Articulation work in subsea operations

Taking teamwork seriously in assessment of subsea operations

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***Abstract*—In this article, we visit the concept of 'articulation work' and its application in a sociotechnical system – subsea system. We analyze the teamwork in subsea operations and present that teamwork should be taken seriously in the assessment of subsea operations. We propose that teamwork is not about cooperation in a solo team; instead, teamwork in subsea operations cross the borders between teams. Moreover, a team needs to react on cooperation and be responsible for their decision-making process when subsea systems are in use. We conclude that sociotechnical systems need more attention on its development and assessment to support teamwork. Such a contribution adds literature for better understanding the Internet of things (IoT) from a social and practice perspective for the maritime domain, teamwork in particular.**

Keywords— Sociotechnical systems; teamwork; activity theory; IoT; subsea

I. INTRODUCTION

Sociotechnical as a joint optimization [1] insignia in the industry-related academic area becomes popular; maritime domain is an example. With such, technical systems are becoming more complex, for example maritime, aviation, air traffic control, nuclear power plants, space missions, and telecommunications. A common feature of these technical systems is teamwork. Thus, teamwork naturally becomes a topic in sociotechnical systems studies. The reason is because of some notable disasters and accidents where failures in sociotechnical systems lead to serious loss of material and human teams, such as the NASA Challenger shuttle explosion [2], the US Black Hawk fratricide incident during first Gulf War Operation Provide Comfort [3], and critical aviation accidents in Warsaw [4].

Teamwork in sociotechnical systems have been studied for many years, and the meaning of the term team is understood in many ways. Among them, for example, researchers understand teamwork in sociotechnical systems is to use technical models in the design of technologies to protect human life [5]. Of course, technology can help to protect human life. However, some other understandings of teamwork might be missing. First, teamwork is understood as a group of people working together to accomplish tasks through the given technical system structures [6]. In line with this, teamwork is linked to physical property. Safety issues in teamwork happen due to those physical properties' unsafe attitude. While, when a team of humans works in sociotechnical systems, safety is something more than physical property. It might address on human performance rather than purely object's characteristics. Thus, such "something more" is about team performance from the human side which calls more attention on it [7]. As Robertson and Wagner argue that teamwork in sociotechnical systems is close to the relations between computer supported cooperative work and IoT. Such understanding of teamwork promise to significantly extend, enrich, and even shift the relationship between people and the world around them gradually resulting in genuine paradigm shift [8].

From an engineering point of view, assessing teamwork in sociotechnical systems is a process of making an agreement of multiple evaluators who study technology in use [9]. Humans in such understanding are subjects in experiments or lab-based investigations [10]. However, from a social computing point of view, humans are not subjects but the main actors who must work with. This reflects on teamwork in complex sociotechnical systems, such as subsea systems. In this article, a picture of subsea systems consists of crane operation systems, remotely operated underwater vehicle systems and dynamic positioning systems. All these systems themselves also include several subsystems. Importantly, humans are involved in all these systems' operation, and some degree plays roles as a part of such sociotechnical systems.

There is no clear way to assess such sociotechnical systems and human operations [11]. Some researchers argue that evaluating of human performance might be fruitful for better understanding the sociotechnical systems [12]. The main point is '*performance of technical work*.' Performance, as defined by Merriam-Webster, is "*performance of a practical work or something involving the practical application of principles or processes*." Through testing pre-selected scenarios to understand whether the systems could work well, human's work practices are dismissed in assessment work. However, one of the core issues in sociotechnical systems is the performance of humans in a team. Safety issues from this perspective might mean that a human work with other humans causes some good or bad performance in their work with sociotechnical systems. Humans instead of the physical properties of the sociotechnical systems may cause unsafe performance.

With such an understanding of safety as human performance, it is not surprising that most studies in both assessment and sociotechnical systems research fields unsuccessfully deal with the relations between the social aspect and technology. Importantly, the relationships are separated as human, technology and a link between them – activity. The cooperation between humans and technology and the society in between needs articulation work as an effort to investigate how an activity is done in teamwork. For example, teamwork in sociotechnical systems is understood as different models in the technical development of systems [13]. However, researchers in workplace studies understand teamwork is a work route in proper social orders of practicing technologies in the workplace [14].

In order to deal with teamwork for subsea operations from human performance aspects, we use activity theory (AT) [15] to analyze two cases that illustrate that safety issues in sociotechnical systems may not happen from hierarchical orders such as technical systems' structure [16]. In our context, subsea operations include dynamic positioning operation, remotely operated underwater vehicle (ROV) operation, diving systems operation and other activities that only refers to offshore operations at sea. We question how work practices of humans can help us to highlight teamwork assessment in a sociotechnical system wherein a team of humans, technology, and their operational relations. Also, such highlighted teamwork performances of humans provide what kinds of metaphor on sociotechnical systems.

The paper is structured as follows: In section 2, we introduce related work in subsea safety operations. In section 3, we introduce articulation work in activity. Section 4 presents the methodology. Then we present the empirical setting with two operational cases in section 5. We analyze the cases with arguments in section 6. And, we conclude the article in Section 7.

II. Related Work

The simulator was first used many years ago in aviation- [17]–[19], medical and surgery- [20], and driving [21]–[23] studies to increase confidence and reduce possible errors in operations. It is a relatively new method for maritime navigation training [24]. Simulators also contribute to avoiding errors in commercial aviation and general aviation [19]. 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 [25]. They have also helped to improve the Los Angeles fire service, with a 19% reduction of all driving errors [22]. Also, medical and surgery simulators have demonstrated a significant contribution, with a 10% reduction of errors in general [26].

Simulators also contribute to strengthening efficiency. Many studies have documented that simulators can increase the preparation speed for truck drivers [25], commercial car drivers, and fire service car drivers [22] from 85% to 88%. Researchers in other domains have also reported that simulators have a considerable impact on increasing the preparation of human operators, such as surgery training (35%) and medicine (29%) [26], transport (45%) [27], and flight training (77%) [28].

However, questions remain when applying simulators in the maritime domain. First, most studies focus on how simulators can contribute in studying individual users. Simulators in such studies aim at enhancing individual users' confidence in known and pre-defined scenarios. For example, regarding human errors in the maritime domain [29], researchers imagine in what conditions simulators can be prepared for those errors or risks. Compared to the maritime domain, some errors and risks cannot be foreseen. One particular example is teamwork. Driving is a solo behavior. A driver only needs to interact with a car and the outside environment while driving. No other factors affect his/her driving and decision-making. On the other hand, subsea operations are team-based activities. One operator may not be able to make his/her 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 in preparing a team for subsea operations. Also, subsea operations are unique. They may be integrated with other general operations for unique operations. It is also notable that these simulator studies do not consider the social aspects of simulators use. Only technical aspects are evaluated. We argue that a team consists of 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. Safety issues and challenge areas may arise during the process of teamwork, among human operations' interaction, their demands, and so on.

Some researchers [30] discuss three ways to investigate and design of sociotechnical systems – human-systems integration, macro-ergonomic, and safety climate. They state that each of the three approaches emphasizes key sociotechnical systems themes, and each prescribes a more holistic perspective on work systems than do traditional theories and methods. However, there is no outlook on how to hand on work with design and assessment of sociotechnical systems. Also, researchers do not focus on teamwork practice.

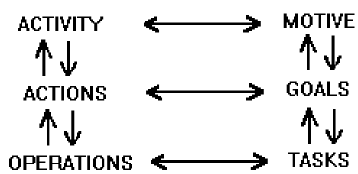
Other simulator studies mainly focus on traditional ways to deal with safety in subsea operations. To name a few, for example, DNV GL promotes a technical guidebook for industry to avoid possible lifting problems in subsea operations [31]. Subsea 7 also has a similar handbook but mainly focus on management of operations, requesting operators to take their duties and responsibilities in their activities [32]. Institutions in Norway also have report facts of technology choices sorted on geographical areas. They seek to provide solutions for different oilfield areas with most appropriate facilities for helping humans to protect property's safety thus indirectly avoid safety issues on humans [33]. No studies focus on the sociotechnical environment. Those studies aim to measure teamwork issues by following the given technical structure of systems could offer opportunities for human factors and other technical experts to evaluate and train marine operators to improve their interactions with user interfaces to improve safety.

III. Activity Theory (AT)

It is necessary to concisely introduce activity theory. Although there are technical and physical theories in the maritime domain, innovation focusing on human performance in some extent are dismissed. The goal of AT is to understand the mental capabilities of the single individual. AT is usually used to describe actions in a sociotechnical system. The fundamental unit of AT is the human activity which has three basic characteristics [34]: object, tool mediation, and social level interlined. Object refers to the objectiveness of the reality; items are considered objective according to natural sciences but also have social and cultural properties. Tool mediation refers to that humans seldom interact with the world directly, rather, an enormous number of artifacts has been developed by humankind to mediate humans' relationship with the world. Social level interlined refers to two dimensions of the dialectical interaction between individuals and the world – 1) internal-external, 2) individual-collective.

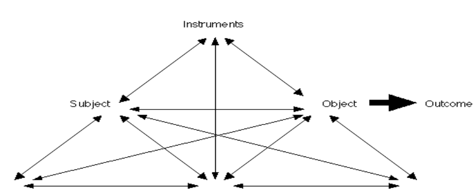
Activity, in general, involves both human activity and activity of any subject. It is understood as a purposeful interaction of the subject with the world, a process in which mutual transformations between the poles of "subject-object" are accomplished [35]. Activities are composed of actions, which are, in turn, composed of operations (see Figure 1). These three levels correspond, respectively, to the motive, goals, and conditions as indicated by bidirectional arrows.

Fig. 1: The structure of activity



Understanding of an activity is necessary to understand the subject and the object separately and then make an inference about their interaction. AT challenges this assumption. AT maintains that no properties of the subject and the object exist before and beyond activities [35]. Activity is considered the key source of development of both the object and the subject. The human mind is intrinsically related to culture and society through process and phenomena that transcended the borders between internal and external, individual and collective. Kuutti [36] notes that the term "activity theory" can be used in two senses: referring the original AT or referring to the international, multi-voiced community applying the original ideas and developing them further [15]. The improved AT proposed a scheme of activity different from that by Leontive (see Figure 2). The notion of rules has been improved to scope the individuals and groups (see Figure 2) as activity subjects compared to the "original joint labor activity" – which has no groups but only has individuals (see Figure 2).

Fig. 2: Leontiev's activity theory



AT provides the design research community theoretical leverage [37]. Several researchers employ AT to design workflow and semi-structured work in workplace studies. Computer artifacts like all other artifacts, mediate human and non-human activity within a practice. Bardram [38] presents the value of AT is not 'whether the theory or framework provides an objective representation of reality,' but rather how well the AT can shape an object of study, highlighting relevant issues.

AT is not only employed in the assessment of workflow supporting systems, but it also applied in semi-structured work. Bardram [39] discusses different levels of activities in dynamics of cooperative work (see Figure 3). Three different levels of activities are opened up – coordinated, cooperative, and co-constructive collaborative activities.

Fig. 3: Dynamics of cooperative work [39]

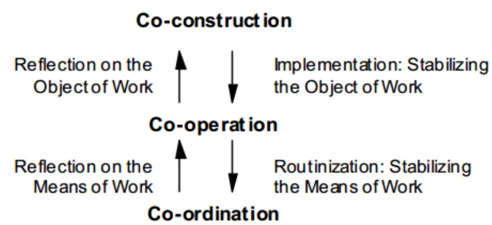
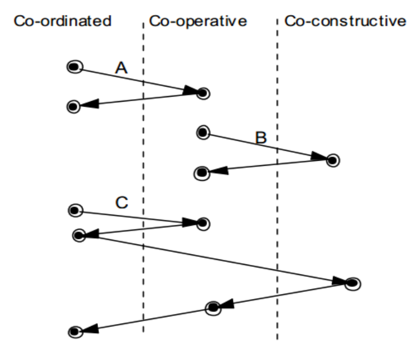


Fig. 4: Dynamic transitions of cooperative work [39]



Hence, AT can be used to analyze both static and dynamic activities of performances between humans from two aspects: 1) What is the relationship between a human and the system he uses. 2) What are the relations of such relationships with other humans and their activities in marine operations? Both aspects could help to relearn subsea safety activities in sociotechnical systems.

IV. Articulation Work in AT

To assess a sociotechnical system, it is necessary to understand the system in the complex social reality of cooperative work. This understanding should be grounded in sociotechnical environments, such as a rich abstract act as a basis for understanding work, and as a bridging link between the social and the technical aspects to provide new insights into how to approach the assessment of social-technical systems. Hence, the concept of articulation work in activity work could be used for analyzing the teamwork in social-technical systems. It is useful for identifying the breakdowns and workflow in teamwork. And it provides suggestions to improve both social-technical systems and the assessment of teamwork.

Articulation work in AT should focus on the understanding of how social and technical system shape or are shaped by interactions in and with the work context. Hence, actions, interactions, processes, trajectories, structural conditions, and the social world should be taken into account since it is difficult to follow a person to map out the relationships in a complex sociotechnical interaction environment. Hence, activity components in this sense include a distinguished object, an active actor (individual or collective) who understands the activity and a community who share the same object and the working environments. The relations between activity components are always mediated by artifacts such as tools, rules, and division of labor. Activities are realized through motives, resulting in a transformation of the objects (outcomes).

In AT, articulation work is divided into two categories – individual and collective articulation. There are also two levels of articulation under these characteristics [3] – 1) articulation of actions within an activity, 2) articulation of operation within an action. For example, in the articulation of action within an activity, Hutchins [24] suggests that work should be analyzed at a system level where the system is a collection of interacting individuals and artifacts in the propagation of knowledge. In the articulation of operation within an action, we need to analyze trajectory projections and schemes of work, such as workflow representations and internal relations of operations, [15]. The notion of trajectories (where trajectory shapes may be part of the resources for action available in the setting) and on the notion of mutual shaping of action and structure is historically way of activities for researchers to follow in a sociotechnical system.

Articulation work in a collaborative work environment uses communication [40]. Rich communication channels are provided to support synchronous and asynchronous communication within and across social worlds. However, the process of communication during the activities of individuals is not necessarily contained within locales but often spans multiple locales over time [15]. A collective way of activities is important in analyzing sociotechnical system. It also should be analyzed by two levels of articulation because the boundary between individual and collective activities is dynamic. Collective activities are punctuated by activities of the individuals and so forth.

Researchers need to have a whole picture of articulation work of individuals when analyzing teamwork as people can be members of multiple social worlds simultaneously, and can be engaged in multiple concurrent activities. For example, Bardram [38] analyses and designs healthcare information systems based on analyzing both individual and collective activities of individuals. Three different levels of activities are opened up to analyze dynamic relations of activities in multiple social worlds where semi-structural works exist. Engeström [12] use the collective activity as a tool to argue how the anticipated outcomes of system development require considerable efforts to resolve development contradictions within and between the different developers' group in the implementation process.

Support of the collective articulation work of social worlds also raises awareness, access constraints, artifacts, communications, and state changes to other participants [15]. It could also be understood as coordination mechanisms in the Internet of things [42]. For example, within a local place, humans should know what objects are available at the moment, how they could be shared with other visitors or cooperators in a long distance and what actions are being performed on them. All actions need to be visible to the humans; such awareness should be clear in humans' sense of what is happening and what will happen in one's own or co-activities, researchers believe audio, and video can support to facilitate awareness in both asynchronous and synchronous modes of work [15]. It can make any action/operation visible to any user accessing the shared object.

These two levels of articulations could help researchers to identify dynamic organizational interactions with social-technical systems. Moreover, it is also to map out operations without breakdown inter-actors' conflicts when questions address on the articulation of collective actions. Meanwhile, it is even easier to identify the sociotechnical systems' borderlines when 'distance' is present. This is a common advantage of articulation work in activity theory.

Hence, in our understanding the decomposition of an activity is well formatted; the processes by which a community of actors articulates operations in context-of-use. Adding notions of community and division of labor, activity theory primarily gives a collection of individualistic perspectives on work. It is fruitful to figure out how a technology is structured or restricted in each different organizational interaction within the dynamic boundaries of sociotechnical systems. Hence, AT could fruitfully describe articulation work in some extent to help measure safety in cooperative work in subsea operations.

V. Methodology

A. Ethnography

The work presented here is part of a larger marine operations project – Integrated Marine Operation Simulator Facilities for Risk Assessment. The aim of the project is to criticize the existing design of marine operational systems and, move beyond criticism of existing marine technologies, in a constructive manner, try to influence specific aspect of creation and implementation of safety in marine operations. After receiving approved ethical consent from the Norwegian Centre for Research Data, the study began in fall 2015 and is still ongoing. The research method for this article is an empirical workplace study. The empirical study presented in this paper relates to the previous study on organizational studies of marine operations with regarding safety issues [43] in work practices. This study is a qualitative research. The intention is to exam how teamwork of marine operators was conducted in simulators. Fieldwork was conducted in autumn of 2016 and spring 2017, focusing on teamwork in subsea operations. How marine operators use their knowledge and insights in the subsea operations was the main interest area. This knowledge and these insights on teamwork in marine operations are valuable for measuring the cooperative work of marine operators in simulators. The methodology guiding the research is ethnography.

B. Method

A combination of methods has been used to generate the empirical material. Combining different methods of data collection also explain more fully the richness and complexity of humans' work practices from more than one standpoint [44]. In this case, we applied different methods in each stage of the study, including participant observation, different types of interviews, photos, and informal discussion during our fieldwork in simulators.

The primary activities comprise interviews with humans' engaged in courses for to evaluate the marine operation. The primary data used also includes an online survey which was distributed to marine operators regarding their concerns of safety marine operations in workplaces – simulators in the university campus. The interview was conducted in the fall of 2015 and spring of 2016. Also, a small part of the informal interview in spring of 2017.

The interview followed a semi-structured question list. The main purpose of the interview was to investigate teamwork in subsea systems, such as simulators. Also, we use an online subsea case that one of the authors experienced before. We make the case pseudonym since we only interest the safety issues rather than who did it belongs to which company and what type of plan was used in that operation. We choose this case because it provides a chance to reflect those still inbox teamwork from a real case.

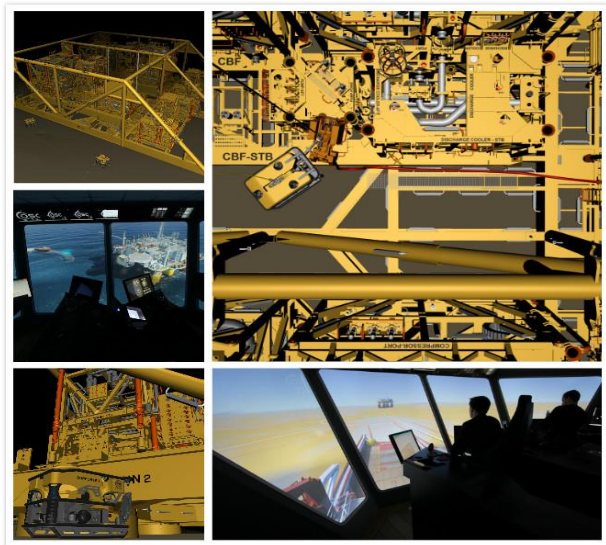
We analyze two cases of marine operations through our empirical studies as well as the experiences one author has to argue that marine operations in practice are not like structured activities with a holistic overview of operation systems. Instead, marine operators teamwork is not hierarchical activities, which make triggers to link other marine operations to evolve safety as work performance in each operation.

VI. EMPIRICAL SETTING

A. Subsea installations

The simulator is built for complex operations. The scenery is a reflection of the real environment to operate in, like oil fields with rigs, or seabed locations. Also, the vessel operated is modelled after the real vessel. Although some of the fixed equipment at the simulator stations may be other than on-board equipment, they have generic properties and are highly up-to-date. Operators are located at stations that are separated, each with their actual view, and crews preparing for an operation alternate in practicing at the station and observing all stations from the observation room displaying camera monitoring. The stations can be run individually if wanted, but for complex operations, the coordination between stations is often the critical part. The simulating facilities consist of bridges, ROV-station, cranes, deck, and DP systems in control room for coordination. The simulator will also develop a dive station, to be fully able to meet the needs for complex subsea operational simulation, and two bridges allow for operations with two interacting vessels (see Figure 5). Further, there are instructor rooms with full monitoring, to inspect, supervise, and develop scenario-specific interventions for the purpose of preparation and training. Scenarios are mainly based on the critical parts of procedures and the operator's need for preparation. The scenarios, or cases, chosen in this subsea preparation were agreed upon between the engineering company and the oil and gas company, and the simulator center delivered the functionality for these scenarios to be played out. The hierarchy of running the subsea operation is based on information from one key informant, and the positions (and their responsibilities in parentheses).

Fig. 5: Simulator-based subsea installation (Photo Credit: OSC)



A shift supervisor has a coordination position in the subsea operation, with high attention and communication workload. The subsea engineers have been supporting the procedure progress. Vessel crew has had the responsibility for DP-operational phases and heading of the vessel for operational outcomes, as well as ballasting adjustment to vessel loadings.

B. A story

On an evening, a rare sequence of events left one of Mendeley Offshores saturation divers stranded in complete darkness in the deep water of the Atlantis Sea. The real experience demonstrates an example of human reaction to changing and challenging circumstances, and how leadership training and the right behaviors, procedures and emergency response actions can tip the balance in life and death scenario.

The event took place on Mendeley, an offshore oil and gas platform, where maintenance and modification work was done on a separator unit during a production shutdown. This specific work demanded preparation, cleaning, scaffolding, mechanic and other types of work to be done inside the unit by personnel from several disciplines in both operator and service companies. During such work, the radioactive sources in level measurement instrumentation systems are supposed to be secured in safe radiation containers. The procedures of work in such units are supposed to take care of this. However, in this case, one of the sources was not secured in its container for several days due to a system glitch. The disciplines responsible for securing the source had not done its job, and it was forgotten even though the procedures and signatures were in place. At least more than 50 workers were exposed to the radiation during those days. The source was not strong, and the radiation doses were low, but the error happened.

VII. Analysis and discussion

From our analysis, we aim to understand the complicated interactions among human and subsea systems in subsea operations. Also, we work to solve known complex problems from social-technical systems to challenge that sociotechnical systems should make from a bottom to up innovations, allowing some autonomy in operations. In such process, articulation work as means could help measure safety in cooperative work.

For example, we may adapt knowledge from human factors to capture a picture of how social, technology and information networks are connected for investigating risk assessment at a macro level, such as the relationships of management, regulation, operation, humans, environment, tools, skills and so on. However, the marine operation might be robust, but may not be resilient. From an AT point of view, every individual cooperates with other individuals in different tasks. If we focus on individual activities and articulation in this individual's work, we focus on the understanding of how social and group work system shapes or are shaped by interactions in and with the work context. Hence, actions, interactions, processes, trajectories, structural conditions, and the social world should be taken into account since it is difficult to follow a person to map out the relationships in a complex sociotechnical interaction environment. Hence, activity components in this sense include a distinguished object, an active actor (individual or collective) who understands the activity and a community who share the same object and the working environments. Artifacts such as tools, rules, and division of labor always mediate the relations between activity components. Activities are realized through motives, resulting in a transformation of the objects (outcomes).

For analyzing our case, we limit our understanding and scope of articulation work to the human body, machine, and teamwork. As the main humans in our cases, is the human operators, one could instructively assume that AT is the more appropriate approach to studying articulation work in subsea operations. The humans in cooperative works are important for their work management, other teams in different locations - both informal and formal will become the community – a way to name things. For example, informal human operators do trajectory work while also contributing in the subsea systems, the human body, and teamwork. This important articulation work gets lost in the analysis, as the persons central to the activity's object still are humans. Also, artifacts like, e.g., ROV artifacts would be just referred to as tools mediating between the subject and object, while here the artifacts are assigned responsibility and become actors. There are many different people working towards the same object in different ways. For example, the act of the informal humans helping the other teams, such as DP operations adjusting their bodies to the subsea systems in the analytical framework of AT. Through this way, AT is good at differentiating between the different types of work and hence uncovering the articulation work, the different actors involved in articulation work are within the scope of the focus of analysis, which is the activity.

In our case, one can offer a better overview of complex systems when problems happen during the naming of different things in order to connect a team; then we look for some backups to solve problems straightforwardly. For example, the shift supervisor is in charge of teams to communicate, react, and cooperate when a breakdown happens during the marine operation. Most important, he knows know how to improve breakdowns for enhancing operations from a micro level, teamwork for example. It is not a top-down proposal to improve each subsystem for subsea operations. The procedures of work in an overall organization of subsea installation might be supportive sociotechnical systems. However, if the naming process is insufficient, the teamwork turns to be a sad story as shown in our story. From an individual level, all crane, ROV, as well as DP systems might support some parts of individual cooperative work. DP operators work with the shift supervisor to position and reposition the vessel. Shift operators could also guide Crane operators to put down the ROV into the sea. This could be understood as the shift supervisor articulating work practices to DP and ROV operators. Shift supervisor's work is about coordination and cooperation. However, sociotechnical systems for subsea operations have issues that could not support cooperative work of humans, in particular if the shift supervisor could not succeed in articulating what is happening in a team.

The procedures of work are supposed to take care of the cooperative work in a team. However, to some degree, it failed. For example, the whole work is articulated by the shift supervisor. Humans in different workplaces are then less responsible to their work, safety for example. As one person says:

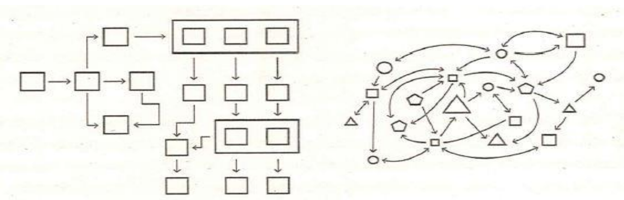
> I work on my task as shift supervisor advice. If there is a safety problem in my operation, I fix it. Otherwise, I report to shifting supervisor.

As shift supervisor replies:

> I try to find a solution to explain what is the problem and coordinate work to bypass the problem in a cooperative team. If DP finds problems in its operations. And, these problems are issues for DP operation but may become difficulties for ROV operations; then I will speak to ROV to avoid such problems. However, there are some unsolvable problems. Thus I ask to take responsibility to ask to redo some work.

From this interview quote, we outline that the scope of articulation work to the body, machine, and safety work happens in a hierarchy based sociotechnical system (see Figure 6). On left part of Figure 6, it is certain that the systems structures of subsea are a well-organized workflow. However, shift supervisor's work is to articulate the breakdowns and non-cooperative pieces of workflow to the right person and machines. Hence, if we look at the nature of cooperative work in the subsea operation, we have a different overview of technical systems and human practices inside of cooperative work (See Figure 6, right).

Fig. 6: Technical systems structures and articulation work in subsea operations [16]



If we look back to see the theory of AT, we can assume that humans and technical systems are the same. It can be people, subsea systems, and interactions. Subsea systems should be adaptation rather than mitigation of complex operations. That is to say, if cooperative work could be coordinated, then the co-construction must be allowed in different cooperative work teams. For example, in our case, the incident happens because a team has less authority to react to their work process. Members of a team have to be articulated and coordinated by a person who is in charge of the whole working process for the subsea installation. This causes the workflow of cooperation in the team to fail.

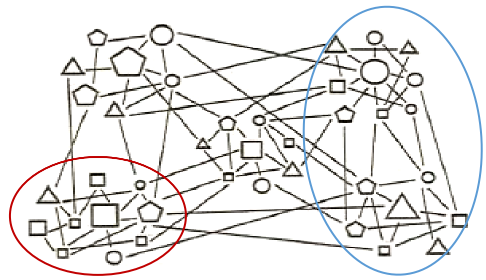
As one of the informants (ROV) says:

> When I face problems, I could articulate to my co-worker. We think it is important that we have our own power to fix the problems. In this case, we could tell DP or Crane to help position the vessel or the subsea machines. Talking with the person who is in charge of part of teamwork is important. In such case, we could react quickly.

Grinter [45] argues that a good teamwork should be based on the 'right' automated systems and supportive tools in a team. The most important thing is to understand the nature of the working model. In our case, we find the working model should focus on the natural team building rather than following the technical structure of subsea systems. For example, when DP, ROV, and crane operators connected as a community to interact with their tools, the group of humans and subsea systems is the team. Following Bardram's steps [38], team building and rebuilding are the processes of a community use instruments. Members of a community in different competences (division of labor) together work on the same task. In such as way, it is called a teamwork.

And we argue that assessment of teamwork in subsea operation also need to acknowledge these steps. It is important to enable a community to articulate its activity during the work practices. Assessment of subsea operation is a process to investigate a team of teams (ToT) work. Such ToT is a non-hierarchy, flat, and even a non-border institutional structure for dynamic positioning (DP), crane, and ROV (see Figure 7). Through following ToT thinking, we find each team operating in an interdependent environment to understand the butterfly-effect ramifications of their work. Each team is aware of the other teams it might never meet and with whom they would have to cooperate to achieve success, which in turn enables the sociotechnical systems to become more robust and resilient. For example, the forgotten job in our sad story happens because both technical systems and humans may feel less responsible for their own teamwork. If such work is always articulated and coordinated by the shift supervisor, we assume most invisible work will be dismissed [40]. Thus, even though all signature is in place, the forgotten job could not be identified and supported by social-technical systems. If each team without a shift supervisor role does the articulation work, the local authority must be granted in order to make teamwork function successfully (see Figure 7).

Fig. 7: Team of teams for group work[16]



On Figure 7, each team consists of humans, machines and their interactions. Each member of the team is responsible for his work as well as the cooperative work with other people and machines in the team (red cycle). Everyone in the team could articulate what, how, and where an activity is done and for what purpose. This is important for other members of the team to know what is happening. This also leaves action spaces for other team members to cooperate if a joint effort is needed. Also, if reaction from multiple teams is necessary, such ToT understanding also allows everyone in the team to articulate what is going on and who is connected in such process (blue cycle). In such efforts, supporting a teamwork is a dynamic process of co-structuring technical systems. In our case, assessment of teamwork becomes to measure a community that consists of individual persons and their usage of subsea machines to accomplish common tasks in a team and deliver useful information (via naming process) to the right person, and systems to make the workflow of subsea operations function. Thus, the assessment focuses on each operational unit rather than how person works on an individual systems. Each operation, in this case, may cross the technical systems borders as well as the team border but focus on a complete task of a huge subsea operation. This, we assert, is an approach to take teamwork seriously in teamwork. In turn, such approach sheds lights to IoT and its further discussion in a teamwork setting.

VIII. Concluding Remarks

In this paper, we discuss the issues of subsea cooperative work in maritime simulators. To measure a teamwork in sociotechnical systems, it is necessary to understand what is a team and their interactive relations. We understand such issues different with the engineering aspect on measuring teamwork in technical systems. We ground work practices of humans in sociotechnical environments, such as a rich abstract act basis for understanding work, and a bridging link between the social and the technical to provide new insights into how to approach designing systems. With a team of teams understanding as our analytical lens, the safety performance of a practical work" from human performance perspectives could be articulated, coordinated and furthermore be co-constructed. In such manner, we believe sociotechnical systems might need more efforts to measure teamwork. Also, such manner might call for attentions to redesign technical systems to fulfilling the meaning of sociotechnical.

Acknowledgment

We would also like to thank Lillian Vederhus for her contributions to the project in 2015 and 2016. The project is supported by NFR, no, 234007.

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