

# Towards a Pluralistic Epistemology: Understanding Human-Technology Interactions in Shipping from Psychological, Sociological and Ecological Perspectives

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**ABSTRACT:** In the shipping domain, many innovative technical systems have been designed and developed in the past decades, aiming to enable the maritime users to achieve the goal of safety, efficiency and effectiveness. The introduction of advanced technologies into workplaces have also created unprecedented challenges. Human users frequently find themselves in a supporting role to serve technology, being responsible for automation issues and blamed for “human errors” that sometimes result in tragic results. These challenges are closely associated with the design and use of technologies. Human-technology interactions has become an important multidisciplinary research topic for shipping. This article reviews theoretical concepts relative to the dimensions of psychology, sociology and ecology in Human Computer Interaction (HCI) in order to form a deeper understanding of human-technology interactions. This paper also discusses the theoretical constructs’ practical relevance by showing how a few cases exemplifying ongoing development sectors in shipping, such as energy efficiency optimisation, supervisory control of autonomous unmanned ships, and eco-systems in engine control rooms, are understood with these theoretical perspectives. By presenting multidisciplinary understandings of human-technology interaction, this paper aims to derive knowledge pertinent to methodological approaches and philosophical stances of future maritime human factors and HCI research.

## 1 INTRODUCTION

### 1.1 *Digitalisation and Automation in Shipping*

While safety, economic and environmental concerns have increased considerably in the shipping industry to deal with the challenges in growth and transport sustainability demands [1], rapid advances in technologies appear to provide solutions for this competitive industry [2]. Shipping has been involved in the global wave of computerisation in an attempt to enhance safety, effectiveness and efficiency of sea transportation operations, to save energy and increase profitability and competitiveness [3-5]. From paper chart and compass in the analog world to all kinds of computerised navigational or monitoring systems in a

digital world, shipping has always been undergoing a transition. Today, there are many automated systems and Information Technology (IT) applications that have been designed, developed and deployed in the maritime domain. The rapid advance of technologies is revolutionizing the way people work - these tools provide both shipboard and shore-based users unprecedented opportunities to enhance operational practices and access information in pursuit of higher efficiency, effectiveness and safety.

The two key words that may best characterise the ongoing transition in the shipping domain are digitalisation and automation. According to the Gartner IT glossary, digitalisation is the use of digital technologies to change a business model and provide

new revenue and value-producing opportunities [6]. For example, the introduction of virtual and augmented reality provides new platforms to support training, retrofitting and design solutions [7]; the adoption of cloud computing reveals great opportunities from scalable computation, security improvement and resource management [8]. Increasing interest or utilization of the big data concept [9, 10] and blockchain [11] creates huge potentials to be more effective and safer. One of the major ongoing international developments is e-Navigation, which proposes to use electronic means to harmonize “collection, integration, exchange, presentation and analysis of marine information on board and ashore, enhance navigation and related services for safety and security at sea” [12]. Many innovation projects regarding information and communication technology (ICT) have been carried out in the European Union under the umbrella of e-Navigation. As examples of European Union funded programmes, Maritime Unmanned Navigation through Intelligence in Networks (MUNIN) studied the feasibility of autonomous unmanned ships, Sea Traffic Management (STM) focused on efficient data exchange between ships and ports and EfficientSea2 aimed to create and implement solutions for efficient, safe and sustainable traffic at sea through improved connectivity for ships. It is noteworthy that, although digitalisation appears to have a profound impact on navigational safety, cargo management, ship/terminal integration, customer service etc., only 30.4% shipping companies have implemented or are currently implementing a digitalisation strategy based on the Shipping Industry Survey [13]. At the same time, autonomy points to what the shipping industry wants to achieve in the future [14, 15], as the prevalence of automation onboard has been increasingly desired by ship-owners to reduce manning levels in order to cut costs [16]. Beside MUNIN, many other projects regarding autonomous ships have been launched in the past several years [17, 18]. All these characterise the modern shipping industry in a transition phase as a slowly evolving but highly tech-driven industry.

## 1.2 Challenges in Human-Technology Interactions

However, the way to incorporate digitalisation and autonomy into the maritime domain is questionable. The rapid introduction of IT solutions without full recognition to the human element and adaptation [4, 19, 20] has been dominantly technology-centric. Technology introduction on board moves much faster than regulatory development. Given this reality the shipping industry lags behind other safety critical industries. Rapid technological advancements create unprecedented challenges and gaps: often these systems usually have little considerations for integration with or cognitive capabilities of the users [21-23]. The lack of equipment standardisation (e.g., in Engine Control Room) and poor usability have brought about information overload issues [4]. Fast introduction of technology is also influencing the crew's traditional learning experience [24], affecting how workers communicate and coordinate with each other [25, 26]. From a more macroscopic perspective to look at the digitalisation development strategy, the slow regulatory progression from the International

Maritime Organisation (IMO), shipping's highest regulatory body, has also compounded the complexity [27, 28]. The typical reaction to an accident has been training and changing of procedures where systemic evaluations or proactive policies have rarely been developed [29]. Therefore, what we see today are “human errors” (regarding humans) and automation issues (regarding machines) in human-technology interactions, revealed in many maritime accident reports and studies [30-32]. “Clumsy automation”, a form of poor coordination between humans and machines, is usually believed to account for incidents [33]. What we see is the ill-design of technology which makes users deploy and use the systems in ways that are not expected by regulators and manufacturers [34, 35]. The systems may also behave in a way not expected by users, e.g., in the form of “automation surprise” [23, 36] such as the automated systems act autonomously and the users may find it hard to understand the machine's true state based on limited feedback (lack of transparency). In the maritime domain, shipping, logistics and management are going to be performed in a completely different way in the future as advanced and yet to be described technologies are introduced. These problems and gaps in shipping are largely concerned with human capabilities, fallibility and characteristics, which are highly relevant research areas in human factors or Human Machine Interaction (HMI) research (Karwowski, 2005).

The concept of HMI can be traced back to the first time a human interacted with a “device” to make sense of its surroundings (e.g., a hammer or a compass). HMI research traditionally focused on the human behaviours in interacting with computing technology of some sort [37] or usability engineering in a dyadic closed-loop human-machine system [38]. The research topics in HMI have drawn significant attention in the last several decades, such as Human Computer Interaction (HCI) [39-41], Human Automation Interaction [42-45] or Human Robot Interaction [46-48]. Spawned from the human factors community (which derives from the problems of designing controls for humans during World War II) and many other older disciplines, HCI, as a field of study, emerged as a focal area of both computer science and of applied psychology in the 80's (e.g., the first conference on Human Factors in Computing Systems was held in 1982 which later turned to the annual ACM SIGCHI conference) [40, 49]. Today the principles and perceptions of HCI are influencing the ways we understand the sociotechnical system of shipping. In the whitepaper of an international project about autonomous shipping funded by Finnish Funding Agency for Technology and Innovation, it is mentioned that “in addition to the interactions of the various components and sub-systems in the technology, human operators and human-technology interaction remain even more important elements in this implementation” [50]. In a textbook of human factors in the maritime domain, a few “examples of HMI problems” on ships are listed, e.g., lack of equipment usability and standardisation, over-reliance on technology, rapid changes in technology, ignoring human factors in the design and development [4]. Nevertheless, how HCI (or human-technology interaction in a more general way) is perceived and understood in its theoretical senses and

the relevance to the shipping domain remains to be explored.

### 1.3 Purpose of the Study

The modern HCI has evolved into a very comprehensive multi-disciplinary research field with a plethora of theoretical constructs and frameworks and academic works (Karwowski, 2005), particularly in the schools of psychology, sociology and ecology. Psychology, a study of the human mind and its functions [51], may provide guidelines for developers and verify the usability of systems [40] based on basic cognitive constraints and essential decision making processes [52]. Sociology, a study of human society including social relationship and social interaction [53], may help us to expand the lens to the social-cultural aspects of work in the context of technology use [54-57]. Ecology, originating from biological studies that deals with the relations of organisms to one another and to their surroundings [58], may help us to scrutinize fundamental phenomenon of human-technology interaction with concerns on human experience, interface design and ecology of the whole system [59, 60]. This conceptual paper first reviews some important theoretical concepts relative to psychology, sociology and ecology to gain a deeper understanding of the evolving themes of HCI and nature of human-technology interaction. Then the paper connects these theoretical lenses to a few maritime applications to synthesise these relevant models, theories and knowledge. A few maritime cases exemplifying ongoing development sectors in shipping, such as Energy Efficiency (EE) optimisation, supervisory control of autonomous unmanned ships, and eco-systems in engine control rooms, are then discussed in the light of these theoretical perspectives to explore the impacts of advanced technologies in shipping (digitalisation and automation), experienced gaps and issues, as well as potential design opportunities. By presenting multidisciplinary understandings of human-technology interaction, it hopes to derive knowledge pertinent to methodological approaches and philosophical stances as to where future maritime human factors and HCI research is heading.

## 2 THEORETICAL FRAMEWORK

### 2.1 Psychological perspective

The fundamental interactive formalities between human and artefacts, "the interaction and communication between human users and a machine, dynamic technical system, via a Human Machine Interface" [61]", remains essentially unchanged over the years. The semiotics is a dyadic framework (i.e., machine presents signs and humans act upon them) that originated with Saussure [62]. The conventional belief is that the user's mind is the only cognitive substance in the dyadic relationship and thus the meaning can only be structured from the inside of the human agent. This has led HCI or HMI to be fundamentally recognized as an information processing task [63]. Historically humans were being viewed as systems with limited-capacity in

information processing tasks and stimuli compete for the resources [64]. A human's cognitive systems and the mechanisms about information processing has been extensively exploited [40, 63, 65]. In fact the human's cognitive systems and the mechanisms about information processing has been extensively exploited via different systematic approaches, looking at vision and attention [66-68], mental models [69, 70], memory functions [71], workload [72, 73], situation awareness [74, 75] and other human performance constructs in different human information processing stages [40, 52, 63].

Card, Newell [37] argued that it would be a natural thing for an applied psychology of HCI to be based theoretically on information processing psychology. To some extent the HCI discipline can be seen as "a type of applied cognitive science, trying to apply what is known from science to the design and construction of machines" [76]. With a goal to make the interaction more efficient, a plethora of research has been dedicated to exploring the usability issues in the ill-designed computer interfaces in terms of how they failed to support the human information processing capabilities or accommodate the human's intrinsic limitations [77-79]. One well-known issue about this was "the Gulf of Execution" and "the Gulf of Evaluation" [80], which respectively reflect "the difference between what the user wants to do and what can actually be done using controls that are available", and "the mismatch between the user's intention and expectation and the actual state of the system" [77].

Attention is very important in information processing [52]. There existed many theories that were trying to account for attention and elucidate what attention is, such as being conceptualized by as a spotlight which spatially disengages from current location, move to the target location and engage at the cue [67], or as a zoom lens that can allocate attention over a variable area so that saccades are directed to the geometric centre of the cues [68, 81], or be characterized with a selective filter in the early selection model [64], or be related to perceptual memory in the late selection model [82], or developing hybrid models [83] or Feature Integration Theory that assumes that the feature of stimulus are coded into a feature map for visual search tasks [84]. Regardless of metaphors or models being developed or used, attention was widely recognized as a selective process that brings stimulus into consciousness or selects parts of visual items for further detailed analysis [52, 85, 86]. The core idea of this selectivity is that it reduces the information [87] while it provides "energy" to various information processing stages [52], given that the supplies of the attentional resources is limited [66].

Another notion that has drawn significant attention that is relative to the information processing paradigm is Situation Awareness (SA), which has an extensive use and theoretical discussion in maritime sectors, aviation industry, military training, teamwork, education and so on [88-90]. There are various definitions and explanations of SA terms and their orientation context [91-93], but Endsley's model has been the most widely referenced SA model to describe it as an operator's knowledge of the environment at a given point of time [74, 75]. There

are three levels of concept in her model, i.e., the perception of the elements in the environment within a volume of time and space (level 1 SA, perception), the comprehension of their meaning (level 2 SA, comprehension) and the projection of their status into the future (level 3 SA, projection/anticipation). SA certainly has some roots in the everyday language about explaining what the operator is not aware of what makes him/her lose the "big picture". A critical assumption of this understanding is that operators must be aware of particular information at critical moments to make critical decisions [94]. This is still a predominant approach to references of SA in accident reports, in which the notion of SA is tightly connected to cognitive aspects such as workload and perceptual factors [95, 96].

In the classic information processing cycle proposed by Neisser [65], the human mind creates a cognitive scheme of the world and directs his actions to look for the anticipated aspects of the information. The sampled results from the world would in return modify and update the internal cognitive map. The cognitive map is framed as *mental model* to represent external reality [69] or conceptualised as a result of the physiological perception [97] or a representation of the world and their meanings and knowledge [70]. Endsley [98] believed that the mental model is a systematic dynamic understanding of how the world works, directing interactive cycles of bottom-up and top-down information processing. Therefore Endsley [74]'s SA model is essentially a model based on information processing mechanism. The information processing cycle also inspired a lot of other research regarding the SA conceptualisation [89, 99-102]. For example, instead of conceptualising SA as a product, Distributed SA proposed by Stanton, Stewart [103] described SA as an emergent system property residing in all of the involved agents, which is beyond the psychological level.

If we still adopt the psychological school of SA conceptualisation, then sufficient SA is required for decision making [104]. Rationality is the implicit motivator behind this process per traditional cognitive science. Simon [105] argued that three activities were involved in decision making: Human need to find or identify the situation, and then invent, develop and analyse possible alternatives, and finally select a specific path from those available. Seemingly segmented stages were used to describe this "rational" information handling (i.e., sensory processing, perception, decision selection, response execution) affected by memory and attentional resources [52]. The point is that logically sound decisions are what a rational decision maker seeks after, though the degree of rationality can vary [106]. The core assumption about rationality in decision making is that objective data and formal process of analysis empowered by the laws of probability, expected utility theory or Bayesian statistics yield optimal judgements [107]. However, there are many critics about the rational decision making approach such as cognitive resource limitations and behaviour biases [108]. Heuristics and experience are frequently mentioned as useful approaches to constrain search [63, 109, 110] and enables rapid responses in decision making, which indicates that humans do not necessarily adhere to the classic optimal decision

making process driven by rationality or probability in many situations. Much research focus had shifted from laboratory settings to dynamic natural settings in 80s to understand how people actually make decisions in complex tasks, leading to the emergence of situated cognition [55], distributed cognition [57], recognition-primed decision making under the framework of naturalistic decision making [110, 111] as examples. One well-known example is that firefighters were found that they did not make algorithmic strategies or comparing alternatives at critical moments, but they just simply recognized the situation with experience and used adaptive ways to put out fires [110]. The recognition of the situation is seemingly consistent with the proposition of "learning by doing" [112] or the dynamics of assimilation and accommodation [113].

If there is a failure of rationality, then errors could occur and propagate like a domino effect following a seemingly linear causal chain. Reason [114]'s "Swiss Cheese Model" is probably one of the most well-known models in terms of understanding accident analysis and human errors. The "defensive planes" or the series of "barriers" (i.e., decision makers, line management, preconditions, productive activities and defences), represented as slices of cheese, illustrated how accidents might occur when a trajectory of accident opportunity through the multiple defences is created. Although the notion of "active failure" triggered by "latent failure" and queries into organisational factors and management issues [114, 115] shows a tendency to go beyond the cognitive psychology, Reason's approach may still be considered as a linear view of accident trajectories [116]. Decisions made at a given moment usually made perfect sense for that particular context and only hindsight can reveal its vulnerability [117].

## 2.2 Sociological perspective

Although HCI's origin has been based on cognitive psychology that tends to study individuals in isolation from the surrounding environment and context, there has been a growing consensus in academia since '80s that the cognitive paradigm has its own limitations and there shall be more room for social and contextual orientation [40]. Activity Theory (AT) provides an alternative to study human consciousness based upon anthropological / psychological theories of Vygotsky [118] and Leont'ev [119] that concentrate on the interactions between humans and artefacts in natural every-day life settings [54, 120]. In AT, consciousness is reflected and manifested by what we do in the social environment [54]. The subjects and objects are people and entities developed in culture and are essentially social, therefore the social activities are chosen as the unit of analysis. This was believed to be a radical deviation from the typical empirical studies in psychology that at time focused on subjective and objective phenomena in observations and controlled experiments [54]. If the classic analytical approach is about studying the subjects and objects separately in an attempt to find some relationship in between, then Vygotsky's theories are looking at the interactions or the "acting of the world". These concepts were further expanded to the AT by Aleksey Leontiev, who

focused on the evolution of mind and introduced the concept “activity” as an analytical tool to understand the fundamental subject-object interaction [121]. The basic representation of activity is the existence of subject (a person or a group), object (an objective that motivates the activity) and the purposeful interactions between them [119]. Vygotsky and Leontiev’s research have shaped a new perspective that activities are not treated as a collection of a linear movement but should be analysed through dynamic lens grounded in cultural and historical developments. Later the scope has been further expanded – Engeström [122] used a notion of “community” and its relations to subject and object to illustrate the relationship between individual and group (e.g., social norms, culture, rules, conventions, etc.) and the relationship between group and organisation (e.g., division of labour).

These studies about collective activities and socio-cultural perspectives has significantly enriched the content and scope of AT, enabling it to be a tool to understand problems in an organisational context [123]. Exclusively focusing on the information processing tasks in many real-life design projects is meaningless, if researchers ignore the gaps between organisations and system design. AT could be helpful to consider all aspects of activity, from motivation to operations, from physical to social conditions of an activity, to address the issues in organisational change and systems design [123]. There are two notions that are central to the evolution of HCI: First is context, which is constituted through the enactment of an activity involving people and artefacts; context is both something internal (e.g., motivation) and something external (e.g., other people, artefacts, environment, settings) [124]. Second is the notion of mediation [125, 126]. Artefacts can shape how we interact with the world and they may also represent how we understand the world. The culturally developed artefacts may become parts of what humans are [127, 128]. Technologies are “the fundamental mediators of purposeful human actions that related human beings to the immediately present objective world and to human culture and history” [54]. The subject uses the technological artefacts in a certain context with attentions and motives and the artefacts’ roles are mediating the relationship between the subject and the object of that activity. By considering the human use of technology within a much wider context of human interaction with the world, the sociological perspective substantially expands the scope of classic information-processing-based HCI [54,125] (Table 1).

The meanings of a behaviour in the activity are embodied in the use of the mediating artefacts in the real-world settings. This could be well explained by the approaches of situated action [55, 129] and distributed cognition [57, 130], which advocate the values to study the actual behaviours in real-life settings and emphasise the importance of context. Situated action is “the activity of persons-acting in setting” [56]. It argues that the context can influence the activity so people can improvise and innovate based on the specific situation, whereas the traditional information processing paradigm asserts that problem solving is a process characterized of rationality [55, 56]. For example learning at work is deemed as a culturally and socially situated activity

[131]. In Lave and Wenger [129]’s concept of communities of practice, groups of workers share a common concern and learn how to improve the ways of doing as the interaction between and within the groups proceeds on a regular basis. Knowledge development is seen as collective and collaborative achievements in the communities of practice [129, 132, 133]. The emphasis is that knowledge development is achieved by increased participation, which refers to the process in which a “newcomer” immerses himself or herself in the sociocultural practices of a community and thus his/her competence would grow as he/she is more knowledgeably skilful through more interactions [129]. The characteristics of situatedness can breed collaborations and innovations through the increased participation [134, 135]. Distributed cognition advocates to direct away the analysis from individual properties or knowledge to a system level, such as the distributed collection of people and artefacts, the functional relationships of the system [130], which is also opposed to the classic view of the information processing paradigm.

### 2.3 Ecological perspective

The limitations of the man-machine dichotomy are that, within the traditional information processing paradigm, it usually treats the elements in isolation without considering the human-environment relationship [136]. How a person perceives the environment and forms the representation of the world has suggested the values of ecological perspectives in psychology [58, 137, 138]. Gibson [58] developed ecological physics to describe a worldview for studying perceptual experience which is no more independent of an observer, opposed to the classical physics [139]. The ecological approach asserted that the laws that relate the observer to the environment are something tightly connected to functional aspects of the environment, i.e., affordances [139]. Gibsonian concepts contend that there is inseparability of the behaviour of the human from the work domain, which is a radical departure from the traditional views of psychology as a study of the human organism [140].

Table 1. Traditional HCI with the information-processing-based psychological approach vs. modern HCI with the social-cultural approach.

	Traditional HCI	Modern HCI
Dominating factors	Psychological factors	Social and cultural factors
Unit of analysis	Low-level analysis on user-interface interaction	High-level analysis on meaningful activity
Context	User-Tool	User-Tool-Environment
Main Focus	Tasks (typically individual)	Mediating artefacts in subject-object relationship (typically collective)
Methods	Laboratory studies	Ethnographic studies focusing on practices in real-life
Approaches	Normative such as task analysis	Descriptive approach such as Activity Theory
Inclusive notion	Affordance, etc.	Computer Supported Cooperative Work (CSCW), etc.

One well-known ecological approach is Ecological Interface Design (EID), which was proposed to guide interface design for complex sociotechnical systems [141-143]. A dominating factor for undesired human performance was found to be the lack of functional relationship of the controlled process thus the interface provided incomplete problem representation [141, 144]. This is essentially a question of 1) how to find a suitable language to describe the complexity of the domain, to reveal the constraints within and unravel the intricate relationship of the variables in the controlled process [143]; 2) how the interface can communicate with the operators [143]. EID proposes to create a mapping relationship between the invariants of the functional systems in the work domain and the interfaces on the display, in order to make the abstract properties of the controlled processes visible to the operators [60, 141]. Such ecological perspective expands the scope of analysis to the work domain, forming a triadic HCI model (human-interface-ecology) to address the concerns of context and functional constraints of the work ecology [62, 145]. It suggests that good design cannot be achieved without adequate knowledge and thorough understanding of the domain [60, 146]. The ecological approach promises a basic but important foundation to allow us to understand sociotechnical systems via a human-environment system perspective [147]. For example, much research regarding Cognitive Work Analysis (CWA) have emerged in recent years [148-153] to identify the technological and organisational requirements and model intrinsic work constraints to inform design [154].

In addition to interface design, the ecological insights have evolved modern HCI studies by encouraging research to “think big” (i.e., take the systems perspectives to understand human-automation relationship and focus on the global ecosystem) [60, 155-158]: Human-Automation System considers that “human operators are intermittently programming and receiving information from a computer that interconnects through artificial sensors

and effectors to the controlled process or task environment” [159]. Over the past four decades, human supervision of automated systems has essentially been developing a formality of coupling and communication between humans and machines [159, 160]. While automation has great advantages for quality control and performance efficiency in handling routine tasks, it might provide the least help for the human operators to solve problem when there are unexpected events. This is known as “ironies of automation” [161]. Woods [162] also described automated systems as “strong, silent, clumsy, and difficult to direct”. There is considerable research literature concerning automation issues and its connection to system effectiveness, such as the strengths and weaknesses of humans and machines (see Table 2). Although many cited works focus on the psychological processes impacted by the introduction of automations, some of them already appreciated the systems perspective to understand the automation issues.

With the trend to use the systems perspective to understand human-automation relationship, some taxonomies that were proposed to describe tasks distributed in a human-automation system were criticised for encouraging reductive thinking [173] and providing little help to address the needs to make humans and machines work together to accomplish complex tasks [23], such as the concepts of level of automation (LOA) or degree of automation (DOA) [45, 174-177]. Automated systems are becoming more capable and truly autonomous but unexpected events and automation failures may hardly be ineradicable, representing huge complexities in the actual field [178]. There is a growing need for the human-automation system to work in teams with common goals [23, 179]. In a human-automation system, what is mostly required for improving effectiveness is not necessarily enhancing each agent’s capability, but their integration in collaborations [23, 157] in sociotechnical systems.

Table 2. Studies that describe automation issues

Study	Context	Negative Outcomes	Primary Analytical Approach
[163]	Aviation	“Physical isolation” (isolated from the physical structure of the airplane and ship) and “mental isolation” (isolated from the system state)	Psychological perspective
[44, 104]	Aviation	Low situation awareness, errant mental models and out-of-the-loop syndrome	Psychological perspective
[164, 165] and Maritime	Aviation and Maritime	Automation bias and complacency (refers to the operator’s purported behaviour of not conducting necessary system check but assuming “all was well” when the dangerous situation actually evolves); mis-use or disuse of automation	Focusing on the cognitive processes involved (psychological perspective)
[166, 167] and [168-171]	Aviation and Aviation	Trust towards automation, automation complacency “Error of omission” (the operator failed to respond or delayed responding to the systems irregularities), “error of commission” (the operator trusted the prominent parameters on one display despite contradictory information on other) of automation bias	Psychological perspective Focusing on the psychological impact of automation on human operators (psychological perspective)
[172]	General sociological,	Over- and under-reliance or trust on automation	Analysed from organisational, interpersonal, psychological, and neurological perspectives
[173]	General	Over- and under-reliance or trust on automation (over trust is a result of high self-directness and low self-sufficiency while under trust is a result of high self-sufficiency and low self-directness)	Analysed from the system’s perspective (the system is modelled with “self-sufficiency” and “self-directness”, freedom from outside control)

It has been observed that in many accidents where safety was obviously compromised, human error has been considered as one dominating factor [31, 180, 181], being understood as an individual or a team's behaviours exceeding certain limits of a system's threshold or deviating from the expected norms. The focus on human fallibility [114] or individual limitations makes it incapable of understanding the system in holistic terms [117, 182]. Based on the ecological approach, variability is manifested in the process during which individuals express their own degree of freedom to adapt to the local constraints [183]. Safety depends on the ability of the system to remain within the boundaries [116] while the system might be drifting all the time [158]. The drift is not because of operators' evil desires, inadequate vigilance or knowledge, instead, the deviation becomes part of norm in high-risk operations. Risks could accumulate during the "incubation period", a period in which the incremental changes that may later contribute to a system-wide collapse get unnoticed [184, 185]. On one hand it shows the importance to build adaptive systems to allow the operators to respond flexibly in an increased margin of manoeuvrability [186]. On the other hand, it suggests to shift the focus from individual capabilities to how the system functions as whole. It is no more just about human-machine interaction but about couplings between human, technology and ecology.

### 3 TOWARDS A PLURALISTIC EPISTEMOLOGY IN MARITIME HUMAN FACTORS RESEARCH

This section will discuss the aforementioned theoretical constructs' practical relevance by presenting a few applied maritime projects. The projects include shore-based control centre development in the autonomous unmanned ship project (Maritime Unmanned Navigation through Intelligence in Networks, MUNIN), tablet-based service for bridge opening information coordination project (GOTRIS, Göta älv River Information Services), Energy Efficiency (EE) optimisation project, maritime connectivity platform (EfficienSea 2 project). The projects had their own specific context but they all involved advanced digitalisation or/and automation development and the human element in complex maritime sociotechnical systems. They are development examples of a few very representative sectors in shipping, such as EE, autonomous shipping, and digitalisation of tools and equipment used onboard. The projects were highly technology-driven and developed mainly by people with technical backgrounds who usually are more tech-savvy and less concerned with human-machine interaction. To perceive human-technology interaction through different lenses may set up an important foundation to allow reflecting and synthesising links between required disciplines in pursuit of a coherent whole and a pluralistic epistemology.

The shipping industry is at full speed towards full autonomy and high degree of digitalisation [187]. MUNIN is a European Union project that examines the feasibility of autonomous unmanned vessels and their automation governance from shore-based facilities during intercontinental deep-sea voyages [188]. Considered in the MUNIN paradigm, an autonomous unmanned dry bulk carrier is controlled by an automated autonomous ship controller that is concurrently monitored by an operator at a Shore Control Center, SCC. A data communication channel connects the SCC control system and controlled process in the autonomous unmanned vessels, forming an essentially remote supervisory control system [159].

One observed human factors issue is that the participant might fail to attend to new alarms if he/she got "trapped" in dealing with an existing alarm [15, 189]. This is exactly what Endsley described as *attentional tunnelling* that the operators "lock in on certain aspects or features of the environment...will either intentionally or inadvertently drop their scanning behaviour" [104], which is the most common situation leading to an SA failure [190]. Although adjacent phenomenon such as information overload can influence attention [191-193], to explore the possible underlying causal factors, we need to go deeper about attention's role in information processing [52] and understand how different mechanisms fundamentally influence the allocation of the selective attention [194, 195]. During the diagnostic process, the operator's goal-directed attention is in the top-down form, depending on the task goals. Mental models play a crucial role in directing attentions because it provides a critical mechanism to interpret the significance of information and make sense of the world [70]. In the SCC, all participants were experienced master mariners, but they were never working as the SCC operators to monitor and control multiple vessels prior to the experimental scenario runs. The dominant mind-set is to maintain the safety of own vessel during navigational activities. With six vessels to be managed, the participants have reasons to be stressful under this unfamiliar situation, which is usually associated with selective attention [142].

The MUNIN studies also suggest that reduced information and transparency in the distributed context can create out-of-the-loop syndrome, introduce automation bias and undermine SA significantly, even highly reliable technical components are utilised [15]. When a navigator conducts ship-handling on a ship bridge, the "gut feeling" is of paramount importance for the navigator to understand the ship status and subtle dynamics within the environment in a more efficient way compared to traditional the electronic displays [196]. For instance, the kinetic movement and vibrations could imply the both the internal ship status (e.g., fully loaded cargo) and external environment effects on the manoeuvrability of the vessel. Being present onboard allows the subjects to actively pay attention to the dynamics to develop sufficient SA. However, it was observed in the MUNIN projects that the operators could only rely on the information on the display - the SCC's interface design did not support

well the human operators to conduct early detection of the irregularities [15, 189].

The common problems accompanying SA degradation, such as “vision tunnelling”, “out-of-the-loop”, “errant mental models”, were identified in the supervisory control of autonomous ships in the MUNIN project. Human limitations are the central issues. It indicates that the design of future supervisory control systems need to explicitly consider how to match the information process of the computer to the mental decision processes of an operator [142]. This is to say that HMI design needs to concern itself with the cognitive attributes of the operator and communicate the results to the operator in a form that is compatible with the operator’s perception-action cycle and decision-making strategy [104, 142, 190]. More importantly, the design must consider that how the interfaces can accommodate for the contextual change, not only reduce the visual demands of displays, but also support the operator’s adaptive performance in dynamic task allocation [197]. The SA requirement analysis as a part of the SA-oriented design [104], may be appreciated for its values in coupling human capabilities/limitations and interface design to generate concrete design guidelines solutions. For example, a specific design instance could be making manoeuvrability of the vessel as salient cues at a proper time as the dynamic situation evolves to the improve the operators’ SA, which could become a hypothesis for future laboratory studies.

However, the findings are not bound to psychological perspectives but reach sociological and ecological dimensions as well. The organisational hierarchy and regulations caused critical problems in the work at SCC [15, 189]. Based on the current chain of command in an unchanged organisational structure, the captain (a role that we assume still exist in SCC) became the team-SA chain’s weakest and most vulnerable link when he had difficulty developing SA about the situation. The organisational factors and the “COLREGs for unmanned ships” (i.e., International Regulations for Preventing Collisions at Sea as the “rules of the road” at sea) were relatively downplayed in this technology-centric project. The participants simply got confused and took different navigational actions when facing the same situation of identification of an unknown object at sea [15]. The vacuum of legal and regulatory policies has created a huge gap for the development of the concept of autonomous unmanned shipping and remote control, manifested by the MUNIN project.

In MUNIN, the shore-based bridge system is prone to serve for “navigational mental models” under the guidance of current COLREGs regulations. It simply assumes all SCC operators have navigation backgrounds. Therefore the SCC supervisory control systems were configured in an “old-wine-in-a-new-bottle” fashion in the project. This design approach may be very efficient in technical system development via directly moving the bridge to the shore and turning navigators to computer system operators, but it ignores the changes of the context and work itself. Beside the sociological perspective, what apparently is missing is an ecological query into the nature of this new work and competence required. A perfect airplane pilot does not make a perfect air traffic

controller as they receive different training suited for their work. As more projects are established and developed for an area of autonomous shipping [14], just as Porathe [198] wondered, shall we need a navigating navigator onboard or a monitoring operator ashore. These concerns are beyond the considerations of a pure cognitive approach but they require a multidisciplinary approach to fathom the emerging issues in the work domain.

### 3.2 Energy efficiency optimisation onboard

A predominant direction in the shipping industry is to focus on the functional development of technological artefacts and its relevance to human cognitive limitations [199-204], such as examining the operator’s SA performance [205, 206] or a usability study in a laboratory environment [207]. Although these constructs are useful to describe the information processing stages and ground design solution based on this “cognitivist approach” [154], they might be incapable of explaining what actually happen in the field. Here we present a case that is beyond the “cognitivist approach”. It takes a socio-cultural approach to understand the issues in the maritime EE sector.

A project regarding EE optimisation onboard ships was conducted [208-210]. The project is about a state-of-the-art performance monitoring system called ETA-pilot, which had been installed on modern ferry vessels to aggregate huge amount of energy consumption related data to supposedly inform the crews about EE. Yet it was found that the this decision making support tool was “not used by the crew members” [210]. Some navigators claimed that by disconnecting ETA-pilot, navigating manually could contribute more fuel saving [208]. In addition, there is a social boundary between the engine and bridge departments to share knowledge with each other. For example, the engineers did have many thoughts on EE and exchanged ideas over lunch but they seldom spoke to the bridge about their opinions [208]. In Kataria, Holder [211]’s study, the division between the engine and deck was framed as “huge Berlin wall”.

In order to investigate if and how the identified gaps in the EE practices can be mitigated and explore opportunities of interaction design, a focus group study was conducted [209]. The study examined the practitioners’ interactivity towards EE as well as explored the potentials of this EE monitoring tool. The results have suggested that building a common ground is a crucial step towards their joint activity, as the engineers and navigators must understand each other’s concerns in order to plan adaptively and perform efficiently for improved EE. Knowledge sharing for a mutual understanding onboard ships is very crucial. The findings also suggest there is an opportunity for interaction design [209]: by taking the distributed cognition perspective, the tool may shape a discussion space between the bridge and the Engine Control Room (ECR) to facilitate their collaborative learning activities. It employed a social-cultural perspective to perceive human-technology interaction. Collaborative learning can provide opportunities to improve, evolve, reinforce, and even

innovate practices [134] and invite mutual learning as collectively shaped activity [132]. In this specific project, it was found that the post-journey reflection among the ship's crews is one practice example yet to be undertaken. Interaction design in such a context may likely influence communication and existing social boundaries between different divisions of labour in an organisational context. This means that the goal of interaction design then becomes to buttress communications and participation of practitioners, i.e., "shaping a communication space" [212]. If the energy monitoring tool could better evaluate the EE performance, the engineers and navigators may be able to go beyond the social boundary and have some concrete materials to address each other's concerns. Informed by Vygotsky [118]'s theory, our cognition is distributed and our knowledge is maintained and improved by such interaction. Learning could be conceptualised as situated action that is inherently integrated with human activities in certain context [129, 134], so navigators could obtain more knowledge about energy consumption from engineers and engineers could understand navigators concerns in ship manoeuvring. This collaborative learning may lead both departments to innovate together to improve their future performance in joint activities.

A social-cultural approach should be appreciated to understand activities among communities of practice and human-technology interaction. Employing technologies to facilitate knowledge mobilisation and social interaction is a key aspect of interaction design in complex sociotechnical systems [132], which has not been addressed that much in maritime human factors research or industrial development. Another article based on the same energy efficiency project [187] has extensively discussed learning and knowledge mobilisation in maritime activities and its connections to future maritime development. The social-cultural perspective can enable us to conceptualise knowledge with a new perspective, i.e., "the result of everyday interaction" [213], in contrast with the traditional view of treating knowledge as merely an object. With this perspective interaction design is associated with knowledge transfer per se.

The human-technology interaction issues in the EE context is not only relevant to sociological constructs but also ecological concerns. One major problem with many shipping organisations is that management does not have sufficient knowledge or an effective monitoring mechanism [214]. The fuel management system used onboard serves as one crucial medium to link design and management. With the data-driven decision support/post-voyage analytical systems, not only the ship's crew could have concrete platforms to self-evaluate performance, but also the management could have possibility to see what is really going on to prepare any organisational adaptation. Big data is essentially concerned about new ways of management [10, 215]. This is to probe the values of data-based management practices in the newly emerging big-data shipping ecology. From the ecological perspective the context of the maritime sociotechnical systems will be influenced dramatically by artificial intelligence and advanced intellectual applications. When the local knowledge (e.g., how to conduct eco-driving on one ship) is institutionalised

with proper organisational support mediated by technologies, what emerges is a collaborative synergy between humans (practitioners at the sharp-end and management team at the blunt-end) and technologies (data-driven decision support systems) on a global level. The impact can even go to an industry and society level, e.g., exploring new approaches for IMO to optimise regulations and policies regarding industrial EE practices in a more adaptive manner, or possibilities to optimise standards like Ship Energy Efficiency Management Plan (SEEMP), which has been identified problems in management system standards [216].

### 3.3 *Managing unruly technologies in ECR*

Today much attention has been paid to technological possibilities to address human limitations or satisfying local needs in technology-driven projects. These projects largely ignored what kind of work and eco-system would evolve towards. There was a case study regarding the eco-system development in ships' ECRs [217]. In ECRs, although the functionality of overview is found to be important for monitoring tasks, the displays and controls are increasingly distributed [28]. This is partly because each manufacturer has their own standards regarding design, none would normally concern about the interoperability or user experience of practitioners working with dozens of heterogeneous products and services onboard. With more technologies introduced to ECRs, local problems might get solved but the overarching ecology is becoming more complex. The situation is not only wracked with the technical hardship but also organisational factors, compounded by the regulatory vacuum which allows a "wild" growth of the intertwined eco-systems in the ECRs [27, 217].

The paper suggests the importance of having a holistic thinking in the shipping industry's ecology (such as the overall architecture) [217]. This is not about how we tackle some usability problem or introduce some "intelligent" IT applications locally, but how we should perceive the issue globally (within an organisation, across organisations, or even in a larger context). A global-level solution was mentioned - Maritime Connectivity Platform (MCP, former known as Maritime Cloud) developed in the EU project "EfficienSea 2" [218] in the *e-Navigation* framework [12]. With more technological applications and services being created, the infrastructure development of the MCP or Maritime Cloud aims to connect all maritime stakeholders for information exchange and shape a more sustainable eco-system in shipping [219, 220]. Although the MCP is *ad-hoc* for ship bridges, the engine and bridge department share the same problem that growing technologies need to be managed on a higher level in the infrastructure. The key to obtain a cross-platform overview with high consistency, accessibility, readability and discoverability lies in the interoperability and standardisation. By introducing the MCP, there would be an "app store" for various kinds of "apps" from a wide scope of service providers and manufacturers. Although the MCP directly concerns the development work in the back-end, i.e., how we manage unruly technologies with design, deployment

and governance of standardisation, such efforts done will also likely influence user experience in the front-end.

What matters most might be not a solution as such, but the needs to conduct a holistic systems perspective to understand human-technology ecology issues in shipping. Ship engineers set up new screens or put up new post-it notes in the ECR to make local adaptations to meet their emerging needs. The shipping industry seems to be developing predominantly in this fashion with more technical solutions being introduced onboard to adapt to individual local circumstances. Human adaptations actually manifest themselves in error mechanisms: errors that are associated with adaptation is in nature a behavioural process of safety boundary seeking, thus adaptations or human errors cannot be eliminated per se [59, 221]. This is to say, local adaptations might be also creating information management problems and leading to human errors at the same time. A critical point in systems perspective is that things go right in the same way as things go wrong [222, 223]. "The technological flexibilities that simply create burdens on the practitioners" could prevail over "the technological flexibilities that are used to increase the range of practitioner adaptive response to the variability resident in the field of activity" [224].

For the tech-driven shipping industry, it is an ecological lesson for us to reflect upon what this industry is evolving towards and find ways to manage unruly technologies for human use. It is important to understand how this shipping system is carrying out "transforming", or in Dekker [158]'s words, "adaptation" or "drifting into failure" in the specific context (i.e., the slow incremental process during which period small deviations that are usually taken for granted as "norms" reverberate, proliferate, and propagate through the web of complex interactions). The situation in ECRs seems to be a manifestation of successful local adaptations, but local adaptiveness can lead to "illusion of assistance" or "mis-calibration" of the dynamic situation, as it might lead the decision makers to ignore the mal-adaptiveness on a global scale [185]. The reflections from the ecology study of ECR are accentuating the importance of having a holistic view and systems thinking in terms of human-technology interaction.

Complexities are the results of a large problem space, large numbers of interacting elements, social-cultural perspectives, heterogeneous perspectives, distributed, dynamic processes, non-linear interactions, highly coupled elements with various interactions (e.g., the element evolves with one another and with the environment) and hard to forecast or predict [154, 225-227]. With the prevalence of imperfect automation today and maybe in the far future, the more exact decision it made for the user, the higher risk of automation bias and more "human errors" is introduced. It is important to integrate human and technology into a sociotechnical system, in which their capabilities are supplementing each other to provide improved system performance - "effectiveness in sociotechnical systems will often depend on whether the technologies function as collaborative system team players" [157]. The most valuable ecological perspective is to consider the

system as a whole (human-technology-ecology), i.e., shifting from structuralism, which primarily focuses on what happen inside an agent, to functionalism, which primarily focuses on what happen inside a system.

### 3.4 *Towards a pluralistic epistemology*

Some of the maritime study cases presented in this paper adopt the psychological school of SA interpretation to "zoom in", while others study employs social-cultural and ecological lenses to "zoom out". To some extent this discourses a dialectical dialog between somewhat contradicted theories and views, between mind and matter, between the old school and new school of HCI research paradigm that is introduced in section 2. Here we can take a more philosophical attitude to understand the "controversy" and value of pluralism in research of human-technology interaction in general.

The debate on metaphysical theories or ontologies informs us, actually, there can be multiple ways of understanding being. The materialism advocates that matters exist independently of thoughts [228]. The world is out there waiting to be "discovered" and the observer has the possibility to take an objective distance between him/herself and the observed phenomena so he/she could take an objective stance towards the nature of matter - this is described as the "discoverer epistemology" by Flach and Voorhorst [128]. The discoverer could be considered as a "detached observer" [229] - the objective reality exists in the rationalistic view in which a cognitive agent perceive cues and forms mental representations (i.e., knowledge) that can be manipulated (i.e., thinking or cognitive activity). This philosophical ontology with the "discoverer" attitude dominates the mind-set of many scientific researchers of multiple disciplines such as chemistry, biology, physics and even computer science. Positivism asserts that there is absolute truth about knowledge and it is gathered from the natural and social world only through rigorous unbiased empirical methods, methods based on hypothesis and empirical fact gathering [230]. This epistemology indicates that we should already have assumption and knowledge. We formulate a falsifiable hypothesis and do the controlled experiment to test and observe so the study becomes "scientific" per Popper [231]'s hypothetical-deductivism (falsification) principles.

But is there always absolute truth of knowledge? Is the study to our mind always subject to laws and theory? Probably positive answers for neuroscience as it is still trying to seek the objective reality in the human brain's structures, but in other cases findings might be no longer independent from the observers. Flach and Voorhorst [128] describe the concept of "inventor epistemology" and that observers immerse themselves intimately into the studied phenomenon and knowing that can only be "invented from inside". Different observers may create different observation's results, similar to "observer's effect" in quantum mechanics [232]. From the epistemological theory's perspective, this is congruent with post-positivism that rejects the assumption that there is an absolute

truth about knowledge [230]. The world is rather complicated and hard to predict, thus the *authentic* accounts of the reality can only be constructed through our interaction with the world itself (e.g., see constructionism in many social science research to understand the socially constructed nature of real-world phenomenon [133, 233]).

The problem in our scientific research concerning the topic of human-technology interaction is that researchers usually take a dualistic ontology for granted in which mind and matter are deemed as two distinctive systems and therefore we have two kinds of realities or even sciences [128]. The consequence is that we might end up observing and understanding the world exclusively through one lens. Many academic debates have been unfolded around this, e.g., “mind versus matter” topic in cognitive science, especially surrounding those well-known constructs such as situation awareness. While some argued the importance of studying cognitive constructs [75], others believed the importance of focusing on the “system” [158].

However, there is an alternative by looking at the actual consequences and considering the practical effects of the objects (i.e., knowledge, concepts, meanings, beliefs, etc). Pragmatism that derived from the work of Peirce [234], James [235], Mead [236], Dewey [237], argues that values and truths are determined by utility and experience to address the problem of the dualism. For example the radical empiricism constructed by James (1976) highlights the notion of experience to eliminate the substantiality of substance and consciousness. Bennett and Flach (2011) contended that human experience is the essentially the “joint function of mind and matter” (p. 460), something that has been echoed in Pirsig [127]’s discourse of experience of driving the motorcycle (a metaphor of technologies). Pragmatism advocates pluralistic approaches to derive knowledge about the problem because knowledge and truth is plural and contextual - “it is not ideal or a fixed conception of reality but a means for dealing with it effectively” [230]. Winograd and Flores [229] contended that cognition should be viewed as “a pattern of behaviour that is relevant to the functioning of the person” (p.71) and “knowledge is always the result of interpretation, which depends on the entire previous experience of the interpreter and on situatedness in a tradition” (p. 75), so knowledge is both subjective and objective. The philosophy of pragmatism invites multiple methods and worldviews to discuss the meaning of interaction and understand the nature of human-technology interaction. Perhaps there are no separate realities or sciences but one unified science (“science of experience”) in which human experience is shaped in the interaction of mind and matter [128]. Pure objectivity can never be achieved [238] and we are part of what we aim to change [128]. What matters for researchers and designers in HCI, in order to understand the complexity of the domain (e.g., shipping), is probably a pluralistic epistemological framework in which we are not necessarily “bound to a stance” but we learn to “appreciate each stance”.

This article explores these values of epistemological pluralism by using the cases in the shipping as examples. As these cases suggest the sociological and ecological concerns are as crucial as

the psychological concerns. We should have a pluralistic epistemology to study and understand human-technology interactions in shipping, i.e., recognising the value of both “think small” and “think big”, both “zoom in” and “zoom out”. Multidisciplinary endeavours are required to achieve the pluralistic epistemology. In addition, the presented cases here have suggested that there are interdisciplinary understandings between disciplinary knowledge. For instance when we realise the limitations of the cognitivist approach, we might be already in the realms of socio-ecological dimensions, such as queries about how a decision support tool could facilitate collaborative learning, management practices in the emerging data-driven era, what the human-machine system in the ECR would evolve towards, etc. The crucial value of a multidisciplinary approach is perhaps helping us to set a foundation to form an interdisciplinary synergy as an emerging language to understand complex sociotechnical systems. This view might benefit the maritime human factors and HCI research community as well as the shipping industry.

#### 4 CONCLUSIONS

This article reviews theoretical concepts relative to the dimensions of psychology, sociology and ecology in order to form a deeper understanding of human-technology interactions. It also discusses the theoretical constructs’ practical relevance by showing how a few cases exemplifying ongoing development sectors in shipping are understood with these theoretical perspectives. Today’s maritime human factors and HCI research has significantly widened its research scope to something that is situated at the intersections of computer science, social science, engineering design, and psychology. The boundaries between the traditional disciplines are diminishing [155]. The shipping industry is at full speed towards digitalisation and automation, but the transition period is, as substantiated by various studies presented in the paper, characterised of fragmented needs of all kinds, lack of human factors concerns, contextual considerations, regulatory support, and wild growth of unruly technologies, etc. With more and more advanced technologies being introduced to the shipping domain, used with people, by people, for people, it is of significant importance to take an attitude of pluralistic epistemology for future maritime development and HCI research. In the author’s opinion, it is not only the apparatus to conduct multidisciplinary/interdisciplinary research, but also this emerging language for us to learn and appreciate the complexity of the world, both industrial and societal.

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