TRANSNAV the International Journal on Marine Navigation and Safety of Sea Transportation
http://www.transnav.eu
Volume 11
Number 1
March 2017

DOI: 10.12716/1001.11.01.03

Scan Pattern for the Maritime Navigator

O.S. Hareide
Royal Norwegian Naval Academy, Bergen, Norway

R. Ostnes
Norwegian University of Science and Technology, Aalesund, Norway

ABSTRACT: The maritime high speed craft navigators` ultimate aim has for decades been to safely and efficient navigate the vessel to its destination. The last decade an increased use of technology has arrived at the maritime ship bridge. The use of Electronic Charts and Integrated Navigation Systems has revolutionized much of the work of the navigator, with the aim of enhancing the safety of navigation. The amount of information has drastically increased, and the need for a proper information management and an efficient visual scan pattern has been identified. Looking to other industries this has been introduced with success, and in this paper the authors present a proposed scan pattern for the maritime navigator. The analysis is based on an eye tracking data set collected from simulator- and field studies on board the world's fastest littoral combat ship.

1 INTRODUCTION

The aim of the INS, and e-navigation, is to enhance safety of navigation, by collecting and providing vital information in a user friendly manner for the navigator. It has raised concern that navigators look more at the displays than controlling the surroundings of the vessel, and concerning the visual focus of the navigator there are not any industry standard or recommendation on the use of the integrated navigation system. Based on the Eye Tracking data set and cross-section knowledge from aviation and other high-risk industries (power plants), this article aims to present a recommended visual scan pattern for the maritime navigator.

1.1 *Integrated Navigation Systems*

New vessels today are highly technological, also at the ship bridge. The use of new sensors and technology, which are highly integrated, are widely used. An example of such is the Rolls Royce Unified Bridge (Rolls-Royce, 2015) in Figure 1 or the K-Bridge INS (Kongsberg, 2016), which goal is to increase the operational safety by efficient workflow which reduces the cognitive workload for the navigator.

The purpose of an Integrated Navigation System (INS) is to enhance the safety of navigation, this is done by providing integrated and augmented functions to avoid geographic, traffic and environmental hazards (IMO, 2007, p. 2). An INS is defined as such if workstations provide Multi-Function Displays (MFD) integrated with at least the following navigational tasks/functions:
- Route Monitoring
- Collision avoidance

and may provide manual and/or automatic navigation control functions (IMO, 2007, p.3)

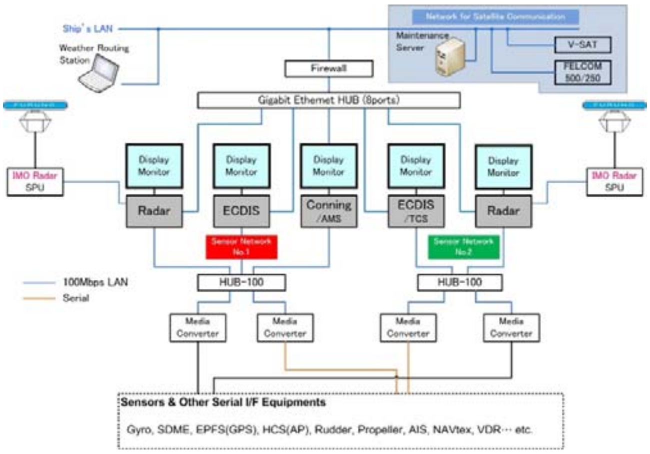


Figure 1. PSV Stril Luna Integrated Navigation System (courtesy of Rolls-Royce).

The INS can consist of several parts, but the most important navigation sensors for the navigator is:

- Electronic Position Fixing System (EPFS) (e.g. GNSS as GPS)
- Heading control system (HCS) (e.g. Gyro)
- Depth sensor (Echo Sounding System, ESS)
- Speed and distance measurement (SDME) sensor (e.g. Electromagnetic Log)

The INS also needs systems and sensors which can provide:

- Collision avoidance (e.g. Radar and AIS)
- Route planning and monitoring (e.g. ECDIS)
- Track Control System (TCS) (e.g. Autopilot)

These sensors and systems are interconnected in some type of network (e.g. NMEA2000, Ethernet, etc.).

The maritime bridge has become more and more digitalized the past years, and retrofitted and new ship bridges are equipped with several MFDs. These MFDs can present

1 Electronic Chart Display and Information System (ECDIS) application, which most commonly consist of an Electronic Navigation Chart (ENC) with navigation sensors integrated.
2 Radio Detection and Ranging (RADAR) application, which is a terrestrial navigation system using radio waves to determine range, angle or velocity of objects.
3 Conning application, which aim is to make key information available for efficient monitoring. Conning information gather all relevant sensor information and navigation data at a glance, and aims to improve accessibility for the navigator.

1.2 *E-navigation*

The International Maritime Organization (IMO) is currently working on an initiative called E-navigation.

The purpose of E-navigation is to improve electronic information exchange to:

- Enhance berth-to-berth navigation
- Provide simplification to improve safety, security and environment
- Facilitate and increase efficiency of maritime trade and transport.

With this in mind, e-navigation aims to minimize navigational errors, incidents and accidents through the transmission and display of positional and navigational information in electronic formats (Weintrit, 2011).

The last decades have seen huge developments in technology within navigation and communication systems. Although ships now carry Global Satellite Navigation Systems (GNSS) and have reliable Electronic Chart Display and Information Systems (ECDIS), their use on board is not fully integrated and harmonized with other existing systems and those of other ships and ashore. The work with Integrated Navigation System Performance Standard and with e-Navigation will enhance this integration and harmonization.

Currently some yards are looking at open system architecture for holistic and user-friendly integration of multi supplier bridge systems to e-navigation, such as the Vard (Fincantieri) Open Bridge (Tennfjord, 2016).

1.3 *Limitations and earlier work with the data set*

The current data set is collected in daylight in good visual conditions (Hareide and Ostnes, 2016a). The data set and its` analyses is described in detail in earlier work. An analysis of the use of simulators has been discussed (Hareide and Ostnes, 2016a), together with the use of eye tracking data when assessing human machine interface (Hareide et al., 2016), and a maritime usability study with the use of eye tracking data (Hareide and Ostnes, 2016b).

2 BACKGROUND

2.1 *Control strategies in the maritime domain*

With the introduction of more sensor and technology to the ship bridges, the degree of automation has increased. There is an ongoing discussion of how much knowledge and skills, and of what type, the modern ship navigator needs when it comes to the use of INS (Torskiy and Topalov, 2013). However, the craftsmanship of navigation has stayed the same during the past hundreds of years, and the methods of earlier days without digital displays still applies (Norris, 2015).

The Royal Norwegian Navy Navigation Competence Centre (RNoNNCC) has teached and trained navigators to the Royal Norwegian Navy (RNoN) for 200 years, and even though the syllabus has changed significantly, the basic methodology has stayed the same. Navigation starts with proper planning. With a good plan in hand, it is easier to conduct a safe passage. In conducting a passage, it is important that the navigator has a methodology to be used during the voyage. The methodology developed by the RNoNNCC has parallels to the DYNAV methodology (Forsman et al., 2011), but is an extended version. The methodology is shown in Figure 2.

Note that the four phases of navigation are utilized after a thorough planning process (as described in

SOLAS) has been conducted, and is the methodology that the navigator is using during the watch. The methodology fits on any type of vessels, but the process is more demanding in confined water and with higher speed. This is also similar to the OODA-loop (Richards, 2004), which is a decision-making strategy with the reoccurring cycle of observe-orient-decide-act.

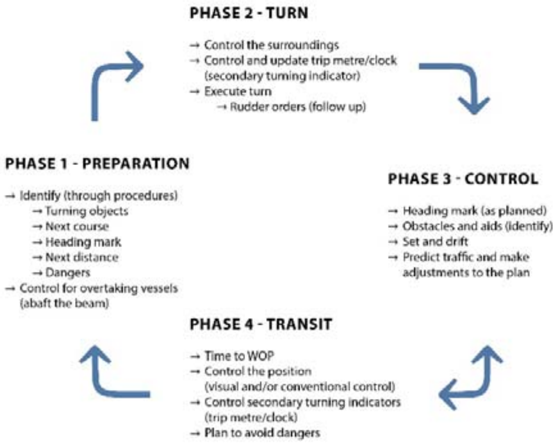


Figure 2. The Four Phases of Navigation

Phase 1 consists of the preparation before a turn is initiated. In this phase it is important to gather and highlight all relevant information to successfully conduct the turning phase.

Phase 2 is the critical turning phase for the vessel, where the vessel alters course. In this phase it is imperative that the navigators` focus is on the conning and surroundings of the ships, to make sure the turn is executed correctly.

Phase 3 consist of the control phase after an alteration of the course. Immediately after the turn, the navigator collects information to establish whether or not the ship is in the predicted (and correct) position. This phase also consists of the reoccurring cycle of predicting the set and drift, and also predicting the surrounding traffic pattern.

Phase 4 is the transit phase, where the vessel is transiting between two wheel over points (WOP). In this phase it is important that the navigator continuously monitors the position of the vessel, both by visual and conventional control methods (Hareide, 2013). Phase 3 and 4 is an iterative process until the next planned WOP is reached and the phases of navigation starts over again.

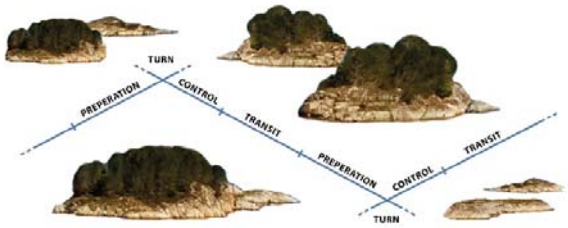
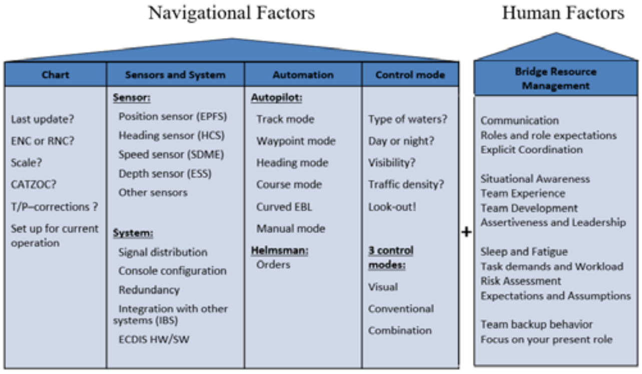


Figure 3. Overview of the Four Phases in Maritime Navigation.

The shift from paper charts to electronic charts was made to enhance the safety of operations. After years of experience, it is clear that the introduction of ECDIS also increases complexity (Wingrove, 2016). This complexity can be shown with a figure that outlines the navigational and human factors which implies when conducting electronic navigation.



Navigational Factors				Human Factors
Chart	Sensors and System	Automation	Control mode	Bridge Resource Management
Last update? ENC or RNC? Scale? CATZOC? T/P–corrections ? Set up for current operation	**Sensor:** Position sensor (EPFS) Heading sensor (HCS) Speed sensor (SDME) Depth sensor (ESS) Other sensors **System:** Signal distribution Console configuration Redundancy Integration with other systems (IBS) ECDIS HW/SW	**Autopilot:** Track mode Waypoint mode Heading mode Course mode Curved EBL Manual mode **Helmsman:** Orders	Type of waters? Day or night? Visibility? Traffic density? Look-out! **3 control modes:** Visual Conventional Combination	Communication Roles and role expectations Explicit Coordination Situational Awareness Team Experience Team Development Assertiveness and Leadership Sleep and Fatigue Task demands and Workload Risk Assessment Expectations and Assumptions Team backup behavior Focus on your present role

Figure 4. Safe and Efficient Electronic Navigation

As shown in Figure 4 above, an important part related to the conduct of the passage is the weather and visual conditions. If the visual conditions are poor, one must use conventional methods (e.g. use of radar) for controlling the passage.

The Figure also shows the importance of system awareness as a navigator. Situational awareness consists of three components; spatial awareness, system awareness and task awareness. System awareness is needed to keep the navigator informed about actions that have been taken by the sensors and systems (automated processes), and it is imperative for the navigator to know what state the system is in (automation). Compared with Figure 4, Sensor/System and automation is important to maintain a desirable System Awareness for the navigator (Wickens, 2002).

Combining Figure 1 and Figure 4 illustrates the importance of and amount of knowledge needed about the navigational factors for the navigator.

2.2 *Control methods in aviation*

Fitts et al. (1949) conducted a series of investigations in order to gather information about the pilots` eye movements during instrument approaches. This research subsequently resulted and formed the basis for the classic “T” arrangement of instruments around the attitude indicator, as shown in Figure 5.

The attitude indicator is in the top center, airspeed indicator top left, altimeter top right and heading indicator under the attitude indicator. The other two, turn-coordinator and vertical-speed indicator, are usually found under the airspeed and altimeter. These instruments are essential for the control of the flight.

When conducting a flight in aviation, there are two sets of rules for the aviator to understand. This is the Visual Flight Rules (VFR) and the Instrument Flight Rules (IFR). In general terms, the IFR means flying "in the cloud" and the pilot only navigates by using the instruments in the cockpit which requires a IFR flight plan and an instrument rating.

Figure 5. Basic T-arrangement (ASB, 2016).

The instrument scan reflects the information needed for the pilot (Brown et al., 2002). There are several studies which collects Eye Tracking data in order to analyze which instruments and AOI the pilot most commonly uses (van de Merwe et al., 2012, Haslbeck et al., 2012, Yu et al., 2016), also when it comes to visual scanning of the cockpit and the outside surroundings of the aircraft (Colvin et al., 2005). When in VFR the most important area for the pilot to observe is the outside, and the pilot should have to look away from the outside for the minimum period of time (RIN General Aviation Navigation Group, 2016).

Integrity is the measure of the trust that can be placed in the correctness of the received information supplied by a (integrated) navigation system, quantified by horizontal- and vertical alert limits (HAL and VAL) (Groves, 2013). The demand for integrity in the system design in aviation is high. In the Flight Management System (FMS), integrity of the sensor is monitored. The aviator reacts on an integrity breach warned by the FMS, and initiate an (emergency) procedure if so occurs.

2.2.1 *Scan pattern*

Scan pattern is a known terminology when it comes to aviation (FAA, 2016, p. 552). It is stated that of the bodies senses, vision is the most important for a safe flight. One of the important areas for efficient use of vision is the technique of scanning when in flight. The Scan (AOPA, 2009) is a technique used to optimize the vision for collision avoidance. It states that there are no "one size fits all" technique, but recommends a timesharing technique, such as block scan, to efficiently search for threats in the surroundings. This technique divides the horizon into blocks, each spanning 10 to 15 degrees. It is important that the eye fixates at the center of each block, because the eye needs one to two seconds to adjust, before they can focus. Focusing on each point allows the eye to detect any potential conflicts within the foveal field, as well as object in the peripheral area between the center of each block scan.

In aviation there are two primary block system scans, side-to-side scanning method and front-to side scanning method. The side-to-side scanning method starts at the left of the area and make a methodical sweep to the right, pausing in each clock of viewing to focus the eye. At the end of the scan, the pilot return to the panel. The front-to-side scanning method starts at the center of the visual field and moves to the left, focusing in each block then swing quickly back to the center block after reaching the last block on the left and repeat the performance to the right (AOPA, 2009). This is shown in Figure 6.

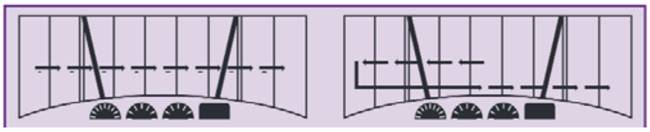


Figure 6. Block System Scan (AOPA, 2009)

When constructing a scan pattern, one should keep in mind that a scan tends to be most concentrated toward the center region of the visual field, avoiding the edges of a display (Wickens et al., 2015). The scan pattern and HMI should thus be design to adhere to this.

In the literature review there are not any findings of scan pattern related to the use of a maritime integrated navigation system.

2.2.2 *Link Analysis*

Link Analysis is a data-analysis technique which can be used to evaluate connections between points or nodes. Link analysis is used when it comes to handling information overload. When a user is confronted with a vast amount of information and data, data analysis techniques are required to make an efficient and effective use of the data. By utilizing a heuristic-based tool one can distill rules from knowledge using structured data such as eye tracking data. A scan pattern analysis for the maritime navigator based on eye tracking data consists of a link analysis. This could contribute to a more efficient and effective use of the data collected by the navigator from the INS and the surroundings of the ship.

2.3 *Eye Tracking*

Eye movements collection in aviation have been a topic of interest for over 60 years (Glaholt, 2014). The collected information has been used as a window onto operator`s processing of information, and has resulted in a whole range of application.

With the use of Eye Tracking Technology, it is possible to collect and analyze data regarding the eye`s movement. In the simplest terms, eye tracking is a measurement of the eye`s movement. By analyzing this data, one of the products is to identify the search pattern of the subject (Holmqvist et al., 2011).

2.3.1 *Eye Tracking data set*

The data set to conduct this analysis is collected on board the Royal Norwegian Navy Corvettes (Figure 7). The Corvettes are the world's fastest combat ship, capable of speeds exceeding 60 knots. It has an INS from Kongsberg Defense Agency (KDA).

Figure 7. Skjold-class Corvette

The total amount of recorded eye tracking data is nearly 3 hours, and the data set is further outlined in earlier work (Hareide and Ostnes, 2016a, Hareide et al., 2016).

Figure 8. Areas of Interest

The Areas of Interest (AOIs) were defined as:

- *Outside* (AOIO): Consists of the surroundings of the ships, and are defined by the boundaries of the windows at the ships bridge.
- *ECDIS* (AOIE): The Electronic Chart Display and Information System (ECDIS) which is presented on the MFD in front of the navigator. AOIE also consists of the Route Monitor window (AOIM) which is in the lower right corner of the ECDIS software
- *Radar* (AOIR): The radar application, presented on the center MFD on the ships bridge.
- *Conning* (AOIC): Consisting of the displays, consoles and autopilot related to the propulsion and steering of the ship.
- *White Space* (AOIW): The other areas than those defined by the AOIs.

2.3.2 *Eye Tracking metrics*

To identify the search pattern of the navigator, both raw eye tracking data and attention maps could be used.

Fixation is defined as the state when the eye remains still over a period of time on a specific point (Holmqvist et al., 2011). Fixation time can thus be used as an indicator to analyze how efficient the navigators scanning technique is.

A saccade is defined as the rapid eye movement between fixations (ibid.). The amount of saccade could reveal if there are improvements in the scanning technique of the navigator.

The dwell time is defined as the total amount of time spent in the specific AOI, as shown in Figure 8. Dwell time can be used to identify if the navigators spend too much time in a (given) AOI.

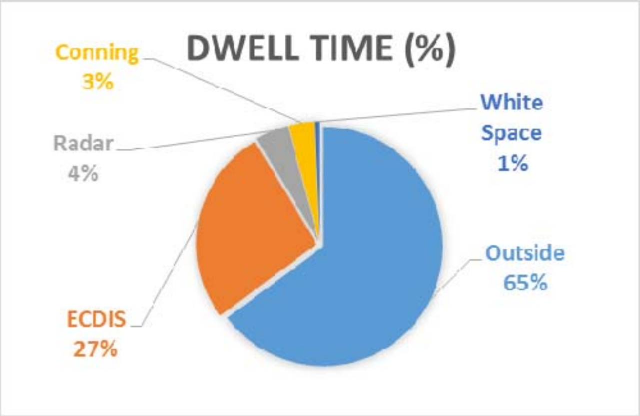


Figure 9. Dwell time in dataset

Attention maps such as a scan path presentation will visualize the scanning technique for the navigator. A scan path is also known as a scan pattern, and originates from the work of Noton and Stark (1971) which defined the term as the fairly abstract concept of a fixed path that is characteristic to a specific participant and his or hers viewing pattern. Today, a scan pattern is defined as the route of oculomotor events through space within a certain timespan (Holmqvist et al., 2011), and is shown in Figure 9.

A fixation in Figure 9 is shown as a circle, and the size of the circle reflects the fixation time. The lines between the circles reflects the saccades.

It is also interesting to look at time-sharing visualization, with the use of sequence charts (figure 11), in order to better understand and analyze where the navigator focus his/her attention.

The sequence chart is a good visualization technique when it comes to analyzing how much time, and how long, the navigator looks at different AOIs.

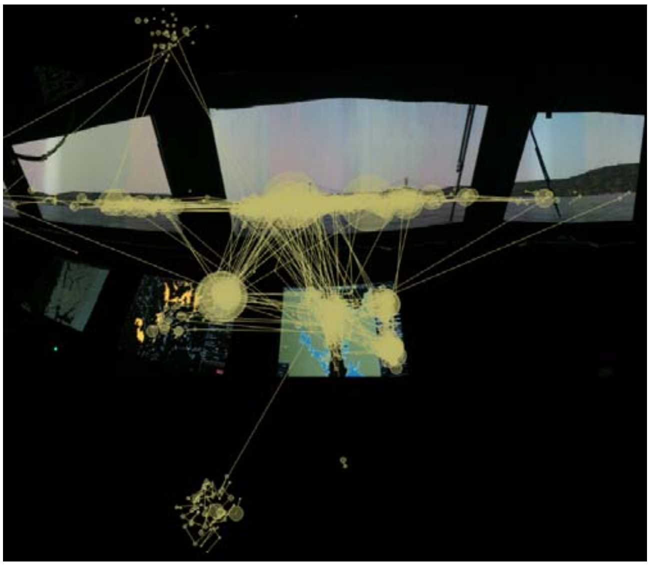


Figure 10. Scan Pattern

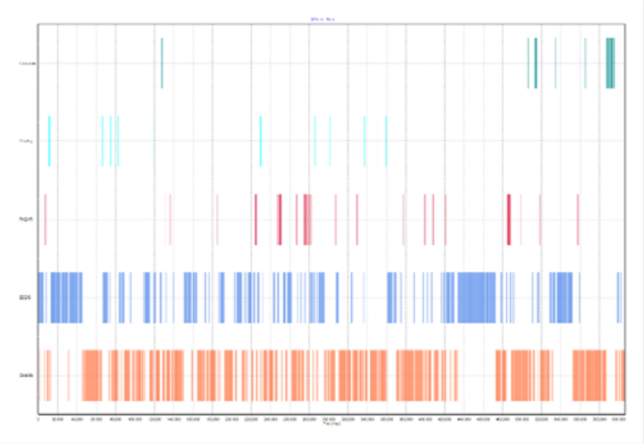


Figure 11. Sequence Chart

One could further analyze the eye tracking data for look-backs and backtracks, which is outline in an article on the use of eye tracking data for maritime usability studies (Hareide and Ostnes, 2016b). When establishing a recommended scan pattern for the maritime navigator, it is of interest to reveal if there are any design issues in any of the essential equipment for the navigator. The information should be accessible, and in the right context of use provide effectiveness and efficiency for the navigator (ISO, 2010).

Eye Tracking data is used to compare a novice and experienced navigator (Forsman et al., 2012), and has also been used to study the effect of stress at the maritime bridge during a passage (Pedrotti, 2014). Eye tracking metrics showed a good potential in both evaluating novices vs experienced boat drivers, and in analyzing the effects of stress at the maritime bridge. Van Westrenen (1999) examined Rotterdam Pilots to establish the dwell time in different AOIs, with the aim of quantifying the amount of time the pilot spends looking out the window. His study shows that the pilots spends 90% of the time looking out the window, checking the surroundings of the ship.

2.3.3 *Analysis of Eye Tracking data*

In the collected data set, the navigators` dwell time is presented in Figure 8. It is identified in earlier work that flaws in HMI steals attention from the navigator, and by adjusting this, more attention can be allocated to the surroundings of the ship (AOIo). In industry quality it has been developed models to predict the amount of time for detection. There is a concurrence between the search time available and the probability of detection (Wickens et al., 2015, p. 78). For the navigator this implies that the amount of time searching the surroundings should be as high as possible.

When looking at the scan pattern collected in the existing data set, AOI outside, ECDIS and radar stands out as important in the scan pattern for the maritime navigator (Figure 9).

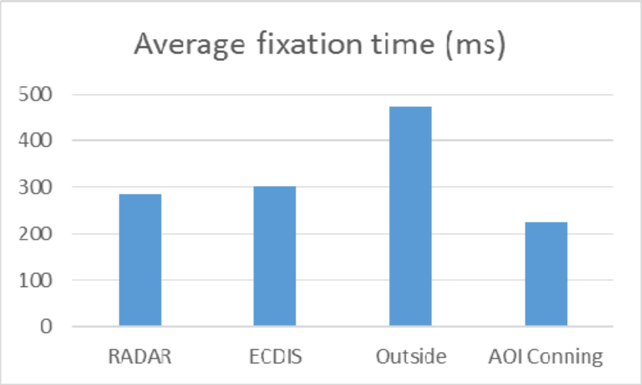


Figure 12. Average fixation time (ms) in AOIs

The average fixation time in AOIo reflects the importance of giving the eye time to actually look for objects in the surroundings, which is also reflected in scanning theory from aviation.

3 UTILIZING THE INTEGRATED NAVIGATION SYSTEM

In order to better exploit the integrated navigations system in conducting a passage, a need has been identified to develop an efficient visual scan pattern for the maritime high speed craft navigator. Link analysis theory can be applied in order to make an efficient and effective use of the collected eye tracking data.

3.1 *Recommended scan pattern*

The primary Area of Interest for the maritime navigator is the surroundings (AOI Outside, AOIO) of the ship (Norris, 2010). When conducting a passage, the navigator continuously cross-checks the information collected from the integrated navigation system. Dependent on weather and area, RADAR or ECDIS will be the second most important tool for the navigator. During nighttime or bad visibility, RADAR is an important navigation aid. When visibility is good, visual scanning supplemented with ECDIS will be the primary navigation aid for the navigator. Monitoring the conning information, with the rudder angles and trust, is important for the safe conduct of the passage.

The methodology of navigation (Figure 2) is the foundation of the recommended search pattern. This methodology implies which information that must be extracted from the INS during a passage:

During Phase 1 (preparation), information must be gathered from the ECDIS. This information should be easy accessible (Hareide et al., 2016) for the navigator, which again results in a short time sequence for the navigator to collect this information, which will be reflected in the sequence chart in Figure 11.

In Phase 2, the attention of the Navigator must be briefly at the conning to see rudder response, and mainly at the surroundings of the vessel (AOI_O) in order to continuously control that the vessel is heading in the right (planned) direction. The secondary turning indicators should have an HMI which supports this (Hareide and Ostnes, 2016b).

Phase 3 starts immediately after the vessel has turned to its` new course. Based on the information collected in Phase 1, the navigator controls the heading mark and course. Based on the analysis of the Eye Tracking data, it could be necessary with a look-back. A look-back can constitute a failure of memory (Gilchrist and Harvey, 2000), and could imply in Phase 3 if the information collected in Phase 1 is forgotten (human error/limitation or poor HMI). It is also a limitation of how much information from Phase 1 the navigator can memorize and use in Phase 3.

Phase 4 is often the longest phase of the voyage, as it consists of the time between turning points. Dependent on the environment, this will vary. In littoral waters and in high speeds, the transit phase can be very short (60 knots (111km/h), 1 nautical mile (NM) = 1 minute). In contradiction, on a journey in 20 knots (37 km/t) between Bergen and Aberdeen (310 NM), the transit phase can be more than 12 hours.

In the transit phase, the navigator controls the position, and continuously adjust the plan. The amount of controls is also dependent on the environment, and on the error and biases in the sensors used in the integrated navigation system. If the errors and biases is known to be high (e.g. terrestrial positioning), the position must be controlled often. If the errors/bias are low (e.g. GNSS as primary positioning), the control can be at increasing intervals.

The foundation in the Four Phases of Navigation must be aligned with a “Maritime Scan”, based on The Scan from aviation (AOPA, 2009, FAA, 2016).

Based on the Collision Regulations (ColReg), a vessel has to give way for a vessel on their starboard side (IMO, 1972). Based on this fact, the Maritime Scan should be based on a Front-to-Side scanning method, with reference to Figure 6. The Maritime Scan should start from the center, move to the right (starboard) side, back to the center, continue to the left (port) side and return to the center (Figure 13, The Maritime Scan). The amount of side scan should be based on collision theory (Grepne-Takle, 2010, p. 26).

$$\alpha_O > \lambda \sin^{-1} \frac{V_T}{V_O} \qquad (1)$$

If the own ship travels at 30 knots (V_O), and you assume that all other vessels (targets) travel at not more than 6 knots (V_T), the search width must be more than 23,1 degrees (α_O) to each side. This is with a safety margin (λ) of two used in Equation 1. This implies that the high speed craft navigator must scan an area with a width of >46.2 degrees (α_O*2). When deciding the width of the visual scan, Equation 1 could be used.

It is important to stress that the eye needs to fixate at the center of each block, because the eye needs one to two seconds to adjust, before they can focus. Thus the navigator must “rest” the eye in each block. As in aviation, 10 degrees’ blocks are recommended.

Between each Scan, the navigator must control the sensor data in the INS. The Maritime Scan consist thus of two subparts, the scan in the surroundings of the ship (outside) which is based on collision theory, and the instrument scan to gain system awareness of the INS.

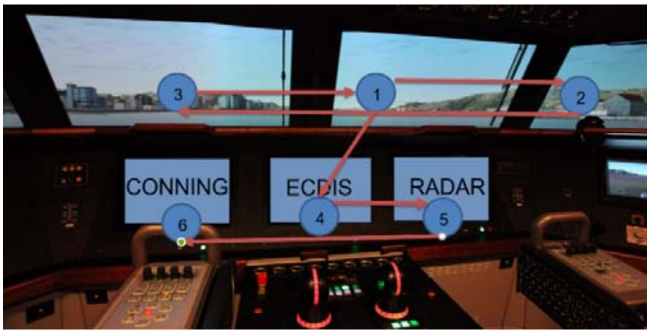


Figure 13: The Maritime Scan

The metrological conditions for conducting the passage is essential when it comes to the scanning pattern and the amount of attention to the Areas of Interest. As in aviation, the maritime has in general two categories. In good visual condition, Visual Sailing Mode (VSM) applies. When the visual conditions deteriorate, and increased use of conventional control (such as radar) is used, Conventional Sailing Mode (CSM) applies.

Table 1. Attention in AOIs in different metrological conditions.

Area of Interest	VSM	CSM
Outside (AOI_O)	80%	5%
ECDIS (AOI_E)	10%	15%
Radar (AOI_R)	7%	75%
Conning (AOI_C + (AOI_D)	3%	5%

The time distribution in AOI_O and AOI_E in VSSP is based on the benefits of better GUI and HMI together with a more efficient search pattern. This will provide more time for the navigator to control the surroundings (AOI_O) of the ships, compared with Figure 8. The amount of time spent focusing on the radar is slightly increased, due to the essential information with regards to collision avoidance which can be provided by the radar. The time distribution for collecting conning information is the same, due to the benefits of a better HMI and GUI by displaying this information in an MFD.

In CSM, the navigator must pay most attention to the Radar (AOIR), as this is an important terrestrial navigation aid when conducting a passage during restricted metrological conditions. Note also that the ColRegs state that any vessel at all times should "maintain a proper look-out by sight and hearing as well as by all available means appropriate in the prevailing circumstances and conditions so as to make a full appraisal of the situation and of the risk of collision" (IMO, 1972). The navigator spends more time in the ECDIS (AOIE) because of the increasing information requirement in restricted metrological conditions. The navigators need to withdraw essential information such as (but not restricted to) parallel indexes, safety indexes and radar turning indexes when in CSM. The time distribution increases for Conning information, due to the increased importance of the navigator checking the key information for the machinery status when not having any visual aid from landfall.

4 CONCLUSION

The efficient use of scan patterns has been known and used for other professions than the maritime. Defining a recommended scan pattern for the maritime navigator, in relation to different metrological conditions, can contribute to a more efficient interaction between the navigator and the INS. This will provide better situational awareness for the navigator, and thus provide a safer passage.

The Maritime Scan consist of two subparts, where the first consist of the outside scanning on the environment. The width of the scanning arc is based on collision theory, and by dividing this scan into blocks and conducting a front-to-side scan, a better situational awareness is expected. The second part consist of the sensor and system data in the navigations system. This data is integrated and presented in the three applications ECDIS, RADAR and Conning. The scan is conducted to increase system knowledge, and to identify if there are any errors or biases in the sensors or system. The amount of time in each of the subparts will vary with regards to the meteorological conditions, and a rule of thumb with regards to dwell time in the different areas of interest is presented in Table 1.

The use of the Maritime Scan will better utilize the spatial and system awareness for the maritime navigator, and as a consequence situational awareness will increase which will enhance safe navigation.

4.1 *Further work*

Collect a data set to verify the effect of the proposed Maritime Scan.

Collect a data set with navigation in poor visibility/nighttime (CSM) and compare the findings with the current data set (VSM).

Implement the findings in existing syllabus and taught courses at Royal Norwegian Naval Academy.

4.2 *Acknowledgement*

This work could not have been accomplished without the great support from:

- Royal Norwegian Navy Navigation Competence Center for financial support.
- Royal Norwegian Navy Corvette and Crew which participated in the collection of the data sets.
- The Norwegian University of Science and Technology (NTNU) Aalesund and Institute for Energy Technology (IFE) for providing Eye Tracking Glasses.

REFERENCES

Aopa 2009. Collision Avoidance Strategies and Tactics. *In:* INSTITUTE, A. S. (ed.) *https://www.aopa.org/-/media/files/aopa/home/pilot-resources/asi/safety-advisors/sa15.pdf?la=en.* Edition 3 ed. Frederik: Bruce Landsberg.

Asb, A. S. B. 2016. Aircraft Instrument Systems. *Aviation Maintenance Technician.* ASB.

Brown, D. L., Bautsch, H. S., Wetzel, P. A. & Anderson, G. M. 2002. Instrument scan strategies of F-117A pilots. DTIC Document.

Colvin, K., Dodhia, R. & Dismukes, R. K. Is pilots' visual scanning adequate to avoid mid-air collisions. Proceedings of the 13th International Symposium on Aviation Psychology, 2005. Citeseer, 104-109.

Faa 2016. Aeronautical Information Manual *In:* ADMINSTRATION, F. A. (ed.). Washington: FAA.

Fitts, P. M., Jones, R. E. & Milton, J. L. 1949. Eye Fixations of Aircraft Pilots. III. Frequency, Duration, and Sequence Fixations When Flying Air Force Ground-Controlled Approach System (GCA). DTIC Document.

Forsman, F., Dahlman, J. & Dobbins, T. Developing a Standard Methodology For Dynamic Navigation in the Littoral Environment. Royal Institute of Naval Architects, International Conference, Human Factors in Ship Design and operation, 2011.

Forsman, F., Sjors, A., Dahlman, J., Falkmer, T. & Lee, H. C. 2012. Eye Tracking During High Speed Navigation at Sea. *Journal of Transportation Technologies,* Vol.02No.03, 8.

Gilchrist, I. D. & Harvey, M. 2000. Refixation frequency and memory mechanisms in visual search. *Current Biology,* 10, 1209-1212.

Glaholt, M. G. 2014. Eye tracking in the cockpit: a review of the relationships between eye movements and the aviator's cognitive state.

Grepne-Takle, R. 2010. *Assessment of Simulator-based Training of Ship Navigation Officers by Implementation of Collision Avoidance Methods other than ARPA Functionalities.* MSc MSc Project, Norwegian University of Science and Technology.

Groves, P. D. 2013. *Principles of GNSS, Inertial, and Multisensor Integrated Navigation Systems,* London, Artech House Publishers.

Hareide, O. S. 2013. *Control of position sensor input to ECDIS on High Speed Craft.* Master of Science (MSc), University of Nottingham.

Hareide, O. S. & Ostnes, R. 2016a. Comparative Study of the Skjold-Class Bridge- and Simulator Navigation Training. *European Journal of Navigation,* 14, 57.

Hareide, O. S. & Ostnes, R. 2016b. Maritime usability study by analysing Eye Tracking data. *Internation Navigation Conference Proceedings,* 17.

Hareide, O. S., Ostnes, R. & Mjelde, F. V. Understanding the Eye of the Navigator. *In:* NAVIGATION, N. I. O., ed. European Navigation Conference, 2016 Helsinki. Confedent International.

Haslbeck, A., Schubert, E., Gontar, P. & Bengler, K. 2012. The relationship between pilots' manual flying skills and their visual behavior: a flight simulator study using eye tracking. *Advances in Human Aspects of Aviation*, 561-568.

Holmqvist, K., Nyström, M., Andersson, R., Dewhurst, R., Jarodzka, H. & Van De Weijer, J. 2011. *Eye tracking: A comprehensive guide to methods and measures*, OUP Oxford.

IMO 1972. International Regulations for Preventing Collisions at Sea (Colregs). London: IMO.

IMO 2007. RESOLUTION MSC.252(83): Adoption of the Revised Performance Standard for Integrated Navigation Systems. London.

ISO 2010. *Ergonomics of human-system interaction: Human-centred design for interactive systems : ISO 9241-210*, ISO.

Kongsberg. 2016. *K-Bridge Integrated Navigation System* [Online]. Kongsberg. Available: https://www.km.kongsberg.com/ks/web/nokbg0397.nsf/AllWeb/62F2BB1A93881801C1257CB7003A7687/$file/KM_K_Bridge.pdf?OpenElement [Accessed 13.11.2016 2016].

Norris, A. 2010. *Integrated Bridge Systems vol 2 ECDIS and Positioning,* London, Nautical Institute.

Norris, A. 2015. Integrity and the Aid to Navigation. *The Navigator,* October.

Noton, D. & Stark, L. 1971. Scanpaths in saccadic eye movements while viewing and recognizing patterns. *Vision research,* 11, 929-IN8.

Pedrotti, M., Et Al. 2014. Automatic stress classification with pupil diameter analysis. *International Journal of Human-Computer Interaction,* 30.3, 16.

Richards, C. 2004. *Certain to Win: The Strategy of John Boyd, Applied to Business*, Xlibris US.

Rin General Aviation Navigation Group, G. 2016. VFR Guide. *In:* NAVIGATION, R. I. O. (ed.) *http://www.rin.org.uk.* London: Royal Institute of Navigation.

Rolls-Royce. 2015. *Unified Bridge Control* [Online]. Rolls Royce. Available: http://www.rolls-royce.com/products-and-services/marine/product-finder/automation-and-control/control-centres-and-bridge-system/unified-bridge-control.aspx#section-product-search [Accessed 23.11 2015].

Tennfjord, G. S. 2016. *Open Bridge* [Online]. Kystverket.no: Kystverket. Available: http://www.kystverket.no/globalassets/prosjekter/e-navigation/ppt-e-nav.no-2016/1230_tennfjord_openbridge_vard.pdf [Accessed 12.11 2016].

Torskiy, V. G. & Topalov, V. P. 2013. On the Reliability of the Navigator? Navigation Complex System. In: A. Weintrit (ed.), *Advances in Marine Navigation, Marine Navigation and Safety of Sea Transportation.* CRC Press/ Balkema, London, UK, 293-296.

Van De Merwe, K., Van Dijk, H. & Zon, R. 2012. Eye movements as an indicator of situation awareness in a flight simulator experiment. *The International Journal of Aviation Psychology*, 22, 78-95.

Van Westrenen, F. 1999. The maritime pilot at work. *Evaluation and use of a time-to-boundary model of mental workload in human-machine systems, HASS,* 11.

Weintrit, A. 2011. *International Recent Issues about ECDIS, e-Navigation and Safety at Sea: Marine Navigation and Safety of Sea Transportation*, Taylor & Francis.

Wickens, C. D. 2002. Situation awareness and workload in aviation. *Current directions in psychological science,* 11, 128-133.

Wickens, C. D., Hollands, J. G., Banbury, S. & Parasuraman, R. 2015. *Engineering psychology & human performance*, Psychology Press.

Wingrove, M. 2016. *Does ECDIS increase the risk of ship collisions?* [Online]. Available: http://www.marinemec.com/news/view,does-ecdis-increase-the-risk-of-ship-collisions_42825.htm [Accessed 05.05.2016].

Yu, C.-S., Wang, E. M.-Y., Li, W.-C., Braithwaite, G. & Greaves, M. 2016. Pilots' Visual Scan Patterns and Attention Distribution During the Pursuit of a Dynamic Target. *Aerospace medicine and human performance,* 87, 40-47.