Report.

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Research Project "ACHT" for Autonomous Cargo Handling on Oil and Chemical Tankers:

-- A concept study --

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1 Introduction

1.1 Background and motivation

On a modern tanker, the ship's officers plan and direct the cargo operations. Cargo handling operations on oil and chemical tanker vessels, vessel-to-vessel and vessel-to-shore loading and discharging procedures, are complex, demanding and are associated with high risks. They involve handling and coordination of dangerous cargo (sometimes of multiple types/grades), ballast and inert gas systems while also simultaneously considering the vessel’s mooring, draft, trim, list, stability, shear forces and bending moments. Tank and pipe system conditions such as level pressure, oxygen content, sequences, temperature, atmosphere, flow rate and line clearance allowances are also being monitored. Therefore, loading and discharging operations are planned carefully in advance by the vessel’s chief officer (CO), agreed and approved with the vessel’s master and, before commenced, agreed upon together with the shore terminal and/or the representatives of the other vessels. Cargo plans are posteriorly followed by the vessel’s officers of the watch (OOWs). They control the loading and discharging operations by regulating fluid flows/pump speeds, and by throttling valves and pumps, etc. To their aid, they have a number of technical systems onboard to monitor and control the cargo handling systems.

Today’s cargo planning systems can reactively alert at predefined levels if deviations to the plan occur during operation (e.g., alerts on stability issues, limits of the hull). Yet, it is the vessel’s officers who operatively predict, decide, and perform the manoeuvres to control the flow of cargo, ballast, and inert gas systems. Today’s cargo handling systems are not integrated (i.e., they do not collaborate) to provide predictive decision support, making the officer of the watch (OOW) the mediator between the different systems. Any potential error in the handling of any of the systems might result in delays, increased costs, and negative environmental impacts.

Today's technological availability should allow for cargo handling systems to become more integrated and facilitate the digitalization of rules and regulations into the system. It should also be able to analyse historical operational data with the use of Artificial Intelligence (AI) and Machine Learning (ML) principles, and therefore provide a) predictions on the time required for cargo handling operations and the next availability of the terminals, etc., and b) decision support to the operator for planning and executing a cargo loading/discharging process. This would expectedly increase efficiency, reduce the vessel’s time at quay and subsequent environmental impact, while maintaining safe operations from events such as the overflow of cargo tanks, etc.

The ability to predict cargo handling operations with higher precision fits well with other development projects with the aim of optimizing shipping operations and timely activities, such as the Sea Traffic Management (STM) project.

1.2 Objective of the project

The title of this project is “ACHT – Autonomous Cargo Handling on Tankers” and it consists of a concept study. Based on the background and motivation described in the section above, the objective of this concept study is to map current cargo handling operations on oil and chemical tankers (including communication with port) and investigate the conditions (gaps, opportunities and operator needs, as well as the technological possibilities) for an optimized cargo handling management system with inter-system communication and increased automatization to predict and control cargo handling on tankers using AI and ML. A design concept and guidelines for the updated cargo handling management system can be outlined as a result.

This concept study is important from the viewpoint of operational performance, safety, and energy efficiency in shipping, at a time where the pressures for reduced emissions are at an all-time high.

The results of this study will serve as the steppingstone for a follow-up project aimed at demonstrating a proof of concept. This will comprise developing the updated cargo handling management software prototype, testing it in a simulated environment with crew (using real-life cargo handling operations data) and involving the classification societies in developing an approval process for the new design for use onboard tankers.

In order to address the objectives of the present study, the following measurable goals were followed:

- **a)** map current cargo handling management operations onboard tankers (including communication with port), as well as the hardware (including sensors) and software systems that are used, their functionalities, information, and data that they provide and the nature of their usage, in order to obtain the overall picture;
- **b)** identify operator needs, potential gaps in existing systems and processes, and opportunities for system effectivization/optimization;
- **c)** identify potential solutions and technological availability with manufacturers and class society based on a) and b);
- **d)** establish design guidelines and an initial design concept of an improved cargo handling management system. This will lay down the roadmap for a follow-up project to test a proof of concept;
- **e)** deliver a report and disseminate its results to the maritime community via newsletter articles in national and international professional fora and via a seminar.

1.3 Scope and delimitations

To approach the subject of cargo handling, we used two available oil and chemical tankers belonging to two separate Swedish ship owners as case studies: Ternsund from company Terntank and Ek-River from company Ektank. The objective was to get a general overview of cargo handling systems used for cargo loading and discharging onboard modern high-performance oil and chemical tankers, namely the tank and ballast sensors, the valves and pumps, the inert gas and cleaning systems, the software tools etc.

1.3.1 Case studies

Table 1 lists the main specifications for each of the vessels considered as case studies in this project.

Table 1. Case studies – vessel specifications.

Vessel - Company	**Specifications**
Ternsund - Terntank	 • M/T TERNSUND • 15.000 DWT • Built 2016 • Oil/chemical tanker • Trading area Nordic countries • 14 cargo tanks • 2 slop tanks • Cargo 98% volume 16.559 m³ • Service slop tanks 242 m³

<table>
<tr>
<td>Ek-River -
Ektank</td>
<td>


• M/T EK-RIVER
• 19.884 DWT
• Built 2018
• Oil/chemical tanker
• Trading area worldwide
• 12 cargo tanks
• 2 slop tanks
• One deepwell pump (electrical driven) in each tank
• Cargo 98% volume 22.020,4 m³
• Service slop tanks 334.9 m³
</td>
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</table>

1.3.2 The cargo handling system(s) and parts considered

Cargo handling requires a cargo plan and operations include loading and discharging. The onboard sub-systems (hardware and software) considered in this study were:

- cargo system,
- ballast system including ballast water treatment system,
- inert gas system,
- tank heating system,
- tank cleaning and ventilation system,
- sounding system (sensors),
- automation computer to control valves and pumps,
- loading computer to make cargo plans and calculate trim and stability.

1.4 Project structure

The concept study was coordinated by the Svenskt Marintekniskt Forum (SMTF) network within RISE Research Institutes of Sweden, with SSPA Sweden AB as project partner.

To address the proposed goals presented above, the work was organized into the following four work packages (WP) and respective methods:

WP1 (WP leader: SMTF; Partner: SSPA) – Mapping how current cargo handling operations on tankers are performed (including communication with port), as well as the hardware (including sensors) and software systems used, their functionalities, information, and data that they provide and the nature of their usage in order to obtain the overall picture. This will include decisions made from the bridge and shoreside.

Cargo handling planning and operations (loading and discharging) are considered.

To perform the mapping, existing literature will be reviewed and a qualitative research approach will be used. This will include a series of observations onboard tankers, interviews/workshops with subject-matter experts from the Swedish maritime cluster i.e., shipping companies, port operators, cargo handling hardware/software manufacturers from the Swedish market and a classification society. Specifically, shipping companies Terntank and Ektank (chemicals and oil tankers), Gothenburg Port, cargo handling system manufacturers Emerson and Kockumation, software data analytics and collaboration company Alkit Communications, and classification society Bureau Veritas Marine & Offshore will be involved. They have confirmed their in-kind contributions.

From the gathered data together with the in-kind contributors, operator needs, potential gaps in existing systems and processes and opportunities for system effectivization will be identified.

WP2 (WP leader: SMTF; Partner: SSPA) – Knowledge gathered from WP1 will provide the basis for WP2. The knowledge will be discussed with the manufacturers and classification society to identify potential solutions and their technological availability. The design guidelines and conceptualization of novel and innovative cargo handling management software will then be established in this concept study. For this, workshop(s) with the manufacturers and classification society will be performed specifically including Emerson and Kockumation, based on their existing cargo handling products commonly used within the tanker business today; Alkit Communications, based on experience from the car industry with regards to AI techniques and Big/Aggregated Data Management; Bureau Veritas Marine & Offshore, with regards to today's class regulatory limits and opportunities for this project's novel design concept (or the adjustment of class regulations).

WP3 (WP leader: SMTF; Partner: SSPA) – Dissemination of the project's results through newsletter articles at national and international levels, public seminar(s) organized by SMTF to which ship-owners, ship designers, technology manufacturers, classification societies, among other relevant maritime actors will be invited, as well as delivery of a final project report.

The project will also have a reference group including M.Sc. Håkan Dahlbom from Cauro Consulting AB, electric engineer with experience in marine electronics; Mikael Thor from Emerson, M.Sc. Civil Engineer and manager of Customer Care, Business Development & Solutions Management; Claes Paulsen from Kockumation; Lars Pennman from Stena Teknik and member of the International Association of Independent Tanker Owners (INTERTANKO), marine engineer and project manager.

WP4 (WP leader: SMTF-RISE) – Project management including budgeting, project status reporting and planning a follow-up project for the development, simulator testing, and classification societies' approval process development for the novel cargo handling management software prototype based on the results from this concept study.

2 Methods

To address the study's goals presented above, a qualitative research approach to data collection and analysis was adopted. The qualitative research approach is interpretative (Creswell & Poth, 2018) as its purpose is to gain an understanding and an overview of the problem being studied, and to discover their variables before quantifying them or testing any hypotheses (Corbin & Strauss, 2008; Creswell & Poth, 2018; Langford & McDonagh, 2003; Patton, 2002).

The research involved observations onboard a tanker and interviews and workshops with subject-matter experts from the Swedish maritime cluster. The subject-matter experts provided their time to the project in kind. A literature review/document analysis was also performed to complement the data.

Data collection and analyses were performed during 2020 and 2021. The order and structure of data collection events were decided upon throughout the project based on the project's objectives, the results of the first data collection events, the availability of the industry collaborators, as well as based on unforeseen circumstances such as the covid-19 pandemic.

Early in the project a plan was established to have onboard visits on the vessels Ternsund from company Terntank and Ek-River from company Ektank (chosen as case studies in the project). The purpose of these visits was to observe typical loading/discharging processes and the use of the existing cargo handling software and hardware, and to identify the specific areas of potential intervention for increased decision support. Due to the pandemic, we were able to secure one visit to Ternsund while the vessel was docked in Port of Gothenburg, close to the researchers' offices, but not a visit to Ek-River, since this would have required travelling farther and was subject to covid-19 restrictions.

Prior to the onboard observation, the consultation of technical documents about the vessels' arrangements and cargo handling systems (hardware and software components), as well as an interview with the CEO of Terntank and another with Technical Inspector of Ektank were performed. The aim was to learn about typical cargo handling procedures and systems before going onboard to capture the procedures in practice.

The methods and materials used for data collection included specifically:

- **Consultation of technical documents** about the vessel arrangements and cargo handling systems (hardware and software components).
- **2020-11-17 Interview** with CEO of tanker company Terntank regarding cargo handling procedures and systems.
- **2020-12-02 Interview** with Technical Inspector of tanker company Ektank regarding cargo handling procedures and systems.
- **2020-12-06/07 Observation onboard** the Ternsund vessel during a cargo loading procedure at Port of Gothenburg, and follow-ups with the CO, captain, chief engineer, and second mates on duty at the time.
- **2021-01-20 Workshop** with industry partners to discuss results from abovementioned observation and feedback.
- **2021-01-29 Interview** with cargo handling system provider Emerson.

- **2021-02-02 Interview** with cargo handling system provider Kockumation.
- **2021-02-03 Interview** with Port of Gothenburg.
- **2021-02-17 Interview** with cargo handling system provider NAPA.
- **2021-04-22 Workshop** with industry partners to perform preliminary risk analysis of a loading procedure with smart cargo handling systems/assisted cargo handling. At this workshop, the CEO of Terntank, the Technical Inspector of Ektank, the CEO of informatics company Alkit, 2 representatives of Emerson, 2 representatives of Kockumation, 1 representative of Port of Gothenburg, and 2 representatives of Bureau Veritas Marine & Offshore were present.
- **2021-04-26 Interview** with CEO of Alkit regarding AI and ML solutions.
- **2021-04-28 Interview** with classification society Bureau Veritas Marine & Offshore regarding the results of the risk analysis, and classification society approvals.
- **2021-05-06 Workshop** with industry partners to map the information exchange needs of vessel and different shore operators. At this workshop, the CEO of Terntank, the Technical Inspector and a representative of the chartering department of Ektank, 2 representatives of Emerson, 1 representative of Kockumation, one representative of Port of Gothenburg, 1 representative of Bureau Veritas Marine & Offshore, 2 representatives of digitalization company Maranics, 1 representative of oil company ST1 and 1 representative of oil company Preem were present.
- **2021-05-24 Reference group meeting** to discuss results so far and receive expert input.
- **2021-06-07 Interview** with Port of Gävle about two ongoing projects developing a port activity application for smartphone and tablet use. This port activity app was mentioned during data collection in the present project and was relevant due to its overlap with the information exchange concept discussed in this project.
- **2021-06-14 Workshop** with the industry partners to perform a more in-depth risk analysis of the further automation of the systems for cargo loading and discharging procedures. At this workshop, the CEO of Terntank, the Technical Inspector of Ektank, 1 representative of Emerson, 1 representative of Port of Gothenburg, 1 representative of oil company Preem, and 2 representatives of Bureau Veritas Marine & Offshore were present. Bureau Veritas Marine & Offshore supported the project in preparing the workshop according to information they as a classification society would need to assess and approve a novel onboard system.
- **2021-09-15 Interview** with organization Marine Single Window (MSW) to get an overview of the tool and how it is used onboard today from a perspective of information exchange and bureaucracy.
- **2021-09-23 Internal meeting** with IT expert at SMTF/RISE.
- **2021-10-13 Design concept meeting** with manufacturers and IT experts to technically delineate the design concept of the proposed assisted cargo handling system.
- **2021-11 News article** about the project published in Sjöfartstidningen's special edition "Greentech".
- **2021-12-16 Final project webinar** to the general public, where the main project results were presented.
- **2022-01**-- Initiated new application and conversations with potential partners for the follow-up project.

2.1 Interviews

Five semi-structured interviews were performed at different points in the project by one or two project representatives of different backgrounds (i.e., human factors, technical expertise) and normally one interviewee. The interviews were initiated based on prepared questions but left open for relevant spontaneous follow up (Patton, 2002). This was important to enable the exploration of problems and thoughts that had not already been identified in the area (Bell, Bryman, & Harley, 2018).

2.2 Field observations

Two in-field direct observations were performed onboard one of the model tankers whilst asking follow-up questions to crew members involved in cargo handling and relevant activities.

Observations entail following one or more people, a scene or object, and looking at the events related to it that can answer the observer's research questions. Direct observations are one way to achieve this, where those being observed are aware of it. The observer(s) may intervene when appropriate to ask clarification questions, avoiding impact to the exercise (Patton, 2002).

The two onboard observations were performed on Terntank's vessel Ternsund (see Figure 1). This was done while the vessel was docked in the Port of Gothenburg to be loaded with cargo. At this time, the vessel was on a charter for oil and bio-products company NEOT Group. The observation was arranged by Terntank's CEO and the ship captain.

The researchers were received onboard by the captain, the CO and the chief engineer and were able to brief them in person about the objectives of the project and of the visit (after having been briefly informed by the CEO prior to our visit). The pre-loading and loading procedures were then shadowed.

Figure 1. The bridge on Ternsund, with the cargo operations station on the left. Layout of the cargo operations station from left to right: 1 screen for ballast and 1 screen for tank valves (Kongsberg), 1 screen for loading software (Kockumation), 1 screen for emails and other files, 1 screen for NEOT reporting system (chartering company at the time of the onboard visit), telephone, papers, and physical files.

2.3 Workshops/Focus groups

Four workshops/focus groups were performed for data collection; they were set up for 3 hours each and moderated by both SMTF and SSPA representatives.

A focus group is a sort of collective interview where a carefully selected group of people are invited to share and discuss their expertise/perceptions on a given topic for a determined number of hours (Patton, 2002), and can be performed to gather user needs or impressions of a new concept, for instance (Jordan, 1998; Nielsen, 1993). Focus groups are participatory events that enable the members to build on each other's ideas/views (Patton, 2002). In this project, the workshops were not just used to disseminate and discuss preliminary results, but also to gain the industry's view on new issues that build on what has been done so far.

At one of the workshops with the industry, the results from the interviews with the ship owners and from the onboard visit were presented and discussed, which provided input for further development.

At the second and third workshops, the participants were divided into two groups to discuss and fill in a prepared matrix by the organizers (see Table 2 created for the workshop on information exchange needs and Table 3 for the risk analysis workshop). The participants were divided into the two groups based on their professions/areas of expertise to allow for a richer discussion and for better coverage of the different perspectives within each group.

Table 2. Matrix for the workshop about the information exchange needs between vessel and shore operators involved in cargo handling.

	Vessel			
Questions / Actors	What information needs to be exchanged between ship and each actor? a) Business-related data b) Safe operation-related data	Related to first question, are there any data that they do not want to share/make accessible to each other due to security/safety/business or other reasons?	What common reports can be generated by/part of the new communication layer? (e.g., ullage report)	How can we make this exchange more seamless (tech solutions)?
Ship owner				
Authorities				
Port				
Shipper				
Charterer				
Surveyor				
Other actors ashore? a) Exchange info with ship during voyage and cargo operation planning (not navigation related)? **b)** And during execution?				

The participants were able to add to the matrix the shore-side actors of relevance that were not already included. The results of both groups were then shared and discussed between all the participants.

2.4 Risk analysis

For the preliminary risk analysis of a loading procedure using proposed smart cargo handling systems/assisted cargo handling, the “what if” method was selected. This was chosen as a first attempt at a risk analysis in the project, based on the project’s timeframe and on the method’s simpler instructions compared to e.g., HAZID (hazard identification analysis) or HAZOP (hazard and operability analysis) methods. The “what if” hazard analysis instructions provided by MIT’s official website (MIT, n.d.) were adopted. Based on the instructions, the following matrix (Table 3) was prepared for the industry partners to fill in during the workshop (with some examples of “what if” questions discussed during the workshop):

Table 3. Matrix for the “what if” risk analysis performed during the workshop, with some examples of “what if” questions that were provided and discussed.

‘What if’ question *(a potential issue/malfunction/mishap that could occur with the systems)*	**Answer** *(if the issue occurs, then what can it lead to?)*	**Likelihood** *(how likely is the issue to occur? Impossible? Remote? Possible? Very likely?)*	**Consequences** *(how serious would the consequences be if the issue occurs? Would they represent a serious safety or environmental hazard? A serious financial cost?)*	**Recommendations** *(what might be the solution(s) to mitigate or eliminate the issue, reduce its likelihood of occurring, or soften its consequences?)*
The manual commands do not work, and the automated commands are following the wrong cargo plan due to some malfunction?				
The systems communication line breaks and ballast and valves stop compensating each other, missing to inform/suggest to the user?				
A failure of IT systems (e.g., programming bugs) occurs?				

The “what if” questions were listed in advance by the workshop organizers, and the participants were asked to submit some questions of their own as well. For this exercise, they were reminded and asked to imagine the following cargo loading procedure scenario (Table 4), which had been defined based on prior data collection in the project:

Table 4. Brief explanation of the type of proposed system, levels of automation and control.

Division:	Ship's CCR
Description of operation:	**Cargo loading procedure**
Type of system:	Smart cargo handling/assisted cargo handling, using A.I. The system will: o Balance the vessel by throttling valves (ballast and cargo), based on planned operation o Balance the vessel by regulating pump rpm (ballast and cargo), based on planned operation o Alert the officer of any trends that indicate surpassing set limits o Alert the officer of pre-set volumes for line clearance and similar requests The system will not: o Conduct critical operations such as topping off/shifting tanks o Conduct final loading sequences
Levels of automation:	A1-A2 A1: Human directed (decision-support - system suggests, human decides which actions to take) A2: Human delegated (system invokes actions, human can reject or accept)
Degree of control:	DC3: full direct control - System is actively monitored and controlled at any time onboard

During the workshop, the participants were divided into two separate groups and asked to fill in the remaining columns in the matrix for a number of "what if" scenarios. Different scenarios were provided to the different groups since many scenarios emerged from the previous brainstorming.

While the first risk analysis workshop focused on a cargo loading procedure concept and the potential risks of possible scenarios, the following risk analysis workshop focused on the potential new risks of each specific proposed add-on function in this project. For this, a list of the proposed new functions was made, and the risks and potential consequences were discussed for each function. See section 3.3 (p.25) for the main results.

The risk analyses performed in this project were preliminary, with the intent of performing more in-depth risk analyses in the coming follow-up project, led by classification society Bureau Veritas Marine & Offshore.

2.5 Audio and video recordings

Audio and video of the interviews and workshops were recorded and annotated (Creswell, 2014). The observations were annotated and documented in photographs.

Audio-visual materials captured through cameras and audio-recorders are useful to study quotes and details of the participants' experiences, tasks and perceptions that the researcher alone cannot manage to note down or analyse whilst running the data collection exercise (Patton, 2002; Silverman, 2014).

The areas of potential improvement were identified and categorized throughout data collection and consolidated posteriorly during analysis. Based on the results, design guidelines and concept for an improved and smarter cargo handling management system using AI techniques could be laid out.

3 Results

3.1 Current cargo handling system

Based on a) the consultation of technical documents about the vessels' arrangements and cargo handling systems (hardware and software components), b) the interview with the CEO of tanker company Terntank and interview with Technical Inspector of tanker company Ektank, as well as c) the observations onboard Ternsund (during planning and cargo loading procedure), the following illustrations, Figure 2 and Figure 3, were made to summarize the various cargo handling systems and inter-connections between them on each vessel. The manufacturers of the onboard systems differ between the vessels, yet they function similarly.

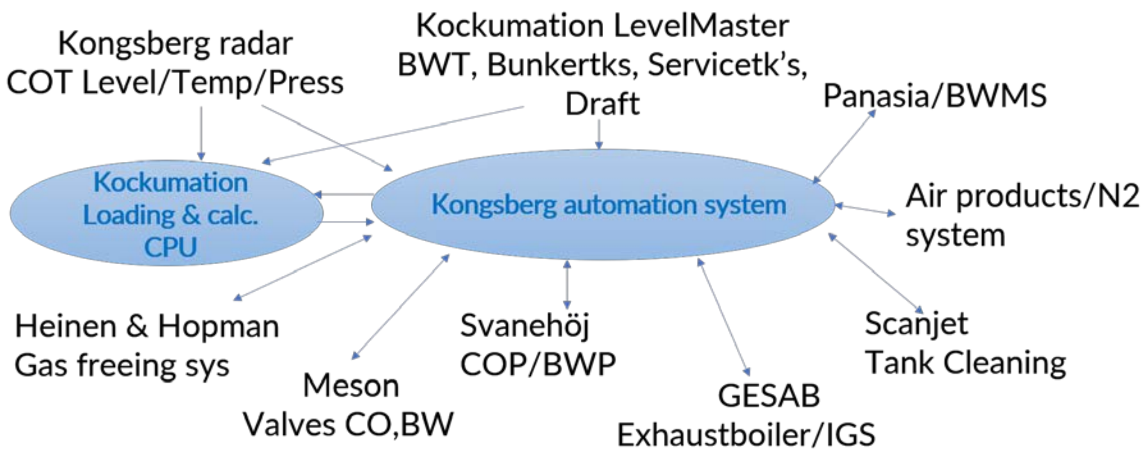


Figure 2. Cargo handling systems onboard Ternsund.

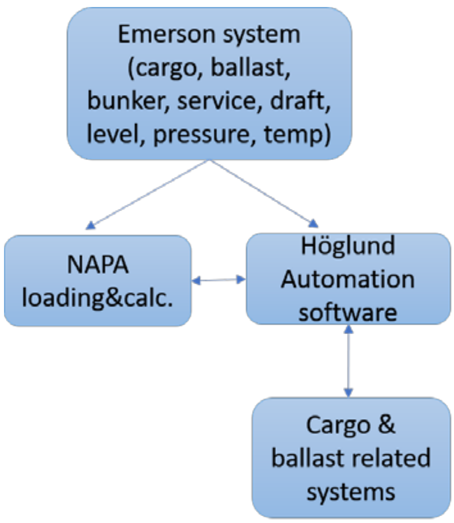


Figure 3. Cargo handling systems onboard Ek-River.

The diagram below depicts the tools used during pre-loading and loading procedure (Figure 4).

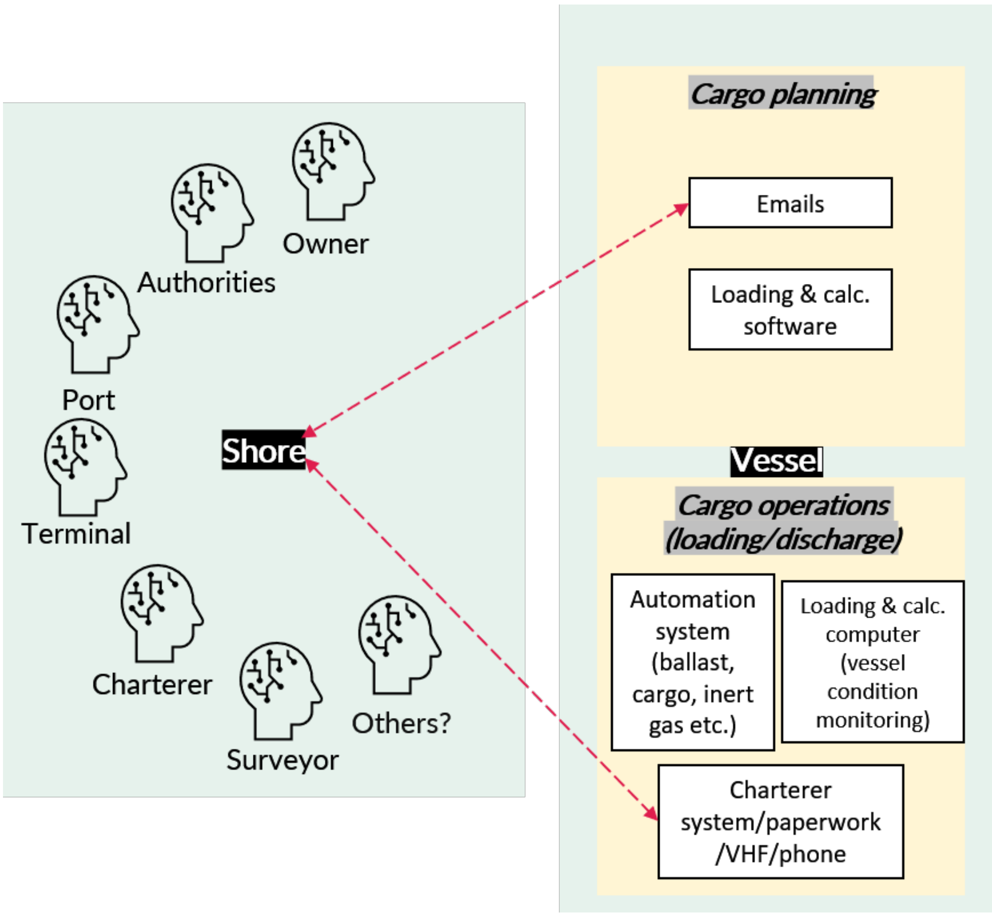
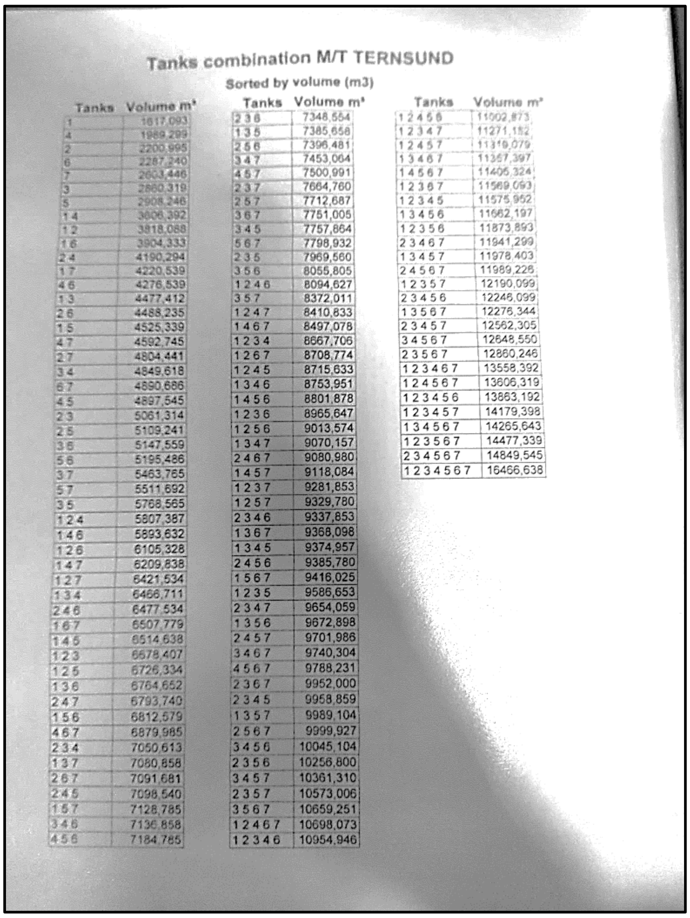


Figure 4. Depiction of current cargo handling management tools used during cargo planning and plan operations, based on technical documents, interviews and onboard observations.

Figure 4 expresses that cargo handling is divided into two main activities: the planning and the execution of the plan. In both circumstances, communication with shore actors is crucial.

Just like planning for a ship voyage from point A to B, the movement of cargo needs to be planned according to certain rules and regulations, company policies, requests from shore customers, and involves communication with different parties. To receive requests of what grades (types of cargo) to carry, the quantities that can be delivered at a given terminal, etc., there is an exchange of emails between ship and shore. The cargo requests and conditions are then considered by the CO along with a printed list of possible cargo/tank combinations and respective volumes, made by the interviewed the CO onboard the Ternsund (see Figure 5), and the alternatives are typed into the loading computer by the CO and 'tested'. Regulations about flow rates from the International Safety Guide for Oil Tankers and Terminals (ISGOTT) also need to be considered by the CO during this process since they are not digitized and automatic in the computer. These alternatives need to be calculated until the officer comes to a final plan which is then recorded in the loading computer. Before a plan is decided upon and recorded, the officer might save the alternatives as PDF files in case he/she needs to return to them at a later point. This process repeats itself for every new cargo plan, including the integration of the regulatory and non-dynamic information.



Tanks combination M/T TERNSUND

Sorted by volume (m3)

Tanks	Volume m³
1	1617,093
4	1989,299
2	2200,995
6	2287,240
7	2603,446
3	2860,319
5	2908,246
1 4	3606,392
1 2	3818,088
1 6	3904,333
2 4	4190,294
1 7	4220,539
4 6	4276,539
1 3	4477,412
2 6	4488,235
1 5	4525,339
4 7	4592,745
2 7	4804,441
3 4	4849,618
6 7	4890,686
4 5	4897,545
2 3	5061,314
2 5	5109,241
3 6	5147,559
5 6	5195,486
3 7	5463,765
5 7	5511,692
3 5	5768,565
1 2 4	5807,387
1 4 6	5893,632
1 2 6	6105,328
1 4 7	6209,838
1 2 7	6421,534
1 3 4	6466,711
2 4 6	6477,534
1 6 7	6507,779
1 4 5	6514,638
1 2 3	6678,407
1 2 5	6726,334
1 3 6	6764,652
2 4 7	6793,740
1 5 6	6812,579
4 6 7	6879,985
2 3 4	7050,613
1 3 7	7080,858
2 6 7	7091,681
2 4 5	7098,540
1 5 7	7128,785
3 4 6	7136,858
4 5 6	7184,785

Tanks	Volume m³
2 3 6	7348,554
1 3 5	7385,658
2 5 6	7396,481
3 4 7	7453,064
4 5 7	7500,991
2 3 7	7664,760
2 5 7	7712,687
3 6 7	7751,005
3 4 5	7757,864
5 6 7	7798,932
2 3 5	7969,560
3 5 6	8055,805
1 2 4 6	8094,627
3 5 7	8372,011
1 2 4 7	8410,833
1 4 6 7	8497,078
1 2 3 4	8667,706
1 2 6 7	8708,774
1 2 4 5	8715,633
1 3 4 6	8753,951
1 4 5 6	8801,878
1 2 3 6	8965,647
1 2 5 6	9013,574
1 3 4 7	9070,157
2 4 6 7	9080,980
1 4 5 7	9118,084
1 2 3 7	9281,853
1 2 5 7	9329,780
2 3 4 6	9337,853
1 3 6 7	9368,098
1 3 4 5	9374,957
2 4 5 6	9385,780
1 5 6 7	9416,025
1 2 3 5	9586,653
2 3 4 7	9654,059
1 3 5 6	9672,898
2 4 5 7	9701,986
3 4 6 7	9740,304
4 5 6 7	9788,231
2 3 6 7	9952,000
2 3 4 5	9958,859
1 3 5 7	9989,104
2 5 6 7	9999,927
3 4 5 6	10045,104
2 3 5 6	10256,800
3 4 5 7	10361,310
2 3 5 7	10573,006
3 5 6 7	10659,251
1 2 4 6 7	10698,073
1 2 3 4 6	10954,946

Tanks	Volume m³
1 2 4 5 6	11002,873
1 2 3 4 7	11271,182
1 2 4 5 7	11319,079
1 3 4 6 7	11357,397
1 4 5 6 7	11405,324
1 2 3 6 7	11569,093
1 2 3 4 5	11575,952
1 3 4 5 6	11662,197
1 2 3 5 6	11873,893
2 3 4 6 7	11941,299
1 3 4 5 7	11978,403
2 4 5 6 7	11989,226
1 2 3 5 7	12190,099
2 3 4 5 6	12246,099
1 3 5 6 7	12276,344
2 3 4 5 7	12562,305
3 4 5 6 7	12648,550
2 3 5 6 7	12860,246
1 2 3 4 6 7	13558,392
1 2 4 5 6 7	13606,319
1 2 3 4 5 6	13863,192
1 2 3 4 5 7	14179,398
1 3 4 5 6 7	14265,643
1 2 3 5 6 7	14477,339
2 3 4 5 6 7	14849,545
1 2 3 4 5 6 7	16466,638

Figure 5. Printed list of tank combinations used onboard the Ternsund for cargo planning.

Once a cargo plan is decided upon together with the chartering department ashore and the vessel is safely alongside the jetty where the loading/discharging is to be performed, the loading/discharging will start when both the vessel and terminal are ready. The OOW will keep the VHF radio at hand to communicate with the able seamen (ABs) on deck and will monitor and control valves and pumps on both the tank screen as well as the ballast screen. Simultaneously, the OOW will consult the loading and calculation computer for information and vessel condition monitoring (no modifications are made in this system during operations) and keep written logs of the critical points of the operation and fill in paper checklists. See Figure 1 (on page 12) for an example of a cargo handling station onboard. See Figure 6-Figure 10 to see examples of the cargo handling graphical user interfaces (GUIs).

Figure 6. Main systems side by side.

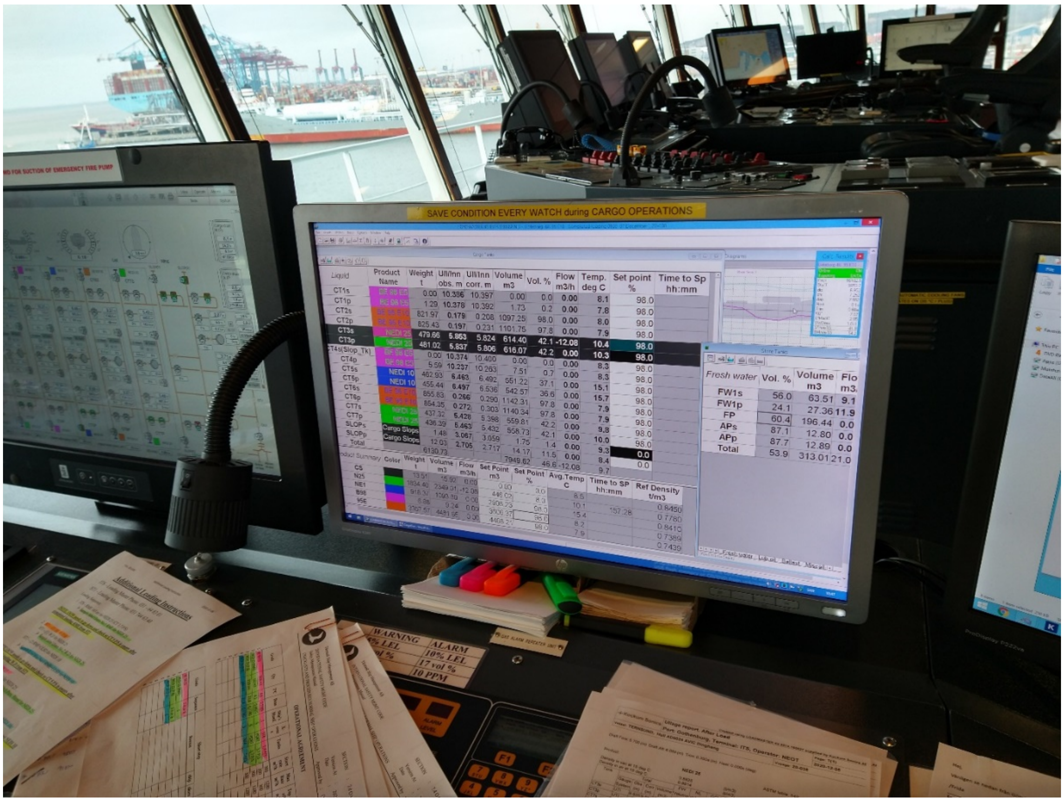


Figure 7. Loading computer (where the planning of the cargo loading or discharging is done).

Figure 8. Cargo tank control system.

Figure 9. Ballast control system.

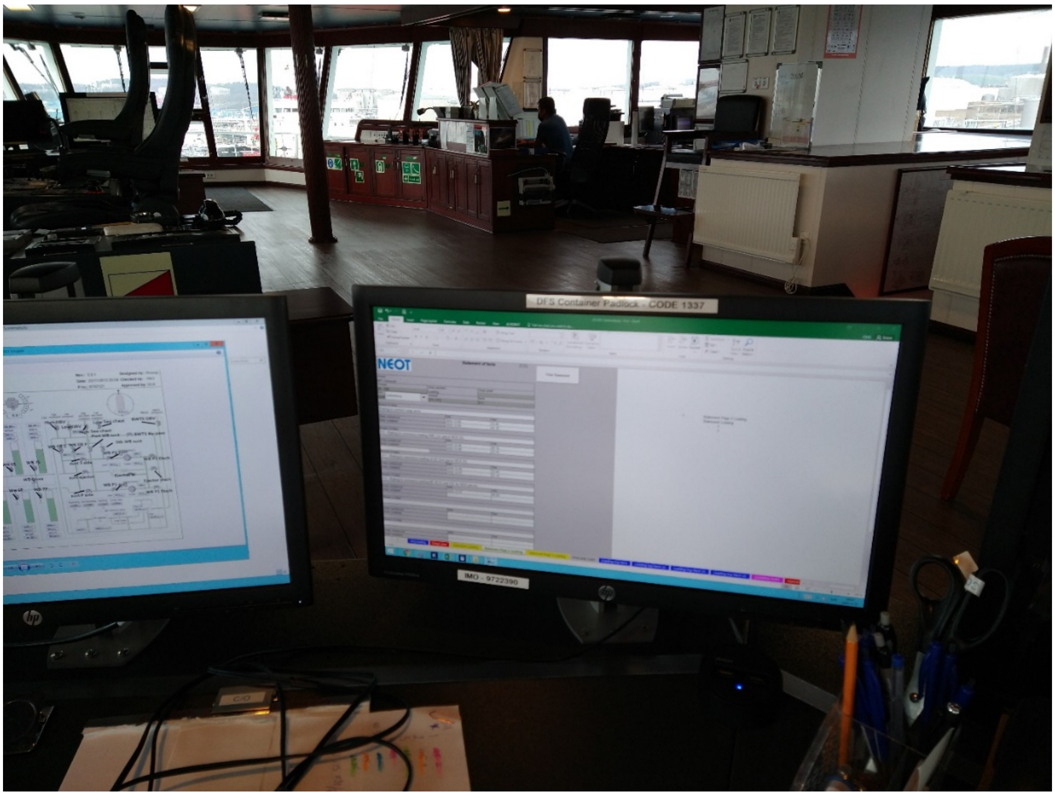


Figure 10. Logbook system by the charterer.

3.2 Identified gaps/opportunities and proposed solutions

When providing a description of the present project to the crew on the first vessel visit, there was a reaction to the project's title "Autonomous Cargo Handling on Tankers", particularly with regards to the term "autonomous" or "automated". The crew emphasized the complexity and uniqueness of each cargo handling operation, involving many parts and actors (e.g., cargos, vessel draft, valves, various screens with information, VHF communications, paperwork) and stated *"machines cannot do it!".* This was valuable feedback to the project and resulted in the need to clarify the title to the crew. "Autonomous" or "automated" in this case refers to a better integration of information and existing systems to predict issues more autonomously during the process of cargo planning and operations, and to be able to provide more decision support and assistance to the officers, not changing the fact that it is the officers who make the decisions, monitor, and approve any actions by the systems. Thus, the intention of the project is not to propose a system that would render cargo handling an unmanned activity, but instead to evaluate current systems and identify the gaps that could benefit from a reliable and usable optimization for increased support to the crew. The term "**smart cargo handling**" or "**assisted cargo handling**" were then proposed in this context as an explanation of the objective of this project.

Based on the data gathered during a) the interview with the CEO of tanker company Terntank and interview with Technical Inspector of tanker company Ektank and b) the observations onboard Ternsund, the following points in Table 5 are seen as opportunities in the current systems and procedures for further development/optimization. For each 'gap', there is a proposed solution presented. These propositions would impact cargo planning and cargo operations, onboard paperwork as well as communication between ship and shore.

Table 5. Aspects of the current systems and procedures, and respective propositions for development.

<table>
<tr><th>Current system – Gap analysis</th><th>Proposed solutions</th></tr>
<tr><td>Cargo planning</td><td></td></tr>
<tr><td>Vessel receives email requests from shore (chartering department) on what grades/quantities to carry and destination, prints it, then based on nominations and tank arrangement (Figure 5, on page 18), tries distribution alternatives on loading computer.</td><td>Cargo combinations' list made onboard to be digitalized and integrated with the loading computer for cargo planning. The computer should be able to suggest on line-up, that to load cargo in a certain way it should have manifold X used for pair of tanks A, which valves to open or close, and this should be part of the checklists.
The sheet in Figure 5 (on page 18) should be certified and provided by the manufacturer of each vessel or of the cargo handling systems.
Ship owner's chartering department should have access to it and be able to make a suggestion when they make a cargo request to the CO.
Emails received with requests from shore to be possible to directly and/or automatically import into the loading computer (by using email template or by moving this sort of communication onto a platform connected to the loading computer).
It should be possible to request cargo plan alternatives from the system, which the officer can approve or change. AI to propose combinations based on input information as well as prior experience, and to learn from officers' approvals or modifications.</td></tr>
<tr><td>The CO manually calculates draft, density, trim for splits and denominations in tanks.</td><td>The loading computer to automatically calculate and offer cargo plan suggestions based on given parameters, and in the future using ML based on previous cargo plans. Officer can approve or reject suggestions and make manual adjustments.</td></tr>
<tr><td>The CO saves cargo plan alternatives as PDFs before trying new alternatives, in order not to lose the previous calculations until a final cargo plan is decided upon with the chartering department.</td><td>Loading computer to have 2 tabs – 1 for planning, 1 for execution of the plan;
Make it possible to automatically save alternatives before choosing.</td></tr>
<tr><td>Regulations/conditions that affect operations (e.g., rate of speed for loading/discharging specific grades; terminal specificities) are fixed/static information but need to be inserted into the system from scratch for every cargo plan.</td><td>Digitalize fixed information into the system;
System to offer cargo plan suggestions with such information in mind, considered into the calculations (and with ML optimization from previous plans);
Offer simulation-check of cargo plan (similar to existing voyage plan check) checking if the cargo plan presents any errors/deviations from previous cargo procedures (using AI/ML). This check should present warnings to the officer if something is deviating from the norm, and suggesting a solution;
Self-check of the technical systems (sensors etc) checking if the hardware is functioning properly before the plan is executed.</td></tr>
</table>

Cargo operations	
Event: Jetty asked the CO for estimated time of completion of cargo loading but the CO could not estimate average per hour before one hour had passed, and with loading rate fluctuations.	• AI/ML to provide ETC estimations based on previous cargo plans or calculate based on current plan • Share with terminal (in a way the terminal understands the validity of the information and cannot use the information for other activities such as order of pilots etc.).
Bill of Lading (shipment receipt required for every terminal and every grade) – the port will write in the bill how much cargo they have delivered to the ship. The CO needs to manually calculate this. When there is a certain difference between the ship's and the port's or the ship's and the surveyor's calculations, the CO must protest the cargo amount and contact P&I insurance.	• Digitalize Bill of Lading; • Have the system measure the amounts of cargo in the tanks and automatically share it with terminal and surveyor.
A log of actions is automatically recorded by the valve software, which generates a long list. When pulling the log from the software, it shows as a separate window on top of the window for valve monitoring and control. This log is not used and, instead, the officers write a logbook manually on paper with time stamps on the progress of the percentage of grade in the tanks and rate of loading.	• Improve the logbook window not to overlap the valve control window; • Make it possible to filter the information as desired or in pre-defined categories, and to print and/or directly share with shore operators.
There is a 10-second delay from radars/sensors to screens. The CO left allowance of 10-20m3 of cargo due to this to avoid spillage during topping off. Besides this, space left in the tank for e.g., adding additives to grade or draining the hose arms/manifold could also be needed (the CO left an extra 1,5m3 of space left for drainage).	• Make a correction for the 10 seconds in the software system, with an on-screen warning for the officer; • Use AI to remind the officer for space for additives or arm drainage as well.
Density values were ambivalent in loading computer and valve screen.	• Fix inter-system communication and alert the officer when values are shown inconsistently, along with support for the officer to interpret the values and which to trust; • Offer self-check during cargo operations to warn if there is anything clashing in terms of inter-system communication or deviating from the approved cargo plan, presenting alarms/warnings. This includes a self-check of the technical systems (sensors etc) checking if the hardware is functioning properly.
Adjusting cargo rates in the different tanks requires compensatory ballast adjustments and vice-versa. The officer is often operating two systems simultaneously. The pressure and flow will be limited by how quickly the ballast tanks can be loaded or discharged. Officer is communicating with the terminal about trim and stability simultaneously.	• The valve control software (for tanks and for ballast) to provide on-screen reminders, predictions, and suggestions to the officer about ballast adjustments in relation to changes to cargo tanks, and vice-versa, and in relation to the cargo plan; • The system to offer an on-and-off function for the computer to run valves automatically according to the approved plan and if the officer so chooses, with on-screen information about the actions, and maintaining an automatic log. The officer can turn it off and manually control the valves; • This 'auto-pilot' function should have a continuous status warning showing whether it is on, off or on stand-by potentially waiting for the officer to take action on an on-screen suggestion or alarm.

Besides logs, the officers need to fill in safety and procedural checklists during the loading/discharging. These are archived onboard in case of a vetting process. Crew gets this information today from manuals onboard, from courses on cargo handling and from the experience of the crew.	• Checklists and other time-consuming paperwork to be digitalized in the system; • To be automatically shared via a common communication platform with shore; • To be made available in an EX-safety tablet for crew working on deck, in a way that the crew could be able to take the tablet on deck and point out where they have checked and tick it off and save it in file folders for history. This way knowledge can also be transferred between crews coming on the same vessel; • By digitalizing checklists, one could more easily get additional information about a checkpoint by clicking on it. This additional information could come from regulations and from company policies, from existing manufacturers' instructions or from experience onboard or from the shipyards that tested the installations.
Energy consumption of flow rate compared to pressure on manifold, number of pumps in operation, etc. – eco-mode/energy-saving mode operation (on/off or default function, like a dish-washer's eco-mode).	With the use of AI/ML and automated calculations, it may be possible to plan for the use of pumps, flow rate and pressure, and time in the terminal, in a way that optimizes energy consumption. The AI/ML will learn overtime from the experience of the crew on the optimized use of the pumps (of course within the minimum and maximum parameters established in the regulations and by the terminal, parameters which should be integrated in the system as well from the cargo planning stage using the new CPU/software). This can be the default way of cargo planning.

See below, in Figure 11, a simplified depiction of the new proposed functions/updates.

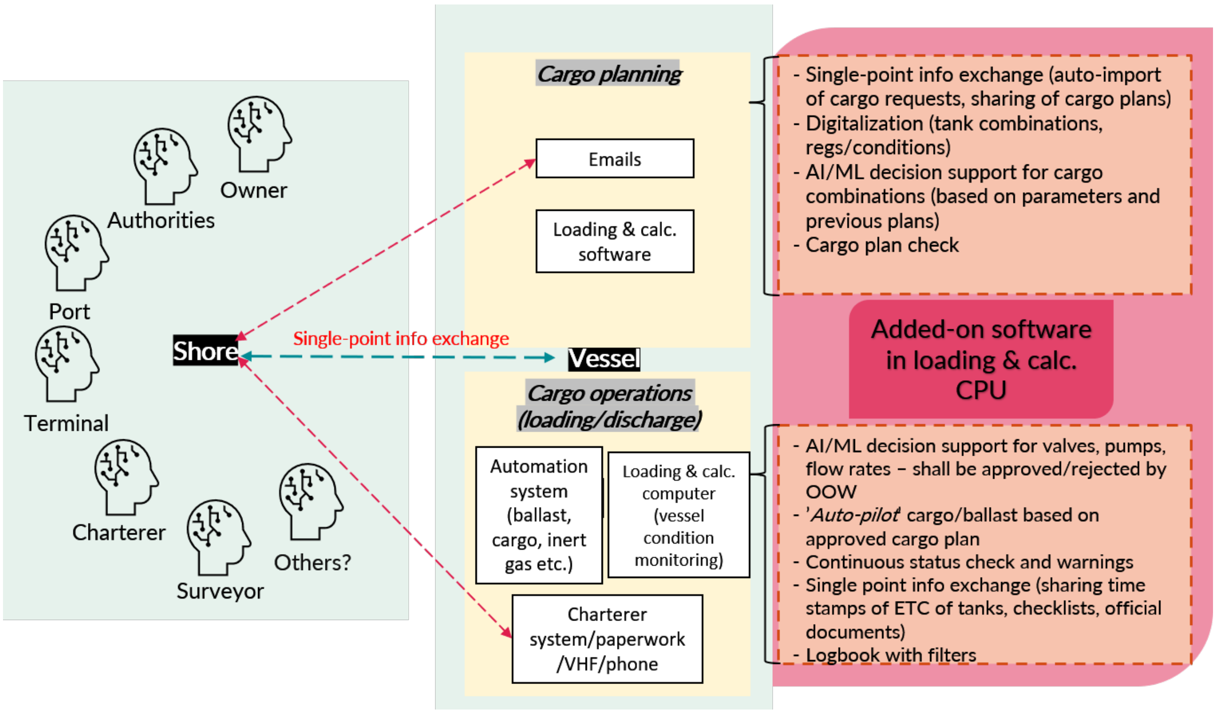


Figure 11. Depiction of current cargo handling management tools used during cargo planning and plan operations, and proposed added functions based on technical documents, interviews, and onboard observations.

Based on feedback from the crew, the manufacturers and the classification society, the level of automation and control proposed for the new solutions is to remain within the definitions in Table 6 (also in Table 4).

Table 6. Levels of automation and of control proposed for the solutions in this project (Bureau Veritas, 2019).

Levels of automation:	A1-A2 A1: Human directed (decision-support - system suggests, human decides which actions to take) A2: Human delegated (system invokes actions, human can reject or accept)
Degree of control:	DC3: full direct control - System is actively monitored and controlled at any time onboard

The proposed solutions should offer functions that support the 'business' side of cargo handling, understood as the cargo planning as well as the communication with shore and all documentation, and the 'operations' side, understood as the loading and discharging procedures.

These propositions might make it easier to share cargo plans before arrival at the quay, as the recently updated ISGOTT regulations require.

Although these propositions are made with the observed system in mind, the same propositions should be possible to be adopted by any cargo handling system provider and any tanker around the world.

3.3 Risks with the new proposed solutions

The proposal of new solutions is based on a will to provide added functionality and support to the users of the systems. Yet, this might come with new associated risks that need to be considered in the design stage and mitigated (possible examples are system integration failures, officers' loss of situational awareness). Two preliminary risk analysis workshops were performed during the project and they focused on the new risks potentiated by the proposed add-ons to the cargo handling systems (see section 2.4, p.14, for a description).

During the second risk analysis workshop, the industry participants were asked about how to implement the proposed solutions, and two options were presented by the project managers: 1) updating existing systems directly or 2) having a separate system (that might involve both hardware and software) that interacts with existing systems by receiving information and sending commands to the existing systems' graphical user interfaces. A manufacturer's representative, two ship owners and a classification society were present at the workshop and deemed the second alternative less cumbersome in terms of the class approval process. Also, should the new functions break down or not be needed, a separate system solution should always make it possible to more easily deactivate them without affecting the existing cargo handling systems, allowing the officers to proceed with the cargo planning and handling activities as they do today. The following discussions at the workshop were hence based on the decision and premise that the proposed functions would come from a separate CPU (hardware) that would communicate with the existing tank and ballast control systems and with the loading computer. During a following workshop, where the discussions with the cargo handling system manufacturers about the design concept were initiated, however, it was concluded that separate hardware would not be necessary. Instead, a separate software installed in the loading master should suffice to safely achieve the new functions being proposed. There should, however, not be an additional screen for the added software. The functions and commands coming from the added software should be sent to the existing systems and appear on the existing screens, integrated with the cargo and ballast control software and with the loading computer screen, and show decision-support pop-ups immediately next to the area or the valve that requires attention. The pop-ups with suggestions, predictions and warnings should appear even when the 'auto-pilot' function is not being used, to provide decision support to the users. The pop-ups can be shut off if the officer prefers. All functions and commands coming from the added software should be clearly marked as new functions so that the officers can distinguish them as coming from the added software and know that they can be shut off if needed.

Since the added software would receive data from existing systems, interpret the data and send out commands and suggestions based on such data, it is essential that the added software can detect loss of data or faulty data and inform the officer about that and have a self-check diagnostics for errors/malfunctions in the software, too. The added software would serve as redundancy for the existing systems in the event of faulty data. In case the software is disconnected or malfunctions, a status/mode check should inform the officer that it is off or on stand-by. This might then require the officer to proceed without the added software functionality. In terms of the 'auto-pilot', if the system is deviating from following the approved cargo plan, this should trigger a screen alarm for the officer and if the system is not able to self-correct, the officer may need to take over again (the system may automatically go into manual mode). The alarms and status information on the screen could be accompanied by a 'traffic light' solution, where *green* represents the automated system running smoothly and following the plan (with the officer monitoring, and with or without checkpoints for the officer to approve or override), the *amber* would represent a deviation from the expected path and an issue coming, and the *red* representing an issue and stopping the automation system from running and requiring action from the officer. The question is if this would require an interruption/shutdown of the cargo loading/discharging until the officer can get full situational awareness and take over the tasks, or if the officer would have enough situational awareness throughout the process and be able to take over immediately. To avoid the officers losing situational awareness, there could be check-points along the 'auto-pilot' which require the officer to confirm the next action. That way the officer might stay more informed of the sequence. If there is no response from the officer, the alert is sent to other available officers or the captain. Any system shutdowns (automatic or done by the officer) should be coordinated with shore.

Another point is if the systems are sharing faulty information back and forth and this goes undetected, this can lead to wrongful on-screen advice and wrong intervention. Hence, mitigation measures need to be put in place. Yet, according to the manufacturer present at the workshop, each system is already today responsible for the quality of the data and has redundancy built in to detect wrongful information. The role of the added software could be to receive the corrected data from all systems and identify if there are ambivalences/inconsistencies between them, offering even more redundancy to existing systems. However, the officers onboard need to know which system(s) to trust in case there is ambivalent information. The added software can also make use of AI/ML to detect corrupted data coming from sensors that might have otherwise gone undetected in an automated system, by checking what are probable or improbable values based on historical data of previous cargo handling events and on pattern recognition.

One additional point about corrected data refers to the 10-second delay issue mentioned under section 3.2 above (on page 21). The delay depends on how the hardware-software system is set up, and on the computer calculating and sending data between systems, and this differs between different vessels and system manufacturers. If this would also be corrected directly in the system (and raw values at the back of the system), the officers must know that the data are corrected for that. Cybersecurity is also necessary (by using trusted sources and secure certificates between the different computers), along with prioritization of alarms.

Using AI/ML to support the officers in calculating the estimated time of completion (ETC) of a cargo handling process was discussed. This would be based on the approved cargo plan as well as on previous cargo plans, perhaps of the same grade and at the same terminal. This technical possibility was perceived by the classification society members present as a risk mitigator and facilitating factor to understand that something might be wrong if the officer's ETC differs very much from the ETC being provided by the system. The system's ETC could as well be directly shared with the shore via this project's proposed system.

For the description of the identified risks for some of the proposed changes, see Table 7:

Table 7. Potential new risks of each of the proposed changes to the identified gaps.

Current system – Gap analysis	**Proposed solutions**	**New risks**
The CO manually calculates draft, density, trim for splits and denominations in tanks.	The loading computer to automatically calculate and offer cargo plan suggestions based on given parameters, and in the future using ML based on previous cargo plans. Officer can approve or reject suggestions and make manual adjustments.	*The risk associated with this is if there is incorrect input data for any reason. Yet, before the CO approves the plan, he/she will check the plan and so will the computer, with a simulation tool identifying errors in the plan.*
Regulations/conditions that affect operations (e.g., rate of speed for loading/discharging specific grades; terminal specificities) are fixed/static information but need to be inserted into the system from scratch for every cargo plan.	• Digitalize fixed information into the system; • System to offer cargo plan suggestions with such information in mind, considered into the calculations (and with ML optimization from previous plans); • Offer simulation-check of cargo plan (similar to existing voyage plan check) checking if the cargo plan presents any errors/deviations from previous cargo procedures (using AI/ML). This check should present warnings to the officer if something is deviating from the norm, and suggesting a solution; • Self-check of the technical systems (sensors etc) checking if the hardware is functioning properly before the plan is executed.	*Not discussed.* *Yet, it was mentioned that for the decision-support pop-ups, the 'auto-pilot' and the 'eco-mode' to run, the minimum and maximum parameters established in the regulations and by the terminal need to be integrated in the system, and this should not present any added risks than it does today as the cargo plan needs to be approved before it is run, and during the cargo loading and discharging, the systems will be monitored and controlled by the officer through various check-points and pop-ups for decision support to be approved or dismissed.*

Event: Jetty asked the CO for estimated time of completion of cargo loading but the CO could not estimate average per hour before one hour had passed, and with loading rate fluctuations.	• AI/ML to provide ETC estimations based on previous cargo plans or calculate based on current plan • Share with terminal (in a way the terminal understands the validity of the information and cannot use the information for other activities such as order of pilots etc.).	*Using AI/ML to support the officers in calculating the estimated time of completion (ETC) of a cargo handling process was discussed. This would be based on the approved cargo plan as well as on previous cargo plans, perhaps of the same grade and at the same terminal. This technical possibility was perceived by the classification society members present as a facilitator to understand that something might be wrong if the officer's ETC differs very much from the ETC being provided by the system. The system's ETC could as well be directly shared with shore via this project's proposed system.*
There is a 10-second delay from radars/sensors to screens. The CO left allowance of 10-20m3 of cargo due to this to avoid spillage during topping off. Besides this, space left in the tank for e.g., adding additives to grade or draining the hose arms/manifold could also be needed (the CO left an extra 1,5m3 of space left for drainage).	• Make a correction for the 10 seconds in the software system, with an on-screen warning for the officer; • Use AI to remind the officer for space for additives or arm drainage as well.	*The delay depends on how the hardware-software system is set up, and on the computer calculating and sending data between systems. This differs between different vessels and system manufacturers. If this would also be corrected directly in the system (and raw values at the back of the system), the officers must know that the data are corrected for that. Each system is already today responsible for the quality of the data and has redundancy built in to detect wrongful information, but the role of the new CPU/software could be to receive the corrected data from all systems and identify if there is ambivalence/inconsistencies between them (and the officer needs to be told which system to trust in this case), and to make use of AI/ML to tell if there are value deviations from the norm based on historical data.*
Density values were ambivalent in loading computer and valve screen.	• Fix inter-system communication and alert the officer when values are shown inconsistently, along with support for the officer to interpret the values and which to trust; • Offer self-check during cargo operations to warn if there is anything clashing in terms of inter-system communication or deviating from the approved cargo plan, presenting alarms/warnings. This includes a self-check of the technical systems (sensors etc) checking if the hardware is functioning properly.	*Same as above.*

Adjusting cargo rates in the different tanks requires compensatory ballast adjustments and vice-versa. The officer is often operating two systems simultaneously. The pressure and flow will be limited by how quickly the ballast tanks can be loaded or discharged. Officer is communicating with the terminal about trim and stability simultaneously.	• The valve control software (for tanks and for ballast) to provide on-screen reminders, predictions, and suggestions to the officer about ballast adjustments in relation to changes to cargo tanks, and vice-versa, and in relation to the cargo plan; • The system to offer an on-and-off function for the computer to run valves automatically according to the approved plan and if the officer so chooses, with on-screen information about the actions, and maintaining an automatic log. The officer can turn it off and manually control the valves; • This 'auto-pilot' function should have a continuous status warning showing whether it is on, off or on stand-by potentially waiting for the officer to take action on an on-screen suggestion or alarm.	*To have a separate CPU/software that interacts with existing systems by receiving information and sending commands that would be integrated in the existing systems' graphical user interfaces was deemed a good solution in terms of the approval process and in case the new functions were to break down or not be needed, since a separate system should always be possible to disconnect and the officers should be able to proceed with the cargo planning and handling activities as they do today. The functions and commands coming from the added CPU/software should be sent to the existing systems and appear on the existing screens, integrated with the cargo and ballast control software and with the loading computer screen, and show pop-ups immediately next to the area or the valve that needs attention. The functions and commands coming from the added CPU/software should be clearly marked as new functions so that the officers can distinguish them as coming from the added CPU/software and know that they can be shut off if needed.* *Since the added CPU/software would receive data from existing systems, interpret the data and send out commands and suggestions based on such data, it is essential that the CPU/software can detect faulty information and inform the officer about that, and have a self-check diagnostics for errors/malfunctions in the CPU/software too. In case the CPU/software is disconnected or malfunctions, a status/mode check should inform the officer that it is off or on stand-by. This might then require the officer to proceed without the CPU/software functionality. For the 'auto-pilot', if the system is deviating from the approved cargo plan, this should trigger a screen alarm for the officer, and if the system is not able to self-correct, the officer may again need to take over from there. The status checks and alarms can be accompanied by a 'traffic light' solution from when the automation is running smoothly to when the cargo process needs to come to a halt. To avoid the officers losing situational awareness, there could be check-points along the 'auto-pilot' which require the officer to confirm the next action. That way the officer stays more informed of the sequence.*

Energy consumption of flow rate compared to pressure on manifold, number of pumps in operation, etc. – eco-mode/energy-saving mode operation (on/off or default function, like a dish-washer's eco-mode).	With the use of AI/ML and automated calculations, it may be possible to plan for the use of pumps, flow rate and pressure, and time in the terminal, in a way that optimizes energy consumption. The AI/ML will learn overtime from the experience of the crew on the optimized use of the pumps (of course within the minimum and maximum parameters established in the regulations and by the terminal, parameters which should be integrated in the system as well from the cargo planning stage using the new CPU/software). This can be the default way of cargo planning.	*No new risks detected.*

One of the main risks we see here with the increased automation is the potential increase of sudden automatic stops to the operations as soon as something faulty is detected by the system which might require the officer to regain full familiarization and manual control of the operations. This must be handled in the design of the systems somehow or even assessed if the increased automation will bring more hassle than benefit in some cases. Just because the technology is available, it does not mean it must be used in every context. This was discussed in this direction by group 2 in the information exchange workshop.

In terms of potential blackouts, the hardware and software systems are already today backed up by uninterruptible power supply/source (UPS).

3.3.1 Concept progress throughout project

The start of the discussion around the design concept was divided into having a set of new functions directly integrated into the existing software, like a common software upgrade, or to having a separate hardware and software for the new functions altogether. Since the existing softwares are class-approved, it was decided that these should not be upgraded with the new functions directly but that the new functions should instead come from a separate software that communicates with the existing ones. It was even decided then that the new software should be installed in a separate, added-on, CPU (hardware) for redundancy. An added-on screen for the new software would however not be necessary.

At a later meeting, the additional CPU idea was dropped as the new software alone was deemed sufficient. The software would be installed in the existing loading calculations CPU. The software would receive data from existing systems and would send commands back, including the 'auto-pilot' commands. The OOW would deal only with the screens and software that they deal with already today, not needing to interact with the new software, which would run in the background.

However, at later meetings, it was decided that the CO should now be required to interact with the new software and input data into its graphical interface during the cargo planning stage, rather than using the existing loading calculations interface. The loading calculations software would still run in the background. This makes training of the officers essential to be able to learn the new software interface and functions.

3.4 Information exchange needs

One important aspect of planning, loading, and discharging is the sharing of certain information and documents related to the loading plans, the execution of the loading plans and associated logbooks, checklists, and reports, from ship to shore. Thus, a part of this project has been to identify ways to unify communication and documentation where possible, perhaps via a single platform/cloud/app connected to the existing cargo planning and control systems using APIs. There was hence one workshop dedicated to the topic of information exchange needs to find out what information is exchanged between ship and shore operators and what information should remain undisclosed. Section 2.3 above (on page 13) describes how the workshop was organized. Table 8 below presents the main results of the workshop.

Table 8. Results from the information workshop, with information exchanged between ship and several shore stakeholders. The shore actors highlighted in yellow were added by the participants during the workshop.

	Vessel			
Questions / **Actors**	What information needs to be exchanged between ship and each actor? **c)** Business-related data **d)** Safe operation-related data	Related to first question, are there any data that they do not want to share/make accessible to each other due to security/safety/business or other reasons?	What common reports can be generated by/part of the new communication layer? (e.g., ullage report)	How can we make this exchange more seamless (tech solutions)?
Ship owner	• Voyage instructions (grades to be loaded etc) • Ship-shore safety checklist (PDF by email) • Cargo handling plan (pdf by email) • Start pumping • Start loading • Stop loading • Change of rate • Alarms • ETC • Stop (decided from vessel or shore? Should have to be agreed)	• No	• Port activity app in Gävle (terminal, port, vessel) - Virtual arrival (notice of readiness) so ship can reduce speed and still keep the queue • If data are available, any report can be generated by aggregation of data. E.g., Ullage report is already produced in loading computer (on NAPA)	• Rest API • Standardized JSON code schemas

Agency *(hub for info sharing between vessel and terminal – info goes through agency and they order pilot and tugboats etc. But sometimes it is the ship owner who performs these tasks rather than an agency)*	• Arranging with the call – information sharing between the vessel and the harbour. Arranging with the tugboat etc.	• Most information between agency and ship owner is not to be shared except for ETA and departure time		
Authorities	• E.g., Sjöfartsverket/Transportstyrelsen, Marine single window (in MSW everything regarding slop, sludge, 24-hour vessel notification, etc.) • ETC • Incidents	• No	• If data are available, any report can be generated	• Rest API • Standardized JSON code schemas
Port	• 24-hour vessel notification • Ship-shore safety checklist (email) (First part “Pre-arrival”) • The cargo type - check which loading arm size to be used • Emergency incidents information in case of emergency (future?). Today’s officer is taking it via VHF • Emergency guide on gangway(?) • ETC	• No	• Similar to Port activity app but by port of GOT – with ETC/ETD in the port • If data are available, any report can be generated	• Rest API • Standardized JSON code schemas

Terminal *(e.g., Preem/ST1 terminal etc.)*	• Check that we have the same grades and quantity • Ship-shore safety checklist (pdf by email) • Loading plan (operational agreement) • Environmental details such as sludge and slop discharge, fuel consumption • Statement of facts • Cargo docs • Note of protests • Ullage report • Dry tank certificate -signed by the surveyor • Notice of readiness • Loading log • Bill of lading - Issuing cargo documents • Certificate of quality and origin • Custom documents • Pumping speed and pressure • High level alarm tests before operation (operational agreement) • Emergency stop • Flow meter data • VHF channel for communication • Start pumping • Start loading • Stop loading • Change of rate • Alarms • ETC • Stop decided from vessel or shore? Should have to be agreed		• Almost everything – but not the cargo details • Final product can be shared – but the content in the for-example diesel cannot be shared • If data are available, any report can be generated • Ullage report	• Rest API • Standardized JSON code schemas

Charterer *(e.g., Neot etc.)*	• Statement of facts • Cargo docs - bill of lading • Note of protests • Ullage report • Dry tank certificate -signed by the surveyor • Notice of readiness • Loading log • Ship shore safety checklist (to be shared in future)	• Unknown but must be a lot(!)		
Surveyor	• Cargo calculations • Sample takings • Ullage taking • Dry tank inspections in case of loading • Cargo handling plan (Email)	• Unknown but must be a lot(!)		
Class	• Alarms • ETC		• If data are available, any report can be generated	• Rest API • Standardized JSON code schemas
Shipper *(this category was ambivalent for the participants. The 1st group considered it as the same as charterer or more an actor that works with dry cargo; the 2nd group considered shipper the same as terminal or charterer) à we assume it as charterer*	• Ship shore safety checklist (future) • ETC			
ODEC *(company doing jetty watch and connecting/disconnecting loading arms)*	• Info on vessel's arrival and departure	• Possible to share most information		
Stena recycling/ NES-Northern energy supply	• Unloading sludge/slop	• Possible to share most information		
Mooring crew company	• Ship arrival	• Possible to share most information		
Pilot/tugs	• Ship arrival, booking	• Possible to share most information		

Bunkering *(with other actors and as a simultaneous operation)* **or jetty work** *(which can hinder or be hindered by loading/discharging procedures)*		• Possible to share most information		

In the relationship between the vessel and the terminal, sharing cargo operation data can be sensitive. The main information to share with the listed shore operators were the ship-shore safety checklist (normally shared by email), the cargo handling plan (also by email), the start and end of loading, change of rate, ETC, alarms, slop and sludge discharge, incidents/emergencies, statement of facts, cargo documents, note of protests, ullage report, dry tank certificate (signed by surveyor), notice of readiness, loading log and the bill of lading. The main shore operators for the vessel to share information with are their ship owner, the charterer and the terminal manager where they will load or discharge. During the loading and discharging operations, the most important line of communication is the vessel and the terminal. Any of the information in the cargo planning and control systems should be able to be sent automatically and/or generate reports in the system. Different parts of a port stay require different information exchange and different shore actors require different information. It should not be the same for all actors, hence the officer onboard should be able to select the exact information they wish to share with whom, and shore actors should be able to send the vessel requests via the same platform.

In terms of risk mitigation, the more information that can be shared between ship-shore, the more checks and balances will be made in the system to identify deviations and issues. This would provide added redundancy although there might be added security risks and information overload.

The port activity app being currently developed by Port of Gävle and Port of Rauma in Finland within an EU project is seen as a good starting point for an information hub/platform for the cargo handling context. An interview with Port of Gävle was performed in this project to request more information on what the app includes. Based on the interview, the tool is defined as an information "showroom" like Maritime Single Window (MSW), where everyone can get a common view of vessel arrivals. It is not a decision-making tool. The app offers timestamps that are estimated and actual. The "showroom" is connected to connectors/APIs from different underlying systems and hence everyone owns their own data but they share them in this app to offer a common view to all. MSW is connected to this app (Port of Gothenburg has a similar solution of their own connected to MSW as well), ship information like AIS (with Machine Learning to estimate time of arrival and departure), STM, pilot systems and terminal systems, etc. The app also includes a feature for the loading masters of tankers where they can insert different cargo types/grades, pumping rate for each grade, and some extra time for sampling or paperwork etc., for an estimation of their time of completion [*an internal comment: this sort of information should not need to be inserted by the loading master in the future; it should be shared directly from the cargo handling systems*]. This information comes from the terminal and not the ship, because most tankers are lacking the functionality to share the pumping rate etc. with shore. Paperwork like Statement of Facts, tank sheets, pumping logs, can also be taken out of the app. Information that might be interesting for competitors is sensitive and stays out of the app, but important and official outputs and timestamps are transparent in this case (the outputs and timestamps they want to share are selected by the information owners).

Yet, different ports, like Port of Gothenburg, are working on developing own solutions, which can make it very difficult for ship owners to keep track.

Another app Port of Gävle is developing is "Just in Time" with Preem and Terntank. This is to plan vessel arrival to be able to navigate while slow steaming. The app will provide a recommended time of arrival based on a queue of ships. Testing is to be done in the autumn of 2021. Port of Gävle is interested in having more of a vessel perspective in the apps as well, and to be able to reduce the vessels' time alongside for energy efficiency. This is a collaboration that could arise from this project.

Sharing certain data that are not shared today could in some cases make for a more transparent operation, yet require new types of charter parties, the clear definition between *data* and *event*, etc. With technology suggested by Maranics, it ought to be possible to create a common log used both by shore and the vessel, for the full harbour operation.

It was deemed during this concept study that ship-shore communication and associated tools/platforms used today are an area of high complexity that involves many stakeholders and can lead to potential collaborations in separate projects with organizations already working on novel communication applications today. Hence, the design concept in this project will not include any updates to the ship-shore communication tools/platforms and will focus solely on cargo handling and systems relating to cargo planning and operations.

3.5 Resulting design concept and guidelines

A series of meetings during the last project period took place with the external project partners, experts in cargo handling hardware and software, and internally, to make decisions on the technical architecture and integration of the proposed novel cargo handling functions.

Figure 12 summarizes and depicts the add-on system proposed to the partners based on the data gathered by the project team during interviews and onboard observations (excluding ship-shore communication aspects).

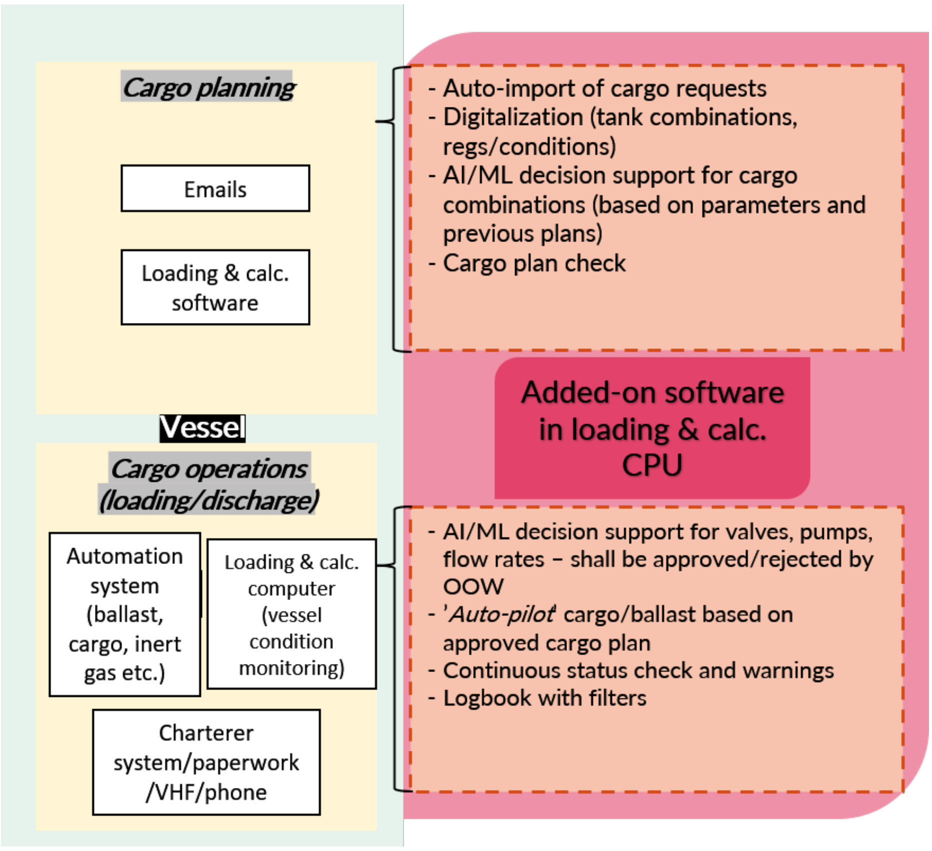


Figure 12. Depiction of cargo handling management systems and tools with add-on CPU/software providing novel commands, based on the onboard observation, interviews, and industry workshops.

It was discussed during the first design concept meeting that a separate software with the new functions should suffice rather than a separate CPU (hardware) as had been proposed earlier in the project. It was also defined that the 'auto-pilot' function should offer three levels to the user:

1) MANUAL MODE: The officer chooses not to use the 'auto-pilot' and handles the cargo loading/discharging procedure manually as done today, except that the new software will now offer decision support during the procedure consisting of on-screen pop-up suggestions sent to the automation software (cargo tank and ballast tank control screens). These suggestions can be rejected/skipped by the officer or approved. If approved, the new software will send a command to the automation software to perform that suggestion automatically (e.g., reduce the flow rate of cargo into tank 1 and 2).

2) SEMI AUTO-PILOT: Officer chooses the 'semi auto-pilot'. This entails that the new software runs the approved cargo plan automatically by regulating valves and pumps while the officer monitors the procedures, except for during critical parts of the loading/discharging procedure where the 'semi auto-pilot' stops running (e.g., topping off tanks). While the 'semi auto-pilot' is running, the automation software will have on-screen information of what is ongoing with loading/discharging. This information is sent from the new software. When the 'semi auto-pilot' stops running for critical moments, the new software will still send instructions/recommendations to the automation software that the officer can reject/skip or

approve. Upon approval of an on-screen recommendation, the new software will run the recommended action automatically (e.g., to automatically reduce the flow rate of cargo into tank 1 and 2).

3) AUTO-PILOT: Officer chooses full 'auto-pilot'. The new software will run the approved cargo plan automatically while the officer monitors it. During this process, the automation software will have on-screen information of what is ongoing with loading/discharging, sent from the new software.

The process charts below (**Error! Reference source not found.**-Figure 16) depict the various tasks/parts of cargo planning and operations that the new software will affect.

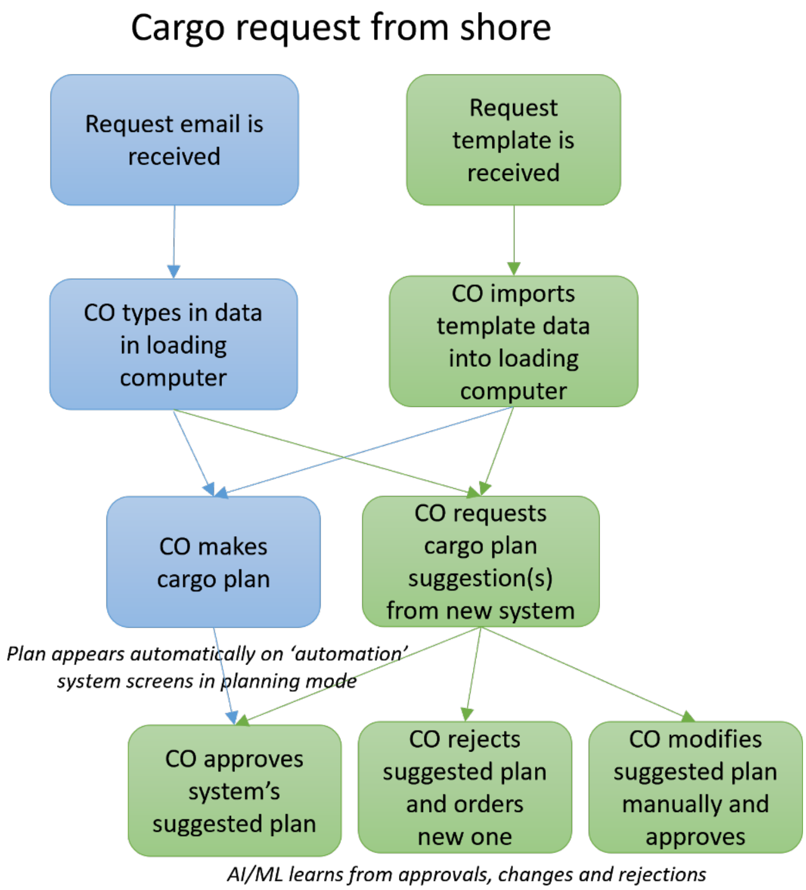


Figure 13. Cargo request from shore – diagram of possible steps taken by CO onboard.

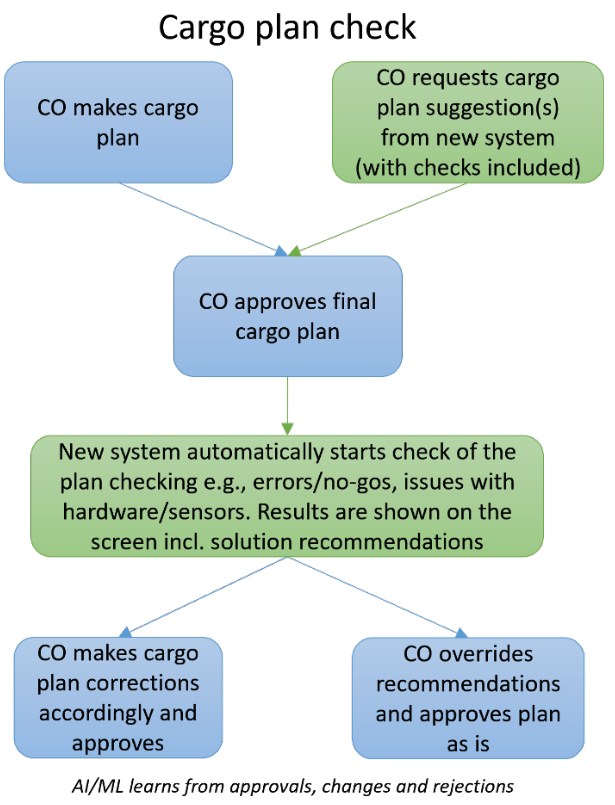


Figure 14. Cargo plan check – diagram of possible steps.

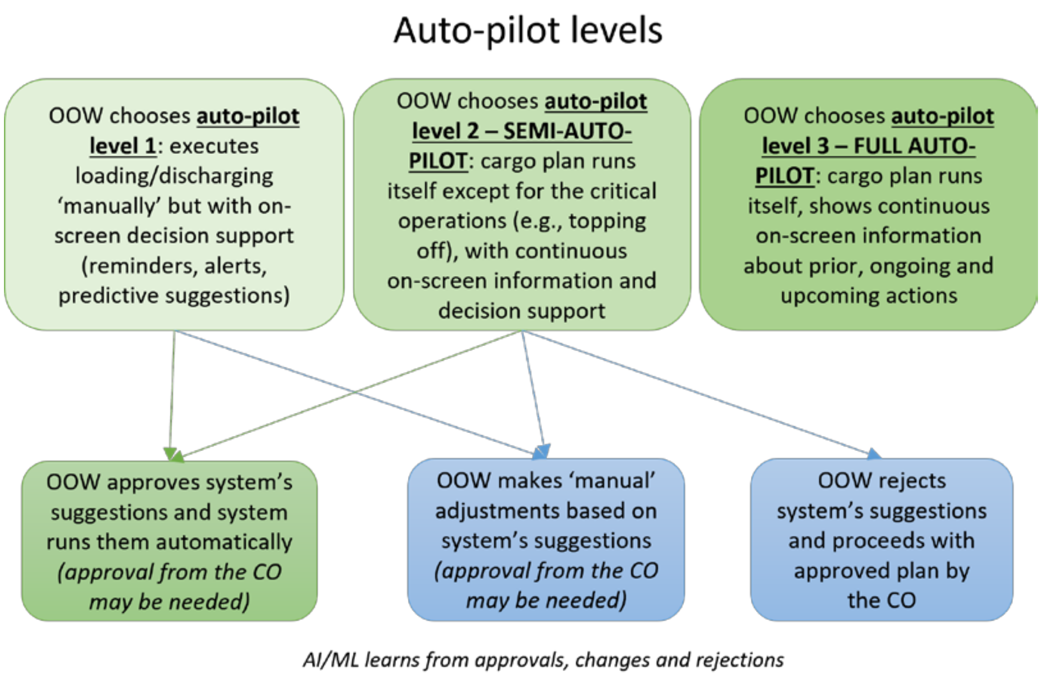


Figure 15. Levels of 'auto-pilot' – diagram of possible steps. The running of 'auto-pilot' is continuously shown on the automation system screens (cargo & ballast) in real-time (this is done via communication between the new system and the automation computer and loading computer). Based on the approved cargo plans, the new system can provide the automation computer with predictions of e.g., the estimated time of completion for a loading/discharge procedure.

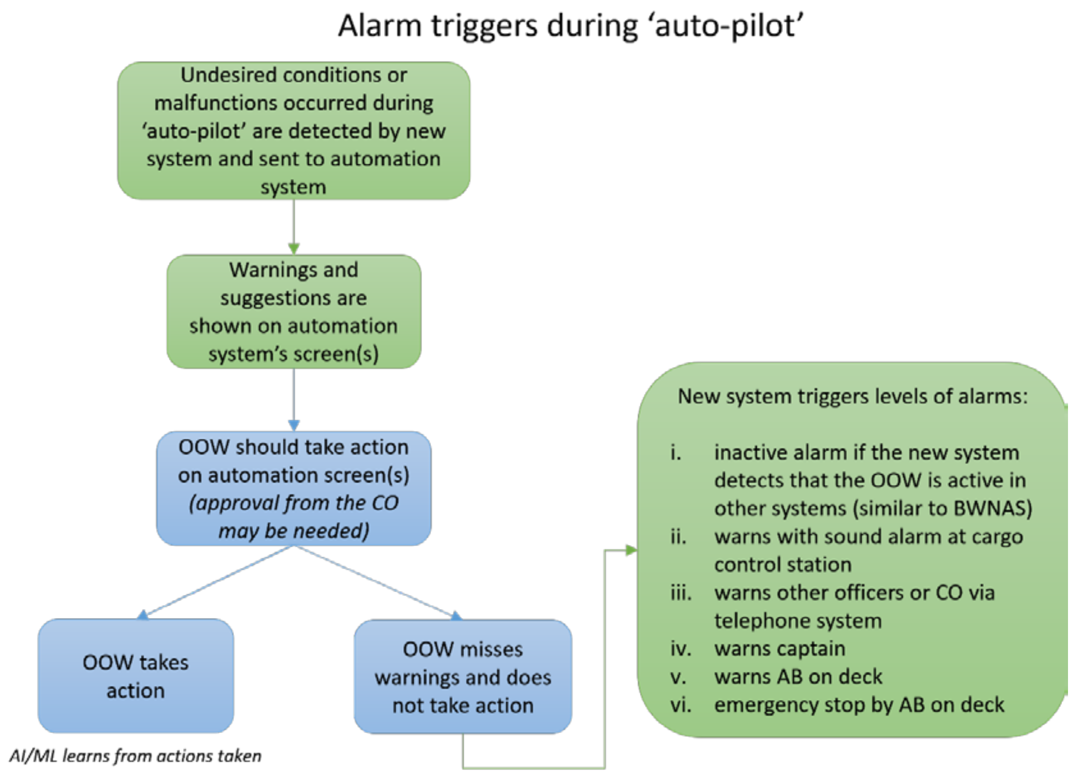


Figure 16. Undesired conditions or malfunctions during 'auto-pilot' and levels of alarms – diagram of possible steps.

For both the cargo planning and operations to be performed using the new proposed software, inter-system communication will be necessary between the new software and the existing cargo management software onboard. Table 9 below presents the communication lines between software and respective levels of communication/permissions being proposed in this project.

Table 9. Inter-system communications and levels/permissions between software for cargo planning and operation.

Cargo planning and Operation ('auto-pilot' levels 1, 2 and 3)	**Level gauging system/software (background system with no use interface)**	**Automation software**	**Loading calculation software**	**New proposed software**
Level gauging system/software (background system gathering sensor data, with no use interface)	-	as is	as is	-
Automation software	as is	-	as is	Sends data, receives data/commands ('auto-pilot' 1,2,3)
Loading calculation software	as is	as is	-	Sends data, receives data (offline)
New proposed software	-	Sends data/commands ('auto-pilot' 1,2,3), receives data	Receives data, sends data (offline)	-

3.5.1 Alarms and alerts

This section lists in the following Table 10 the static and dynamic operational alarms and their triggers that are relevant in the updates proposed in this project. Manufacturers of the new added software need to consider said alarms and set their limits based on operational and manufacturing conditions as well as the vessels' construction etc.

Table 10. Matrix for static and dynamic alert and alarm triggers.

Data source/sensor	Dynamic	Static	Note
Draft	x		
Trim	x		
List	x		
Cargo/slop valves position	x	x	Dynamic for risk of cargo contamination. Static alarms to eliminate risk of cargo loop transfer
Ballast valves position	x	x	Static alarms to eliminate risk of ballast loop transfer
Cargo/slop tank temperature	x	x	Min/max cargo temperature dynamic. Construction, coating min/max static
Ballast tank temperature	x		
Cargo/slop tank press		x	
Vapour return pressure	x	x	Dynamic agreed min/max, Static design max pressure
Ballast tank press		x	
Cargo/slop line press	x	x	
Cargo drain tanks ullage	x		
Cargo/slop tanks ullage	x		
Ballast tank ullage/innage	x		
Cargo/Slop pump pwr/amp		x	
Cargo/slop pump rpm		x	
Cargo/Slop pump press in/out	x		
Manifold press	x	x	Max/Min back pressure dynamic. Design pressure static
Manifold temperature	x		
Cargo/Slop pump bearings temperature		x	
Ballast pump pwr/rpm		x	
Ballast pump press in/out	x		
Ballast pump bearings temperature		X	
O2 content after burner	X	X	
IGS O2 content in percent	X		
IGS pressure		X	
IGS system generated alarms		X	
BWMS		X	All alarms generated by system (UV rad, flowrates, pressures)
Water temperature after Tank C heaters/Coolers	x		
Cargo flow rate	X		
Time to tank completion	X		
Time to operation completion	X		
Anomalies on flowrates	X		
Hi and HiHi level (95-98%) Cot		x	
Service air pressure	x		
N2 system pressure	X		

Static triggers – set points based on technical limitations etc
Dynamic – triggers set points based on operational limits
Hybrid = Dynamic/Static

The data available from the system could also be used to generate operational reports to see status and potential anomalies within the different systems.

4 Discussion

During the observations onboard, it was made clear that the cargo operations are complex, involve many actors and information, and much of it is dynamically occurring and requiring decisions and actions to be taken by the officer there and then. The intention of this project is not to propose an autonomous cargo handling system that will replace the role of the officers onboard, but to propose an updated system with new modern features that can facilitate/support cargo planning and a typical cargo loading/discharging procedure by providing more digitalization and decision support based on data to the officers. On top of this, an optional 'auto-pilot' function is being proposed for running valves based on the officer's cargo plan.

In terms of having a separate CPU, the pros and cons were discussed, and it was deemed sufficient to have a separate new software installed in the loading master. However, for testing the proof of concept, separate hardware might be used. Eventually even separate software might not be necessary and the same functionality integrated in the existing software systems as system updates instead, including a) improvements to the existing loading computer with rules and regulations and tank combinations integration; automatically calculating trim etc; an option to propose a cargo plan based on such parameters as well as on previous cargo plans (using ML); running an automated simulation/check before the approval of the cargo plan; and b) getting on-screen decision support 'pop-ups' and having the option to run the 'auto-pilot' and the 'eco-mode' functions connected to the existing cargo planning and control systems using APIs.

To be carefully considered with this new proposal is that:

- the officers will type in information and use the new functions directly within the new software, meaning that the new software requires a user interface and possibly a new screen, which is not what had been previously agreed upon due to the impact on the officers.
- this also means that the officers need to learn yet a new user interface and change their common use of the loading calculation interface, since the cargo planning is now almost entirely done in the new software instead.
- there will be cybersecurity aspects of data exchange and legal aspects of the 'auto-pilot' to be taken into consideration together with the classification societies.

The design concept and guidelines proposed here are intended to be further developed and tested in a follow-up project dedicated to the proof of concept.

4.1 Limitations

Due to the covid-19 pandemic, the opportunities for vessel visits were limited and only one vessel was visited (vessel Ternsund). This limited our observations and perspectives of the use of the systems to one single ship and bridge crew. Other officers might have performed the same procedures or used existing systems slightly differently.

Although this project was aimed at a Swedish perspective and project partners, and at the collaboration with selected tanker companies and system providers, the takeaways from this project should be applicable to any cargo handling system provider and any tanker around the world.

5 Conclusions and future work

This concept study investigated existing cargo handling systems onboard oil and chemical tankers, especially how the different softwares are connected to each other and what functions they allow the officers onboard to execute. It was concluded that aspects of the existing systems in terms of cargo planning as well as operations (for loading and discharging) can be improved to provide better assistance to the users with better utilization of information and historical data, decision support, integration and automation at A1-A2 automation levels (Bureau Veritas, 2019). The following updates are some of the main ones being proposed for cargo planning, loading/discharging in this project:

- Digitalizing rules and regulations, as well as possible tank combinations, etc., necessary for each cargo planning alternative;
- Importing cargo requests from email format directly into the planning software;
- Offering a function that calculates trim and stability automatically and goes through possible cargo plans based on input parameters and historical data, and suggests an optimal cargo plan;
- Using machine learning to record historical data and identify patterns that can suggest better cargo plans over time;
- Offering predictions, decision support and alerts during planning and operations based on historical data, on identified malfunctions, and on approved cargo plans;
- Using machine learning to record historical data of 'rejections' and 'approvals' of system suggestions to provide better decision support to officers over time;
- Offering an 'auto-pilot' function to run the approved cargo plan in terms of opening and closing valves and adjusting flow rates;
- Maximizing utilization of the digital logbook on the automation computer to facilitate archiving onboard and reporting to shore-side.

Further work will include a funding application for a continuation project where a proof of concept will be tested. This will focus on updating the cargo planning and operations processes onboard oil and chemical tankers. This will look at existing software for cargo monitoring and control and incorporate the new proposed functions for information integration, intersystem communication, decision support and automation. This will not include any updates to the ship-shore communication platforms used today, as this was deemed during this concept study as an area of high complexity that involves many stakeholders and can lead to potential collaborations in separate projects with organizations already working on novel communication applications today.

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