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The shift toward autonomous European inland waterway shipping: Identifying the gaps in the emerging socio-technical system

R Saha[1], M Lundh[2], S N MacKinnon[3]
[1] Doctoral student, [2] Associate Professor, [3] Full Professor; Department of Mechanics and Maritime Sciences, Chalmers University of Technology, Gothenburg, Sweden.

Corresponding author: Rana.Saha@Chalmers.se

Abstract. The introduction of automated solutions for inland waterways shipping supports the European vision for a sustainable and greener shift within maritime management and logistics. Despite increasing investments, impressive technological advancements, and active discussion to solve the regulatory and business model barriers, socio-technical aspects are still less studied in the preparation for the future of autonomous shipping. This study examines stakeholder and technology roles to map the gaps and challenges created in this emerging space using a system theory approach, specifically a recently developed work design system analysis tool named Change Agent Infrastructure (CHAI) analysis [1]. This framework was chosen to better understand the likely changes of the system with the introduction of automated technology and higher degrees of automation and digitalization in the European inland waterways. The analysis identifies that there are multiple receivers of the change and regulatory bodies will also be actors with considerable responsibilities to direct these changes.

Keywords: Autonomous ships, Inland waterways, Socio-technical system, Actor network

1. Background

More than 37000 km of inland waterways (IWW) connect European cities and industrial regions. Inland waterway transport (IWT) remains an efficient, cost effective, reliable, and low emission mode of transport, especially in the hinterlands remote from large European ports located in Belgium, the Netherlands, and Germany [2]. The European Union (EU) green deal, described within the 'Sustainable and Smart Mobility strategy', provides guidance towards a 90% reduction of Green House Gas (GHG) emissions within the transportation sector - including the availability of commercial zero emission vessels by 2030 [3]. The EU green deal further aims to increase IWW and Short Sea Shipping (SSS) transport by 25% by 2030 and by 50% by 2050 compared to 2015 benchmarks [3]. This has led to the EC increasing its research funding envelopes for projects on technological innovation in this domain [4].

While there is an increase in research and innovation, the socio-technical aspects have not drawn sufficient attention in Autonomous shipping research. This may be due to incorrect perceptions that automation is purely a technology-centric challenge. When we think about autonomy and autonomous systems in general, we often consider them as a 'widely independent and self-sufficient' system that takes care of itself. In fact, the word 'autonomous' means 'having the freedom to govern itself or control its own affair'. While increasing levels of automation and the influences of artificial intelligence may reduce the need for direct human engagement in various operational functions, it is unlikely that the human will completely disappear within the concepts of operations, rather human roles and functions within the system will evolve.

This study is intended to review the existing socio-technical system (STS) within European inland waterways to identify the gaps and challenges with the possible intervention of automation and digitalization within the system. The work reviewed the existing STS within European IWW to define who are the stakeholders as they are interacting within the current STS using mostly conventional control systems in fully manned conditions. Eventually, with a conceptual framework analysis, the paper will present the potential changes of these systems with the introduction of higher degrees of automation and automated technologies into the European IWT system.

2. Complex Socio-Technical Systems

An STS builds upon the strategy of considering both 'social' and 'technical' aspects to understand and improve the system for achieving optimized performances. The STS deals with both codified artefacts and tacit work processes i.e., software, hardware, and humans. Here, technical component(s) work together with the human elements to achieve a common goal. Historically, shipping is a complex system with several inter-dependencies both internal (controllable such as speed, stability, etc.) and external (uncontrollable such as weather, delays in the hinterland, etc.) factors. Inland shipping itself is a more complex system compared to ocean shipping in terms of actor engagements, time consistency, waterway complexity, as example. Furthermore, inland waterways are characterized by further challenges such as decentralized governance, heavy reliance on limited collective resources e.g., shared terminals or limited navigational channels, a highly interdependent network of transactional relationships, and susceptibility to both natural and manmade hazards and disruptions [5]. With the introduction of disruptive systems e.g., autonomous shipping, it will acquire another dimension and the industry needs to prepare to manage foreseeable and unforeseeable impacts due to these disruptions.

The basis of this study is that IWT systems can be considered as a complex STS where Human Machine Interactions are significant in operations. Where different operators and regulators (amongst others) are the humans, and the machines are the vessels, channels, port facilities, communication, safety features/equipment etc. [5]. Humans and machines interact as ¨actors¨ and ¨tools¨ within this system. Actors can be different operators such as skippers, barge owners, VTS and port operators, port agents, cargo agents and so on. On the other hand, tools are the systems that accommodate and facilitate the actors such as the Barge or the port systems. All of these interact with each other to enable the STS to function effectively.

3. CHAI analysis and findings

To visualise the change in actors' roles with the introduction of 'Automation and Digitalization' in the collaborative STS of IWT, a CHAI analysis has been carried out [1]. It's a procedural stepwise analysis process to analyse human factors integration of intervention in any work design system from the stakeholder's perspectives [1] introduced by [6]. An overview of CHAI analysis is presented in *Figure 1*.

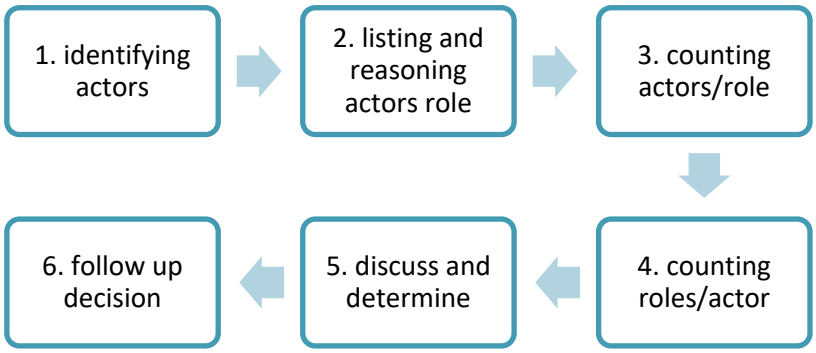

Figure 1: procedural steps of CHAI analysis.

Table 1: CHAI analysis of 'Intervention of Automation and Digitalization'.

ACTORS	Initiators	Sponsors	Convincers	Change Owners	Subjects / Receivers	Blockers	Solution builders	Documenters
shipowner		investor				for now: they are less interested to move for the changes		
technology developers							main backhand of the change. Develop, test, and verify the reliability of the changes	
regulatory bodies	talking with the stakeholders and outside	they may not be involved actively always		can enable it at a national/international level		they are pretty slow to allow/amend the change		document handler
crew/ skipper					have to deal with it /changes due to it have to adapt their work culture in some degree			
port operators (agents)								
port authority								document/ data handler
suppliers					have to adapt their work culture in some degree			
society (the people)		demand sustainable water in their locality						
researcher	studying and engaging the society		providing findings of their works					
insurance company				can legitimate it within their mandates				
company (personnel)					have to adapt their work culture in some degree			

Stepwise processes followed for this study to analyse the impact of 'Intervention of Automation and digitalization' are detailed below:

The process begins with identifying the stakeholders (actors) who are part of the system (step 1). In *Table 1*, we identified the actors in the left-hand column. The cells stating different roles by different actors' roles and relationships with the intervention are then populated. Actor Network Theory (ANT) [7] which also forms the basis of the CHAI analysis [1], has been used to list the actors initially. Then using unstructured interviews discussed the actors list with 5 expert academicians within nautical science domain where a minimum of 4 of them have either a sailing background or more than 20 years of experience. The face-to-face discussion opened up with the initially listed actors' network as a mind map showing how they are interacting in the current IWW STS to verify the list. And the list was revised accordingly to contextualise CHAI actors within the IWW shipping domain. Once actors are listed in the left-hand column, the cells are populated with logical statements (step 2).

Quantification occurred once the table was populated (steps 3 & 4). This began with a counting of actors per role to investigate if any role is populated by several actors. This also identified if any role was not assumed by any actor. In our analysis, the role of 'subject/receiver' is populated by four different actors. The next quantification was counting the roles per actor. This is to investigate if there are several roles by a single actor or if any actor remained assigned no role within the proposed system. An actor with many roles may indicate possible conflicts of interest, time, and resource limitations. For example, in our analysis, the actor 'regulatory body' had five different roles.

The analysis then moved into a qualitative analysis (step 5), to determine if the current role distribution was ideal. As identified, there are two occasions of (a) several actors for a single role (subjects/receiver, Sponsor) and one occasion of (b) various roles for a single actor (regulatory body). Both issues need to be addressed to improve the IWW STS to adapt the intervention of the changes. The final part (step 6) is to determine if a follow-up analysis is necessary when in the future, increasing levels of automation (LoA) are introduced into the system. In the IWW STS, the role of the actors will likely change with the increasing introduction of new technologies, concepts of operations and increasing levels of automation and digitalization. For example, shifting from 'manned remote operation' to 'unmanned remote operation' will introduce a major shift in the STS of IWW. A follow-up analysis will be required to access/manage this change.

In summary, the CHAI analysis suggests three major findings:

a. The subject/receiver role is performed by several actors- crew, port operators, suppliers, and companies. All these actors require to coordinate to create Collaborative Decision Making (CDM) model effectively to perform their roles in the system. Another role 'Sponsor' is also performed by three different actors: the shipowner, the regulatory body, and the society. They all need to support the change.
b. 'Regulatory body' have several roles as an actor. It creates a challenge for the actors to manage time and resources which eventually restrict or slow down the changing processes of the system which we see in the current system as well. The regulatory barriers are often indicated as major obstacles to introducing new automation and digital solution. It may also raise possible conflicts of interest as well.
c. Technology keeps evolving often very first. The same is true for IWW sectors as well. With the progress of newer automated and digitalized solution the STS in IWW will keep changing which require follow-up analysis once the changes take place.

4. Discussion

4.1. Clarification is required

As indicated in the final finding *c*, the technical solutions keep changing thus the STS will also change. There is some confusion when 'autonomous shipping' is introduced to a general audience. Even within the industry, there remains considerable debate about what is a manned or unmanned state and its

relationship to the varying LoAs. In part, this confusion is catalysed by a lack of cross-industry agreement on how to define and operationalise various LoAs.

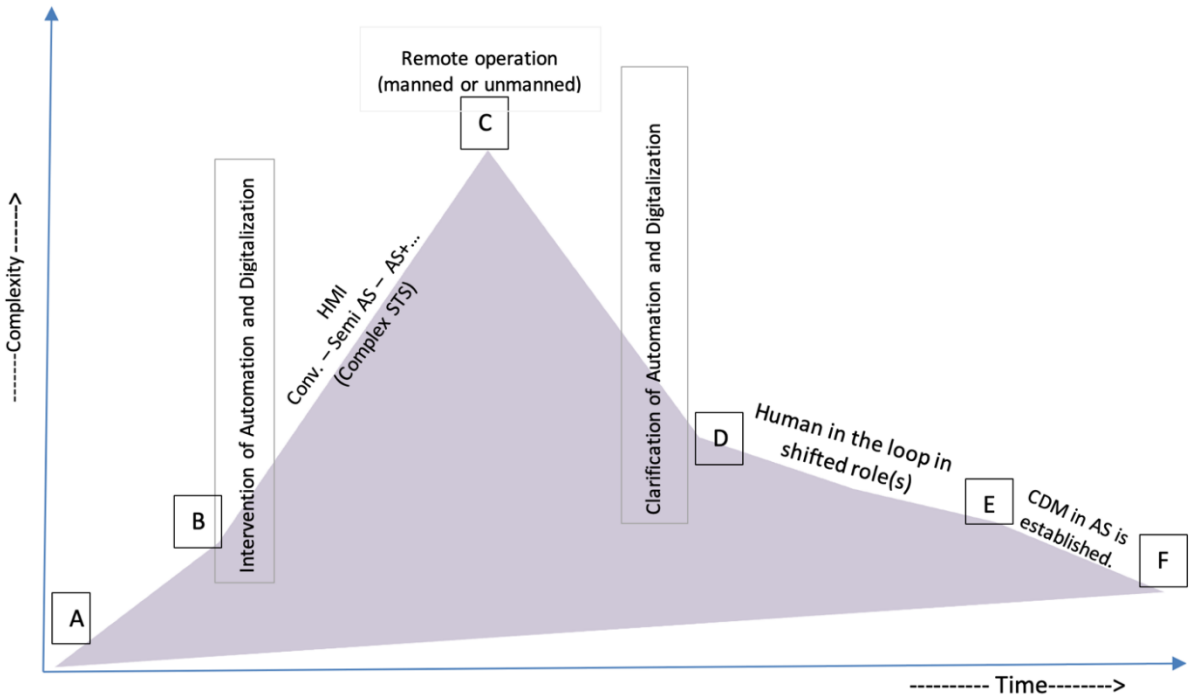

Figure 2: clarification of LoA and Digitalization within IWW STS in the foreseeable future.

In *Figure 2* we introduced 'complexity over time'. The conventional way of shipping (A) is already known to the society where a human is always present in the operational loop. However, once automation and digital solutions are introduced (B), HMI, its design and integration within the STS will start to shift. STS will evolve and *likely* become more complex, resulting in new models of operations i.e., semi-autonomous and autonomous. For the foreseeable future, there will be a blending of conventional shipping practices with vessels operating under some level of automation within the same waterways. A heterogeneous STS will prevail where the role of human may have different contexts. In complex traffic situations, it seems more prudent act will require to have the human in the loop (D) due to navigational complexity, variable independent stakeholders, and various other natural and system disruptions and hazards [5]. Moreover, In the foreseeable near future, there will not be any independent self-driven vessel, human-system interaction will still require in some degree [8]. That means, the vessel will be controlled remotely with/without human onboard. The remote/shore control centre concept is more viable here from where a remote operator will be operating/supervising/ emergency responding for the automated vessel depending on the level of autonomy embedded in the system[9]. Once clarified, it will be easier to establish common grounds for collaborative decision making (CDM) in AS (E) and getting acceptance (F) for the latest STS.

4.2. Mapping the HMI

Once the shifted human roles in the new system have been clarified, there will always be a human presence in safety critical and complex IWW STS, particularly in IWW shipping segments where civilian passengers are on board. Again, there will be an increased presence of automation, digitalization, and Artificial Intelligence (AI) within the IWW STS. Especially in the first layer of operation, with the support of the increasing presence of automation and digitalization, many tasks will be executed by

machines which are currently performed by human operators. However, automation will not replace human rather will increasingly require the human to interact with technologies [10]. Eventually, the role or functions of the human will be shifted or redefined. It's often related to the interaction and interfaces between data and information.

Table 2 details HMI and data coordination in various LoAs. There is no unified LoA for inland shipping [11]. However, there are several LoA exists given by stakeholders from different shipping segments including IWT sector e.g., CCNR, CESNI. Here, we considered the LoAs for Maritime Autonomous Surface Ship as defined by IMO [12] which synchronize with other existing LoAs [8] and therefore chosen for benchmarking purposes in Table 2. Levels 0 & 1 are already operational and thus labelled as 'work as done' [13] where we have real data/ information about concepts of operations and safety (for example). The remaining LoAs are not yet available for wider commercial operation thus labelled as 'work as imagined' where the data/information from commercial operations are not sufficient thus mostly imaginary based on current STS. As we see from the analysis in *Table 1*, the actors' roles will keep evolving with the progression through various LoAs. From a regulatory perspective, we considered international IWW shipping for the European context which often requires additional time and work compared to individual flag states who can adjust regulatory scopes for AS, even with a rapid temporary exception.

Table 2: HMI and data coordination in different LoA.

STS	LoA	Flow of data/ communication channels	Design approach	Actors (both H & M) communication	Remarks
Work as done	**0**	**H-H**	**HCD**	**VHF, sign & symbols**	**Existing long since**
	1	**H-H, H-M-H**	**HCD**	**VHF, satellite**	**existing widely**
Work as imagi-ned	2	M-H, M-H-M, H-M-M, M-M	HBD[1]	Machine to machine	Foreseeable by 2030
	Mixed traffic scenarios	TBD	TBD	Machine to VHF or Human?	Required regulatory approval
	3	M-M. M–M (H)-M(H)-M	HBD[2]	AI to AI?	Challenges: Regulation, proven and approved Technology.
	4	M-M	TBD	TBD	Challenges: Business case, Reliability, Safety and security, and so on.

M = Machine = product, artefact, virtual workplace, technical system, device, gadget etc.
H = Human = operator, regulator, agent, direct and indirect influencers etc.
TBD = To Be Decided/determined.
HCD = Human Centered Design; HBD[1] = Human Beside Design; HBD[2] = Human Behind Design.

It is important to clarify that data are processed by machines and information is processed by humans. and HMIs are the connector in between to process the data into information or vice-versa. The table further detailed the flow of data and information in different LoAs, as well as different design approaches in LoAs from a human factors perspective. Examples of various means of communication are also listed.

As the CHAI findings suggest, the actor's role will keep changing with the change in the system. It's a collective consequence which requires collaborative approaches to grip the changes in the system effectively. Actors' role analysis is the foundational work that has to be done before addressing those changes. Once the actor's role is clarified, clarification of different levels and layers is the next prerequisite to address and adapt those within the system.

5. Conclusions

Autonomous vessels, in different forms and scales, are already in the water. However, many within the industry disagree on the interactions between actors and technology and how a successful business model might be applied to exploit autonomous systems in IWWs. However, there is a strong prediction that Autonomous ships will interact with other autonomous ships as well as with conventional ships within a decade or so. Whenever we discuss autonomous shipping ecosystems, we must not take out the human completely from the loop, at least for the coming future until when a high level of autonomy is tested and available. A human will be somewhere in the loop to monitor, verify, and sometimes to perform some of the roles [14]. With the increasing presence of Artificial Intelligence (AI) and high level of autonomy in the sociotechnical applications technical system e.g., navigation systems will be assisting and collaborating with highly skilled human operators [15]. It could be similar to an aviation pilot monitoring the automated navigation in place, or a remote operator like a drone pilot controlling it from a remote location [16]. However, with the improvement and increasing reliability of the system, over time, human supervision might be reduced on a large scale and will only be required in emergencies.

Technological innovation, Machine Learning and AI, and geopolitical realities will have a profound impact on how IWW systems emerge. These disruptions are often difficult to foresee. The current model is addressing the intervention expected by foreseeable attributes based on known automation and digitalization. However, technology keeps transforming ahead very first and sometimes have some disruptive interventions such as AI which will eventually transform the attributes of the current model too. This work introduces a theoretical framework to understand the roles of actors and technologies that will have an impact on the evolution of an STS in the IWW system. However further investigation which is already planned in the next phase of this ongoing study is required to include the latest insights from the existing actors i.e., the IWW stakeholders.

6. References

[1] C. Berlin, L. Bligård, M. Babapour Chafi, and S. Eriksson, 'Development of a stakeholder identification and analysis method for human factors integration in work system design interventions–Change Agent Infrastructure', *Hum. Factors Ergon. Manuf. Serv. Ind.*, vol. 32, no. 1, pp. 151–170, 2022.
[2] C. Alias and J. Zum Felde, 'Evaluating the economic performance of a decentralized waterborne container transportation service using autonomous inland vessels', presented at the 2022 IEEE 25th International Conference on Intelligent Transportation Systems (ITSC), IEEE, 2022, pp. 3571–3576.
[3] European Commission (EC), 'Sustainable and Smart Mobility Strategy—Putting European Transport on Track for the Future', 2020.
[4] K. Gkoumas, F. L. Marques dos Santos, M. Stepniak, and F. Pekár, 'Research and Innovation Supporting the European Sustainable and Smart Mobility Strategy: A Technology Perspective from Recent European Union Projects', *Appl. Sci.*, vol. 11, no. 24, p. 11981, 2021.

[5] D. C. Amodeo, 'Empirical Study of the Role of Human Cognition in the Resilience Management of Inland Waterway Transportation Systems', 2020.
[6] C. Berlin, J. Berglund, and E. Lindskog, 'Change agent infrastructure (CHAI)—a stakeholder analysis tool for ergonomics-and work environment-related change projects', presented at the Advances in Human Factors, Business Management, Training and Education: Proceedings of the AHFE 2016 International Conference on Human Factors, Business Management and Society, July 27-31, 2016, Walt Disney World®, Florida, USA, Springer, 2017, pp. 715–726.
[7] B. Latour, *Reassembling the social: An introduction to actor-network-theory*. Oup Oxford, 2007.
[8] R. Saha, 'Mapping competence requirements for future shore control center operators', *Marit. Policy Manag.*, pp. 1–13, 2021.
[9] R. Rylander and Y. Man, 'Autonomous safety on vessels', *Lighthouse Swed. Marit. Competence Cent.*, 2016.
[10] T. B. Sheridan and R. Parasuraman, 'Human-automation interaction', *Rev. Hum. Factors Ergon.*, vol. 1, no. 1, pp. 89–129, 2005.
[11] W. Nzengu, J. Faivre, A.-S. Pauwelyn, V. Bolbot, L. A. Lien Wennersberg, and G. Theotokatos, 'Regulatory framework analysis for the unmanned inland waterway vessel', *WMU J. Marit. Aff.*, vol. 20, no. 3, pp. 357–376, 2021.
[12] IMO, 'IMO takes first steps to address autonomous ships.', May 2018. [Online]. Available: http://www.imo.org/en/MediaCentre/PressBriefings/Pages/08-MSC-99-MASS-scoping.aspx
[13] K. Aylward, 'Automated functions: Their potential for impact upon maritime sociotechnical systems', 2020.
[14] E. Veitch and O. A. Alsos, 'A systematic review of human-AI interaction in autonomous ship systems', *Saf. Sci.*, vol. 152, p. 105778, 2022.
[15] E. Veitch, H. Dybvik, M. Steinert, and O. A. Alsos, 'Collaborative Work with Highly Automated Marine Navigation Systems', *Comput. Support. Coop. Work CSCW*, pp. 1–32, 2022.
[16] R. R. Negenborn *et al.*, 'Autonomous ships are on the horizon: here's what we need to know', *Nature*, vol. 615, no. 7950, pp. 30–33, 2023.

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