CHARACTERISTICS OF CRITICAL INCIDENTS IN DYNAMIC POSITIONING

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Abstract

The maritime operations are growing more complex and increasingly dependent on Dynamic Positioning. Critical incidents in DP have a potential for economic loss and disastrous consequences for human life and the natural environment. DP operators make time-critical decisions in order to rapidly and effectively handle unexpected critical situations. A large number of incidents do not lead to accidents because the operators manage to recover to normal operation mode. It is interesting to understand the characteristics of human operators handling of critical incidents and to see how they are able to recover. The purpose of this study was to identify characteristics of critical incidents in DP and characteristics of decision-making. Semi-structured interviews were conducted with 13 experienced DP operators, sampled purposively from shipping companies, drilling companies and a DP training centre among others. The interviews provided 24 incident recollections that were transcribed and thematically analyzed. The main findings were four characteristics themes of critical incidents in DP. The themes were *Situation Awareness, Experience, Human and Automation and Decision Strategy.* This study contributes to understanding characteristics of critical incidents in DP. Furthermore, identifying factors that impact DP operator decision-making during critical incidents.

Introduction

The maritime and offshore industry is increasingly becoming dependent on automated vessel station keeping for demanding operations at sea (Fossen, 1994; Sørensen, 2011). Working as a dynamic positioning (DP) operator (DPO) is popularly described as 99% boredom and 1% panic. The statement reveals that automated systems are highly reliable, but also dependent on the human operator to quickly resolve situations when the technical artefacts fail. Sophisticated automation intends to reduce operator error and enhance efficiency (Parasuraman & Mouloua, 1996; Leveson & Palmer, 1997; Satchell, 1998). However, this is not always achieved. Errors and accidents continue to occur and it has been shown that automation can induce new types of operator errors (Sarter, Woods & Billings, 1997).

Referring to human error as the cause of 80-90 percent of all accidents has become quite fashionable. Large-scale accidents, such as Chernobyl, Three Mile Island and the Costa Concordia grounding, have primarily been attributed to operator error (Meshkati, 1991; Eagle, Davis & Reason, 1992; IMIT Report, 2012; Schröder-Hinrichs, Hollnagel & Baldauf, 2012). Human error has been described as one undesired consequence of human automation interaction (Sarter & Woods, 1994; Reason, 1997). Highly automated systems have been associated with human out-of-the-loop problems. In highly automated systems the human role shifts from active involvement to mere interruption management (Sarter, 2000). The human operator is challenged to distribute attention according to the automated systems needs. Unable to anticipate the automated systems' needs, the human operator is trapped in the situation and becomes error prone.

However, a vast number of factors are involved in large scale accidents (Perrow, 1981; Reason, 1997), such as equipment design, information flow, task procedures and training. Although the human operator is heavily involved in performing errors, full understanding of the errors' origin is found within the complexity of the work setting as a system, including all elements and interaction.

Routine Operation, Critical incidents and Large-Scale Accidents

Accidents are characterized by unique sequence of events. Only destructions and losses are common denominators in large-scale accidents (Reason, 1997; Perrow, 2008). Large-scale accidents are few in number, but they provide great learning potential (Cooke & Rohleder, 2006).

Routine missions are readily observable in large numbers, but it is very challenging to single out the specifics leading to goal achievement. Furthermore, routine operations usually occur in stable and predictable environments that do not create difficulties for the human operators. On the other hand, critical incidents are events that are unplanned, non-routine and that have a high damage potential. The industry uses the term “near misses” and such incidents have in common the fact that they are recovered throughout the sequence of events. Increased understanding of what characterize critical situations that end well could reveal important information about how large scale incidents can be prevented.

Humans Working in Systems With Automation

Introducing automated systems impose new demands on the socio-technical systems, including the human operator (Sarter and Woods, 1997). Unexpected effects, also referred to as *automation surprises* (Woods & Sarter, 2000), are not just a result of over-automation or human error, but can be an indication of unintended side effects of a design strategy (Norman, 1990). Technology developers experience challenges in developing design for a coordinated team interaction between human operators and technical artefacts as one cooperative system (Sarter & Woods, 1997).

A machine-centred perspective ruled in the early days of introducing automation. The belief was that people make mistakes and limiting human involvement would reduce human error. Automation took over lower level action (Norman 1990), leading the human operator to becoming a supervisor and manager of automated systems (Bainbridge, 1983). The human operators' role has changed from active control to management by exception (Dekker & Woods, 1999). Consequently, the challenges in human machine interaction are intrinsically hidden in work patterns that are not visible to the naked eye (Reason, 1990).

When new automation is introduced into a system, or when there is an increase in the autonomy of automated systems, developers often assume that adding automation is a simple substitution of a machine activity for human activity (see substitution myth, Woods & Sarter, 2000). Empirical data on the relationship of people and technology suggest that this is not the case and that traditional automation has several negative performance and safety consequences associated with it stemming from the human out-of-the-loop (OOL) performance problem (Endsley & Kiris, 1995; Kaber & Endsley, 2004).

The OOL performance problem prevents human operators of automated systems from taking over operations in the event of automation failure (Endsley & Kiris, 1995), and has been attributed to a number of underlying factors, including human vigilance decrements (Billings, 1991), complacency (Parasuraman, Molly & Singh, 1993, 1997), skill degradation (Parasuraman, Sheridan & Wickens, 2000) and loss of operator situation awareness (SA) (Endsley, 1995; Endsley & Kiris, 1995).

Automation can result in the human operator becoming a passive supervisor unable to intervene if necessary (Endsley, 1996). When a human operator is out of the loop, instances will occur, when he cannot maintain control over the system (Norman, 1990). A supervisory role requires a different set of cognitive skills (Bainbridge, 1983) than the role of control and intervention. Thus, system design must take into consideration the elements that determine the quality of task performance (Woods and Roth 1988b in Roth, Patterson and Mumaw, 2002).

Dynamic positioning. In the maritime field DP has been introduced as an automated aid, taking over the performance of tasks previously performed by people, with the intention of increasing performance and safety (Parasuraman & Mouloua, 1996; Sheridan, 1992;

Wickens, 1998). DP is an automated system for vessel station keeping. A computer control system automatically maintains a vessel's position and heading by controlling machinery power, propellers and thrusters. Position reference sensors, along with wind sensors, motion sensors and gyro compasses provide input to the computer in order to maintain the vessel's position, making allowances for the size and direction of environmental forces (Sørensen, 2011).

Situation Awareness

At the point in time when the automation's capacity is exhausted it is up to the operator to take over. The operators' awareness at this point is essential to the outcome. The difference between "out" or "in" the loop cognition can be understood through the theory of SA. Situation Awareness has been defined as *" the perception of the elements in the environment within a volume of space, the comprehension of their meaning and the projection of their status in the near future"* (Endsley, 1995, p. 5). Endsley (1995) developed a three level model to explain SA. Level 1, *perception*, refers to the perception of attributes and dynamics of, elements in an environment. Level 2, *comprehension*, refers to the integration and interpretation of that information to understand what is happening in a situation. Level 3, *projection*, involves the operator's estimation of the system's future states. The outcome from this continuous assessment of the current situation can be utilized to determine on future courses of action.

The three level SA model (Endsley, 1995) reveals how deficiencies in developing and maintaining this awareness can lead to serious problems. Most research on SA has studied dynamic environments such as aviation (Wickens, 2000) and air traffic control (Endsley & Smolensky, 1998). In their study of aircrew performance Jentsch, Bowers, Bartnett and Salas, (1999) found that the loss of SA could lead to errors in assessments that could result in major accidents. A sudden loss of SA by a pilot due to inadequate detection of changes in the position of a hostile aircraft could allow the hostile aircraft to manoeuvre into a superior tactical position (Jentsch et al., 1999). The failure to perceive the change might lead to an incorrect understanding of the situation and hence prediction of where the hostile aircraft might be. An incomplete overview might result in poor or erroneous decisions such as placing one's own aircraft at a disadvantageous position. SA is therefore an important component of sound decision-making (Endsley, 1995; Lipshitz, Klein, Orasanu & Salas, 2001).

Decision Making in Natural Settings

Major revisions to the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (the STCW Convention), and its associated Code were adopted at a Diplomatic Conference in Manila (The Manila Amendments), in June 2010. The Manila amendments set the course for future maritime leadership and teamwork training addressing SA and decision-making.

The recent convention require maritime officers to be able to recognize the importance of SA to decision-making, state the three levels of SA and list factors affecting SA (IMO, revised STCW, 2010). Specific demands also require ship officers to have the knowledge and ability to apply the following decision-making techniques: *situation and risk assessment, identifying and generating options, selection of course of action and evaluation of outcome effectiveness* (IMO, revised STCW, 2010). When implementing these requirements to decision making during maritime operations, the IMO is faithful to rational decision theory (Simon, 1972; Simon, Dantzig, Hogarth, Plott, Raiffa, Schelling & Winther, 1987) and fail to recognize the constraints that affect decision-making in demanding and time limited settings. Is it believable that DP operators are able to follow the specific decision-making techniques demanded by the STCW when an incident occurs?

Decision-making has been defined by Yates (2001) as the process that leads to the commitment to an action, the aim of which is to produce satisfying outcomes. There have been a number of models created to explain the decision-making process over the course of history. Rational decision theory (Edwards, 1954; North, 1968) saw the human as a rational and analytical decision maker. In its simplest form rational decision-making can be viewed as generating all alternatives, validating the alternatives and selecting the optimal alternative.

In recent history it has been argued that rational theories of decision-making fail when applied to real-life decision-making (Beach & Lipshitz, 1993; Klein, 2008). It has been suggested that in a natural decision-making situation a rational model of decision-making does not adequately describe the decision process (Klein, 1993). The search for a more appropriate model of decision-making under these conditions has seen the development of Naturalistic Decision Making (NDM) theory (Cannon-Bowers, Salas & Pruitt, 1996). Zsambok (1997) defines NDM as: "*how experienced people, working as individuals or groups in dynamic, uncertain, and often fast paced environments, identify and assess their situation, make decisions and take actions whose consequences are meaningful to them and to the larger organization in which they operate."* (p. 5). In other words, NDM research investigates how people use experience to make decisions in naturalistic environments (e.g.

under time pressure, shifting conditions, unclear goals, degraded information and within team interactions). Consistent with this definition of NDM, research has aimed to identify more fitting models of decision-making to be applied to real life context. Relevant research on this particular issue includes the Recognition Primed Decision Making model (RPDM) (Klein, 1993) and mental models and schema theory of decision-making (Lipshitz & Shaul, 1997).

The RPDM model (Klein, Calderwood and Clinton-Cirrocco, 1986) was developed from interviews and observations of fire ground commanders working in difficult and challenging circumstances (Klein et al., 1986). It was anticipated that, under complex circumstances involving time pressures, the commanders would make limited comparisons between possible outcomes. However, the early research revealed that they were making no comparisons at all. In fact, 80% of decisions made in this task were made in less than one minute. From this, Klein et al. (1986) identified the following specific features about NMD decision-making, describing how experienced professionals can make rapid decisions in time limited situations. *First*, the fire ground commanders drew on their previous experience to recognize a typical action to take. *Second*, they did not have to find an optimal solution, merely a workable one. *Third*, they mentally simulated the solution to check that it would work.

Situation assessment in the RPDM model considers understanding of plausible goals, recognition of important contextual cues, the forming of expectations and identification of courses of action as the four most vital aspects (Klein, 1993). Such a situation assessment, including mental simulation, explains how experienced decision makers can identify a reasonable good option as the first one they consider, rather than generating and evaluating a series of alternatives.

Expertise has been found to be essential in order to make decisions in uncertain contexts (Kahneman & Klein, 2009). Expertise is characterized by a high ability of skill and/or and knowledge within a domain (Salas, Rosen, & DiazGranados, 2010). Even though experts often deliberate when they make decisions, they also make expertise-based intuitive decisions that do not occur on a conscious, analytical level (Klein, Calderwood, & MacGregor, 1989; Lipshitz & Strauss, 1997; Salas et al., 2010). Expertise-based intuition, (Kahneman & Klein, 2009), is the rapid, automatic generation of single decision options, rooted in extensive domain-specific knowledge and the recognition of patterns from past events (Salas et al., 2010).

Lipshitz and Shaul (1997) stated that the RPDM model failed to thoroughly describe the processes in NDM, especially the process of recognition. Therefore, they adapted the

RPDM model by substituting the recognition process with schemas and mental models. Schemas are past experience and knowledge that form mental models and mental models are more specific representations of situations (Craik, 1943; Johnson-Laird, 1983; Vaughan & Hogg, 1995; Johnson-Laird & Byrne, 2002). This accounted for experts' ability to collect more information and explained how experts made skilled intuitive decisions because they recognized patterns from past events (Kahneman & Klein, 2009).

The purpose of the study presented in this thesis deals with critical situations and human operators' decision making in DP mode. Critical incidents are situations which suddenly changes from a routine situation to a scenario with large damage potential. In order for humans to perform efficiently, factors that influence their performance, ranging from technological, through environmental to organizational factors must be considered. To investigate what factors contribute to the avoidance of disaster this study employs a qualitative framework, exploring empirical data with the aim of addressing two research questions. The first research question is; *what characterizes critical incident in DP?, and the second research question is; what characterizes human operator decision-making in critical incidents in DP ?*

Although no two situations in complex maritime operations can be blueprinted, searching for commonalities and shared patterns can reveal frames or structures that are characteristic features of critical incidents. In this study DP operators shared their observations of critical incidents. These observations were the source for identifying clusters of essential attributes in the DP domain that were relevant to the outcome of critical incidents. The first research question aims to identify characteristics prevalent across incidents recollections regardless of each incident's uniqueness including the human operator, the technical artefacts and the environment. The second research question took a closer look at the human operator and what factors in the situation affected decision-making in time-limited situations.

Method

Sampling

The study relied on a non-probabilistic and purposive sampling strategy to target experienced DP operators to gain information about critical incidents during DP operations. Informants were contacted through various channels such as a DP training centre in western Norway, maritime educational institutions, drilling companies and shipping companies.

Inclusion criteria for informants. All informants were required to have a minimum of 5 years seagoing experience and 3 years or more as a fully trained DP operator. All had a nautical education and unlimited DP certificates.

Inclusion criteria for critical incidents. The informants had to have been on board the vessel at the time of the incident and been actively involved in the incident. Incident recollections that were not personally experienced were excluded from the study.

Only incident reports where all questions from the interview guide were responded to was included in the study. Collecting from various sources ensured reports of critical incidents reports from broad range of DP operations.

Expert DP operators in Norway are often socially connected and have a considerable mutual history and experiences. Hence, limiting the number of experts recruited from the same source ensured more efficient collection of critical incidents and prevented the same incident from reoccurring. To ensure that the same critical incidents would not appear more than once, no more than two incidents were sampled from the same vessel.

Informants

The informants in this study were DP operators who described their experiences of critical incidents. A total of 42 candidates were approached between January and May in 2013. Five qualified candidates declined to participate. A total of 24 potential informants were found to be unqualified and were not included in the study.

The final sample consisted of 13 informants. The age ranged from 29 to 69 (mean = 44,3; σ = 12,1). Seagoing experience varied from 5 to 40 years (mean = 20,2; σ = 11,4). Experience as DP operators ranged from 4,5 to 33 years (mean = 12,9; σ = 8,1). Three informants had experience from one DP vessel type only, while one informant had experience from 8 different DP vessel types. On average was experience from 4,3 DP vessel types (σ = 2,3).

Critical Incidents

The informants provided 24 incident reports for further analysis. All 13 informants were asked to remember two critical incidents they had been involved in. Two informants were not able to recall more than one incident.

Data Collection

This thesis was based on qualitative data collected to explore characteristics of critical incidents in dynamic positioning operations, drawing on the experiences of DP operators.

Critical incidents were defined as challenging, non-routine events with an uncertain outcome. A demographic questionnaire collected data about DP operator expert characteristics. A semi-structured interview based on the Critical Decision Method (CDM) collected data on DP operator decision-making in critical incidents.

Procedure. A researcher (the author) approached each informant personally and collected all data. The initial contact was obtained via e-mail or telephone. The informants were informed briefly about the study and its purpose and were free to accept or decline the request. If the informant agreed to an interview time and setting was scheduled.

Before beginning with an interview a written consent form was presented to the informant. The written consent included information about ethical considerations, but also information about the research objective and that the interview would request information about critical incidents. The informants were presented with information about what their involvement would entail such as anticipated duration of the interview and where it would be conducted. General information about measures taken to guarantee confidentiality was also provided. Informants were informed that participation in the study was voluntary and that the interviews would be used for research purposes. Candidates were informed that they were free to withdraw from the study and have all the recordings deleted at any point. Finally, information about the people responsible for the project was provided, as well as information that the Norwegian Social Science Data Services had approved the project. If the candidate agreed, an interview session was scheduled and signed consent was collected

A demographic questionnaire was presented to the informant along with the informed consent form, following a short description of the study objective, interview objective and procedure. The questionnaire included 7 questions, determining sex, age, nautical education and experience, dynamic positioning education and experience and a brief description of the dynamic positioning experience.

After the informant signed the written consent and responded to the demographic questionnaire, the interview was conducted using the Critical Decision Method. Interviews were conducted at various locations which were comfortable to the informant and which afforded privacy, such as ship bridges, conference rooms or offices. None of the informants were on watch during the interviews. The semi-structured (CDM) interview allowed the researcher to come up with follow up questions if the informant presented areas of interest that might not have emerged otherwise. Interview sessions lasted between one and one and a half hour.

Critical decision method. The Critical Decision Method (CDM) is a semi-structured interview technique that uses cognitive probes in order to ascertain information of importance to critical decision-making. In this study the interview was constructed based on the CDM (Klein, Calderwood & MacGregor, 1989). The CDM helped to identify factors that influence and predispose decisions made in critical situations and was therefore suitable for investigating characteristics present in critical incidents and critical decision-making (Weitzenfeld, Freeman, Riedl & Klein, 1990). The semi-structured interview had 13 questions based on 11 out of the 12 CDM probes as presented in Table 1 below. The CDM proposes 12 probes, and a total of 11 probes were deemed relevant for a descriptive study of critical incidents on DP.

Initially, the domain experts were asked to describe a regular workday. The second question inquired about their personal definition of a critical incident. In question 3 through 13 the informants went on to describe two separate critical incidents they had experienced.

Table 1: *Interview guide*

	Interview questions:	Type of question/CDM probe:
1	Can you describe a regular workday in DP-mode?	Baseline reference
2	How do you define critical incident?	Baseline reference
3	What happened? Please describe	Problem
4	What were you trying to achieve when this incident occurred?	Goal
5	How did you act?	Cue
6	Did you expect something to occur?	Expectancy
7	Can you describe which information were available for you at the time?	Situation awareness
8	What was the most important piece of information available?	Information integration
9	Were you at any time uncertain about the reliability or relevance of the information available to you?	Uncertainty
10	Could you have acted differently in this situation? Made a different decision?	Conceptual
11	Was it at any point challenging to process the information available to you?	Decision blocking
12	In this incident, were you reminded of previous experiences, where a similar decision was made?	Recognition
13	In this incident, were you reminded of previous experiences, where a different decision was made?	Recognition

Note. The interviews included 13 questions that were designed to probe for incident attributes.

Data Analysis

The interviews were analysed using thematic analysis to find patterns of meaning within the qualitative data. The procedure involved five phases; familiarizing with the data; initial generation of codes; searching for themes; evaluation of themes and final definition of themes Braun and Clarke (2006).

Familiarizing with the data. All the interviews were tape-recorded and transcribed word by word for use in data analysis. Verbal and non-verbal cues were included in the transcriptions. The interviewer transcribed the interviews shortly after the interview, which ensured that the interviews were accurately interpreted and reported.

After the transcription, the interviews were read twice before a timeline for each incident was constructed. The outline of the incident identified the sequence of events, decision points, cues and all technical and human operators involved in the incident.

Initial generation of codes. A bottom up approach characterized the phase of initial coding. Similar units of meaning were coded more than once, only if the extraction represented a different perspective. The objective of the coding was to identify relevant aspects or patterns that were relevant throughout the data.

Searching for themes. After the initial coding, codes were organized and merged into larger units organizing those that were similar in meaning. This merging of codes into larger units persisted until there remained only a few codes that represented potential themes. By the end of this phase a list of 21 candidate themes for further analysis were named.

Evaluation of themes. In this phase the extractions and codes under each theme were read and evaluated again. Some extractions were moved and one theme was merged with another. Finally, 20 themes emerged from the data set.

Final definition of themes. During the final phase it was clear that the number of themes had to be reduced further. Only themes that were consistently described in every question in every incident report were defined as relevant for describing the characteristics of critical incidents in DP operations. The themes were defined by simply accounting for frequency of occurrences in the interviews. It was assumed that the most frequent themes were also the most relevant themes. Four themes out of 20 themes were present in all questions, in all incidents and all interviews.

Inter-Rater Reliability

A test of inter-rater reliability was performed to assess the reliability of the coding framework. A sample of the data coded by the analyst was compared to an independent rater. Two incidents were randomly selected for rating. The independent raters were presented with the statements coded in the interviews, a coding procedure and a list of the original 20 themes. No measures to mediate disagreements between raters were taken. The statistical measure Cohen's Kappa was used to rate reliability.

Ethical Considerations

Norsk samfunnsvitenskapelig datatjeneste (NSD) approved the research for this thesis, see Appendix A. The application to NSD included the demographic questionnaire, the interview questions and a consent form, as well as procedures for handling and sharing of research data. The written informed consent form was constructed according to NSD requirements and presented to each informant before the interview begun. The written consent ensured anonymity for the informant. In order to minimize risk of harm all tape recordings were kept available only to the student researcher and supervisor, and were deleted at the end of the research process. The informants were provided the right to withdraw from the study at any time. All interviews were conducted in areas where the informant felt comfortable and not exposed.

Results

Inter-rater Reliability

The two independent raters coded two randomly chosen incidents. Incident 14 scored Cohen's Kappa = .689, $p < .001$. Incident 19 scored Cohen´s Kappa = .593, $p < .001$. The overall agreement between both incidents scored Cohen's Kappa of = .645, $p < .001$.

Incident Characteristics

The incidents were divided into 8 different categories of DP operations. The categories of DP operation were; Accommodation, Construction/Support, Drilling, Sea Trial, Anchor Handling, Offloading, Supply, Diving and ROV Survey. Furthermore, the incidents were divided into 5 categories of consequences and 5 categories of base events. The five categories of consequences were Drive off, Drift off, Force off, Collision course and Keep Position. All consequence categories were familiar and established notions in the DP domain. Base events in this study were the initiating events as defined by the informants. The five categories of base events were Power Management System/DP (PMS/DP), Human Error, DP Reference System, DP Software, Environmental Impact and Component Failure. The correspondence between base events and operational type can be seen in Table 2.

Table 2: *Relationship Between Type of Operation and Base Event*

		Base Event PMS/DP	Human Error	DP Reference System	DP Software	Environmental Impact	Component Failure	Total
Type of Operation	Accommodation	2	0	1	0	1	0	4
	Construction/Support	2	2	1	0	0	0	5
	Drilling	0	0	0	0	2	0	2
	Sea Trial	0	0	0	0	1	0	1
	Anchor Handling	0	1	0	0	0	0	1
	Offloading	0	1	0	1	0	0	2
	Supply	2	1	0	0	0	1	4
	Diving	0	0	0	0	3	0	3
	ROC Survey	0	1	0	0	0	1	2
Total		6	6	2	1	7	2	24

Note. The table displays the incident frequency distribution of the relationship between categories of operations and base events.(PMS/DP = Power Management System/Dynamic Positioning).

A statistical cross tabulation analysis summarized the categories to provide a picture of the interrelation between the categories. There was no dependency between type of operation and the base events (χ^2= 47.23, df = 40, p = .201, see table 2) or between type of operation and the consequence (χ^2 = 32.85, df = 32, p = .425, see table 3). The Chi Square test did not indicate any dependency between types of operation and base events or types of operation and consequence, as the results were to be considered non-significant.

Table 3: *Relationship Between Consequence of Incident and Types of Operation*

		Consequence of Incident Drive Off	Drift Off	Force Off	Collision Course	Keep Position	Total
Type of Operation	Accommodation	1	2	1	0	0	4
	Construction/Support	3	1	0	0	1	5
	Drilling	0	0	2	0	0	2
	Sea Trial	0	0	1	0	0	1
	Anchor Handling	0	1	0	0	0	1
	Offloading	1	0	1	0	0	2
	Supply	1	1	0	1	1	4
	Diving	0	0	3	0	0	3
	ROC Survey	0	1	0	0	1	2
Total		6	6	8	1	3	24

Note. The table displays the incident frequency distribution of the relationship between categories of operations and consequences. (PMS/DP=Power Management System/Dynamic Positioning).

However, there was a statistically significant dependency between initiating event and consequence ($\chi^2 = 47.5$, df = 20, $p < .001$, see also table 4). The significant dependency was expected as environmental impact and force off can be explained by a natural relationship.

Table 4: *Relationship Between Base Event and Consequence of Incident*

		Consequence of Incident					Total
		Drive Off	Drift Off	Force Off	Collision Course	Keep Position	
Base Event	PMS/DP	1	4	0	0	1	6
	Human Error	2	2	1	1	0	6
	DP Reference System	2	0	0	0	0	2
	DP Software	1	0	0	0	0	1
	Environmental Impact	0	0	7	0	0	7
	Component Failure	0	0	0	0	2	2
Total		6	6	8	1	3	24

Note. The table displays the incident frequency distribution of the relationship between categories of base events and consequences. (PMS/DP = Power Management System/Dynamic Positioning).

Results of Thematic Analysis

A thematic analysis of 13 interviews and 24 critical incidents identified a total of 20 themes. See themes listed in Table 5 on the following page. See appendix F for descriptions of themes.

Contents of a normal work situation. The interviews begun by asking the DP operators: "Can you describe a regular workday in DP mode?". All informants described a regular work ay as a DP operator. Five themes emerged, *Human & Automation; Situation Awareness; Workload; Operating Envelope and Team.* The following statement provided a description of the experience of working as a DP operator:

> *"A regular workday in DP tends to be incredibly boring. A lot of the work around DP is sitting watching the DP system. Not actually doing anything. On some vessel types you will be constantly moving around. Accommodation units is sitting in one place all the time. Something like diving is much more intense, because if you make a mistake someone will*

die. Here it will be equipment damage. Most of the time DP is boring with short periods of excitement."

Table 5: *Frequency of theme statements in interviews*

Theme	Q1	Q2	Q3-13 Mean (σ)	Total	Occur in incidents
Situation Awareness	16	6	9.2 (10.4)	119	24
Experience & Recognition			8.4 (9.7)	109	24
Human & Automation	16	11	7.2 (7.7)	94	24
Decision Strategy			6.7 (7.7)	87	24
Uncertainty		12	5.5 (6.7)	71	23
Time	9		4.0 (4.4)	52	23
Team			3.8 (7.1)	50	21
Automation Feedback			2.8 (4.3)	37	21
Procedures			2.8 (2.9)	37	13
System Understanding			2.5 (5.0)	32	16
Operation Envelope	11		2.3 (4.9)	30	16
Automation Surprise			2.0 (5.1)	26	14
Hindsight			1.7 (2.5)	22	11
Workload	13		1.2 (4.3)	15	2
Information Selection			2.2 (6.5)	28	21
Alert Level			1.2 (2.5)	15	12
Confidence			0.6 (1.3)	8	6
Problem Identification			0.4 (1.0)	5	3
Personality Type			0.2 (0.7)	3	3
Working Environment			0.3 (0.7)	4	4

Note. Along with the total number of statement for each theme, the table also displays the frequency of occurrence of thematic statements distributed by interview questions. Furthermore the table shows in how many incidents the thematic statements occurred. Q1 = Interview question number 1,Q2 = Interview question number2, Q3-13 = Interview questions number 3-13.

Definitions of a critical incident. All DP operators were asked to describe with their own words their personal definition of a critical incident in DP. Three themes emerged to describe a critical incident in DP operations; *Situation Awareness, Human and Automation* and *Uncertainty*. One of the participants defined a critical incident as follows:

" I would call it a critical situation if the DP is not functioning anymore and the vessel cannot be controlled from the DP level anymore."

After a brief description of the DP operators' daily work and their definition of critical incidents, the remaining interview questions provided a more comprehensive description of the research question and the characteristics of critical incidents on DP.

Characteristics of critical incidents in dynamic positioning. Four themes occurred in all 24 incidents and are considered the main results of the thematic analysis. These categories have been labelled as *"Situation Awareness," "Experience and Recognition," "Human and Automation," and "Decision Strategy".*

While these four main themes captured the recurring patterns across the dataset, sub-themes existed underneath the umbrella of each theme. A total of 14 sub-themes contributed to the description of critical incidents, see table 6. The Sub-themes focused on specific and notable elements, but within the same central concept as the main theme.

Table 6: *Main Themes and Sub-themes Overview.*

Main themes	Sub-themes
Situation Awareness	Situation assessment process. Sudden changes in SA.
Experience & Recognition	Experience and recognition affect decision-making. DP operators describe patterns of experiences used as recipes for decisions. DP operators mentally simulate the outcome of both real and "what if" scenarios. DP operators transfer their experiences from one situation to another.
Human & Automation	In critical incidents the DP operators' role transforms from monitoring to intervention. DP operators intervene by lowering the level of automation. DP operator cooperation with automated DP systems was affected by system understanding. The DP system's ability to communicate with the DP operator affects critical incidents.
Decision Strategies	DP operators utilize three different decision strategies. Types of decision strategies are determined by the compatibility between schemas and the current situation assessment. Decisions during incidents on DP are made based on specific information or parts of patterns that are recognized. DP operators recognize a limited number of options during the incident.

Note. The main themes included a number of characteristics regarding critical incidents. This table presents these characteristics as sub-themes organized under the constituant main theme.

In the following sections the four themes including the sub-themes will be introduced along with statements from the interviews. All findings are presented with the number of incidents relevant and one statement from the interviews.

Situation Awareness. SA was the theme that occurred the most throughout the incident recollections and was mentioned 119 times. In critical incidents DP operators were directed by overarching risk awareness. The level of awareness was determined through an assessment process (Endsley, 1995; Klein et. al, 1986). The findings implied that the situation assessment process was affected by cues, expectancy, problem and goal identification, time limitation, uncertainty and the identification of base events. Further, sudden changes and continuous updating characterized SA in critical incidents on DP. This is in line with the idea that SA is dynamic and alters along with internal and/or external influences (Smith & Hancock, 1995; Bedny & Meister, 1999).

Situation assessment process. The DP operators strove to reach an optimal level of SA through an assessment of the situation. The assessment of the situation involved an overarching evaluation of perceived potential risk. All 24 informants mentioned risk as an element in situation assessment, as illustrated by the following:

> *"The most important thing was to secure the gangway, close the traffic on the gangway to protect people from stepping on the gangway. Stop the vessel from drifting and avoid collision with the installation."*

In all the incidents the problem awareness was triggered by a cue in the external environment. In 9 of the incidents the informants realized the problem due to auditory cues. Visual cues were the main cues in the other 15 incidents. One informant described how he became aware of the problem:

> *"It was the Jr. DPO. He had said the vessel was moving, and then obviously the first stage and second stage alarms that were set at 3 and 5 meters."*

In 19 of the incidents the situation was unexpected. Five incidents were not unexpected. An informant stated that the incident was unexpected:

> *"Nooo, complete surprise. Nothing expected."*

Problem recognition occurred in 19 of the incidents. In 5 incidents the DP operator at the point did not understand the problem when the initial decision was made.
A DP operator described his initial problem understanding.

> *"I didn't understand what happened. I saw the vessel moving forward towards the first alarm limit, without sounding any alarm, and then I knew*

something was wrong. I didn't understand why. It wasn't supposed to happen, so I called the captain"

The findings revealed that all 24 informants defined a goal, although they did not fully understand the problem. As one informant said:

We were going forward, so I wanted to stop the vessel from moving forward."

The DP operator’s sense of time in the incidents affected critical incidents. In 19 of the incidents the DP operator did not feel he had adequate time to think. In the other 5 incidents the DP operator stated that they had enough time to think. In the quote below, one informant described his perception of time during an incident.

Interviewer: *"Was there any other information that would have been useful in that situation?"*
Informant: *"...there wasn't that much that I needed to look at because I saw what happened. And.. that the guys on the bridge didn't have control over what was going on. I didn't think about that at that point. I didn't have the time for that. I just threw myself on the desk and drove."*

Uncertainty was described as an issue affecting the DP operator in 17 of the incidents. In the other 7 incidents the DP operators did not feel uncertainty. The following statement described one informants' uncertainty during decision-making in a critical incident.

"Yes, I was uncertain in the beginning, about whether what I saw on the DP screen was correct, before I could physically see the hawser slacking. So, sure I was uncertain. I had to check that first"

In 14 of the incidents the DP operator recognized the base event before the initial decision strategy was formed. Ten DP operators did not recognize the base event before making a decision. A DP operator explained how he knew what caused the incident:

"Yeah, the thing was. I mean, as I said, it was fine weather and the decision to go back towards the installation could have been seen as quite strange, but in my head I had pinpointed what the problem was. I knew it was thruster 5."

The assessment process changed, triggered by cues in the environment. At that point the level of SA also changed.

Sudden changes in the external environment challenged SA. In all of the 24 recollections, the incident brought with it a sudden shift in SA. Recent research have found that high levels of SA are needed to project a situation (Endsley, 1995) and sudden shifts in the situation, often lead to an incomplete overview over the situation. An incomplete overview of the situation means the DP operator does not have all the information he needs to keep a high level of SA. In situations where the automated technical equipment no longer projects the next correct action, the human operator must do exactly that. Consequently, the DP operators immediately engaged in an intense evaluation of the situation, producing a strategy for problem solving. In other words the DP operator’s SA was determined by the availability of information and the ability to undergo a cognitive process of information processing quickly enough to make a sound decision. One informant described how he reacted to a sudden change and engaged in a process of obtaining an overview of the situation in order to react correctly.

Interviewer: *"Did you expect this to happen?*

Informant: *"No, it was sudden. It seemed like we just went into a shadow, momentarily. It was completely quiet and the vessel moved. It wasn't.....you didn't.... It was completely quiet. In the middle of summer."*

Sudden changes in critical incidents require the DP operator to make decisions about courses of action. One of the conditions that determined the ability to meet the demands of the situation was the operators' ability to utilize prior experience.

Experience and recognition. Experience and Recognition was the second most occurring theme in all of the incident recollection, mentioned a total of 109 times. The findings identified that experience and recognition affected the DP operators' decision-making. The DP operators depended on mental schemas for how to handle situation and form decision strategies. These schemas stemmed from experience and were saved and transferred from situation to situation. Finally, the DP operators seemed to create mental models from experiences that had not occurred in real life. The informants described how they imagined scenarios that had not yet happened and how they were aware of conditions in the work setting that they imagined could lead to the development of a critical situation.

Experience affects decision-making. The retrospective incidents accounts presented a picture of the DP operator as action takers during incidents, assessing the event based on prior experience, recognition and planning within operational limitations in order to avoid serious consequences. In 19 out of 24 incidents the DP operator stated that he used experiences from similar past decisions, thus being indicative of a type of Recognition Primed Decision-Making (Klein, 1993).

In the other 5 incidents the informants stated that they were inexperienced with regards to the operation, position on board or vessel at the time of the incident and were therefore affected by lack of experience. Seventeen DP operators had situations where dissimilar decisions were made. A total of 6 informants were unable to remember incidents where they had used prior experiences from situations where they had made decisions that were different. One informant did not respond. The informants explained how prior experiences affected incident decision-making, as exemplified in the following extract from one interview:

> Interviewer: *"In this incident were you reminded of past experiences where you had made similar decisions?"*
> Informant: *"Yes, I should say so. Many times. On all vessels. I can mention one example from the Ekofisk field. We were on supply and there were a lot of bad weather. We were on the limit for having to stop operation and go in....."*

Another informant described how his inexperience affected an incident:

> Interviewer: *"In this incident were you reminded of past experiences where you had made similar decisions?"*
> Informant: *"No, I just didn't have that experience with anchor handling. Also, before this I had been on Alstom systems, cable laying. So, I was new*

to Kongsberg, the Kongsberg screens, set up, displays. It was all very, very new."

Experiences affected DP operators in many aspects. Particularly, the informants described how experiences were stored in memory and utilized in future situations, like a recipe. This brings us to the next element of how experiences affect decision-making.

DP operators use experiences as recipes for decisions. In the interviews, all 24 incidents the DP operators explained how they collect experiences. The experience-collection can be compared to a mental database of patterns utilized for immediately knowing how to respond to various situations (Bhattacharya & Han, 2001; Lipshitz & Shaul, 1997; Klein, 1993). Schemas (Craik, 1943) are built up from actual experience, training and mental simulation exercises. Specific patterns were often developed for vessel or operation characteristics. One informant explained how the experience database increased with time and enhanced the ability to be proactive in different situation:

"We were operating off the coast of England. In Bristol Bay and around that area there is at times a strong current, and then you had to have an idea of how much machinery power you would need to keep your position, somewhat. So after some time we learned. To sit and watch. Well, now it's 40 %, 50 %, perhaps. So that when it stops, I know. Then you can ...(take correct action)"

Schemas originated not just from real life experiences, but also from training sessions or mental simulation as described in the following paragraph.

DP operator mentally simulate the outcomes of both real and "what if" scenarios. All 24 informants described how they prepare themselves mentally by mental simulating incidents that has not happened, but could potentially occur. The DP operators referred to situations where they sat and imagined "what if" incidents and reflected on how to solve and prevent such situations. In all incidents the informants referred to work procedures and emergency procedures as the baseline pattern for performing operations. In particular, one informant described how he was drilled by his superiors to imagine/visualize how he would handle different critical scenarios.

> *"The captain drilled us to think: What will you do if you lose your reference system or the DP doesn't stop when it should?..... I sat for three years on duty and though that if this happens you will press this key and then use joystick.. It has been useful many times."*

In all incidents the informants referred to work procedures and emergency procedures as the baseline pattern for performing operations. Specific patterns were often developed for vessel or operation characteristics. Simulation exercises, mental or actual, or procedures are seldom a blueprint of real life experiences. All situations and experiences are unique. However, DP operators stated that experiences and recognition was useful in dissimilar situations as well.

DP operators transfer their experiences from one situation to another. DP operators stated that you will never have the exact same experience twice, but that experience gained from one incident/situation can be utilized in a future incidents. In all 24 incidents, the DP operators, described how experiences can be utilized in situations that are not unique to the actual experience.

> Interviewer: *"In this incident were you reminded of past experiences where you had made different decisions?"*
>
> *Informant: " Well, I don't think that experience is something that you have to repeat. I mean that experience is such that you repeat your action. It is just that you have events in you past that you have learned something from, but it doesn't mean that each time you have to make the same decision based on the experience. Maybe that previous experience will cause you to act differently actually than last time. So it's not just repeating the action. It is understanding and making a decision. Projecting the end."*

In the last quote the informant also and described how experience can affect SA. Experience transfer can enhance situation awareness and thereby provoke more efficient or safer actions (Endsley, 1995; Stanton; Chambers and Piggott 2001; Underwood, Ngai and Underwood, 2012). In critical incidents experience was important for situation assessment. Furthermore, operator interaction with automated systems was another condition that affected the outcome of critical incidents.

Humans and Automation. Humans and Automation was the third theme that occurred in all 24 incident reports with 94 occurrences. The findings suggested that the DP operators' role transforms from monitoring to becoming the intervening party during incidents. Also the DP operator's intervention involved reducing the level of automation during incidents. Furthermore, understanding and knowledge about the DP system affected the DP operators' actions in critical incidents. Finally, communication between the human operator and the DP system affected the DP operators' decision-making.

In critical incidents the DP operators' role transforms from monitoring to intervention. Intervention from the DP operator was important for the recovery of all 24 critical events. The DP system was not operational in 7 of the incidents and the DP operator was forced to take over. In 17 of the incidents the DP operator chooses to take over control of DP system. One informant said:

> *"You don't need a DP operator if everything works as expected. When the system is in position and everything, you are not... You don't need a DP operator on the desk. The job of the DP operator is actually to act when something is wrong. That is why we are sitting there. We have to be ready to take action when something goes wrong."*

Whether or not the DP operators are forced to take over, or choose to, they all do so by manually controlling all or parts of the technical system.

DP operators intervene by lowering the level of automation. DP systems out of order required manual handling of the vessel and concerns 7 incidents. Out of the 17 incidents, where the DP operator intervened by choice and the DP system was still available, the DP operator handled the vessel in manual mode in 8 incidents. In the other 9 incidents the DP operator initiated mode changes and cooperated with the DP system. One informant said:

> *"The alternative was to just sit and watch, monitor. My opinion is that it is better to be proactive. Better safe than sorry. So, I just started up what I felt was needed. And... it is my full right....So I don't think it was the wrong decision. No, it wasn't."*

One reason for choosing to manually control the DP system was uncertainty and lack of knowledge about how the system would act.

DP operator cooperation with automated DP systems was affected by system understanding. In 16 incidents system understanding was described as a factor that influenced the incidents progression. In 8 incidents system understanding was not mentioned specifically. One informant described:

> *" It was all happening very fast. But, my advantage in that situation, was that I had been a part.... It was a converted rig. Converted from conventional anchored... So I had been part of the modification team and I knew the system very well. How it was set up on that rig. So, that was what made me.... you could say... save the day."*

The DP operators' lack of understanding for the DP system combined with the DP systems inability to provide the correct feedback to the human operator is clearly an issue of importance for handling of critical incidents.

The DP system's ability to communicate with the DP operator affects critical incidents. In 24 incidents the informants described communication with the DP systems as a factor that affected the DP operators' actions. In 2 incident recollections communication with the DP system was not mentioned. In the quote below an informant explained that the DP system did not provide sufficient information for him to determine whether the problem was DP related or not. As a result of lacking information the DP operator chose to withdraw the vessel from the situation. As one informant recalled:

> *"At that point we weren't a 100% sure it was the DP system that had run us astern. Because the DP runs the thrusters in a certain way. That could also cause a list. At that point we knew we had listed and we knew we had moved off. But we have to know why that happened. You will always pull off, clear and then check through everything. It is important to know why. We don't go back in if we are unsure."*

Critical incidents were affected by operator cooperation with automated technical artefacts**.** The informants described how decision strategies were formed based on experiences and comprehension of the situation.

Decision strategies. With 87 occurrences, Decision Strategy was the fourth theme to emerge from the data analysis. The analysis showed that the critical incidents are characterized by the utilization of three different decision strategies. In critical incidents DP operator seek compatibility between schemas and the actual situation to reach decision strategies. Furthermore, DP operators recognized a limited number of options in decision-making scenarios. Finally, the DP operators made decisions based on specific information or parts of schemas.

DP operators utilize three different decision strategies. In all 24 incidents the DP operators described that they had to react, and a strategy was laid out for ensuring a controlled recovery and a return to an acceptable risk level. Three types of decision strategies were identified from the data analysis. *First*, the DP operators were trained to follow predetermined procedures and 18 critical events were recovered by following prescriptive procedural rules. *Second*, In 3 incidents the DP operator consciously chose to break procedures in order to carry out a more efficient strategy. *Third,* three incidents were recovered utilizing a more efficient strategy without violating procedures. The statements below are extractions from incident recollections and exemplify the three different decision strategies.

> Informant followed procedure: *"That is never questioned. The decision to withdraw."*
> Informant broke procedure for more efficient strategy: *"We were both aware of it, but we chose to do it." "I our judgment the situation we had the situation under control."*
> One informant utilized a more efficient decision strategy, but within procedures: *"But if things had happened faster, then I might have had to take it in manual. By the book."*

The DP operators did not consider the choice of decision strategy as a random selection, but explained that prior experiences were compared to the current scenario before a decision was made.

Type of decision strategies is determined by the compatibility between schemas and the current situation assessment. In 19 of the incidents the assessment was matched with a pattern the DP operator recognized. Of these, 13 made the decision to follow procedures. A more efficient strategy within procedure was chosen in 3 incidents. In 3 incidents the informants chose a decision strategy that matched the situation assessment with their experience and broke procedures.

In 5 incidents the assessment of the actual situation was not compatible with patterns recognized from experience. All of these 5 proceeded with a decision strategy that involved following procedures. One informant explained how he made his decision.

> *"Well, I think that in this moment I had to use all my experiences from previous minor situations or incidents. They influenced my decision-making process. For instance that I didn't hesitate to switch over to red light and making the decision to just move out. That was my previous experience."*

This process of matching experiences with the on-going situation usually did not produce a large number of alternative options.

DP operators recognized a limited number of options during the incident. Seventeen of the informants stated that they only had one decision option at the point when the decision strategy was laid out. In 7 incidents the DP operator had more than one option. At the initial decision point, all DP operators except one, chose the superior decision strategy. The statement below exemplified how one informant regarded his decision options.

> *"No, not in this case. There was only one thing to do."*

Decisions are made based on specific information or parts of patterns that are recognized. All 24 informants pointed to specific information that was vital for the decisions they made. During critical incidents, specific information relevant to the incident was selected. The recognition of this information stemmed from correspondence with patterns that exist in the experience database. More often than not only parts of the patterns were recognized, but decisions to act were still made. In the statement below, one informant described how he only recognized parts of a previous experience.

> *"There was something wrong obviously, because we were moving. According to the DP, the thrusters weren't effective. The difference between the Rolls Royce panel and the manual controls on the DP, you know... So it took a second look so to speak. Then.. there was... That doesn't tie up"*

Overview of Incident Findings

The findings were summarized in three models to simplify and display the results. *First,* an event tree displayed the characteristics affecting assessment of critical incidents in

DP from base events to incident (see Figure 1). *Second*, an event tree showed the assessment characteristics and decision strategies in from incident to final consequence (see Figure 2). *Finally*, a bow tie model combined the operator's reasoning from base events to consequences in decision-making in an overarching risk perspective, including time, situation assessment and the role of human operator as important characteristics of critical incidents in dynamic operations (see Figure 3).

Base event identification in critical incidents on DP. In all 24 incident recollections describe causal reasoning during the event. However, the DP operators are not always able to identify the base event. The base event was identified at during the situation assessment in 10 incidents and identified after the incident in 14 incidents.

Figure 1 displays the relationship between characteristics that influence DP operator assessment in critical incidents. Cues, anticipation of imminent incidents, problem realization and base event identification affected DP operator decision-making in critical incidents. The event tree shows how each characteristic represent a sequence in the situation assessment from incident to base event. Each sequence includes the frequency of occurrence given by the data analysis.

The DP operators' situation assessment in critical incidents is triggered by cues in the external environment, which may or may not lead to expectations about the imminent events. Whether anticipations arise or not, the DP operators may or may not realize the problem and may or may not identify the base event before reaching a decision strategy.

Consequence prediction in critical incidents on DP. In all 24 incidents recollections the DP operators were able to describe the outcome of the situation. However, during the incident the DP operators were also able to predict the outcome, even though only 5 DP operators said certain cues lead them to expect the incident before it happened.

The process of predicting the outcome starts with perception of cues in the external environment (Endsley, 1995). Cues, such as an unusual vibration in the hull, can be meaningful and lead to anticipations about the fact that the current situation differs from plan or routine. This discrepancy is a problem. The ability to read cues in the environment determines whether the problem is identified. Identifying a problem infer a goal. Reaching the goal requires a strategy for a solution. Before formulating a strategy the DP operators are affected by time limitations and uncertainty.

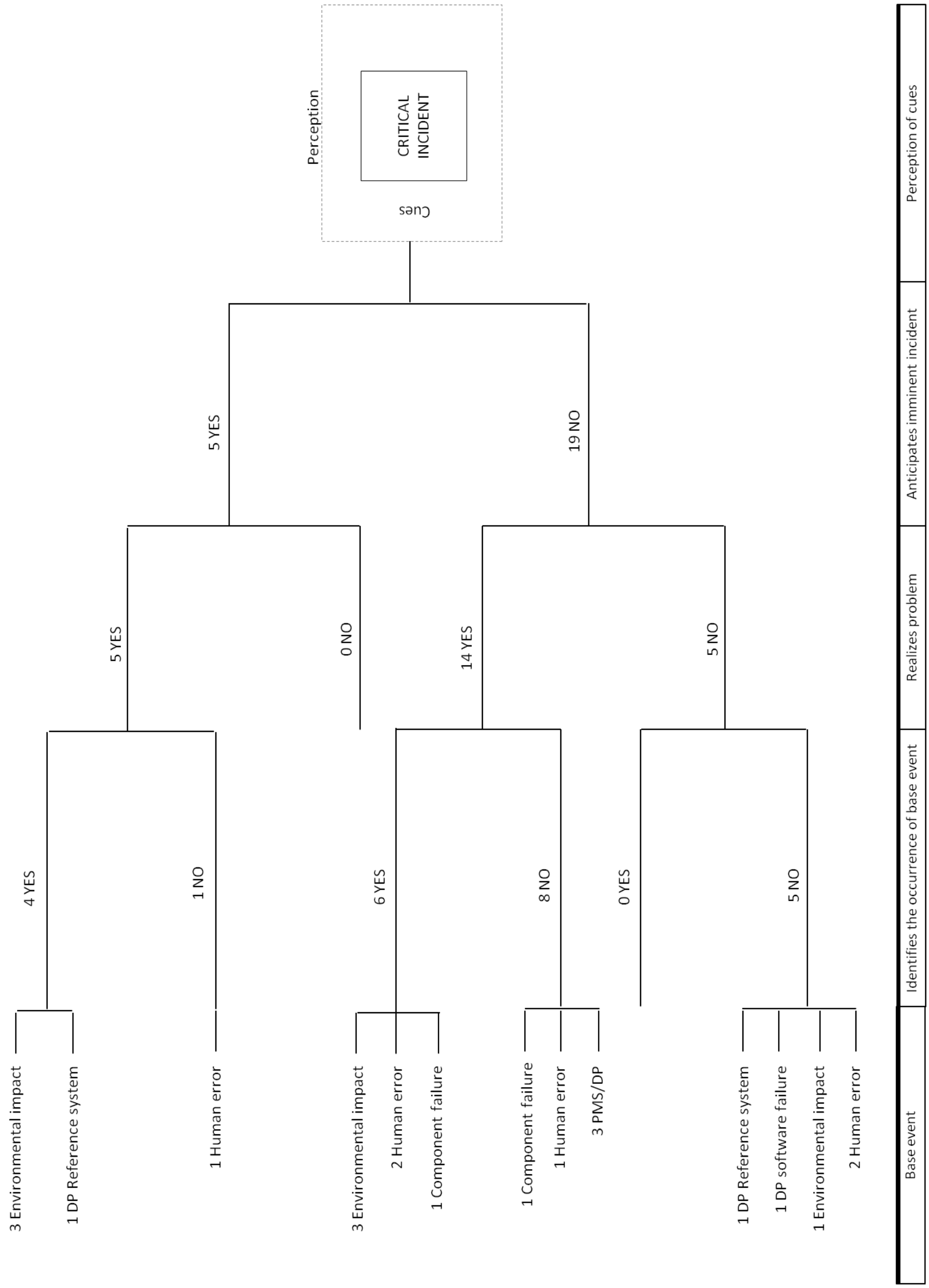

Figure 1. Base event identification in critical decisions in DP. The top events, or critical incidents, were events that were undesirable, critical, had an uncertain outcome and needed to be controlled. A total of 24 incidents were included in the event tree analysis and the square box to the right represented all 24 critical incidents collectively. A base event was the event that initiated or caused the incident. The base events are identified on the left side of the figure. The lower level events; Cues, Anticipation of imminent incident, Problem realization and Base event identification affect DP operator's situation assessment in critical incidents.

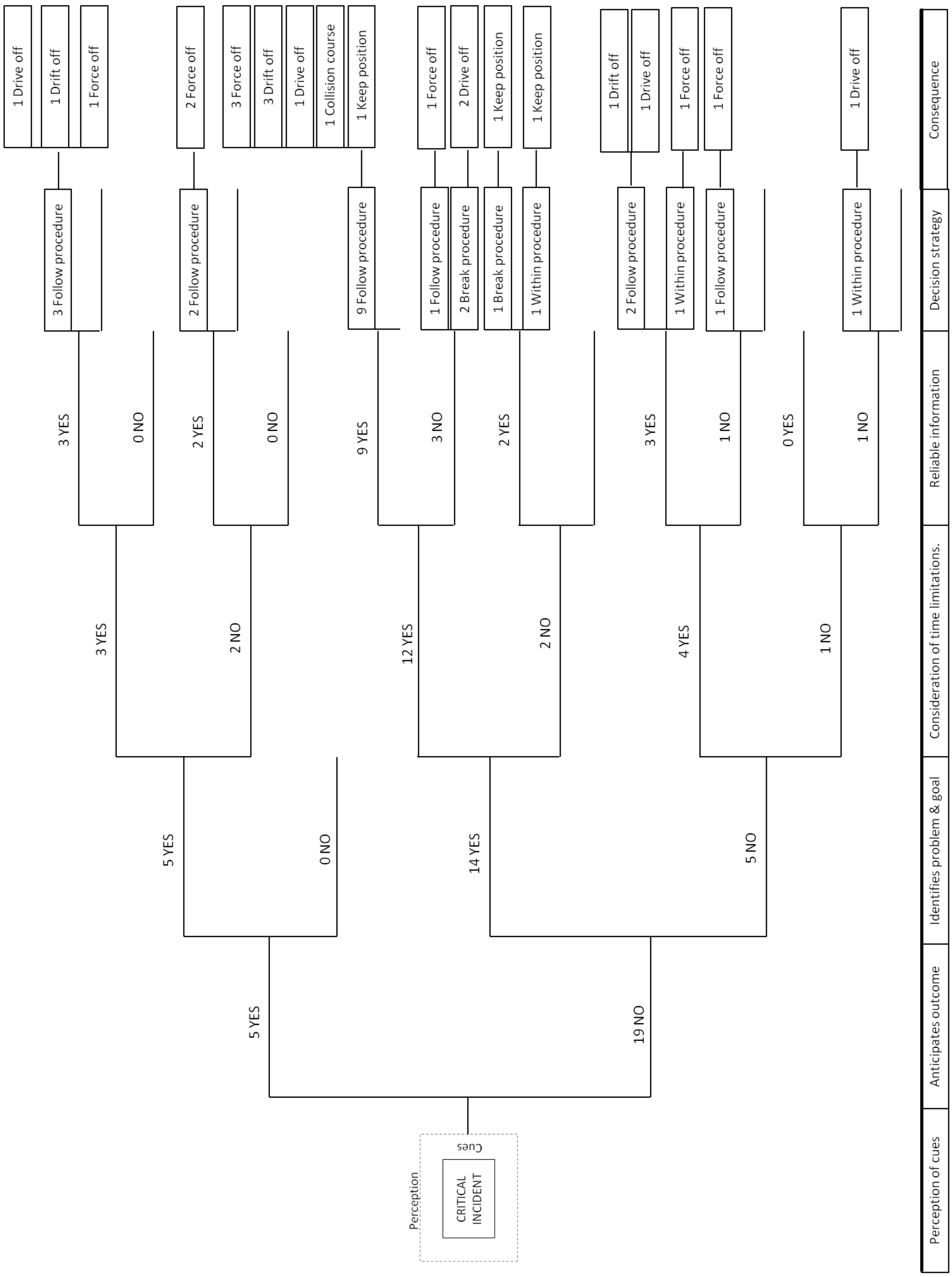

Figure 2. Consequence prediction in critical incidents on DP. A total of 24 incidents are included in the fault tree analysis and the square box to the left represents all 24 top events collectively. Top events were events that were undesirable, critical, have an uncertain outcome and need to be controlled. The consequences are on the right side of the figure. This study identified 5 types of consequences; drive off, drift off, force off, keep position and collision course. Cues, Anticipation of outcome, Identification of problem and goal, Consideration of time limitation and Reliability of information are lower level events that affect DP operator choice of decision strategy and thereby also consequence in critical incidents. All events were represented by the frequency of occurrence given by the data collection.

How much time is available is also read from of the surrounding cues. The cues may or may not match the DP operator's expectations, or schemas, and leads to uncertainty. When cues in the real world match the DP operator's expectation, or schemas, uncertainty is reduced effectively. The choice of decision strategy will affect the outcome of the situation. The DP operators mainly chose to follow procedures and therefore avoid a high level of risk in the decision strategy. A few DP operators chose a more creative decision strategy and broke the procedures because they predicted a more efficient outcome during the assessment.

The event tree seen in Figure 2 displayed the chain of events from incident to consequences seen in decision-making during critical incidents in dynamic positioning. Characteristics, identified in the data analysis, as affecting situation assessment were displayed as logical sequences. The event tree specified the frequency of occurrence from incident to consequence on each sequence.

The event trees in Figure 1, and Figure 2, showed how DP operators' decision-making in critical incidents really is a super fast risk assessment that involves identification of hazards and barriers in a cause-consequence perspective. In the following bow tie model (Figure 3) both perspectives are included.

Bow-tie representation of critical incidents characteristics in dynamic positioning. The bow tie is traditionally for linking hazards and consequences through a series of events. In this model, the bow-tie model is used to represent the overarching risk assessment that DP operators engage in during critical incidents. The model linked base events to consequences through a sequence of characteristics that affected DP operator situation assessment and decision-making. DP operators were able to reason with stated facts, specific cues and general knowledge to identify base events and predict imminent events and predict final consequences. The model shows that during an incident the human operator engaged in a cause-consequence assessment. On the left side of the model the operator tried to identify the base event. Being able to identify the base event was helpful for imminent event prediction, assisting the human operator in identification of possible preventive actions. On the right side, the DP operator predicted the outcome of the situation through an assessment that was affected by cues, anticipation, identification of problem and goal, consideration of time limitations and the reliability of the information. The assessment assisted the DP operator in finding potential control or recovery actions and formulating a decision strategy. The model represented all four themes from the thematic analysis. Experience and Recognition was fundamental in SA and relevant for the whole cause-consequence assessment. Reaching a level SA influenced the choice of decision strategy. The model shows how Situation Awareness, Experience and Recognition and Decision Strategy affected how the DP operator worked with the automated DP system. The statement below exemplifies characteristics of decision-making during critical incidents that can be found in Figure 3. In this particular incident the DP operator was triggered by a cue that led to anticipation of incident. He understood the problem and identified the base event as technical challenges with the reference system. The same cue also led him to anticipate the outcome of driving off towards nearby installations. Since he identified the problem he also had a goal of getting the vessel to move away from installations in the vicinity. The vessel moved fast enough for him to recognize that there was not sufficient time to risk alternative decision options. Uncertainty of information was not an issue since he knew from experience that the information displayed matched the actual situation. The decision strategy involved following procedures and taking manual control of the vessel. The extraction below exemplifies characteristics of decision-making in a DP incident.

> *"We're in position and have been for about half an hour. Suddenly, both GPS's drop out* [cues]. *It's obvious that they are in shadow of the platform* [anticipates the incident]. *Like I said, they are in auto voting* [understand the problem]. *When you have two GPS's, it's usual that,... eeehh, for the most part, it chooses to have more faith in the GPS's, which were failing* [identifies the base event]. *Or displaying different from the Fanbeam. Something that makes the vessel start moving towards the platform* [anticipates the outcome] . *The DP goes to Dead Reckoning. It should have gone to... eeehh. Approaching the platform, the Fanbeam drops out also. Because it's in shadow. Something is blocking the reflector. I can't remember if it was a container. It was something anyway. And then it goes to Dead Reckoning. It should have stayed in position, but the vessel chooses to drive towards the platform* [identifies problem and goal]. *Not with all force, but still....* [time limitations], [reliability of information]. *(........) I changed to DP joystick. And got out* [decision strategy]. *After a while the GPS's came back and everything was fine."*

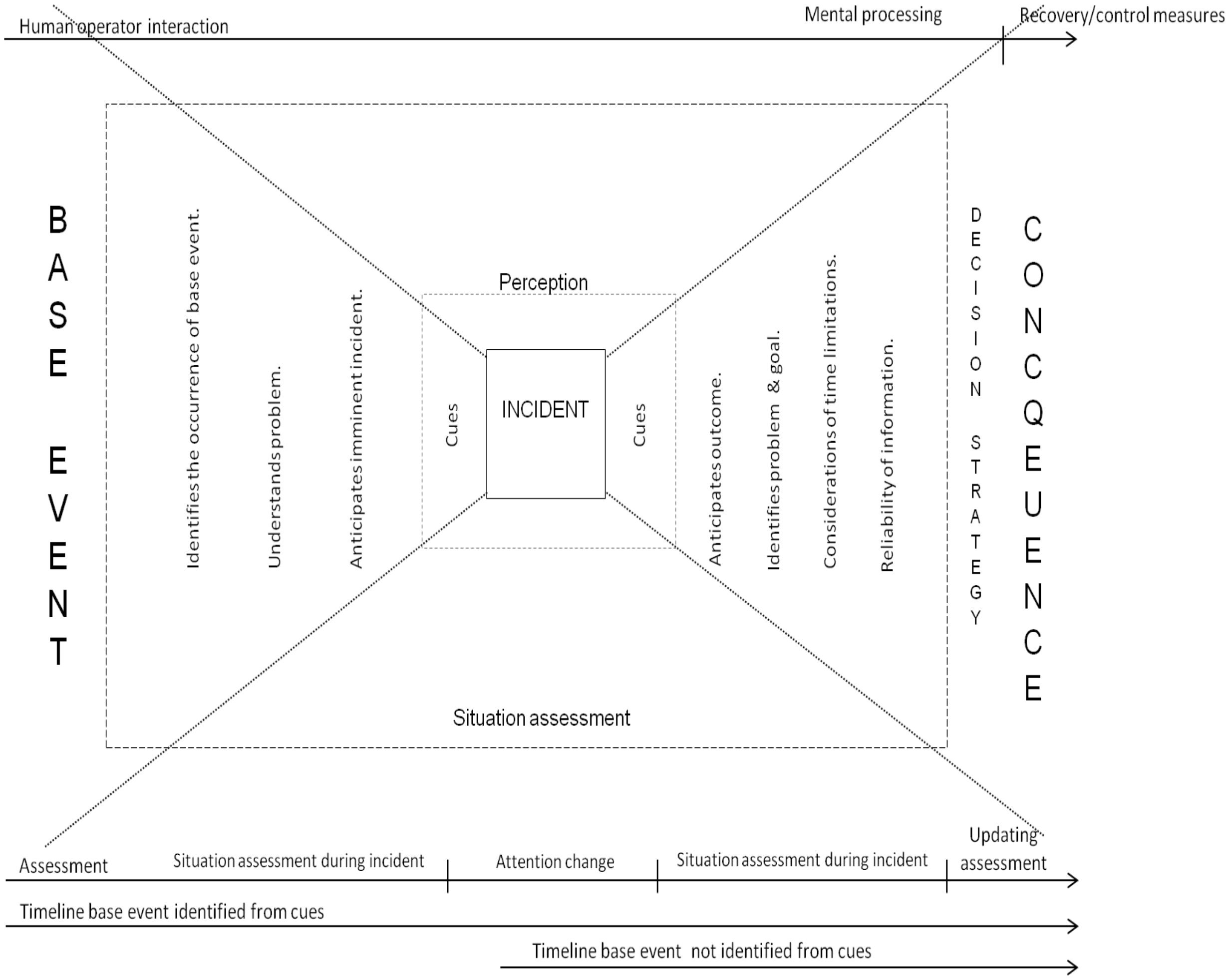

Figure 3. Bow tie model of characteristics affecting critical incidents in DP. The model describes the relationship between Situation Awareness, Experience and Recognition, Decision Strategy and Human and Automation during a critical incident.

Discussion

The objective of this study was to identify characteristics in critical incidents and how DP operators made decisions in critical incidents in dynamic positioning. Through a thematic analysis of the DP operators' reflections, four themes emerged as representative for the main characteristics of critical incidents. These themes were *Experience and Recognition*, *Situation Awareness*, *Decision Strategy and Human and Automation*. In the following sections the results of this study will be evaluated in relation to prior research and findings. First, the characteristics of critical incidents in DP will be discussed, before moving on to a discussion about the decision making process.

What Characterizes Critical Incidents in DP?

Adapting to the unexpected. From the incident recollections 5 categories of consequences, 5 categories of base events and 9 categories of operations were identified. There was no significant relationship between any categories, except a significant dependency between the base event of environmental impact leading to the vessel being forced off its position. Lack of dependencies between categories showed that critical incidents in DP were highly dynamic and complex socio-technical systems. Critical situations appeared *suddenly* and were *unexpected* by the DP operators. The unexpected change might stem from an impact in the external environment, from a human team-member or from a piece of equipment. These sudden alterations proposed a great challenge to the DP operators as supervisors and included changes in wind, waves and currents, structures in the vicinity, simultaneous operations, colleagues that interfered with work tasks, DP equipment out of function and thrusters that malfunction. Whatever the origin, the unexpected impact affected the automated system and its behaviour.

Prior research on critical situations in complex and dynamic domains with human-automation interaction, particularly aviation (Sarter, Woods, & Billings, 1997), has shown that operators often were unable to anticipate and track automation activities and changes. Furthermore, research has shown that failure to anticipate *Automation Surprises* (see Sarter & Woods, 1997) are rooted in misassessments and miscommunications between the automation and the human operator, which creates a gap between the human operator's comprehension of what the automated system is programmed to do and how the automated system actually will handle whatever impact has initiated a change (Sarter & Woods, 1997). From this it follows that in a critical situation it comes to the human operators' ability to detect unexpected and undesirable impacts in time to prevent or recover from negative consequences.

In this study none of the incidents had disastrous outcomes, but they had the potential to develop into full-blown maritime accidents. The primary reason people are present in complex socio-technical systems is to play the role of knowledge worker by engaging in adaptive problem solving (Vicente, 2002). The DP operators saw themselves as having to intervene in order to gain control over the system, when an imbalance occurred. This translated to the other elements in the socio-technical system not being sufficiently adaptive. One informant said: " *The DP system might have managed, but it takes too long. I would not risk it"*. During a critical incident the human operator was required to adapt “on the fly”. This is in accordance with Vicente and Rasmussen (1992) who argued that routine tasks are easily automated but that a socio-technical system is an extended work domain and hence more than the sum of individual tasks. When an unanticipated event occur the human operator is left with having to solve problems by creating new work procedures and thereby adapt to unexpected changes that have not been anticipated in system design. Vicente (2002) argues that the element of unexpectedness is impossible to prepare for on a task analysis level but that a work domain has a set of properties that can, if identified, be utilized as guidelines for managing unexpected change.

A few issues from the thematic analysis stood out as particularly interesting about how DP operators coped with imbalances in complex and dynamic socio-technical systems.

DP operators fight to stay in the loop. A much-discussed potential consequence of automated systems is the out-of-the-loop (OOTL) performance problem (e.g., Billings, 1991; Endsley & Kiris, 1995; Sarter & Woods, 1995b; Wickens, 1992). Operators working with automated systems presumably passively monitor the automation and were therefore slower to intervene when the automation failed (Endsley & Kiris, 1995).

In this study the experienced DP operators saw themselves as the one who was required to control any situation when the automated system failed. They described their role as changing from monitoring to controller in an instant. Being able to avoid crisis clearly showed that the DP operators were capable of overcoming this exact challenge. This may not be the whole truth about critical incident in DP. Endsley and Kaber (1997) described the out of the loop performance problem as including four major negative consequences; vigilance decrement, complacency, skill degradation and loss of SA. The following characteristics were found to be present in the majority of interviews on critical incidents in DP.

Complacency. The accounts from the DP operators clearly showed that concepts similar to what has been described as vigilance and complacency are present in the DP operators' workday. The DP operators describe a work setting where they are aware of, fear for and struggle to avoid vigilance and complacency.

The term complacency originated from accidents or incidents in which airline pilots, air traffic controllers, or other operators seemingly did not conduct sufficient checks of system state and assumed "all was well" when in fact a dangerous condition was developing that led to the accident (Sheridan & Vaplanck, 1978; Parasuraman, Molloy & Singh, 1993; Parasuraman & Manzey, 2010). From this definition the informants in this study described behaviours very different from complacency and vigilance decrement. In experiments Parasuraman, Molloy and Singh (1993) found that complacency affected performance when operators were under the impression that the automated system was highly reliable. In our study, the DP operators said that they had to trust the DP system in daily operation, but *that* *they always also had to remain critical to its performance since they knew from experience it could fail unexpectedly.* This fact - in addition to risk awareness - would lead DP operators to fight complacency with a number of preventive measures such as keeping busy with multitasking, team discussions, actively using the DP systems' software interface and menus and imagining "what if" scenarios. One informant said that when he was bored and everything was working fine he would start to "*think into the system"* in order to get an idea of what was going on in the DP system and therefore keep his focus. This suggests that prior experience of system unreliability influenced and significantly reduced complacency and hence is in agreement with the findings of Parasuraman et al. (1993).

A majority of the informants explained that they were aware of their inability as humans to keep a high level of vigilance towards the DP system over time. As mentioned the DP operators also described techniques and exercises they used to keep focused. It seemed the DP operators lived with a day-to-day struggle, fighting their human nature, afraid of becoming passive and putting themselves at risk. Research on vigilance has shown that humans are poorly suited for monitoring an automated system for failure (Davies & Parasuraman, 1982; Parasuraman, 1987; Wiener 1987; Donderi 1994). In contrast to these findings the DP operators were still able to observe signals from elements in the socio-technical system and intervened before the situation escalated into a disaster in all the incident recollections.

In their research on complacency Parasuraman, Molloy and Singh (1993) found, in contrast to their predictions, that the initial level of automation reliability did not determine the level of detection of automation failure. Rather the dominant influence on complacency was the automation's performance consistency. As already mentioned the DP operators' experiences suggested they should expect inconsistency in DP system performance. In other words operator experience of automation reliability influences both vigilance and complacency.

Trust in automation. Research on trust in automation describe a flawed partnership between human operators and automation and have found human operators often underutilize (disuse) and overly rely on (misuse) automated aids (Parasuraman and Riley, 1997).

In our study, the DP operators described a situation where they never fully trusted the DP system. One informant said, *"You always have to be critical towards the system. If not you should not be in that chair."* On the other hand, the informants also described how they forced themselves to trust the system, simply because they had to in order to perform work tasks. One informant said, *"You have to chose to trust the system. If not you'll go mad".* These statements demonstrate the impact that variability in automation reliability has on DP work settings. The fact that DP operators are forced to rely on a system they cannot fully trust generates a severe challenge to the DP operators, who's limited attention resources and system understanding leave them are unable to provide constant surveillance over the system

This suggests that trust in automation is not a simple binary process but a more complicated and graded process. However, in time critical DP incidents the decision strategy is to lower the automation level in the majority of incidents. It follows that due to time pressure relying on the DP system to solve the problem is not a valid alternative for DP operators. This is in agreement with Madhavan and Wiegmann(2007), as well as Dzindolet, Peterson, Pomranky, Pierce, & Beck (2003) who found that trust in automation can break down rapidly under time pressure or when conspicuous system faults or errors exist.

Manual Skill Degradation. Research on skill degradation in automation has shown that manual control skills dissipate because automation removed the need for direct human control (Sheridan, 1997; Archer, 2012). In this study the DP operators were experienced navigators and were all very confident in controlling the vessel manually. The action taken in the majority of the incidents was to lower the level of automation and manually control the vessel.

Situation Awareness and the Out-of-the-Loop-Problem. The OOTL problem is also concerned with loss of SA. Most of the informants followed procedures and controlled the vessel in manual mode and therefore managed the situation. Does this mean that their SA is high, sufficient or lost? As mentioned earlier DP operators strived to have sufficient understanding of the situation. Sufficient SA in a critical incident in DP meant the ability to predict the correct next action to take (Endsley, 1995). They did have some level of SA because they chose to manually control the vessel and prevented the situation from escalating. However, they did not have the ability to predict the forthcoming events without lowering the level of automation. In other words they were not confident to predict the DP systems next actions.

Procedures versus Skilled Improvisation Without the ability to predict forthcoming events it is understandable why the majority of incidents were resolved by following procedures (lowering the level of automation). Procedures are pre-defined action steps with an already determined priority of tasks. Procedures are included in training, re-training and emergency drills and integrated into everyday routines in DP operation. Six DP operators described incidents where they were able to recover the incident more efficiently by creatively constructing solutions that may or may not be within procedures. These same DP operators also described a deeper understanding of the DP system and were able to exploit the opportunities within the system. This information was not easily accessible and requires knowledge and experience about the DP system. One informant said: *"It was a breach of procedure, but I knew we had sufficient power".*

This shows that the level of SA was not only dependent on the individual, but also on the extended environment (Stanton, Stewart, Harris & Houghton, 2006). In most incidents the DP operators did not have enough information or understanding about the complexity of the dynamic socio-technical system. Neither, did the other elements in the system, such as the DP system. If it did, it was not able to effectively communicate information to the human operator. From a perspective of Distributed SA (Salmon, Stanton, Walker, Baber, Jenkins, McMaster & Young, 2008; Sorensen, Stanton & Banks, 2011) the system did not have SA because the elements in the socio-technical system lacked coordination and failed to facilitate a sufficient level of SA in order for the human operator to act with certainty and confidence. In their findings Sorensen, Stanton and Banks (2011) stated that SA emerges from interaction between humans, artefact and the environment and that Distributed SA becomes necessary when there is more than one adaptive agent present in a socio-technical system. The goal was not for the all systems elements to share all available information, but rather ensure that each element received and provided specific information needed to carry out designated work tasks (Salmon et al., 2008).

Consequence prediction enables DP operators to take control in critical incidents. One characteristic of critical incidents was that the DP operators were continuously updating SA, adapting to the contextual demands. Both in routine and in critical incidents, the DP operators were in a situation where the surroundings changed rapidly. During sudden and unexpected changes it was impossible to remain at a specific and constant level of SA, but they did attempt to maintain sufficient SA by constantly assessing the situation.

Throughout all the incidents the DP operators strived to predict the next event and the situation assessment evolved with the development of the incident. This was in accordance with Endsley's model of individual SA (Endsley, 1995) Similarly, Klein et al. (1986) found that in most cases the fire-ground commanders maintained the initial SA only to elaborate with additional information.

DP operators appeared to maintain whatever degree of awareness they found necessary to perform their work effectively in order to optimize available mental resources. In routine operations this typically included minimal or selective awareness with a focus on monitoring and tracking of necessary information. In critical incidents prediction of forthcoming events were required and the DP operators' role changed from monitoring to action taker. This is consistent with general SA theory (Endsley, 1995, Salmon et al., 2008; Stanton et al. 2006) since SA in DP incidents was determined by task relevance. Before and during critical incidents DP operators received and gave information in a context constructed from a number of conditions. In critical incidents DP operators appeared to have simultaneous, but different levels of SA concerning various aspects of the situation. Therefore the process of reaching levels of SA in critical incidents is not entirely sequential, as Endsley proposes, but could be both sequential and parallel depending on the human operator's attention resources and information available. In the following statement one informant described how he became aware that something was not right, how he formed his decision strategy to follow emergency procedures, but still managed to engage in parallel information processing together with his work partner and successfully recover the incident by updating SA and adapt actions during the incident.

> *"The information on the screen was correct. You saw that the ship moved in (to Emergency Shut Down Zone). You saw the hawser getting slack. You saw it physically happening. But there was no alarm. We were in control. It was a serious and undesired situation. (....................) I didn't understand what was happening. I saw the ship move forward towards the alarm limit (ESD). When the bow passed the first alarm-limit, that's when I knew something was wrong. I didn't understand why. It wasn't supposed to happen. So, I called up the captain. He kept a cool head and said that we should wait and see. We were ready to go to manual in case she would not stop. We stood there and watched her pass the ESD 2 (Emergency Shut Down Line 2). We agreed to try to switch mode and then switch back. Then she reacted and started moving back herself".*

Time is limited and affects decision strategy.-The final characteristic of critical incidents was the fact that DP operators did not mention workload in critical incidents, but emphasized workload in day-to-day operations. The sudden changes in the situation required acute priority of specific work tasks. Workload was not present because of prioritization of work tasks and therefore the DP operators were able to avoid experiencing stress.

The reason was simply because there was just not enough time. Unexpected events were closely related to the amount of time available to evaluate the incident, time to select actions and time to execute actions (Hollnagel, 2001). The majority of informants stated they did not feel they have enough time to think things through.

The ability to correctly anticipate future events and depended on a number of things, such as knowledge and experience, quality of information available, procedures, the regularity of the process and the environment (Hollnagel, 2002). From the interviews it was clear that DP operators depend on procedures in order to control unexpected incidents. Procedures relieve the DP operators from reasoning, save time and enable control of the situation without awareness about what will happen. Procedures are familiar and effective and therefore reduce uncertainty in demanding situations.

What Characterizes Decision-Making in Critical Incidents in DP?

The findings of this study were grounded in NDM and were comparable to the RPDM model (Zsambok, 1997; Klein, 1998; Klein, 2004; Crandall, Klein & Hoffman, 2006). Decision making during critical incidents where characterised by several well-known aspects of Recognition-Primed Decision Making. *First*, DP operators recognized a limited number of decision options during the incident. Eighteen of the DP operator stated that they only had one decision option at the point when the decision strategy was laid out. These findings were in agreement with Klein et al. (1986) who found that experienced decision-makers rarely considered two or more options and tried to figure out which was better. In 1985 research on fire ground commanders in naturalistic settings, Klein et al. (1986) did not find any signs that fire ground commanders attempted to identify several options and evaluate them before concluding. Instead they found that options were directly generated and evaluated for adequacy. The DP operators' descriptions were therefore consistent with Klein et al. (1986) and naturalistic decision-making. *Second*, DP operators recognized patterns of experiences. In this study the DP operators described that they saved their experience as patterns that could be compared to a mental database of recipes utilized for immediately knowing how to respond to various situations. DP operators explained that patterns were built up from actual experience, training and even mental simulation exercises. And, *Lastly*, DP operators used previous experiences in identifying response options. The RPD model emphasizes the role of schematic knowledge structures based upon expertise and experience in allowing a soldier or a fire fighter to make sense of a situation and rapidly to formulate an action (Klein, 1998). All of the DP operators relied on schematic knowledge in their decision-making process and this study supports Klein's findings. One example was from an informant who recalled: *"When we passed ESD 1 and didn't get an alarm, I called the captain"*. This statement showed how the DP operator had a mental representation of what the situation should be. When the actual situation deviated from his mental idea, it triggered him to identify a problem, an objective and finally a decision.

Mental simulation of real and "what if" scenarios. Also interesting is that DP operator mentally simulates the outcome of both real and "what if" scenarios. The findings revealed that all 24 informants described how they prepare themselves mentally by mental simulating incidents that has not happened, but could potentially occur. This is in accordance with Klein, Calderwood and Clinton-Cirocco (1985) who found that fire-ground commanders evaluated a course of action by using mental simulation to imagine how it would play out within the context of the current situation. The findings of this study did not confirm that DP operators mentally simulated courses of action during the incident. It could be that mental simulation with the purpose of evaluating the decision strategy is too time consuming or that the experienced DP operator does not need to mentally simulate because he is certain of the effectiveness of the strategy. The DP operators did however describe mental simulation prior to incidents. The informants described how they spent time mentally constructing and visualizing potential incidents by evaluating possible actions and outcomes. It seems they were able to expand their schemata by imagining scenarios and therefore were able to be better prepared for unplanned situations. Limited time during critical situations in DP could perhaps explain why the operators did not engage in mental simulation during incidents, but rather spent time imagining situations that might not occur. Also the informants described this as a technique to combat vigilance and complacency and keep focused during routine operations.

Situation assessment. With regard to the assessment of situations this study also unveiled some interesting findings. *First*, DP operators engaged in situation assessment to achieve situation awareness, so that they could predict the correct course of action. DP operators reported that they assessed any situation based on their perception of risk. The DP operators described risk as the parameter to measure all scenarios against. High stakes and time pressure are known features of decision making in a naturalistic settings (Klein and Klinger, 1991). This is also the case for DP operators. *Second*, DP operators' situation assessments in critical incidents can be thought of a timeline of mapping out the situation from base event to consequence (see Figure 2). Sudden shifts in awareness when an incident occurs characterized critical incidents. At this moment the DP operator engaged in an intense assessment process to formulate a decision strategy. Situation assessment did not suddenly begin at this moment, but intensified. The DP operators explained how they immediately knew what the base event was or not, something that revealed that they already had a certain level of awareness, based on experience and recognition. T*hird*, The DP operators reported that they recognized certain cues that revealed the underlying cause or base event for the incident. Recognizing the base event, or not, had an effect on expectations, uncertainty and the course of action in critical incidents on DP. In their research on fire ground commanders Klein et al. (1985) found that in some cases certain cues revealed the cause and that knowing the cause had an effect on the situation assessment. The same was found for the DP operators and one informant explained that he knew the vessel's history and system design so well, that when he spotted a change in rpm on the thruster screen, he pinpointed the problem and identified a course of action immediately. Henceforth, these findings are in agreement with the RPDM (Klein, 1993).

Identification of cues. Identification of base event was important to the DP operators because it often made it easier to identify the correct course of action, but it was not necessary to predict an outcome and formulate a decision strategy. The DP operator did not waste more than a moment plundering about the base event. This was also in accordance with RPDM (Klein, 1993). Certain cues in the environment determined how the DP operator assessed the situation. In some incidents one particular cue identified both the base event and triggered the decision strategy. Other times several cues were needed in the assessment. Klein (1993) described cues as necessary to recognize the situation and guide the selection of proper actions. The decision maker identified critical cues that marked the type of the situation and causal factors that explained what was happening and what was going to happen. The DP operators' recollections complied with Klein's findings about critical cues. One informant said: *" The lights went out, everything was quiet. I knew it was a blackout. (....) There was only so many things I could do".*

In the research leading to the development of the RPDM, Klein et al.(1986) found that recognition of cues generated expectations. This was also found in the DP operators' incident reports. An informant described how he recognized a clicking sound from a DP related artefact and therefore expected a specific reference system would fail in the near future.

Effect of time on decision-making. The DP operators said that they had to act quickly because there was no time to think. It seemed that they knew from experience how much time was available and therefore the DP operator’s sense of time in the incidents affected decision-making. The DP operators had difficulties describing time pressure. It was stated in 19 incidents that they did not have time to think and did not experience much stress during the incident. Most of the incidents were reported to be over in between 2 and 4 minutes and that the time to reach a decision took just about one minute. This was consistent with the finding of Chen & Moan (2004), who questioned 17 DP operators about detection and recovery time in collisions in tandem offloading. They found that recovery action initiation varied from 40 seconds and up to a minute. Stop time was from 120 seconds and up to a few minutes.

Endsley and Garland (2000) described the concept of time in SA when they stated that understanding how much time is available until some event occurs or action must be taken, is a critical part of SA. Endsley and Garland (2000) included time as an important part in information integration and projection. The DP operator reports support Endsley's view on time as a strong factor of maintaining high levels of SA. On a different note, Endsley (2000) moved away from real-world time constraints when she stated, *"more SA is always better".* In a naturalistic setting and critical situation this becomes difficult as exemplified by Hollnagel's Efficiency-Thoroughness-Trade-off (ETTO) (Hollnagel, 2009).

Over time the RPDM has evolved and Klein & Crandall (1996) proposes three RPDM strategies. The RPDM strategy chosen by the fire ground commanders depends on the amount of time available for mental simulation and evaluation of the course of actions that were identified in the situation assessment (Klein & Crandall, 1996). The DP operators' decision strategies were consistent with the first and simplest RPDM strategy, as the DP operators did not have time or perhaps found it necessary to mentally simulate the outcome of proposed courses of action. The 19 DP operators who immediately knew they were limited by time did not engage in mental simulation. Thus the findings from this study was very similar to those of Klein and Crandall (1996) and Klein, Calderwood, & Clinton-Cirocco (1985).

Uncertainty of available information. The DP operators were affected by uncertainty in the situation assessment. In the interviews the informants explained that they always critically evaluated the information they received from the external environment. On a different note only 7 DP operators stated that they were uncertain about the information they based their decision on. These results were somewhat conflicting describing DP operators as either suffering from being especially efficient at selecting and evaluating the correct and necessary information or suffering from over-reliance. The RPDM does not include uncertainty in the assessment phase. However, uncertainty is an established feature of naturalistic decision-making (Tversky, Slovic & Kahneman, 1982). Founded on the features of NDM, the RPDM consider uncertainty as an overarching constraint in the decision making process. For the DP operators this seemed to be an important part of situation assessment in critical incidents. One informant explained how the fact that he did not get an alarm when he expected one, made him very uncertain and that this caused him to take a certain course of action. This shows that uncertainty about information clearly affect the decision making process.

Implications for RPDM and SA theory. Critical incidents in DP the assessment process includes the aspects of NMD and RPDM (Klein, 1993) referred to at the beginning of this section, but *differs in the fact that the assessment process is directly affected by time, uncertainty and the identification of base event*. The aim of the situation assessment was to reach the necessary SA level and to formulate a decision strategy. If the assessment process did not provide a high level of SA, then the decision strategy would not be the most efficient and perhaps lack creativity. It is possible that an insufficient situation assessment process and lack of SA contributes to explaining why the majority of DP operators chose to follow procedures and withdraw from the situation. On the other hand, the assessment process also, like the RPDM, explained how DP operators were able to formulate courses of action with limited information, time and certainty. In some incidents the operators were seemingly able to establish a high level SA without having an adequate low level SA. This is not in accordance with individual theory of SA (Endsley, 1995;See also Salmon et al., 2008 for similar arguments of individual SA) and is in conflict with the assumptions of a sequential build up of SA from a low level, relating to the immediate situation, to a high level SA, involving predictions of future system states.

Limitations of This Study

There were three primary limitations of this study: the purposive sampling, the interview technique and the thematic analysis.

Sampling. Only experienced DP operators were sampled, the study cannot say whether there are a difference between experts and novice DP operators. The variety in types of operation was widespread. There were 9 different categories of types of operation and 24 incidents. The study therefore had too low validity to make statements on characteristics related to type of operation.

Interviews. It is possible that the DP operators were reluctant to share information about incidents where they were had lost face or had made decisions they regretted. Furthermore, such incidents involve some degree of controversy since there are always many parties and reputations involved. Social acceptance about what information should be shared in a research setting, such as this, could have affected data collection. It is possible that, in the maritime industry some issues are not acceptable to speak of while others are focused on. Incidents with dramatic outcomes was one type if information that could have been withheld from this study. Another important factor that could have compromised the quality of the data was the DP operators' memories of the incidents. Some incidents were far back in time and some aspects of the incidents might have been lost.

Analysis. One limitation of the analysis was the process of creating meaningful units of information. Definitions of a meaningful unit of information, or code, are hard to verify and was therefore a source of researcher bias and subjectivity. Reliability was improved with definitions of unit content and consistency in the coding process.

Creating theme categories with the ability to convey the content of numerous codes was challenging. A result of not being able to establish a simple definition of each theme was that using well-known and established categories from the human factors field became a substitute solution. The advantage of using already exiting categories was a shared understanding of such categories. The disadvantage was possible limitations in new emergent categories and misinterpreted codes. The thematic analysis produced 20 themes, however, only four themes were found relevant for discussion. It is possible that a different coding process would produce a different weighting of themes. This issue especially concerns the themes on or close to the boundaries created by inclusion criteria.

Reliability. The inter-rater agreement tests where moderate. The moderacy of inter-rater agreement where such that we ougth to consider whether the results were somewhat affected by elements such as researcher bias, inconsistency between raters, random disagreement or that the constructs measured differ from rater to rater. It is likely that agreement would improve if a retest were performed. Detailed rating procedures, definitions of codes and procedures should be thorough and instructive to ensure rating consistency.

Validity. The results of this study are applicable for experienced DP operators in real life critical situations in general as the characteristics identified about critical incidents and time-limited decision-making are thought to be similar for all critical incidents in DP.

Conclusion

Critical incidents in DP were characterized by dynamic and complex socio-technical systems entering into a phase of imbalance due to unexpected changes in the external environment. The human operator was the adaptable element and therefore was required to take control over the situation. The performance of the DP operator depends on situation awareness, vigilance, complacency and manual control skills. In critical incidents time was limited and affected the choice of decision strategy.

Decision-making in critical incidents in DP is naturalistic and recognition-primed. One particular trait and assumed consequence of time limitation was the DP operators' mental simulation of but potential future incidents. The decision-making process was sequential and time dependent. The DP operator's ability to predict forthcoming events was affected and therefore also affected choice of decision strategy. During critical incidents inadequate situation awareness, due to time limitations, presumably inferred highly procedural decision strategies. DP operators' levels of SA were not constant. Process of gaining SA did not sequentially follow the three levels of SA (Endsley, 1995), but the build-up was adaptive and dependent on the information available and how each agent processed the information in the system.

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Appendix A

Norsk samfunnsvitenskapelig datatjeneste AS
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3103 TØNSBERG

Vår dato: 06.02.2013 Vår ref:33042 / 3 / LMR Deres dato: Deres ref:

TILBAKEMELDING PÅ MELDING OM BEHANDLING AV PERSONOPPLYSNINGER

Vi viser til melding om behandling av personopplysninger, mottatt 28.01.2013. Meldingen gjelder prosjektet:

33042	*SITUMAR - Situation Awareness and Decision Support Systems in Demanding Maritime Operations. Delprosjekttittel: A Day in the Life of a DP-operator*
Behandlingsansvarlig	*Høgskolen i Vestfold, ved institusjonens øverste leder*
Daglig ansvarlig	*Kjell Ivar Øvergård*
Student	*Tone Janeth Skare Martinsen*

Personvernombudet har vurdert prosjektet og finner at behandlingen av personopplysninger er meldepliktig i henhold til personopplysningsloven § 31. Behandlingen tilfredsstiller kravene i personopplysningsloven.

Personvernombudets vurdering forutsetter at prosjektet gjennomføres i tråd med opplysningene gitt i meldeskjemaet, korrespondanse med ombudet, eventuelle kommentarer samt personopplysningsloven og helseregisterloven med forskrifter. Behandlingen av personopplysninger kan settes i gang.

Det gjøres oppmerksom på at det skal gis ny melding dersom behandlingen endres i forhold til de opplysninger som ligger til grunn for personvernombudets vurdering. Endringsmeldinger gis via et eget skjema http://www.nsd.uib.no/personvern/meldeplikt/skjema.html. Det skal også gis melding etter tre år dersom prosjektet fortsatt pågår. Meldinger skal skje skriftlig til ombudet.

Personvernombudet har lagt ut opplysninger om prosjektet i en offentlig database, http://pvo.nsd.no/prosjekt.

Personvernombudet vil ved prosjektets avslutning, 31.12.2014, rette en henvendelse angående status for behandlingen av personopplysninger.

Vennlig hilsen

Vigdis Namtvedt Kvalheim

Linn-Merethe Rød

Linn-Merethe Rød tlf: 55 58 89 11
Vedlegg: Prosjektvurdering
Kopi: Tone Janeth Skare Martinsen, Vestre Karmøyveg 266, 4275 SÆVELANDSVIK

Appendix B

Interview Questions

A. Can you describe a regular workday in DP-mode

B. We are going to talk about critical incidents in this interview.

-How do you define critical incident? Hva legger du i begrepet kritisk hendelse?

-Do you experience critical incidents often when doing operations in DP? How often would you say critical incidents occur?

-Can you remember a critical incident when doing operations in DP?

1. What happened? Please describe.

2. What were you trying to achieve when this incident occurred?

3. How did you act?

- Which cues had influence on how you made your decision?

-How did you become aware that something was wrong?

-What were you looking for? Which information in your surroundings…?

- Which information did you use to reach your decision?

4. Did you expect something to occur?

-How did such expectations affect your decision?

5. Can you describe which information were available for you at the time?

-did you use all available information?

-can you think of other information which could have been useful?

6. What was the most important piece of information available?

7. Were you at any time uncertain about the reliability or relevance of the information available to you?

-were you at any time uncertain about your decision?

8. Could you have acted differently in this situation? Made a different decision?

9. Was it at any point challenging to process the information available to you?

-How did it affect you?

10. In this incident, were you reminded of previous experiences, where a similar decision was made?

11. In this incident, were you reminded of previous experiences, where a different decision was made?

Appendix C

Demographic Questionnaire

1. Are you? Male☐ Female☐

2. Age -----

3. Do you have a nautical education? Yes☐ No☐

4. How many years experience do you have as a seaman? -----

5. Please describe your DP-education/certification?

6. How many years of experience do you have as a DP-operator?

7. Please describe your DP experience?
   (type of vessel, type of DP-system, type of operations, vessel DP-class, your position on board, how many years on vessel types, etc)

Appendix D

Participant Consent Form

As part of the SITUMAR-project the Human Factors Research Group at Vestfold University College, Institute of Maritime Technology and Innovation would like to conduct a research project that aims describe and understand the work situation of DP-operators. The Norwegian Research Council (NFR- project nr. 217503) and Kongsberg Maritime are co-financing the SITUMAR project.

The research project aims to further the understanding of the work situation of DP-operators and to identify elements that occur prior to and during critical incidents in DP-operation. This knowledge will then be used to design the next generation decision support systems for use in demanding maritime operations.

The research will be based upon an interviews performed by Tone Martinsen. The duration of the interview is circa one hour. To ensure your anonymity only you and Tone Martinsen will be present during the interview.

During the interview we will ask about the normal daily work day. We will further ask participants to describe two critical incidents concerning DP-operations that they have experienced. The interview will be an open conversation involving a set of questions relating to activities before and during critical incidents. The aim will be to uncover challenges with DP-systems and the interaction between DP-systems and DP-operators.

All informants will be ensured full anonymity. All information will be treated confidentially, and it will not be possible to trace the information back to one individual in any publications which spring from this research project. A sound recorder device will be used during the interviews. Access to the recordings will be restricted via password access and only Tone Martinsen and Kjell Ivar Øvergård will have access to the sound files.

The interview will be transcribed for use in data analysis. Transcripts of the interviews will be de-identified so the contents are not possible to track back to a single person. The sound recordings will be deleted and the participant fully anonymized when the master thesis is completed, 31.12.2014 at the latest.

Please direct comments and questions to Tone Martinsen (email: tone.martinsen@student.hive.no) or to the Project leader at Vestfold University College, Professor Kjell Ivar Øvergård (phone: +47 986 48 233; email: koe@hive.no).

You can withdraw from the interview at any time. In that case, the information you have given, will be deleted and not used.

If you would like to participate, please sign to consent. In giving my consent I acknowledge that:

- I have been informed of the purpose of the research and how the information will be treated.
- The procedures for the interview have been explained to me.
- I understand that I can withdraw from the study at any time without any consequences.
- I understand that my involvement is confidential and no information about me will be used in a way that can reveal my identity.
- I understand that the written results of this study may be presented in a master thesis, and at research conferences and in scientific articles.

Name____(date and signature)

Thank you very much for your time and support.

Transcript of Random Interview

Interviewer:

Now we're on.

Can you describe a regular day in DP mode?

Participant:

In DP mode. It's 12 hours shift with one hour swings on the desk. So the operation is routine. It really depends on the operation.

Pause (Fire watch reports on the radio)

So it depends on the operation, cause sometimes it seems to be quite steady routine operations with not much happening. If have f.eks. technical drilling, floatel. It just general monitoring of the system performance/vessel performance on the position. Just controlling everything is within the limits. The weather is within limits. If the vessel is within the class requirements for operation.

On the other hand if you have diving, subsea construction or ROV operations, sometimes it is quite busy. A lot of movements on the vessel. Position changes, alterations. Bumping from one location to another. Changing from DP mode to conventional navigational mode. Transiting a few miles away to a new location. Setting the vessel again in DP, going through the checks, resuming the D operating. So it all depends on the operation.

It depends on the operation?

Sometimes it is very steady very routine.

Interviewer:

Yeah

Participant:

DP actually DP related issues are not bothering you very much. Sometimes you have to be much more focused on other activities. Related to our position. Like ballasting the vessel. Cooperation with other vessels on the field. Like Supply vessels. Some times all sorts of administrative work. Communication. So, all these.... Other jobs that are not directly related to . So rather like officer of the watch duties.

Interviewer:

We will move on to talk about critical incidents. How would you define a critical incident? What is in that definition for you?

Participant:

For me a critical incident an incident which is something related to the incoming guidelines on the DP. A vessels. A red DP status. Loss of the control of the vessel at the DP level. If you are talking about the DP operation I would call it DP critical situation if the incident when the DP is not functioning anymore or the vessel cannot be controlled from the DP level anymore. And we have to change the mode, or we are forced to change the mode. That is for me critical situation.

Interviewer:

So, do you... Would you say you experience critical incidents often in DP?

Participant:

No, actually for ten years of my experience as a DP operator, I only experienced such situation once, where we had total loss of control over the vessel. In DP, and we had to transfer the emergency mode into manual control. So it happened once.

There were on various occasions single failures. But as the majority of the vessels now and the majority of the vessels I used to work on, meet at least class 2 requirements. DP class 2 requirements. Such single failures should, and they don't lead to a critical situation. So it's still within the limits and control. Giving us enough time to react and suspend the operation in a safe manner. There was only one occurrence with red light critical situation over those ten years.

Was that a situation when something really dangerous happened? Yes the vessel was drifting alongside an installation with the gangway connected and, so that was a critical situation. So it was very critical and potential consequences could be really serious. Multiple fatalities if we had hit the installation. drifting towards the installation It would be a major and serious accident.

Interviewer:

Ok, so if I ask you to remember two critical incidents from your experience...

Participant:

No, I would recall. I would say as per my definition of a critical incident as loss over the control over the DP system, I experienced only one. So all other failures and problems were limited to like a single failure. Yeah. So these was a failure of the one component within the DP system, which still can be recovered by the redundancy. So it doesn't lead to such a critical situation where you have to switch out of DP and move to manual control or lose control over the vessel. So as long we are able to control the vessel it's not a critical situation for me. It could be dangerous situation, but it's still within the limit of the control.

Sorry. *(radio communication with deck crew)*

So that's one thing a DP operator has to handle *(referring to radio interruption)*

Interviewer:

Yes, I understand

Participant:

It's much more job than controlling the vessel.

Sorry again *(Another radio interruption.)*

Interviewer:

You described what you defined as a critical incident, and you said that ...

Participant:

And it happened only once

Interviewer:

And then we went on to see if you experienced critical incidents often and you said it was not a daily thing it was not routine.

Participant:

No, no, and it shouldn't happen often as the vessels are protected by class rules against single failures or critical failures. Usual experience is single failure, which can be resolved before a critical situation or That s the whole idea of redundancy, to survive such single failure.

Interviewer:

Can you remember one incident where you were involved and what happened?

Participant:

Are you talking about a critical one?

Interviewer:

Yes , a critical incident.

An incident you would say was out of normal operation.

Participant:

Well...

Interviewer:

It does not mean that there would have to be a bad ending. Something out of normal operation

Participant:

Such problems happens very often, as I said, but usually it is limited to single failure. So it is something which you can control. So such single failures happens.. several times...mmm.... difficult to recall all of the... partial blackout, drop of reference, happens on occasions.

Interviewer:

So, now we're going try to remember two critical incidents. We'll go through one and then the other.

Participant:

Well, the critical one was loss of thruster control. It was related to the interface between the DP system and the thruster control system and it resulted in a loss of thruster on the DP desk and uncontrolled drift of the vessel. So we had to switch over from the DP control to manual control and control the vessel in manual mode, choosing the manual levers and controlling the individual thrusters. So that's the most serious accident I experienced.

Interviewer:

What were you trying to achieve when this happened? What was your mission?

Participant:

The most important thing was to secure the gangway, close the traffic on the gangway to protect people from stepping on the gangway. and the vessel drifting and avoid collision with the installation. The main goal was to avoid collision with the installation. working at.

Interviewer:

What was your operation at the time

Participant:

It was a floatel

Interviewer:

As a floatel

Participant:

The main goal was to avoid collision

Interviewer:

How did you act?

Participant:

Well...... after we concluded we lost control over the thruster on DP and we just followed our emergency procedures. Like calling the master, closing the traffic on the gangway, switching the red light on, Then switching over from DP control to manual control. Controlling the vessel manually trying our best to limit the extent of the incident and regain control of the rig.

Interviewer:

Which cues had influence on how you made your decision at the time? What impressions from the environment, from the technical equipment or... What made you reach a decision?

Participant:

Well, it was the general overview of the situation. That's why we are on the bridge. To monitor, so you ..mmm... to monitor the situation the performance of the system. so you use all inputs available. So you monitor the DP displays the visual monitoring the surrounding areas, positions in reference to the nearby platform. We use the reference system to monitor the position, but also visual reference monitoring. Indicators of the individual thrusters. So its ...All available input we control we are on shift on the DP desk, we control all available input. Just monitor the performance. Having the input from many sources we concluded the vessel is out of control, the failure in the system and we just made our decision based on this information. So there is no single source, but multiple sources of information and then we make our decisions just sing all available resources.

Interviewer:

Ok

So you were not looking for some specific information, you used all of it

Participant:

No, We use all information yeah as well as our own experience and also our own judgment

Interviewer:

Experience and judgment

Participant:

Sometimes it can be quite an individual decision, quite individual situation, the development of the accident could depend on the individual. How she or he receive interpret the situation. So, it is also comes with the individual persona, experience...

Interviewer:

So, did you expect anything to occur when you were on DP watch, sitting there.... Did you have any expectations that something would go wrong...?

Participant:

Yes, that it is always what I feel like at watch. It's my reason to be there. You don't need a DP operator if everything works as expected. When the system is out of position and everything works as it should you are not. You don't need DP on the desk. The job of the DP is actually to act when something goes wrong. That is why we are sitting there. That what we have to be ready for, for taking action if something goes wrong.

Interviewer:

But was it anything in particular in this situation, scene or situation that..

Participant:

No, but this is my general approach. Always when I take a seat at the desk. I'm thinking about, preparing for taking the watch. I consider, ok, what potential hazards can develop and how do I react to it. Working on for instant escape routes. How I move in case of any problem. What would happen with the vessel? How should we be drifting? If the vessel is going to drift towards the installation or off the installation. These are all factors that a DPO should consider, should be aware, should be prepared for, and implement later on in case of emergency.

Interviewer:

Catch the impressions so you can use them later on.

Participant:

Yes, and be prepared and ready for emergency any time. Actually that's the key thing, which is the most difficult to achieve. Work with DP is like 98% of the time it's boring with nothing to do and then there is just like 2% excitements and having to perform with the highest standards. Cause this is when you respond to any problems.

Interviewer:

So, you have a general approach when you sit down at the desk to keep you at a level of awareness in a way.

Participant:

Yes, of course we depend on your location and operation and if you have any risk involved with an installation or.... Divers in the water. That is the highest risk operations. That is when you have to be highly alerted all the time and ready to respond, because in such situations we are close to the installations or have divers in the water there is not much time to respond. So if something happens there is no time to think about the possible solutions or to think how I will respond. You should have your response prepared or ready. You should be ready to respond, we need to have emergency plans ready. So that's how you should, how I prepare..

Interviewer:

So, we talk about information available to you, right. Can you describe a little more about which specific information are available to you. At the time you made the decision.

Participant:

mmm. ... so first is situation awareness. What's our surroundings, potential hazards related to this. So potential hazards related to the job, potential hazards the location. A nearby platform, maybe another vessel operating nearby. So, mmm , for sure weather in the situation, weather versus vessel capabilities. so, How the vessel is performing in this particular weather, within the limits we have, or safety margins. Power wise. That's the information, input you have to control all the time and consider. How much power or power margins are left vs. weather or operation. Sometimes the operation itself will require extra power consumption.

Interviewer:

So in this situation when you had this problem, being a floatel, what happened. You withdrew by manual.

Participant:

Yes, we escaped collision by driving the vessel manually.

Interviewer:

Then you described all the information available to you. Now, did you use all the information available to you? Or did you use only specific parts of the information.

Participant:

Mmmm. I think all information was taken into account as a factor or influenced the final decision cause that has to be considered. There are so many factors that you cannot limit it to only a few sources. Cause everything matters. Wind direction, sea direction it matters it will affect the drift. The distance to the platform. It will affect. The available thrusters, the available power it also affects so you have to use all possible information.

Interviewer:

So can you think of any other information that you didn't have that could have been useful to you?

Participant:

Well, mmmm, not really. Not really. I think we had everything we needed.

Interviewer:

Would you say there was one piece of information that was vital, that stood out from the other information?

Participant:

For sure, the most important was the alarms on the desk and the information our case it was information regarding the thruster performance. Cause that was the problem. The information about the system status and conditions and the components. Particularly the components we had a problem with. Then this information would be vital. Because that is where your decision starts from. You have to know what the problem where it is. Which component is causing the problem

Interviewer:

and then you..

Participant:

And then you have to start from there.. yeah. and then ok That is where I have a problem. These are the potential consequences of this problem. This is how the situation is developing. Ok this is how I can counteract or react to the situation.

Interviewer:

So, where you at any time uncertain about the information, the reliability or relevance of the information?

Participant:

Yes, because as we had a problem with the thrusters it was quite difficult to get insurance that the thrusters actually didn't work in DP. They were lost because the information we had it was very confusing, cause the system was indicating that the thruster were available and working and the next second it was showing that the thrusters weren't available and wasn't working. And then again that it worked. So that was a confusing part and the most difficult, the most critical step to verify using other methods. The status of the thrusters if it works or not?

Interviewer:

Would you say that uncertainty would affect your decision

Participant:

For sure it could affect.

Interviewer:

Did it in this situation?

Participant:

No, it didn't affect in our case. But I can imagine situations where it would affect, depending also on the experience of the person and the approach to the situation.

Interviewer:

How familiar with the vessel, the operations...??

Participant:

Yes yes

So, it could potentially affect the decision process, because it was very confusing to actually decide if we already had a problem or if it was just a wrong indication. But this was a very particular problem, I think a very specific situation

Interviewer:

Could you have acted differently in this situation?

Participant:

Of course there was options or possibilities to act differently. Also it was not only myself who made the decision. We were working as a team, two DPO's. It was teamwork. But yes there was a risk when the decision was made, that the decision would be wrong. This wrong decision could be based on the misleading information from the system.

What we actually did after the whole accident. It was reviewed and it was perfectly correct. So, actually we were lucky. So we acted as expected, but there was a possibility that we could have made the wrong decision.

Interviewer:

Would you say that at any point it was challenging to process all the information given to you from the surroundings?

Participant:

well, if something goes wrong it could be challenging? In this particular incident, scenario or situation or experience definitely it was a challenge.

Interviewer:

How did that affect you? Did it make you stressed uncertain??

Participant:

Not in the situation, because the situation was developing so quickly that you don't have the time to stress. You just need to react, but afterwards of course it was a stressful situation. It was quite a serious accident and not many DPO's experience this. Total loss of control over the vessel. Definitely it was a stressful situation afterwards. The whole investigation process. It is not very nice when all your actions are questioned and you have to explain and justify every decision that was made and just prove that all was as it should be. So as whole the situation was stressful, but when it was happening you don't have the time.

Interviewer:

So in the moment when you have to make the decision, the information processing is....

Participant:

No, you are so focused that you don't think or consider if you are stressed. The whole event was over in less than two minutes. The adrenaline rush is later.

Interviewer:

So you are calm in the situation and then you have a reaction:....

Participant:

Of course after you get to safety, then you realize it was close to a really serious accident.

Interviewer:

In this incident were you reminded about previous experiences, where similar decisions were made?

Participant:

Well, I think that at this moment I had to use all my experience from previous minor situation or incidents. They influenced my decision making process. For instance that I didn't hesitate to switch over to switch to red light and making the decision to just move out. That was my previous experience. There shouldn't be any hesitation. I feel like doing something in a situation I should follow it and not feel.... . I felt like a was in charge. Like Having total freedom to make any decision. That came from my previous experience. I didn't hesitate for instance to switch from DP control to manual control. I knew that it was.... I shouldn't hesitate, be afraid to do it. I'm in control now. It is my decision. I don't bother about potential consequences, for instance excuses from management for why I had done it. maybe you should stay there.

Interviewer:

You didn't take that into consideration...

Participant:

That was for sure from my previous experience. I was afraid to take control and to act as to my best knowledge. I was quite confident about what I was doing.

Interviewer:

If I turn the question...

In this incident were you reminded about previous experiences, where a different decisions were made? Not a similar decision, but a different decision?

Participant:

If you could clarify what..

Interviewer:

In the last question we were looking at your previous experience and relating it to similar experiences and making similar decisions. If we turn it around and say can you remember if you have used experience where you have not made a similar decision?

Participant:

Well, I don't think that experience is something that you have to repeat. I mean that experience is such that you repeat your action. It is just that you have events in you past that you have learned something from, but it doesn't mean that each time you have to make the same decision based on the experience. Maybe that previous experience will cause you to act differently actually than last time. So it is not just repeating the action it is understanding and making a decision. Projecting the end.

Interviewer:

So can you remember any. In this incident were you reminded of any previous experiences that were of a different kind of decision making?

Participant:

Not really. I think it's just with experience. Confidence in your actions. the greatest lesson I learned from this was gaining my confidence in my knowledge and experience in my decision making process. Being able of taking the responsibility and acting as expect. That is like the biggest experience from this particular accident. Confidence. It doesn't mean that next time a similar situation happens, I will make the same decision. But I think I will have the confidence that ok I will. Each situation is different and I'll have to judge and assess the situation individually. And what is the gain from this is that the next time I will be more confident in what I am doing.

Interviewer:

Now we have gone through one incident. Now ca you remember a second incident?

Participant:

I'll try to remember. Ok. Something. It could be a blackout. Blackouts happens often. Actually that time I acted completely different.

Interviewer:

What happened them?

Participant:

We had like a blackout. Diesel drive

Interviewer:

What kind of vessel

Participant:

Pipe laying vessel

Interviewer:

DP 2 or DP 3?

Participant:

class 3

We had a situation where we had total blackout on the vessel. But the thrusters were driven by diesel engines, so actually this blackout didn't affect the position keeping. What actually we could do was to rise the arms and just panicking about the position, but actually we stayed cool on the bridge and we just knew that it was a blackout. And most of the vessels would drift away from the position. In our case, due to the particular design of the vessel, actually we maintained the position, despite that everything was black and the majority of the equipment on the bridge didn't operate. Some system servers were working maintained by UPS. We were able to maintain position. So actually no reaction was a good reaction. To the extent of the DP.

Interviewer:

Were you doing pipe laying operations?

Participant:

Yes, it was S-lay with movements 20meters, welding joint, So-called Rigged Pipe S-lay.

Interviewer:

How did you react?

Participant:

Actually we just, of course we activated the alarms which were expected or required by procedures. Actually, not taking any actions in regards to the DP system was the correct action, because we lost a lot of equipment and we lost the information about the position and anyway the vessel was maintaining the position. So, because as I said it was a tricky situation because we had lost all electricity onboard, but anyway due to the particular design of the vessel...

there was no second source to confirm what was happening in DP. We were quite,.. our trust in DP indications are always limited. We always like to have this information doubled from independent indicators.

Interviewer:

Did you expect this to happen?

Participant:

Not that a blackout would occur, but in general we are always prepared.

Interviewer:

What information was available to you?

Participant:

It was a blackout. Most screens were black. Only what was on UPS, but you could not control anything. We could see position from independent equipment. We had alarms. We could hear the thrusters still running.

Interviewer:

What would you say in this incident was the most important piece of information?

Participant:

In this particular incident the position it was the independent source of position.

Interviewer:

Where you uncertain about the reliability of the information available to you?

Participant:

Yes, in the moment yes. This type of blackout, it shouldn't affect the position keeping, but anyway it was not a usual situation to lose all power on a boat. So of course we were looking for independent sources to confirm that the system performed as expected.

Interviewer:

Were you at any time uncertain about your decision?

Participant:

No, I don't think so, but it's such a long time ago. It is difficult to recall it.

Interviewer:

Could you have acted differently, made a different decision?

Participant:

No, not really. I don't think so

Interviewer:

Was it at any time challenging to process all the information available to you?

Participant:

No, because the information was very limited. The most challenging was not to have the information. Having this confidence that the system would perform as it was expected to. This is why I recall this incident, because it was slightly different. You shouldn't take any action, just believe and have the confidence in the system.

Interviewer:

In this incident were you reminded of previous experiences where you have made similar decisions?

Participant:

No because I have never been on such designed vessel before. It was due to the design of the vessel that the ship performed as it did. It was my first such experience for me. And that is why it was actually a strange feeling for me. Because usually when you have a black out, usually it is a partial blackout. You lose some engine, ... So there is an interaction with the position keeping. On this occasion a black out occurred and it was a total blackout. Our generators were lost. Because we had diesel drives for the thrusters, the system and vessel was performing on position like nothing happened. That was the whole problem and tricky situation. Sitting and waiting for the system.

Usually the DPO's are afraid of black outs and loss of power, the greatest fear. And it happened and there was no consequence. That was confusing and strange. The whole situation.

Interviewer:

Then we turn the question again. In this incident were you reminded of any previous experience where you had made a different decision?

Participant:

Not really, I don't recall such a situation.

Interviewer:

Because this was such a particular kind of vessel and situation. Black out

Participant:

Yes very particular set up and circumstances.

Interviewer:

You did not have any similar experience.

Participant:

No it was the first time on such a designed vessel.

Interviewer:

Ok that was it.

Appendix F

Description of Themes From Thematic Analysis

In the following paragraphs 13 themes will be described and exemplified with a statement from the interviews. Seven themes (Hindsight, Workload, Alert level, Confidence, Problem identification, Personality type and Working environment) are not described further due to low frequency of occurrence and are therefore considered off less importance in this study as they were mentioned in less than half of the incidents.

Situation Awareness. Maintaining necessary awareness is a key factor to cope with the challenge of the contrasting human operator role in DP. The informants stated that SA is ensured by several tools and routines such as checklists, handovers, Table Top discussions and other work routines. The level of risk and type of operation affected the operators' initial level of SA. SA was continuously updated and not constant and was affected by sudden changes in the situation (Endsley, 1995). The level of SA was dependent on the assessment process. The following statement demonstrate the importance of SA when a new shift begins: *".....you begin your watch with a handover and checklists. Get to know what has happened on the last watch."*

Experience and Recognition. Experience seems to affect every aspect of a DP operator's work, both in routine and non-routine operations. DP operators gained experiences over time from daily operations, training and education. Experienced DP operators claimed that experience affected their decision-making process. DP operators relied on mental patterns stored in memory to solve problems. DP operators stated that these patterns were gained from experiences or simulation of potential situations. Experience and patterns were transferable and used in both similar and dissimilar situations. One informant stated that: *"I find it often comes down to experience."*

Human and Automation. Vessel station keeping through the use of DP affected the DP operators' workday. The informants described their work as composed of long periods of supervision and monitoring followed by intense periods where they are having to take over the controls when the automated system fails. Knowledge of and understanding of the automated systems varied from operator to operator and challenged the human-automation cooperation. The following statement described the theme Human & Automation during a blackout where all screens went black and the information was limited, but the vessel's redundancy helped the vessel keep position. The following statement exemplifies.
"Actually, not taking any actions in regards to the DP system was the correct action.........due to the particular design of the vessel...... This is why I recall this accident, because it was

slightly different. You shouldn't take any action, just believe and have the confidence in the system."

Decision Strategy. DP operators had to make decisions within a limited timeframe. In this study the DP operators utilized three decision strategies. Mandatory emergency procedures, time, trust in information and confidence were some of the factors that affected the choice of decision strategy. The DP operators said they made their decisions based on prior experience (Klein et al. 1986). Also, they stated that no two situations are the same, but that they recognized sequences or parts of situations they had encountered before, and used such experiences as the basis for decisions. During the decision-making process the DP operators produced very few decision options. In most incidents only one option was generated. The following statements exemplifies: *"The lights went out and them I knew what to do. I didn't even look at any screens."*

Uncertainty. Trust is an issue that concerns the automated system, but also the certainty about information from other sources affected the human operators. Co-workers, navigational equipment, weather forecasts and external technical personnel were mentioned in the interviews. The degree of certainty affected the decision-making process and how the DP operators' work with the DP system.

The operators claimed that it was necessary to remain critical towards the technical artefacts. On the other hand they said that they, on some level, had to trust the DP system. However, there was an underlying element of uncertainty in every aspect of being a DP operator. As one informant said, *"Of course, like I say, you should be able to trust the system. But you cannot let it live a life of its own. You need to be prepared, somehow, for unexpected things to happen."*.

Time. DP operators either have too much time or too little time. Normal operation was characterized by long hours with little activity. This is an important characteristic of working with DP systems. The informants described their regular work day as boring and that they undertook both practical and mental activities two keep focused and help pass time more quickly. On the other hand, sudden shifts and time limitation characterize critical incidents.

DP operators seemed to know from the very early stages of a critical incident, how much time was available. They recognized information in the situation that told them if they had time to think or not. This affected their decision-making process. One informant explained how limited time to think affected his decision: *"No, I didn't have time for that. I just used the joystick."*

Team. Teamwork is a part of being a DP operator, although most of the time the operator was monitoring the system alone. DP operations often involved cooperation with several other parties such as divers, drilling crew, other vessels, management personnel, etc. Influences from other members of the team can affected decision-making. Hierarchy is a strong concept in the maritime industry and was mentioned by the informants as both helpful and clarifying as well as challenging and a source of confusion. The following statement exemplifies teamwork in operation monitoring:

"Anyway, one of us starts with the DP checklist. The one who takes first watch. When he is finished, the other one quickly looks through and signs that he is familiar with the set up and whatever else is in the handover. The other one goes through the thrusters system and cross that checklist."

Automation Feedback. The DP operators stated that the automated systems' ability to communicate what it is doing and what it is going to do affected their decision, particularly during critical incidents. One informant described how conflicting information from the DP system affected him: *" .....it was very confusing, cause the system was indicating that the thrusters were available and working and the next second it was showing that the thrusters weren't available and wasn't working."*

System understanding. Knowledge of how the DP system worked, was set-up and limitations were included in DP training. The informants explained that system understanding affected decision-making in critical situations. They also described how their understanding of the system increased with experience. System understanding therefore differed between DP operators. Several of the DP operators stated that they believe system understanding is necessary in order to be prepared for unexpected situations and that they see it as their responsibility to educate themselves. The statement below described the reaction of a DP operator who did not understand the system.

"I'm not sure what he was doing, but he ended up losing both operator stations. He, he, and it all went black. He totally panicked and was running around. I asked him what the problem was and told him that we are not moving anywhere. (.......) I think he was re-booting or something. He was in full panic because the screens went black. He wanted to go to manual and I don't know what. (.....)It's just a computer. It freezes, but as long as the controllers are up, you are keeping position."

Operating Envelope. DP operations were limited by the characteristics of all the elements in the system, often referred to as the operating envelope. The operating envelope was determined by a number of boundaries, such as vessel capabilities and weather conditions. One informant described how such boundaries affected his work of performing complex operations within these boundaries: *"Just controlling everything is within the limits. The weather is within limits. If the vessel is within the class requirements for operation."*

Procedures. Work procedures and emergency procedures are vital and mandatory in maritime operations. The interviews revealed that procedures are important in DP operations and procedures served as a guide in operations, both in planning activity, during operations and in critical incidents. In critical situations the decision to follow procedures dominated alternative solutions. The DP operators described procedures as both a helpful tool and an obstacle forcing their actions to follow a defined sequence: *" We always follow procedures. That is never a discussion".*

Information selection. In DP operations information could be scarce or overwhelming. The DP operators described how they only picked out specific information that they relied on and utilized in further decision-making. Information sources in DP operations were the DP system, the natural environment, colleagues, other technical equipment and the DP operators' knowledge base. The following statement exemplifies how only specific information is selected: *" I had all the information, but I only used the thruster screen."*

In summary these 13 themes describe DP operations as experienced by the informants. The themes show that DP operations are demanding due to shifting operational settings. Variation in operational settings affected the human operator and decision-making in critical situations.