Volume XXI 2018
ISSUE no.1
MBNA Publishing House Constanta 2018

Scientific Bulletin of Naval Academy

SBNA PAPER • OPEN ACCESS

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To cite this article: F G Dias, J F Neves, V P Conceição and V Lobo, Scientific Bulletin of Naval Academy, Vol. XXI 2018, pg. 203-215.

Available online at www.anmb.ro

ISSN: 2392-8956; ISSN-L: 1454-864X

doi: 10.21279/1454-864X-18-I1-033

Maritime Situational Awareness, the singular approach of a dual-use Navy

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Abstract. *The increasing complexity of activities in the maritime domain raised new challenges to all coastal states. In the case of Portugal, it is also required to promptly react to the needs of Portuguese flag vessels around the world. In line with this, the Portuguese Navy developed a study, focused on the requirements assessment for an enhanced Maritime Situational Awareness (MSA) system. The study started with a review of SA concept models to better understand and analyse the MSA concept used by Portuguese Navy. Maritime Situational Awareness is a concept that has been widely discussed in the maritime surveillance field; on the other hand there are some authors with well-established definitions of Situational Awareness (SA). This paper address three SA concepts and associated models. The first presents an embedded world view with an ecological approach, the second, focuses on a reflective quality with an activity approach and the third focuses on the structure of information processing. These models are later related with the current MSA model used by the Portuguese Navy, considering the strengths and weaknesses of each model. From this comparative analysis, an integrated methodology is proposed to determine requirements for the MSA system of the Portuguese Navy Operational Centre (COMAR).*

1. Introduction

The sea is the main communication channel among distant communities. Nowadays, about 80% of the world trade volume is done by shipping, whether it is raw materials, finished goods, food, and fuels among others[1]. The United Nations Conference on Trade and Development (UNCTAD) forecasted a growth in transported volume of 2.8% to 2017 and an average annual growth by 2022 of 3,2% [1]. The world merchant navigation is growing, contributing to increasing challenges on safety and security at sea. The Portuguese Navy (PN) is facing additional challenges, like the possible extension of more than 120% of the Portuguese continental shelf area, or the increasing number of merchant ships with Portuguese flag [1], bringing new responsibilities according to the Montego Bay Convention [2]. In this forecasted scenario, the competent authorities have to generate better decisions, providing enhanced maritime safety and security. This demands improvements on the capability to produce and disseminate information and increase level of awareness.

The Portuguese Maritime Operation Centre (COMAR) and Maritime Rescue Coordination Centre (MRCC Lisbon) are two command and control (C2) centres, standing in the same space and organizational structure, under responsibility of Fleet commander of the Portuguese Navy. Their major objectives are respectively "*to guarantee the duties of State authority and security in maritime spaces*" and "*save the lives of those who use the Portuguese sea*" [3]. COMAR and MRCC Lisbon, since the creation of the Portuguese Navy Shipping Centre (PNSC), in November 2017, are also tasked to monitor, advice and protect all the Portuguese flag ships around the world. This means that, above their current task to support naval operation and coast guard duties, they are also responsible for the safety and security of all vessels navigating in Portuguese jurisdiction waters, and also other emerging economic activities like aquaculture or offshore renewable energy. To ensure the highest level of performance, monitoring and decision-making are supported by information systems providing the Recognized Maritime Picture (RMP). Additionally, observations and measurements of the elements and events in the maritime environment must be supported by redundant systems.

This paper presents the undergoing work of developing a methodology that will support the definition of operational requirements for Maritime Situational Awareness (MSA) information system. In order to understand MSA it was considered pertinent to address the different theoretical approaches on Situational Awareness (SA) Considerations are made over the definition of Situational Awareness (SA) from three consolidated models, which are then compared with the PN approach on MSA. After a comparative analysis on the SA model's strengths, differences and limitations, we suggest a new methodology to be adopted for the assessment of the PN MSA requirements.

2. MSA concept

MSA can be interpreted, as an application of SA concept to the maritime domain or as a capacity or a product. NATO defined MSA as "*the understanding of military and non-military events, activities and circumstances within and associated with the maritime environment that are relevant for current and future NATO operations and exercises where the Maritime Environment (ME) is the oceans, seas, bays, estuaries, waterways, coastal regions and ports*" [4, pp. 13–14].

On the other hand, the U.S agency National Maritime Domain Awareness Coordination Office (NMDACO) defined Maritime Domain Awareness (MDA) "*as the effective understanding of anything associated with maritime activities that could impact the security, safety, economy, or environment of the sea*". The same agency also defined Global MSA as "*the comprehensive fusion of data from every agency and by every nation to improve knowledge of the maritime domain. Global MSA results from persistent monitoring of maritime activities in such a way that trends can be identified and anomalies detected*…" [5]. The European Maritime Safety Agency (EMSA), a technical maritime body of the EU, seems also to adopt those two concepts [6, p. 1].

The MDA suggests a concept based on the process of "*understanding*", and the expression "*data fusion*" results from the Global MSA definition, suggesting that MSA is a systems' product, that contributes for the MDA. Therefore the NATO MSA and the NMDACO MDA concepts seems to be very similar, having in common the idea of "*understanding*" the elements in the maritime environment. To fully understand the NATO MSA concept as a process of "*understanding*" the environment, we looked for Situational Awareness (SA) theoretical frameworks.

3. SA Concept

According to Gilson, the concept of SA was identified during the first World War by Oswald Boelke who realized the importance of being aware of the enemy before he has the same level of consciousness of his opponent, and defined methods to achieve this end [7]. The idea of the existence of two distinct realities, the perception of the operators over a system and the effective state of a system, is the basis of the definition of the concept of SA [8]. This idea did not receive much attention until the eighties, but since then, it has been a central theme in scientific research. The main responsible for the origin of the concept and increasing studies in this area was the aviation industry. There was enormous pressure on pilots and air traffic controllers to be as aware as possible of the air environment, in order to have the highest level of, what it would be called, SA, guaranteeing good levels of safety [9].

Initially, the importance of having a good SA was related with the idea that a continuous secure control over an aircraft could not be achieved, without knowing the increasingly dynamic, complex and dangerous environment where the aircraft' pilot operates. A study of over 200 aircraft accidents suggested that the main cause was lack of SA [10]. In fact, Endsley, in her studies, shows how most of the accidents are associated with information compilation issues, visualization or lack of information in the system. All these factors are related with primary problems in the design of a system [11]. There are several approaches for the definition of SA, three of them were considered for this study, due to their being wide referencing in most of the studies. The first definition presents an embedded world view with an ecological approach, the second, looks on the dynamic reflection on the situation by an individual with an activity approach and the third focuses on the structure of information processing. According to Stanton's review of SA conceptual models [12], the three-level model seems to be the most developed.

3.1. 1st model: The perceptual cycle of Smith & Hancock

Smith and Hancock define SA as "*adaptive, externally directed consciousness*", presenting it as the "*invariant in the agent-environment system that generates the momentary knowledge and behavior required to attain the goals specified by an arbiter of performance in the environment*" [13, pp. 137–138].

This model originated from Niesser's work on the perceptual cycle model, describes the interaction of an individual with the world and the role of the conception or schemes of this world in this interaction [14]. This model considers that interactions or "*explorations*", by Niesser's words [15], with the world, are driven by a scheme produced internally by the individual. One of the effects of this "*explorations*" is the modification of individual's scheme, which in turn leads to the next "*exploration*". This process of interaction-driven interaction and modification is repeated indefinitely, naturally and imperceptibly. Smith & Hancock have a more holistic approach, viewing SA as a "*generative process of knowledge creation and informed action taking*" [13]. The

Perceptual Cycle model is schematically represented in Figure 1. The inner circle depicts the perceptual cycle and the outer circle depicts the general exploratory cycle.

Smith & Hancock argue that SA exists neither in the individual, neither in the environment, but in the interaction between both. They argue that the process of acquiring SA resides around the mental models maintained by the individual. These mental models facilitate the anticipation of environmental events, guiding the individual's attention to specific characteristics or elements of the environment and leading his action. Then, the individual checks if the situation has evolved according to his expectations and elaborates on the observed environment. Any unexpected event will be used to request further research and explanations, which in turn modifies the existing individual's mental model. This model can be used to explain human's information processes in control rooms. According to Stanton, it is quite satisfactory to explain the dynamic aspect of situational awareness, the way in which momentary knowledge changes and is used permanently in the search for information about the environment [12]. This model provides an in depth description of environment influence over individual's cognitive map, and the understanding of how this map is constantly changing due to the interactions with the environment. However, other aspects of the way in which interactions with the environment are made, are not equated.[12]

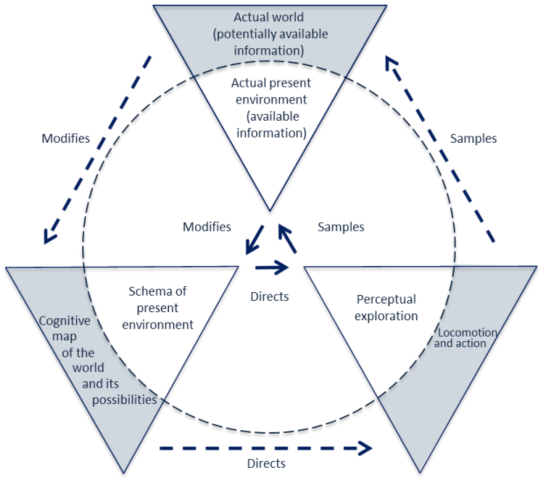


Figure 1. Expended view of the perceptual cycle. Adapted from Smith & Hancock [13].

3.2. 2nd model: SA and the Activity Theory

In this view: "*Situational awareness is the conscious dynamic reflection on the situation by an individual. It provides a dynamic orientation to the situation, the opportunity to reflect not only the past, present and future, but the potential features of the situation. The dynamic reflection contains logical-conceptual, imaginative, conscious and unconscious components that enables individuals to develop mental models of external events*" [16].

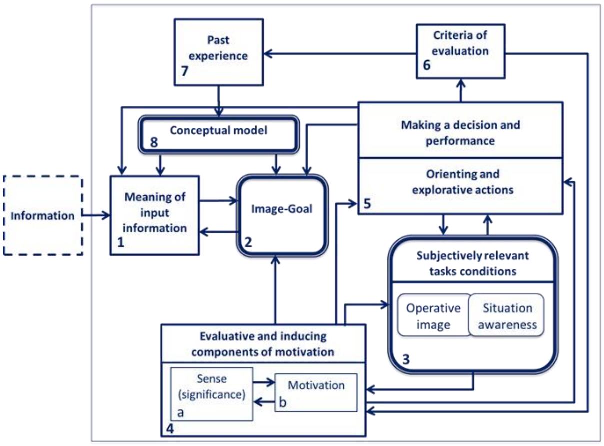
This Bedny & Meister's definition is based on the Activity Theory (AT), proposing a guided activity model compressed in eight blocks of functions. AT is an interactive, cognitive, and subsystem approach, that has been restricted for decades to Russia, origin country of this model creators (Leont) [17, p. 122]. This approach does not specify processes that are traditional to cognitive psychology, such as perception, memory, or even thinking or action execution [12, p. 6]. In this theory, processes, involved in situational assessment, depend on the nature of the task and individual's objectives. As shown in Figure 2, each of the eight blocks has a specific task in the development of SA and in the structure of the activity.

Despite presenting a well-established SA concept, Bedny & Meister aimed to explain the concept of situational assessment. The authors argue that SA is the consciousness about a given environment, i.e., the level of cognitive representation of reality. The model describes the mechanisms and information necessary to create a reflection of reality which is, however, personal [16]. The eight functional blocks are linked by feedback and feedforward loops. A summary of the role of each block is presented in the table of figure 2.

The diagram presented in figure 2, shows that when new information reaches the first block, through sensory perception systems, it will be interpreted in light of the conceptual models of each individual (Block 8). This interpretation is also guided by the image that the individual has about the purpose (block 2) and by the kind of activity or task it is expected to develop (block 5). On the other hand, the same interpretation of the input information (block 1) shapes the final idea about the goal (block 2). Block 3 represents the function of determining which elements or characteristics of the environment are most relevant. This reflection is done taking into account not only the motivation and meaning attributed to the objective of the task (block 4) but also its relation and involvement with the environment (block 5). Although not directly, the level of commitment in the goal task determined in block 2 is influenced by the criteria of evaluation (block 6), determined by the individual when interacting with the environment. The perception of the state of the environment at that moment (block 3) also shapes the conceptual image-goal.

From the interactions that are going on with the environment, experience is stored (block 7) according to the rules of evaluation (block 6). That experience has a very relevant impact on the way information is interpreted, contributing to the conceptual models (block 8). Therefore, the knowledge acquired by the actions of the individual (block 5) and the information obtained by their conceptual models (block 8) are fundamental, and are basically the starting point for the interpretation of the information which is received from the environment (block 1) [16].

According to Stanton [12, p. 8], Bedny & Meister's model for describing situational assessment, as a systems theory of activity, looks incomplete. The first inconsistency is the apparent lack of a connection between block 2 and block 4, because the interaction between those two blocks should be bidirectional. Furthermore, Stanton pointed to the absence of any connection of block 5 with the environment, which would be expected. Beside the previous point, Bedny & Meister explain that the most important process in SA is the combination of conceptual models (block 8), image-goal (block 2) and subjectively relevant task conditions (block 3). They also suggest that the conceptual models and the objective image (blocks 8 and 2) are relatively stable, while block 3 changes significantly [16]. Consequently, if what the individual considers to be subjectively relevant is incorrect or biased, then it may give wrong orientation to the situation (block 5). This can be considered as an unsuitable SA example, because once established such path, through which all future guidance and exploratory activity will be guided, it can be difficult to reorient the individual to evaluate what is objectively important and to develop a more realistic reflection or perception of the environment [12].



Block	Function	Input Block	Summary of role
1	Meaning	0, 2, 5, 7	Interpretation of information from world
2	Image	1, 4, 5, 8	Conceptual "image" of information-task-goal
3	Conditions	4, 5	Dynamic reflection of situation and task
4	Evaluation	3, 6	Comparing motivation and performance
5	Performance	3, 4	Interacting with the world
6	Criteria	4, 5	Determining relevant criteria for evaluation
7	Experience	6	Modify experience to interpret new information
8	Model	7	Modify world model to interpret new information

Figure 2. An interactive sub-systems approach to situational assessment and summary of the role and inputs to function blocks.Adapted from [16][12].

3.3. 3rd model: 3 level SA Model of Endsley

Endsley [11, p. 13] 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 further considers that the conception of "*knowledge*" is strongly linked to the kind of information that is relevant to a given task or goal. The 3 level model of SA is usually adopted for operational situations mainly because it was designed during software development studies to support the decision of military aircraft pilots and air traffic control and has being used in numerous fields such as education, pilotage, maintenance, health, weather forecasting, traffic control, etc. Endsley claims that the individual elements of SA of this conceptual model can vary greatly from one domain to another. Its importance as a groundwork and foundation for decision making and performance are found in practically all fields of application [11].

Endsley concept of SA disassembles into 3 distinct and sequential levels, as illustrated in figure 3. The first level is related to the perception of elements in a given environment, the second is related to the understanding of current situation and the last is associated to the projection or prediction of the future situation [11].

The first step to achieve SA is to collect and compile attributes or characteristics and states of the relevant elements. For each domain the information requirements are quite different, and the perception of this information can be made by any sense or by any combination of the information from each of the senses [11].

In the second level of SA the paradigm is to understand the elements of level 1, assigning them their own meaning according to the objective or tasks of the operator. It also had to integrate data in order to generate information and assign levels of importance to this information, possibly prioritizing them [11]. Sharing information, created from data interpretation, is also a very relevant process, both with other operators and with other organizations, being a key element of the second level of SA.

Level 3 of SA is characterized by the ability to predict the behaviour of these elements, according to an objective. Good Level 3 of SA is only achieved if there is a good Level 2 of SA as well as a thorough knowledge of the dynamics of the environment or the domain in which they are operating. Therefore, it is necessary to create a consolidated mental model, which is a cognitive demanding task. Having a good level 3 of SA allows to be proactive instead of reactive, in order to avoid undesirable situations [11].

The 3-level model is built around the decision making loop (figure 3) with the interaction of additional external and internal factors. According to Wickens [18], this model, seems to be very generic, with a great level of abstraction, being based on generic cognitive processes, thus offering a theoretical framework with a high number of applications.

SA is largely influenced by the cognitive limitation of individuals when interacting with complex and dynamic systems. Individuals can use numerous mechanisms to overcome these limitations, setting high priority objectives, having rational focus on objectives, using mental models, expectations and automatisms. In addition, sensitivity to the problems, training, experience to develop technical and non-technical competences in a particular domain can contribute largely to SA. It is also suggested that SA is personal, it varies from individual to individual. The design of the tool or system, which the individual interacts with the environment, also influences the quality of SA that is reached.

Wickens [18, p. 401] states that the discussion between SA and the long-term memory remains open. In part because the concept of SA can be applied to conceptual constructions, such as climate, which may change significantly over a relatively long-time interval (hours and days). There is still a group of critics on Endsley's model that raise doubts about the validity and viability of this model [19]. They argue that unnecessary constructs are made over already existing elements such as attention. The absence of the temporal dimension, or

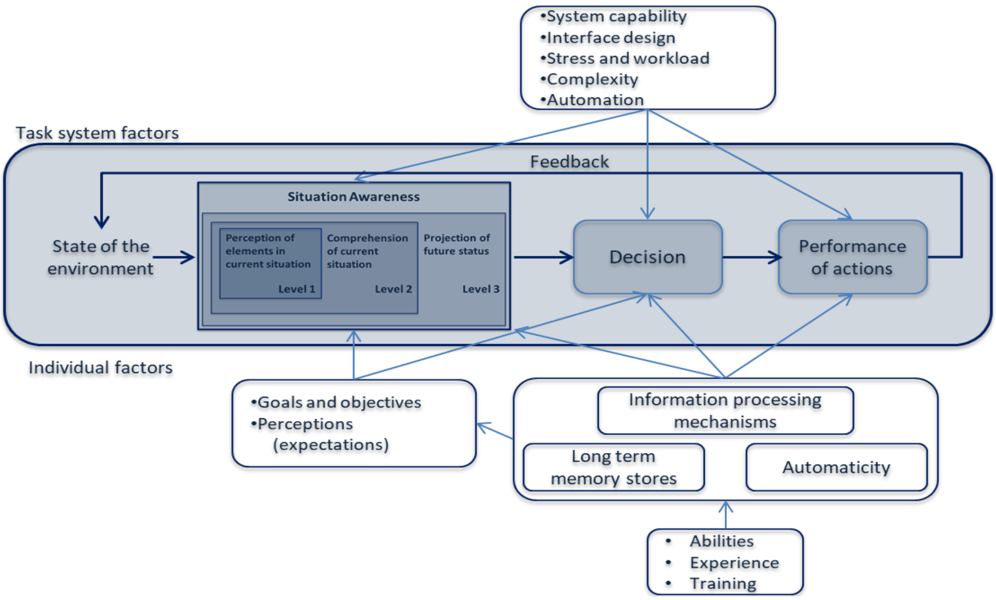


Figure 3. The 3 level model of SA in dynamic decision making. Adapted from Endsley [11].

at least a central role of it, is considered a limitation in the Endsley model that other models have been trying to address but which is also a common limitation to other models.

Other researchers [16] in the field of human activity claim that Endsley's approach is logically inconsistent because the concept of SA is represented by a step in the sequential diagram of the human-information processing system. SA, decision making and action, are explained as phases of information processing. To Bedny & Meister none of these phases can happen, without the involvement of various cognitive processes, which are not contemplated in the model [16].

Depending on the specific task to be performed by the individual, the contents of the cognitive processes involved in each "*box*" vary. Thus, the "*Information Processing Mechanisms*" box should not be described as an independent stage of information processing. Bedny & Meister add that the variables described in the model as system capability, interface design and complexity describe the state of the system and can't be interpreted as cognitive mechanisms [16].

4. Portuguese Navy MSA model

Even though the Portuguese Navy does not formally address SA definition, doctrine [20] derived from the 2011 Naval Directive, refers Maritime Situational Awareness (MSA) as a capability. MSA concept is developed from an institutional perspective, establishing standards, norms and the approach to adopt. The goal was to "*establish the MSA concept in the Portuguese Navy (PN), defining lines of action to be followed to build this capability and be the starting point for the assessment of Operational Requirements*"[1] [20, p. 1–1]. This approach on MSA will be briefly described.

The Portuguese Navy (PN) defines MSA as "*the product resulting from the integrated management of a diverse set of data acquisition and processing systems, aimed to understanding activities of interest related to maritime safety and security, facilitating the decision-making process and allowing an effective operational response*"[2] [20, p. B-1]. It proposes three Knowledge Dimensions (KD); physical, virtual and human; that meet the multidimensional reality that characterizes the maritime domain. The physical KD is defined as "*the surface of the sea, the water column and the seabed, the adjacent land and the surrounding airspace and space*" [20, p. 3–2]. The virtual KD is associated "*to data generated from sensors, information systems and information distribution networks*"[20, p. 3–2]. It is in this dimension that the SA is constructed through the cycle of: compilation, validation, fusion, analysis and dissemination. Finally, the human KD "*comprises social, moral and cognitive elements essential to human action in this context*. [20, pp. 3–2]." This dimension is responsible for improving MSA products, giving feedback, analysing, identifying and mitigating the error, through the organizational culture and experience [20, p. 3–2]. Further on, it proposes an approach to the production of MSA based on the Observe-Orient-Decide-Act (OODA) loop model [20, pp. 3–2]., addressing the physical (V in figure 5), virtual (VI in figure 5) and human (IV in figure 5) KD as illustrated on figure 5.

4.1. OODA Loop

Boyd's OODA Loop [21], illustrated in figure 4, was originally developed as an attempt to explain why American pilots were more successful than their opponents in the Korean war, in the one-on-one air hostilities *or "dog-fight*". This model described the activity of pilots in four stages or phases. Later on, Boyd developed a more abstract model, represented in Figure 4, for any form of combat [22]. This OODA Loop, first presented in 1986, is nowadays the dominant model adopted on Command and Control (C2) matters, in the military domain, and it is difficult to find any recent briefing without a reference to this model. This model integrates the military doctrine of U.S. Air Force, U.S. Navy as well as many other Navies [22] also due to the influence of NATO standardization.

The Portuguese Navy also adopted this model to design the conduction of operations from the C2 centres. However, besides his briefings, Boyd has published very little to civil society and so, this model reached the present day mainly through the armed forces. It is a model widely known and used for its simplicity and objectivity. Its steps are, according to Grant & Kooter [23], the following:

- **Observe** (a in figure 4): process of acquiring information about the environment by interacting with it, through the senses, or by receiving messages about it. This phase receive feedback from the other three phases;

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[1] Translation by de author.

[2] Translation by the author, original version in Portuguese: *"o Conhecimento Situacional Marítimo (CSM) é o produto resultante da gestão integrada de um conjunto diversificado de sistemas de aquisição e processamento de dados, que visa a compreensão de atividades de interesse relacionadas com a segurança marítima, facilitando o processo de tomada decisão e permitindo uma resposta operacional efetiva*" [20, p. B-1].

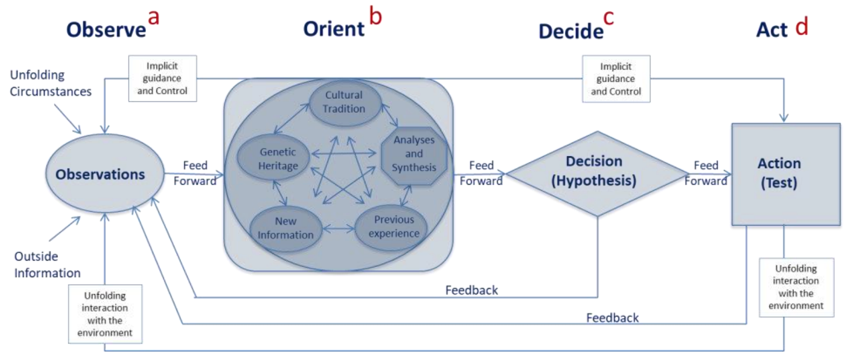

Figure 5. The OODA Loop. Adopted from Boyd's [21].

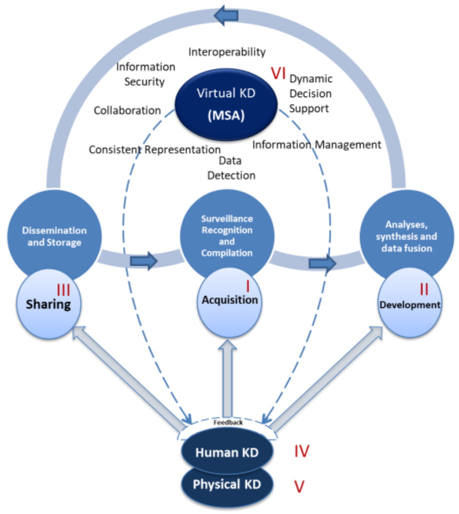

Figure 4. The Portuguese Navy model of MSA production, based on OODA Loop

- **Orient** (b in figure 4): defined by Boyd as "... *an interactive process of many-sided implicit cross-referencing projections, empathies, correlations, and rejections that is shaped by and interplay of genetic heritage, cultural tradition, previous experiences, and unfolding circumstances. […]. It shapes the way […]we observe, the way we decide, the way we act* [24].
- **Decide** (c in figure 4): is understood as the process of making a choice about the environmental situation considering the outcome that may have. The decision is aligned with the Guidelines, output from the previous step, and produces feedback for the first step, Observe.
- **Act** (d in figure 4):: process of testing the decision made by interacting with the environment. This step is conducted with input from the Orient and Decide phases and produces feedback for the Observe phase.

It was assessed by initial, unstructured interviews for this study that COMAR C2 centre was conceptualized with the same idea of a war ship C2 centre, and therefore, the model adopted to drive action in COMAR is also the OODA loop [20].

4.2. MSA production cycle

In the PN view, inspired from the OODA loop model, the Observing (a in Figure 4) stage adopted the designation "*Acquisition*" (I in figure 5) that comprises the tasks of Surveillance and Reconnaissance and the compilation of the resulting information, using a sensor infrastructure and all available data sources. The Orienting and Deciding stages adopt de designation "*Development*" (II in Figure 5). This stage is related with the analysis and data fusion tasks. Finally, Act stage adopt de designation "*Sharing*" (III in Figure 5), that is, the swift, accurate and valid exchange corresponds to the Acting step of the OODA cycle, comprising the tasks of Dissemination and Storage. In this model, Archive is part of the MSA construction and it is defined as the procedure for storing data and information obtained for later consultation [20]. The PN OODA Loop approach is represented schematically in figure 5. Figure 6 illustrates the PN model for MSA production supporting decision-making process.

MSA production is obtained from a cycle, with 3 distinct phases: Acquisition (I in Figure 5), Development (II in Figure 5) and Sharing (III in Figure 5). This cycle is developed with 7 fundamental principles in mind: Data Detection and Acquisition, Interoperability, Management of Received Information, Information Security, Consistent Representation, Distributed Collaboration, and Dynamic Decision Support. These principles are criteria that must be taken in consideration when designing the components of the MSA system, like information systems, networks, algorithms, alarms and warnings. For the operator, to some extent, it is important to know that they have been considered, even though it does not directly affect their actions.

In the Acquisition stage (I in Figure 5), it is assumed that the system carries out surveillance, reconnaissance and compilation activities through the available sensors. The products obtained in this phase are used in the next one. In the Development phase (II in Figure 5), it is expected that the system carries out analysis, data fusion and alarm production based on predefined or operator-defined criteria. The Sharing phase (III in Figure 5) aims for dissemination, both inside the organization and externally sharing, as well as the storage of data or information, for later consultation. Each phase happens sequentially in a permanent process, creating a cycle. Even the way it compiles and recognizes information must reflect information previously stored. This cycle produces MSA, which represents part of the Virtual KD (VI in Figure 5).

When interacting with MSA production cycle, individuals (Human KD, IV in Figure 5) influence how each of the MSA production cycle phases are processed. For example, in the Acquisition phase (I in Figure 5), it happens when the operator is prioritizing surveillance zones, selecting the visualization colour or categorizing any element missed by the system due to lack of information. In the Development (II in Figure 5) phase, an example can be the definition of alarms or prediction criteria. At the last phase, Sharing (III in Figure 5), we may consider the task of choosing the most relevant data to share and decide with whom.

It is assumed that it is the human element that observes and assesses the final product of MSA, creates its conception of the maritime environment, and it is used to interact with it through the OODA cycle. It is implicit that the human KD (IV in Figure 5) exists, both at the level of the operator and the organization. For example, the organization can establish some certain alarms criteria on a specific maritime area based on statistics, while the operator's experience is applied on the understanding of specific behaviours patterns, unforeseen situations or events.

4.3. MSA production and decision making

In the SA frameworks, SA, is a process that precedes decision making. Likewise, MSA, as a process or product, contributes to the quality of decision-making. Observing figure 6, MSA, as an outcome of information systems, is an element belonging to the Observation stage (a in figure 4 and 6) of the OODA cycle, which is the adopted model to direct operations at the C2 centre. In addition, MSA phases (I, II, III in figure 6) are aligned with three stages of the OODA cycle (a, b, d in figure 4 and 6). Surveillance, recognition and compilation tasks incorporate the Observe phase (a in figure 6) of the cycle. When data is analysed and fused, part of the MSA Development stage (II in figure 6) that is part of stage Orient (b in figure 6). Storage and Dissemination are tasks contained in

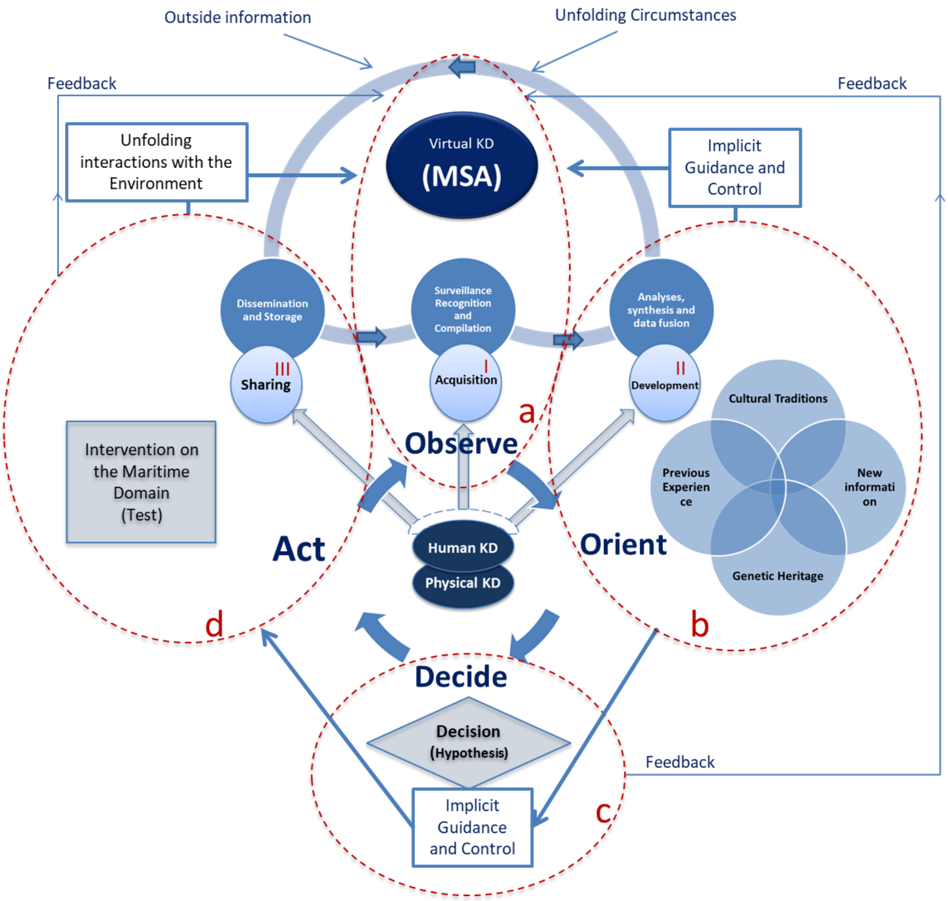

Figure 6. Portuguese Navy model for MSA production in decision-making process, based on OODA loop.

the Acting (b in figure 6) phase.

5. Analysis

In this analysis, first it will be made some considerations about Boyd's OODA Loop. Then it will be addressed some parallelisms between MSA and SA, finally it will be discussed de PN MSA production model.

5.1. OODA Loop

Notwithstanding the vague references to the temporal issue in Boyd's framework: "*in order to win, we should operate at a faster tempo or rhythm than our adversaries or, better yet, get inside the adversary's Observation-Orientation-Decision-Action-loop*"[24], it has been identified that the OODA cycle does not clearly consider the time factor [25].

This decision making framework fails to suggest the importance of multiprocessing. Decision making appears as a process that is always consistent with previous ones and not a parallel process. OODA Loop adapts to a single process circumstance, without parallel phases, which raises the doubt if, when applied to crisis situations, the model will be permanently in the decision phase [25]. Despite its popularity, in the military domain, OODA Loop is considered a poor model to explain human activity, for having little cognitive validity, mainly because it does not refer any cognitive process such as attention or memory. [23].

Another limitation of OODA Loop is the difference between the real environment and the individual's perception of the environment, which are not addressed. Individual's mental models aren't mention too [26].

According to Grant & Kooter [23], other issues have to be considered, such as the non-existence of the enemy's influence, which would be expected since this is a model drawn from this premise: the existence of an enemy.

This model also raises some uncertainties regarding its applicability to environments with large numbers of subjects, since it was designed for the dogfight situation. Although widely adopted in complex environments with numerous participants, it is a good indicator but it is not a guarantee of its validity. Finally, this model does not consider group dynamics or joint decisions. Processes such as distribution of information, development of shared SA, redistribution of tasks, authorization, delegation, etc. are not considered [23]. Keus's [27] has extended OODA Loop to teams, proposing additional processes for information distribution, development of shared situation awareness, task re-allocation, confirmation and authorisation [23].

Adopting the OODA Loop, PN model for MSA production in a decision-making process, inherits four weaknesses: do not refer the time factor, do not conceive the multiprocessing possibility, individual's perception of the environment and team processes.

5.2. MSA and SA frameworks

NMDACO MSA and PN MSA are both defined as a product of systems, therefore it is not possible stablish a association with the SA definition according the presented SA frameworks. However the PN model, based on the OODA loop have some elements in common with the SA frameworks presented, because in all of them is consider the decision making process.

The word "understanding" in the NATO MSA and MDA definition suggest an application of SA concept to maritime environment. Therefore, it is possible to establish a relation between them and SA. However, PN MSA approach never address SA concept.

The PN definition of MSA, as a product of a set of systems, is similar perspective of the U.S. Global MSA concept in the sense that is a product and not a process. However, it is possible to find some similar concepts derived from SA theoretical frameworks. In the PN model, the human interpretation of the system's outcome it is not addressed. The Figure 6 presents an interpretative schema of the Portuguese Navy approach on decision-making and MSA production. The OODA loop models is used not only to design the conducting operations in the C2 centre of maritime operations, but also to establish a framework for the MSA production.

In relation to the concepts of NATO MSA and MDA, the PN definition of MSA does not consider the "*understanding*" or in other words, the human interpretation. The product of a set of systems, even if it results from numerous and cyclical interactions, refinements and improvements, as result of human interaction, is not awareness, as it is seen from the three SA frameworks. Based on these frameworks, awareness is a state or process that lies in the subject (individual or team), not in the systems. Thus, the product of the MSA information systems could be, eventually, situational information. For example, when a computer system predicts behaviours, with sophisticated algorithms, Awareness only exists after individual's interpretation of the algorithm's outcome. The lack of any reference to the idea of awareness as an understanding of the individual comes as main limitation of PN MSA definition. It is suggest that PN present a definition of MSA and, eventually adopt a SA definition.

5.3. PN MSA Model and SA

To the best of our knowledge, the idea of knowledge being organized in 3 dimensions (virtual, human and physic KD) with the MSA delivered in the virtual dimension, is an uncommon design and not sufficiently grounded in theoretical foundations. However, there is some logic validity in the PN model, due the similarity to the OODA cycle, with the respective limitations found in this model.

The concepts of mental models or mental conceptions are central in the interaction of the individual with the environment, according the three SA models presented. Therefore, this study suggests that the use of those mental models or schemas aren´t considered by PN approach on MSA. Nevertheless, understanding how operators produce awareness, apart from the systems outcome, could bring great benefits for the organization. These mental models, influenced by experience and by the organizations that provide those experiences, may be the key to understand how operators set up misconceptions of the environment. Some questions raise about this issue. Does the organization influence the mental models of the operators? Is there a pattern in the mental models of operators in the Navy? Have the most experienced operators' better mental models? Therefore, it was proposed to develop a study, based on common crises scenarios, to understand the influence of operators metal models.

It is also suggested, based on the presented models and respective SA definitions, that defining MSA as the outcome of a set of systems, without considering the SA concept, is not advisable. It is recommended further clarification on this issue. It is suggested to adopt the MDA concept or rename the "outcome of the set of systems". Before addressing an organizational perspective on MSA, an MSA definition which considers the individual interpretation on the environment needs to be adopted. It would not be wise to define requirements based on a SA concept that do not consider a difference between the individual interpretation on the environment, the representation of the environment by the outcome of a set of systems and the real environment.

Another concept, not mentioned in this paper but very relevant to the SA process is the confidence level associated to data and derived information, outcomes of analyses, data fusion, alarms and prediction. Endsley addressed this issue as a critical element of SA level 1 [11, p. 14].

PN MSA model have no similarities to Smith & Hancock's perceptual cycle. Perceptual cycle is based on the idea of the individual's schema of the environment, which is not considered in the PN model, being one of its main fragilities.

The sub-systems approach to situational assessment from Bedny and Meister [16] is robust and contemplates some coincident elements to the PN MSA model, yet with some differences in their functions. For example in the [16] model, past experience of individual's have a central role in the process of decision making, while in the PN model, it seems to just influence the Orient phase (b in figure 6). Bedny and Meister's [16] model conceptualizes other elements not considered in the PN model, such as the objective or Goal, central in human activity, and the elements associated with human involvement. Bedny and Meister model [16] is abstract and does not show the existence of computer systems, once this model applies to any human activity. The main difference, however, is that the [16] model is not cyclical but sub-systemic. Although [16] model may have some logical limitations as identified by Stanton [12].

Endsley's SA model is much close to the PN model, having also a cyclical and chained structure considering not only the idea that individual's perception about the environment prevails but also the use of information systems. Two additional factors are considered. One is the objectives and the other is the ability, technical experience and training. All these factors have been considered essential for C2 activities however, they are not reflected in the PN Model.

Endsley has a tested and validated methodology on determining requirements for SA support systems, based on her 3 level model of SA in dynamic decision making. Her methodology, the Goal-Directed Task Analysis (GDTA) [11, p. 64] is based on definition of goals, sub-goals, necessary decisions to achieve those goals and the information needed for each decision. The goals, decisions and information need are analysed and transformed into system requirements. These requirements are then organized according the 3 levels of SA (Perception, Comprehension and Projection). This methodology is based on unstructured interviews to the "*subject matter experts"*[11, p. 24] as described in [11, Ch. 5].

Endsley GDTA methodology has a developed SA model that supports it and has cycle approach centred on decision making like PN MSA model. Even knowing her model limitations, we must acknowledge the similarity and complementarity between the two models. The lack of difference between the real environment state and the individual perception of it is not addressed in the PN model but is a central idea on Endsley's model. The detail discrimination on external and internal factors that affect SA and decision-making are much more logically and satisfactory in the Endsley model than it is in the OODA Loop. In the OODA loop internal and external factors, described as "*Cultural Traditions", "New Information", "Genetic Heritage" and "Previous Experience"* are all addressed in the Orient Stage (b in figure 4 and 6). In Endsley's approach, internal and external factors affect directly the processes of SA, "*decision"* and "*performance of actions"*. Besides that, Endsley has a more complete description on the possible factors, also considering Systems characteristics.

The applicability of OODA Loop model to groups environments raises some uncertainties [23]. Endsley's model contemplates the possibility to be applied for teams and that is reflected on her GDTA tested methodology.

Therefore, accepting the following two premises: an Information System (IS) to support MSA is a SA IS developed for the Maritime environment; and Endsley approach on SA is the most similar and complementary model to the PN model on MSA construction; it is considered adequate to adopt Endsley's methodology for requirements definition.

Considering the PN model, it is clear that the goals for achieving MSA will be related with the tasks of each phase (I, II, III in figure 6) for MSA production (Dissemination and Storage; Surveillance, Reconnaissance and the Compilation; Analysis and Data Fusion). Therefore, for an IS to support MSA in PN, it must full fill the requirements for the tasks described above. Thereby, it is also suggested, after defining the requirements by the GDTA, to correlate the requirements with the tasks and respective phases (I, II, III in figure 6) of the PN model. If there was any requirement defined that did not correspond to any task, it means that there is a new Task to be defined, not contemplated initially in the PN model. Therefore, the model must be reconsidered.

It is not worse to mention that the work developed under this paper is still undergoing and it is expected to have a thorough analysis in the next upcoming months.

6. Conclusions and future work

We propose some additional clarification on definition of MSA for the PN model. The difference between MSA as process and MSA as product needs further clarifications. Two different but related concepts need to be defined. The first based on a SA definition, applied to the maritime environment. The second based on a product of a set of Information Systems to support SA.

The OODA loop model is used not only to design the conducting operations in the maritime operations C2 centre, but also to establish a framework for the MSA production. There is some logic validity in the PN model, due the similarity to the OODA cycle, with the respective limitations found in this model. The lack of any reference to the idea of awareness as an understanding of the individual comes as the main limitation of the PN MSA model.

The concept of mental model, or mental conceptions are central in the interaction of the individual with the environment, according the three SA models presented. Consequently, it is proposed to develop a study on operators' metal models based on prepared typical crises scenarios.

Finally, due to the PN and Endsley models similarity and complementarity, GDTA, complemented with a Task correlation analyses, this model will be adopted for determining requirements for a SA support system for PNSC.

References

[1] UNCTAD, 'Review of Maritime Transport', United Nations, Geneva, 2017.

[2] República Portuguesa Assembleia da República, *Resolução da Assembleia da República nº 60-B/97, Diário da Republica, I Série nº 238, 15 de Outubro de 1997, pp 5486-(3) - 5486-(192)*. .

[3] Portuguese Navy Shipping Centre, *GUIDANCE AND GUIDELINES - Standard procedures for merchant vessels hoisting the Portuguese national flag*. Lisboa: Portuguese Navy, 2017.

[4] NATO, 'Multinational Experimentation 5 MSA, final report', 2008.

[5] National Maritime Domain Awarness Coordination Office, 'National Concept of Operations for

Maritime Domain Awarness', 2007. [Online]. Available: https://web.archive.org/web/20111004213300/http://www.gmsa.gov/twiki/bin/view/Main/MDAConOps. [Accessed: 21-Mar-2018].

[6] M. Chintoan, 'Integrated Maritime Safety & Surveillance systems - EMSA capability to provide real time integrated maritime information capability to provide real time integrated maritime information services', 2013, no. October 2013.

[7] R. D. Gilson, 'Situation Awareness - Special Issue Preface', *Hum. Factors J. Hum. Factors Ergon. Soc.*, vol. 37, no. 1, pp. 3–4, 1995.

[8] D. D. Woods, 'Coping with complexity: The psychology of human behaviour in complex systems', *Tasks, errors, Ment. Model.*, no. JANUARY 1988, pp. 128–148, 1988.

[9] R. S. Jensen, 'The Boundaries of Aviation Psychology, Human Factors, Aeronautical Decision Making, Situation Awareness, and Crew Resource Management', *Int. J. Aviat. Psychol.*, vol. 7, no. 4, pp. 331–341, 1997.

[10] C. E. J. Hartel, K. Smith, and C. Prince, 'Defining Aircrew Coordination', in *Sixth International Symposium on Aviation Psychology*, 1991.

[11] M. R. Endsley and D. G. Jones, *Designing for Situation Awareness*, 2nd ed. New York: CRC Press, 2004.

[12] N. A. Stanton, P. R. G. Chambers, and J. Piggott, 'Situational awareness and safety', *Saf. Sci.*, vol. 39, no. 3, pp. 189–204, 2001.

[13] K. Smith and P. A. Hancock, 'Situation Awareness Is Adaptive, Externally Directed Consciousness', *Hum. Factors J. Hum. Factors Ergon. Soc.*, vol. 37, no. 1, pp. 137–148, 1995.

[14] P. M. Salmon *et al.*, 'What really is going on? Review of situation awareness models for individuals and teams', *Theor. Issues Ergon. Sci.*, vol. 9, no. 4, pp. 297–323, 2008.

[15] U. Niesser, 'Cognition and Reality: Principles and Implications of Cognitive Psychology', 1976.

[16] G. Bedny and D. Meister, 'Theory of Activity and Situation Awareness', *Int. J. Cogn. Ergon.*, vol. 3, no. 1, pp. 63–72, 1999.

[17] T. D. Wilson, 'Activity Theory and Information Seeking', *Annu. Rev. Inf. Sci. Technol.*, vol. 42, no. 1, pp. 119–161, 2008.

[18] C. D. Wickens, 'Situation Awareness: Review of Mica Endsley's 1995 Articles on Situation Awareness Theory and Measurement', *Hum. Factors*, vol. 50, no. 3, pp. 397–403, 2008.

[19] S. Dekker and E. Hollnagel, 'Human factors and folk models', pp. 79–86, 2004.

[20] Estado-Maior Da Armada, *Conceito de Conhecimento Situacional Marítimo (IOA 114)*. Lisboa: Ministério da Defesa Nacional, Marinha, Estado-Maior da Armada, 2012.

[21] J. Boyd, 'The Essence of Winning and Losing, by John R. Boyd', no. August, 1995.

[22] B. Brehmer, ‘The Dynamic OODA Loop: Amalgamating Boyd’s OODA Loop and the Cybernetic Approach to Command and Control’, *Proc. 10th Int. Command Control Res. Technol. Symp. Futur. C2*, no. December, 2005.

[23] T. Grant and B. Kooter, ‘Comparing OODA & other models as Operational View C2 Architecture’, in *10th International Command and Control Research and Technology Symposium the Future of C2*, 2005.

[24] J. Boyd, ‘Destruction and Creation’, in *A Discourse on Winning and Losing*, 1976, pp. 1–9.

[25] A. Koskinen-kannisto, ‘SITUATIONAL AWARENESS CONCEPT IN A MULTINATIONAL COLLABORATION ENVIRONMENT Challenges in the Information Sharing Framework Situational awareness Challenges in the information sharing framework’, National Defence University, 2013.

[26] D. M. Dehn, ‘Private communication’, *Natl. Aerosp. Lab. (NLR), Amsterdam, Netherlands,* 2004.

[27] H. E. Keus, ‘A Framework for Analysis of Decision Processes in Teams.’, in *Proceedings, CCRP Symposium, June 2002*, 2002.