Situation awareness information requirements for maritime navigation: A goal directed task analysis.

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Situation Awareness information requirements for maritime navigation: A Goal Directed Task Analysis

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Abstract. Maritime shipping transports about 90% of the international trade and is considered a high-risk industry. Among all daily operations carried out by merchant ships, navigation is deemed the most critical. With the ever-increasing dimensions of ocean-going ships and the threat possessed by dangerous cargoes in the event of an accident to individual lives and environment alike, the human factors which affect the navigation of merchant ships require paramount consideration to enhance safety in maritime operations. In this study, we explore the concept of Situation Awareness (SA) within the maritime domain, identifying the SA information requirements of navigators and factors affecting their SA. A total of 7 experienced navigators were interviewed in this exploratory study to determine the SA information requirements by a Goal-Directed Task Analysis (GDTA). Three Subject Matter Experts (SMEs) possessing Captain's license for merchant ships were used for validation of initial findings. The findings reveal the information navigators use during the pilotage phase of navigation and further classify them in three levels. The findings shed light on the factors that affect SA of navigators and are discussed with their potential implications for the procedures and practices which better support SA in maritime navigation.

Keywords: Situation awareness · Navigation · Pilotage · Goal-directed task analysis

1 Introduction

Many modern industries can be best described as complex socio-technical systems where human and technological elements operate in tandem and have interdependencies to achieve system objectives (Walker et al. 2008). The role of human operator is particularly discussed when highlighting vulnerabilities of the system as *"the human error"* is frequently cited in accident reports (Grech et al. 2008, p.12). Attributing the entire culpability to the human element would be incorrect when considering the socio-technical model, but the error on the part of operator can contribute to make the system more vulnerable (Kim et al. 2016). Modern day operators are faced with an increasing volume of information to process and comprehend before making critical decisions. The introduction of automation has also brought some unexpected outcomes (Nazir et al. 2014). While the introduction of automation has reduced operator load, at times it has left operator with what often is termed as *"Out of Loop"* syndrome where s/he is unable to respond adequately to challenges posed by the system (Endsley and Kiris 1995).

Situation Awareness (SA) is a general term given for operator's dynamic awareness of the ongoing external situation (Salmon et al. 2009, p.8). The concept of SA which traces its origins from the military aviation domain (Endsley 1995a) has also led to research in other domains and can be termed as a fundamental concept in the operation of complex socio-technical systems (Masys 2005). The maritime domain, like other high risk industries, utilizes the socio-technical model for formulation of procedures, design of equipment, and training of personnel (Grech et al. 2008, p.32). In their analyses of maritime accidents for the period between 1987 and 2001, Grech et al. (2002) have stated that 71% of the human errors can be attributed to SA-related problems.

Maritime shipping is attributed to the carriage of around 90% of the global trade. Amongst the various activities carried out by a merchant ship in day to day operations, navigation is deemed to be the most critical. The technological changes related to navigation that have been introduced in past few years; most notably the Electronic Chart Display and Information System (ECDIS), have added another layer in the complexity of navigation. Technological changes, while increasing information processing can have a detrimental effect on SA (Grech and Horberry 2002 as cited in Grech et al. 2002, p.1721). Modern day ships are being designed with ever increasing dimensions and carrying more dangerous cargoes than their predecessors. The consequence of a navigation-related accident can be catastrophic for a ship. The risks are even more accentuated when the ship is in a coastal leg of navigation, more specifically, during the pilotage leg of navigation. Accidents during pilotage involving modern ships can result in loss of lives and can have severe long term ecological and commercial implications as well. An accident involving LNG tanker, for example, has the potential to blow-up part of a city (Perrow 1999, p.171). Pilotage refers to the critical phase of navigation where the ship ends the sea voyage and manoeuvres within the port limits either to berth at the port or when it leaves the port and goes outbound for sea voyage. This operation is usually carried out with the help of pilot – who is an experienced navigator familiar with the port in question. Recent accidents show the vulnerabilities associated with SA in pilotage operations, e.g. Crete Cement, Federal Kivalina and Godafoss (Accident Investigation Board 2010a; Accident Investigation Board 2010b; Accident Investigation Board 2012). The analysis of factors such as SA affecting navigational performance in pilotage operations therefore requires paramount consideration to enhance safety in maritime operations.

Determining the SA information requirements is usually the first step in creating a SA oriented system. The SA information requirements can then be used as basis for system design and finally the process of SA measurement can be carried out to evaluate the system. The aim of the present study is to determine the SA information that is required to execute the decisions for conducting pilotage leg of navigation on a merchant vessel and to define the factors that affect their SA. The focus of the study is narrowed down to pilotage operations as it is considered critical and the associated risks are greater. A method widely used to determine SA requirements is the Goal-directed task analysis (GDTA) (Endsley 1993). GDTA is a modified form of cognitive task analysis that has been utilized by proponents of SA theory for determining SA requirements for varied fields like aviation, army, railroad and nuclear (Bolstad et al. 2002; Endsley 1993; Endsley et al. 1998; Endsley and Rodgers 1994). The method has also found its applicability in determining SA requirements in some other domains like assistive technologies and computer science (Alkhanifer and Ludi 2014; Horn and D'Amico 2011).

The primary research question thus framed for achieving research objective and contributing to the maritime knowledge base is - "*What are the SA information requirements for navigators during pilotage operation?*". The secondary research question is: *"What factors can affect SA of navigators?"*. The next section provides a review of selected literature to give an overview of the construct and associated research undertaken in maritime domain which provided the theoretical framework for the present study.

2 Situation Awareness: theoretical framework and its application

2.1 The concept of SA

The concept of SA traces its origins in the era of World War I, where it was recognized by the military pilots as an important precursor of gaining tactical advantage over enemy aircrafts (Gilson 1995). The importance of SA as a construct in the research literature and its application in military aviation and other domains was realized in the late 1980s when there was a real effort to provide a scientifically grounded approach towards the construct and its measurement (Stanton et al. 2001, 2006). Various definitions of SA have been put forward since, with variations in terminology occurring due to difference in the domain of origin (Endsley 2000). Sarter and Woods (1991) have defined SA as "*the accessibility of a comprehensive and coherent situation representation which is continuously being updated in accordance with the results of situation assessments*" (Sarter and Woods 1991, p.52). Smith and Hancock (1995) refer to SA as *"externally directed consciousness"* and taking an ecological approach have defined SA as "*the invariant in the agent-environment system that generates the momentary knowledge and behavior required to attain goals specified by an arbiter of performance in the environment*" (Smith and Hancock 1995, p.145). However, the definition which is widely adopted and universally used for SA is given by Endsley (1988) where she has defined SA as *"the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future"* (Endsley 1988, p.792). Following this definition, there are three levels of SA which the operator can have while interacting with the dynamic systems:

<u>Level 1 SA - Perception of elements in the environment:</u> The first level of SA refers to the perception of information elements in the environment by the operator. For a navigator, the information elements such as GPS position, speed, course, heading, targets etc. are required to be perceived first in order to be aware of the external state of environment.

Level 2 SA – Comprehension of the current situation: The second level of SA refers to the comprehension of the situation by the operator by deriving meaning from the perceived information elements. For a navigator, parameters such as Closest point of approach (CPA) to target or Time to closest point of approach (TCPA) may provide meaning in terms of the existing targets. This level of awareness provides a meaning of the existing state and helps the operator to determine a course of action (if any) which will be required.

Level 3 SA – Projection of future status: The third and the highest level of SA refers to the ability of operator to make projections about the future state of the system basis on the derived comprehension of situation. For a navigator, the parameters such as vector extension of targets and radar simulation provide a projected view of basis on which, it may be possible to predict a future outcome of the system state.

2.2 SA in maritime domain

The concept of SA which has been extensively used in some high-risk domains has found its applicability in the maritime domain as well. SA is increasingly being applied for accident analysis and suggesting guidelines for training and operations in maritime domain. Hetherington et al. (2006) have addressed the importance of human element in shipping and identified that loss of SA as one of the individual factors which is apparent as the immediate cause of maritime accidents. In their study pertaining to maritime accidents analysis, Grech et al. (2002) state that SA related problems account for about 71% of the human errors. They further break-down the figures using Endsley's taxonomy model (Endsley 1995b) to demonstrate a trend in the SA related errors with 58.5% errors occurring at Level 1, 32.7% at Level 2 and 8.8% at Level 3.These figures are congruent to the ones obtained by Jones and Endsley (1996) for aviation domain. Similar studies were carried out by Sneddon et al. (2006) and Sandhåland et al. (2015) where they carried out accident analysis for offshore segment and identified factors affecting the SA of the operators and navigators respectively. Cordon et al. (2017) in their study, listed factors such as spatial aptitude, attention, organization, awareness and leadership and further divided them as per Endsley's three level model in their aptitude model. Sætrevik and Hystad (2017) have hypothesized that SA of crew members could also be a function of Captain's leadership style. The next section provides an overview of pilotage operation in maritime domain which is the focus of present study.

2.3 Pilotage operations in maritime domain

Pilotage can be termed as one of the most complex and critical operation in the maritime domain (Sharma and Nazir 2017). The importance of piloting vessels with continuously increasing dimensions and hazardous cargoes in the vicinity of some of the biggest metropolitan areas in the world has been undermined in the research literature and by the industry Even after ignoring the factors like culture, weather and geographical challenges, studies involving pilotage has received less attention in their basic form as well. Lappalainen et al. (2014) have pointed out that pilotage is studied very little internationally or otherwise and have argued for pilotage based on established *"good practices"* as deemed by the literature.

Bruno and Lützhöft (2009) have defined pilotage as the control of a complex system and theorized that combination of feedback and feedforward mechanism is used in the pilotage to build a construct and exercise control on the system. Although the composition of bridge team varies depending upon the type of vessel and other factors, it can be postulated that bridge team during pilotage effectively involves coordination between Captain, Pilot and Duty officer.

The Captain has the overall responsibility of the safe execution of operation and acts on the advice given to him by the pilot pertaining to specific information to be considered when manoeuvring in the port. Pilot is an individual, usually a master mariner himself, who has the specific knowledge related to navigation and traffic regulations in the port of call. Duty officer is the navigation officer present in the bridge who usually assist the captain in navigation by performing associated secondary functions (such as monitoring the helm orders, cross-checking position etc.) and acts in a supportive capacity.

Review of existing literature suggests that topic of SA is contentious. With different definitions and approaches adopted by human factors researchers to explain the construct. Endsley's three level model presents an approach amongst the other various models associated with SA research. With an objective to contribute to state of art literature associated with the concept of SA in maritime domain and factors affecting it, interviews were conducted with experienced navigators. The focus of study, as outlined in next section, was to determine SA information requirements used by navigators during pilotage and the factors affecting it. A goal-directed task analysis and content analysis of transcripts was conducted to answer the research objectives.

3 Method

3.1 Interview of experienced navigators

A total of 7 participants were interviewed (Mean age = 27.9, SD = 4.4). The interviews were semi-structured with the purpose to elicit expert knowledge as per the methodology outlined by Endsley & Jones (2012). Prior to the interviews, a notification message was sent to Norwegian Center for Research Data (NSD), informing the nature of the study. The participants were recruited by the professional contacts of the research group. A consent form was given to the participants informing them about nature of the study and their right to withdraw at any time during the process. Most of the interviews were conducted Face-to-Face, however due to certain limitations on the participants' side, two of the interviews were conducted on Skype™. The average length of the interviews was 34 mins, with the shortest interview of 25 min and the longest of 52 mins. The participants on an average possessed 4.2 years of experience working at sea. This denotes the total sea time. The participants were in average a decade into their sea going careers accounting their down time. Along with collecting physical notes, the interviews were audio-recorded and transcribed verbatim. The following questions were the focus of the interviews:

(1) Can you briefly describe the initial checks carried out when the pilotage commences?

(2) What will be the major sub-goals in the pilotage which will help you to achieve the overall goal?
(3) What decisions do you make to achieve the sub-goals?
(4) How can the decisions go wrong? Can you provide examples?
(5) What information do you need to make the decisions?

The semi-structured nature of interview gave the interviewers an opportunity to digress and ask follow up questions, eliciting more knowledge where required, while ensuring that the necessary information was acquired. The interview guide was developed based on the previous studies carried out using GDTA methodology outlined in the introduction section.

3.2 Goal-directed task analysis

For constructing the GDTA, a content analysis of interview notes and interview transcripts was performed. The analysis based on distinguishing three central elements in the GDTA: Goals, decisions and information requirements. GDTA methodology identifies the overall goal and sub-goals of the operator and the decisions needed for execution of these goals and finally the information elements needed by the operators to execute the decisions. Figure 1 highlights the relationship between these elements in the GDTA.

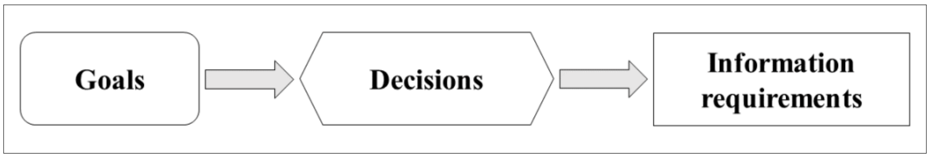

Fig. 1 Elements of the GDTA (Adapted from Endsley and Jones, 2012)

The differentiation in these elements were based on definitions and criteria provided by Endsley and Jones (2012). Goals were divided into sub-goals, decisions and finally the information requirements needed to execute them. The SA information requirements were further divided into three levels. Similar goals or decisions were grouped together to avoid redundancy. The GDTA constructed was sent to three SMEs for revision and comments. The SMEs in average possessed 13.3 years of experience working at sea. This denotes the total sea time. The SMEs in average had been employed as seafarers for many years accounting for their down time and therefore can be considered very experienced. The revisions suggested by SMEs were incorporated and Final GDTA was constructed. All the SMEs held Captain's license for merchant ships.

3.3 Transcript analysis

For the secondary research question, data analysis involved using content analysis of transcripts. The software NVivo© pro version – 11.2.1.616 was used for coding the responses related to factors that affect SA of navigators. Figure 2 below illustrates the various stages involved in the construction of GDTA and determination of SA information requirements.

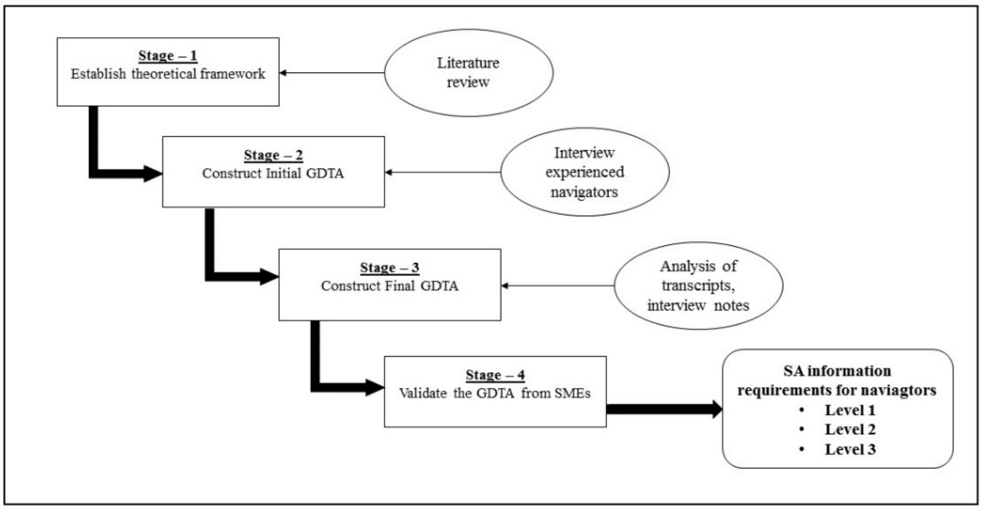

Fig. 2 Stages involved in the construction of GDTA

4 Results

The analysis identified several SA information requirements for each of the three SA levels; 1 (perception), 2 (comprehension) and 3 (projection), that are important for meeting the goals during pilotage. At the highest level, the overall major goal was recognized as “Navigate the vessel safely from pilot point to berth or vice versa”.

This overall goal was further decomposed into four goals namely:

(1) Ensure appropriate information exchange with pilot
(2) Execute the passage plan safely and effectively
(3) Monitor the progress and use resources optimally
(4) Manoeuvre safely either working together with the pilot or working without the pilot

There was good consensus amongst all the participants for the four major goals describing the pilotage. Each of the major goals were further decomposed into sub-goals, decisions and SA information requirements. Table 4.1 provides an overview of major goals and sub-goals associated with pilotage.

Table 4.1

Navigator goals during pilotage

Navigate the vessel safely from pilot point to berth or vice-versa

1.0 Ensure appropriate information exchange with pilot
- 1.1 Brief pilot about vessel characteristics
  - 1.1.1 Verbal exchange about key vessel characteristics
  - 1.1.2 Verbal exchange about any abnormality
  - 1.1.3 Ensure documentation is completed
- 1.2 Determine the route to be followed in consultation with the pilot
  - 1.2.1 Assess route plan
    - 1.2.1.1 Avoid obstacles and shallow waters
    - 1.2.1.2 Avoid traffic and no-go areas
  - 1.2.2 Discuss contingency measure
    - 1.2.2.1 Discuss the emergency procedures
    - 1.2.2.2 Establish contingency anchorages and abort points
  - 1.2.3 Discuss meteorological data
    - 1.2.3.1 Discuss tidal streams, tidal range and direction
    - 1.2.3.2 Discuss prevailing weather
  - 1.2.4 Discuss traffic data
    - 1.2.4.1 Discuss inbound/outbound traffic
    - 1.2.4.2 Check reporting data for Vessel Traffic Services (VTS)
- 1.3 Configure the ship for pilotage
  - 1.3.1 Configure the navigation system
  - 1.3.2 Configure the radio system

2.0 Execute the passage plan safely and effectively
- 2.1 Navigate the ship as per passage plan
  - 2.1.1 Manoeuvre the ship within plan limits
  - 2.1.2 Maintain desired path
- 2.2 Avoid traffic conflicts
  - 2.2.1 Avoid obstacles and shallow waters
  - 2.2.2 Resolve traffic conflict
- 2.3 Minimize the impact of abnormal situations

3.0 Monitor the progress and use resources optimally
- 3.1 Tailor the operations according to bridge team functionality
  - 3.1.1 Determine bridge team functionality
  - 3.1.2 Determine the impact of bridge team functionality
- 3.2 Communicate with Ship's crew and VTS
  - 3.2.1 Information exchange with deck crew
  - 3.2.2 Information exchange with engine room
  - 3.2.3 Information exchange with VTS
  - 3.2.4 Information exchange with Pilot
- 3.3 Configure the ship for manoeuvring
  - 3.3.1 Ensure readiness of bridge equipment for manoeuvring
  - 3.3.2 Ensure readiness of deck equipment for manoeuvring
  - 3.3.3 Ensure readiness of engine controls for manoeuvring
- 3.4 Minimize the impact of unexpected system abnormality

4.0 Manoeuvre safely either going alongside or dropping pilot
- 4.1 Perform manoeuvres
- 4.2 Perform post operation checks

4.1 Grouping of information requirements into three levels

As described earlier in section 2.1, the three levels of SA as described in Endsley (1995a) model consists of Perception of information elements in the environment, comprehension of the current status and projection of future status. During the interviews with the navigators, they highlighted the need to perceive certain attributes and basic parameters to form an initial understanding of the system state. The information elements like ship's speed, position, heading etc. fall under these levels but are not limited to these but also consists of characteristics of surrounding traffic such as location and number of targets and so on. The classification of information elements listed by navigators to Level-1 was based on the Endsley 1995 model where similar examples in the context of aviation are described, for instance: *"A pilot would perceive elements such as aircraft, mountains, or warning lights along with their relevant characteristics (e.g., color, size, speed location)"* (Endsley, 1995a, pg. 36). For Level - 2, the navigators hinted at understanding the difference between ideal system state and the current system state. The example from Endsley 1995 model where she puts Level – 2 in context as: *"The operator of a power plant needs to put together disparate bits of data on individual system variables to determine how well different system components are working, deviations from expected values, and the specific locus of any deviant readings."* (Endsley, 1995a, pg. 37). For Level – 3 requirements, navigators indicated the need to anticipate traffic movements and weather conditions. Level-3 of SA as described in general terms by Endsley: *"An automobile driver also needs to detect possible future collisions in order to act effectively"* (Endsley, 1995a, pg. 37). An example of transcript text and their classification into three levels is provided in Table 4.2

Table 4.2

Levels of SA and classification

Level	Definition	Excerpt from interview	Identification of element
Level 1	Perception of information elements in the environment	"Usually the officer on duty, he reports speed in knots, course and some relevant information….."	Speed and Course

Level 2	Comprehension of the present situation	"I would get a better idea of how the currents are acting in the direction that….."	Impact of tidal stream
Level 3	Projection of the future status	"If there is any traffic nearby. If somebody's going to come or if I'm going to meet some vessel at some point….."	Projected movement of own ship/targets

4.2 Level-1 SA information requirements

The first level in SA information requirements i.e. the perception stage consist of ship status, equipment status, route, traffic and weather conditions. The navigators need to perceive information elements related to their goals for constructing an initial picture of the prevalent situation.

Table 4.3

Level-1 SA information requirements for navigators

Level 1

Ship status

- Position
- Speed
- Gyro heading
- Magnetic heading
- Under keel clearance

Equipment status

- Operational status of
    - Navigation system – GPS, ECDIS, Radar, Automatic Identification System (AIS) data.
    - Radio system – VHF/MF.
    - Steering system
    - Communication channels – Portable radios, PA systems.
    - Fire and safety equipment
    - Signal lights
    - Deck equipment
    - Engine controls

Route plan

- Planned route
- Distance to waypoints
- Planned speed for each leg
- Air draft

Traffic and obstacles

- Location of targets
- Number of targets
- Traffic Separation Scheme (TSS) to be followed
- Vessel Traffic Service (VTS) communication frequency
- VTS standing instructions
- Location of navigational hazards
- Anchorage areas
- Location of shoals, under water rocks
- Density of traffic

Weather

- Conditions
    - Visibility
    - Temperature
    - Sea temperature
- Wind
    - Speed
    - Direction
- Current or tidal stream
    - Speed
    - Direction
    - Range of tides

4.3 Level-2 SA information requirements

The second level in SA information requirements i.e. comprehension stage consist of comprehending the ship and system states as well as their impact. Further, navigators need to comprehend the effect of traffic and weather conditions in comparison to planned or expected conditions.

Table 4.4

Level-2 SA information requirements for navigators

Level 2

Ship and equipment • Deviation between current position and planned position (XTE) • Deviation between current heading and planned heading • Deviation between minimum required Under Keel Clearance (UKC) and current UKC • Validity of - Position, speed, heading and other indicators • Risk level of system related emergencies	Impact of • Traffic conditions • Ship maneoveres • Ship performance • Alteration of course • Alteration of speed • Weather conditions • Wind speed • Tidal streams
Route • Deviation between current speed and planned speed • Deviation between planned course and course made good • Current separation between own ship and other ships • Current distance to nearest obstacles	Emergencies • Confidence level in alarms • Available sea room • Available manpower • Applicable checklist • Available time limit • Fire-fighting system settings • VTS communication frequency

4.4 Level-3 SA information requirements

The third level in SA information requirements i.e. projection stage consist of projecting or predicting the information available to navigators with respect to different conditions during pilotage and their impact on goals of navigators.

Table 4.5

Level-3 SA information requirements for navigators

Level 3	
Traffic and route • Projected position of own ship • Projected movement of targets • Projected relative separation • Projected traffic congestion • ETA to waypoints	Meteorological data • Projected weather conditions • Projected visibility • Projected wind speed • Projected currents or tidal streams

4.5 Factors affecting SA of navigators

For identifying the factors that affect SA of the navigators during pilotage, the participants were asked the question *"What factors can affect your SA?"*. From this question, 18 themes emerged from the transcripts. The themes which occurred with a frequency of 2 or fewer occurrences in the transcript of interviews derived from the participant responses were rejected and therefore only 9 themes were qualified. The 9 themes identified had a total number of 55 references in the interview transcripts. These are as listed in table 4.6 below where "sources" refer to the number of participants which listed a particular theme and the term "references" pertain to total number of times the theme occurred in the transcripts.

Table 4.6

Factors that affect SA of the navigators during pilotage

Theme	Sources	References
1. Shift in focus	4	12
2. Irrelevant communication	2	9
3. Communication with teammate	3	6
4. Actions carried out by teammate	2	5
5. External factors	5	5
6. Individual factors	3	5
7. Noise on radio channels	1	5
8. Re-orientation towards a task	3	5
9. Attentional narrowing	2	3

5 Discussion

Based on the analysis of SA information requirements and the factors affecting SA of the navigators, several observations can be made. Among the goals listed in the Table 4.1, it was noted that more than one goal may be relevant for the navigators. However, the priority allotted to each goal may be different. It was also possible that the goals may be conflicting with each other. For e.g. the (sub) goal 2.2.1 Avoid obstacles and shallow waters may be in odds with the (sub) goal 2.2.2 Resolve traffic conflict as in the process of evading shallow waters, vessel may be heading in direct way of nearby traffic. It depends upon the expert judgement of navigators as to how each goal can be met without compromising safety. The analysis did not aim to establish priority among the identified goal which may be the function of current phase of pilotage.

Reviewing the goals of navigators during pilotage also revealed significant dependency upon pilot to provide certain information thus affecting the SA. For e.g. the navigators may make an initial passage plan and estimate of available depth of water for the pilotage, but the pilot upon boarding the vessel supplies relevant and accurate information about available depth of water, prevailing currents and tides. The dependency on pilot for this information, which is not surprising, highlights the need for a pertinent initial information exchange with the pilot.

It was noted that there was a substantial overlap between some of the goals and therefore recurrent SA information requirement were present in some of the goals. This was expected as some of the goals are inter-related. For e.g. the (sub) goal 2.1.1 Manoeuvre the ship within plan limit will share some of the SA information requirements such as Speed, Gyro-heading etc. with (sub) goal 4.1 Perform manoeuvres as they are related. Further, there were some of the SA requirements that were observed to be used throughout the pilotage and some would be only required at certain stage. For e.g. Speed, Under Keel Clearance (UKC), Gyro heading, Cross track error (XTE) etc. would be required throughout the pilotage whereas target numbers, target location etc. may become relevant only when there is conflicting traffic. This indicates that the operation may have varied SA information demands during the time period it is being executed and it is necessary that when the demands reach peak, they are adequately supported for the navigators that are engaged in the operation.

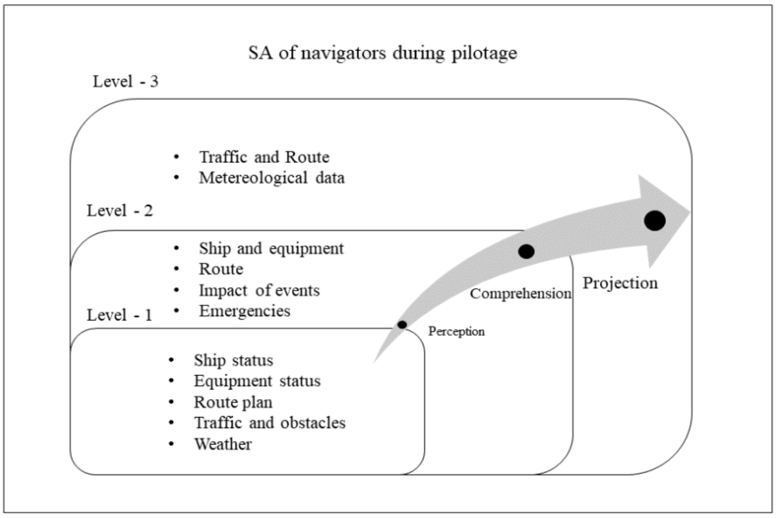

Fig 3. SA of navigators during pilotage

The Level-1 information requirements identified for navigators were grouped into ship status, equipment status, route, traffic and weather. They involved information such as speed, position, location of targets and so on. The Level-2 information requirements identified for navigators were grouped into ship & equipment, route, information related to emergencies and impact of various elements on ship. They consisted of information elements such as deviation between planned route, speed, position etc. and current route status. They also consisted of confidence level in certain ship parameters as well as expected impact of traffic, manoeuvres, weather etc. on ship. The navigators indicated that for achieving Level-2 SA, they look for the deviation between ideal system state and current system state, as well as the impact of certain events on navigation. The information elements identified for Level-3 included projected position of own ship, projected movements of targets, projected weather conditions and so on. It was noticed that there are not lot of information elements navigators would like to anticipate during pilotage. This could be attributed to specific nature of pilotage operations where only projected traffic movement and meteorological data is of immediate interest for navigators. The navigators held that not much can be done with regard to state of equipment or other systems when the operation is underway and majority of information requirements related to Level-1 and Level-2 are strived to be met with good planning practices, team work and training prior to commencement of operation. Also, as can be seen by the major groups of information requirements identified at three levels of navigators, conscient to the theory, the navigator use prior level of awareness to gain comprehension of the present or project the future state of the system. Figure 3 illustrates the relationship between three levels of SA and their ascending nature (Endsley 2015a).

It should be noted that standard procedures and regulations are also SA information requirements and were determined to be required in the analysis and included in the final GDTA for the navigators, but excluded from the list in results as the purpose is to focus on dynamic SA requirements rather than static. Further, there is no absolute boundary between the SA levels listed in the tables. The SA levels may overlap to some extent and they are separated as per the information derived from collected data (Endsley & Jones 2012, p. 73).

Navigators also face some challenges while trying to get all their SA information requirements met. As discussed above, the participants indicated that they depend to a great extent on the pilot for supplying up to date information about specificalities of the port of call for the ship. They spend some effort to build an initial rapport within short time with the pilot and have all the relevant information needed. Insufficient team cohesion or rapport between the bridge team and pilot could also increase the probability of errors.

Further, importance of preparedness was highlighted by the participants for being able to meet all the information requirements required for pilotage. Majority of the information requirements needed to be prepared in advance of the pilotage with regards to applicable procedures using the checklists mentioned above as well as consulting port specific information by using the books like the *Admiralty Sailing Directions (ASD)* or the *Admiralty List of Radio Signals (ALRS)* for obtaining all the relevant local information. The importance of planning process for pilotage therefore cannot be overemphasized here. The better prepared navigators are, the more they are able to meet SA information requirements.

Lastly, it is worth mentioning that the approach in determining the SA information is normative, i.e. it is assumed that the fulfillment of SA information requirement of navigators should result in safer operations. It is worth mentioning that there have been maritime accidents in the past and some notable ones in the recent past that have pointed out the limitations of the causal accident analysis mode. It will be incorrect to assume that the meeting of these SA information requirement will necessarily mean navigators as a team will not commit mistakes or ship will be essentially safe. With the increased complexity of modern maritime operations, the traditional approach in designing systems and training has been seriously questioned (Schroder-Hinrichs et al 2012). It has been argued that the concept of resilience engineering is to be increasingly adopted to cater for these limitations from design to training. However, resilience engineering as a concept remains mostly theoretical at the moment and further studies are required to investigate its applicability in various high-risk domains (Oltedal, 2018)

Regarding the various factors that affect SA of navigators, the themes which have been identified point out to most of the factors related to attention and communication. The attention as a theme in SA is often linked to Perception (Level-1) stage of Endsley (1995a) model (Wickens et al., 2007). Majority of SA related errors are attributed to the perception stage; therefore, it is important to address attention management for the navigators during pilotage (Grech et al., 2002). Shebilske et al (2000) suggested that attentional management strategies are central for understanding how operators in socio-technical system may react to expected, unexpected and novel situations. They further state that *"Because an operator's mental model of a complex environment can never be fully complete, human-centered training should prepare skilled operators to encounter complex novel events."* (Shebilske et al., 2000, p. 318). The participants also listed re-orientation towards a task after attending another conflicting task as particularly problematic. As an example, one of the participant had narrated that keeping a proper lookout at bridge is important but another conflicting task such as acquiring the echo of another ship which may not be visually recognized at the particular instance could mean shifting the focus temporarily but re-orientating oneself after that could be not easy. Navigator may lose track of ships he/she was visually observing or there may be new targets visible which were not there previously. This novel information will require some new time and cognitive energy on the navigators' part to achieve the same level of SA as prior to switching between the task. Related to this, another sub-theme identified as attentional tunneling which means the navigators tend to lose SA while attending to one task, was also identified as one contributory factor detrimental to SA during pilotage. Attentional tunneling is identified as one of the eight *"SA demons"* as termed by Endsley and Jones (2012, p. 31).

Communication was another important factor that affects SA of the navigators. The participants listed irrelevant communication and noise on radio channels as some of the factors that affect their SA during pilotage. It is purported that communication in teams is a mean for transmitting situation awareness and teams with higher communication frequency have shown to perform better, although the relevancy and accuracy of the communication also needs to be considered (Sorensen & Stanton, 2016). Irrelevant communication and noise on radio channels can distract the navigators thereby interfering with situation assessment process. The navigator may require more attention to complete a task or they may require to reorient themselves towards the task which may result in longer time taken to complete the task.

The remaining can be surmised as individual factors which are unique to the operator in question (e.g. level of fatigue). Communication and attention as listed by navigators as an important factor affecting their SA is conscient to research carried out in the context of complex collaborative systems (Sorensen and Stanton 2016). While there have been some efforts to address the attention and its utilization as a resource in other domains for e.g. aviation (Wickens et al. 2007), maritime domain at present lacks training and design of system targeting these constructs related to the human component in the socio-technical system.

There are some evident limitations with the present study. First, like all the task analyses, GDTA is subjective in nature. This issue is offset by validation from SMEs but the nature of analysis still remains subjective. Another limitation would be the number of participants and SMEs involved. The study employed the use of 7 participants and 3 SMEs for constructing GDTA which imposes certain limitations on the scope and the method of recruiting them was purposive i.e. in a non-randomized manner. Even though the constituents are from diverse background and with varying experiences, a larger number of participants recruited randomly, and additional number of SMEs will contribute to greater validation of the results.

Regardless, three practical implications can be drawn from these findings. 1) Information about SA derived through the GDTA can contribute to design of the workplace and operating procedures. For instance, understanding the connection between route plan (level 1) and all the way to operator's projection of the meteorological data (level 3) can provide insight into bridge design. 2) These findings can provide input to training and assessment design of maritime operators. Understanding necessary competence requirements with regards to SA has shown to yield beneficial results in other domains (e.g., aviation – Salas et al. 2017). And lastly, 3), SA requirements in pilotage navigation may help to better describe and understand maritime pilotage accidents. These accidents, as discussed earlier, still occurs. By better understanding the accidents, more learning can be derived from the accident analysis. SA requirements derived in this paper may contribute to elevate the understanding of pilotage accidents. The aim of the present study was to be exploratory in nature and contribute to state of art literature related to SA theory in maritime domain and provide stimulation and basis for further research and application in various maritime operations in merchant shipping.

6 Conclusion

The study explored a less investigated area in the existing knowledge involving intersection of SA theory, maritime domain and pilotage operations. The goals and information requirements were identified for pilotage which can be used for SA measurement in experiments, construct exploration or training purposes. Thus, demonstrating the applicability of the construct in one more high-risk sector and highlighting an important but less discussed operation in the maritime domain. The GDTA constructed from the data collected with participants identified the SA information requirements in all three levels for the navigators during pilotage and further classified them in terms of information requirements related to - ship, equipment, route, weather etc. and the factors affecting SA of navigators were identified. Basis on the findings in the present study and the discussion about their implications, there are several areas which merit further exploration. The future research should be directed in the mitigation of the factors which affect SA of navigators and supporting their overall SA.

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