Simulation-Based Learning: Comparative Review between Maritime Simulation and Other Domains

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Simulation-based-learning (SBL) has been used in various domains such as maritime, medical, defense, aviation and nuclear power plant operation to increase performance and decrease risk of human errors for decades. Our study compares how the maritime domain differ from other domains and organization types in using SBL as a risk intervention and performance training tool. We aim to describe how and to what extent SBL reduces risk and human factor errors in different high-reliability work domains, through training performance, teamwork, situational awareness, communication procedural skills and verification, familiarization, crisis management, decision making, confidence and correcting mental models.
A literature review is done to identify effect, differences, similarities and potential research areas and learning areas in use of SBL as a tool for risk reduction and performance increase between maritime and other domains and organization types.
The literature review shows how effect, methods and goals of risk and human error reduction through SBL differ between various organizations and domains. Results from the review show that even though overall goal of risk decrease and performance increase is similar in maritime operation training and other domains, there are differences in methods and partial goals in SBL and a conscious relation to these differences will increase quality of maritime domain SBL.

I. INTRODUCTION

One definition of the term simulation is “the representation of the behavior of characteristics of one system through the use of another system” [1].Simulations have been practiced for centuries for training skills, judgement and problem solving. A line can be drawn from early examples such as simulations of battles through the board game Chaturanga which was developed in India around the 6th century AD up to modern day computer based simulator centers. In the book, Human Factors in Simulation and Training by Vincenzi et al. (2008) [2] the reasons simulator training has evolved is described as cost effectiveness compared to real life training. Further, Vincenzi et al. states that simulators can be available 24/7 and do not require the physical presence of the object simulated. In addition, the scenarios can be tailored to the necessary training. Another reason for using simulation-based learning (SBL) is safety, through providing a possibility of exposure to various conditions in a safe and non-threatening environment the simulations have a potential of reducing damage to personnel, equipment and environment and gives opportunity for training on situations too dangerous for live training. The training environment can also be standardized or tailored for the necessary training goals, for instance standard ship navigation training or ship navigation in a particular harbor or with a specific equipment failure. Further to this SBT also has a possibility to incorporate features that enhance operator-instructor intervention through instantaneous feedback, performance analysis, playback, performance measurement and performance comparison. Although the focus of this review is to identify how simulation is used in different domains, and positive training effects of simulation in these, scientific approaches to simulation also means being aware of any adverse effects that may arise, whether short or long term.

As stated by Klüge et al. (2009) [3] regular training is an operator-centered approach to providing preconditions for high reliability in high-risk environments. The above-mentioned reasons make simulation a tool for training in many fields working in high-risk environments, such as maritime, aviation, surgery, military, process plants, nuclear plants, etc. Common for all these fields is that individuals and teams are put in more or less complex situations, using complex technologies with demands for strong and flawless performance [2] with possible interactions between humans and complex automated systems. Further, in the maritime domain, the safety of the maritime operators are to a large degree self-sufficient, dependent on their own skills to ensure safe operations and to cope with situations as they arise. Bad performance in both technical and non-technical skills can potentially cause large consequences on life, equipment and environment. The main reason for using simulators in maritime training is to provide effective and goal-directed training, and the authors mean this is imperative to ensure good performance, hence safety at sea. There are similarities between challenges operators meet in maritime and the

high-risk domains medicine, commercial aviation, industrial plant, military and commercial maritime. Further, SBL is used providing a range of more or less intertwined skills in all these fields. Through simulator course arrangements the operators have learning goals spanning from pure technical skill-building to non-technical skills such as, situational awareness, communication, procedural skills and verification, familiarization, crisis management, decision making, confidence and correcting mental models at both individual and team level. These terms are used similarly in all domains reviewed and they are to a large degree anchored in the same theories. Technical skills refers to subject knowledge and skills required to accomplish specific tasks, such "knobology", maneuvering a vehicle or using medical equipment. Non-technical skills refers to cognitive, social and personal resource skills that complement the technical skills [4]. These skills include teamwork, situation awareness, communication, decision-making, leadership, etc., which are all skills that can improve performance and reduce likelihood and consequence of mishaps and accidents. The term collectivistic skills refers to how personnel from distributed workstations integrate their efforts to reach a common goal through skills such as decision-making, procedural skills, situational awareness, etc. Examples are maritime operations where operators on several ships and rigs have to cooperate to move an anchor or military operations where different groups from various disciplines are interdependent.
Grounded in this, a systematic literature search was conducted of studies on simulator-based training in the high-risk domains medicine, commercial aviation, industrial plant operation, military and commercial maritime to answer the research questions:

RQ1: How do maritime domain differ from other domains and organizations in using SBL as a risk intervention and performance training tool?

RQ2: How and to what extent does SBL reduce risk and human factor errors in different high reliability work domains through training performance, teamwork, situational awareness, communication procedural skills and verification, familiarization, crisis management, decision-making, confidence and correcting mental models?

II. METHOD

A literature search and review of published research was conducted. All study types was considered, there were no exclusion criteria set for type of sample in the reviewed studies, meaning results from both novices and professionals are taken into account. The term team is used repeatedly in the paper, the meaning of the term in this paper is as defined by Salas et al. (1992) [5]: "a distinguishable set of two or more people who interact dynamically, interdependently, and adaptively toward a common and valued goal/object/mission, who have each been assigned specific roles or functions to perform, and who have a limited life span of membership. The primary search included the databases Scopus, Ebscohost, Springer and Google Scholar using combinations of the terms simulation-based-learning, simulation-based-teaching, simulation-based-training, effect, simulator, risk and crisis management for the different domains up to March 2016. An additional search in the references of the relevant articles was also conducted. The reviewed literature was analyzed to see how SBL is used, and the effect it has on the operators. The inclusion criteria were that the studies had to contain information on the use of simulators as a training tool, therefore we have not focused on simulators as an engineering tool or tool for experiments in this review. No studies depicting risk reduction and performance increase directly were found. To answer how and to what extent SBL reduce risk and human factor errors in the different domains we have looked at transfer of training, which refers to how the positive effects of prior learning of given skills influence performance on later activities. Hence, effect in this review is describing all positive and negative impacts on operators' reactions, attitudes, skills, knowledge, on-the-job behavior and results on performance.

The initial searches identified 7384 hits, whereof 76 papers was considered relevant and examined in full text. Of these, 45 were suitable for inclusion, of which 17 were from the medical domain, 9 from maritime, 8 from military, 6 from aviation and 2 from plant control. A further search into the references of these papers resulted in 26 additional relevant papers. A comprehensive description of the studies is beyond the scope of this review, only the most important aspects for the research questions will be addressed.

From the review process it is evident that there are several types of limitations in the studies addressed, many of the studies have limited sample sizes giving only indications and not significant data. Much of the results rely on the self-assessments or self-reports in interviews with the persons who have done the simulations and simulation curriculums. There are also possibilities of biases and attributions because many of the studies assessed are performed by researchers working at universities or training centers offering simulator training. There is also a shortage of published studies addressing the research questions for all other fields than medicine.

Data describing effect of SBL from chosen studies were extracted by the first author and checked by two others using data extraction tables.

III. RESULTS

The results section is structured with separate paragraphs describing how SBL has developed and is used in the different domains. A comparison between maritime and the other domains based on the information obtained in the review is presented in the discussion section.

III.I. Medical simulations

Simulator use in medical education started in the early 1960s with mannequin dolls for mouth-to-mouth ventilation. These dolls initiated the development of numerous medical task trainers. In 1969, the first computer-controlled patient simulator was developed by Abrahamson and Denson at the University of Southern California [6]. These early low-fidelity trainers were used to train basic medical skills and technical skills. Since then, there has been a continuous increase in technology allowing increased realism, extra features and new training possibilities. These advances in computer technology, and new medical and surgical procedures calling for long learning curves and complex skills, resulted in significant advances in medical simulations in the 1990s [7]. During the 1990s, the focus also turned to training of non-technical skills in medicine simulators, because these were proven to cause a majority of medical failures [8]. Simulation based education is continuously increasing in medicine domains, also shown by the fact that during the years 2000 - 2015 more than 350 articles with simulation as a major methodology have been published in the 10 highest impact surgical journals [9].

In the reviewed papers, there is a focus on ethics and patient safety, and there seems to be a consensus that simulator training is a way to develop expertise in a safe and flexible environment without risking injuries to patients. Simulations are also a ways to train skills that are hard to train in real life situations [10, 11]. Clau-Terrè et al. (2014) [12] states that training with live patients can give difficulties in providing focused training at the same time as patients' needs are managed. Further, since medical training programs are overstretched with big curriculums, simulations are considered an effective way of mitigating this.

SBL in the medical sector is used to reduce the risk of human factor errors and increase performance in several different ways. It is used as a tool for pure individual technical-skill building, for building clinical knowledge and personal confidence [10, 13]. It is also used to train teams and individuals in scenarios that are rare and infrequent. However, technical skills are necessary, but often not sufficient for optimal performance. Failures in cooperative skills and non-technical skills such as communication, situation awareness and decision-making have been identified as a large contributor to patient harm and near misses in the medical domain [9, 10, 14]. Where multi-professional teams potentially experience complex situations under combinations of time pressure, uncertain and insufficient information flow and multiple and concurrent tasks [15]. Surgical teams, critical care teams and anesthetic teams are examples of teams in the medical domain where simulation is an important tool for training non-technical skills such as communication [9, 10, 13, 11, 12], procedural skills [9, 10, 13, 11, 12], teamwork [9, 10, 13, 11, 12], crisis management[9, 10, 12], decision making [9, 10, 13, 12] , situational awareness [10, 13, 11, 12] and confidence[10, 13, 15].

SBL has also been used for assessment of both technical and non-technical skills, but a need for more research on metrics, measures, methods, performance criteria, reliability and validity is identified in several papers [9, 13]. Further, Krage et al. (2015) [13] states that assessments for certifications and recertification need more awareness, dedicated decision-makers and research data on how to do it wisely.

There seems to be much research on effects of simulation in the medical domain. Nine papers addressing this were identified in the reviewed texts (see table I). Many of the studies have limitations in the form of small sample sizes, lack of objective measurements and lack of control groups. However, the results are overall positive concerning simulations as a tool for increased performance both for technical and non-technical skills. In the review by Boling et al. (2016) [10], the use of high fidelity simulators to improve confidence and knowledge in medical personnel to make up for deficiencies in clinical experiences are studied. The results show that both for studies using self-assessed confidence and self-assessed knowledge, for studies with pre-/post-test setups and studies using validated tests, there are indications of improvements in test scores following SBL. Clau-Terrè et al. (2014) [12] have conducted a review to describe the effectiveness in use of echocardiographic simulators, where three of the studies addressed simulator-based training as opposed to traditional learning methods, and their results from pre-/post tests indicate better effects from simulator-based training. In the review by Dawe et al. (2014) [11], the transfer of skills after surgical SBL is assessed, giving the findings that simulation based training have advantages over no training, and there were no significantly inferior results from SBL compared to patient based training. Further, the results show that curriculums with both traditional learning methods and simulator training provide better results than just traditional learning. This positive effect of adding simulator training into the curriculum can also be found in the studies by Steadman et al. (2006) [16] and Prat et al. (2016) [17]. Studies investigating transfer of non-technical skill from simulator training Gjeraa et al. (2014) [15], Wallin et al. (2007) [18] and Yee et al. (2005) [19] also present a clear overweight of positive results.

TABLE I. Review of simulator training effects in medical domains

Study	Design	Research question	Summary of findings	Population
Boling et al. 2016 [10]	Review	What is the effect of high fidelity simulation on knowledge and confidence	Confidence increase in 12 of 12 studies. Knowledge increase in 16 of 16 studies	Mixed, physicians and nurses
Clau-Terrè et al. 2014 [12]	Review	What is the effectiveness of echocardiograph simulator compared to traditional learning methods	3 of 3 studies assessing this show better results	Anesthetic students
Dawe et al. 2014 [11]	Review	What is the effect of simulator training compared to no simulator training on surgical technical skills	23 out of 28 studies reported simulator trained students had better performance	Medical students
		What is the effect of simulator-based training compared to patient-based training on surgical technical skills	4 out of 4 studies reported no significant poorer performance in simulator groups compared to patient-based learning groups	
Gjeraa et al. 2014 [15]	Review	What is the effect of team training in simulator on trauma teams	10 out of 10 (7 of 10 significantly) studies showed various positive trends in teamwork skills from simulation, knowledge, confidence or performance	Trauma teams
Prat et al. 2016 [17]	Prospective study	What is the effect on learning curve of transesophageal hemodynamic assessment from echocardiographic simulation	Inclusion of simulator sessions in standardized curriculum may improve learning curve. Results seem to improve	Anesthiologists, cardiologists
Wallin et al. 2007 [18]	Prospective study	What is the effect on teamwork and attitude behavior in critical care teams from use of simulator training	Nine out of ten team skills assessed improved significantly in response to practice, no effect on attitudes towards safe teamwork registered	Critical care teams
Yee et al. 2005 [19]	Prospective study	What is the effect on non-technical skills from repeated anesthesia crisis simulations	Positive results on non-technical skills from first simulation	Anesthesiologists
Weller et al. 2003 [20]	Prospective study	What is the long- term change of practice following simulation based crisis management training	Simulation based training effective form of continuing medical education for crisis management for anesthetists	Anesthesiologists
Steadman et al. 2006 [16]	Experimental study	Is full scale simulation better then problem-based learning for teaching medical students acute care assessment and management skills	For fourth year medical students simulation based learning was superior to problem based learning for acquisition of critical assessment ant management skills	Medical students

III.II. Commercial aviation simulations

The origin of modern flight simulators can be traced back to 1929 when Edward A. Link patented an air actuated plane model, which demonstrated and made control movements apparent for instructors. During the Second World War, the US military utilized ten thousand units based on this system for pilot training. The use of computers for flight simulation began in the 1960s. After this, there has been a continuous development of flight simulators, resulting in aviation simulation becoming a large industry [21]. An example of this is the fact that the largest aviation simulation company in the world had 8000 employees and a revenue of more than 2 billion USD in 2014 [22]. Up to 1980, the aviation simulator training mainly focused on technical skills. This started changing after 1979, when research in air transport accidents presented at the NASA sponsored workshop Resource management on the flight deck, identified human error aspects, such as failures of interpersonal communications, decision making and leadership, as causes for the majority of air accidents. This new focus on human factors led to the development of the term crew resource management (CRM). CRM is a team training strategy focused on improving crew coordination and performance [23] through training crews in effectively using all of their resources such as people, equipment and information in decision-making, error management and leadership to minimize risk [24]. CRM training became mandatory for military flight crews in early 1990s and 1998 for commercial crews [23]. Simulation based training are reported to have become an indispensable tool in pilot education due to increased computer power resulting in increased fidelity and opportunities, reduction of hazard for accidents with real plane training, possibility of training performance and skills that is hard to train in real aircrafts, such as adverse conditions and malfunctions. The cost savings can also be substantial through fuel- and timesavings. One aspect for civil airliners is that they use all their planes for income generating flights and have no planes to spare for training. In addition to this, modern aircrafts have complex and automated operating environments that give need for in depth training that can more easily be achieved in simulators than real-life. Simulators in commercial aviation are also the most used method of assessing, qualifying and certifying pilots and aircrew in different skills. [2].

Lofaro and Smith (in Vincenzi et al. [2]) states that the end result of all pilot training should be to prepare a pilot to identify, assess and manage risk. SBL in civil aviation does this through training basic technical skills such as maneuvering skills and instrument training, non-technical skills such as decision making, situational awareness and error management and interpersonal skills such as crew resource management training, teamwork and communications [25].

Only two studies were identified from the review showing transfer of training from simulator training in aviation (see table II). One is a review of effectiveness of CRM courses by Salas et al. (2006) [23], who identified that transfer of training outcomes from various CRM courses in aviation leads to overall positive reactions. In a longitudinal study, Macchiarella et al. (2006) [26] followed performance of pilots from a novice condition to certification as private pilots, and compared all-flight training to a hybrid simulator/airplane training group where the participants practiced each task to standard before training in actual airplanes. This study showed positive transfer of training in 33 out of 34 tasks and significantly positive results in 18 out of 34 tasks in the hybrid curriculums favor.

TABLE II. Review of simulator training effects in commercial aviation domain

Study	**Design**	**Research question**	**Summary of findings**	**Population**
Salas et al. 2006 [23]	Review	Does CRM training work	9 studies evaluated, generally positive reactions to training and positive effects on non-technical skill performance	Pilots
Macchiarella et al. 2006 [26]	Longitudinal comparative study	What is transfer of training effect in simulator/flight training compared to flight only?	Positive transfer of training results in 33 out of 34 tasks, significantly positive in 18 out of 34 in simulator/flight curriculums favor	Pilots training from novice to certificate

III.III. Military simulations

There is a long history of using simulations for training skills and operations in the military, from stones in sand pits to modern day computer simulations. The military uses simulators for several different disciplines, e.g. aviation [27, 28], naval [29], army [30] and battle command decision-making [31, 32, 33]. Increased technology along with demand for safe, effective, and low cost training leads to the military spending substantial amounts of resources on training development. Examples of major US projects utilizing SBL is IMAT/DSOT (Interactive Multi-Sensor Analysis/Deployable Sonar Operator Trainer). Further, AET (Advanced Embedded Training) provides tactical training and team training for naval air defense teams through simulation. VE-SUB (Virtual environment submarine) gives practice in maneuvering submarines into harbor through virtual reality. CCTT (Close Combat Tactical Trainer), provides armor and mechanized infantry training through networked systems and AN/USQ-T46(V) Battle Force Tactical Training System for shipboard tactical combat training at unit, group or force levels [29, 34]. There is a large movement towards networked simulators in defense domains to train collective and distributed skills where multiple personnel from several disciplines and weapon branches can train in the same scenario [2].

As for the other domains reviewed in this paper, cost, safety, and non-availability of time or space are described as the main reasons for using simulations for training. Further to this, there are issues with peacetime training rules such as weather restrictions, limitations in communication jamming, separation between aircrafts, resource limitations in the form of available equipment, available flying hours and sizes of training ranges, and technical constraints in the form of limitations in electronic warfare systems and performance measurement [28]. One important aspect for military simulator training stated by Scmhorrow et al. (in Vincenzi et al. [2]) is that many military branches spend long periods in deployment without access to training facilities; this has made simulation-training solutions to be used in deployment an important research area. Further, he states that different military branches experience continuous increases in operational tempo and mission complexity, which calls for innovative solutions for meeting increasing training demands. Furthermore, the mission complexity and need for strong performance leads to an increased emphasis on distributed decision making down to the lowest ranked level personnel. Soldiers who earlier were only required to remember procedures and follow orders must now make decisions in the field and have a deeper understanding of the interconnectivity on the battlefield [31]. Large investments are made into distributed mission training capabilities in simulators to train technical skills, but also to help develop doctrines and tactics, decision-making training and mission training [35]. Education goals in military simulations are individual technical skills such as vehicle driving, gunnery, and electronic warfare. Further goals of simulations are crew and individual training on non-technical skills such as decision-making, situational awareness, crisis management and reactions on enemy actions and distributed mission training on combat situations and coordination with friendly forces through tactical operations training through networked simulators.

There are only five studies [28, 30, 27, 36, 37] (See table III) identified in the review looking at effects of simulator training in military domains, and the results are overall positive in these five. In a study by Oskarsson et al. (2009) [30], crew at armored vehicles self-reported a transfer of training to real life, especially early in the education. In Butavicius et al.'s (2012) [36] study of training in a parachute jump simulator, they found no performance difference between classroom and simulator trained groups, but the simulator-trained group needed less instructor corrections during live jumping. Sclechter et al. (1997) [37] conducted a study of virtual training programs on platoon leaders, which gave positive increase in skills and confidence both from participant and instructor assessments. Bell et al's. review (2009) [28] of transfer of training for simulator trained combat pilots showed overall positive results from simulator training on real life skills, but one study in this review showed negative effects of simulator training if the cockpit setup is different from simulated environment to real-life environment. Also, a meta-analysis by Hays et al. (1992) [27] examining effects of simulator training for commercial and military air crew showed positive effects of simulator and real-life aircraft training combined in more than 90% of the 19 studies reviewed, compared to real-life aircraft training solely. Another finding in this meta-analysis was that simulator training allowing operators to progress at their own pace was more effective than lock-step training.

TABLE III. Review of simulator training effects in military domains

Study	**Design**	**Research question**	**Summary of findings**	**Population**
Oskarsson et al. 2009 [30]	Experimental study	What is the training effect in low fidelity combat vehicle simulator	Trainee-assessed transfer of training to reality was rated high in early part of education, lower in later parts. Effect on team training increased from low scores early in the education to high scores late in the education	Armored vehicle crew
Butavicius et al. 2012 [36]	Experimental study	What is the difference between performance between simulator-trained group and classroom trained group?	No significant differences in performance between groups, however participants trained in simulator required less feedback correction during jumps.	Parachute jumping
Schlechter et al. 1997 [37]	Prospective study	What is the effect of home station preparation with virtual training program?	Pre-post training assessments from participants showed positive impact on confidence in own tactical proficiency. Assessments from instructors showed positive effects in tactical performance	Platoon leaders
Bell et al. 2009 [28]	Review	Is there positive transfer of skills from simulator to airplane in delivery of air to surface conventional weapons	5 of 6 studies show better performance in pilots from simulator group compared to pilots from non-simulator group	Military pilots
		Is there positive transfer of skills from simulator to airplane in interdiction and close air support	3 of 3 studies show positive effects. One of the studies show negative effect on performance when cockpit had different configuration than simulator	
		Is there positive effect of simulator training on performance in air to air combat	6 out of 7 studies showed positive effect of simulator training on performance	
		Is multi-participant simulations valuable	No transfer of training studies. 3 of 3 studies measuring pilot opinion and in-simulator performance show positive results	
Hays et al. 1992 [27]	Meta -analysis	What are the characteristics associated with effectiveness of simulator training	Over 90% of 19 studies with jets show positive effects of simulator and aircraft training over aircraft training alone	Pilots

III.IV. Industrial simulations

The use of simulators for plant operation purposes started in 1957 in the form of nuclear power plant control room replicas in the US, followed by European and Asian countries in the late 1960s and early 1970s, and later followed by simulations in fossil power plants. Oil and gas well drilling simulators started appearing in the late 1970s (Amico et al. 1984 [38], cited in Kluge, 2009 [3]). The first computer based control room simulators for nuclear power plants came into service in the 1970s. In the 1980s, a review of lessons learned from operating experience and adequacy of training resulted in, amongst others, far more stringent requirements for simulator training and greater reliance on simulators in qualification and authorization of nuclear power plant control room operators [39].

Accidents at industrial facilities such as nuclear power plants, processing plants, chemical plants etc. can have large consequences on human life, environment and costs. One source of these accidents is incorrect manipulation of process units [40, 41]. Burkolter et al. (2010) [42] state that industrial facilities that are highly automated involve complex and dynamic process control tasks that present complex and demanding tasks for the. Industrial operators play a role in reducing the probability of accidents by utilizing their awareness and understanding of the system and situation during normal and abnormal operating conditions [43]. Simulators are used for providing preconditions for high reliability in this domain through training without disrupting normal plant operations, simulate infrequent events and high-risk events, which can be impossible to train in real life. Further to this, it is used for demonstrating aspects of plant behavior, for procedural and checklist practice, to test and evaluate operators' knowledge [3] and for accident management [42]. In some countries, simulator courses are mandatory for control room operators and shift engineers in nuclear power plants [3].

This review only resulted in one study looking at effect of simulator-based training in the industrial domain [44] (See table IV). This lack of evidence on transfer of training is addressed in IAEAs 2004 report. This report states that only anecdotal evidence of simulators contributing to increased safety performance in nuclear power plants exist. However, full-scope simulators are recognized worldwide as the only realistic method to provide hands-on training of operators on mitigating and responding to accidents and support development of and validate correctness of normal and emergency procedures [39].

TABLE IV. Review of simulator training effects in industrial domain

Study	**Design**	**Research question**	**Summary of findings**	**Population**
Nazir et al. 2015 [44]	Experimental study	What is the effect of two distinct training methods on distributed situation awareness and safety related performance of industrial operators during accident scenario	Participants trained in 3D virtual environment were able to maintain better distributed situational awareness and performed more effectively in simulated scenario than those trained with conventional training method	

III.V. Commercial maritime simulations

The norm in maritime education was on-the-job training until the late twentieth century. This changed when maritime accidents as well as technological advancements like ECDIS (Electronic chart display information system) and AIS (automatic identification system) necessitated changes in maritime education. Classroom education in addition to on-the-job training was the method until computer simulations became an important addition due to enabling technology. The earliest bridge simulators emerged in the 1970s and were used primarily for passage planning and for training master-pilot relationships. During the 1980s, engine room and cargo handling simulators became available [45]. The use of maritime computer-based simulators have expanded along with advancements in computer technology, and is now considered the method of choice in maritime education for risk reduction [46]. The Standards of Training, Certification and Watchkeeping (STCW) was adopted at an International Maritime Organization (IMO) conference in 1978 as a means to standardize training, certification and watchkeeping requirements for mariners. At this time, the focus in marine safety was still on the technical state of vessels and equipment. The STCW established qualification demands for navigators, officers and other watchkeeping personnel on commercial vessels. The STCW was revised in 1995 and shifted focus to practical skills and competence based on practical knowledge and increased focus on human factors. The convention was again amended in 2010, further focusing on competence and incorporating new technology. This convention makes simulator training an important means to train and demonstrate competence in passage planning, navigation, use of navigational aids and bridge resource management (BRM, non-technical skills), emergency response, engine room resource management (ERM, non-technical skills), etc. For radar, ARPA (Automatic radar plotting aid), and electronic chart display (ECDIS) skills, simulation assessment is mandatory. In all other instances, demanding training and assessment such as bridge resource management, GMDSS (Global maritime distress safety system) communication, ship handling and cargo handling, the use of simulator is not mandatory, but accepted as a method [47]. The trend in maritime simulations is also going into networking of simulators for training both technical and non-technical individual and collective skills. Examples are BRM/ERM, where bridge and engine room simulators often are networked, and training for anchor handling with stations for deck personnel, rig personnel and bridge personnel [48]. Training for higher complexity has become an opportunity, as in crane operations with bridge, crane and deck operators, and in unique operation training with remotely operated submarine, crane, engine room, bridge and shift supervisor stations networked [49].

In a maritime operation, a high degree of automation and complex systems interact, e.g. navigational aids, diagnostic systems, communication systems, remotely operated vehicles, cranes, winches etc. Interactions between these systems and more or less distributed crewmembers is required. Further to this, the ship bridge is designed to provide as much information as possible to the operators, resulting in potentially large amounts of information available for the operator, who has to sort out what information is needed, at the same time he/she has to fill in the gaps of missing information by using personal mental models to interpret sensory input [50]. This technology and automation increase in navigation and ship handling have the potential of leaving personnel trusting and complacent, and less skilled at performing conventional navigation when necessary. Alton G. Seamon states that increased training is needed to operate the systems designed to prevent accidents (Alton G. Seamon in Vincenzi et al. [2]). Perdok and Wewerinke (1995) [51] argues that there are more demands on flexibility, skills and knowledge of bridge crew and pilots than ever before. Some reasons mentioned for this are the tendency to reduce crews, the increasing number of tasks apart from navigation and communication, a decrease of operational time on board, increasing need of flexibility of ship crew and pilots, different levels and/or standards of automation and different types of equipment, differences in procedures on different ships, etc. Studies of the role of human factors associated with ship accidents point to fatigue, decision-making, lack in teamwork and lack of situational awareness as important factors [52]. A marine operation can consist of several vessels, rigs and work stations depending on communication for coordination. Nautical simulators are used in training on all of the skills mentioned here through training pure technical skills and procedural skills at an individual and team level such as navigation, use of instruments, engine maintenance, crane operations and ROV training and teamwork competencies, such as communication and interpersonal skills, problem solving, decision-making and crisis management skills, and collective operation training with many workstations and vessels operating together.

The review resulted in only one study considering effects of simulator training in the commercial maritime domain. This is a study by Håvold et al. (2014) [48] describing anchor handling courses giving basic training, team performance training and critical situation and emergency drill training. This particular study is looking at the effect of a simulator course with the goal of improving teambuilding, leadership and communication, where 369 participants from anchor-handling team training courses rated how the simulator course altered attitudes, improved skills and knowledge, and the extent to which the learning was applied in real-life. The training resulted in improved self-assessed knowledge, skills and understanding.

TABLE V. Review of simulator training effects in commercial marine domain

Study	**Design**	**Research question**	**Summary of findings**	**Population**
Håvold et al. 2014 [48]	Survey	What is the effect of simulator team training on attitudes, skills, knowledge and use of this in real-life	Training course influenced positively at group and individual level	Cadets and navigators

IV. DISCUSSION

The studies assessed in the review encompass many different training procedures and training goals in the high-risk domains medicine, commercial aviation, military, industrial plant operations and commercial maritime, all characterized by individual and teams of operators being exposed to complex situations using complex technologies demanding strong performance for safe and good outcomes. In spite of the limitations described in the methods section, the results of the review indicate positive transfer of training from SBL compared to classroom based training. Further, there seems to be an overall consensus that simulation based learning in all reviewed fields have a positive effect on transfer of training to real life situations and a number of benefits can be drawn from it, such as increased performance both in technical and non-technical skills. Increase in technical performance, teamwork, situational awareness, communication procedural skills and verification, familiarization, crisis management, decision-making, confidence and correcting mental models are considered as important ways of lowering operational risk. However, a positive transfer of training cannot be attributed only to the simulator and simulator facilities, but to how it is used for training, the instructors, the curriculum, instructor-feedback, etc. It is also important to have a conscious perspective regarding possible negative effects of simulation. Examples of this is the phenomenon Bell et al.(1998) [28] describe where combat pilots experienced negative transfer of training when setup in simulator cockpit differed from real-life cockpit, and what Clau-Terrè (2014) [12] describes as “have a go hero”, where simulation training can give a rapid increase in enthusiasm, potentially resulting in incidents and omissions. These kind of negative results of SBL can also extend time needed in real-life training to unlearn bad habits [53].

The findings in the literature review show that development and expansion of learning goals in SBL in the five applied fields have followed a similar trend closely related to technological improvements and trends in accident causation (see figure 1). The technological improvements provide better simulation possibilities through increased computer power, fidelity and networking. Moreover, trends in accident causation emphasize technical factors up to the 1970s, focuses on human as failure causes from the 1970s, before expanding into underlying causes such as complexity and organization associated problems from the 1990s [54]. The complexity of tasks and degree of automation have also increased during this time, with more specific areas of expertise, more multi-skilled teams and more automation. We can see an evolution of learning goals (see figure I), going from acquiring technical skills for good performance and lowering risks for a single operator (ship maneuvering, aircraft maneuvering, process control room) expanding into non-technical skills such as teamwork, leadership, crisis management, situational awareness, etc., further expanding into collective skills and complex operations training with several networked workstations. For the training of single operators, in technical skills the similarities are obvious between the maritime and the other reviewed domains both in goals and in methods. The main method is for operators to play through cases with a learning goal followed by a debrief session with feedback on their performance. For the training of non-technical skills, there are also large similarities, with teams or cooperative persons more or less distributed on workstations playing through scenarios that demand situational awareness, decision making, communication, etc., followed by a debrief session. A difference identified between modern maritime and medical, commercial aviation and industrial field SBL is the emphasis on training collectivistic skills among distributed crew and workstations. Safe operation at sea depends highly on interaction between different departments and specialized disciplines. The personnel are often distributed as crew at different locations onboard the ship, or at different ships and rigs working together, depending on a high degree of coordination and communication systems for interaction, and this communication aspect seems to be specially addressed in both learning goals in STCW and in simulator training studies.

The accident rate in marine transport (total losses per thousand vessels worldwide) [55] and commercial aviation (annual accident rate per million departures) [56] has declined over the last decades. This can be attributed to amongst others technical developments, legislations, procedures and protocols. The impact SBL has on this risk decrease is hard to deduce Therefore we have focused on transfer of training studies in the different domains to investigate how simulation based learning reduces risk and increases performance. Several studies report operators’ opinions of their simulator training and increases in performance in a simulated setting, but there is a lack of publications on transfer-of-training to real-life situations, such as increased patient-safety, fewer air crashes and ship accidents. The reason for this might be a scarcity of data due to the rarity of incidents. However, if used correctly, there seems to be a consensus that SBL may be the only feasible way to get “realistic” training for many high-risk scenarios. With increased computer power, use of simulation as a tool for unique operations has been acknowledged. In the domains of military, special surgery and advanced marine operations, studies are identified where participants have trained in dry runs to verify procedures, train technical skills and teamwork, and to discover what works and does not work in the operation.

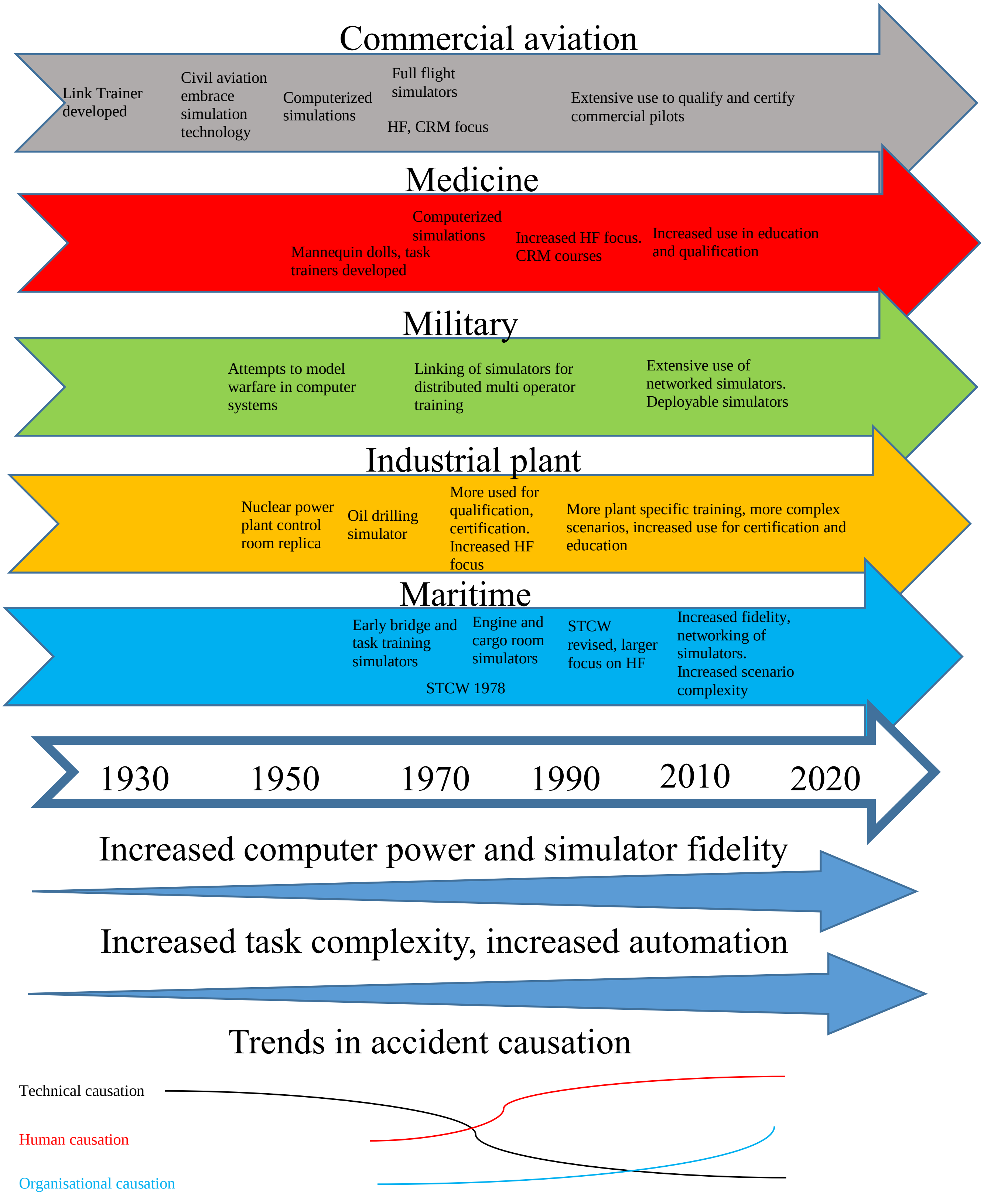

Figure I. Development of simulation-based learning from 1930 to present

V. CONCLUSION AND FUTURE WORK

The results from the review indicate that simulation-based training is a good alternative to standard classroom based education, and can be a strong alternative for on-the-job training if implemented properly in the domains reviewed. Simulator training is found to improve knowledge and skills both for standard and rare situations, it is risk free and enables training for eventualities that are hard or impossible to train in real-life. Hence, simulator training is a tool to improve the operator's performance in real-life situations and decrease risk both through improved technical, non-technical and collectivistic skills and through eliminating the risk associated with real-life training. The overall learning goals have developed in a similar manner for the reviewed domains, along with increased computer technology increasing technical possibilities and feasibility in the simulator, increased task complexity and use of automation in the real life operations, as well as trends in accident causation expanding from technical-related to human-related to organizational causes. The work with the review has highlighted a need for more refined research on the transfer of skill to real-life settings for all the domains. Another important research area is the use of increased possibilities from simulation derived technological improvements and rapid programming possibilities in the purpose of training or preparing operators for unique operations, and likewise to test procedures and assess feasibility of such operations. The use of simulators for unique operations have been identified in recent papers in both medical, military and maritime simulation training, and is a promising tool for increasing performance and reducing risks, not only through training in risk reducing measures but also for discovering hidden risk factors. Further, it can increase effectiveness through operation dry runs, testing and washing of procedures and help in selection of personnel.

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