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Assisting anomaly detection in maritime shore-based operator work

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This article reports findings from a study on risk identification and mitigation in maritime traffic information services. A human-centered design approach has been employed to develop and evaluate a concept on support for shore-based operators, in the task of providing timely and necessary information to ensure safe movements and mitigate the risk of a collision or grounding. Asa first step, an analysis of incident reports from 2016-2019 was conducted. Further, one online and one onsite workshop with Vessel Traffic Service (VTS) operators were held to explore how experts identify, classify and act upon information available within the current system. In the concept development phase, two specific scenarios (grounding, collision) were used to discuss what an automation could potentially act upon and how the information should be communicated to the shore-based operator. In the final step, the concept was evaluated within a demonstrator workstation setup. Four shore-based operators participated in the evaluation. They thought that the concept generated meaningful suggestions for risk mitigation, which could be used to generate a wider timeframe for an operator to act. However, the operators also raised concerns regarding responsibility, communication needs and the ability to understand what an automation basis its assessment on. Overall, while the support in anomaly detection and the identification of risk mitigating measures is appreciated, a refinement of the current concept is needed to become meaningful in the eyes of the operator.

Keywords: Vessel Traffic Service (VTS), human-automation teaming, human-centered design, risk identification

1. Introduction

On July 23, 2018, at 07:21 the car carrier MAKASSAR HIGHWAY bound for Södertälje grounded outside of Västervik after a change of course deviating from her voyage plan. At the time of the accident, the Officer of the Watch (OOW) was alone on the bridge, and the investigation concluded that he was disoriented and to some extent incapacitated to conduct the vessel safely. The grounding was discovered by the Vessel Traffic Service (VTS) in Södertälje that contacted the Joint Rescue Coordination Center (JRCC) about the vessel which appeared to be laying still (SHK 2019).

This incident shows a crucial part of how coastal authorities and services react in the case of an incident. The VTS noticed an unusual traffic situation outside of the service's area of responsibility and alarmed the JRCC. The JRCC operator contacted the vessel to confirm the grounding. Once confirmed, the Coast Guard, the Swedish Sea Rescue Society and other authorities were contacted and to dispatch units and organize the rescue mission (SHK, 2019).

While the reaction towards the unanticipated adverse event was timely conducted and well-organized, a question remains on whether this had been preventable, if the deviation from the voyage plan had been identified early by the shore-based services.

The Swedish coastline stretches along 3218 km, but only approximately 10% of this area are monitored by either a Ship Reporting System (SRS) or Vessel Traffic Service (VTS), services to support navigation in area with high traffic loads, navigational challenges, and in the proximity to ports. Thus, this study explores whether unsupervised areas alongside the coastline can be monitored by advanced automation to detect deviations in the traffic picture and identify potential risks early so that shore-based service operators can mitigate adverse events.

The aim of this study has been to evaluate a concept for automatic traffic surveillance alongside the Swedish coast, the AUTOMON-concept. AUTOMON was a national research project (2019-2021) funded by the Swedish Transport Agency exploring how artificial intelligence can be utilized to enhance the traffic monitoring in unsupervised areas alongside the Swedish coastline.

2. Background

Vessel Traffic Service (VTS) is a service provided to the merchant fleet in proximity to ports and other areas which require complex navigation with the aim to monitor and manage traffic safely (IALA, 2024). VTS is an advisory service, i.e. the responsibility for safe navigation remains with the Master of a vessel. VTS is provided by VTS operators (VTSOs) on the VHF radio. The VTSOs transmit information to one or more vessels to promote safe, fluent and efficient traffic movements within their area of responsibility, the VTS area. Within this area, the VTSOs monitor traffic movements and patterns and work proactively by contacting vessels that behave in an unexpected and potentially risky way, e.g. when deviating from what is considered as normal behavior (Lundberg et al., 2024).

Previous research studying shore-based services has primarily focused on human-centered design of specific decision support tools, exploring operator work through qualitative inquiry, and studied traffic management and resilience within the VTS domain. (Brodje et al., 2013) and (Costa, Lundh, & MacKinnon, 2018) explored how operators monitor and identify cues within VHF communication as trigger for interacting with traffic. Similar findings are presented in(Praetorius & Hollnagel, 2014) who identified that safety and resilience are actively created on a system level by how the VTSOs monitor the traffic movements and create foresight and predictability through transmitting information to the vessels. (Aylward et al. 2020) studied the effect of automation on operator decision making and found that low-level automation made work more proactive and was more beneficial at lower traffic densities but offered less support in time-critical situations. These findings also support the work conducted by (Costa, Lundh, & Mackinnon 2018) who found that additional information available through e-navigation services may not always have a positive effect on safety and system performance but may rather introduce uncertainty into the interaction between ship and shore actors.

Therefore, means and measures to successfully support traffic monitoring and anomaly detection need to consider how operators in shore-side services work, what information they use to identify deviations, and what timing aspects affect their decision to intervene within a developing situation.

3. Methodology

This study has been based on a human-centered design (HCD) approach (ISO, 2019). The research team closely collaborated with domain experts to develop a concept for automated anomaly detection iteratively.

3.1. Incident analysis

To identify potential scenarios for operator and design workshops, incidents in Swedish waters between 2016 and 2019 were analyzed. Information about reported incidents from the Swedish Maritime Administration and Sweden Transport Agency were compiled and sorted by one domain expert and one researcher. The dataset included a total of reported 759 incidents, including personal accidents, groundings and collisions. In a first step, all personal accidents, as well as incidents involving vessels less than 300 GRT or 50m of lengths were excluded. Further, based on the information available about the event, all adverse events caused by technological or equipment failures, such as blackouts, as well as if the vessel collided with a non-visual floating object, were excluded based on the assumption that even if identified by an automation, an operator would not likely be able to inform the vessel in time to allow for the bridge team to take appropriate action to prevent their occurrence. 35 groundings and 5 collisions remained of the initial dataset. These were analyzed guided by when the event was detectable, what information available about the event could potentially have been useful for either the automation or an operator, and finally, how this information could have been used for early detection. However, only in four cases, which had officially been investigated by the Accident Investigation Board sufficient information for the analysis was available.

3.2. Operator workshops

Based on the incident analysis, two expert workshops with VTSOs were held, one in person and one online. The workshops were designed as focus group interviews (Patton, 2014) with the aim of gaining insights about traffic monitoring and anomaly detection within shore-based operator work.

The first workshop was held at a VTS centre. Four VTS operators (VTSOs) and one VTS manager participated. The workshop was moderated by a VTS expert who used recordings from incidents as a trigger for discussions. During the first session, three incident recordings served as means for discussing visual cues in anomaly detection. The second session used audio recordings from 3 incidents to explore what auditive cues operators react to. The third part of the workshop focused on means of contact, i.e. once an anomaly has been detected, when and how do VTSOs contact the vessel, as well as what is the message that they transmit.

The second operator workshop was held online on Zoom and focused on a single fictive scenario recreating the voyage of a vessel with an grounding as at the end of the scenario. Screenshots from a simulator were used to structure the discussion. The aim was to continue exploring how, when and in what way an automatic anomaly detection could support the work of shore-based operators. Three researchers, one VTS expert and two VTSOs participated in the online workshop.

Both workshops were audio-recorded and fieldnotes were taken to complement the recordings. The recordings were partially described verbatim for the analysis.

3.3. Design workshops

Two design workshops with an expert group consisting of one navigational expert (former master mariner), one VTS expert (former VTSO) and three senior researchers with expertise in human factors, interaction design and cognitive systems engineering were conducted.

The workshops used two distinct recorded scenarios, one grounding (SHK 2019) and one collision (MAIB 2021), to discuss the overall functionality of the automation and ways in which an anomaly could be detected during automated traffic monitoring. It was also discussed how the automation should contact the VTS or other potential shore actors, such as Sweden Traffic, a service overseeing traffic separation schemes in Swedish waters.

The scenarios, which were based on real life events, were recreated in the simulator and recorded. The screen recordings served as a design artefact (Dordlofva & Törlind 2020; Johnson et al. 2017) to discuss how the automation could potentially support and interact with a shore-based operator.

3.4 Evaluation

Based on the previous series of workshops, a Wizard of Oz simulation (Benyon et al., 2005) was created to evaluate the AUTOMON concept. Four experts working as shore-based operators from two different centers and services participated in the evaluation. Three of the four had previously participated in the operator workshops.

3.4.1 AUTOMON Workstation

The AUTOMON workstation consisted of three screens, a keyboard and a mouse (fig 1).

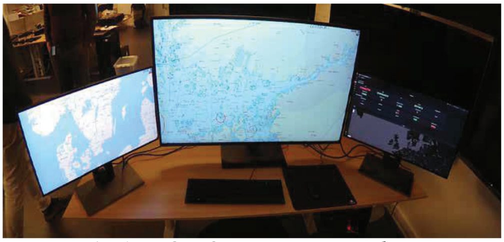

Figure 1: AUTOMON-operator workstation

The operator was seated in front of the workstation. The screen to the left provided an overview of the Swedish coastline showing the current traffic movements of vessels based on real-time data (AIS). Vessels were presented with labels displaying their names (fig2). In this overview display, it was possible to zoom in and out in areas of interest to observe traffic movements in specific areas or follow-up on an event.

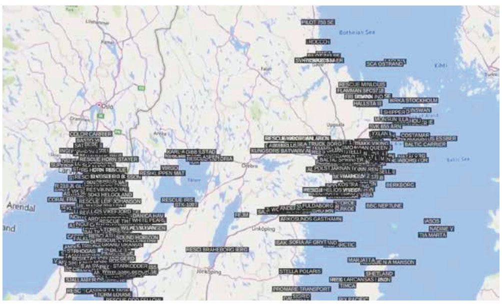

Figure 2: Display presenting all current traffic in Swedish waters. Vessels are displayed by vessel name on a black label

An electronic sea chart was displayed in the center of the workstation, where the operator could choose to inspect the geographical area, in which the anomaly has been detected. The anomaly was presented as textbox including a suggested conflict solution (fig 3)

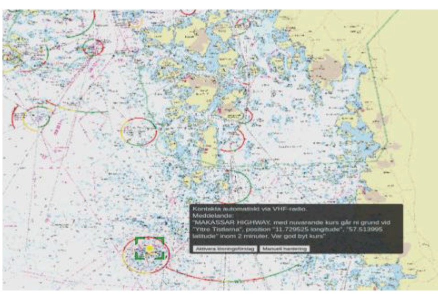

Figure 3: Electronic chart with highlighted anomaly.

To the right in the workstation, a dashboard with detailed vessel information, such as IMO number, callsign, speed, draught, direction and size, was available to support the operator's decision making.

3.4.2 Procedure

The evaluation consisted of three parts. First, a demonstration of the system's capabilities through two short scenarios, second, an individual debriefing and short interview, and third, a group debriefing.

The demonstration of the AUTOMON-concept was conducted in a simulator laboratory. Two short scenarios, one grounding and one collision, were created and were displayed in the system. The scenarios were controlled from a station located in the same room. After a short familiarization with the workstation and the system setup, the simulation started. Throughout the simulation, the participant was asked to think aloud. The first scenario during the simulation was the grounding. It occurred within 2 minutes after the simulation had started. The label on the sea chart indicated the location of the deviation and a suggested solution. The operator had the option to interact with the system in an attempt to prevent a negative outcome. The same procedure was followed during the collision scenario. In total, each simulator session lasted for about 20 minutes and was followed by an individual debrief and short interview about the participant's perception of the system, the HMI and potential strengths and weaknesses of the developed concept.

The individual sessions were followed by 45 minutes of group discussions where the experts had an opportunity to share experiences and perceptions. These were noted down at a whiteboard and grouped through a moderated discussion.

The simulations were video recorded, while both individual and group debrief were audio recorded. The recordings were transcribed verbatim.

4. Results

4.1 Incident analysis

The incident analysis showed that early information to a shore-based service would likely have influenced the timing of when a deviation or risk would have been identified. Providing information on deviations and potential risks early enhances an operator's available time to react and the ability to make an informed choice of action on whether, or not, to intervene in a developing situation. It would also allow the operator to provide essential information earlier to the vessels, which would likely prevent, as pointed out in two of the reports, a lack of information provided to the vessels, or lack of taking action from the shore-based operator as contributing factors to an incident (SHK, 2010, 2017). In both cases, information on deviations was available, but not utilized in a timely manner. Two of the studied incidents also raised a question about how to handle situations outside of the own area of responsibility. As an example, in the case of the MAKASSAR HIGHWAY (SHK, 2019), it was the operator who activated the response after having identified an unusual vessel position and movement within his system, but still outside of his formal responsibility.

4.2 Operator workshops

The operator workshops used the results of the incident analysis to further explore aspects of information, timing and interaction within the VTS domain.

The VTSOs identified vectors indicating course and speed as essential sources to detect deviations. Further, whether a vessel's speed is deviating from what is to be expected based on size and type, as well as AIS information and position in the fairway are used to follow traffic patterns and identify risks and deviations. Further, verbal cues in the VHF contact are important for the decision on how to act in a situation. Specifically, not using closed-loop communication, miscommunication between two vessels when making an agreement, and slow or unclear communication were identified as warning signs. With regards to means of communication, it was stressed that VHF and DSC are preferred in risky situations. However, if a message is sent to a vessel, it should be clear and standardized and if outside a VTS area, it should not be transmitted by the VTS, but by another actor.

4.3 Design workshops

The design workshops focused on the capabilities of the automation and what type of anomaly detection would be feasible and meaningful to implement as operator support. The automation should be capable of identifying if a vessel is deviating from her own voyage plan. This may include to turn, or not to turn in some cases, as expected. Furthermore, anomaly detection also needs to identify deviations from the expected traffic flow and patterns, i.e. for a given vessel of a given size, unanticipated changes in course and speed not corresponding for how traffic at large, and this type of vessel in specific, normally flows. Further, based on historical data, it should also be possible to detect if a given deviation is something that occurs routinely, i.e. while there is an increased risk, it is part of normal operations for a specific vessel.

Additionally, the workshops also discussed whether, and if so what type, of suggestions for conflict resolutions or other action should be provided with information on an identified anomaly. Based on the assumption that sometimes time to react is short, a suggested action could provide additional decision support and help the operator to understand the situation and decide upon a course of action.

4.4 Concept evaluation

Overall, the operators were positive towards the concept of anomaly detection and automated traffic monitoring as decision support. As this evaluation targeted the concept as such, the HMI had not been fully developed, yet, which triggered comments on how the workstation was organized and how information on the interface was presented and assessable in comparison to a normal shore service station. Furthermore, the operators also commented on the lengths of the scenarios which were experienced as too short, that time to familiarize themselves with the system had been too limited and that it would have been of benefit to have normal traffic flows before the incident. These considerations were noted for future iterations of the concept.

4.4.1 Suggested solutions

The experts' perceptions about the suggested solutions were positive, but they felt that the information was very short-handed and would not be of a lot of assistance for the vessels involved. If a transmission is made to prevent an incident, the message needs to be short, concise and accurate as there is otherwise a risk that it worsens the situation rather than improving it. The time-horizon to consider for suggestions towards operator and traffic should rather be on 10-15 minutes than 2 minutes frame (as in the simulation), as a suggested solution is only a part of how to resolve a developing situation. If transmitted, it also needs to be followed up, i.e. the operators need to see whether the vessel(s) receive the information and act on it.

"If it is four in the morning and I am tired and the crew is tired, then it might be very good to get this call out while I use the time to formulate my own call" (Operator 1)

However, the operators still felt that this type of information may be positive especially as it can be used as a means to create more time for the operator to understand the problem and find a suitable solution for the situation.

4.4.2 Trust and transparency

To be able to effectively use this type of system, it is important to understand how the automation has identified an anomaly and what information the suggested solutions are based on. This is a necessity to be able to judge whether this solution is appropriate for the problem at hand, or whether there are other and more suitable possibilities to resolve the situation. Especially as this concept addresses areas that are beyond the responsibility of a VTS, it is essential to be able to track information to gain a thorough understanding of what is happening. Suggested means from the operators included voice traces and time-sliding so that it would be possible to follow what happened before the anomaly was detected by the automation.

4.4.3 Operator role and competences

Another line of discussions addressed the current operator role, necessary competences and the legal mandate that would be required to effectively implement this concept.

Currently VTSOs are only responsible for monitoring and informing the traffic in a determined area. If there are alarms outside of the area that are provided by the automated monitoring system, it would require a thorough geographical knowledge to be able to quickly understand the situation and act to prevent a collision or grounding. It would also require set rules on what work to prioritize, i.e. should the VTSO leave the monitoring of the VTS area while taking care of the deviation? What would happen in case of an alarm outside the VTS area, while there is also a situation to act upon within the own area of responsibility? These were some of the questions raised during the discussion.

Further, the operators also felt that there would be a risk of changing the overall relationship between shore-based services and vessel traffic. Currently, information is provided proactively, i.e. all information that vessel needs ahead to be safely navigated. In case of the AUTOMON-concept, the operators are set into a rather reactive role as the identified anomaly is the trigger for the interaction. Figures are to be inserted into the text nearest its first reference. The text in the figures should be large enough so that the text is reasonably readable. Authors are advised that all photographs will be finally reproduced in grayscale/black and white.

5. Discussion

In the current maritime transport system (MTS) only areas in proximity to ports or areas that are challenging to navigate, e.g. due to certain geographical features or high traffic density, are actively monitored by the VTS or SRS services. The AUTOMON concept for automated traffic monitoring and anomaly detection aims to support shore-based services in the early identification of potential risks and suggest suitable mitigation measures. However, the results of this study show that while supporting shore operators to some extent, the concept will also inevitably change the relationship between ship and shore.

Today's MTS is designed as distributed, or polycentric, system (van Westrenen & Praetorius 2012) in which only few areas are monitored by shore services. While these services provide information supporting safe navigation, the responsibility for the safe conduct remains with the master of a vessel. By introducing an automated monitoring system, a need to identify and define who will receive the information from such a system and what should be done with it arises. The experts in this study highlighted the benefit of such support as it may create a larger time horizon to make decisions about how to intervene in the case of an anomaly, but at the same time raised concerns that the suggested solutions required vessels to follow instructions from shore, i.e. actively imposing control. Furthermore, the participants also stressed that, to be able to understand a situation fully and act upon it, geographical knowledge would be required to ensure safe advice in the interventions.

This may be interpreted as the need to be able to understand, interpret and organize the information at hand to quickly being able to assess constraints and judge the suggested solution. Van Westrenen and Praetorius (2012) argue that situation awareness in the VTS domain is actively built by VTS operators through how they organize and structure the available information. In the case of the current system iteration, this has not fully been considered. Further, it was also discussed how much details about what happened before the anomaly was detected would be needed to understand the situation at hand and identify a potential conflict resolution.

The experts additionally stressed that the character of the service may change from being proactive to reactive if operators are bound to act on information rather than actively seeking and identifying anomalies and deviations themselves. Thus, it is important to further explore how automated anomaly detection outside of a VTS area can be integrated into the present cluster of services (marine traffic services, VTS, SRS and JRCC) and to whom the information should be provided in different stages during a developing incident.

Further, as VTSOs still prefer using VHF communication over automated message transmissions, it is also important to consider how, what and when suggestions for solutions of a given problem are presented, especially if these contain a direct message to the vessel(s) involved. In addition, it was highlighted that it is also necessary to include the design of a feedback loop from ship to shore to ensure that necessary information has been received and will be acted upon. The experts referred to the need for closed loop communication if an automated monitoring system is to support their work.

5.1 Limitations and future work

This article presented findings from the first iteration of the concept. The design was developed through a series of workshops to which experts were recruited through opportunistic sampling. This may have impacted on the design solutions for the automated monitoring system.

The scenarios developed during this first iteration were based on an incident analysis focused on groundings and collisions. In future iterations, it would be possible to widen the scope for anomaly detection. This could potentially be based on a wider analysis, such as considering near misses and reported security breaches alongside the coastline.

Further, the evaluation was conducted through two short scenarios with limited time for the operators to become familiar with the system and the workstation. The interaction was further limited by the chosen Wizard of Oz-technique. One option for future evaluations is a more stringent experimental design to explore how operator work is affected with regards to potential increases in workload, effects on the operators' situation awareness, and timing aspects in the interaction between automation and operators. Another option is to introduce an experimental test station for operators, to fine-tune and assess the concepts by working with real-time or historical maritime data.

The current iteration was concept focused, which meant that certain design features in the HMI and the layout of the workstation were distinctly different from normal shore-based stations thus decreasing the ecological validity of the evaluation. However, the feedback gained from the experts will be integrated into future system iterations.

6. Conclusions

This article has presented findings from the development of a concept for automated monitoring alongside the Swedish coast. The study shows that automated monitoring and detection is an important and promising step, but that several issues then follows, to bring the concept further toward operational use. Our main conclusion is that the concept would effectively change both the role of the operator, the legal mandate and the relationship between ship and shore side within the maritime transport system. The study also resulted in several areas of concept refinement. Primarily, to achieve an operational "picture" of the situation, including details of perhaps unfamiliar waters, to be able to intervene. Ideas for this such as an interactive timeline were brought up but must also be assessed in future studies.

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