11-11-2021

The Maritime Domain Awareness Center– A Human-Centered Design Approach

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Original Publication Citation
Gomez, G. (2021). The Maritime Domain Awareness Center– A Human-Centered Design Approach. Paper presented at the 1st International Arabian-Gulf Security Conference, American University in the Emirates. 32 pp.

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Presented at:
1st International Arabian-Gulf Security Conference
November 10th-11th, 2021
American University in the Emirates, Dubai, United Arab Emirates
https://iagsc.aue.ae/

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Abstract

This paper contends that Maritime Domain Awareness Center (MDAC) design should be a holistic approach integrating established knowledge about human factors, decision making, cognitive tasks, complexity science, and human information interaction. The design effort should not be primarily a technology effort that focuses on computer screens, information feeds, display technologies, or user interfaces. The existence of a room with access to vast amounts of information and wall-to-wall video screens of ships, aircraft, weather data, and other regional information does not necessarily correlate to possessing situation awareness. Fundamental principles of human-centered information design should guide MDAC design and technology selection, and it is imperative that they be addressed early in system development. The design approach should address the reason and purpose for a given MDAC. Subsequent design efforts should address ergonomic interaction with information – the relationship of the brain to the information ecosystem provided by the MDAC, and the cognitive science of situation awareness and decision making. This understanding will guide technology functionality. The system user and decision maker should be the focus of the information design specifications, and this user population must participate and influence the information design. Accordingly, this paper provides a "design gestalt" by which to approach the design and development of an MDAC.

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Introduction

The combination of highly capable maritime surveillance and reporting technologies and the associated information demands has resulted in a deluge of information for the maritime decision-maker ashore. “The problem is no longer lack of information, but finding what is needed when needed.”[1] This situation spawned an equally robust demand for command and control centers and information display technology, a concept influenced by one of the first such centers, NASA Mission Control. But the mere existence of a room with access to vast amounts of information and wall-to-wall video screens of ships, aircraft, weather data, and other regional information does not necessarily correlate to creating or possessing situation awareness. The ability to fuse information feeds into visually pleasing displays has improved exponentially over the years. But has the amalgamation of technology into one physical space, as in a maritime situation awareness or command and control centers, appropriately been influenced by human factors and mission tasks?

NASA Mission Control **-** 1962

The maritime environs are a highly complex ecosystem of activity. Human behavior is often as unpredictable as sandstorms and rogue waves. Speed of activity can range from massive container ships operating at 10kts to commercial and military aircraft operating at 400kts, both of which can require decisions conveyed and executed quickly. Disabled vessels in critical chokepoints require prompt situation awareness and decisions to prevent or mitigate subsequent disastrous chain of events. And complex political factors with ships and aircraft operating in international waters and airspace can create tense episodes daily.

Carnival Cruise Line Fleet Operations Center – 2018

This paper contends that Maritime Domain Awareness Center (MDAC) design should be a holistic approach integrating established knowledge about human factors, decision making, cognitive tasks, complexity science, and human information interaction. MDAC design should not be primarily a technology effort that focuses on computer screens, information feeds, display technologies, or user interfaces. Fundamental principles of human-centered information design should guide MDAC design and technology selection, and they must be addressed early in system development. The design approach should address the reason and purpose for a given MDAC. Once this is established, design efforts should address ergonomic interaction with information – the relationship of the brain to the information ecosystem provided by the MDAC, and the cognitive science of situation awareness and decision making. This understanding will guide technology functionality. The focus of the information design specifications should be the system user and decision-maker, and this user population must participate and influence the information design. This paper contends that "true situation awareness only exists in the mind of the human operator [and] presenting a ton of data will do no good unless it is successfully transmitted, absorbed and assimilated in a timely manner by the human to form situation awareness."[2] Accordingly, this paper provides a "design gestalt" by which to approach the design and development of an MDAC,

The Maritime Domain

The term 'maritime domain' is in such widespread use that it can invoke a variety of definitions and mental images depending upon which aspect of the maritime domain one is involved. A commonly accepted definition identifies it as all areas and things of, on, under, relating to, adjacent to, or bordering on a sea, ocean, or other navigable waterways, including all maritime-related activities, infrastructure, people, cargo, and vessels and other conveyances. The maritime domain is not just objects and activities on the open seas. A maritime domain can also include commercial and military aircraft activity and air traffic routes. It includes activity in and around the littorals, intermodal transportation (rail, road, and navigable waterway), maritime and land access to and from ports, and environmental activity, which includes natural (weather) and human impact (e.g., hazardous cargo discharge or spill). The amalgamation of this activity makes the maritime domain a complex ecosystem influenced by a plethora of human, political, social, economic, military, maritime, airborne, and environmental events. It can be an environment "where acts of piracy, drug trafficking, and other threatening events become obscured in the crowd of everyday fisheries, cargo traders, ferries and pleasure cruises, hindering situation awareness."[3]

Understanding and articulating what a complex environment truly is will influence expectations of an MDAC its component technology and impact how decision-makers interact with its component systems. Complexity science aids the understanding of the maritime domain, which can help MDAC and component technology design. Complexity science is about "the unpredictable, disorderly, and unstable aspects of organizations."[4] Per complexity science, a complex system is "composed of a large number of interacting components, without central control, whose emergent 'global' behavior . . . is more complex than can be explained or predicted from understanding the sum of the behavior of the individual components."[5] The maritime domain is indeed a "complex system made up of many interacting parts" the interaction of which often leading "to large-scale behaviors which are not easily predicted from knowledge only of the behavior of the individual agents."[6] Simply knowing the location, direction, and ownership of vessels displayed on numerous large screens does not necessarily lend itself to an improved understanding of the regional maritime domain. Understanding the maritime domain as a complex organism should augment what can be considered awareness in the maritime domain or maritime domain awareness.

The International Maritime Organization (IMO) defines maritime domain awareness (MDA) as the effective understanding of anything associated with the maritime domain that could impact security, safety, the economy, or the marine environment.[7] And the U.S National Maritime Domain Awareness Coordination Office (NMDACO) defines 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. MDA is often mainly associated with security and military operations. But as the above definition provides, security is just one component of MDA. Uninterrupted economic activity (e.g., commercial shipping, fisheries) and environmental events (e.g., severe weather, oil spills) require timely monitoring. Commercial technology providers also use the term MDA to describe maritime monitoring systems (surveillance, information feeds, visualization, screen displays, etc.). For example, one technology provider states that "Pole Star's MDA platform is a comprehensive AIS integrated maritime data solution for those that require complete situational awareness"[8], thus contending that the mere presence of data results in maritime domain awareness. Effective maritime domain understanding and awareness are goals for which a system is designed and developed, and the body of knowledge that best addresses achieving those goals is situation awareness.

<u>What Precisely is Situation Awareness?</u>

The definition of awareness can seem intuitive. But as with the maritime domain, it is essential to have a clear and shared understanding of what constitutes awareness, especially in the complex maritime domain. Awareness in this context is not expansive but focused on a particular maritime area, a specific maritime environment, or a situation. Therefore, awareness shall be explored in the context of an equally pervasive term – situation awareness (SA).

Every day, people find themselves in situations like driving a car or scouring the internet for information and seeking awareness of the physical or information surroundings to make optimum decisions. One example pertinent to this discussion is air traffic control, where human controllers must quickly assimilate information, develop understanding, make decisions, and convey directions in a short time. The air domain has specific information feeds and unique traffic control system needs, but only specific air command and control aspects relate to maritime SA. Understanding the purpose and scope of SA in the context of a particular domain is essential as it guides how and for what SA centers are designed. To the basics of SA, Stanton provides that SA has three perspectives[9]:

- "The approach from psychology places situation awareness as something that can only exist in the minds of people in a system. This means that the unit of analysis is the individual and that team situation awareness is the summation of individual situation awareness.
- The engineering perspective puts situation awareness in the world, represented in the artifacts and objects that people use. This means that the unit of analysis is the things that people interact with.
- The systems ergonomics perspective places emphasis on the interaction between people and their artifacts in the world to propose that situation awareness functions like distributed cognition. This means that the unit of analysis is the whole socio-technical system."

Commercial maritime technology providers align with the engineering and systems ergonomics perspective. While there is merit in all these perspectives, it is helpful to understand that not all maritime domains are the same. Some maritime environments are much more complex than others, containing more artifacts or objects (i.e., ships, aircraft, rail, and road transport) and more activity (e.g., straits and canals) and environmental and political influences. As complexity increases, so does the requirement for enhanced knowledge and cognitive understanding – factors that cannot be supplied by simply presenting data on screens. For the purposes of this discussion, SA is based on the premise that situational awareness is a human state of mind, not a technological capability or product. As Endsley offers, "situation awareness can be thought of as an internalized mental model of the current state of the operator's environment"[10], and goes on to define 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".[11]

Endsley's concept of SA disassembles into three distinct and sequential levels, as illustrated in Figure 1. The first level is related to the perception of elements in a given environment. The second is associated with the understanding of the current situation. The last is associated with the projection or prediction of the future situation.[12]

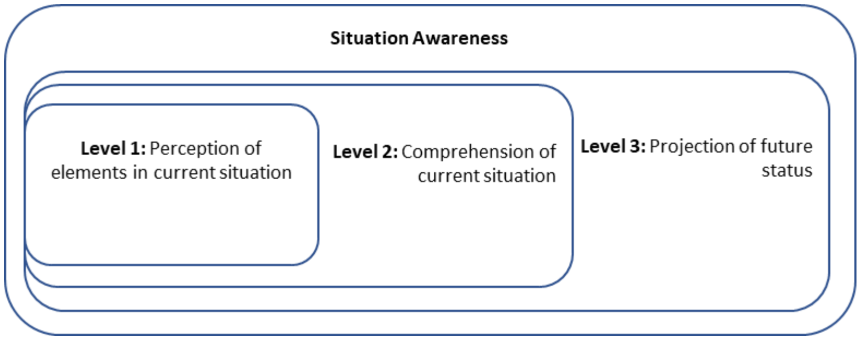


Figure 1: SA Levels

Endsley's approach is also consistent with concepts of maritime situation awareness (MSA). NATO defines MSA as "the understanding of military and non-military events, activities and circumstances within and associated with the maritime environment . . . where the Maritime Environment (ME) is the oceans, seas, bays, estuaries, waterways, coastal regions, and ports".[13] And The U.S. National Maritime Domain Awareness Coordination Office definition implies a convergence of MDA and SA, defining 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 so that trends can be identified, and anomalies detected…"[14] These definitions seem consistent with the concept of MDA, which is based on the process of understanding and suggests that MSA contributes to MDA. Neves looks to situational awareness theoretical frameworks to fully understand the MSA concept as a process of understanding the environment.[15] Neves notes that Endsley's model of SA is usually adopted for operational situations mainly because it was designed to support the decision-making environments of military aircraft pilots and air traffic control. Neves notes that while Endsley claims that the individual elements of SA of this conceptual model can vary significantly from one domain to another, the model is a sound foundation for developing SA systems in a broad array of applications.[16]

Awareness, in this construct, shall be considered understanding the current state of activities in a geospatial environment and informational domain that supports knowledge-based anticipation of future events and decision making. This 'understanding,' the first stage of developing situational awareness, is cognitive. Computers and wall screens do not provide understanding. Understanding is a human condition generated by assimilating information coupled with existing experiential knowledge. This view is consistent with Endsley's approach that the conception of knowledge, a prerequisite for understanding, is strongly linked to the kind of information relevant to a given task or goal.[17]

It is also essential to understand that not all SA environments and needs are the same. SA for a military tactical pilot is different from that of a tugboat captain; SA for a cyber network is different from that of an airline pilot. And not all maritime domains are equal. Some maritime environments are much more complex than others, requiring a higher fidelity of information across a wider variety of information sources and subject to influences from rational and non-rational state and non-state actors.

Purpose for MDAC

Like command and control in military settings, situational awareness is not an end in itself, but a means to achieve some task, objective, or goal.[18] Ostensibly, maritime situation awareness aims to possess enough information to make informed decisions. Part of decision-making is also making informed assessments about the future of an event or a region. To that end, Alberts and Hayes contend[19]:

> "To understand something does not mean that one can predict a behavior or an event. Prediction requires more than understanding . . . prediction requires actionable knowledge . . . Operationally, the most that can be expected is to identify meaningfully different alternative futures and indicators that those alternatives are becoming more or less likely over time."

Traditional national concerns for monitoring a regional maritime domain have focused on military defense, but there are more reasons. One of the purposes for an MDAC can include economic exclusion zone monitoring for fishing, mining, and other resource harvesting and ensuring safe and expeditious trade activities, both for home ports and transient shipping. Environmental events, which can impact those economic issues and conventional security, include monitoring for hazardous weather or pollution events. And since the maritime domain is closely tied to intermodal (road and rail transport to and from ports), monitoring land activity in those areas is also of import to an MDAC. But monitoring is not a purpose in and of itself. Real-time information access is provided to make decisions about routine, emergency, or anomalous events in the maritime domain. An MDAC is, in essence, a decision support system and must support the cognitive needs associated with human decision-making within a specific mission.

Expanding on her basic depiction of the components of situation awareness, Endsley provides an outline (Figure 2) of what information and input help develop SA and factors that influence SA and the tasks associated with developing decisions and performance of actions (or courses of action – COA).[20]

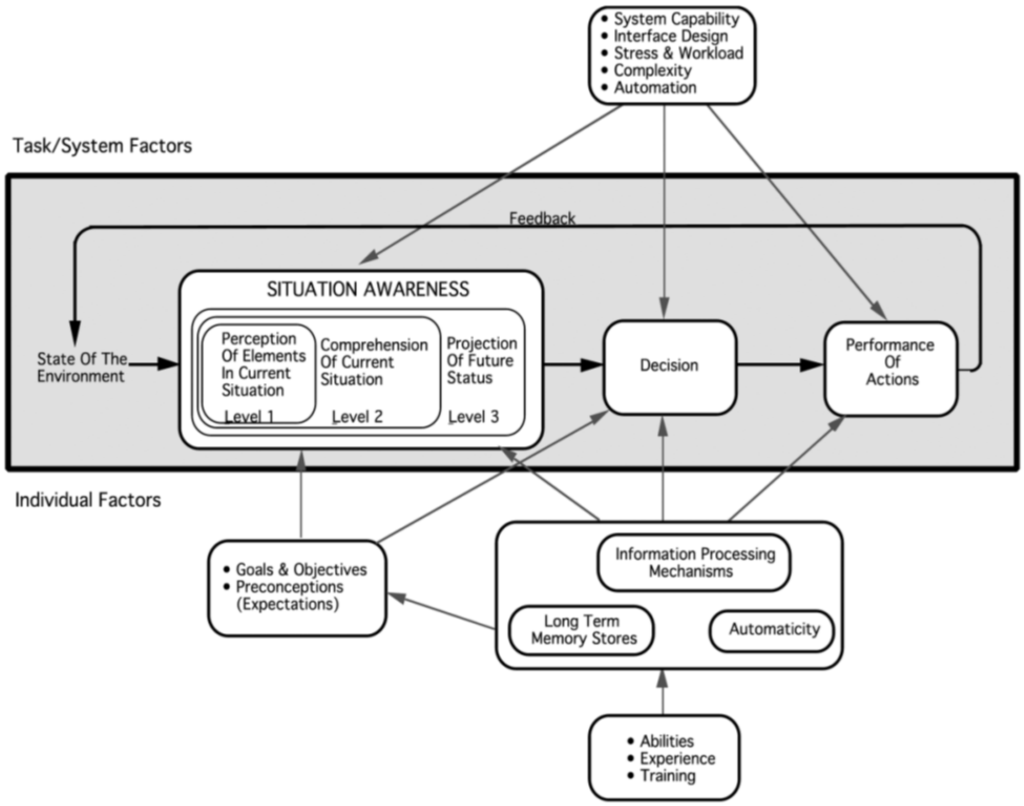


Figure 2: SA Decision Making and COA

As Endsley's model shows, situation awareness is geared towards decision and performance of actions, or courses of action (COA). A critical step in making decisions is developing understanding and making sense of a given situation, or sensemaking. Sensemaking "is focused on how people work to make sense of the information and situations in which they find themselves . . ."[21] It is "synthesizing information, using story building and mental models" that accounts for and explains events.[22] MDAC decision-makers use "a combination of pattern-matching, conscious analysis, story building, [and] mental simulation" to form SA.[23] Endsley further contends that SA is "often based on a highly automatic process of situation recognition, using a schema of prototypical situations, that is dynamic and ongoing. . ."[24]

Having made sense of the situation, the decision-maker is now working on a decision or course of action (COA). MDAC decision-makers, for the most part, have a higher degree of experience in the maritime realm than most. This experienced user base has a more truncated decision-making process which can influence the type of information required by the system (hence this user-centered design approach). While individual console operators may be system or information experts, ultimately, an experienced lead watchstander is tasked with making a decision or alerting others who make decisions. These watchstanders have 'seen' numerous events in the past and have developed a repertoire of reactions to events. They tend to use mental shortcuts or heuristics to make decisions based on previous situations. Research has shown it can take ten years of domain experience to develop accurate, intuitive heuristics.[25] As Klein et al. contend, expert decision-makers will act first to classify and understand a situation and then adopt a course of action that, based on experience, has shown to be effective in the same or similar conditions. Klein et al. termed this naturalistic decision-making style of how experienced people can make rapid decisions as *Recognition Primed Decision* (RPD).[26]

Klein's team developed this concept by observing decision and response protocols from urban firefighting commanders in actual emergency events. These events include fighting building fires, initiating search and rescue, taking offensive or defensive firefighting actions, and allocating resources.[27] Klein and his researchers discovered that firefighter commanders' decision-making did not fit into a classic decision tree framework. They were not making choices, considering alternatives, or assessing probabilities. They were focused on finding workable, timely, and effective actions.[28] Klein further discovered the firefighting commanders instinctively sought to recognize and classify a situation based on their vast experience and knowledge of what works in specific situations. If time allowed, other courses of action may be considered, and actions may be modified, but not at the expense of a late or low probability of success decision.[29] Scheepens offers that Endsley also observes that "decision-makers compare the current situation to a set of prototypical situations in memory with a corresponding course of action using a form of pattern matching"[30]. Consistent with that view, Scheepens contends that

> ". . . human operators work with default information, which is the information that can be assumed about an element if no specific information is available, *i.e.*, a kind of normal model based on operator experience and knowledge . . . For example, an operator perceives a suspect cargo vessel and, without knowing the capabilities of this specific vessel, can make certain assumptions about how fast this vessel can move."[31]

The RPD model applies to MDAC design for several reasons. The nature of the maritime domain is such that a decision-maker is not always in possession of all the information. Scheepens opines that "the operators may have a certain level of confidence in information, which can influence the decisions the operator makes based on this information. Both these constructs allow humans to achieve some degree of SA based on incomplete information."[32] Every day, mariners make decisions that seek the best available outcome achievable in the compressed time frame available. Klein provides some RPD model features that apply to an MDAC decision-making environment. Some attributes provided by Klein include:[33]

- *"The RPD model focuses on situation assessment rather than judging one option to be superior to others."* The MDAC decision-maker needs 'here and now' information to support decision-making.
- *"The RPD model asserts that experienced decision-makers can identify a reasonably good option as the first one they consider, rather than treating option generation as a semi-random process, requiring the decision-maker to generate many options."* The nature of maritime operations is that situations do not always provide multiple options from which to choose or create. Heuristics developed through experience promptly identify reasonable options.
- *"The RPD model focuses on serial evaluation of options and thereby avoids the requirement for concurrent deliberation between options that marks the focus on the*

"moment of choice." This attribute considers that decisions in the maritime environment are a moment in time and most often require prompt decision over deliberation.

- *"The RPD model asserts that experienced decision-makers evaluate an option by conducting mental simulations of a course of action to see if it will work, rather than having to contrast strengths and weaknesses of different options."* Proper MDAC information design can consider the types and priority of information required to support what any technology cannot replace – the speed and power of human sensemaking and intuition.

Klein concludes that the RPD model "explains how people can make decisions without having to compare options"[34] and shows that "recognitional decision making is more likely when the decision-maker is experienced, when time pressure is more significant, and when conditions are less stable. "[35] MDAC information capabilities (type of information and how it is presented) should be engineered mindful of the types of courses of action (COA) available to decision-makers. These are nominally routine, and exigent COAs and are derived from an understanding of the specific maritime domain and decision-maker needs. The RPD model is helpful in MDAC design because it provides a framework for establishing information delivery and access protocols, watch center business processes, and physical MDAC layout.

Anomaly Detection

Recognition Primed Decision (RPD) is predicated upon decision-makers experiencing numerous events over a long period, with these events becoming less and less novel over time. As such, the decision-maker will be processing information based on patterns of activity that fit previous experiences. But the complexity of the maritime domain, as routine as it can be, dictates that genuinely new and emergent events will also occur as complete surprises to the most experienced maritime professional. Such instances can occur due to rational or non-rational actors new to a maritime domain or ships and aircraft with new capabilities and goals. As much as there is value in optimizing the RPD model for experienced users, it should also be recognized that such experience comes with cognitive bias in detecting and identifying new influences or situations in a specific maritime domain. A decision-maker may force fit seemingly familiar information patterns into a previous experience when in fact, it is a genuinely new and emergent event. The task then is to aid the decision-maker in recognizing actual new and emergent activity as early as possible. Understanding complexity science and activity-based intelligence (ABI) can help decision-makers in these situations.

Complexity science does not mean the maritime domain is an unordered mess of human and machine activity. It simply recognizes that problems in this domain are dynamic, unpredictable, and multi-dimensional, consisting of a collection of interconnected relationships and parts.[36] It is an environment that can be impacted by unforeseen and routing events, with the potential for non-linear reactions that can be equally unforeseen or routine. Conventional linear thinking may not detect such occurrences. It is also true that some maritime domains, like other complex systems, can be "capable of adapting to changing inputs/environment and in such cases sometimes referred to as complex adaptive systems."[37] And as Zimmerman contends, "these complex adaptive systems can develop patterns of relationships within them, and how these relationships are sustained, how they self-organize, and even how outcomes emerge can be studied."[38] Indeed, the maritime domain is adaptive in that actors have the "capacity to alter or change" and "learn from experience" and ultimately operate based on a "schema and local knowledge".[39] And as a group in a defined space with other similar agents, they develop new behaviors that possess identifiable attributes. New patterns of activity can emerge, and the MDAC watch standing decision-maker will need help recognizing such anomalous events. The principles of activity-based intelligence (ABI) can provide such aid.

Activity-based intelligence (ABI) can support the discovery of abnormal activities based on an understanding of behavior patterns embedded in the figurative and literal sea of routine events. "The intention of ABI is to develop patterns of life, determine which activities and transactions are abnormal, and seek to understand those patterns to develop courses of action. ABI is focused on understanding relationships between various entities and their activities and transactions."[40] As Benson opines, an accurate picture of the maritime domain is required ". . . in order to establish normal patterns of life at sea" and identify suspicious activity.[41] The maritime domain experts can define activity, scenarios, and patterns from which abnormal patterns can be developed. Hanna provides the following five elements that summarize this knowledge base:

1. Collect, characterize and locate activities and transactions.
2. Identify and locate actors and entities conducting the activities and transactions.
3. Identify and locate networks of actors.
4. Understand the relationships between networks.
5. Develop patterns of life.

Criminal or hostile actors will seek to mask activity to make it appear routine and non-threatening. The subtle nature of some active denial and deception techniques may not be identified by the most experienced MDAC users due simply to the volume of activity and diverse nature of a specific maritime domain. To address this, MDAC information technology can be designed with attributes of potentially anomalous activity that can prompt the MDAC user to investigate further. One example is what Dror Salzman of the technology firm Windward calls a "handshake":

> "A tanker sails, its transponder off . . . it [then] meets a vessel that came from elsewhere, its transponder on. The second vessel then turns its transponder off just as the first starts to send out signals mimicking the second's transponder and proceeds to port. . . After the impostor drops off its [cargo], it returns, relinquishing the transponder signal to its waiting double, and disappears."[42]

But anomaly detection cannot always alert to truly new or abnormal activity. The MDAC decision-maker must be able to question activity that at first seems accurate but circumstantially may be questionable. For example, in June 2021, the AIS tracking data of two NATO warships was altered to show they were at a Russian-controlled naval base in the Black Sea, clearly a provocative situation. But in actuality, the ships were in port in Odesa, Ukraine, 180 miles away. This information was confirmed by a review of live port webcam feeds, via YouTube, in Odessa at the time.[43] In cases like this, questioning raw data requires geopolitical awareness and the desire to confirm initially provocative information.

Information systems can be developed with algorithms based on knowledge provided by experts. These algorithms can alert decision-makers when activity is either outside the parameters of normal or when activity within the parameters of suspicion is noted. One example is, as Glandrup notes, that "strange behavior is mostly related to kinematic data (course, speed, position) of vessels"[44]. Characteristics of this type of behavior can be captured by defining parameters such as[45]:

• Speed of movement:
– Absolute speed is larger than 25 knots in the open sea
– Loitering or hovering in an area
– Sudden increase or decrease of the speed
– Type of vessel in relation to its speed
• Direction of movement:
– Making 180 ◦ or 360 ◦ turns
– Sailing against traffic
– Sailing through anchor areas
– An unusually large number of course changes
• Vessels outside the historical behavior
• Unknown origin and destination of vessels

Table 1: Anomaly Characteristics

Reasoning software can help the decision-maker recognize complex patterns and alert them to possible patterns of life anomalies. The current trend is to apply artificial intelligence (AI) support in this area. AI can be programmed with parameters that define routine ship and aircraft operations and other behaviors associated with the maritime environs such as fisheries, research, tourism, etc. AI can be particularly adept at recognizing and alerting to behaviors that may seem harmless to humans because of sophisticated deception and denial efforts by hostile actors. AI may also help alert based on slight deviations in seemingly unrelated events.

But as technology improves, we must temper our expectations about its impact. AI technologies help speed raw information processing and unburden the MDAC decision-maker. AI may also be helpful in responding to direct inquiries by the user or decision-maker. The user can provide situational data and circumstances that AI can model for possible outcomes and courses of action. AI may also help as a system 'tutor', offering input on which system capabilities or functions may be leveraged to support understanding a situation. But AI cannot replace the human cognitive power to detect patterns and anomalies – the proverbial 'connecting the dots' - by filling in information gaps referencing that same human repository of experience. Innovative information design can support the ability of the decision-maker to make sense of a situation. But AI should not be applied to replace the human element.

Human Information Interaction (HII)

Further substantiating the value in incorporating cognitive needs into the design of an MDAC is the science of human information interaction (HII) and cognitive ergonomics. The combination of HII and cognitive ergonomics can be called *information ergonomics*, defined as:

> The human-centered design of information structures and access that allows for the intuitive and unencumbered cognitive interaction with information for analysis and decision making.[46]

The term ergonomics is commonly associated with body comfort – office chairs, desk height, computer screen distance, and angle. But fundamentally, ergonomics is about designing for people. The International Ergonomics Association states that ergonomics helps harmonize things that interact with people's needs. Ergonomics consulting firm Humanscale says it is the science of fitting a workplace to the user's needs to increase efficiency and productivity and reduce discomfort. In this case, the workplace is not an office, furniture, or a system; it is the interactive space between a person and the information itself. The interface is not the eye or physical appendages (hand, fingers) but the brain. This approach relates to the established discipline of cognitive ergonomics, which is concerned with mental processes, such as perception, memory, reasoning, and motor response, as they affect interactions between humans and a system. In the MDAC context, the relevant components of cognitive ergonomics include mental workload, decision-making, and skilled performance. Conventional information design is closely associated with techniques for displaying information for effectiveness and function versus pure aesthetics. The most commonly known solutions include data visualization (visualization of raw data) and information visualization (visualization of processed or synthesized data) solutions. They have tended to be variations on the same themes: scatter plots, graphs, geospatial time-space maps, word maps, network association plots, information dashboards, etc. But HII is not just about the visual structure of information, but the type of information, its content, and when it is provided.

HII is about the "interaction between people and information, rather than on those between people and technology (as in human-computer interaction)"[47] or user interface as in windows, mouse and cursor, and pull-down menus. Human information interaction addresses how humans interact with the essential information and how that information is effectively conveyed, received, and processed. Fully understanding cognitive ergonomics and HII can influence how information is structured, when it is provided, if information visualization is appropriate, and which visualization techniques would be most effective. HII addresses content, structure, organization, information display, and how people interact with information to support specific goals or tasks. Information provided in an MDAC must support the user in making sense of the information for SA and decision making. To achieve this, cognitive engineering principles can be applied to develop information structures that reduce cognitive load and provide decision-makers with intuitive information, both in understanding and how it relates to the situation and ultimate decision.

Fundamental to understanding information requirements and structures in an MDAC is the decision-making information needs. These needs generate information seeking efforts, whether they are scanning computers or wall display panels or submitting information queries to databases or information portals. Researchers contend that information needs are best understood and articulated when associated with understanding the task or tasks generating the information effort.[48] Fidel, noting that information is "that which reduces uncertainty,"[49] contends that since "the need for information arises when a decision is to be made, then information is for decision making."[50]

Another factor in HII is information overload. Information to support numerous goals and tasks will not come from one source but multiple disparate sources and often in different formats. If not correctly done, this information fusion can adversely impact how users interact with information. As Smart observes, the problem "of information overload and its solution lies in the ability to filter information in a manner that befits the knowledge and information processing objectives of key knowledge workers".[51] Avoiding information overload is not just a case of volume management, but informed information selection provided in an impactful and cogent manner. In the case of information and situation awareness, quantity has its own quality when offering a broad and common picture of actors, events, and actions. But finding or developing "more expressive mediums" for the conveyance of information content can help "attenuate the problem of information overload."[52] Another approach would be the ability of an MDAC component system to "assess the semantic relevance of received information and deliver filtered" information to users promptly and characterizing the information based on "task context, organizational affiliation, and executive role play. "[53]

<u>Visualization</u>

Humans are visual creatures and possess the ability to make sense and develop an understanding of complex issues through the visualization of information. But as Scheepens opines, "visualization is not just about generating aesthetically pleasing images."[54] Presenting large amounts of information on high-definition wall screens does not in and of itself equate to effective situational awareness. There is science behind why visualization is both aesthetically pleasing and cognitively supportive, and properly applied, it can guide what and how to visualize information. Ware provides some fundamental advantages of visualization which can show how visualization technology is used in an MDAC[55]:

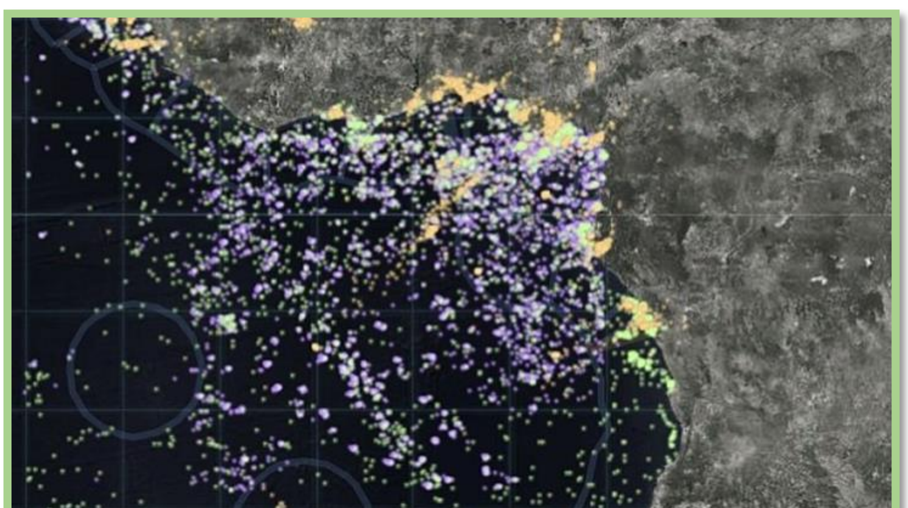
- *Visualization provides an ability to comprehend huge amounts of data.* Properly designed, visualization technology can incorporate data or information from numerous sources into one or two views. While this is of great benefit, design efforts should caution against compacting too much information into a view.
- *Visualization allows the perception of emergent properties that were not anticipated.* For this discussion, suffice it to say the human brain can 'see' patterns in visualized representations that would otherwise take too much time to realize in other modalities.
- *Visualization often enables problems with the data itself to become immediately apparent ... With an appropriate visualization, errors and artifacts in the data often jump out at you.* Visualization leverages the innate cognitive ability to see disparities or incongruities in a situation that might not be apparent in other depictions.
- *Visualization facilitates understanding of both large–scale and small–scale features of the data. It can be precious in allowing the perception of patterns linking local features.*

Visualization can portray or convey links between and among actors and patterns of behavior.

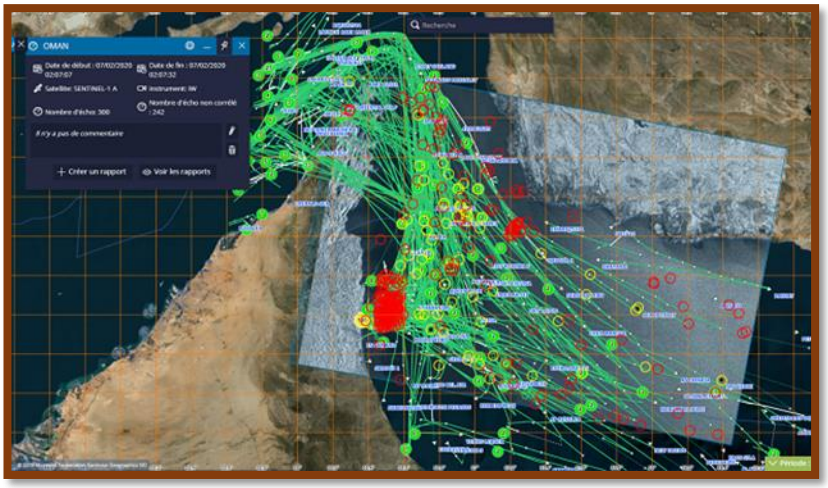
- *Visualization facilitates hypothesis formulation.* Visualization can aid the decision-maker by 'seeing' (mental models) possible courses of action (COA) or decision options.

As in any other information system, information supports decision-making best when it is provided in context to the specific situation. Visualization is an MDAC enabler and augments decision-making – it is not a panacea for ensuring clear SA. Understanding fundamental visualization categories is critically vital before selecting or designing visualization technologies.

It must first be understood that information visualization is not the same as user interface (UI). UI design is the process of building interfaces in software or computers. It is commonly considered how a human physically interacts with a system (e.g., pull-down menus, windows, touch screen, voice control, etc.).[56] For this discussion, there are three basic types of visualization: data, information, and knowledge, and two activities that visualization support: analysis and decision making. Data visualization is the pictorial presentation of raw, unprocessed data, as in geospatial coordinates. This can also include graphs, charts, scatter plots. Information visualization is the pictorial presentation of initially processed and occasionally merged data, as in the direction of movement, projected path, and object attributes like vessel name, type, and country of origin. This can also include human relation diagrams and cyber network diagrams. Knowledge visualization is the pictorial presentation of analyzed data and information that provides the decision-maker an assessment, judgment, or forecast of activity or events. Visual analytics supports analytic efforts facilitated by interactive visual representations and interfaces. The analyst can manipulate raw data to show structures, affiliations, activity, or attributes that help the analyst provide an assessment. Decision support visualization portrays information and data specifically aimed at supporting the decision-making process for a specific mission or business process.



Data Visualization: Raw ship positions based on radar sensing in western Africa
(Source: *HawkEye 360* Satellite Tracking)



Information Visualization: Ship position and movement data with corresponding vessel attributes such as name, flag, etc. (Source: *Collecte Localisation Satellites* (CLS))

While visualization is optically pleasing and highly intuitive, effective visualization techniques should be selected primarily based on domain applicability and information need, not aesthetics. As Wright opines:

> “Information visualization can be difficult to apply. Mapping data to visual form requires knowledge of graphics design and the task domain as well as visualization techniques. Subtle flaws in design can eliminate performance improvements and even diminish performance . . . Poor graphics design will obscure the data and its meanings. . .”[57]

Developing maritime domain and information based visualization requirements should be guided by the same principles as those provided by Endsley when considering situation awareness needs: analysis, perception, comprehension, and projection. Fundamental considerations include: [58]

- <u>Analysis</u>: Develop visualization tools and techniques to *analyze* and summarize patterns. This effort can “require expert rules, domain knowledge, or normal models” provided by maritime domain experts. The goal should be to provide a visualization that enables users “to find critical areas and to verify what is normal or anomalous behavior.”
- <u>Perception</u>: Visualization should aid the MDAC user, and decision-maker perceive a situation. The user needs to “perceive the status, attributes, and dynamics of relevant elements in the environment. For example, which of the hundreds of vessels on screen require attention from the operator and which do not?”
- <u>Comprehension</u>: Visualization should help the operator comprehend a situation. The user must be enabled to “understand why elements, their relationships, and events are relevant. For example, why is a vessel suspected of smuggling?”
- <u>Projection</u>: Visualization should help the operator project a current situation into the future. Making a decision requires the decision-maker “to project how the situation is

> going to evolve into the future. For example, is the vessel suspected of piracy going to attack a nearby merchant vessel?"

One common problem associated with visualizing complex and dynamic environments like the maritime domain is the volume and density of information available. Because visualization is such an effective and comforting capability, there can be a tendency to provide as much information as possible in a finite amount of screen space. This problem is often revealed only after initial use by users or during late stage development testing. This clutter can occur when large numbers of glyphs overlap or occlude other glyphs or geospatial representations (a glyph is a character, symbol, or pictograph representing an item of interest, information, or data). As a result, only a subset of all the information available can cause erroneous understanding and inhibit true situational awareness. The resultant display is visual clutter requiring excessive mental work to constantly filter and process information. One fix has been to disperse information among additional display screens. This may resolve the screen information density problem but can result in incongruous information access and alter established and effective business task flows. Other fixes include displacing glyphs to eliminate overlap. This is where the position of a glyph is offset from its actual geospatial position and requires another visual aid to represent where the vessel or information truly is located. The data set can also be simplified/reduced, requiring users to triage information needs. Another common solution is to aggregate data items in a density map using multivariate glyphs, adding functionality that allows zoom in and out to reveal or hide data on demand.[59] Another fix has been to create a "de-clutter" functionality by which the user can manually select desired information layers based on information needs at the moment. Again, this fix may interrupt cognitive sensemaking with physical user interface efforts and create a series of non-ergonomic shifts among information selection, processing, and decision making.

One effort by the U.S. Army Research Lab Computer Information Systems Directorate addressed the viability of conveying "meaning through variable sizes and proportions through the blobology concept."[60] Blobology (Image 1) is a visualization technique that shows groupings of similar and different entities when they are close together but still accurately represent where they are and some critical attributes. Varying colors and color shades, density, texture, shape, and even 3D perspective can provide information at the macro level while allowing for quick and intuitive zoom in to increase data granularity.

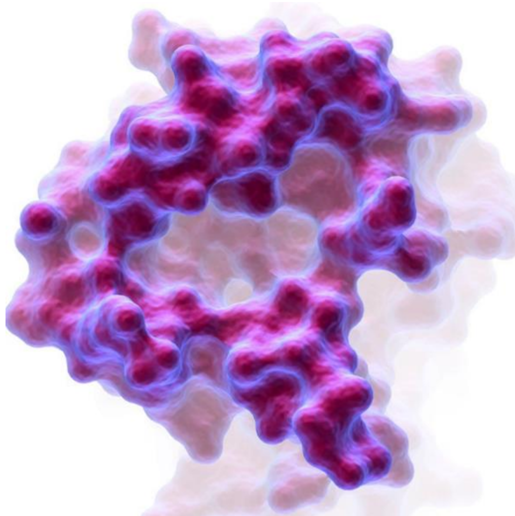


Image 1: Blobology Example
(Source: BBC News)

Image 2: Travel time map of London public transit.

Actual blobology applications include representations of time and travel in mass transit (Image 2). This visualization portrays London public transit and shows how long it takes to travel between locations (contour lines represent half-hour intervals) and areas where no such travel is possible.[61]

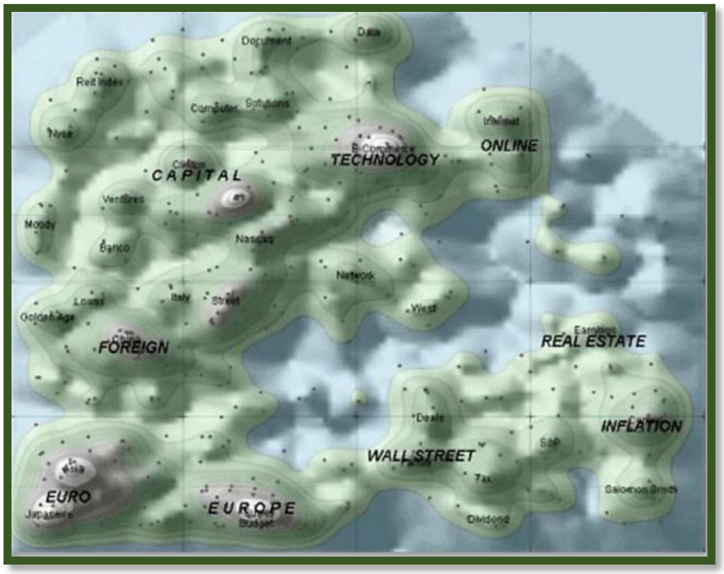


Image 3: A themescape representation of 700 articles related to the financial industry

These visualizations can also be known as 'themescapes' (Image 3). This technique leverages the common understanding of map features to convey the relative importance and volume of a given subject or entity. Larger mounds, taller (with the aid of 3D perspective), convey increased volume and or significance. Varying color shades can also emphasize this and convey common areas or fusion of entities, information, or ideas.

<u>Human-Centered Design Principles and Processes</u>

<u>Design Principles</u>

Traditional technology design has been centered on the "physical and perceptual characteristics of system components, rather than how the integrated systems need to function from a cognitive standpoint".[62] These approaches include familiar areas like human-computer interaction (HCI) such as mouse and cursor, touch screen, windows options, and pull-down menus. And display technology is a prominent factor in command and control center design due to the ability to provide large, high fidelity screens that can interact with other screens. These design approaches support some fundamental aspects of human visual processing and interaction needs. But the development of an MDAC should be focused primarily on cognitive, business process, and maritime domain information needs of the system users and decision-makers. As Endsley contends, "technology should be organized around the way users process information and make decisions [and] around the user's goals, tasks, and abilities."[63] Novel, advanced, or aspirational technology should not be the primary determinant in system configuration. However, knowledge of *proven* advanced or new capabilities can help users express system and information needs. In addition, MDAC design and technology needs should also be influenced by unique regional attributes. This user needs requirements effort, arguably the most important in developing an MDAC, should be one of the very first tasks of the development process. But obtaining users' needs is not just about asking users what technology and information they want and giving it to them. As Endsley contends, users

> “. . . generally have very limited knowledge on how to effectively present information and design human interactions with complex systems. These issues are compounded by the fact that most systems must be used by many different individuals, each of whom can have significantly different ideas on what they would like to see implemented in a new design effort. The result of this approach is an endless and costly cycle of implementing new ideas, only to have the next team of users decide they want something different.”[64]

This view is echoed by Gould, who suggests that:

> “Getting useful design information from prospective users is not just a matter of asking. Many users have never considered alternate or improved ways of performing their tasks and are unaware of the options available for a new design. Further, in trying to communicate, designers may unwittingly intimidate users, and users may unfortunately become unresponsive.”[65]

But the above approach is not to prohibit direct interaction with potential MDAC users, watchstanders, and decision-makers. Indeed, conducting a survey in which users provide information needs and business process is a viable effort – it just should not be the only mode of gathering and developing information. As Gould suggests, “designers must understand who the users will be. . . in part by directly studying their cognitive, behavioral, anthropometric, and attitudinal characteristics, and in part by studying the nature of the work expected to be accomplished.”[66] This, Gould contends, is different from an effort to “identify,” “describe,” “stereotype,” or “ascertain them,” as some potential users have characterized user needs survey efforts.[67] But even in ideal situations, it can be challenging to get the end-user to participate. Prospective MDAC users have work to perform, and organizations do not want to lose their time on the job. Organizations may also feel this is what they are paying for – someone that knows their business and can design, develop, build, and deliver an information system without such help. Even when they participate, users can have difficulty providing input, often not knowing what they want because they feel constrained not knowing how technology can support information delivery and display. Decision-makers may find it difficult to put into words what is wanted because MDAC decision-making can include intuition, conjecture, and supposition components. It can be difficult to translate user information requirements into design and software coding language or protocols, even when provided. One option to improve user participation is to provide non-technical end-users with one day of training on techniques to help them define and express their information structure and presentation requirements.

As a conceptual guide and first step to any SA requirements process, Endsley provides a set of design principles based on her model of the mechanics and processes involved in developing and maintaining situational awareness in dynamic complex systems. These principles provide a global design perspective from which to develop specific MDAC information and system requirements:[68]

1. Seek to support the presentation of higher level SA information needs, a form of overall regional view, rather than numerous lower level topical or geographical views that require users to integrate and interpret manually

2. Goal, task, or purpose-oriented information displays should be organized and physically situated to information needs for particular co-located mission areas and support decision-making processes associated with that element.

3. Support integrated SA by providing an overview of the situation across all topical and mission areas at increasingly detailed levels of information directed by the users.

4. The interface design of all component MDAC systems needs to provide appropriate event cues based on user-centered schemata that indicate prototypical situations and support intuitive cognitive attention switching in critical, high paced, complex conditions.

5. The information design needs to be acutely aware of the propensity to provide too much information and induce information overload simply. Information input to an MDAC needs to be related to specific SA needs to be balanced with the above needs to provide a broader perspective.

Endsley's principles are also consistent with the recognition primed decision (RPD) model in which Klein provides four user-centered design principles:[69]

(a) Understanding the types of goals that can be reasonably accomplished in the situation.
(b) Increasing the salience of important cues within the context of the situation.
(c) Forming expectations that can serve as a check on the accuracy of the situation assessment.
(d) Identifying the typical actions to take.

<u>Design Processes</u>
This effort involves capturing the combination of business tasks, information needs, and information conveyance requirements integrated with an understanding of the cognitive influences on all of those factors. As such, "some form of task analysis is required that not only captures the goals to be achieved but also the psychological processes underpinning their achievement."[70] Several proven processes are available to apply.

Fundamentally, "task analysis is the analysis of how a task is accomplished, including a detailed description of both manual and mental activities, task and element durations, task frequency, task allocation, task complexity, environmental conditions, necessary. . . equipment, and any other unique factors involved in or required for one or more people to perform a given task."[71] Any task analysis will require not only the identification of a unique task but breaking down of a task into specific levels. For example, usability.gov suggests the following process:

1. Identify the task to be analyzed.
2. Break this high-level task down into 4 to 8 subtasks. The subtask should be specified in terms of objectives and should cover the whole area of interest between them.
3. Draw a layered task diagram of each subtask, ensuring that it is complete
4. Produce a written account as well as the decomposition diagram.
5. Present the analysis to someone else who has not been involved in the decomposition but who knows the tasks well enough to check for consistency

This decomposition process is consistent with the majority of system design protocols. Applicable generic task analysis process includes:[72]

- Cognitive Task Analysis – Applicable where there are substantial mental demands instead of physical demands. CTA aims to understand and define the breakdown of mental processes such as decision making, problem solving, and judgment.

- Hierarchical Task Analysis – Both analyses describe tasks and sub-tasks at a detailed level that allows designers to illustrate different potential task sequences that may occur through an interaction with a system. HTA decomposes high-level tasks into subtasks.

- Cognitive Work Analysis – a guide for designing technology for use in the workplace. It is used to analyze real-life phenomena while retaining their complexity. It applies to information behavior and guides the analysis of human-information interaction to inform the design of information systems.

There are different processes by which to derive the information that influences the design of an SA system. Processes are provided to give structure to design efforts. While it is essential to adhere to the process, it is also necessary to understand the ultimate system goal and SA environs and adjust as required. For example, Minorta contends that cognitive work analysis supports SA system design and performance.[73] Design processes are based on solid research and reasoning but should not be considered equivalent to the immutable laws of physics. Dogmatic adherence to conventional task analysis nomenclature should not detract from developing complete and accurate user requirements. Whatever process(es) used, an information requirement should be associated with tasks – even if one information requirement or source is related to multiple tasks. When doing so, the information provided should be clearly identified. For example, AIS can be cited as the information source supporting multiple information and decision support requirements, but the specific information requirement might be vessel name, point of origin, destination, speed, course, etc. All MDAC / SA related goals (decision options) and tasks must be captured.

Endsley provides a human-centered information design process developed around the needs for situation awareness and can be adjusted based on unique SA environs and a particular MDAC mission. Endsley's cognitive task based goal directed task analysis (GDTA) was developed to address the human-centered design of a broad spectrum situation awareness systems. For MDAC decision-makers, the goal is to be informed. Subservient to this goal, tasks are performed to support decision making, e.g., system interface activity and information queries to support a specific activity response such as territorial water or maritime airspace incursion. Endsley describes GDTA thus:

> "In this analysis process, SA requirements are defined as those dynamic information needs associated with the major goals or sub-goals of the operator in performing his or her job . . . This type of analysis is based on goals or objectives, not tasks (as a traditional task analysis might). This is because goals form the basis for decision making in many complex environments."[74]

This task analysis is structured around MDAC goals and subgoals that equate to Endsley's SA levels. This format provides a process and structure to identify the various MDAC tasks and accompanying information needs.

1.0 Goal
1.1 Subgoal
➢ Projection (SA Level 3)
• Comprehension (SA Level 2)
○ Data (SA Level 1)

Table 2: Format of Goal-Directed Task Analysis[75]

Endsley's GDTA is a form of cognitive task analysis (CTA). It is important to understand that Endsley's GDTA was developed around situation awareness environments with well-defined goals and tasks such as air traffic control, military command and control, and power plant control. While there may be similarities between these areas and maritime domain awareness, it is essential to consider some substantive differences in both information provided and goals and tasks. Appropriate modifications to requirements gathering and documentation protocols should be considered. For example, a given MDAC mission may not have the authorities or even charter to dictate actions to actors in the same way as air traffic control or military command and control. The goals associated with air traffic control are safe and expeditious routing of aircraft in well-defined airspace under international rules and regulations, which are followed most of the time. Aircraft operators not only adhere to air traffic control but expect a degree of positive control from controllers. Such is not the case in maritime environs. AIS reporting is routinely disabled; disputes abound regarding the location of international and national waters, to include EEZs; sea lanes can often be simply commonly used routes, not mandated as with airway routes; and even with shore-based radar and satellite monitoring, tracking non-reporting vessels ranges from difficult to impossible. Also, there are well defined decisions and goals associated with air traffic control. This is not the case in many maritime domains. Often, merely knowing about an activity is the goal, even if nothing can be done to influence the event. As the discussion about situation task analysis evolves, these factors should be kept in mind and influence changes to processes and terminology associated with the maritime environs.

Conducting this analysis and capturing the requirements includes activities like "expert elicitation, observation of operator performance of tasks, verbal protocols, analysis of written materials and documentation, and formal questionnaires. . .. with a number of operators, who are interviewed, observed, and recorded individually. . . "[76] Table 3 is an example of an end product of such requirements documentation. On the left is an example provided by Endsley relating to air traffic control. On the right is an example provided by the author regarding a notional goal for an MDAC – "Maintain Awareness of Maritime Vessels" (another effort for an MDAC could include Maintain Awareness of Airborne Vehicles):

1.0 Maintain Aircraft Conformance (Source: Endsley, "Designing for Complex Systems," 9)	**1.0 Maintain Awareness of Maritime Vessels (Source: Author)**
1.1 Assess aircraft conformance to assigned parameters	**1.1 Know vessel conformance to movement parameters**
➢ *aircraft at/proceeding to assigned altitude*	➢ *vessel at/proceeding to assigned or expected location*
➢ *aircraft proceeding to assigned altitude fast enough?*	➢ *vessel proceeding to assigned or expected location?*
• time until aircraft reaches assigned altitude	• time until vessel reaches assigned or expected location
• amount of altitude deviation	• deviation between expected and planned arrival
• climb/descent	
○ altitude (current)	
○ altitude (assigned)	
○ altitude rate of change (ascending/descending)	
➢ *aircraft at /proceeding to assigned airspeed?*	➢ *vessel at / proceeding to assigned, expected, or projected speed?*
➢ *aircraft proceeding to assigned airspeed fast enough?*	➢ *vessel maintain assigned, expected, or projected speed?*
• time until aircraft reaches assigned airspeed	• time until vessel reaches assigned, expected, or projected speed
• amount of airspeed deviation	• deviation from assigned, expected, or projected speed.
○ airspeed (indicated)	○ speed (AIS)
○ airspeed (assigned)	○ speed (other sensor)
○ groundspeed	○ actual track speed
➢ *aircraft on / proceeding to assigned route?*	➢ *vessel on / proceeding to assigned, expected, or projected route?*
➢ *aircraft proceeding to assigned route fast enough?*	➢ *vessel proceeding to assigned, expected, or projected route fast enough?*
➢ *aircraft turning?*	➢ *vessel turning?*
• time until aircraft reaches assigned route/heading	• time until vessel achieves assigned, expected, or projected route and/or heading
• amount of route deviation	• amount of route deviation
○ aircraft position (current)	○ vessel position (current)
○ aircraft heading (current)	○ vessel heading (current)
○ route/heading (assigned)	○ route/heading (assigned, expected, or projected)
• aircraft turn rate (current)	• vessel turn rate (current)
○ aircraft heading (current)	○ vessel heading (current)
○ aircraft heading (past)	○ vessel heading (previous tracks)
○ aircraft turn capabilities	○ vessel turn capabilities

• aircraft type	• vessel type
• altitude	
○ aircraft groundspeed	○ vessel track speed
○ weather	○ weather
○ winds (direction, magnitude)	○ winds (direction, magnitude)
	○ current
	○ tides

Table 3: Example of Goal-Directed Task Analysis - Air Traffic Control v. Maritime Domain Awareness

Information requirements can also be developed and captured through a decision-making-focused structure. A decision ladder developed by Jens Rasmussen (Figure 3)[77] provides a format by which to identify decision tasks and information needs appropriate to situation awareness and the MDAC mission. The decision ladder is characterized by three distinct phases – situation analysis, evaluation, and planning – which are populated in the MDAC design stage with knowledge states (circles) and information processing actions (rectangular boxes). This ladder can serve as the format by which to capture the various decisional situations of an MDAC (e.g., fisheries, search and rescue, homeland security, border integrity, port security, etc.) and the unique task scenarios and information needs of each. This decision ladder is also compatible with Klein's RPD model. The information derived from maritime experts would populate the knowledge states and information processing and capture the heuristic shortcuts noted on the ladder that are used almost intuitively by maritime experts.

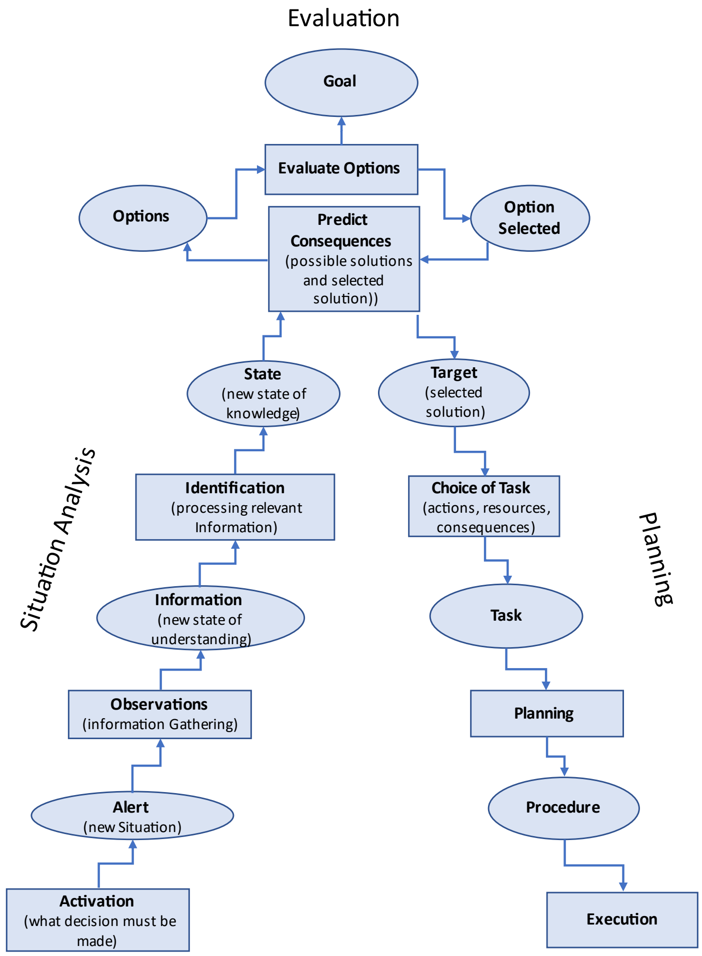


Figure 3: Decision Ladder

To populate the information required in GDTA or the Decision Ladder, it is helpful to understand the basic principles associated with naturalistic decision-making (NDM) and what questions to pose to elicit the information requirements. NDM focuses on decisions in operational settings, particularly under challenging conditions.[78] But as Klein et al. contend, "design engineers are frequently asked to work on systems, subsystems, and interfaces without being given the information about how the people operating the system will use it to make decisions. . . And designers are rarely given information about the nature of the decision strategy—how the operator will likely use certain rules of thumb and comparisons.[79] Klein states that "the primary value of NDM is to define the decision requirements for a system being developed. These decision requirements can clarify information needs . . ."[80] Klein opines that conventional task analysis and data flow diagrams work well for tasks that "consist of merely following already existing procedures [but] are not so helpful for tasks that require judgment and decision making."[81] While this view may be seen as incompatible with the application of GDTA or the Decision Ladder, there is also an opportunity to use the questions posed by NDM to populate GDTA/Decision Ladder. With appropriate modifications to GDTA and Decision Ladder terms, this approach can provide MDAC design documentation in a structured format. This approach would allow for understanding the type of information needed and the way it would be used. NDM is a way to “elicit the cognitive, decision-making needs and to let the designer understand these decision requirements [and] to provide direction in figuring out what the user needs.[82] During user and decision-maker engagement, MDAC designers should develop an overall understanding of the categories of information circumstances that characterize the MDAC operational and decision-making environment. Questions to ask system developers about the operators' decision needs include:[83]

- What are the key decisions the operators must make?
- What cues do they depend on?
- What relationships between cues are important to monitor?
- How are the operators deriving inferences from the cues?
- Will the new system support these inferences?

Answers to these and other questions would inform the MDAC information requirements (type of information and source), information structures (e.g., text, visualization, imagery), prioritization of information, and delivery modalities. Some maritime specific information and design questions include:

- Is it essential to show and alert immediate course change, or only after a new track is established?
- When should AIS On/Off alerts be provided?
- Is detailed bathymetric data (e.g., depth soundings) required to be displayed all the time?
- How is weather information displayed?
    - Only during defined times of unique or severe conditions?
    - Provide detailed real-time barometric pressure or trends?
- Is there a need to link real-time FMV (full motion video) and imagery to selected objects?
- Is there a requirement to correlate radar detection (raw radar contact return and open-source, radar emission signatures) with AIS, imagery, or other sensors?

Developed and correlated information provides the foundation for the MDAC information design guidance. Ideally, this guidance depicts goals (i.e., MDAC missions) with their associated tasks and information needs and sources. It will guide decisions on technology functionality and selection and the physical layout of the MDAC. Such decisions must also be driven by broad design principles, many of which are the results of lessons learned from previous situation awareness design efforts. Endsley has developed 50 such situation awareness-oriented design (SAOD) principles. They are arranged in six categories of principles: *General SA; Certainty Design; Complexity Design; Alarm Design; Automation Design; and Multioperator Design*.[84] These principles help the design process take a broader review, a step back of sorts, of information needs and functionality after conducting an in depth, highly detailed requirements effort. A sampling of the principles is provided:

No. 4 – Support Global SA. This relates to ensuring the 'big picture' is continuously provided and seeks to avoid having attention directed and excessive focus paid to a subset of information, resulting in a lack of attention to other critical events. This can result from "excessive menuing and windowing" obscuring additional information.[85]

No. 9 – Explicitly identify missing information. Experienced decision-makers have developed the ability to deal with ambiguity. That doesn't mean they like it or even accept it, but they know that they cannot obtain all the necessary information. Also, as shown in the above discussion about RPD and naturalistic decision-making, those decision-makers often do not require every single bit of information. They just need to know if the information does not exist or cannot be accessed. As Endsley states, "it can be quite difficult to tell whether no information presented in an area means there are no . . . objects of interest in that area, or whether that area has not been searched, or sensors are not working."[86]

No. 14 – Support uncertainty management activities.[87] Decision-makers also need to know the relative reliability of information if its accuracy is questioned. If a sensor is working at reduced capacity, it will impact the accuracy of the information provided. If an information source is a reliable intelligence service or an open-source social media feed, that can affect information reliability. Information ambiguity and system reliability must be available to the decision-maker to the maximum extent possible.

No. 15 – Say no to feature creep.[88] This relates to the propensity of technology users to be enamored with a novel, sometimes aspirational, system functionality regardless of whether its applicability relates to established information needs or mission tasks. Just because a new functionality can do a thing doesn't mean it needs to be added to a new system or integrated into an existing system. New technological functionality should be sought to meet mission, goals, tasks, and information needs.

No. 25 – Don't make people reliant on alarms – provide projection support.[89] In the conventional sense, warnings alert to something that has already occurred and requires immediate attention. As such, decision-makers are put in a reactive mode that introduces stress associated with a sense of being behind in SA, accompanied by a frantic search for what is happening now. Instead, using activity-based intelligence (ABI) and the patterns of activity approach, set the system up to notify the decision-maker when certain activities appear to be trending in an unconventional way. This provides activity projection so a decision-maker can either attempt to influence the trend or be prepared when an event occurs.

Conclusion

This requirements development process is arguably the most critical aspect of MDAC design. The process to develop MDAC information and system requirements requires direct engagement with the notional users and decision-makers of the MDAC. This effort can be time consuming and labor intensive, more so than the conventional technology design and build efforts that propose functionality first and applicability next. Approaching this task with a plan developed around the above concepts, considerations, and processes can streamline the user engagement process, resulting in high fidelity information and system requirements and ultimately a highly informed, effective, and efficient MDAC. The MDAC requirements process should occur before and apart from the technology selection and physical design efforts. After these human-centered information and system requirements are documented, proposed or aspirational technological capabilities may be considered for MDAC applicability. And it is important to understand that human-centered requirements documentation is a living effort, growing and changing as MDAC missions and technology evolve.

This paper has brought research from various disciplines to bear on MDAC design. What is at first a seemingly daunting array of disparate perspectives is, in actuality, a coalition of compatible knowledge with one goal – to improve human understanding and situational awareness. Applying this knowledge can result in clear and cogent design guidance to which technology can then be intelligently applied.

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