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Investigation of Statutory and Class society Based Requirements for Electronic Lookout

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Novel advanced systems, employing information and communication technology, are emerging. An example of such a system is the electronic lookout (e-lookout), which functions as the visual lookout performed by humans on ships. In this paper, we investigated what types of requirements may arise for e-lookout based on an analysis of statutory documents and existing class society guidelines for autonomous ships. To this end, first, we identified e-lookout functions based on a functional breakdown, considering both existing maritime function classifications as well as experts' opinion. Second, we investigated the class society guidelines for autonomous ships concerning e-lookout and the applicability of existing regulatory requirements for conventional human lookout including those specified by STCW, COLREGS, and SOLAS. Considering the existing regulatory requirements for lookout, we proposed alternative equivalent requirements for e-lookout. Specifically, based on the analysis, we specified seventeen novel requirements for functionality, reliability, availability, maintainability, and safety. It is expected that the analysis implemented, and methodology presented will support the development of an appropriate regulatory framework for e-lookout and autonomous ships.

Keywords: Autonomous Ships, Electronic lookout, Functions, Requirements, Safety, Goal-based Standards, Regulatory scoping exercise.

1. Introduction

Autonomous Ships (AS) are on the horizon, yet the progress on the amendments required to enable such ships is rather slow (Negenborn et al. 2023). A potential way to accelerate the AS adoption is by focusing on the Key Enabling Technologies (KET) for AS, by following the classical "divide and conquer" approach (Machiavelli 1521). Some of the AS' KET can

be applied in low automation degree AS with humans present where their challenges are relatively easy to be tackled. After several simple KET challenges have been addressed, the requirements for more complex and automated ship operations and potential integration issues can be investigated further.

An example of such a relatively simple KET is the electronic lookout (e-lookout) (Tervo and Lehtovaara 2021). The e-lookout can effectively replace significant subset of navigational safety-related lookout functions currently implemented by the bridge officers using advanced sensory systems and algorithms for the detection and recognition of safety-related navigational objects. The development of e-lookout is a prerequisite for AS since it will provide safety critical information to collision avoidance system and remote-control center (Bruhn et al. 2014). Yet, it could also be applied in conventional ships with rather few modifications (Tervo and Lehtovaara 2021).

As an outcome of the Regulatory Scoping Exercise (RSE) at International Maritime Organization (IMO 2021), three main identified strategies for developing AS requirements have been specified. The first is the development of requirements considering equivalence to existing regulatory instruments, the second approach incorporates amending the existing instruments and in the third one, novel regulatory instruments will be developed. Modification of the instruments has been proposed for low-level automation functions implemented in navigation in the RSE.

As another outcome of the RSE, the use of Goal-Based Standards (GBS) (IMO 2019) has been also proposed for the development of the requirements for AS and AS KETs. The GBS starts from the high-level goals (Tier I) and progresses towards the functional requirements (Tier II) using Risk Assessment (RA). After the verification of the RA (Tier III), the requirements should be crosschecked with existing class societies' rules and regulations (Tier III and IV) and industry standards (Tier V) and if these rules, regulations, and standards are applicable, they can be used for the development of novel requirements for AS KET's.

Despite the examples provided in the GBS circular (IMO 2019) and the relevant publications (Bergström et al. 2018; Heikkilä et al. 2017; Bolbot et al. 2022) there is still ambiguity with respect to the application of the GBS to AS. The aim of this research is to provide some practical examples of how the initial set of requirements can be developed for e-lookout by focusing on Tier IV requirements for the conventional lookout and the existing requirements for e-lookout in class societies guidelines for AS.

This paper is structured as follows. In the next section, the methodology that we followed is presented. Then the results of the methodology application are provided. In section four we discuss the limitations of our approach. In the conclusions, the main research findings are provided and directions for further research are elaborated.

2. Methodology

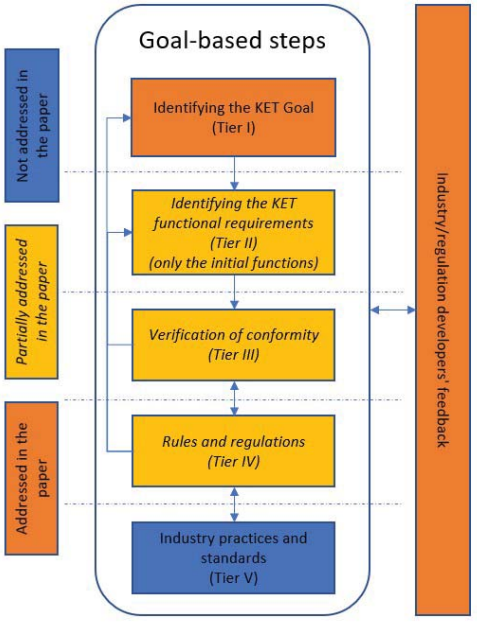

Fig. 1. The GBS framework elements considered in our analysis based on (IMO 2019).

Herein, the GBS framework have been used as a basis for the development of the requirements. However, we concentrated on those aspects related to the analysis of the regulations and class societies' rules (Tier III and Tier IV) and not the implementation of RA. Also, we did not investigate the requirements for e-lookout that

stem from industrial standards. The scope and the boundaries are demonstrated in Fig.1. The parts of the GBS framework that we considered are presented in more detail in the next section. We refer only to the specific steps of the methodology we followed, whilst the results are provided in the subsequent paper section.

2.1. *Tier I E-lookout goal definition*

The definition of the e-lookout goal has been an outcome of discussions that we had internally, with the other ECAMARIS project partners including system manufacturers and with the personnel from One Sea Association (One Sea 2023) working on the AS regulatory amendments. The target was to use the least number of words to accurately portray the main purpose of the e-lookout. The process of determining the goal has been iterative and the goal was updated after considering the results achieved in the following steps and considering the feedback from project partners and system manufacturers.

2.2. *Tier II E-lookout functions definition*

As a follow-up step, we specified a hierarchical set of functions that are implemented by e-lookout. As an initial basis, we referred to the AS functions classification list from AUTOSHIP (Rødseth et al. 2020) relevant to the ship situation awareness and visual observation. This supported the initial breakdown of the e-lookout functions. Considering the specificity of the e-lookout, we used the classifications of image interpretation processes related to Detection, Recognition, and Identification (DRI) (Johnson 1958) as defined by (Hollands, Terhaar, and Pavlovic 2018), which is reportedly used in other industries for similar situation awareness functions as a basis with some adjustments:

- Detection: discriminating an object of interest from its background (i.e., a target is present).
- Recognition: classifying an object into a specific category (e.g., the target is a ship, land…).
- Identification: specify the unique identity of the object (e.g., the IMO number of a ship, sea mark, etc.).

This supported further refinement of the e-lookout functions. Additionally, the function list was updated considering the conventional ship lookout operations. We took into consideration the feedback we received from the One Sea Association and the equipment manufacturers and designers.

2.3. *Tier III E-lookout conformity verification*

Having in mind the initial set of e-lookout functions (which was based on DRI and AUTOSHIP classification and consideration of operations in conventional ships) we proceeded with the investigation of the IMO regulations and class societies rules for AS. We specifically identified the requirements relevant to the conventional lookout and discussed how these can be relevant to the e-lookout. This analysis required recursive derivation of requirements and mergers of overlapping requirements which we could locate in the various rules and regulations. We also updated some of the initial e-lookout functions based on the relevant regulations and rules. As a basis for the e-lookout requirements, we considered that the same requirements as for conventional lookout should apply as a starting point in the absence of e-lookout specific regulation.

2.4. Tier IV E-lookout requirements initial proposal

Once the initial list of the relevant requirements was identified they were reviewed by the ECAMARIS partners. Based on that, some of the initially proposed requirements were removed, whilst others were updated considering equivalence in performance to the conventional lookout operations (relevant examples are provided in the results). Then we enhanced the list by deriving requirements from additional regulatory and class society documentation. This supported the identification of the initial lists of high-level functional requirements. During the analysis in Tier III and Tier IV reliability, availability, maintainability, and safety requirements were also specified. The requirements were presented using ISO 29148 (ISO 2018) as a basis for the requirements structuring.

3. Results and discussion

3.1. Tier I E-lookout goal definition

The e-lookout goal is to act as a system undertaking sole visual lookout on a ship with a minimally crewed bridge consisting of the Office

of the Watch (OOW), and an autonomous e-lookout during ship operations and to detection, recognition, and identification of navigation safety-related objects in the ship's vicinity.

This goal is much shorter than the definition used by One Sea partners and the definition we used for developing the ECAMARIS e-lookout concept of operation (CONOPS), though it was considered fit for this analysis. We considered that the system would substitute some of the functions currently performed by the bridge officers and deck ratings, which could enable reduction in bridge crewing under conditions. The influence on the derived e-lookout functions is elaborated below.

3.2. Tier II E-lookout functions definition

We considered the following minimum functions set for e-lookout:

(i) Collect surroundings data about the external navigational safety-related objects and relevant atmospheric conditions.
(ii) Detect navigational safety-related objects.
(iii) Estimate objects' attributes (relative bearing, optionally relative speed and distance).
(iv) Detect people/ships in distress.
(v) Allow data attributes enhancement for recognition (e.g., camera zoom).
(vi) Provide information on external objects of interest relevant to the OOW for recognition, navigation and decision-making.
(vii) *Provide alert about deviation from operational design conditions.*
(viii) *Collect system condition data.*
(ix) *Collect information on the sea condition.*
(x) *Recognize visibility level.*
(xi) *Recognize whether the e-lookout is operating within the design operational conditions.*
(xii) *Recognize own system performance condition.*
(xiii) *Provide alert about its own condition.*

Storing the video data or the information recordings is considered an optional novel function for the Voyage Data Recording system on ships having e-lookout systems at this stage, but may yet be required for incident investigation or compliance with ethical guidelines. We also considered that prioritizing the detection of animate objects is not a function, but rather a requirement for the detection functions stemming from ethical standards, which were not analyzed in this study. It was considered that the OOW is still responsible for assessing the navigation risk in each situation, although an advanced version of the e-lookout could potentially do that as well in the future. The OOW is also considered responsible for recognition of cloud cover and recognition of people in distress. The detection recognition of the sea condition (relevant to the recognition of operation conditions) is left as a function to other systems (gyroscope, anemometer, etc.).

We excluded from the list of functions any reference to timely performance, as this is implied. We also excluded the recognition/ identification of objects since this is still possible to be delegated to OOW. Yet, this would be different in the case of fully autonomous ships or periodically unattended bridges where recognition/identification functions would be included. The same applies to assessing the risk of navigation situation as required by COLREGs (COLREGS 1972), it should be a function of periodically unattended bridge, but not essential for e-lookout as it is also done by OOW.

This functions list was updated by considering the results of regulatory framework analysis in Tier III and Tier IV, as requirements for some of them e.g. bearing estimation, stems from regulations (STCW). Also, instead of optical zoom recommended in DNV guidelines for AS, (DNVGL-CG-0264) we included "allow data attributes enhancement for recognition", which is more generic and flexible for development of requirements, albeit optical zoom can be finally the selected technical solution by manufacturers.

The functions associated with the recognition of operational condition and system conditions (functions vii to xiii) can be viewed as supportive functions and shared together with alarm and monitoring system, but not as the core functions for e-lookout. They stem indirectly from the requirements for bridge alert management and SCTW.

3.3. Tier III E-lookout conformity verification

The following regulations have been considered for the investigation.
From the IMO:

- COLREGS - International Regulations for Preventing Collisions at Sea
- International Convention for the Safety of Life at Sea (SOLAS 74 as amended)
- STCW (Standards of Training, Certification, & Watchkeeping for Seafarers) including 2010 Manila amendment)
- Resolution A.1047(27) Principles of minimum safe manning
- IMO Resolution MSC 302(87), Adoption of Performance standards for bridge alert management
- IMO Resolution A. 694(17), General requirements for shipborne radio equipment forming part of the global maritime distress and safety system and for electronic navigational

From the Finnish regulatory framework:

- Act on Ships' Crews and the Safety Management of Ships (1687/2009; amendments up to 1528/2019 included)

From the Class society guidelines for AS:

- ABS: Requirements for Autonomous and Remote Control Functions (2022)
- ABS: Guide for Smart Functions for Marine Vessels and Offshore Units (2022)
- ABS: Guidance Notes on Smart Functions Implementation (2018)
- BV: BV Guideline Note 641-NI-2019-10 - Guidelines for Autonomous Shipping (2019)
- ClassNK: Guidelines for Automated/ Autonomous Operation on Ships, Version 1.0 (2020)
- DNV: DNVGL-CG-0264 - Autonomous and Remotely Operated Ships (2018)
- Lloyd's Register: Design Code for Unmanned Marine Systems (2017)

These documents constituted the main references for the identification of the initial set of requirements that are provided in the next section.

3.4. Tier IV E-lookout requirements initial proposal

The requirements from these multiple documents were grouped and are presented in Table 1 and Table 2. In Table 1 we included the Functional (F) requirements identified in the regulations, whilst in Table 2 the requirements related to Reliability, Availability, Maintainability and Safety (RAMS) are provided. In Table 1 for demonstration purposes, we have included also the relevant regulatory and class society source.

The list of minimum essential functions assigned to e-lookout (13 in total) could have been easily transformed into the functional requirements. For instance, the function (ii) "Detect navigational safety related objects " can be transformed into "the e-lookout shall detect navigational safety related objects". So, the discussion in step 1 already supported the identification of some of the functional requirements necessary for the e-lookout. However, further analysis of the regulatory framework enhanced the requirements, especially the RAMS provided in Table 2. It also facilitated the enrichment and grouping of the already known functional requirements stemming from the functions as can be observed in Table 1 and provided a link to the existing regulations enhancing the credibility of these requirements. So, the analysis of the regulatory framework is indeed necessary in addition to the functional and operational breakdown and crosschecking of the currently implemented operations in conventional shipping (conventional lookout operations).

In the list of provided requirements in two cases we deviated from the requirements specified in the regulations or class society rules. As a part of the conventional lookout, the approximate relative bearing estimation is required (STCW Table A-II). However, we included the relative speed and distance, as this is typically identified by the bridge officers, if it is proved technologically feasible and contribute to the overall performance of the bridge team. Still this can be also done by the OOW. Also, in contrast to the DNV requirement for e-lookout (which is based on equivalence to Line of Sight regulations), we considered that the Field of Vision should be 360^{o} in the horizontal direction to reflect the fact that the bridge officers can move around the bridge and to the bridge wing, so their effective Field of Vision is significantly larger than the specification for the bridge Field of Vision. In both cases, the consideration of equivalence to human performance led to the requirements that are seemingly more stringent than the direct equivalence to the regulations. However, this is in line with the recommendations from RSE for the navigational functions (IMO 2021).

Some of the RAMS requirements that we considered are already included in the Safety

Management System requirements such as the maintenance management and training of the operators. However, we decided to include them for the sake of consistency.

We attempted to have similar granularity for the requirements without going into much detail. That is why the requirements remained mostly at a high level. This supports the discussion on the relevance of requirements to the e-lookout. Further details on these requirements can be provided through the analysis on the Tier V level, where more technical details are added alongside Human-Automation Teaming and ethical requirements.

Through the implemented analysis we could observe even before the RA that some of the anticipated hazards are already addressed in the regulatory framework. Examining the results of this evaluation prior to the RA can be beneficial, to avoid duplication of effort, to have a more complete list of hazards and have more resources allocated towards the novel hazards.

Table 1. The Functional (F) requirements for e-lookout based on the analysis of regulations and class societies guidelines for AS.

a/a	Functions	Requirement	Source
1F	Detect navigational safety related objects.	Shapes described in COLREGs shall be detectable and recognizable when using e-lookout under foreseen pitching and rolling conditions.	COLREGs Rule 22 STCW Table A-II/1 Maintain a safe navigation watch DNVGL-CG-0264 Section 4 Chapter 3.1.1. Section 4 Chapter 3.1.1.4 Section 4 Chapter 3.1.1.6 Section 4 Chapter 3.2.3 Section 4 Chapter 4.1 LR Ch 6 Sec 3.1.1 BV Guidelines for autonomous shipping NI 641 DT R01 E Section 2 – 2.3.4 Section 4 – 2.12 Section 4 – 2.7.3
2F	Detect navigational safety related objects. Detect people/ships in distress.	Ability to transmit and receive Morse light signals shall be ensured with electronic lookout	STCW Table A-II/1 Transmit and receive information by visual signaling
3F	Estimate objects attributes (relative bearing, relative speed, and distance).	The e-lookout shall provide approximated relative bearing, relative speed, and distance for the objects	STCW Table A-II/4 DNVGL-CG-0264 Section 4 Chapter 3.1.2.1
4F	Recognize whether the e-lookout is operating within the design operational conditions. Provide alert about deviation from operational design conditions.	The e-lookout shall alert if a significant change in the operating environment is observed (e.g. new object has been detected) and have priority for the alerts/escalation of alerts in line with MSC 302 87	STCW code A VIII part 3 – 13 DNVGL-CG-0264 Section 4 Chapter 3.1.1 IMO Resolution MSC 302(87), Adoption of Performance standards for bridge alert management, May 2010
5F	Detect navigational safety related objects. Detect people/ships in distress.	The e-lookout shall detect and recognize objects in distress.	STCW code A VIII part 3 – 13 DNVGL-CG-0264 Section 4 Chapter 3.1.1.4
6F	Collect system condition data.	The e-lookout shall indicate its operational status (internal status) and	SOLAS V Safety of navigation Regulation 15 DNVGL-CG-0264 Section 2 Chapter 2

	Recognize own system condition. Provide alert about its own condition.	give alert if detects limitation in operational status/failure and have priority for the alerts/escalation of alerts in line with MSC 302 87	DNVGL-CG-0264 Section 2 Chapter 9 DNVGL-CG-0264 Section 4 Chapter 10.1 BV Guidelines for autonomous shipping NI 641 DT R01 E Section 4 – 2.12. ABS Autonomous and remote control functions Section 5 3.4.2 Requirements – Monitoring and Alarm systems ClassNK Guidelines for Automated/Autonomous Operation on ships Chapter 3.2.1.2 ABS Guide for smart functions for marine vessels and offshore units Section 3 IMO Resolution MSC 302(87), May 2010
7F	Collect surroundings data about the external navigational safety-related objects and relevant atmospheric conditions.	The Field of Vision in e-lookout shall be 360º.	SOLAS chapter V regulation 22. DNVGL-CG-0264 Section 4 Chapter 3.1.1.1-3

Table 2. The RAMS requirements for e-lookout based on the analysis of regulations and class societies guidelines for AS.

a/a	Requirement
8RAMS	The functionality of e-lookout in all the environmental conditions in the operating environment shall be ensured (ship movements, temperature, humidity, illumination, vibration).
9RAMS	E-lookout or conventional lookout shall be provided with sufficient level of availability according to standard procedures.
10RAMS	Failure in e-lookout shall not impede the operation of other systems.
11RAMS	It shall be ensured that no single failure in e-lookout does impede the operation of e-lookout.
12RAMS	The software error shall be prevented to the extent possible by: • E-lookout software shall be designed and developed according to well-established standards for software design. • Access control and authority of change should be strictly controlled to avoid any unauthorized software changes. • Upgrading of the e-lookout and handling of bugs should be generally performed by the system supplier throughout
13RAMS	E-lookout machine-learning mechanisms should be trained with well-defined datasets
14RAMS	The OOW shall be appropriately trained in using the e-lookout and be aware of the operational limitations for the use of e-lookout.
15RAMS	The e-lookout shall be protected against cyberattacks and leakages of raw data.
16RAMS	The e-lookout hardware shall be properly maintained.
17RAMS	Safe human e-lookout interactions shall be ensured in electronic lookout

4. Limitations

As already referred, the requirements provided in the paper do not include the results of RA required in the GBS. This is a work in progress in the ECAMARIS project. So, potentially more requirements will be specified for the e-lookout based on RA results. A cognitive workload analysis would provide evidence as to whether the OOW cognitive load is acceptable under different traffic situations.

Some of the requirements that we identified could be further refined. For instance, we could analyze in much greater detail the human-e-lookout interactions considering information from the class society guidelines. However, we considered that it would be more effective to analyze these requirements in more detail using some industrial standards and frameworks, like those published by the MITRE Corporation (McDermott et al. 2018). But this is outside the scope of the present analysis, as it refers to the Tier V level and will be addressed in follow-up research. The same applies to ethical

requirements like prioritization of detection of animate over the inanimate creatures, as this was not specified in regulatory and class society requirements for lookout we analyzed. So, this constitutes one of the constraints of our analysis and derived requirements.

The approach that we followed was highly non-linear and involved several feedback loops. This strongly complicated the analysis but also supported the enrichment of results in different GBS Tier levels. The approach also suffered from subjectivity as it was based on dialectic method and cooperation between different partners, and hence influenced by the skills and expertise of the participants. This is a well-recognized problem for the RA (Sadeghi and Goerlandt 2023) as well, so the use of RA would not provide a solution. To overcome this issue, we believe it is necessary to involve additional perspectives and expertise, achieved through open and transparent discussions and processes.

5. Conclusions

In this paper, by following the GBS approach and using multiple techniques, such as functional classifications lists, regulatory framework analysis, principles of equivalence to regulations and human performance, and feedback from industry, we derived some initial requirements for the e-lookout.

The main findings of our research are as follows:

- The use of functional breakdown for AS systems and regulatory framework analysis can lead to the initial set of functional and RAMS requirements for these systems.
- Novel requirements development constitutes a complex and non-linear process, so it seems that following the spiral approach would be more effective for the development of regulations.
- The application of the equivalence principle to the existing regulatory requirements can have misleading conclusions and actual operations (equivalence to humans' operations) shall be also considered when deriving requirements/essential functions for novel AS systems.
- It is important to accommodate as many perspectives as possible during the requirements development to reduce uncertainty and subjectivity during regulatory analysis.
- 17 functional and RAMS requirements were proposed for the e-lookout but this list can be further enriched.

In the follow-up ECAMARIS research these requirements will be refined and enriched based on the results of RA, considering Tier V level requirements and verification results.

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