wrong or closed email-addresses, yielding maximal n = 78, of which 20 returned answers – a response rate of 25.6%.

The questionnaire was designed to measure six factors during the preparation of maritime experts in simulators: *risk*, *performance, procedures, familiarization*, *teamwork*, and *awareness*. A five-point Likert scale is used, asking respondents for their agreement with the statements, as shown in Table 1:

Table 1. Questionnaire template

Q1	The simulation contributed to my understanding of risks in operations	Risk
Q2	The simulation enabled me to handle risks	
Q3	Via simulation I built up my own performance for operations	Performance
Q4	The simulation contributed in preparing me to manage my mental demand for the operation	
Q5	The simulation contributed to increase my individual capacity for the operation	
Q6	The simulation allowed me to make changes for my own tasks in procedure	Procedure
Q7	The critical parts of the simulation were equivalent to those in the operation	
Q8	The procedures in the simulation prepared my readiness for unpredictable events	
Q9	I felt I was a team member in the operation	Teamwork
Q10	I felt I could follow up on team communication	
Q11	The simulation improved the others' understanding of operations	Awareness
Q12	The simulation improved the ability to anticipate next phases in the operation	
Q13	The simulation provided problem solving abilities for my simulation tasks	Impact
Q14	The simulation contributed to increased leadership for the operation	

The questionnaire was distributed digitally using SurveyXact [16], a web-based application widely used in Scandinavian institutions and companies for gathering data. We handed out questionnaire links with two reminders to try to obtain sufficient sample size. However, a response rate of 25.6% is less than we hoped for, so any interpretation may be subject to biases from responders' versus non-responders' characteristics, but the value of the study is still sufficiently high due to the importance of the tendencies in the material.

III. RESEARCH RESULTS

III.I BACKGROUND AND EXPERIENCES

Among the 20 operators, 12 specialized in remotely operated underwater vehicle (ROV) operations. Two are crew members from the ship bridge, two operators of crane/special handling system (SHS), two shift supervisors/managers of operation rooms, and two operators had other roles during the preparation session, i.e. engine. The average experience of the ROV operators was 11.7 years. For the ship bridge crew, the shift supervisor/manager/operation room and others had an average of 5.5 years' experience, while that of the crane/SHS crew was 6.5 years. The operators are not novice users in their specialized field. Hence, we believe that they have acquired skills for their work environments and work procedures based on an individual experiences.

III.II RISK, PERFORMANCE, PROCEDURES, FAMILIARIZATION, TEAMWORK, AND AWARENESS

From the questionnaire, we illustrate the results in terms of mean values and dispersion of the variables, as shown in Fig 1. As we can see, maritime experts agreed more that they were part of a team and engaged in teamwork and team communication (means of 3.7 and 3.75; standard deviations (SD) of .571 and .550, respectively). Regarding the question about awareness—*To what degree did the simulation improved the other's understanding of operations?*—the mean value was 3.6 (SD .821). In addition, regarding the degree to which *the procedures in the simulation prepared them for unpredictable events*, we obtained a mean value of 3.05 and standard deviation of .999. We also had higher mean values for questions about *leadership* (3.5), *the simulation improved the ability to anticipate the next phases in the operation* (3.35), *the simulation contributed to my understanding of the risks in operations* (3.30), *mental demand preparation* (3.25), *increased individual capacity* (3.15), *critical equivalent* (3.05), and *performance building* (3.10). We found that the standard deviations for these questions were also greater than 1.0. It is noticeable that when questioning participants about the simulations' contribution to *problem solving ability*, *risk handling*, and *making possible changes of work procedures*, we found lower scores of 2.95, 2.90, and 2.85 with higher standard deviations, 1.099, 1.165, and 1.387.

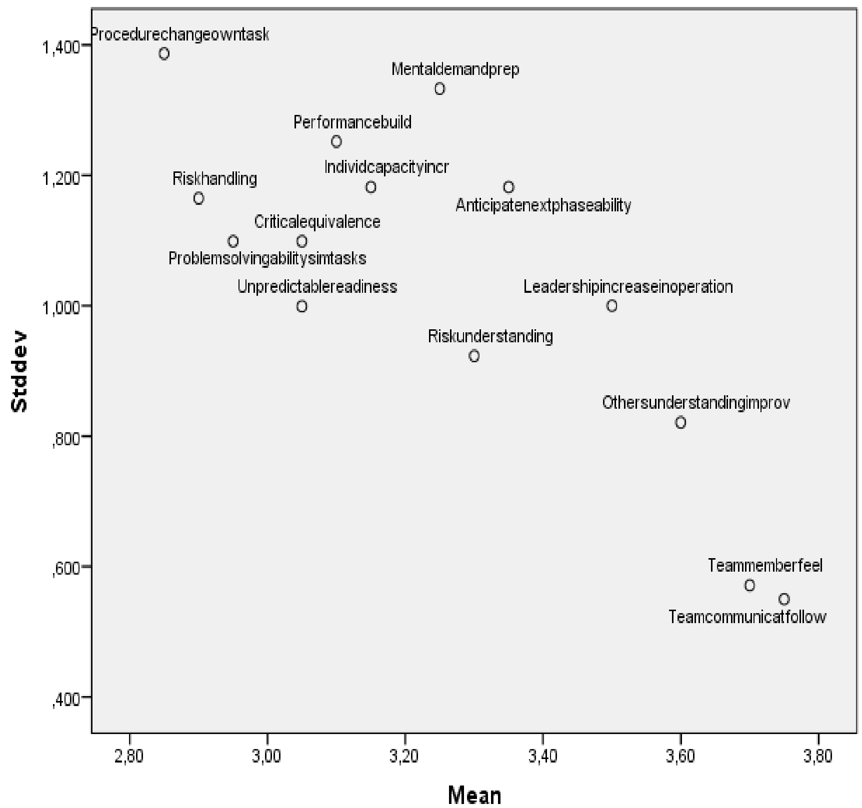

Fig. 1: Mean values for 14 questions and their distribution range.

We also conducted a principal components analysis, as shown in Table 2. For leadership, feeling like a team and following up with team communication have higher scores in component 2. It is likely that during the preparation of maritime experts, these factors were highlighted by instructors and thereby related, or experts enhanced such feelings by human natural activities involving teamwork and interpersonal contact, but other factors were left to the simulator itself. For example, maritime experts may also not think they are a part of a simulator. They may overlook their influences on simulation development and practice but only expect what engineers can offer them—a good simulator.

Table 2: Component matrix for analyzing performance

Component matrix
PCA, Varimax rotation converged in 3 iterations

	Component	
	1	2
Mentaldemandprep	,924	,233
Riskhandling	,899	,186
Procedurechangeowntask	,872	,377
Performancebuild	,868	,425
Anticipatenextphaseability	,855	,389
Individcapacityincr	,850	,223
Criticalequivalence	,847	,403
Othersunderstandingimprov	,817	,285
Problemsolvingabilitysimtasks	,796	,369
Riskunderstanding	,793	,326
Unpredictablereadiness	,774	,242
Teammemberfeel	,263	,872
Teamcommunicatfollow	,198	,814
Leadershipincreaseinoperation	,452	,809

We also assessed the relationships between stations, experiences, and the 14 questions (one-way ANOVA). We obtained several significant results. The most important is the difference between SHS/crane operations with other operations in the team. For example, there was a significant difference (.028) between groups' responses to the question: *To what extent did the simulation enable me to handle risks*? SHS/crane experts has significant differences in responding to this question compared to other maritime experts. Similarly, SHS/crane experts differed from other team members regarding *mental demand in preparing via the simulator* (.013), *increasing individual ability via the simulator* (.036), and comparing the simulator with real-life operations regarding *critical parts* in operations (.041). In addition, when examining the relationships between different stations' responses to *risk handling, mental demand, individual ability,* and whether *critical parts are equivalent to real operations,* we found significant differences between shift/manager/operation room and SHS/crane operators; .014, .024, .048, and .032, respectively. We also found significant differences between SHS/crane and ROV operators regarding *mental demand*, *individual ability,* and *critical parts are equivalent to real operations:* .024, .035, and .036, respectively. There was also another significant difference between bridge and ROV operators regarding their responses to *individual ability* (.014).

In addition, it is interesting to examine the feedback at the end of the questionnaire, where we asked our operators to share their feelings regarding their influences on development, both in the simulation and offshore. Seven out of 20 operators stated that the simulator helped a great deal in preparation for subsea installation. Seven reported that the simulator slightly helped; four were neutral in their responses, and two did not respond at all. Most operators highlight that good communication in team operations as well as simulators can help to foresee real-life work procedures. At the same time, most operators state that the simulator itself is not ready for use. Moreover, there are errors in the simulator and some of the functions in the simulator do not match practice in reality.

We believe that these operators' performance results in two main loads which are relevant to component 1 and 2. (See Table 2). Our results indicate teamwork and its communications load in more close to component 2 (.872, .814, .809 respectively). And the rest is more relevant to component 1 (above .774). Meanwhile, our results also show that those operators could follow the procedures that was designed by systems engineers for individual operations (average std. deviation is .747). They could properly perform their existing skills, such as risk handling, performance building, mental demand, and individual ability and so on.

IV. DISCUSSION

The main findings in this study were the maritime operators' satisfaction with teamwork and team communication. The maritime operators in the study seemed to be pleased with these facilities that the simulator offered, such as simulation of some part of work environments. On one hand, we understand this contribution comes from the operation room shift supervisor/manager who spends efforts on teamwork building and communication during the subsea installation. In our previous study, one participant described the role of the shift supervisor as "the director of the orchestra" (Vederhus & Pan, 2016). From the data analysis above, these advantages of simulators were verified by maritime operators with a high average number (>3.0) and a low standard deviation (< 1.0). In addition, good teamwork building and communication among team members were confirmed by management groups [13]. However, we believe there is a room for improving simulators, e.g., in crane operations. Regarding the results above, SHS/crane operators were less satisfied the simulator compared to other experts in other stations, such as bridge, ROV, shift supervisor/manager/operation room and others. To some extent, this indirectly indicates that crane operations do not fit well when incorporating this sub-simulator for crane operations into subsea installation as a whole. For example, it might be necessary to change the SHS/crane operator's tasks due to many other dynamically changing factors, such as wind, waves, and lift weights. In simulators, however, these requirements may be not optional choices for SHS/crane operators, or the work procedure may not allow experts to adopt their behaviors to do their job. However, this might be not a mandatory requirement for other operators. Hence, the results indicate low satisfaction from SHS/crane when compared to other operators as well as significant differences (<.05) when answering such questions.

In addition, SHS/crane experts do not think simulators can contribute to increasing their individual ability and disagree with what is a critical part or not compared to operation in reality. For subsea installation, one of the important operations may be crane/SHS. For SHS/crane operators, teamwork might have a different meaning; for instance, there are differences between how they work together (with each other as a team, i.e., bridge operators, ROV and SHS/crane operators). SHS/crane operators are the people who make the work to be accomplished. Other operators in the team to some degree have the roles of assisting SHS/crane operations. Besides these assumptions, crane operators might require more "real" functions in simulators during the teamwork preparation for subsea installation. Their confidence can be enhanced via simulators in terms of all required information can be accessed, such as extreme situations, non-extreme situations, and normal work procedures. As said, Bannon [17] argues, end-users are the professional experts in their work context. Our work is to better support professional operators to better understand work practices and prepare them to achieve desired results—less risk and safe operations. Since the simulator was developed without the enlistment of SHS/crane experts during its development, it is not surprising to see negative feedback from the SHS/crane experts, e.g.: "we did not have any influence on the simulator's development and offshore project in real operations," and "the [simulator] needs to be fixed of all bugs and to make the functions of SHS closer to reality." Moreover, the significant difference between operation room shift supervisors/managers and SHS/crane operators indicates that we could make simulators to better support preparing maritime operators. For example, the shift supervisor served as a coordinator when the simulator had breakdowns.

This contributes to teamwork building and team communications. In turn, such coordination overcomes the possible limitations of simulators For example, in spite of errors/bugs occur in preparation, all operators still reported that they felt they were part of a team and were able to communicate effectively even though they had significant differences in their responses regarding *risk handling, mental demand,* and so on. It might be difficult to reveal the drawbacks of the current simulator from the management group if only understanding teamwork as two separate worlds [18] —simulator and maritime operators. We must understand that when maritime operators practice using simulators, they are able to picture the shortcomings of simulators. In turn, this could provide us with insight into how we can improve them. On one hand, we suggest that to make a simulator that encourages teamwork, we must ensure there is good coordination during the preparation of teamwork in using the simulator. Both instructors and coordinator can support this. On the other hand, we believe it is also essential that the simulator itself should be prepared well to support teamwork. It should be prepared sufficiently with engaged human operators, managers, and most importantly, course instructors. In addition, course instructors have the opportunity to represent the ideas of human operators when they lack the ability to communicate with engineers. This is understandable since maritime operators might have limited authority to present what they need in simulators. Course instructors should be addressed such development requirements because they have the ability to assess maritime operations as well as indicate to what level and where to improve simulators.

V. CONCLUDING REMARKS

In this article, we used a questionnaire to investigate how a simulator helped to prepare maritime experts for unique subsea installation. Neither coordination nor simulators can make a team function as a team as well as it would in real-life situations; we found that coordination work and simulators in practice support teamwork. We suggest that to understand how simulators can contribute to professional team preparation, simulators shall be fully functionalized and support maritime operations as well as given optional choices for operators to practice using simulators in different conditions. This is essential to ensure that simulators closely mimic reality. In order to improve simulators, all stakeholders, managers, operators, shift supervisors, and designers need to work together. In the future, we will look at ways to improve simulators for unique maritime operations with more focus on crane operations. As identified from this study, this is a weakness in current simulators during teamwork preparation. This allows room for more investigations and development of simulators in practice when preparing teams to finish unique operations.

ACKNOWLEDGEMENT

We would like to express our special thanks of gratitude to all participants who answered the questionnaire. We thank our colleagues in the department, all our external partners of the project and staff of maritime courses from the Faculty of Maritime Technology and Operations at NTNU Aalesund who provided insight and expertise that greatly assisted the research. The Research Council of Norway supported this research.

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