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# Maritime Energy Efficiency in a Sociotechnical System: A Collaborative Learning Synergy via Mediating Technologies

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ABSTRACT: Previous research in the domain of maritime energy efficiency has mainly addressed concerns regarding individual experiences and organizational barriers. Reflection on the reciprocal human-technology relationship, interaction design and its impact on the practitioners' learning and organizational decision-making process is rather scarce. Informed by focus group interviews, this paper describes the essence of practitioners' activities and the nature of interaction design and proposed improved design for energy efficiency monitoring systems. Findings suggest knowledge sharing for a mutual understanding onboard ships is critical to energy efficiency. Learning can go beyond the embodiment of individual cognitive change but becomes a collective and collaborative achievement mediated by technology, which informs opportunities for interaction design. The design needs to consider the context in which knowledge mobilisation occurs and facilitate collaborative learning. With more intelligent systems introduced to the shipping industry, it is important to consider the impact of mediating technologies in management practices and mediating technologies can be integrated into a broader collaborative learning paradigm emerging between the ship and shore. This study highlights those social-cultural dimensions important to establishing a common ground between practitioners, management and advanced technologies.

## 1 INTRODUCTION

Maritime emission of greenhouse gases (GHG) in the shipping industry is projected to increase by 50% to 250% in the period to 2050 [1], with potentially huge impact on the global environment and human health [2]. As a dominating transportation sector, the global shipping industry has been striving hard to reduce the maritime footprint of its GHG emissions for years in recognition of the climate change challenges. In 2012 shipping emitted 938 million tonnes of $CO_2$ with 2.6% of the total emission volume in the world, in contrast with 1100 million tonnes of $CO_2$ from shipping with 3.5% of the total global emission volume in 2007 [1]. The increase of energy efficiency (EE) is a pivotal contributor behind the significant changes in these numbers, as it could lead to reduce 25% to 75% of $CO_2$ emission, according to the second IMO GHG study [3].

The Ship Energy Efficiency Management Plan (SEEMP) [4] prescribed mandatory regulations about how energy conservation should be organized in the field, i.e. how to develop the best practices for fuel-efficient ship operations. A direct outcome is to decrease fuel consumption while maintaining at least the same level of transportation services. The strong focus on optimization of energy consumption is tightly related to the economic factors, that improving energy efficiency can often lead to increased profitability [5]. However, it has been observed that it is the ship's crew who usually have this direct and considerable impact on EE through their operational practice [6, 7]. This paper will review previous relevant research work and describe practical ship visits with respect to the ship's crew's EE performance in the maritime domain and its connection to human factors and interaction design.

## 2 REVIEW OF RELATED LITERATURE

### 2.1 *Gaps in inter-department collaborations*

The engine and bridge departments come with different skill sets: bridge officers are responsible for navigating the ship safely and efficiently with an appropriate voyage plan, while ship engineers are dealing predominantly with the engines and other systems for ship propulsion and power generation [8]. Thus, communication is essential to help coordinate information and meet operational goals in such complex socio-technical environments [9]. Previous research [10] has attempted to explore the ship's interdepartmental communication via the joint activity approach [11] which is concerned with contextualizing communication in the lens of *criteria*, *requirements* and *choreography*. Kataria, Holder [10] has informed inter-departmental communication scenarios (such as to prepare the vessel to be ready for certain actions or incidents) and identified that there were perceived fissures between the two departments: "…a lack of understanding of the other group's work, what engineers do, and bridge officers concerns bridge. Bridge officers noted that they do not always know the difficulties and concerns for engineers related to a manoeuvre such as when they want to go from full ahead to full astern…the engineers might ask why so many engine orders were required. There can be a difference in priorities in the two departments, namely concern for the engines vs. optimal speed of ship handling" (p. 173).

Ship energy optimisation requires an coordinating effort by two departments [6]. It is essentially a joint activity, which is described as "behaviours that carried out by an ensemble of people who are coordinating with each other". As Klein, Feltovich [11] describe, only by meeting *criteria* (i.e. intention and interdependence), *requirements* (interpredictability, common ground, directability) and *choreography* (phases, signalling, coordination devices, coordination costs), can a joint activity be achieved successfully. Noteworthy is that coordination depends on the ability to predict the action of other parties and most important basis for interpredictability is common ground, a communicating, mutual understanding establishing process that can be significantly influenced by mutual knowledge [11, 12]. How they can develop the mutual understanding and knowledge, especially via the mediating tools (as part of coordination devices [11, 13]) remains to be elucidated upon in the context of EE.

### 2.2 *Collaborative learning and knowledge sharing*

Activity Theory [14-16] has informed that the meaning of the things or the goals that make people act on reality has its profound root in social interaction and thus knowledge is maintained in such interaction. The production of knowledge and attention of the departments can be diverse, as they have different socio-culture experiences, which can contribute to the fissure described by Kataria, Holder [10].

Previous knowledge management literatures in the EE domain that knowledge and skills are identified to be the central social constructs [5], shaping meanings of things that people do. Other studies have also recognized the importance of the crew's awareness, knowledge, motivation and ideas in EE operations [17] and addressed concerns regarding the education and knowledge development process [18]. Viktorelius and Lundh [6] identified that 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 [6]. In Kataria, Holder [10]'s study, the division between the engine and deck was framed as "huge Berlin wall". There is a certain need to overcome barriers and create the context to allow knowledge development.

The intuitive solution would be what Kataria, Holder [10] proposed, using training to develop knowledge, for potentially enhancing collaboration to improve EE. But knowledge mobilisation in the shipping domain is usually in a formal, explicit, salient professional form like what Viktorelius and Lundh [6] observed: 'crew members…had been sent to a one day course for how to use the fuel management system'. This is consistent with the common perspective in knowledge management research that knowledge is considered as object and asset thus learning becomes the process of *transferring* the objects from producer to receptacles to produce actions [19-21]. One limitation is that it brings benefits mostly at an individual level based on the knowledge network framework prosed by Büchel and Raub [22]. Additionally, the professional training can be normative per se, infusing information to the practitioners about "what should be done" instead of supporting their own ways of "muddling through" [23] in each of their situated context. Though this type of formal education may be beneficial in developing a common ground concerning system usage in routine tasks, it may also have its intrinsic limitation in cultivating dynamic problem-solving capacity required under unanticipated situations [23, 24].

Knowledge development could also transcend the traditional notion if we take a distributed cognition perspective, such as the socio-cultural approach [25, 26] or situated cognition approach [27]. The distributed cognition perspective concentrates on that human cognition is embedded in the social-cultural context and the focus is from individual cognitive change to distributed functioning in the environment of working groups [28, 29] and tools. Knowledge mobilisation among the peers is not *transferring* the objects but carried out in an implicit and tacit form [30]. Viktorelius and Lundh [6] showed that the ship engineers might come up with new ideas in an unstructured form, which could shaped itself differently from traditional classroom learning.

Knowledge sharing can become a natural product of the mutual engagement, or a 'dynamic by-product of interactions' [31].

In Lave and Wenger [32]'s concept in *community 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 [30, 32, 33]. Learning at work is essentially both a culturally and socially situated activity [34]. 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. His/her competence would grow as he/she is more knowledgably skilful through more interactions [32]. The benefit of situated learning is that the characteristics of situatedness can breed collaborations and innovations through the participation of multiple agents [35, 36]. A collaborative learning approach is emerged in this sense that it occurs "in a situation in which two or more people (a small group, class, community or society) learn or attempt to learn something together" [37] and collaborations among workers, the joint intellectual effort, becomes a way to achieve learning [28]. Collaborative learning could lead to greater problem-solving success than individual learning [38].

The relationship between learning as an individual phenomenon and as a collective phenomenon can be conceptualized considering an inter-subjectivity perspective [14, 15, 28, 39-41]. Vygotsky [14] argued that the psychological development is from inter-psychological to intra-psychological (e.g. an engineer may progressively understand navigational knowledge from the bridge department when he is frequently interacting with them, thus "the community influences the individual"); but Cole and Engeström [41] contended that it could also be from intra-psychological to inter-psychological ("the individual influences the community") as learning could be a bi-directional phenomenon (e.g. the navigators could get influenced by the engineer). A collaborative learning experience is reflected through the socio-communicative process in which plurality of perspectives and social coordination is presented [28].

### 2.3 *Problems in Ship-Shore Management*

Knowledge production and mobilisation onboard ships at the sharp-end can be influenced by shore-based support and management at the blunt-end. Johnson and Andersson (2016) suggested that current organizational structures inhibit learning and innovation in EE. It was found that the practitioners who directly influence energy consumption on the front lines could be organisationally too far removed to be included in the crucial organizational decision making process [7]. A body of energy efficiency research addressed the concerns from the managerial perspective, e.g. the quality and awareness of information [42], inaccuracy of information [43], etc. This came along with a broadened discussion grounded in the societal and organizational views to understand the gaps in energy management such as management standards [44], information asymmetries and power structures within organizations [7], how the organisational change influences human behaviour [18], energy performance monitoring competence, data accessibility, data analysis and actionabilities of improved operational measures [45]. The practitioners' voices were not necessarily heard in the important ship-shore communication [46] and they usually get poor learning support from the organization [6], as the shipping industry is essentially a top-down management system [18].

### 2.4 *Tool Mediation and Interaction Design*

Collaborative learning can be in various forms such as face-to-face communication or computer mediated [37]. Much knowledge management and organisational research identified problems in the ship EE context [7, 44, 46], compounding the gap issue in inter-department collaboration. However, solutions regarding such issues, specifically, how collaborative learning activities and interactions between bridge and engine and even between ship and shore can be supported have not been addressed. Is there any "niche" for the supporting tools? If so, how should the tools address the users' needs?

The working environment onboard is characterised by task distribution across the ship's crew and accessibility of mediating tools [47]. Mediation means that human experience is shaped by the tools and it is the mediator (the tools) that connects the human workers organically and intimately to the world, so the technology use shall not be limited to a mechanical input-output relation between human and machine [48]. Kataria, Holder [10] suggested that technology mediated collaboration is very important for interdepartmental interactions, such as using shared displays to create better situational awareness. In today's context of EE, technologies have been mainly exploited in the manner of sensing complex environmental factors contributing to EE and automatically manipulating operational configurations for optimized performance [49-51]. They are not necessarily designed in a way to support the practitioners' awareness and assessment of EE performance or collaborative learning activities, which are considered crucial in energy saving activities [42, 43, 52].

Viktorelius and Lundh [6] reported that a state-of-the-art performance monitoring system called ETA-pilot had been installed on modern ferry vessels to aggregate huge amount of energy consumption related data to supposedly inform the crews about energy efficiency. The authors of this paper conducted several visits to the same modern ferry ships and interviewed with the designer of the ETA-pilot as pre-studies to understand how the existing EE monitoring system worked in theory and in practice. Sailing speed is directly relevant to EE. The ETA-pilot takes in fixed parameters of ship characteristics (e.g. parameters of the ship hull etc.) and dynamic parameters (e.g. draft, trim etc.), the profile of water depth during the voyage, forecasted weather information, together with estimated time of arrival and distance. Proposed speed profiles in real-time are generated and the technology directly regulates the speed, until the navigators intervene (e.g. when there is a traffic situation that requires a speed or direction change). The fuel consumption is calculated in real-time (kg per nautical miles) and displayed as a dynamic curve along with other dynamic parameters in a complex graph. Once the ferry arrives the port, a number of EE related data has been generated and would be transferred to the shore-based management office for further analyses. Figure 1 illustrates how the ETA-pilot records how the fuel consumption varies along the voyage together with a total fuel consumption (27816 kg).

In the pre-study, one of the authors of this paper was informed by the designer of the ETA-pilot that there was no universal optimal use of the tool but had to depend on the navigators' own experience and interpretation, as there are many factors that the current algorithm of the tool cannot universally account for, e.g. different routes, different efficiency from different propellers, different potentials to save fuel on different ships. The designer also expected that the tool could enhance the collaboration between bridge and engine departments and certain analysis could be done to inform future improvements on EE.


Figure 1. The ETA-pilot interface once the ship arrives the destination.

However, this was not what the actual practices reflected. One observed phenomenon was the users have different "tool-related competence", a notion described as the capability in terms of tool using by Kaptelinin [53]. Viktorelius and Lundh [6]'s study reported that some even claimed that by disconnecting ETA-pilot, navigating manually could contribute more fuel saving. In the pre-study, it had verified that a lot of data were generated but "not used by the crew members" [54]. The shipping company only used the EE data sent from ETA-pilot to check the fuel consumption after major maintenance activities like cleaning the hull [54, 55]. Viktorelius and Lundh [6] concluded that this is a problem of "underdevelopment of evaluating activities" or "inadequate knowledge".

## 3 PURPOSE OF THE STUDY

The purpose of the study is to investigate if and how the identified gaps in the EE practices can be mitigated through addressing the end-users concerns in the EE context and exploring opportunities of interaction design. The purpose of the paper is to understand the relationships between collective activities and mediating technologies and their implications to knowledge transfer and management practices in the context of energy efficiency onboard ships.

## 4 METHODS

### 4.1 *Participant demographics*

In total, five male ship engineers and eight male bridge officers were invited to participate two focus groups that were conducted chronologically in this study. All participants are Swedes. For engineers, their ages ranged from 39 to 49 years with a mean age 44.4 (SD = 3.9) years. The engineers had between 6 and 96 months of experience at their current positions with a mean period of 52.5 (SD = 34.3) months. For navigators, their ages ranged from 32 to 52 years old with a mean age 44.3 (SD = 6.2) years. They had between 12 and 156 months of experience at their current positions with a mean period of 69 (SD = 47.9) months. Most of them come from a shipping company that is one of the largest ferry operators in the world.

### 4.2 *Procedure for data collection*

A digital consent form was mailed to the participants to inform them about how the collection of the data as well as treatment of data and their identities would fulfil the ethical demands for academic research. All participants were aware that their participation was voluntary, signed the written consent forms and filled in the demographic details prior to the focus group interviews.

The focus groups were pre-planned carefully together with *Sweship Energy*, a platform created by the Swedish Maritime Association and supported by the Swedish Energy Authority and Swedish Maritime Administration to organize recurring workshops for knowledge sharing and learning among ship practitioners with different knowledge backgrounds and capabilities. The focus groups were carried out in the workshops on two separate occasions. In the first workshop, there were three engineers and four navigators who signed up with the purpose of sharing EE knowledge and participated the focus group. In the second workshop, there were two engineers and four navigators signed up and participated the focus group. All participants are already involved in various EE activities onboard. These two focus groups have identical orchestration with respect to the topic, posed questions, controlled process, field notes taking, assistants and moderator.

The two focus groups were led by the same moderator in a structural way which lasted approximately one hour. During the session, three assistants were present to distribute various hand-outs with the questions for discussion, take discussion notes, and probe the participants' responses when appropriate. Each focus group was divided into two parts. The first part was a brief discussion on a few general questions pertaining to EE operations onboard, including today's measure practices to achieve energy optimization, plus an objective prioritization of four aspects, i.e. 'passenger/cargo safety', 'ship safety', 'energy efficiency' and 'passenger comfort'. The second part was an in-depth discussion on their perceived values, challenges and expectations towards the design and usage of an ideal digitalized EE monitoring tool in terms of the three major phases of a voyage sailing, i.e. before the voyage, during the voyage, after the voyage.

Noteworthy is that the posed questions were framed in a way to attempt to make them reflect upon the gains and pains related to their current EE related practices (i.e. how the engineers and navigators interact with each other and how they engage with the mediated computerised systems onboard to improve EE), instead of requiring them to wear hats of an IT expert. Each question was both presented on a projector screen and the handouts. All participants were informed to write their own opinions on the handouts first and then discussed with the group about their knowledge and ideas. The hand-outs were collected upon completion of the focus group.

### 4.3 *Data analysis approach*

Considering the homogeneity of the two focus groups, the gathered data were merged to form a larger base to allow findings to be emerged. To analyse the qualitative data, all hand-outs were analysed jointly with field notes in an iterative manner guided by the Grounded Theory [56]. Grounded Theory is a qualitative data analysis method that strives to categorize themes in the transcripts and generate explanatory propositions that correspond to real-world phenomena [56, 57]. Grounded theory allows theoretical concepts or frameworks to be emerged from the data throughout the research process [56]. 'Open coding', an iterative process of aligning pieces of text to different categories with attached code memos [57], was used to portray the relationships between emerging concepts in pursuit of a higher-level categorization and theorizing. All participants' responses were imported into MAXQDA 12 (www.maxqda.com), a computer assisted software mainly used for qualitative data analysis, to be coded for qualitative text analysis [58].

## 5 RESULTS

### 5.1 *Brief discussion on goal priorities and practical operations*

Due to the small size of the sample, it was easy to observe that all participants agreed 'ship safety' and 'passenger/cargo safety' were the top two in their priority list and most of them thought 'passenger comfort' was the least important. This was also confirmed in the later discussion. All participants agreed that safety outweighed EE, although EE was also a very important goal to them.

The main message derived from the discussions was that both the bridge and engine department recognized the importance to collaborate and inspire each other to improve EE. The mixed-background participants pointed out that it was critical for them to share information and learn from each other in a distributed working environment (i.e. bridge and engine), such as '*when we discuss, we actually cooperate (…) use the benefits of they* (i.e. engineers) *having great idea and we have bad idea*', '*open mind for new thoughts from the crew*', '*have discussions regarding decisions be made*', '*display simple information so everybody can feel that they can participating*', '*thinking about how to reduce energy usage in different ways*', etc. They believed that bridge-engine collaboration could become a useful approach to increase personal awareness, especially dealing with some 'trivial' details in operations toward energy optimization. For example, a navigator admitted that he '*sometimes (…) forget about adjusting the speed pilot*' because they went to drink coffee. Some engineers thought it could be beneficial to communicate about how many engines would be used ('*thoughtfulness regarding the number of machines*') because it can influence fuel consumption.

The participants not just stated their motivations about collaboration and learning for improved EE, they also made a link to a prominent factor influencing effectiveness and efficiency of EE performance – the mediating tools. They addressed the concerns of losing transparency by introducing complex automated tools like the ETA-pilot that they did not necessarily understand a system's status which made it hard to communicate with their peers. Some engineers even expressed that using '*blunt instruments*' like hands-on tasks, sounds, vibrations, slowly ticking measurement was more efficiently contributing to their understanding of the circumstances in the old days. An engineer mentioned that the fuel monitoring system had '*too much information*' to become usable and supportive for the crew members to plan the voyage.

Reliability and functionalities of the tools were also briefly discussed. As the direct users of the automatic eco-driving systems (including ETA-pilot), the navigators particularly expressed that their ship-handling experience was the key to achieve sufficient situation awareness and deliver improved EE performance, as the tools are '*not as perfect as you think*'. Both engineers and navigators agreed that usability of the tools and information sharing plays an important role in their activities pertaining to energy optimization, such as '*whatever information, has to be simple, clear for both engine room and bridge*', '*the most important is that we have the same information on the screens*', etc.

### 5.2 *In-depth discussion on activities, values, expectations and challenges*

The participants' responses in the in-depth discussions from the two focus groups were organized around three phases of a voyage, i.e. before the journey, during the journey and after the journey. Table 1 summarizes the key findings and presents an emerging collaborative learning synergy between the bridge and engine departments in pursuit of improved EE onboard ships via mediating technology, based on the user requirements elicitation. To support the need of information sharing, communicating and collaborative learning via mediating technology on EE optimization became the emerging theme, woven into the participants' discourse of their activities (either experienced or anticipated) throughout the three phrases. A more detailed elucidation on the findings is followed by the table.

Table 1. The participants addressed the key activities that contribute to EE, the values of mediating technologies in terms of how they can contribute to mutual understanding and the common ground, as well as the potential barriers to achieve improved EE performance in three phases of a voyage. Noteworthy is that the phrase of "after the journey" was merely anticipated yet the stated activities had not been perform.

| | Before the journey | During the journey | After the journey |
|---|---|---|---|
| Identified key activity contributing to EE (experienced or/and expected) | Voyage planning collaboratively by the engine and bridge departments | Eco-driving and sharing situational information between the engine and bridge | Performance evaluation and learning for future improved EE practices together |
| Expectations on the mediating tools and their values in contributing to a mutual understanding for building the and common ground | Sharing an overview of the systems status, route options, weather information, estimated fuel consumption and time constraints | Sharing important situational information such as current, wind, traffic, speed/ETA, real-time fuel consumption and its consumption benchmarks | Summarizing and analysing the journey's EE performance to provide a concrete medium for inter-departmental discussion learning |
| Potential challenges (barriers to the achieve improved EE performance via employing the expected tools) | System complexity, time constraints, data reliability | Motivation and system complexity, data reliability, time constraints, weather/ traffic dynamics | Lack of capabilities to analyse raw data or motivations, time constraints, technical uncertainties |

#### 5.2.1 *Before the journey*

In the pre-departure phase, the participants expected that the key activity, voyage planning tasks, shall be supported with the provision of an overview of the systems, route options, etc. Although the engine and bridge can different concerns (navigators addressed the need for speed/route recommendation based on the analysis of water depth, predicted weather status, traffic forecast etc. while engineers desired the estimated fuel consumption and time constraints like estimated time of arrival (ETA) and departure time), all participants agreed that it is important the activity is done in collaborative way supported by the tools. The engineer participants pointed out that it was necessary to '*involve the engine department in the voyage planning*' and it was crucial to '*always reconcile bridge and engine control room if something deviates from the norm. For example, maintenance, which means that not all machines are available and when it is expected to be completed*'. The navigator participants also expressed that information sharing between departments can contribute to their learning too, e.g. '*more people and more data so it is better decision bases*'.

#### 5.2.2 *During the journey*

During the voyages, both the navigators and engineers expected that the tool can support relevant situational information sharing like sea current, wind and traffic so that eco-driving can be achieved via a team effort. An open contact mediated by tools (e.g. a shared display and voice communications) were appreciated during the voyage, e.g. '*continuous contact with the control room and the discussion of the same information*' mentioned by a navigator. All engineer participants believed such open contact could allow the bridge and engine departments to diagnose '*abnormal situations*' and increase mutual understanding about decision making in the voyage, such as '*why we do not run with X number of machines*', '*how many machines…should be consulted on the basis of exhaust gas boiler, lubricative oil, axle generator*'. In terms of the features of the shared displays, it was noticed that that in addition to the key information of speed/ETA, real-time fuel consumption, the participants also appreciated some sort of benchmarks to be presented in the fuel consumption curves to not only support navigators navigational decision making but also contribute to mutual understanding of the engine-deck team.

#### 5.2.3 *After the journey*

The post-journey activities that they expected to undertake was the most enlightening part of the focus group findings. Performance evaluation and collaborative learning experiences with the engagement of the tool were highlighted by all the participants yet they do not exist today as common practice or even standard operating procedures. The participants acknowledged that there were no analytical actions being taken once the ship arrived the port, mainly because they lacked the capabilities and opportunities (e.g. time constraints and the existing tool did not support them to learn). They suggested that the reality was that large amount of operational and factual data were collected, plotted, ignored while the shore-based management did not conduct effective analysis either. The most appreciated and desired value of the tool was to analyse the data and further support the inter-departmental collaborative learning activities later on, such as review the journey and discuss about how to do a better job by each department. The participants considered the fuel consumption performance evaluation provided by the tool as a concrete medium for the navigators and engineers to inspire each other and reflect upon their past behaviours and decisions, such as '*know what was good, what can be done differently*', '*learn things for the next trip*', '*get feedback to see if the trip has been completed within the planned parameters or deviated from the theoretical plan*', '*obtain a summary…which parts of the trip cost more fuel*', '*get material for discussion at various meetings*', '*feedback on* *what the consumption was for a certain action/driving*' etc. In the post-journey analysis activity, communication was extremely important for team reflections, like one participant addressed, '… (The engineers and navigators) *should discuss that information* (about the most recently completed journey) *during various encounters onboard*'.

### 5.2.4 *Challenges*

The participants also discussed the barriers to affect EE performance via employing the expected tools. Besides the system complexity and technical challenges, the participants pointed out that time is a crucial constraint factor influencing their collaborative learning and decision making across all three stages of a voyage. In addition, ease-of-use of the tool was also mentioned. The participants used such expressions as '*an easily understandable system*', '*simplicity operations*', '*easy to use*', '*present this in good way*' to accentuate importance of their usability requirements. This part appeared to be a further elaboration of the brief discussion on the '*blunt instrument*' – they seem to prefer usability over functionality in tool using. To them lack of transparency due to increasing automation is a problem.

## 6 DISCUSSION

### 6.1 *Methodological limitations*

While this size of the focus group (i.e. from six to eight) is considered ideal to balance the collection of fine details with a breadth of perspectives [59], the participants per focus group is mixed of backgrounds, consisting of engineers and navigators. The heterogeneity of participants is usually to be avoided as this might make people less comfortable in sharing experiences and lead to less interaction between people pertaining to different professions [59]. However, the focused groups are arranged in the workshops which are open to both engineers and navigators, thus the sign-up participants are intrinsically mixed and it is hard to control prior to the focus group study. Nevertheless, the specialization of the research scope and context of the research retains a certain degree of legitimacy in such group settings. Focus groups are suitable for identifying problems, finding desires, and values from the stakeholders' view [60]. Given the main interest is the collaborative work on energy efficiency between the bridge and engine control room, the heterogeneity became advantageous when plurality of perspectives and backgrounds is presented. The interaction between engineers and navigators was found to be beneficial to develop a mutual understanding of the concerns outside each of their individual professional realm and build a common ground shared in the EE context. Thus, an overall comprehension of the challenges in the whole system and wider consensus of the system requirements among the participants aiming at improving the EE performance could be reached. In addition, the heterogeneity is mainly reflected in the profession, as all participants are Swedish males sharing the Scandinavian navigational culture, plus they all have considerable sea experience and the majority had experience dealing with energy performance monitoring systems.

The data collection drew from a sample size of thirteen participants. The rationale to merge the two focus groups into a larger base for data analysis is the common context of the focus groups, participant's background composition and data collection approach. The focus of both workshops was to facilitate knowledge sharing on EE.

It is important to generate theoretical insights, but the authors would contend it is more important to associate these views with design as a means to contribute to problem solving in the field and user experience improvement. Flach and Voorhorst [61] argued that the "experience" cannot be fully understood from a perspective that considers the users as objects independent from the artefacts (conventional social science) or from a perspective that considers the artefacts as objects independent from the users (conventional engineering). In the EE context, a critical question is how to incorporate collaborative learning into the practitioner's daily operations, which conventional engineering or technology-centric design seldom consider.

### 6.2 *Collaborative learning synergy mediated by the tools*

### 6.2.1 *Mutual understanding and distributed cognition*

Engineers and navigators work at distributed places and thus can be considered as distributed working communities of practice. Previous research [10] has addressed the inter-departmental gaps, but they did not study the collaboration in the context of EE. Informed by the participants' needs in information and knowledge sharing in the three stages of a voyage for an improved EE performance, this paper has identified a critical point in their joint EE activity, i.e. how to facilitate their mutual understanding in their distributed EE practices. The results suggest that the distributed communities can be interdependent upon each other's work for improved EE and need to communicate and collaborate with each other in order to get the job done better. For example, how many main engines and auxiliary engines will be available depends on the work in the ECR and the bridge must take this factor into account in the voyage planning. The engineers requested to be informed about ETA and substantial manoeuvring changes made by the bridge so the engine department could properly adjust the operational status, change configurations of engines. The decision making on the bridge during the voyage due to traffic situation or weather can influence the engineers' maintenance plan, which in turn might affect energy optimisation performance.

The results identified that the engineers and navigators share the same intention to maintain safety and save fuel (this is also probably because all the workshop's attendees are active practitioners for fuel saving onboard). Thus, they may have a foundation to share *criteria* for a joint activity [11]. Building a common ground is a crucial step towards their joint activity - the results verified that 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 thus vital to EE. This process needs to be incorporated into their common practice.

The results regarding the post journey analysis revealed how an envisioned collaborative activity mediated by technology could have potentials to contribute to knowledge sharing. Taking the distributed cognition perspective can allow us to understand the value of this collaborative learning activity. Learning is conceptualized as situated action that is inherently integrated with human activities in certain context [32, 35]. Once the journey is completed, if the mediating tool could analyse the data and shape a communication space for the engineers and navigators to reflect upon the newly finished voyage, then an opportunity might be created to influence the aforementioned socio-boundary [6] between the two departments. This is because, learning and knowing are essentially addressing 'relations among people engage in activity in, with, and arising from the socially and cultural structured world' [27]. Collaborative learning can provide opportunities to improve, evolve, reinforce, and even innovate practices [35] and invite mutual learning as collectively shaped activity [33]. To some extent, the activities at this stage could likely bring much value in the improvement of their future practices. The navigators and engineers may use this process to not only understand each other's concerns during the past journey, but also learn ideas and tacit knowledge from the team that may result in more fuel-saving. In addition, it also creates an opportunity for the distributed working communities to have computer-mediated and face-to-face promotive interaction at the same time, which are fundamental elements involved in collaborative learning [37, 62].

The dynamic between the individual and the social can also be addressed by an inter-subjective perspective. One example is to assess of one's development through *the zone of proximal development* [14]. That is, the level of the development is not grounded in that individual's absolute performance, but the distance between the level indicator of independent problem solving and level indicator of problem solving with support from other capable peers or mediating tools. One example is that the engineers might not necessarily understand why an extra engine is required due to changed weather and the navigators might not necessarily understand the relationship between pitch and RPM (Revolutions per minute) and how its coupling could affect speed and fuel saving. The results have suggest that the (distributed) EE work needs joint intellectual effort mediated by the tools. The engineers and navigators must communicate with each other and depend on each other, in which the process the mediating technology need to consider how to support their knowledge sharing and form a basis to increase their mutual understanding. The study result has clearly demonstrated that in the EE domain, there is no "all-round" workers in either engine or bridge department, but it is possible to shorten the *distance* by increasing capabilities via more communication and interactions, i.e. via a collaborative learning approach.

### 6.2.2 *Implications for interaction design*

The results revealed many user requirements on the EE monitoring systems in terms of collaborative learning and information sharing. It is important that the mediating tools need to support their collaborative learning activities and development of their common ground. But why would ETA-pilot fail to address these concerns, as Viktorelius and Lundh [6] reported that it was "not used by the crew members"? Why would the results suggest that users are suffering from usability issues or lost transparency nowadays? What lessons we can learn for interaction design?

What ETA-pilot does is to collect sensor information and plotting dozens of parameters (wind, trim, fuel consumption etc.) on the display. Software systems like this have been largely designed to store, search, and process, formulate and visualize energy consumption related information [63-65]. The human-technology interaction process could be conceptualized as an individual learning activity, i.e. a result of cognitive change in the human operator's head stimulated by the software. The focus in the the industry has been predominantly on the causal relationship between enhanced IT capabilities (stimulus) and learning outcome (response), i.e. how the introduced features of technologies could support the practitioners' information processing activities [66]. Such design fashion has a historical root in the traditional Human-Machine Interaction framework [67] that it is a dyadic semiotic paradigm in a Human-Artefact relationship. This relationship usually refers 'meaning' (i.e. something a human agent learnt) to 'a state internal to the agent' [68]. Therefore learning as such is considered a process of internalization of knowledge typically in individual learners. The ETA-pilot assumes that providing fuel-consumption data curve equals knowledge creation. That is, the tool decontextualizes knowledge and deemphasizes the context in which the knowledge could be applied.

This probably explains why the users want to have some sort of benchmark displayed in the fuel consumption monitoring system during the journey and expect the tools to analyse the data in some ways to shape a discussion basis after the journey, because they want information to be contextualized in which process the numbers become value-creating knowledge towards their EE goal. For example, in the ETA-pilot, 20 kg fuel consumption per nautical mile might not mean much to them but the trend to spend more than 5 kg fuel per nautical mile than the "historical average consumption value" might do. The point is that the "*providing too much information*" as mentioned by the participants would not help if the design ignores the context in which knowledge would be generated, disseminated and applied.

The results of what users expects after the journey unfolds a richer notion for knowledge mobilisation and indicate an important direction for the interaction design, i.e. how mediating technology should support collaborative learning and communication. Situated actions 'depend in essential ways on its material and social circumstances' [69]. The dependence on the mediating material suggests the vast potentials of technologies in influencing the social interaction among distributed work communities and context in which the knowledge mobilisation occurs. Learning is conceptualized by social interaction and participation [32]. This collective aspect of learning invites new possibilities to design the EE monitoring software as a shared repertoire of the communities. By facilitating communication and learning, it is expected to greatly influence the individual-collective dimension [16].

Here we propose one simplified design possibility opposed to the original design in ETA-pilot (see Figure 3). This is an attempt to associate theoretical reflections with practical design solutions.

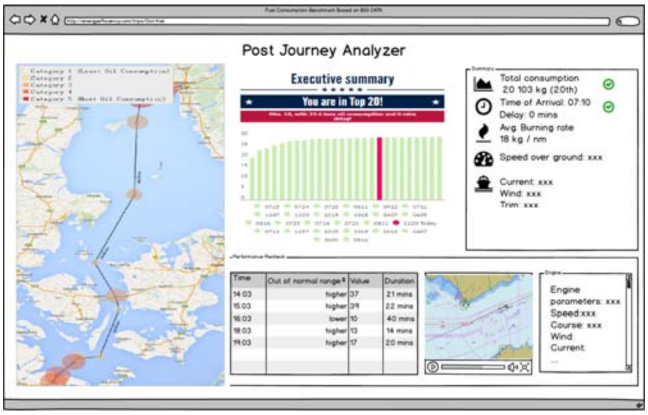


Figure 3. A simplified proposed design for post journey analysis.

The interface not only lists the actual consumption for the journey but also provides historical data on fuel consumptions for the purpose of enabling comparative analysis and illustrating how good it was among the journeys done under the similar conditions (wind, current, trim, etc.). The voyage was plotted on the left side to give an overview about consumption situation for each leg (e.g. what areas are usually the most energy consuming area). The fuel consumption curve along the journey could fall "outside the normal range" (i.e. consumes more than worst case or less than the best case), which introduces discussion and learning opportunities. On the bottom of the interface, these periods were logged, listed in a table, aggregated and populated inside an interactive Electronic Chart Display and Information System (ECDIS) for "voyage replay". Engineers and navigators can replay what happened in each period of significant increase/decrease of fuel consumption and reflect upon '*what was good, what can be done differently*'. When an engineer explained to a navigator how the extra use of the main engine contributed to the precipitous increase in the consumption curve rendered by the tool, or the navigator explained to the engineer how the sea traffic situation of a certain period looked like, the IT system is essentially facilitating their mutual understanding. Frequent interactions among individuals pertaining to different professional realms breed innovations and new knowledge [35]. The tool can shape a space for interaction and functions as an open platform to buttress communications and participation, to allow practitioners of cross-functional communities to exchange opinions, formulate questions, share expertise, and discuss solutions based on the data from the real-world. Learning would be conceptualized as a collective achievement mediated by the tools.

The aim of proposing an interface here is not to provide a detailed panacea but to inspire the design directions and reflect the role of mediating tools: how it can be beyond the traditional concept of supporting "information processing". Tools can be used to support collaborative learning among the distributed communities of practice.

The dynamism of learning and practice suggests that the relationship between practice and interaction design is mutually sustained [33]. Practice is not only an output of a certain design but also an input for interaction design [70]. Interaction design is thus framed as 'a process that is arranged within existing resource constraints to create, shape and decide all use-oriented qualities of a digital artefact for one or many clients' on a human-artefact level [71], or conceptualized as 'shaping a communication space' [72]. Interaction design is more than embodying human-machine engagement. With the emphasis on the collective aspect of learning and distributed cognition, a collaborative learning support tool could be an opportunity to chart a path towards the goal of ameliorating collaborations between bridge and engine department on EE. The study results suggest that the emerging paradigm, Computer Support for Collaborative Learning (CSCL) [73, 74], is increasingly important.

#### 6.2.3 *Organisational support and technology in a socio-technical system*

Time constraints along with the system complexity and technical challenges were mentioned in the focus group studies as prominent challenges. Participants may have motivations to communicate, learn and share but such practices are currently not supported by the company's operational guidelines or codes. The collected EE performance data were not evaluated by the company. This actually echoes with many previously identified gaps in the shore-based management [6, 7, 18, 45] etc. Here we employed a holistic perspective to understand the complex socio-technical system in shipping [47].

Today's work demands onboard ships have dramatically changed over time with more technological artefacts being introduced onboard; at the same time the operational tasks becoming unprecedentedly complex [75, 76]. It is increasingly requiring the ship's crew at the sharp-end to communicate and learn in apprentice-like forms, in actions and practice, to improve EE [55]. The major problem with the shipping organisations is that the management do not have sufficient knowledge, information or an effective monitoring mechanism regarding EE performance, thus the considerations generated at the sharp-end would be rarely taken into account in organisational decision making processes [7]. On the other hand, more artificial intelligence (AI) applications have been developed in the shipping domain, having great potential impact on knowledge creation, conventional operations and whole industry [77, 78].

Johnson and Andersson [7] suggest that a solution for the shipping companies to address the organisational barriers could be the establishment of "best practices". We would contend that this process must take the impact of mediating technologies into account and discuss how it can be integrated into a broader collaborative paradigm emerging between the sharp-end (i.e. the ship's crew) and blunt-end (the management or larger regulatory bodies). If advanced data-driven intelligence can effectively monitor the EE performance and resolve the issues of information asymmetry, then it is likely going to provide a means to shape the communication space between ship and shore and enable a bottom-up approach for energy management. The bottom-up approach would be valuable for the organisation to learn the process of adopting new measures for EE and address the knowledge gaps in organizational decision making process [18]. The value of the "best practice" approach might be limited without considering knowledge mobilisation across the whole organisation, e.g. how to evolve the informal and tacit knowledge sharing onboard to institutionalized form of knowledge.

A profound understanding on the human element about energy efficient operations should be multi-layered and intertwined with sociotechnical perspectives [18]. It is critical to employ a holistic view that technology is not isolated from the context in which it gets used [61]. This is even more important when considering the data-driven intelligence has potentials to change the fundamental ways of how organizations make decisions [79]. A collaborative synergy between engineers and navigators, between practitioners and management, mediated by technology, is emerging in the EE business of the shipping industry. A long vision is to find a way to maximize the joint efforts of the whole system in the human-machine reconfigurations. It will certainly raise more important questions of how intellectual assets are developed and maintained in the intertwined relationship between advanced automations and human workers, and how to find a common ground to situate practitioners, management and advanced technologies in a system-wide 'collaborative work'. Such questions are vital to address the maritime EE challenges and human factors concern. The design-based research and development should take a sociotechnical stance to obtain a deepened understanding of the essential role of technologies that work closely with the workers, for the workers, by the workers.

## 7 CONCLUSIONS

Previous research has identified various barriers concerning maritime EE, but too little research exists to provide understanding of inter-departmental collaboration in the EE context, the role of tool mediation, collaborative learning and management practices. The research on practitioners' demands, activities and design considerations in the EE domain is rather scarce. The practitioners' demand and requirements on the EE monitoring system plays a pivotal role to connect the theoretical exploitation and practical design implications. This paper has explored how the end-users' needs with regard to the EE monitoring system can inform knowledge sharing and interaction design. Informed by the users' requirements, this paper uncovers the social underpinnings of their situated work and identifies that knowledge sharing for a mutual understanding onboard ships is critical to energy efficiency. The practitioners' collaborative practice and system requirements are positioned within the social-cultural perspectives, which informs new opportunities for interaction design and management practices. The findings reveal that learning onboard ships in the EE context is a collective and collaborative achievement, forming a collaborative learning synergy via mediating technologies. This builds us a basis to understand the role of technology mediation and its potential values in collaborative learning, knowledge mobilisation and organizational decision-making processes. With more intelligent systems introduced to the shipping industry, it is important to concern the social-cultural dimensions important to establishing a common ground between practitioners, management and advanced technologies. Thus, this study might also shape a basis to discuss human-computer interaction discipline with a wider scope in the future.


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