# A Human Perspective on Maritime Autonomy

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**Abstract.** As for all of the transport segments, autonomy is gaining increasing interest by researchers and for development in the maritime industry, and introducing autonomy is expected to create new possibilities to increase efficiency and safety. Autonomy could lead to drastic changes in roles and responsibilities for involved agents (both technical systems and humans), and these changes will be an important driver for changing the rules which regulate the responsibilities of the involved actors in the maritime domain. This paper suggests a perspective of autonomy as a process of change as opposed to a defined state. The paper discusses three areas that warrant more attention in the development of autonomy in navigation in the maritime industry. Firstly; rather than the traditional reductionist safety models, it considers complexity in maritime systems with increased autonomy and explore systemic safety models to amplify positive human performance variability. Secondly; it argues that humans will be important also in systems with increased autonomy, and discusses the human involvement on *strategic, tactical* and *operational* levels. Thirdly; it discusses the importance of defining the concepts responsibility, authority and control from the perspective of *humans*, rather than that of the *vessel*.

**Keywords:** Human centred design, maritime autonomy, methods of control, responsibility, authority, remote operations

## 1 Introduction

There is a belief that the future of maritime industry will see an increased use of autonomous solutions. The International Maritime Organisation (IMO) decided to include the issue of marine autonomous surface ships on its agenda in their Maritime Safety Committee in June 2017 [1], which is a solid sign of the importance of the topic. The dissension grows when discussing what autonomy *is*, and *how* it will affect maritime industry.

In contrast to what seems to drive the development of maritime autonomy, autonomy as a concept has no direct link with technology. Autonomy has been used since the early 17$^{th}$ century and comes from the Greek *autonomia*; from *autos* “self” + *nomos* “law”. The Oxford Dictionaries explains autonomy as *the right or condition of self-*

*government*, and further as the *freedom from external control or influence: independence* [2]. In maritime history, we can easily find examples that fall under the definition of autonomy. The explorers who sailed into the unknown more than 700 years ago were self-governed from when they left the harbour, with no shipping company or authority to influence their choices. Another example would be fishermen sailing from Europe to the Antarctic 100 years ago, staying away for months, also with little or no influence from their owner in the home country. However, arguing that the maritime domain was more autonomous in the past than what we expect of the future might not be very helpful to reduce the dissension about what autonomy is, but it does show that we might interpret autonomy differently than the original meaning of the term. This paper discusses what autonomy is today, and further elaborates on the human role in the development of autonomy in maritime systems. A system is defined as "an assemblage or combination of functionally related elements or parts forming a unitary whole" [3]. The parts of the system could be technical or human agents, where an agent is defined as a " 'thing' in an environment with capacities to sense states and effect aspects of the environment" [4].

## 2 What is this thing called autonomy?

Apparently, the term autonomy is used differently in colloquial language than in the technical definition. In addition it is interpreted in various ways both in the maritime industry and other industries. Automation and autonomy are often used interchangeably in the discussion of the technological development in the maritime industry. Parasuraman and Riley [5] define automation as "*the execution by a machine agent (usually a computer) of a function that was previously carried out by a human"*. Some attempts have been made to create a more distinct difference between automation and autonomy by transforming *Levels of Automation* (LOA) developed by Sheridan & Verplank in 1978 into various *Levels of Autonomy* [6]. The attempts have neither been able to create a common understanding of the distinction between automation and autonomy, nor reach consent on whether using *levels* is suitable for describing concepts. Endsley [7] states that using *levels* is beneficial to communicating design options to stakeholders in both automated and autonomous systems, and especially for explaining the continuum between fully manual and fully automated. However using levels to describe autonomy has been criticised for being unidimensional and not reflecting the real problems in developing systems, and for not allowing for dynamically changing functions in various contexts [8]. Parts of this criticism is rejected by Kaber [9] who claims that it confuses automation with autonomy, and he states that the *"research focused on one construct (i.e automation as a technology) yet made criticism from the perspective of another (i.e autonomy as a state of being)"*. To distinguish between automation and autonomy is difficult, and the Society of Automotive Engineers (SAE) has decided to put the term "autonomous" in their section of deprecated terms. They state that the term has become synonymous to automation since the use of it has broadened to not only encompass decision-making but include the entire system functionality [10]. Parasuraman [11] presented his version on the Levels of Automation, where the highest level of automation is defined as the computer deciding everything, acting autonomously, and ignoring humans. According to this definition, autonomy is gained at the highest level of automation, which could support the criticism of unidimensionality of the concept of autonomy.

There is no unified definition of what autonomy *is* in the context of developing systems. The challenge is apparently to define *a state of being* which includes all aspects of the benefits and complications within human and technology interaction in various contexts and changing scenarios. The reason for introducing autonomy in a system is to improve the performance of the system; hence, increased autonomy will not be a goal in itself. Relating autonomy to a change process based on system needs will give various answers of what autonomy is from system to system, and will vary over time. This paper suggests that autonomy, similar to Parasuraman and Riley's definition of automation, is a process rather than a defined state. Similar to automation, the use of technology is a main component in the change process, and autonomy especially implies the use of digitalization such as sensor fusion, control algorithms and communication and connectivity [12]. The other main component in the change process is the degree of involvement of humans in the operations, and the aim to reduce human presence in dangerous and hostile environments [13][14].

The similarities between automation and autonomy are many, and several of the challenges Woods and Dekker [15] discuss about how humans and technology get along in highly automated systems, is the same challenges more recently discussed considering autonomous operations [16]. With an interchangeable use of the two terms, it is tempting to follow SAEs path by discarding autonomy as a term and stick to the use of automation. However, there is one solid argument for keeping autonomy as a term. While automation could span from a simple exchange of functions between humans and technology, to highly automated systems comparable with autonomy, autonomy implies a *significant* change to the system. This significant change also imply that understanding all effects of changes are more complex. Lee [17] describes autonomy from a network perspective, where automation and people are nodes in a network that produce emergent properties that are not predictable by looking at the nodes in isolation.

The main difference between autonomy and automation is therefore that autonomy implies a significant change to the system where emergent properties are expected to affect the performance of the system. This perspective takes into account that there is no single solution on what to change, nor is there a unified end-state of the change process. It opens for autonomy being different from system to system, varying over time and being affected by the context. This approach might seem complex and a rejection of the existing research on autonomy, but the purpose is the opposite. By agreeing on a significant level of the change, it is possible to discuss how complexity and emergent properties will affect performance of a system with increased autonomy. This will not limit autonomy to a few defined factors, but will be dynamic and adaptable based on context and the previous state/s of the system.

# 3 Humans and autonomy in maritime systems

There are two main directions of development in the maritime domain that fall under the above-mentioned perspective of autonomy. One is the development of self-navigating vessels[1], and the other is remotely operated vessels. The similarity is the aim to reduce human presence on the bridge or even to reduce human presence on the entire vessel. Both directions could cause a *significant change* to maritime systems when humans are moved away from the bridge, to a position on shore (or elsewhere). The difference between remotely operated vessels and self-navigating vessels is *how* the humans are involved by remotely operating the vessel or taking a role of controlling the operations by monitoring or supervising from a distance. As discussed later in the paper, the two directions will create different challenges to overcome.

Increased autonomy is expected to provide benefits such as less environmental emission and increased efficiency and safety [18]. This paper is limited to discussing the challenges related to the effect on safety, and the navigation function, where the humans operate, monitor or supervise navigation from shore. The paper discusses the human involvement in three areas; a systemic approach which advocates for human as strengthening the system, the human role on strategic, tactical and operational levels and finally how humans will be responsible and remain in control in systems with increased autonomy.

## 3.1 Humans will strengthen the system

Increased safety is an expectation and a motivation for developing solutions with increased autonomy. It is claimed that increased safety will be achieved by reducing the likelihood of *human error* when introducing more autonomy [12] [19]. There is no reason to dispute the fact that reducing human error will increase safety, but it is necessary to be wary of the belief that introducing more technology is coherent to reduction of human error, and Bainbridge "Ironies of Automation" [20] is still as valid today as it was 35 years ago [21].

Since autonomy entails significant changes to systems, it could be compared to what Boy [22] defines as a typical twenty-first century problem, with "*global and non-linear"* problems where the number of components and interactions are far larger than in

[1] Self-navigating vessels refers to the development of vessels that are able to follow a pre-defined route and have a capability to detect and avoid obstacles en route.

the twentieth century where the problems were "*local and linear"*. He claims that *complexity science* will be one of the most important sciences to understand these challenges. The term complexity science was introduced by Anderson in 1972 [23], and he has later defined complexity science to be:

> *"(..)the search for general concepts, principles and methods for dealing with systems which are so large and intricate that they show autonomous behavior which is not just reducible to the properties of the parts of which they are made"* [24]

He describes the developing discussion within physics science, where physics science has been subject to reductionism, in trying to reduce complexity to simplicity by explaining the construction of the universe in smaller and smaller entities. This traditional modelling of decomposition into structural elements has been challenged for a time and Rasmussen [25] described the problem of reductionism by *"all work situations leave many degrees of freedom to the actors for choice of means and time for action"* and argued for a functional abstraction on a higher level rather than structural decomposition. Anderson [24] states that there is a growing interest to develop complexity out of simplicity. The new perspective highlights the importance of *emergent properties*, where emergence implies that there are new properties that did not pre-exist or were expected or pre-programmed in the system. Safety could be regarded as an emergent property, and safety is created from the interaction of system components [26]. This means that we need to understand and identify emergent properties to assess safety in complex socio-technical systems. When safety is an emergent property in complex socio-technical systems it is necessary to understand what affects safety in other terms than a traditional reductionist perspective. Since the complexity in socio-technical systems leads to gradually more intractable systems and work environments, it is stated that *performance variability* is a prerequisite for functioning systems [27]. It is especially important to study humans at work to understand the nature of performance variability, with the intention not to limit by constraining how people work, but by addressing reasons for variability, identifying ways to monitor variability and understanding consequences and means to control variability [28].

A fundamental change in how the maritime industry assesses safety is needed, considering the increased complexity. The immediate risk is that we choose an approach which limits the focus to the individual vessel alone. We could measure safety based on an assessment of technical components or isolated processes and by verifying that they are covered by an autonomous solution. Such an approach tends to use traditional risk assessment methods, but is a reductionist approach which does not take the whole system into consideration [29] [30]. A limited focus on the vessel alone could result in the conclusion that autonomy is as safe, or safer, than shipping is today. This may not be a correct safety assessment from a systems perspective, since vessels do not operate as single standalone vessels. A safety assessment needs to be elevated from the perspective of a single vessel (as a sub-system in a system) to an assessment of safety in a both a system and a system-of-systems perspective where the vessel interacts with other vessels, with Vessel Traffic Service Centres (VTS), with marine pilots and several other systems in the maritime industry as well as systems from other industries. Only by using this perspective, it will be possible to discuss safety as an *emergent property*, and find out more about what affects *performance variability* due to changes in the system.

Sheridan's statement *"overall design of large–scale human-automation systems (for example, design of modern airplanes or air traffic systems) will continue to be a matter mostly of experience, art, and iterative trial and error"*[31], indicates that there are difficulties in identifying challenges in novel systems. However, we must acknowledge the importance of emergent properties, and especially the ability to amplify positive performance variability and reduce negative performance variability. In recent years several systemic safety models have gained interest such as Functional Resonance Analysis Model (FRAM) [32], Systemic Theoretic Accident Models (STAMP) [26], AcciMap [25] and EAST broken-links approach [30]. The systemic safety models aim to address the limitations of more traditional cause-effect chain models, which focus on blame and tend to search for single root causes after accidents. Systemic safety models create models that consider the entire socio-technical system, and relationships between parts of the system [26]. This paper will not elaborate on which systemic models are best suited for considering complexity in maritime operations with increased autonomy, but as all of them have a holistic approach to safety, they could all be candidates for assessing safety in designing novel systems.

The ownership of the challenge of assessing safety in a system perspective is not obvious. It remains to be seen if, and how, IMO, governmental authorities, shipping companies, technology groups or other stakeholders assume the responsibility to select methods with which to choose a systemic safety approach. Taking this responsibility implies performing large-scale testing and identifying new agents and interactions to assess safety. The other option, which is not sustainable and should be avoided, is to take the easy way out; concentrating on sub-systems and components and assuming there are no other solutions available.

### 3.2 Humans will be in the loop, but there will be new loops

Increased autonomy in navigation will impact the role of the master and will be a paradigm shift in maritime industry. To change the role of the master constitutes a drastic change to the maritime industry, not only in how to operate, but also regarding internal responsibilities for the state of the vessel, and external responsibilities towards other actors in the industry and society. A hasty and simplified approach to understanding the consequences of changing this role, could fail to uncover important aspects that affect safety, as the role of the master has a long tradition and includes many formal and informal tasks.

Autonomy aims to reduce human presence in dangerous and hostile environments, but in the maritime industry as for most of the other industries, this does not imply a total removal of humans in the system. Autonomy in the navigation function would most likely lead to relocating the humans from the bridge to a position on shore, and it is important to understand which role humans will have in such new systems.

When designing new concepts it is essential to understand *why* we need humans in the (new) loop. To create this understanding, we suggest using the terms *strategic*, *tactical* and *operational* levels to describe types of decisions in the system and where to expect change. The three terms do not have unified definitions but were initially introduced in the military literature [33]. Today they are widely used, for instance in on-road automated system development [10] where they are based on behavioural models and generalised to the problem solving task of the driver on three levels (strategical, tactical and operational) of skill and control [34]. Discussing maritime specific characteristics on each level could be a step towards understanding the human role in future maritime systems. The literature does not concur on the order of *tactical* and *operational* level, but in military doctrine the tactical level is often referred to as the lowest level of operation and operational level is the mid-level [35] [36]. In the Contextual Control Model Hollnagel describes the strategic level as being focused on the high-level goals, and is followed by the tactical level of beyond the present [37]. Coherent with this model, the paper choose to define the tactical level as subordinate to the strategic level.

<u>Strategic level:</u>

*Strategic decisions set objectives for the organization as a whole, relatively long-range objectives, and formulate policies and principles intended to govern selection of means by which the objectives specified are to be pursued.* [33]. Strategic decisions would fall under the three dimensions Boy [22] describe as important for an organisation; safety, efficiency and comfort.

<u>Tactical level:</u>

The tactical level could be described as the criteria derived from the goals set at the strategic level [34]. In navigation this would be both long-term and short-term planning on how to act, such as planning and deciding on the route, or weather routing during the voyage.

<u>Operational level:</u>

The operational level is the imminent response within strategic and tactical boundaries to occurring events. In navigation this would be the choice of whether to alter speed or heading in response to the immediate surroundings.

As illustrated initially in this article, autonomy is difficult to describe as a state-of-being. Since autonomy is a process of change, the role humans will play in the system will also change over time. However, the change of the role of humans is initially expected to occur mainly on the *operational* level, to a lesser extent on the tactical level and is not expected to affect the strategic level. The main reason for this expectation is based on the acknowledgement of maritime socio-technical systems being intractable and such systems work because people are able to adjust what they do [27, 38]. In particular this applies to managing the constant trade-off between objectives on the strategic and tactical levels, for example the balance between safety and efficiency, which is an area where humans are still superior to technology [27]. The prediction that change will occur mainly on the operational level will probably change, and a natural development would be that a successful implementation of increased autonomy on the operational level triggers an investigation of possible benefits of autonomy on the tactical level.

We do know that there will be humans in the loop, and even though the operational level will gain more autonomy, there will still be humans to take strategic and tactical decisions. *Why* we need humans in the new loops is fundamental to the understanding of the importance of taking humans into account in the entire concept design.

### 3.3 Humans will be responsible and will remain in control

The final challenge presented in this paper is to create an understanding of *how* the humans should be involved and kept in the loop. The similarities between automation and autonomy are many, and one similarity is the challenge of how to optimize the sharing of functions between humans and technology based on human strengths and weaknesses. In systems engineering a function refers to *"a specific or discrete action (or series of actions) that is necessary to achieve a given objective*" [3]. These functions are derived from the system requirements in a hierarchy where top-level functions are broken down to second-level functions and further to lower level functions. In the conceptual phase of systems design the purpose is to develop a top-level system architecture and initially to identify *what* needs to be accomplished, and less focus is put on how to accomplish it [3].

A widespread concept in Human-Automation Interaction (HAI) is to combine Levels of Automation (LOA) with *function allocation* which uses a four-stage model of HAI; information acquisition, information analysis, decision selection and action implementation [39]. Each of these four stages is described in a continuum (the Levels of Automation) ranging from no technological involvement to a complete technological ownership. The concept is criticized for not taking into account the complexity of operating environments which leads to imprecise and unreliable predictions, which again leads to a concept which is difficult to apply in practice [40]. There is an on-going discussion between the defenders of the concept and those who challenge the concept. Both sides seem to agree that there are weaknesses such as difficulties in predicting human behaviour and imprecise behavioural constructs, and that there is a need for a more concise operational definition of the concept [9] [40] [41]. The solution to the problem is more contested, in that the defenders of the concept are suggesting an evolution of the model to get a more accurate and precise prediction of human-automation system performance [9], and the opponents are suggesting to leave the LOA paradigm entirely [40].

Those involved in the development of autonomy in the maritime industry need to pay attention to the limitations of the existing models, and the on-going debate on proposed solutions. A mutual agreement on a best practice to describe interactions between human and technology does not exist, which be a challenge for the practitioners that are designing novel systems with increased autonomy.

Bearing in mind the first challenge in this paper which argues for a holistic approach rather than a reductionist approach, it will not be beneficial to aim for complete functional allocation. There is a need to search for solutions that encompass complexity and a need for development of more dynamic models of HAI. A possible first step that does not contradict neither the defenders nor the opponents of the concept of LOA and function allocation could be to identify the system's top-functions, and then move on to exploring the human role in the top-function in terms of responsibility, authority and control.

Navigation could be a top-level function, and the discussion could start with exploring the responsibility, authority and control within this function. Amy R. Pritchett describes the relationship between responsibility and authority as "*authority is generally used to describe who is assigned the execution of a function in operational sense, responsibility identifies who will be held accountable in an organizational and legal sense for the outcome"* [42]. Execution in this definition is presumed to include all four stages from information acquisition to action implementation, and is not solely linked to the action implementation.

*Control* does not, as many of the other terms in this paper, fall under a uniform definition. Like the term autonomy, the Society of Automotive Engineers has placed the term control in their section of deprecated terms in their recommended practice. The reason is that the term has numerous meanings in technical, legal and popular language [10]. Taking a systems perspective, Leveson [43] states *that "control processes operate between levels to control the processes at lower level in the hierarchy. These control processes enforce the safety constraints for which the control process is responsible"*. Control is linked to both responsibility and authority, and control is the process where the *responsible* agent of the function ensures that the agent with given *authority* executes its function in accordance with the system's requirement (see Fig. 1).

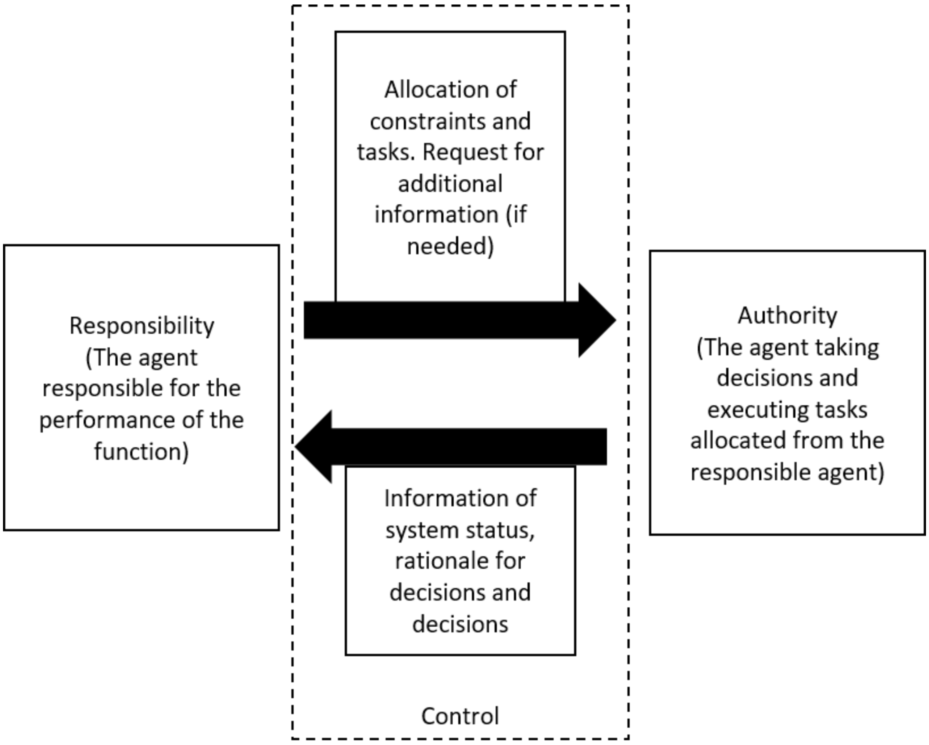


**Fig. 1.** : Control links the responsibility and authority

SARUMS *"methods of control"* describes the relationship between human and vessel ranging from method 1 which is "Operated" (remote control, tele-operation or manual operation), to method 5 which is "Autonomous" [44] [45] . The *"methods of control*" are a valuable contribution to create a more accurate characterisation of control, however the approach is not the best fitted for discussing how humans will be involved in future systems with increased autonomy. The responsible agent of a top-function needs to ensure that the system's requirements, decided on the strategic level, are translated to safety constraints that then are complied with on the operational level. Both responsibility and control will, at least for the near future, be allocated to humans, and hence *methods of control* should be defined from the perspective of the *humans* rather than the *vessel*.

This perspective should be explored in depth, since even though most of the published documents of maritime autonomy address some human interaction, it is predominantly discussed from the perspective of the vessel. Scoping a system based on responsibility, authority and control from the *human perspective* will bring the human into a central role, and pave the way for a human-centred design approach.

A human perspective on *authority* will take into account the challenges of humans directly involved as “executor” but from a position on shore (e.g for remote operated vessels, or intervening if a self-navigating vessel is out of its constraints). The authority sharing will include many of the traditional challenges in HAI, which includes the discussion of what and how to share functions between human and technology.

A human perspective on *methods of control* will be able to describe different types of control to ensure that the function is executed in accordance with the system’s requirement and human capabilities. The different methods of control will experience different challenges that the system needs to take into account. Examples of methods of control could be direct involvement (combined role with authority), monitoring (continuously assessing the executor’s decisions) or supervising (intermittently assessing the executor’s decisions). However, these methods of controls are simplified, and the best fitted methods of control for maritime autonomy should be further explored.

A human perspective on *responsibility* will discuss which responsibilities are linked to the top-function, and if there are areas of responsibility that are not accounted for in a new concept. It will contribute to the discussion of competencies and legal accountability, and it will be important for designing a concept that could be approved by authorities.

Further, it is important that we encounter for internal and external variations in the system. In practice, this means that we cannot develop a static concept with *one* agent given authority to execute and choose *one* method of control. In navigation of a vessel we will see different requirements in congested waters than in open waters. The terminology we use needs to be able to describe a dynamic concept, and handle the complexity that follows with changing authority and methods of control during an operation.

How the humans are involved will change, and we will see that technical agents will be given more authority to execute functions. However, humans will remain responsible and humans will remain in control. It is therefore imperative that we develop a terminology that is best fitted to describe responsibility, control and authority from the human perspective. The way humans will be involved in future autonomous operation leads to new challenges, and these challenges need to be overcome to prove the safety status of novel system.

## 4 Conclusion

The increasing interest in autonomy in transport segments is also present in the maritime industry. Even though it is gaining a lot of attention, there is no unified definition of what autonomy is. This paper argues that agreeing on a defined state of being for autonomy would not be possible, and focuses on the autonomy as *a process of change.* As for automation, autonomy is about how to increase the use of machine agents in functionalities previously done by humans. The use of levels of autonomy as a state of being would be imprecise since what is defined as a high level of autonomy today (as self-navigating vessels monitored from shore) will be a lower level of autonomy in few years (if the machine agents are replacing humans on shore). This perspective acknowledges that autonomy is different from system to system, and will vary over time and be affected by the context. The purpose of changing the focus from a state of being to a change process is to learn from many aspects of autonomy and allow for different factors based on context and previous state of the system.

The paper discusses the importance of considering humans in the development of autonomy in three areas concerning the safety of the navigation function. The first area is to leave the traditional safety approach, where systems are reduced to components and these components are assessed in isolation. The paper argues for a systemic approach to safety with a holistic perspective, where safety is an emergent property of the system, and human performance variability is essential for improving safety.

The second area is to understand why there will be humans in the new loops of systems with increased autonomy. The paper uses the levels strategic, tactical and operational to argue that autonomy would initially be experienced on the operational level, while the human ability to perform trade-offs between strategic and tactical objectives is still superior to the technology. System designers need to understand the importance of humans in the loop of future systems.

The third area is to know how to involve humans in the system, and for system designers it will be essential to follow the on-going discussion of the validity of the concept of function allocation and levels of automation to describe HAI. Both improving the concept and leaving the concept will lead to major implications within HAI. Independently of this discussion the paper argues for taking a human perspective on responsibility, authority and control of the top-function, such as navigation. As humans will be involved in the loop, at least on tactical and strategic levels, they will also be responsible and be involved in control processes of the execution of function, and the paper highlights the importance of developing *methods of control* from the human perspectives in the development of autonomy in the maritime industry.

## References


1. IMO.: MSC 98th session. http://www.imo.org/en/MediaCentre/MeetingSummaries/MSC/Pages/MSC-98th-session.aspx. Accessed 5 Oct 2017 (2017)
2. English Oxford Living Dictionaries.: Definition of autonomy. https://en.oxforddictionaries.com/definition/autonomy. Accessed 19 Dec 2017
3. Blanchard, BS., Fabrycky, WJ.: System Engineering and Analysis, 5th ed. Pearson Education Limited (2013)
4. Kaber, DB.: A conceptual framework of autonomous and automated agents. Theoretical

Issues in Ergonomics Science 1–25 (2017) 10.1080/1463922X.2017.1363314
5. Parasuraman, R., Riley, V.: Humans and Automation: Use, Misuse, Disuse, Abuse. Human Factors: The Journal of the Human Factors and Ergonomics Society 39:230–253 (1997) 10.1518/001872097778543886
6. Lloyds Register.: LR Code for Unmanned Marine Systems (2017)
7. Endsley, MR.: Level of Automation Forms a Key Aspect of Autonomy Design. Journal of Cognitive Engineering and Decision Making (2017) 10.1177/1555343417723432
8. Bradshaw, JM., Hoffman, RR., Johnson, M., Woods, DD.: The Seven Deadly Myths of "Autonomous Systems." IEEE Intelligent Systems 28:54–61 (2013) 10.1109/MIS.2013.70
9. Kaber, DB.: Issues in Human-Automation Interaction Modeling: Presumptive Aspects of Frameworks of Types and Levels of Automation. Journal of Cognitive Engineering and Decision Making (2017) 10.1177/1555343417737203
10. SAE International.: Surface Vehicle Recommended Practice J3016 (2016)
11. Parasuraman, R.: Designing automation for human use: Empirical studies and quantitative models. Ergonomics 43:931–951 (2000) 10.1080/001401300409125
12. Rolls-Royce.: Autonomous ships: The next step. AAWA: Advanced Autonomous Waterborne Applications 7 (2016)
13. Insaurralde, CC., Petillot, YR.: Capability-oriented robot architecture for maritime autonomy. Robotics and Autonomous Systems 67:87–104 (2015) 10.1016/j.robot.2014.10.003
14. Wahlström, M., Hakulinen, J., Karvonen, H., Lindborg, I.: Human Factors Challenges in Unmanned Ship Operations – Insights from Other Domains. Procedia Manufacturing 3:1038–1045 (2015) 10.1016/j.promfg.2015.07.167
15. Dekker, SWA., Woods, DD.: MABA-MABA or Abracadabra? Progress on Human-Automation Co-ordination. Cognition, Technology & Work 4:240–244 (2002) 10.1007/s101110200022
16. Broek, H Van Den., Schraagen, JM., Brake, G., Van, J.: Approaching full autonomy in the maritime domain : paradigm choices and Human Factors challenges. 1–11 (2017)
17. Lee, JD.: Perspectives on Automotive Automation and Autonomy. Journal of Cognitive Engineering and Decision Making 155534341772647 (2017) 10.1177/1555343417726476
18. Munin.: MUNIN's Rationale | MUNIN. http://www.unmanned-ship.org/munin/about/munins-rational/. Accessed 6 Oct 2017 (2016)
19. Allianz.: Safety and Shipping Review 2015. 36 (2015)
20. Bainbridge, L.: Ironies of automation. Automatica 19:775–779 (1983) 10.1016/0005-1098(83)90046-8
21. Strauch, B.: Ironies of Automation: Still Unresolved After All These Years. IEEE Transactions on Human-Machine Systems 1–15 (2017) 10.1109/THMS.2017.2732506
22. Boy, GA.: Orchestrating Human-Centered Design. Springer London, London (2013)
23. Anderson, PW.: More is different. Science 177 (4047) 393–396 (1972)
24. Anderson, PW.: More and Different: Notes from a Thoughtful Curmudgeon. World Scientific Publishing Company, Singapore (2011)
25. Rasmussen, J.: Risk management in a dynamic society - A modelling problem. Safety Science 27:183–213 (1997)

26. Leveson, N.: A new accident model for engineering safer systems. Safety Science 42:237–270 (2004) 10.1016/S0925-7535(03)00047-X
27. Hollnagel, E.: A tale of two safeties. Nuclear Safety and Simulation 4:1–9 (2012)
28. Hollnagel, E.: Coping with complexity: Past, present and future. Cognition, Technology and Work 14:199–205 (2012) 10.1007/s10111-011-0202-7
29. Stanton, NA., Salmon, PM., Rafferty, LA., Walker, GH., Baber, C., Jenkins, DP.: Human Factors Methods - A Practical Guide for Engineering and Design, 2nd ed. Ashgate Publishing Limited (2013)
30. Stanton, NA., Harvey, C.: Beyond human error taxonomies in assessment of risk in sociotechnical systems: a new paradigm with the EAST "broken-links" approach. Ergonomics 60:221–233 (2017) 10.1080/00140139.2016.1232841
31. Sheridan, TB.: Comments on "Issues in Human–Automation Interaction Modeling: Presumptive Aspects of Frameworks of Types and Levels of Automation" by David B. Kaber. Journal of Cognitive Engineering and Decision Making 155534341772496 (2017) 10.1177/1555343417724964
32. Hollnagel, E.: FRAM : The Functional Resonance Analysis Method:Modelling Complex Socio-technical Systems. Farnham: Ashgate Publishing Ltd (2012)
33. Ackoff, RL.: Strategy. Systems practice 3:521–524 (1990) 10.1007/BF01059636
34. Michon, JA.: A Critical View of Driver Behavior Models. In: Human behavior and traffic safety. pp 485–520 (1985)
35. Forsvaret.: Forsvarets fellesoperative doktrine - Norwegian Armed Forces Joint Operational Doctrine (2014)
36. NATO.: Nato Standard AJP-01 Allied Joint Doctrine (2017)
37. Hollnagel, E.: Time and time again. Theoretical Issues in Ergonomics Science 3:143–158 (2002) 10.1080/14639220210124111
38. Hollnagel, E.: Safer Complex Industrial Environments. CRC Press (2009)
39. Parasuraman, R., Sheridan, TB., Wickens, CD.: A model for types and levels of human interaction with automation. IEEE Transactions on Systems, Man, and Cybernetics - Part A: Systems and Humans 30:286–297 (2000) 10.1109/3468.844354
40. Jamieson, GA., Skraaning, G.: Levels of Automation in Human Factors Models for Automation Design: Why We Might Consider Throwing the Baby Out With the Bathwater. Journal of Cognitive Engineering and Decision Making 155534341773285 (2017) 10.1177/1555343417732856
41. Wickens, C.: Automation Stages & Levels, 20 Years After. Journal of Cognitive Engineering and Decision Making 155534341772743 (2017) 10.1177/1555343417727438
42. Pritchett, AR., Kim, SY., Feigh, KM.: Modeling Human–Automation Function Allocation. Journal of Cognitive Engineering and Decision Making 8:33–51 (2014) 10.1177/1555343413490944
43. Leveson, NG.: Engineering a Safer World: Systems Thinking Applied to Safety (2011)
44. Ornfelt, M (SARUMS).: Safety and Regulations for Unmanned Martime Systems. In: Unmanned Surface Vessel Regulation Conference. http://www.ukmarinealliance.co.uk/sites/default/files/SARUMS-2016-MASRWG.pdf (2016)
45. Lighthouse- Swedish Maritime Competence: Autonomous safety on vessels (2016)