

# Distributed Situation Awareness in a Demanding Maritime Operation: A Case Study of the Subsea Segment

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**ABSTRACT:** Maritime subsea operations have increased significantly in size and complexity during the last decades as a result of the advances in the offshore oil industry. Despite the fact that subsea operations can involve hundreds of personnel, working together with complex technology, limited research can be found regarding the operations in the available literature. This study aims to analyze a routine subsea operation using the Distributed Situation Awareness (DSA) framework and understand how the operators on board maintain their DSA in routine operations through a case study. In order to understand how the operation unfolds in complex sociotechnical systems and how situational awareness (SA) is distributed across agents and artefacts, the theoretical framework of DSA can be useful as the focus is on the interactions at a systemic level. To achieve the research objectives, a combination of qualitative methods was utilized to illustrate DSA on board a subsea vessel. Initially an observation was conducted during a live subsea survey operation to capture the interaction between personnel and instruments. Furthermore, all observed personnel were subjected to retrospective interviews to elicit further knowledge of the operation. Finally, the data was analyzed according to the propositional network approach and Hierarchical Task Analysis (HTA). The result of this study portrays the SA of a subsea survey operation as propositional networks for the main phases identified in the HTA. The main findings of the study show a significant difference in DSA among the Bridge personnel and personnel located in the Online Control Room (ONCR). Furthermore, it was found that the dynamic of the system allowed personnel to have different levels of DSA without jeopardizing the overall operation. Finally, the summary of the findings provides a basic understanding of how a routine subsea survey operation unfolds.

## 1 INTRODUCTION

More than twenty years have passed since Hutchins portrayed the distributed cognition of a maritime operation (1995a). By observing the environment and eliciting knowledge, his research has gained insight into operations which previously was restricted to the individuals involved. Subsequently, the distributed cognition approach has been utilized to analyze the situational awareness of complex collaborative environments (Artman & Garbis, 1998, Nazir et al., 2015). More recently the DSA approach has portrayed

the awareness of more complex maritime operations by the use of activated information elements (Stanton, 2014; 2006, Sharma & Nazir, 2017).

Notwithstanding the above developments, operations in some specialized maritime segments such as subsea survey operations remain to be understood in greater detail. Even though these kinds of operations include several teams working together with complex technology, relatively less research is available for the context. As a multibillion industry, the potential for an accident concerning a subsea

vessel could be of major consequences. In addition, the consequences in case of accidents could be fatal for the personnel on board.

By analyzing the distribution of SA during a subsea operation it is possible to portray the operation at the system level. Thus, analyzing the system itself to identify flow of information and/or facilitation of operations. Furthermore, the elaboration of information elements used during the operation may prove beneficial in training and evaluation of personnel involved in subsea operations. Based on the limited research related to operations in this field, this article aims to explore and analyze a complex subsea operation by utilizing the framework of DSA.

## 2 FIELD STUDY

A field observation was conducted from September to October 2017 on board a subsea vessel operating in the North Sea. As the purpose of the research was to analyze collaborative interaction in a complex operation, it was found beneficial to observe a subsea operation in a demanding scenario. Such complex interactions can be best understood via naturalistic observation (1995a). For the above reason, a field study was conducted on board a subsea vessel in its natural setting. The subsea operation chosen for the scenario was a pipeline survey, as this kind of operation requires collaboration of several teams on board. While the Remotely Operated Vehicle (ROV) is moving along the pipeline subsea, the vessel needs to follow at surface level. Consequently, the team operating the ROV needs to collaborate with the Bridge team. Furthermore, the main purpose for such a scenario is to collect survey data of the pipeline and the subsea environment, which requires the involvement of additional personnel with specialized competence. The collaboration between all these personnel and technological agents working together to achieve a single goal fits the purpose of a complex subsea operation. In addition, the pipeline survey chosen for the observation was conducted in its final phase where the vessel approaches the end manifold located in an area clustered with pipes and subsea assets. Moreover, the observation was performed in a time-period where marginal weather condition was forecasted, generating an additional challenge for the team members.

### 2.1 Observation environment

The subsea survey operation observed was conducted near the UK coast of the North Sea which is considered a challenging environment for maritime operations globally. To avoid the assets coming into contact with fishing trawling equipment or other hazards, the manifold is operated with a 500m safety zone governed by a Floating Production Storage and Offloading (FPSO) vessel anchored in the area. The bridge officers onboard were actively communicating with the FPSO and required a permission before entering the 500m zone. Present on the field was also a standby boat working in the FPSOs vicinity. During the initial phase of the observation, the weather conditions were moderate with about 30knots wind

and an estimated significant wave height of 2,5m which is considered marginal weather for a subsea survey operation. In addition, the weather was forecasted to increase significantly the next hours. Most activity was expected in the ONCR and Bridge, which therefore was the focus of this study and subject to observation. In addition, communication was observed from the Offline Control Room (OFFCR) and the FPSO. An overview of the observed agents is illustrated in figure 1 as a network structure.

Figure 1 illustrate the network structure of the personnel involved in the observed scenario. In accordance with the DSA framework proposed by Stanton et al. (2006), the involved personnel can be seen as agents in a larger system. Thus, illustrating the agent's ability to have different but compatible view of the situation through communication. The majority of agents were located in the ONCR and were all within verbal communication range of each other.

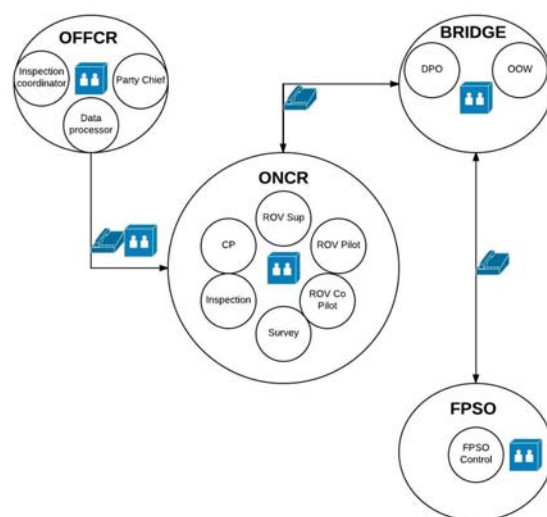


Figure 1 Network structure in Subsea vessel.

As expected, most communication occurred between these parties. However, agents located in the OFFCR were also directly involved in some of the observed phases. Second to the ONCR, most communication occurred on the Bridge between the DPO and OOW. These agents also communicated directly with the ONCR by an online intercom system and externally with the FPSO, utilizing the VHF.

The observation was conducted on board a modern subsea vessel of newer construction and which was commissioned recently. At the time of observation, a total of 50 persons were on board the vessel contributing to the operation in different ways. However, only a few of the personnel were directly involved in the scenario and were subjects to the observation. Among these, the majority was located in the ONCR which can be considered the heart of the operation. The online personnel are limited to the most essential positions directly involved in the operation such as the ROV Pilots (RP), Inspection Engineer (IE), Survey engineer (SE) and Cathode Protection engineer (CP). In addition, other personnel are located in the adjacent OFFCR, which is separated to minimize disturbance. The layout of the observed control room is illustrated in Figure 2.

Figure 2 illustrates the layout of the environment observed during the scenario with the actual location of participants. The ROV Pilot and ROV Co-pilot (RC) are sitting beside each other at the ROV operator station, maneuvering the ROV subsea according to the ROV Supervisor (RS) and engineer's instructions. Due to the design of the ONCR all the participants were within verbal communication range of each other and could therefore communicate directly. In addition, each station was equipped with a party-line intercom system linked to the OFFCR, Bridge and other strategic positions around the vessel.

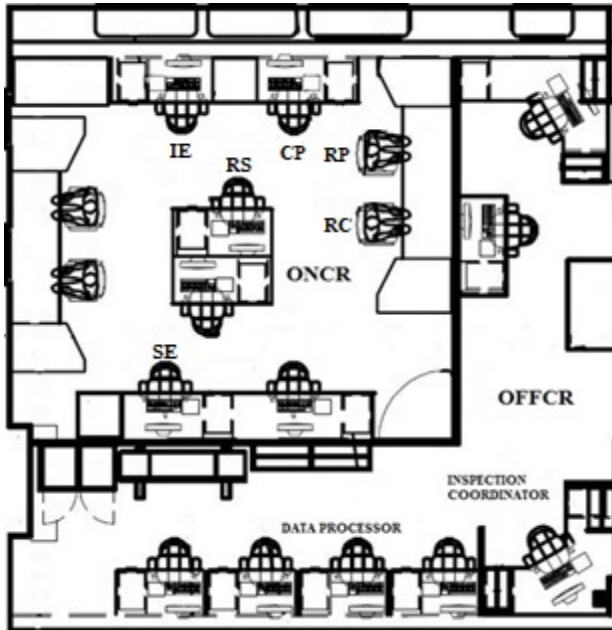


Figure 2. Control room layout in Subsea vessel

Furthermore, the Bridge team consisting of the Officer on Watch (OOW) and Dynamic Positioning Operator (DPO) were also observed during the scenario. While being physically separated from the ONCR, the Bridge team are still collaborating closely with the online personnel with regards to vessel movements. To collect adequate data and avoid ROV damage, it is of vital importance that the vessel moves along the pipeline at a specific distance and speed set by the ONCR. Consequently, the DPO is following the instructions communicated from the online personnel and maneuvers the vessel accordingly through the Dynamic Positioning (DP) system. For this reason, the DP station was presumed as a central location in the network and therefore a focus point of the observation. In addition, the bridge team is responsible for the navigation of the vessel and can in that respect reject any request from the ONCR that compromises the safety of the vessel.

## 2.2 Observation

Since the research aims to uncover the DSA in the selected scenario by following the propositional network methodology, information elements must be identified. This can be done through the analysis of verbal transcription, while the frequency of events and interaction among the agents are observed (Salmon et al., 2009). Consequently, an observation schedule was developed for the observed scenario.

Furthermore, the schedule was developed to an event log as displayed in table 1.

Table 1. Abstract from observation schedule

Time	Output	Input	Information / Activity
13:00:54	RS	DPO	Bridge – Quasar, can you give me an update of the weather please?
13:01:02	DPO	RS	Yeah, the wind is gusting to 30knots now, direction south east
13:01:11	RS	DPO	What's the wave height?
13:01:23	DPO	RS	Around 2 - 2,5m I would say
13:01:27	RS	DPO	Roger

To capture the social context, the time was logged for when information was sent and received. As the time was captured more accurately by audio recorders it was necessary to identify the agent that transmitted and received the information. Consequently, the observation schedule included an output and input section for the observer to log the agents involved as illustrated in Table 1.

Furthermore, the main section of the observation schedule concerned what kind of information elements that was passed and received. The observer was instructed to write the information exchanged verbally, by radio and hand gestures. In addition, other relevant activities or tasks observed were written down as comments on the observation log. It was recognized that the task of transcribing verbal communication directly may be difficult in a collaborative environment. However, audio recorders were positioned on strategic places during the scenario which simplified the transcribing. Further attention was therefore given to capture what the audio recorders could not capture.

After the observations performed on the bridge and in the ONCR, these were transcribed into an event log. The event log was constructed both based on the transcriptions from the recordings, but also through the field notes constructed during the observations. The final event log contains the exact times of the agent's actions and communications, as well as interactions with artifacts (Artman & Garbis, 1998; Hutchins, 1995a, 1995b; Stanton et al., 2006).

## 2.3 Hierarchical Task Analysis

To enable the portrayal of the DSA, an HTA was conducted where the scenario was described through its goals and tasks. The HTA was initially conducted to consider "what should happen" in the scenario (Stanton, 2006, p. 56). Further on, this was altered after the observation, and then presented to the Subject matter experts (SME's) during the Critical decision method (CDM) interviews, to uncover "what actually happens" (Stanton, 2006, p. 56). In this study the overall goal of the task was to conduct a subsea pipeline survey. Subsequently the sub-goals required to reach this overall goal were determined. Finally, the last step was to decompose the sub-goals even further (Stanton, Baber, & Harris, 2008). After establishing the goals and sub-goals in a decomposition level, an HTA plan was constructed. Stanton et al. (2008) advises that the plan not

necessarily needs to be linear, but can be designed in a variety of ways as presented in Table 2.

Table 2. HTA plans (Adapted from Stanton et al., 2008)

Plan	Example
Linear	Do 1 then 2 then 3
Non-linear	Do 1, 2 and 3 in any order
Simultaneous	Do 1, then 2 and 3 at the same time
Branching	Do 1, if X present then do 2 then 3, if X is not present then EXIT
Cyclical Selection	Do 1 then 2 then 3 and repeat until X Do 1 then 2 or 3

#### 2.4 CDM interviews

CDM interviews were conducted after the observation to eliminate possible misunderstandings. The CDM was developed to extract knowledge and thereby achieve a greater understanding of a real world scenario (Hoffman, Crandall, & Shadbolt, 1998). The interview procedure for this study was constructed after the observation, based on Hoffman et al. (1998). Adopted to suit the chosen HTA, observation and CDM combination approach. The structure of the CDM interviews was based on O'Hare, Wiggins, Williams, and Wong (2000) probes. Furthermore, the designated probes were modified to fit the specific objectives of this research (Stanton et al., 2008). These probes were utilized in a combination with the CDM framework as an interview guide.

Following the DSA approach (Stanton et al., 2006), a content analysis was conducted to extract key words representing information elements. Subsequently, the text in the event log and the CDM transcripts was broken down to smaller components. This was done in accordance with the DSA framework, where the aim was to separate the content words from the function words (Stanton et al., 2006).

#### 2.5 Propositional network

A propositional network is constructed to highlight the information elements distributed in a system (Salmon, Stanton, & Walker, 2009). Salmon et al. (2009) defines a propositional network as; "a network depicting the information underlying a system's awareness and the relationships between the different pieces of information" (Salmon et al., 2009, p. 60) The information elements are illustrated as nodes connected to each other through different taxonomies (Salmon et al., 2009; Stanton et al., 2008). The commonly used taxonomy is; has, is, are, causes, knows, needs, requires and prevents (Stanton et al., 2008). Consequently, these taxonomies were utilized in this study.

The propositional network was constructed based on information elements extracted in the content analysis of the transcribed CDM interviews (Salmon et al., 2009). These were also compared with the observation event log to increase the reliability of the study. Additionally, during the finalizing of the HTA and the content analysis, two of the authors analyzed the data. Afterwards a comparison was made, where only the same goals and content words were utilized to increase the reliability of the findings. The HTA

was then utilized to present a propositional network for each of the four main tasks; *Identification, Navigation, Positioning and Data collection*, which were found during the finalizing of the HTA. Subsequently, the different nodes are then shaded to portray their usage in the designated tasks (Salmon et al., 2009).

#### 2.6 Population and sample

This study aims to represent a system representative for the majority of subsea vessels. It was therefore of interest to interview participants with experience from other subsea vessels to verify the generalizability of the study.

To portray the operations from different viewpoints, all the informants were observed and interviewed in relation to their position in the system. This was found necessary as some of the informant's switched roles during the scenario. This was the case for the OOW stepping in as DPO, and ROV supervisor acting as an ROV Pilot in some of the phases. To avoid conflicting data, the informants were requested to portray their (D)SA in accordance with their current position at the time of observation. Table 3 presents the informants which were subjects to observation and retrospective interviews.

Table 3. Informants subjected to observation and CDM interview

Participants	Type	Data collection
No.1 - ROV Supervisor	Face to face	Observation & CDM
No.2 - ROV Pilot	Face to face	Observation & CDM
No.3 - ROV Co Pilot	Face to face	Observation & CDM
No.4 - Survey Engineer	Face to face	Observation & CDM
No.5 - Insp. Engineer	Face to face	Observation & CDM
No.6 - CP Engineer	Face to face	Observation & CDM
No.7 - DPO	Face to face	Observation & CDM
No.8 - OOW	Face to face	Observation & CDM

### 3 RESULTS

Numerous activities and task were observed during the scenario and extracted from the CDM interviews. After analyzing the data several times in cooperation with SMEs a final HTA was developed. Subsequently these tasks were used to divide the scenario into the following four phases: *Identification, Navigation, Positioning and Data Collection*.

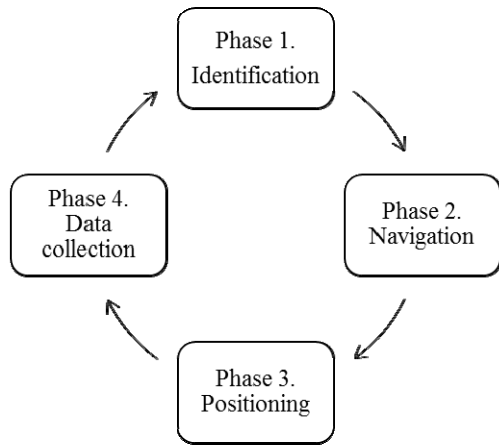


Figure 3. Phases of the observed scenario

The phases of the subsea pipeline survey are illustrated as a process in Figure 3. During the scenario the process was conducted several times and was also aborted at different phases. In addition, several of the phases was sometimes conducted in a different order and can therefore not be seen as a completely linear process. However, the figure is sufficient for the purpose of providing a simplistic view of this complex operation.

### 3.1 Propositional network

Each of the four main phases identified in the HTA were utilized to construct propositional network diagrams, illustrating the activation of information elements as shaded nodes for the specific phase. Figures 4 to 7 illustrate various phases and corresponding information elements used. It is recognized that several of the information elements in the system are utilized in connection with other phases. However, for illustration purposes, only the information elements explicitly linked to the specific phase are highlighted. Finally, the propositional networks in figure 8 & 9 illustrates the DSA at the department level by activation of the information elements utilized by the agents located in the ONCR and Bridge.

The identification phase was chosen as the first step of the pipeline survey process as the navigation phase cannot commence before the destination position is known. The propositional network for the identification phase in figure 4 highlights that the activated information elements is restricted to the

agents in the ONCR. More specifically between the RS, RP, RC and IE. This must be seen in connection with the purpose of the identification task which is to identify the subsea pipeline. Consequently, none of the agents on the bridge were directly involved in this task.

Furthermore, the navigation of the vessel and ROV needs to be planned. This phase includes both subsea navigation and ship navigation at surface level. The information elements utilized in the navigation phase is illustrated in figure 5 and shows a large part of the system is activated. While the ROV team is concerned with subsea objects, the agents on the bridge were observed to consider other factors such as vessel traffic. In addition, environmental conditions were considered in this phase as an integrated part of navigation.

The propositional network in figure 6 illustrates the DSA during the positioning phase which includes the maneuvering of the vessel and ROV, as well as other interaction between operators and machinery such as operating the tether winch, camera booms and manipulators. The DPO and ROV pilot was observed to be key agents during this phase as they are performing the maneuvering. In addition, the co-pilot was observed to have an active role in assisting the ROV pilot during maneuvering. A common feature found with both operator stations is the automated systems that assist the maneuvering. While the vessel is controlled by a fully automated DP system, the ROV has optional automated features such as heading, depth and altitude.

Finally, when the ROV is positioned at the identified pipeline the data collection commences which is the overall purpose of a subsea pipeline survey. The propositional network of the data collection phase in figure 7 shows less activated information elements than the other phases. This must be seen in connection with the decision of isolating the information elements to those which has an explicit role regarding data collection. Thus, not shading information elements that led to the actual data collection as they are activated in previous phases. Moreover, the agents directly involved in collecting data is restricted to a few of the agents in the overall system. Hence, IE for eventing, SE for multibeam data and CP for collecting CP data. In addition, the RC was observed to have a direct role in eventing as he adjusts the cameras according to the IEs instructions.

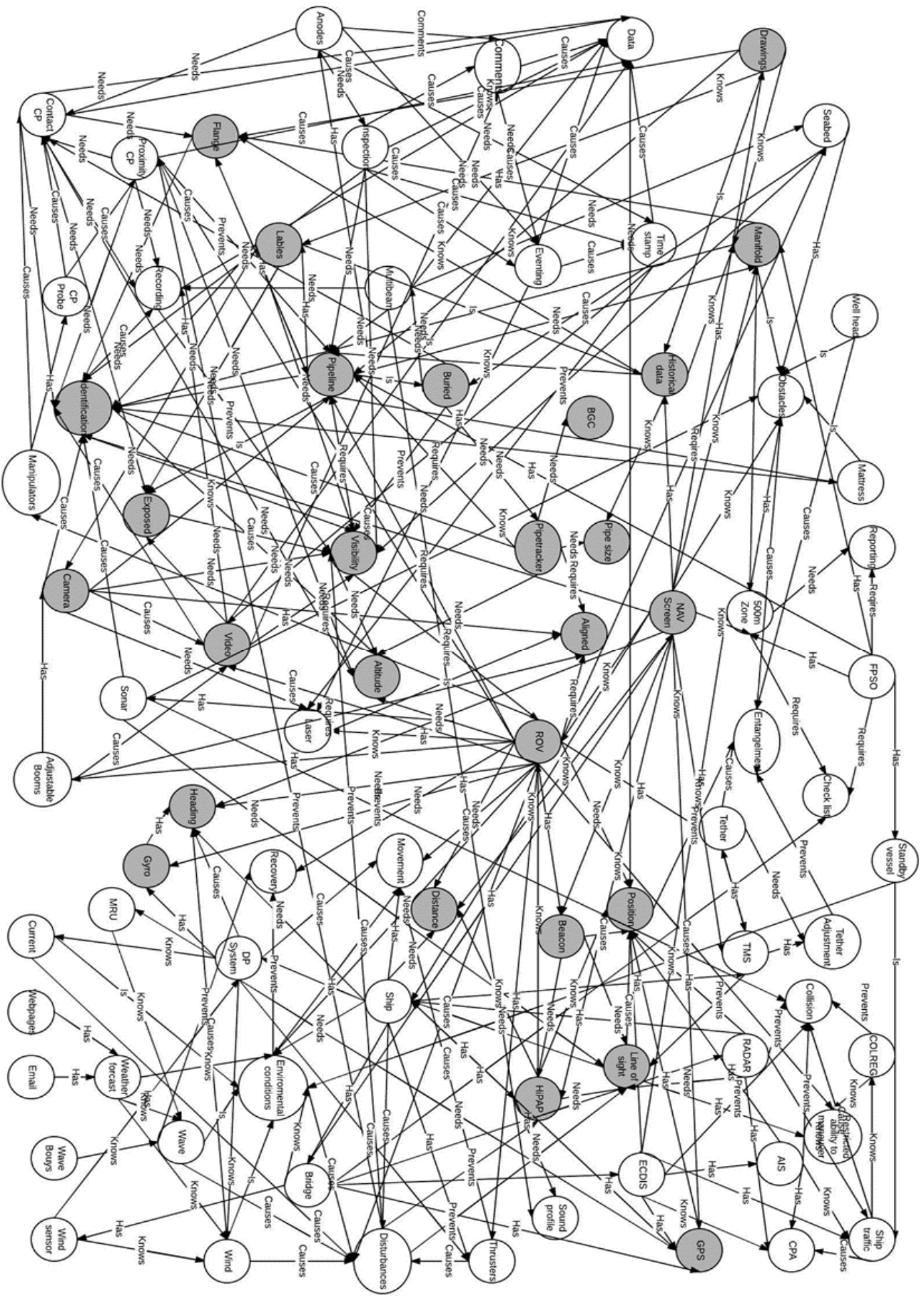


Figure 4. Knowledge activation of agents during the Identification phase







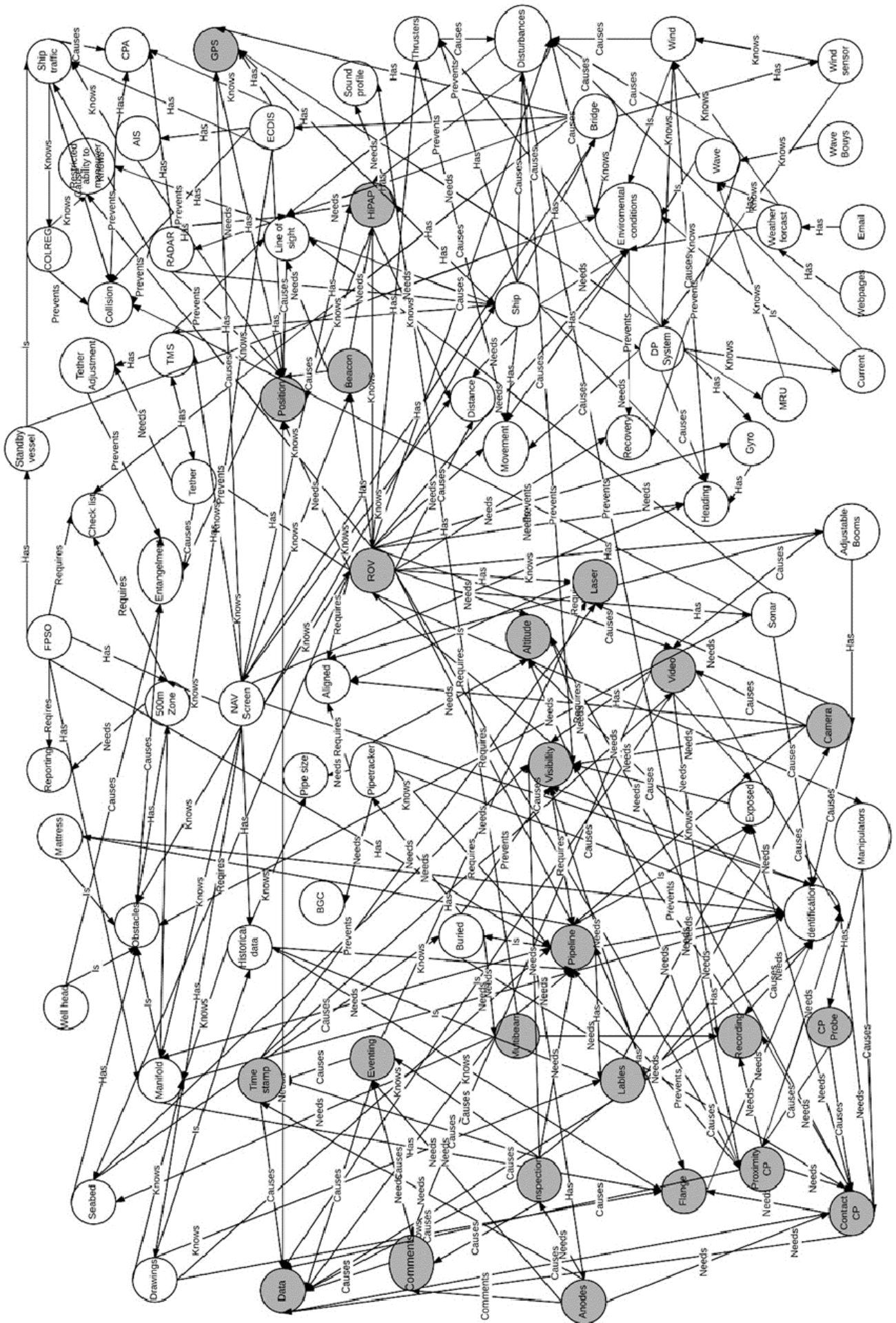


Figure 7. Knowledge activation of agents during the Data collection phase





## 4 CONCLUSION

The aim of this study was to describe DSA in a subsea operation. Therefore, an observation was conducted on board a subsea vessel during a live operation in the North Sea. Afterwards, CDM interviews were performed with all participants following the DSA framework. The DSA of the subsea survey operation was described through a combination of HTA, observation transcripts, interview citation and propositional network. These altogether provided a basic understanding of DSA during a subsea pipeline survey. Moreover, it was found conducive to utilize the designated method in such an unknown, complex and dynamic scenario.

Primarily the results show that the SA is distributed locally within the distinct departments between agents and artefacts. Moreover, most DSA was found to occur among agents involved in similar tasks, such as the RP & RC. Furthermore, it was uncovered that most information distributed between the Bridge and ONCR concerned the sub tasks of Navigation, more specifically, regarding vessel position moves and environmental conditions.

### 4.1 Contribution of the research

This study explored the specialized subsea segment which still is considered a minor but important part of the maritime industry. As two thirds of the earth is covered by water and the developments in the maritime industry with the aim to explore areas farther offshore, subsea operations are expected to increase in the future. Consequently, it can be argued that this study contributes to creating a platform to explore the dynamic and complex subsea survey operations by describing DSA in different phases. Finally, the study provides a framework that allows researchers to explore the segment even further for system design and training purposes.

### 4.2 Future research

Limited research exists regarding DSA in the subsea segment. Due to the generalizability of the results within the specific segment, this study provides a framework for future research to build on. The future research directions can benefit from analyzing operations in complex and demanding operations such as above and with the greater understanding related to the roles assigned to different agents and the system design can be optimized for the same. Thus, opening for the utilization of the same methodology in a great variety of maritime operations.

While this study focused on a few key agents involved in subsea pipeline survey, other subsea operations can be considered even more complex as they include far more people and artefacts. Such an

operation could be subsea construction which adds the subsea crane interaction to the system. In addition, such operations can include several vessels and ROVs operating in close vicinity while collaborating to achieve their common goal. By adapting the methodology utilized in this research the DSA of such operations could be analysed at the system level. Moreover, it could highlight the strengths and weaknesses of the system that ultimately can lead to improving the safety and efficiency of the operation.

## REFERENCE

- Artman, H., & Garbis, C. (1998). Situation awareness as distributed cognition.
- Hoffman, R. R., Crandall, B., & Shadbolt, N. (1998). Use of the critical decision method to elicit expert knowledge: A case study in the methodology of cognitive task analysis. *Human factors*, 40(2), 254-276.
- Hutchins, E. (1995a). *Cognition in the wild*. Cambridge, Mass: MIT Press.
- Hutchins, E. (1995b). How a cockpit remembers its speeds. *Cognitive science*, 19(3), 265-288.
- Klein, G., & Armstrong, A. A. (2004). Critical decision method. In N. A. Stanton, A. Hedge, K. Brookhuis, E. Salas, & H. W. Hendrick (Eds.), *Handbook of human factors and ergonomics methods* (pp. 35.31-35.38): CRC press.
- O'Hare, D., Wiggins, M., Williams, A., & Wong, W. (2000). Cognitive task analyses for decision centred design and training. In J. Annett & N. A. Stanton (Eds.), *Task Analysis*. London: London: CRC Press.
- Nazir, S., Sorensen, L. J., Øvergård, K. I., & Manca, D. (2015b). Impact of training methods on Distributed Situation Awareness of industrial operators. *Safety science*, 73, 136-145.
- Nazir, S., Carvalho, P. V. R., Øvergård, K. I., Gomes, J. O., Vidal, M. C., & Manca, D. (2015a). Distributed Situation Awareness in Nuclear, Chemical, and Maritime Domains. *Chemical Engineering Transactions*, 36, 409-414.
- Salmon, P. M., Stanton, N. A., & Walker, G. H. (2009). *Distributed Situation Awareness: Theory, Measurement and Application to Teamwork*. Farnham: Ashgate Publishing Ltd.
- Sharma, A., & Nazir, S. (2017). Distributed Situation Awareness in pilotage operations: implications and challenges. *TransNav: International Journal on Marine Navigation and Safety of Sea Transportation*, 11(2), 289-293.
- Stanton, N. A. (2006). Hierarchical task analysis: Developments, applications, and extensions. *Applied ergonomics*, 37(1), 55-79.
- Stanton, N. A. (2014). Representing distributed cognition in complex systems: how a submarine returns to periscope depth. *Ergonomics*, 57(3), 403-418.
- Stanton, N. A., Baber, C., & Harris, D. (2008). *Modelling Command and Control: Event Analysis of Systemic Teamwork*. Farnham: Ashgate Publishing Ltd.
- Stanton, N. A., Stewart, R., Harris, D., Houghton, R. J., Baber, C., McMaster, R., . . . Young, M. S. (2006). Distributed situation awareness in dynamic systems: theoretical development and application of an ergonomics methodology. *Ergonomics*, 49(12-13), 1288-1311