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Executive summary

This report contains the results of the in-depth qualitative and quantitative analysis of the concept of an autonomous vessel as developed in the MUNIN project. It covers three dimensions: safety and security impacts, economic impacts and applicable areas of law.

The MUNIN project has principally shown that an autonomous vessel is technically feasible. The hazard identification and the corresponding risk control options have been shown on a qualitative level to be sufficient to make the unmanned ship a feasible concept. A full quantitative analysis has not been done as for many risk control options this requires a much more detailed system design than the MUNIN project has been able to provide. However, an in-depth analysis of collision and foundering scenarios for the MUNIN ship was conducted as part of the work on a master thesis. The results from the analysis show that for the foundering and collision scenarios the MUNIN ship has a lower risk than a conventional vessel. This report also includes a short assessment of propulsion and steering reliability which together with foundering and collision arguably are the most critical events that can be expected.

In the financial analysis this report argues that a MUNIN bulker would be commercially viable under certain circumstances. The added value of the concept relative to a base case “conventionally manned bulker” is determined as the difference between cost savings (reduced expenses for crew, better fuel efficiency) and additional investments and costs (higher initial investments, new shore and port based services). In a base scenario the MUNIN bulker is found to improve the expected present value by mUSD 7 over a 25-year period compared to the reference bulker. While still associated with a high level of uncertainty - due to the early stage of concept development and the limited scope of the project MUNIN – the results show that the trend of reducing crewing levels further will quite likely become a reality on many modern ships. This is for one reason in particular as this analysis will argue: besides cost savings associated with reducing crew levels an autonomous ship brings along the potential to create additional benefits due to changes in ship design.

The legal analysis provided in this report is both broad in scope and in depth. It covers all important points identified following a detailed analysis of key technical results of the MUNIN project. Namely, this analysis covers: legal issues regarding navigation, manning in the Shore Control Centre (SCC) and engine and maintenance. It then discusses overall issues of contractual, tort and criminal liability in the context of an unmanned ship, and concludes with an explanation of likely insurance issues arising out of the operation of an unmanned ship. The main conclusions are that the existing legal framework will

require some formal amendments, where it currently explicitly requires to have recourse to human input, or where it requires specific pieces of equipment. However, there are no fundamental substantive obstacles in law which could not be overcome. As the project confidently demonstrates that the MUNIN unmanned ship can operate at least as safely as a traditional manned ship, the law can be adapted.

List of Abbreviations

ABS	American Bureau of Shipping
B0	b zero (scenario in MUNIN, where the bridge is partly unmanned)
E0	DNV Class notation for periodically unattended machinery space
HFO	Heavy fuel oil
kn	Knots
kW	kilowatts
m	Meter
MCR	Maximum continuous rating
MDO	Marine diesel oil
mUSD	Million US Dollar
NP	Nominal power
NPV	Net Present Value
PSV	Platform supply vessel
t	Tonne
UAV	Unmanned Autonomous Vessel
WACC	Weighted average cost of capital
WP	Work Package

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1 Introduction

Building on the results presented in the previous reports on the assessment of the concept of an autonomous vessel as developed in the MUNIN project this report will continue with an in-depth qualitative and quantitative analysis. Three dimensions of particular relevance within MUNIN are covered by the different project partners involved in the assessment of an autonomous ship. Marintek was responsible for a safety and security analysis, the financial analysis was provided by Fraunhofer CML and applicable areas of law were analysed in depth by University College Cork.

A master thesis did an in depth study of collision and foundering scenarios and the main results from that is included in the report. The conclusion is that the unmanned ship presents a slightly lower risk of an accident happening and additionally consequences will be lower. The analysis also included other scenarios that could cause a collision or foundering such as, e.g. fires, machinery problems, SCC problems and navigational system errors. On other types of safety hazards such as ship dead in water or hijacking, only a semi-quantitative analysis is provided. This is partly because of a lack in detailed statistical data and partly because a detailed analysis needs a more detailed design of the autonomous vessel technical systems. Although there is significant uncertainty in all these analyses, the results points toward the original assumption that unmanned ships are at least as safe as manned ships. The safety and security issues are discussed in Chapter 2.

The economic in-depth assessment in Chapter 3 focuses on the economic viability of the concept for an autonomous ship as developed in MUNIN. Crew size of ocean going ships has been reduced significantly over the past. Whether this development will continue in future depends on the impact smaller crews (along with more sophisticated technology on board) have on the profitability of shipping companies. Unless an innovation – in this case the autonomous ship - is commercially viable it is not going to be adopted. Thus the quantitative cost-benefit analysis in this report focuses on the economic feasibility of the developed concept by taking on a microeconomic view on operating cost, voyage cost and capital cost. Based on a shipping cash-flow model potential cost savings associated with the MUNIN concept as well as additional costs of an autonomous vessel are identified and estimated quantitatively. In a scenario approach the expected present value of cost over the lifetime of the autonomous ship is calculated and compared with a conventional vessel. The results of the financial analysis show under which circumstances and assumptions an autonomous ship – in this case a bulk carrier - is favorable compared to a conventionally manned ship and also allow an estimation of the order of magnitude the cost over the lifetime of the vessel are lower (or higher).

The legal analysis in Chapter 4 follows the technical findings made in the MUNIN project. Its objective is to determine which rules or areas of law would need change to allow an unmanned ship to be fully compliant with a modern legal system. The analysis considers extensively and in depth all relevant issues arising in International Law. It was originally believed that it would also be necessary to consider Civil and Common Law issues in depth, however, as progress went on, it appeared that all important and necessary legal issues were arising under International Law. Indeed, it is now clear that any change that will be required to the current legal system will have to be done by way of international action (at IMO level for example), rather than by internal modifications. Therefore, the report focusses its attention on this level of law, while also providing some examples taken from the UK Common Law. To this end, the legal analysis is divided into 5 sections. First, the issue of navigation is examined, particularly as the MUNIN unmanned ship would operate without a 'human' look out being physically present on board for the deep sea part of its journey. Second, manning requirements are considered, from the point of view of the ship masters' responsibilities, and crewing needs in the Shore Control Centre. Third, the operation of the Automatic Engine Room, including its maintenance, are looked at. The final two section deal with specific and in depth liability issues (contractual, tort and criminal), and the question of insurance.

Chapter 5 gives a summary of the overall conclusions.

2 Safety & security in-depth assessment

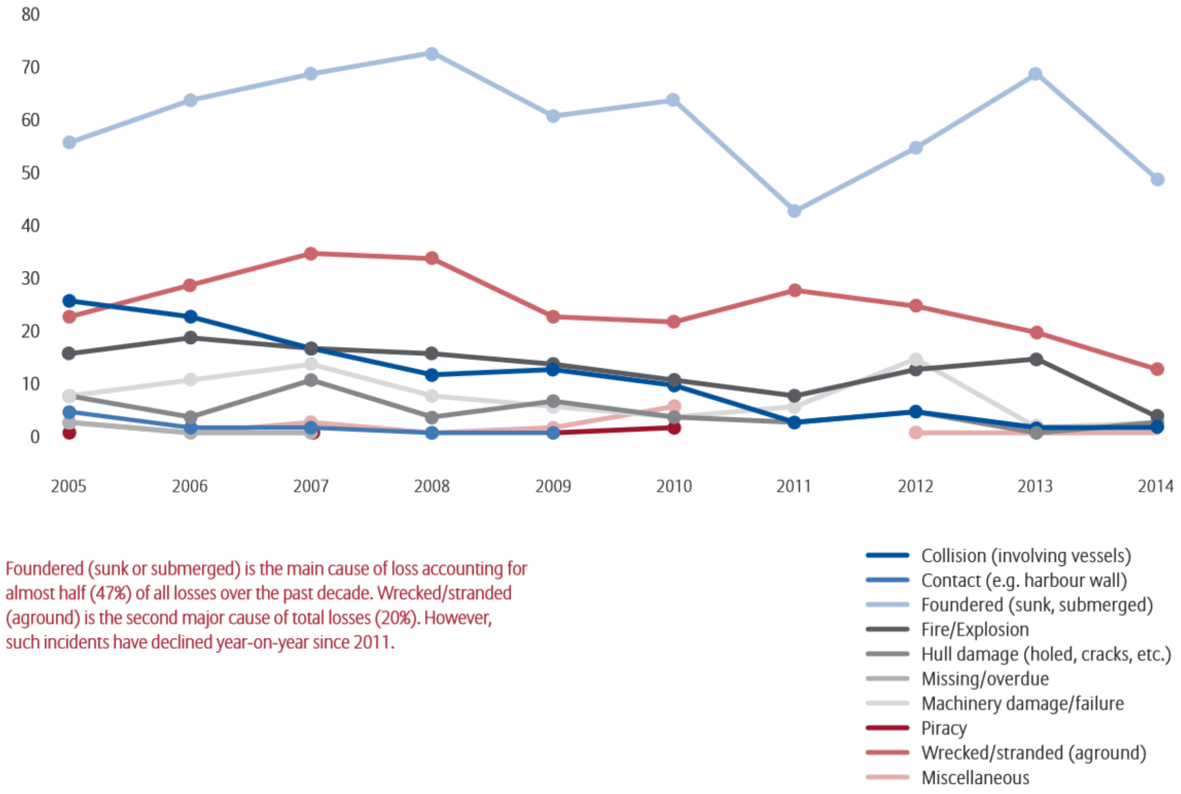
The first report on the assessment of the MUNIN concept for an autonomous vessel looked at the impact of the different main components of the MUNIN system on the overall safety of the unmanned ship. /56/ The conclusion of that analysis was that most systems would have a positive or in a few cases a neutral impact on safety and security, except for the issue of cyber-crime, where many subsystems would increase exposure unless appropriate risk control options were put in place. Particular positive effects were gained by adding the shore control centre and the advanced sensor module.

The subsequent qualitative assessment report (see /58/) took this discussion further by looking at the qualitative effects of the proposed risk control options, in light of the most significant risks the unmanned ship faced. The conclusion here was that available risk control options, if implemented properly, would indeed help to make an unmanned ship safer than a corresponding manned ship.

This report will take at a more quantitative approach to the safety and security risks and risk control options. For collision and foundering, this is based on an in depth master thesis. For other incident types, a higher level semi-quantitative approach has been used.

2.1 General risk picture for shipping

World-wide ship accidents that have caused a total loss have been plotted in the graph in Figure 1 /1/.



Foundered (sunk or submerged) is the main cause of loss accounting for almost half (47%) of all losses over the past decade. Wrecked/stranded (aground) is the second major cause of total losses (20%). However, such incidents have declined year-on-year since 2011.

Figure 1 Total ship losses /1/

As one can see, foundering is the main contributing event while wrecked/stranded, fire/explosion and then collisions are the next most important causes over the period shown. After this comes machinery damage.

Looking at all incidents, including those that has not caused a total loss, but in this case limited to Europe, gives a somewhat different view as can be seen in Figure 2 /2/. Loss of control is one of the most important factors and this is normally associated with engine, rudder or propulsion problems. Listing the same incidents by severity is given in Figure 3.

If one looks at severe incidents (Figure 3), one gets a similar picture as in Figure 1 where foundering and collisions are much more dominant. The figure also shows that machinery problems have a very high frequency for less serious incidents. These will normally be very much more severe for unmanned ships, although the incidents normally will not threaten life.

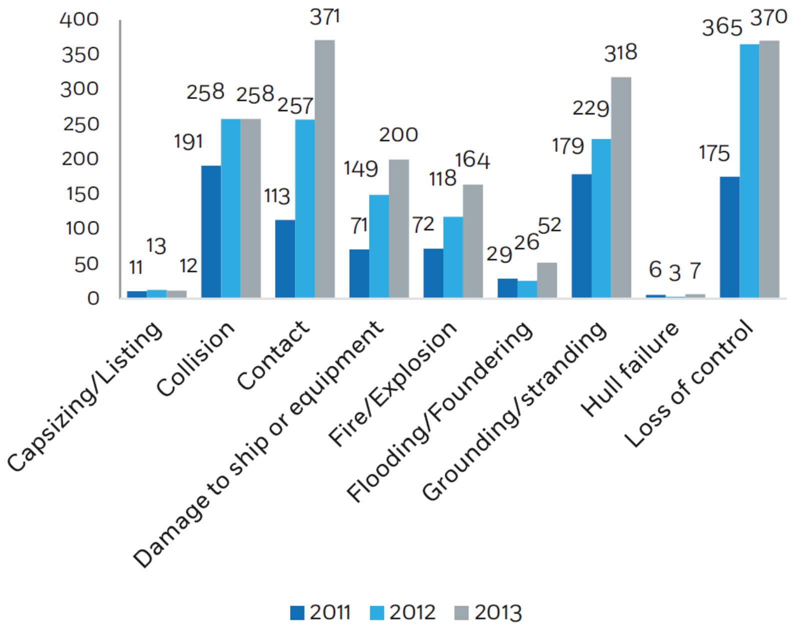


Figure 2 European incidents by year and type /2/

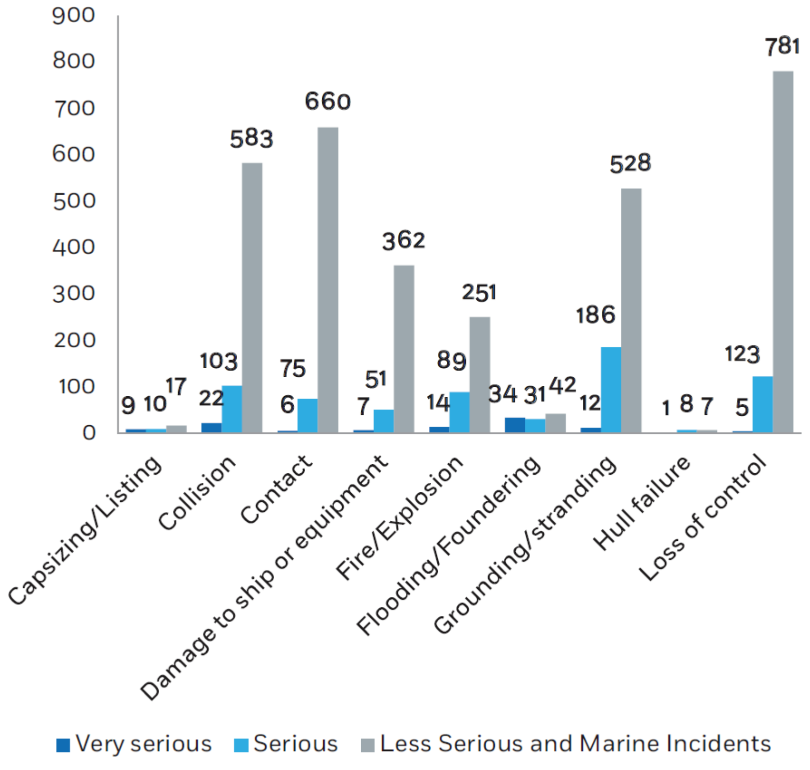


Figure 3

Figure 3: European incidents by severity and type /2/

2.2 Incident types covered in this report

Unmanned ships of the MUNIN category are supposed to operate autonomously on the high seas only. They will be manned or remotely controlled during port approaches and in areas close to land or with high traffic. Accordingly the most relevant accidents for the autonomous ship are foundering and collision at high seas. This was also the conclusion of a master's degree student who wrote her thesis on the main risks associated with unmanned shipping /3/. The analysis also included other incidents, such as fire or engine problems, as triggering events. The main conclusions of this work are discussed in Section 2.3.

To complete the picture, contact, grounding and stranding will be discussed as well, but only on a qualitative level. As the ship is mostly operating autonomously on the deep sea passage, the impact of the SCC will be important particularly on the port approach and departure. As this cannot be modelled adequately at this time, it is very difficult to say anything quantitative about contacts, grounding or stranding. This will be discussed in Section 2.4.

Engine and propulsion system failures were included as causative events in the analysis of foundering and collisions. However, these incidents can also cause a ship dead in the water that has to be rescued by another ship. This is a costly operation that has been highlighted as an unacceptable risk. A brief and general discussion on technical problems will be included in Section 2.5. It will also cover the category "damage to ship or equipment".

Another incident that can disable the ship is fire and explosion which is discussed in Section 2.6

Finally, the issue of cyber-crimes, piracy and terrorists is a major concern for unmanned ships and a discussion of these issues are included in Section 2.7.

2.3 Collision and Foundering

The work on identification of safety and security hazards and the initial assessment is summarized in previous assessment report *Qualitative assessment* (see /57/) The initial risk assessment was based on expert judgement in workshop sessions, which works for a rough sorting of the hazards and identification of main risks. For a more in-depth analysis of the risks, methods like fault trees, event trees, Bayesian belief networks, or methods or tools specialized for a given problem field must be used in order to determine the probability or frequency of events and possible outcomes of the events, and the cost or consequences of the outcomes.

An in-depth analysis of collision and foundering scenarios for an unmanned MUNIN vessel was done in a master thesis "Hazard and Risk Assessment of Unmanned Dry Bulk Carriers on the High Seas" in cooperation with the MUNIN project /3/. In this work, incidents like propulsion failure, blackout and weather conditions are used as base events for the scenarios, and the scenarios include several of the other hazards identified, like communication failure and object detection failure as intermediate events.

The analysis uses event tree analysis for the possible outcomes of the scenarios. In-depth analyses are performed on intermediate events, using fault trees, calculation tools for collision situations, and pilot charts for calculations on critical weather conditions. For the foundering scenarios, in addition to the event trees the work uses a correction factor based on literature studies on conditions leading to foundering. Both the uncorrected and corrected values are shown in the thesis and listed in the tables in this section.

In addition to the analyses for unmanned ship, analyses are also done for a conventional manned ship, thus enabling comparison of the two ship types. The result of the probability analyses are shown in Table 1.

The result from this analysis is that the unmanned ship is "safer" than a manned ship at a factor of between 5 and 10. The reasons for this is mainly that it is assumed that the unmanned ship will have a higher degree of redundancy, fewer human errors in some of the decision making steps and better sensor systems. These benefits are to a certain degree offset by a higher likelihood that certain technical problems cannot be fixed, that systems are more complex and that heavy weather handling may be more difficult on an unmanned ship. However, the general conclusion is that benefits outweigh the problems.

Table 1: Accident occurrence probabilities for the unmanned, autonomous and the conventionally operated vessel /3/

		Collision	Foundering	Foundering with factor
Unmanned vessel	Propulsion failure event tree	$4.8 \cdot 10^{-8}$		
	Blackout event tree	$9.6 \cdot 10^{-8}$		
	Total	$1.4 \cdot 10^{-7}$	$1.5 \cdot 10^{-3}$	$2.2 \cdot 10^{-5}$
Conventional vessel	Propulsion failure event tree	$1.1 \cdot 10^{-6}$		
	Blackout event tree	$1.2 \cdot 10^{-7}$		
	Total	$1.2 \cdot 10^{-6}$	$8.0 \cdot 10^{-3}$	$1.2 \cdot 10^{-4}$

The thesis also conducted a consequence estimation, including damage to persons, environment and material. The total consequences were estimated for collision and foundering scenarios, and represented as expected cost for each incident and the resulting total risk. This is shown in Table 2.

Table 2: Calculated risk for collision and foundering /3/

		Occurrence probability	Average Consequence [Mio. €]	Associated risk [Mio. €]
MUNIN-ship	Collision	$1.4 \cdot 10^{-7}$	15.627	$2.2 \cdot 10^{-6}$
	Foundering	$1.5 \cdot 10^{-3}$	39.053	$5.8 \cdot 10^{-2}$
	Foundering with factor	$2.2 \cdot 10^{-5}$	39.053	$8.6 \cdot 10^{-4}$
Conventional ship	Collision	$1.2 \cdot 10^{-6}$	15.763	$1.9 \cdot 10^{-5}$
	Foundering	$8.0 \cdot 10^{-3}$	51.553	$4.1 \cdot 10^{-1}$
	Foundering with factor	$1.1 \cdot 10^{-4}$	51.553	$6.1 \cdot 10^{-3}$

An important factor in average consequence cost is that the consequence of foundering is much lower for the unmanned ship as there is no crew on board. Collision consequences will be slightly lower due to the same effect. In these figures is a somewhat higher cost of the unmanned ship included as the original MUNIN concept with a retrofitted bulk carrier was used as baseline. This may not necessarily be true in all cases.

Taken together with the lower probability for an accident, the results of the analyses show that the unmanned ship has a lower risk from the collision and foundering scenarios than the conventional ship by the order of ten.

2.4 Grounding, contact and stranding

As mentioned above, this has not been included in the detailed analysis. The main reason is that autonomous operation happens well outside areas where these accidents can occur, but it is also an issue that there is insufficient quantitative data available on the possible effects of the SCC on the risk for these incidents. One could argue that many of the same technical and human causes for accidents apply similarly in these scenarios as in collision and foundering. However, as the SCC will be heavily involved in these operations, it cannot be ascertained without significant investigations that this holds true.

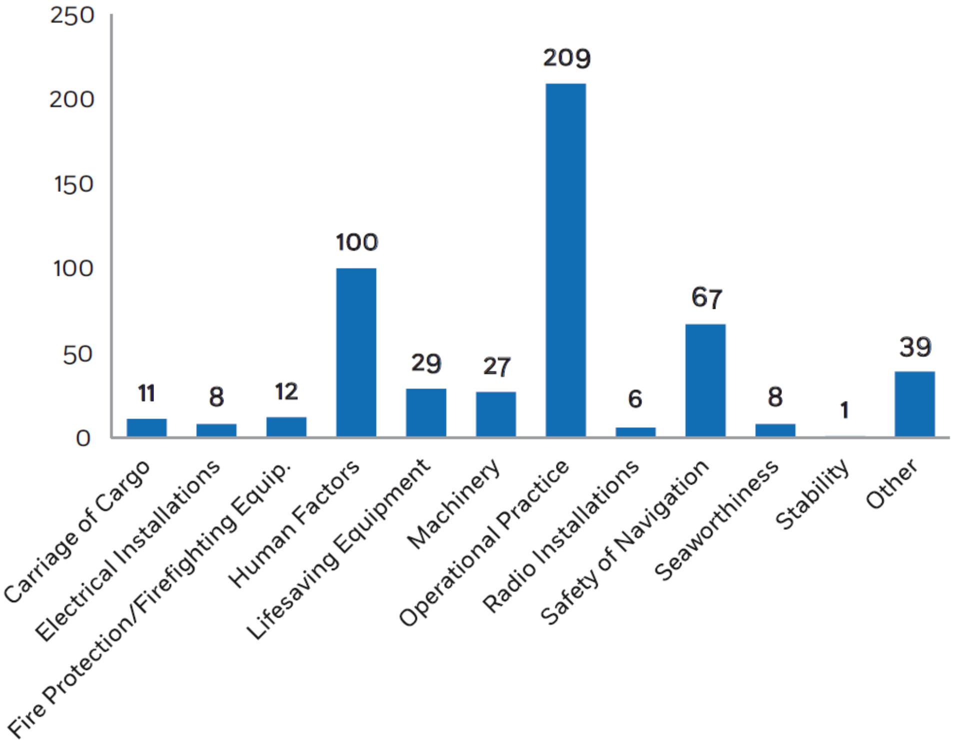


Figure 4: Number of safety recommendations issued per focus area /2/

In this context it is also interesting to see the statistics on safety recommendations issued by EMSA (see /2/) where operational practice and human factors represent about 60% of all recommendations. This is also a confirmation that the human often is the weakest link when accidents occur. On the other hand, it also points to the need to train SCC operators properly and to provide good decision support systems for them so that the human error incidents are not just transferred from ship to shore.

2.5 Engines and propulsion

As can be seen from Figure 3, technical problems are main factors in shipping incidents although not so often in total losses. This issue has been discussed extensively in MUNIN and it is clear that both improved maintenance systems and increased redundancy in technical systems are required for the unmanned ship.

Doing a quantitative analysis of this is very difficult as little data exists on technical problems on ships, apart for the high level statistics presented here. Also, a quantitative analysis would have to be done on an actual example other than the one initially specified in MUNIN. An actual unmanned ship would have to be purpose built with fully redundant energy production and propulsion systems. This was also confirmed by an FMECA done on the engine and propulsion systems in MUNIN.

To give an estimate of the size of the problem, one can use some data from European monitoring systems. EMSA reported an average number of 16 800 different ships that were reporting their AIS positions into SafeSeaNet in the first half of 2010 /4/. Compared to the number of engine incidents reported (Figure 2, also for Europe), one can estimate that reported loss of control incidents occur approximately in 2% (0.023) of the ships over a year. This corresponds to about 781 incidents over 33 600 ship years.

If this is assumed to be the likelihood of a serious engine problem over a ship-year and further assuming that the unmanned ship would have fully redundant propulsion and energy production systems, one could argue that the resulting likelihood of both system failing would be $(0.023)^2$ per year. This assumes that there are no common mode faults, i.e., faults that will always occur in both systems at the same time. This would give a corresponding probability of an engine failure of 326 per million ship years. This is far lower than the mean total loss of ships which were around 100 of a fleet of less than 100 000 per year (Figure 1).

This argument does not take into consideration minor problems that occur on manned ships that are immediately fixed, but which would lead to a full stop for the unmanned ship. This highlights the need for good maintenance management systems in addition to redundancy and simplification of technical systems.

2.6 Fire and explosions

In general, it is expected that the risk associated with fires and explosions are lower for an unmanned ship than for a manned. The arguments for this are:

1. Many fires are initiated by human activity, e.g. welding or other hot work, glowing cigarettes in incinerator silos, in galleys due to cooking etc. These incidents will not occur on an unmanned ship.
2. The unmanned ship can have more effective extinguishing systems as there is guaranteed to be none in any enclosed spaces. Spaces can also more easily remain enclosed and more suitable for use of, e.g., CO_2 or foam systems.

Increased risks may occur as there is no continuous monitoring and maintenance of machinery systems. Leakage of oil or fuel may cause fires if left unattended. However, this can to some degree be remedied by better automated monitoring by instruments and CCTV.

With reference to Figure 2 one can argue that this means that it can be assumed that fire and explosion is less of an issue for unmanned ships and that the total risk may be acceptable. However, to do a full quantitative assessment, one needs a detailed design as well as more detailed fire and explosion incidence data.

2.7 Cyber-security and piracy

According to Figure 1, pirates have been responsible for 5 total losses in the period 2005 to 2014, thus accounting for only 0.4% of all losses during that period (1271) /1/. Attacks and severity has been reduced over the last few years due to more focus on the issue and the naval presence in the Aden area. Thus, this is not a very significant risk.

Also, as there is no crew to ransom and as it is easier to make control systems that cannot be used by unauthorized persons, piracy should be a significantly lower probability for an unmanned vessel.

Cyber-crime may be a more important threat and particularly when used to use a vessel to block a port or channel. However, technical measures exist to minimize these risks, but they require very high attention on the problem and a systematic approach to blocking vectors of attack, including attacks on the SCC.

2.8 Conclusions

Due to the lack of technical details on the SCC and the actual design of the ship, the in-depth safety analysis is limited in its scope. However, as has been argued above, there is reason to believe that the unmanned ship will turn out to be as safe as manned ship and often safer when the relevant operational and technical constraints are observed.

The collision and foundering analysis has been fairly detailed and give good reasons to support this view, also quantitatively. This is also the area, where most - almost 50% - of all losses have been registered between 2005 and 2014. However, the analysis indicates that unmanned ships will be on an order of around 10 less risk-prone for these incident groups. While, the analysis is not exhaustive in the factors it has included, the figures are encouraging.

This chapter has also done a high level assessment of other incident groups that can affect the unmanned vessel. The conclusion in each of these groups is that it is likely that the unmanned ship in most areas will have a lower risk than the manned vessel.

3 Economic in-depth assessment

Crew size of ocean going ships has been reduced significantly over the past 150 years (see Figure 5). While in absolute terms the reduction has slowed down it has been quite constant in relative terms. Nonetheless, it is not clear whether crew sizes - as they are found today - have reached a lower bound or (at least in relative terms) a further reduction will continue in future. The technology to reduce crew size further is available today – as has been shown by the technical results of the project MUNIN. But, a technological feasibility does not necessarily entail that the technology will be used to automate ships further in order to reduce crew count even more. The reason is simple: *There ain't no such thing as a free lunch*. Employing more sophisticated technology on a ship to reduce crew will come with a price which is the cost of additional and more sophisticated technology deployed on board. Thus, besides the technological feasibility it is indispensable to explore the economic feasibility of small crew sizes as well.

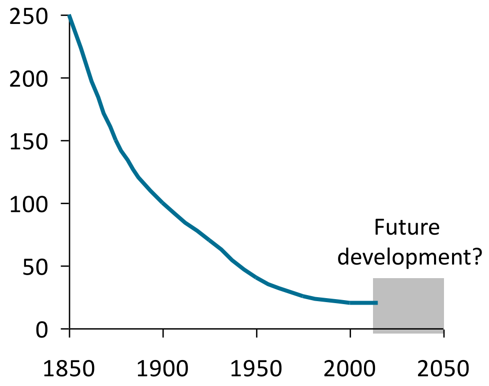


Figure 5: Development of crew size of ocean going ships

A reduction in crew size is essentially a trade-off between increased capital costs and reduced (crew related) costs plus other potential benefits associated with automation on board (see Figure 6). And it is fair to assume that as crew sizes become smaller, the trade-off becomes less attractive. At some stage, the increased capital costs required to achieve further reductions will more than offset achievable savings. Where exactly this tipping point is located at is not clear. Having no crew on board will not necessarily be the optimal solution in future. Nevertheless, the trend of reducing crewing levels further will quite likely become a reality on many modern ships. This is for one reason in particular, as this analysis will argue: besides cost savings associated with reducing crew levels an autonomous ship brings along the potential to create additional benefits due to changes in ship design.

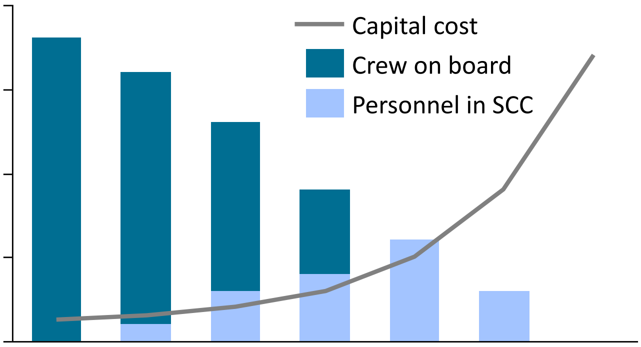


Figure 6: Principal correlation between crew size and new building cost

All in all the successful introduction of innovative technologies on board – which in this case enable a reduction of crew sizes – depends essentially on their impact on the profitability of shipping companies. Unless an innovation is commercially viable it will not find its way into practice. Taking this into consideration the quantitative cost-benefit analysis hereafter focuses on the economic feasibility of the developed concept for an autonomous ship in the project MUNIN by taking on a microeconomic view on costs of operating a ship. It identifies and determines potential cost savings associated with the MUNIN concept as well as additional costs of an autonomous vessel by looking at operating cost, voyage cost and capital cost. Thus, the cost of transporting goods with an autonomous ship can be determined and compared against a conventional ship.

The project MUNIN has developed a concept for an unmanned bulk carrier. At the start of the project long distance dry bulk shipping was seen as the most promising area for the application of autonomy in shipping. Over the duration of the project other ideas have emerged and alternative approaches and ship types might represent very promising applications for autonomy as well (see e.g. /5/, /9/). Nonetheless for reasons of consistency the economic analysis will look at a medium size bulk carrier in international trade as the object of investigation. A reference cost model will be developed for a baseline scenario "conventional bulk carrier" and subsequently compared with two scenarios developed in the MUNIN project for a bulker: a periodically unmanned bridge "B0"[1] and the fully unmanned ship.

The structure of this chapter is as follows: first it is argued why the chosen approach is suitable to accomplish the outlined goal of determining the economic viability of an autonomous ship before the methodology used to calculate the cost structure of a conventional and an autonomous ship is outlined. Then the reference cost model of a

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[1] B0 was selected as an appropriate combination of near-term realizable modules. The methodology for the analysis of the autonomous bulker is slightly adapted to examine the advantageousness of B0.

conventional bulk carrier is described followed by the discussion and estimation of cost changes for an autonomous ship that find consideration in the analysis. Finally the results of different business case scenario calculations are shown where crucial input parameters and underlying assumptions are altered respectively.

3.1 Methodology

In order to assess the economic viability of autonomous ships a methodology for the financial analysis is derived from a shipping cash-flow model. This model is used to reason why it is appropriate to focus on cost associated with an autonomous ship and compare these against the cost of a conventional ship while the revenue side stays unconsidered in the analysis. To begin with, the scope of the analysis defines which effects form the broad area of innovations associated with the concept of an autonomous ship are taken into account in the financial analysis conducted.

3.1.1 Scope of the analysis

Several innovation clusters can be identified in waterborne transport at this point all of which show a rapid development in the recent past. Amongst others this includes the unmanned ship – innovations that aim for a higher degree of automation on board – the intelligent ship –which comprises of innovations that make use of evermore data generated on board in smart applications – and the efficient ship – focusing on clever ways to improve the hardware and design of a ship (see Table 3). Unsurprisingly, many individual innovations relate to more than one of the innovation clusters making a clear attribution difficult. A good example is the concept for an autonomous vessel as it has been developed in the MUNIN project. Besides a higher automation on board it also covers several aspects closely related to the intelligent ship such as optimized (weather) routing or on-board energy efficiency management.

Table 3: Selected innovation clusters in waterborne transport

Innovation cluster	
Unmanned ship	- Reduced crew - New ship designs - (Improved safety)
Intelligent ship	- Optimized (weather) routing - On-board energy efficiency management - Voyage performance management - Condition monitoring and management
Efficient ship	- Hull form optimization - Energy-saving devices - Machinery technology

The assessment of impacts associated with an autonomous ship in the context of this report lays its focus on benefits associated directly with unmanned ships. Benefits associated with ship intelligence, even though part of the MUNIN project to some point, are out of scope and thus not considered. The reason for this is as follows: although the development of autonomous ships fosters innovations from the field of ship intelligence these innovations are principally available for both conventional and autonomous ships. The idea of this economic analysis of an autonomous ship is, however, to identify and assess effects associated directly (and only) with a higher degree of automation on board not a mixture of effects due to higher ship intelligence and autonomy combined. As safety and security considerations are dealt with in a separate part of this report any associated implications of improved safety on the financial performance of an autonomous vessel are not considered in this analysis.

3.1.2 Shipping cash-flow model

A shipping cash-flow model is used as basis for the financial analysis /6/. It describes how revenue is generated by a ship and after costs are deducted creates free cash flow which is used to cover taxes, pay dividends and generate a profit for the ship owner (see Figure 7).

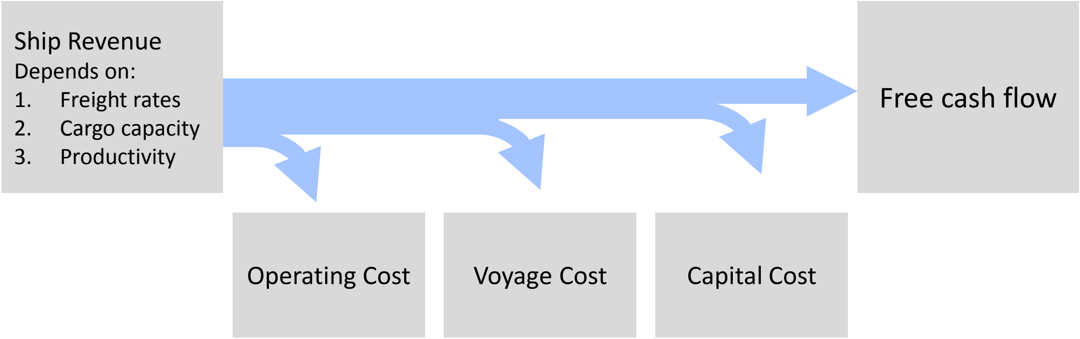

Figure 7: Shipping cash-flow model

The ship generates revenue by transporting goods. Taken together three factors - freight rate, cargo capacity and productivity - determine how large (or small) the revenue of a vessel is. First of all the amount of revenue depends on the freight rate. The freight rate (price per ton mille of cargo transported) a ship owner receives for the transport service is determined externally by supply and demand. In a functioning market the individual ship owner has very little influence on this market price. Regarding the second factor influencing ship revenue – cargo capacity – the ship owner has more influence. In terms of economies of scale, higher cargo capacity will increase the amount of cargo transported by a given ship and thus lead to higher revenue. Moreover, there is a third factor – productivity –which the ship owner can influence directly. Productivity refers to a smart deployment of the ship (e.g. good operational planning, optimal speed, reduced off hire time, etc.) which will increase its productivity and thus the revenue it generates over a given period of time.

On the other side the shipping company bears different costs which need to be covered by the revenue generated by the ship. In this context of this analysis the following three cost categories shall be distinguished: /6/

- Operating cost consists of all expenses incurred to keep the ship in an operational status. For the ship owner these costs are fixed (unless the ship is laid up) and independent of a particular voyage the ship may or may not be trading in. Operating cost includes e.g. cost for the crew, regular maintenance cost, insurance cost and cost of administration.
- Voyage cost, on the contrary, is variable cost directly associated with a particular deployment of the vessel. Thus they only accrue if a ship enters a particular voyage and can be directly attributed to that voyage. Voyage cost includes e.g. fuel cost, cargo handling cost and port call cost.
- Capital cost is expenses related to the purchase of a ship (obligation to pay the shipyard for construction of the vessel in terms of the new building price) and associated cost (e.g. cost of financing). For the ship owner capital cost typically consist of an initial sum payed upon acquisition of the vessel and periodic cash payments to lenders involved in financing the vessel (banks or investors).

3.1.3 Methodology of the analysis

With reference to the shipping cash-flow model introduced above it is straight forward that for two ships with an identical potential to generate revenue the ship which has lower total cost will create a higher free cash flow. Thus, in case an autonomous bulker has the same potential to generate revenue over its lifetime and total cost over that period is lower than the cost of a conventional bulker the autonomous vessel will generate a higher free cash flow.

With regard to the freight rate as an influencing factor on revenue it is safe to assume that it is set exogenous and predominantly influenced by commodity price as has been shown in literature /7//8/. Thus no difference between an autonomous and a conventional bulker is expected. Cargo capacity on the other hand is more difficult. For an autonomous vessel new ship designs might become feasible with lower light ship weight (see Chapter 3.3 and /9/). This would have an impact on cargo capacity or fuel consumption. Generally for deadweight limited vessels such as bulk carriers a reduction of light ship weight is used best by increasing deadweight and therefore cargo payload. This would make the assumption of identical revenue for an autonomous bulker inapplicable. However, while less advantageous and thus a more conservative approach, a reduced light ship weight might also be used to reduce fuel consumption with constant cargo payload /10/. Accordingly, following the latter case, an assumption of a constant cargo capacity is applicable. The last factor is productivity. Here particularly innovations associated with the intelligent ship are expected to lead to a significant improvement. However, as defined before, effects of the intelligent ship shall not be considered in this analysis. Another issue in the context of productivity of an autonomous vessel is off-hire time. Improved maintenance regimes on an autonomous vessel may lead to reduced off-hire time. On the other hand, since no maintenance work can be done during the voyage, dry docking time and thus off hire may increase. For the purpose of this assessment both effects are presumed to cancel out and thus an identical off-hire time for the conventional and autonomous bulker is assumed. It follows that productivity can be considered to be equal for both cases: the conventional and the autonomous bulker.

On the basis of the considerations above the main assumption for the financial analysis is that both an autonomous bulker and a conventional manned bulker have the same potential to generate revenue over their operating life. Accordingly the analysis will focus on the cost part of the shipping cash flow model by identifying and determining cost changes resulting from implementing the developed concepts and components for an autonomous vessel. The chosen methodology for the analysis is shown in Figure 8.

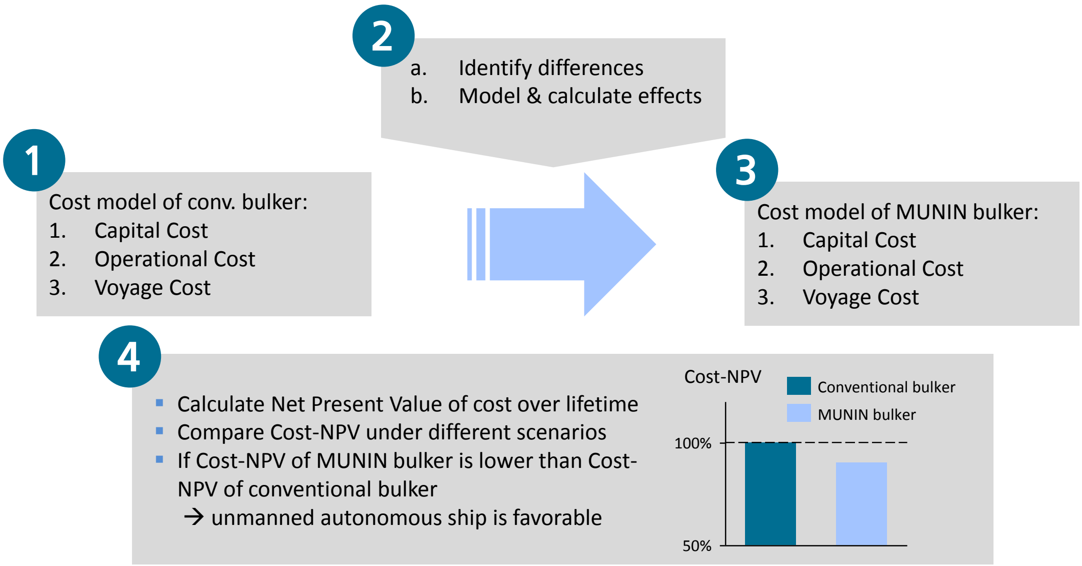

Figure 8: Methodology of financial analysis

(1) First a cost model for a conventional manned bulker - representing the as-is-processes and technical systems - is developed based on average cost figures for operating a bulk carrier under an assumed yearly operating profile.

(2) Starting from here changes in operating cost, voyage cost and capital cost for an autonomous vessel are identified. Appropriate methods are applied to come up with a quantitative estimation of the extent cost will change. Cost estimation methods available in this context are shown in Table 4. Due to the early stage of development and accordingly the low maturity of solutions and concepts for an autonomous bulker as well as the limited scope of the project MUNIN the applicability of cost estimation methods was somewhat limited and it was necessary to rely on qualified assumptions in the assessment to some extent.

Table 4: Ship cost estimation methods /11/

Available cost estimation methods	Applicability
Expert Opinion: based on past experience experts come up with an estimation	Low design maturity
Analogy: system or subsystem is like something else for with the cost is known	
Parametric: there is a relationship between cost and a technical characteristic, such as USD/ton	
Bottoms-up Engineering: build-up of costs for smaller discrete elements of the total system	
Actual Costs: cost returns on same or similar systems	High design maturity

(3) Under consideration of the identified cost changes a cost model for the autonomous MUNIN bulker is developed.

(4) Cost of operating a conventional and an autonomous bulker is calculated over the assumed operational lifetime of 25 years. Time value of money dictates that time has an impact on the value of cash flows. Thus the net present value of cost over lifetime is calculated and compared under different scenarios. In order to calculate the NPV it is necessary to set an appropriate discount rate value. The discount rate can be based on a company's own (risk adjusted) weighted average cost of capital (WACC) or a typical WACC found for companies in the industry /12/. To get an impression of the range WACC takes on in companies in the shipping industry: calculations for three companies come up with values in the range from 9% to 12.5%. /13/ The discount rate chosen in this assessment is set a little lower at 8% to be consistent with an economic evaluation in the MUNIN report *Constant engine efficiency concept* (see /14/).

The outcome of the financial analysis is interpreted as follows: in case the Cost-NPV of the autonomous MUNIN bulker is lower than the Cost-NPV of the conventional bulker it can be concluded that the unmanned autonomous ship is favorable.

3.2 Reference cost model of the conventional bulker

A reference cost model for a conventional bulker is developed in this section. Table 5 contains main ship particulars of the ship under consideration. The ship's bridge is conventionally manned at all times while the engine room is usually only manned during daytime working hours. Maintenance work is carried out continuously by the crew. The main engine is conventionally fueled by heavy fuel oil (HFO) and drives a single fixed propeller as ship propulsion. Auxiliary engines run on marine diesel oil (MDO).

Table 5: Ship particulars of the reference panamax bulker

Length Over All	230 m
Breadth	32 m
Design Draught	14,5 m
Service speed	15,5 kn
Displacement	90600 t
Main Engine	10230 kW

In order to determine the economic performance of both the conventional bulker and the concept of an autonomous bulker an assumed operating profile is required. Data from the Marorka Online database for a collection of bulk carriers with similar specifications as the MUNIN vessel was used to define a yearly operational profile for the ship (see Table 6)./14/ This operational profile is referred to both for the base case "conventional bulk carrier" and for the MUNIN scenario of an autonomous bulker.

Table 6: Assumed yearly operational profile[2]

Ship at berth / waiting	120 days
Ship maneuvering	29 days
Ship in sea passage	216 days

3.2.1 Operating cost

Operating cost are all expenses needed to keep the ship in an operational status. They will be different for every ship depending on, amongst others, company policy, flag, ship type and age. In the financial analysis carried out here statistics on average operating

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[2] "In sea passage" state is defined as the path between pilot points. "Ship at berth or waiting" is ship not moving. "Ship manoeuvring" is a collection of all other states.

cost for a large number of panamax bulkers published by Drewry constitute the starting point for developing the reference structure of operating cost /15/. To some extent other sources are referred to in order complement the data.

Crew cost: Crew or manning cost account for the largest part of operating cost. They include several direct and indirect costs such as wage, travel, victualling, training, recruitment and agency expenses, social dues etc. Crew wages for a panamax bulker are estimated at 735,840 USD per year for a crew of 20. /15/ A main determining factor for crew cost is the manning level on board which typically increases as the ship gets older. /6/ In the crew cost calculation for the reference bulker the crew is assumed to increase from 19 to 22 over the operational lifetime of the ship. Additional crew related cost (travel, victualling, etc.) are estimated at 24% of crew cost. /16/ On average crew cost account for about 45% of operating cost.

Stores & consumables: This category summarizes the cost of consumables used on board. General stores (e.g. deck, cabin, engine stores) and lubricants can be distinguished. Both sums up to an estimated 288,836 USD per year while the new build vessel receives a negative age adjustment and the cost for the aged vessel is higher /15/. On average, expenses for stores and consumables account for about 14.3% of operating cost.

Regular maintenance & repair: Maintenance and repair cost can be differentiated in routine basic work which is performed on-board and more complex actions performed by experts and suppliers during maintenance inspection at port. Regular maintenance and repair on board together with spares is set at an average of 268,151 USD per year while an age factor considers the fact that both cost for maintenance and spares increases over time. /15/ Expenses for maintenance and repair account for about 12.7% of operating cost on average.

Insurance: Insurance cost basically refers to insurance of the asset itself (Hull and Machinery insurance) and insurance for broader risks, typically third party liabilities (Protection and Indemnity insurance). An average yearly insurance cost of 312,780 USD is assumed. /15/ In the case of insurance cost a small premium is considered for a new build vessel which diminishes over time. On average insurance cost account for about 15.2% of operating cost in the developed reference cost model.

General cost: General cost sums up several expenses associated with administration and management of the vessel including management fees, flag state expense communication cost, etc. In the developed reference model general cost are assumed to be 269,275 USD per annum. /15/ This represents about 12.8% of operating cost.

Periodic maintenance: Besides continuous maintenance there is also regular periodic maintenance in terms of dry dockings. Periodic maintenance is usually not stated as part of operating cost but has the same characteristic of not being connected to an individual voyage of the ship. Thus, in this analysis it is not directly included in operating cost but featured in this chapter. Costs for dry dockings every 60 month are assumed to amount to 100% of the average annual operational budget. /17/ In consequence periodic maintenance is considered with 420,000 USD per year on average. However a strong age dependency is considered for dry docking cost over the lifetime of the vessel. /6/

3.2.2 Voyage cost

Voyage cost is variable cost directly associated with a particular voyage. In this analysis they consist of cost for main and auxiliary engine fuel and port call cost. Yearly fuel cost is determined by ship-specific fuel consumption, the operational profile, the type of fuel used and fuel price. Port call cost contains different fees and charges associated with services the vessel receives in port and is determined basically by the pricing policy of the port.

Fuel price: Fuel cost alone can represent between 50% and 70% of the total costs of owning and operating a ship. Accordingly changes in fuel prices dwarf all other cost related input parameters and future fuel price developments are the number one uncertainty when evaluating voyage costs.

Unfortunately it is impossible to predict how fuel prices will develop in future. Nonetheless, in order to conduct a financial analysis it is necessary to make an assumption about the price of HFO and MDO. The high volatility of fuel prices in the recent past makes things even more difficult (see Figure 9). To take this into account different fuel price scenarios are considered in the calculation of the business case scenarios for the conventional and autonomous ship.

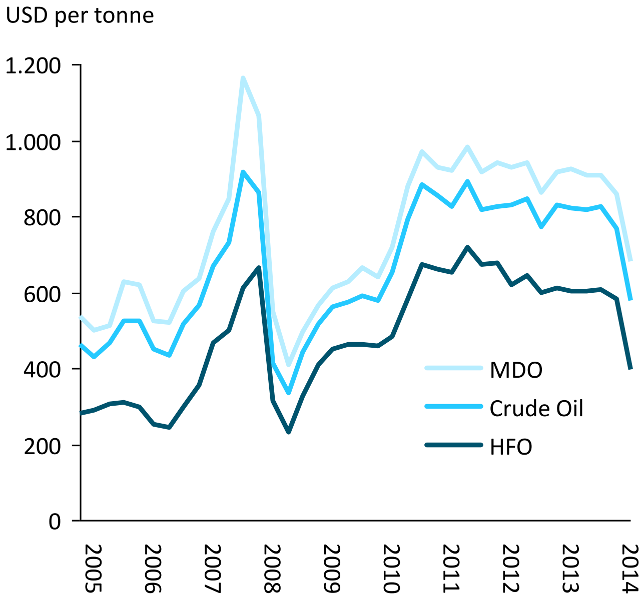

Figure 9: Crude oil and marine fuel price development from 2005 to 2014 /18//19//20/

The approach to forecast future fuel prices is based on a forecast for crude oil prices published by the IEA World Energy Outlook (see Table 7).

Table 7: Forecast of crude oil price /21/

	2020	2025	2030	2035
Crude Oil [USD/barrel]	119.5	121.9	123.6	125

Crude oil prices are converted into HFO and MDO prices based on the past ratio between them over the period from 2005 to 2014. HFO was trading at about 70% of the price of crude oil while MDO was trading at about 115% of the price of crude oil. In no way is there any certainty that this past ratio will continue in future. In fact there are good arguments it will not. E.g. global Sulphur limits could make HFO more expensive compared to crude oil. Nonetheless to complicate matters no further no additional uncertain assumptions about the future are taken into consideration. Instead besides a reference scenario assuming a price of crude oil of 125 USD/barrel, two additional scenarios are determined: a low scenario with a 20% lower price and a high scenario where prices are 20% above the reference scenario. Table 8 contains the HFO, crude oil and MDO prices for all fuel price scenarios considered in this analysis. Even though these prices are significantly higher than todays they don't seem unrealistic if compared to prices that had already been realized in past (see Figure 9).

Table 8: Fuel price scenarios considered in the financial analysis

Fuel price [USD/ton]	HFO	Crude oil	MDO
Low scenario	527	753	866
Reference scenario	659	941	1,082
High scenario	790	1,129	1,299

Fuel cost – main engine: In order to obtain yearly fuel cost - besides fuel price - an assumption about the ships specific fuel consumption, its operational profile and fuel type used is required. The operational profile was already specified above. Two-thirds of days in sea passage are assumed to be in loaded condition while the remaining one-third is in ballast condition. Fuel type is HFO in sea passage and MDO when the ship is maneuvering. By assuming that MDO is used during maneuvering developments towards tighter environmental standards that require high grade fuel - particularly close to shore in Sulphur Emission Controlled Areas - are taken into account. Fuel consumption is determined for a standard motor type (6G50ME-C9) of vessels comparable to the reference vessel /22/. With an operating point at 85% Maximum Continuous Rating (MCR) - at service speed and loaded - and including a 11.5% mark-up to correct for test bench conditions a fuel consumption of 182.5 g/kWh is calculated. /23/ For the vessel sailing at service speed under loaded conditions this sums up to a fuel consumption of 38 tons per day. In ballast condition – due to a reduction of propulsion power demand - the fuel consumption is expected to be less with 26 tons per day. Overall this fuel consumption corresponds well with figures found in literature /15/. Based on the above, fuel cost of the main engine is calculated at 73.4% of voyage cost in the reference case of the financial analysis.

Fuel cost – auxiliary engines: For reasons of comparability both the autonomous vessel and the conventional reference bulker rely on an auxiliary engine system consisting of diesel generator sets for the supply of electric power on board. The fuel cost associated with this auxiliary engine system is determined by the electric energy consumption on board, the specific fuel consumption and the fuel type used to run the diesel generators. Fuel type in this case is MDO. Specific fuel consumption is determined for a standard type generator set (L28/32H) as proposed in *Specification concept of the general technical system redesign /24/.* For the operating point at 85% MCR and including a 11.5% mark-up to correct for test bench conditions a specific fuel consumption of 213.1 g/kWh is calculated /25/. To keep things simple at this point no distinction between different operating points is made regarding the specific fuel consumption. On the other hand electric energy consumption on board is distinguished for different operational statuses in terms of ship at berth / waiting, ship maneuvering and ship in sea passage. Based on data collected by the California Air Resources Board in

2005 an auxiliary to propulsion ratio and auxiliary engine load factors are used to come up with an electric energy consumption on board for different operational statuses (see Table 9 and Table 10) /26/. The shown energy consumption for different operational statuses has further been discussed with and verified by MUNIN project partners.

Table 9: Assumed auxiliary engine to main engine power ratio

Ship Type	Power main engine (kW)	Auxiliary to main engine ratio	Power auxiliary engines (kW)
Bulk Carrier	10,230	0.22	2,271

Table 10: Electric energy consumption for different operational statuses

	Theoretical maximum	Ship in sea passage	Ship maneuvering	Ship at berth / waiting
Aux. engine load factor	1	0.17	0.45	0.22
Energy consumption (kW)	2,271	386	1,022	500

Based on the above, a fuel consumption of two tons of MDO per day is calculated for the ship in sea passage. Fuel cost of the auxiliary engine is calculated at 10.4% of voyage cost in the reference case of the financial analysis.

Port call cost: Port call cost is the last component of voyage cost considered in this analysis. Charging practices vary considerably from one port to another, thus it is difficult to come up with a sensible estimation of port call cost without specifying a set of voyages and thus ports a vessel calls during a particular period under consideration. As one an example Stopford gives port call cost of USD 147,000 for a panamax bulker trip from Australia to Europe /6/. In another example costs per port call for bulk carriers are indicated to be in the range of USD 35,000 to USD 40,000. /27/ In this analysis an average cost per port call of USD 100,000 is assumed. Taking routes between Europe and South America with a voyage time of 14 days as a reference - as envisaged in the MUNIN project /28/ - the ship is assumed to have 15 port calls per year. Thus port call cost of the reference vessel is calculated at 16.3% of voyage cost.

3.2.3 Capital cost

Capital cost is all expenses associated with the purchase of the vessel. In practice they will comprise of the new building price of the vessel, cost of financing and a payment received upon the sale of the vessel. For the ship owner – besides own funds invested up front – they would typically be in the form of regular payments of interest and redemption. However, in this financial analysis capital cost are treated as a one-time payment at the commissioning of the ship. Thus, the assumed capital cost is to be understood as the discounted value of all payments associated with the purchase (and sale) of the vessel.

To come up with an estimation of the capital cost for the reference vessel new building prices of panamax bulk carriers are referred to. Figure 10 shows the development of new building prices for capesize, panamax and handysize bulk carriers between 2002 and 2013. It can be seen that new building price have been quite volatile in recent past. The average new building price for a panamax bulker during that period was mUSD 34. As there is no certainty how new building prices will develop in future, the capital cost of the conventional bulker assumed to be equal to the above mentioned average new building price of mUSD 34. This is quite high but since additional cost, such as financing cost, are not estimated separately, it is assumed to be reasonable.

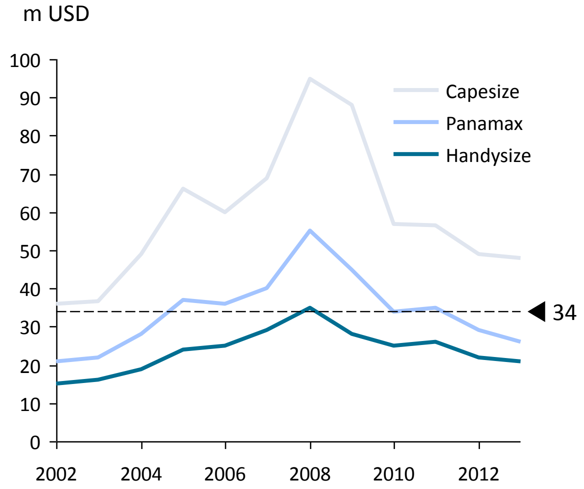

Figure 10: Recent development of bulker new building prices /29/

To put this assumptive capital cost into perspective the following Table 11 shows all cost incurred – operating cost, voyage cost and capital cost – over the lifetime of the vessel discounted to the time of commissioning of the ship. Capital cost of the reference vessel is calculated at 21% of the present value of total cost over the lifetime of 25 years in the financial analysis.

Table 11: NPV of cost for reference vessel over lifetime of 25 years

NPV of cost over lifetime	in mUSD	in %
Operating cost	25.9	16
Voyage cost	98.5	62
Capital cost	34.0	21
Total cost	158.4	100

3.3 Considered cost changes for the autonomous bulker

On the one side obvious cost saving associated with an autonomous vessel lies in eliminating or reducing the crew on board. On the other side e.g. additional technology that enables the autonomous functioning of the vessel and additional staff in a shore control center which monitors the autonomous voyage will come with a price. In this section changes in operating cost, voyage cost and capital cost for an autonomous bulker considered in this financial analysis are identified and quantitative estimations of the extent cost will change are given. This way a cost model for the autonomous MUNIN bulker is developed.

Table 12 summarizes the issues discussed in the following section. For each issue the impact on the respective cost is given in parenthesis - a minus (-) represents a reduction of cost and a plus (+) an increase.

Table 12: Considered cost changing factors in the autonomous bulker cost model

Operating cost	Voyage cost	Capital cost
- Crew wages (-) - Crew related cost on board (-) - New shore/port services incl. SCC (+)	- Reduced air resistance (-) - Reduced Light Ship Weight (-) - No hotel systems (-) - Twin skeg / two engines design (+/-) - Boarding crew for port calls (+)	- No deckhouse (-) - No hotel system (-) - Autonomous ship technology (+) - Redundancy of technical systems (+)

3.3.1 Operating cost

Changed operating cost of the autonomous bulker result from reduced crew and crew related cost as well as cost for new shore and port services.

Crew wages: Wages for the crew on board and associated cost (travel, victualling, etc.) are no longer an issue for an autonomous ship. They amount to average savings of USD 945,000 per year in this analysis.

Crew related cost on board: Further, it is safe to assume that additional cost items from operating cost will be reduced. This cost is directly related to the crew living on board for longer periods of time. On the one hand this refers to general stores (medical, cabin, safety equipment and protective equipment) which reduces cost by an estimated USD 23,000 on average per year. On the other hand maintenance cost for servicing of life rafts is saved and the need for spares is reduced (generator engines, auxiliary machinery, electrical systems and systems) since there is no longer a fully equipped hotel system on board (air conditioning, heating, ventilation, etc.) and the need for electric power is reduced. Together this amounts to estimated savings of USD 44,000 on average per year.

New shore/port services: The autonomous ship as developed in the MUNIN project is associated with a new cost factor: as crew is shifted from ship to shore additional costs for land based services have to be considered. In the shore control center this includes personnel cost and equipment, rent, etc. Further maintenance crews - who conduct necessary repairs while the ship is in port - have to be paid. In this analysis it is assumed that the autonomous ship is a used and established concept. Among other things this means that there exists a job market for the employees of a shore control center and no special courses are necessary at the beginning of the employment.

Personnel cost for the shore control center: The organizational layout of the shore control center referred to here is based on *Organizational lay-out of SOC.* /30/ It includes 5 situation rooms and 45 work stations. The shore control center has one department for a 24/7 monitoring of the autonomous ship and another for planning and support activities following a one shift operation (see Table 13). With this set up the shore control center monitors 90 vessels at one time. In order to enable a 24/7 operation at one workstation at least 5.7 employees are required (3 shifts per day plus additional resources to cover vacation, training, absence). An even higher ratio of seven people per position is found in in vessel traffic centers in Sweden today. /31/ Accordingly a total of 169 employees are necessary to monitor 90 vessels assigned to one shore control center. Wages of the employees in the shore control center – and thus personnel cost –

are based on wages specified for 2014 in the ITF Uniform "TCC" Collective Agreement. /32/ For each position in the shore control center an equivalent in the ITF wage scale was chosen. Net wages are increased by an assumed employer contribution of 35% for e.g. social benefits and administration. /31/

Table 13: Employment plan for the shore control center

24/7 operation	Per shift	Total number	Equivalent in ITF wage scale
Operators (1 per 6 vessels)	15	86	3rd Off
Back up operator (1 per 5 operators)	3	17	3rd Off
Watch keeping supervisor	3	17	Master
Watch keeping engineer	3	17	Ch. Eng.
Watch keeping captain	3	17	Master
One shift operation			
Voyage planners		5	2nd Off
Maintenance planners		5	1st Eng.
Admin personal		5	3rd Off

According to this estimate, overall personal cost of the shore control center amounts to mUSD 10.4 per year and USD 116.000 per vessel per year.

Investment and operating costs for the shore control center: Besides personnel cost there are several investment and operating cost associated with setting up and running the shore control center. In this analysis one-time cost for equipment (e.g. situations rooms, software, hardware, office equipment) and annual costs in terms of rent of office space and operational costs (e.g. power supply, software, training costs) are considered. Altogether, investment cost adds up to mUSD 2.1 - with a replacement time of equipment between 3 and 13 years - and operating costs per year amount to USD 873,957. Per vessel monitored the value is reduced accordingly. [3]

Maintenance crews in port: On an autonomous vessel a boarding crew will be responsible for maintaining the propulsion plant, auxiliary plants, supply systems, electrical and automation systems, etc. during stays in port. To come up with an estimation of associated cost the composition of a boarding crew is defined as in Table 14. The composition is derived from the engine room crew on a conventionally manned

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[3] An overview of calculated investment and operating cost for the SCC is given in the Annex.

vessel. For the time the ship is at berth or waiting (120 out of 365 days) this boarding crew is assumed to be hired. Wages for the boarding crew members are adopted from ITF Uniform "TCC" Collective Agreement (see /32/) increased by an assumed employer contribution of 35%. Based on these assumptions yearly cost for maintenance crews per vessel are calculated at USD 135,281.

Table 14: Assumed composition of maintenance boarding crew

Rank	Number
Ch. Eng.	1
1st Eng.	1
2nd Eng.	1
3rd Eng.	1
Electrician	1
Fitter/Repairer	2
Fireman/motorman	2

3.3.2 Voyage cost

As it has been shown in the previous section, voyage cost is dominated by fuel cost which in turn is influenced by fuel price, fuel efficiency and the type of fuel used by the vessel. Due to high risks and technical challenges for an autonomous operation using HFO as main fuel, the technically best and simplest solution for an autonomous vessel was found to be a distillate fuel oil system (see /24/). However, using MDO on an autonomous vessel would have a serious impact on its voyage cost due to the large price premium compared HFO.

On the other hand there are several aspects which contribute to a higher fuel efficiency of the autonomous vessel. These result from e.g. reduced air resistance of the vessel, a lower light ship weight and no necessity for a fully equipped hotel system on board. Additionally a redundant propulsion system with a two engines design and a twin skeg might lead to additional gains in fuel efficiency as will be discussed later. Compared to other estimations of potential fuel savings for an autonomous ship – e.g. 12 to 15% (see /33/) - the evaluation in this financial analysis comes to a rather conservative estimate regarding fuel efficiency.

Air resistance: Autonomous ships will no longer need to support a crew living on board and are not bound to minimum sight restrictions from the bridge. This will make new ship designs feasible that no longer feature a deckshouse structure as it is found on conventional vessels today (see conceptual designs of autonomous vessels from Rolls Royce, MUNIN and DNV GL in Figure 11)

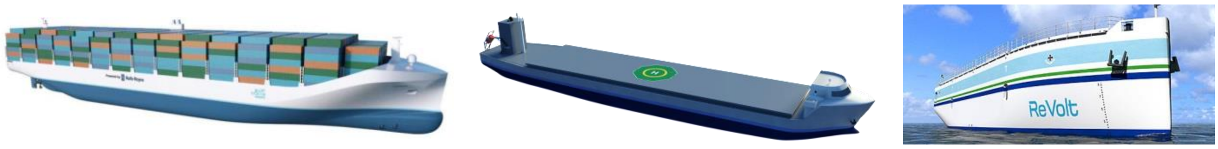

Figure 11: Conceptual designs of autonomous vessels

In clam conditions air resistance is basically a function of the ships speed and the surface area exposed to the wind above the waterline. It typically represents about 2% of the total resistance of a vessel but potentially much more in head winds. /34/ In case the surface area of an autonomous vessel exposed to the wind is reduced due to no or only a very downsized ship superstructure this will result in a reduction of air resistance. Accordingly propulsive power and fuel consumption will be lower. By how much propulsive power can be reduced is estimated by calculating frontal air resistance with and without deckshouse surface area. Frontal wind resistance is given by:

$$R_W = \frac{\rho}{2} \cdot c_d \cdot {v_{app}}^2 \cdot A_F \quad /35/$$

With

R_W: wind resistance
ρ: air density
c_d: wind resistance coefficient
v_{app}: apparent wind speed
A_F: frontal reference surface

Suitable wind resistance coefficients for a vessel with and without deckshouse are adopted form Blendermann /36/: for the reference vessel $c_d = 0.68$ (specified for a tanker) is used and for the unmanned vessel $c_d = 0.45$ (specified for a car carrier with a closed fore section) is assumed. Apparent wind is equal to ship speed plus true wind. Wind area frontal for a panamax bulk carrier is estimated to be 422 m^2 in design condition and 617 m^2 in ballast condition. Wind area frontal of the deckshouse alone is calculated with 313 m^2 following the Müller-Köster method /37/. (see Figure 12)

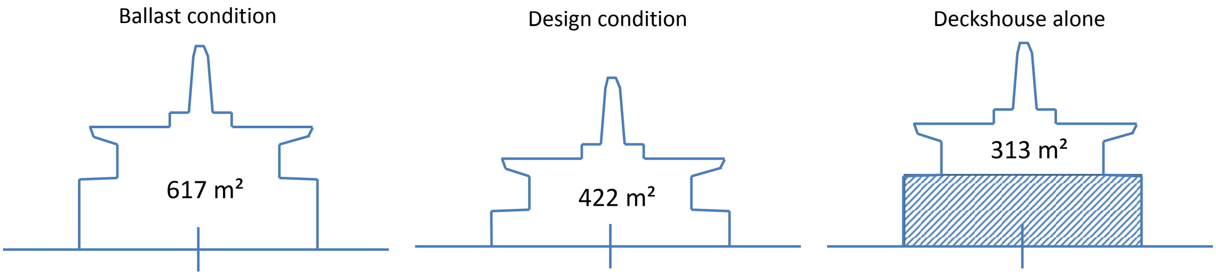

Figure 12: Wind area frontal for a panamax bulk carrier

The resulting reduction of propulsion power demand at vessel service speed and bft 0 respectively bft 3 headwind is given in Table 15. At service speed in loaded condition this corresponds to a reduction of propulsion power by about 1 %. Associated reductions in fuel consumption are assumed to be proportional.

Table 15: Reduction of propulsion power demand due to lower air resistance

	Reduction of propulsion power demand at bft 0	Reduction of propulsion power demand at bft 3
Design condition	79.7 kW	185.3 kW
Ballast condition	94.7 kW	220.1 kW

Light ship weight: The fact that autonomous ships will make new ship designs possible (no deckshouse structure as on today's vessels) will result in a reduction of the light ship weight. As had been discussed in section 3.1.3, a decrease in light ship weight has an impact on fuel consumption. For a panamax tanker American Bureau of Shipping (ABS) indicates a 0.34% change in fuel consumption for 1% change in steel weight by adjusting the block coefficient with deadweight maintained constant. /10/

Details of the subdivision of a ship's light weight are rarely published. Thus, in order to come up with a reasonable estimation of the light ship weight reduction of the autonomous vessel, suitable formulas for an approximation have to be used. Steel weight of superstructure and deckhouse is calculated with the Müller-Köster method to be 430 t. /37/ Further, equipment and outfitting of the living quarters is considered which includes e.g. cabin and corridor walls insulation, sanitary installations, kitchens, furniture and accommodation inventory. Weights in the accommodation area can be related to the associated volume of the deckshouse. In this case a weight of 70 kg/m^3 is assumed for a calculated volume of the decks house of 4690 m^3. /37/ Accordingly weight of equipment and outfitting in the accommodation and living quarters is estimated to be 328 t. Additionally, it is assumed that there are further systems not covered by the weight estimation of equipment and outfitting in the living quarters. This miscellaneous equipment and systems (partly below the main deck) includes e.g. life rafts plus mountings, waste water treatment systems, air conditioning, fresh water tanks as well as associated auxiliary systems. Weight of additional miscellaneous systems is assumed to be 20% of the weight of the deckshouse or 152 t. /37/

Based on analogy with comparable vessels and specifications given by Mikelis (see /38/) the light ship weight of the reference bulker is defined as 12,000 t. Taken together the weight estimations for steel structure, equipment and outfitting in the living quarters, miscellaneous equipment and systems the light ship weight reduction for an autonomous ship is estimated at 7.6%. With the relation between light ship weight and fuel consumption given by ABS (see /10/) this corresponds to a fuel consumption reduction for the autonomous vessel by 2.6%.

Hotel system: the third issue which is affected by shifting the crew from ship to shore and thus removing the deckshouse structure and associated hotel systems is electric power consumption. In order to estimate what part of the total electric power consumption on board is related to the crew living on board an electrical power balance of a container ship is shown in Table 16. In the last column consumers thought to be directly related to the crew living on board are removed from the nominal power in normal operation at sea. This way the total connected load for the given vessel is reduced by 40% (from 1227.2 kW to 739 kW). Even though it is unlikely that the reduction of total connected load (given for a container vessel) is transferable to a bulk carrier it is assumed that the relative reduction of electrical power consumption between the reference and the autonomous bulker is likely to be in the same order of magnitude. Accordingly it is assumed that the electric energy consumption of the autonomous bulker in sea passage will be only 60% of the electric energy consumption calculated for the conventional bulker in sea passage. This corresponds to a reduction by 154 kW. For the other operational statuses an equal reduction by 154 kW is assumed. Savings in fuel cost can be calculated with the specific fuel oil consumption and assumed fuel price.

Table 16: Electrical power balance for a reference container vessel with and without crew related electrical loads /39/[4]

Consumer	Total nominal power (NP)	NP – operation at sea		
	in kW	in kW	Without crew in kW	Assumed reduction
Auxiliary systems for propulsion service	1168	403.9	403.9	-
Auxiliary systems for ship operation	142.8	76.6	76.6	-
Heating ventilation air conditioning	374.3	309.3	0	100%
Galley and laundry	178.6	138.4	0	100%
Deck machinery	609.5	137.5	137.5	-
Ventilation cargo space	49.6	43.5	43.5	-
Lighting	91	81	40.5	50%
Other auxiliary systems	42.2	37	37	-
Total connected load	**2656**	**1227.2**	**739**	**40%**

Two engines / twin skeg: One of the main conclusions of the general technical system redesign for the autonomous vessel was that a high level of redundancy, up to installation of complete redundant systems with all components, was inevitable for a safe operation. For the propulsion unit of the vessel one feasible solution was identified in the installation of a pump jet in the forward part of the ship in order to ensure a minimum of maneuverability of the vessel in case of defects with the main propulsion or steering system. The option to go for two independent machinery plants was discussed in this context as well. /24/ Choosing a two engines design together with a twin skeg hull form might be advantageous in some cases compared to the pump jet solution. A good example in this context is given by Mærsk. The new Triple-E class features a twin-skeg propulsion system contrary to Emma Mærsk with a single engine/single propeller system. This allows Mærsk to reduce the energy consumption of Triple-E class vessels

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[4] Cargo refrigeration system given in the source is not shown here since it is assumed not to be relevant for the bulk carrier in this analysis.

by approximately 4% compared to the previous Emma-class vessels. /40/ Altogether, potential benefits associated with a twin-skeg design are multiple (see /41/, /42/, /43/, /44/):

- Two propulsion systems mean higher redundancy and thus an increase in reliability and safety.
- Two propellers often make an optimized propeller design possible. Propellers are more lightly loaded which increases the propeller efficiency.
- Two rudders and propellers typically increases (low speed) maneuverability and provide for a good course stability which reduces fuel consumption.
- Twin skeg designs can be much beamier. Shorter ships with equal deadweight enable savings in hull steel.
- Twin skeg designs allow a more aft located center of buoyancy associated with a slenderer fore body and reduced hull resistance.
- Shorter engine rooms make larger cargo holds possible which increases transport capacity.
- For specific designs twin skeg / two engine configurations have reduced power demand and lower fuel consumption than a comparable single screw design.

Not all types of vessels benefit from a twin skeg design though. Advantages are particularly likely for ships with highly loaded propellers, full hull forms or restricted draft. An important aspect that needs to be considered in this context as well is the efficiency of the engine. As two-stroke engines generally have smaller specific fuel oil consumption the larger they get, replacing one large engine with two smaller ones will likely result in overall higher specific fuel oil consumption. As an example a low speed small bore engine with electronic control (6S35ME-B9) and a power of 5,220 kW – thus two of this engine deliver about the same power as the engine selected for the reference vessel – has a specific fuel consumption of 176 g/kWh against 162,5 g/kWh for the larger engine with 10320 kW (6G50ME-C9). /45/ Thus, whether the benefits of a twin skeg design would outweigh the drawbacks for a specific autonomous ship cannot be said without having a full scale ship design at hand. Consequentially, potential benefits associated with a twin skeg / two engines design are not considered further in the financial analysis.

Boarding crew for port calls: The initial idea of the MUNIN project envisioned a boarding crew from a local departure and approach service in a given port to handle the vessel from port / berth to the open seas / pilot point (respectively the other way round). Thus, approaching and berthing is still executed by a conventional crew on board. Naturally this represents an additional service a conventional vessel does not require associated with a certain cost for the ship owner. MUNIN has developed several ideas how boarding crews might be dispatched in future. Options include a transfer of the crew by helicopter or crew transfer vessel. Other ideas foresee a remote control of the vessel from a pilot boat / tug boat (see /46/). Overall the concepts for crew transfer and manning during approaching and berthing are not worked out to a degree of maturity however, which would enable a sensible estimation of the cost associated. Instead an assumption that port call will be 20% higher for the autonomous vessel has to be referred to in the base case of the financial analysis.

3.3.3 Capital cost

Capital costs from the perspective of the ship owner are all expenses associated with the purchase of the vessel. Besides cost of financing they are primarily determined by the new building price of the vessel which in turn represents the production cost at the shipyard (plus a profit margin). Since the new building price is influenced by market forces (and thus difficult to determine) production cost are a better indicator to estimate capital cost respectively a change in capital cost. Two considerations are decisive to identify how capital cost for the autonomous bulker will differ from the conventional bulker:

- On the one hand several systems compulsory on a conventional ship are no longer required on an autonomous ship. As has been discussed in the previous sections this is primarily systems which support the crew on board. Consequently material and production cost for the deckhouse as it is found on today's ships as well as cost for the hotel system on board (air conditioning, water, sewage, etc.) are reduced for the autonomous vessel.
- On the other hand the autonomous vessel requires new systems which are not necessary on a conventional ship. For safe operation the vessel has to be equipped with specific autonomous ship technology (e.g. advanced sensor module, deep-sea navigation system) and feature a redundancy of certain technical systems (e.g. communication, electrical system, propulsion). Both will increase the production cost of the vessel and accordingly capital cost.

Coming up with estimates of the cost savings potential and any additional cost incurred is necessary in order to define the capital cost for an autonomous vessel and thus identify how capital cost will differ from a conventional ship. Several methods to estimate the construction cost of a ship are discussed in literature. /47//48/ Two general approaches for production cost estimation can be distinguished /49/:

- Top-down approaches
- Bottom-up approaches

The latter is a micro engineering analysis that comes to a rational estimate of production cost. It breaks down the whole project into smaller and smaller units until a basic element is reached. Then costs of each basic element as well as production cost of assembling several basic elements into an interim product on the next higher level are identified (which is repeated until the final level - the ship - is reached). The cost of the vessel is the sum of costs for all basic elements and costs of their assembly into interim products. While able to provide quite realistic estimates, this approach is associated with great effort and extensive requirements for detailed information. /47/ Thus, per se it is less suitable for estimating the cost of a system in a (very) early stage of development – as it is the case for the concept of an autonomous ship developed in the MUNIN project.

The former methodology is a macro approach usually weight and historical data based which relies on empirical or statistical relationships. It is often used in rather early stages of design and determines the cost based on parameters such as ship type and size and the estimated weight of individual systems of the ship (e.g. engine, hull, auxiliary system, outfitting and furniture). Methods and rules to specify the weight of individual systems with only limited information early in the design process are available in naval engineering (see for example /37/). Further, since weight characterizes the amount of physical material used for the construction of the vessel it often correlates well with cost. The parametric relation between cost and weight - sometimes complemented by estimations for the required labor - for a particular vessel type and size is identified by applying statistical methods on historical (known) cost data for comparable vessels. While there are several drawbacks associated with a top-down approach, its advantage is that it requires a comparatively limited information base and less effort than the bottom-up approach. /47//49/

With regards to a reduction of production cost – due to the fact that deckhouse and hotel system in their current form are no longer necessary – a top-down approach would principally lead to the desired result. Even though – due to the limited scope of the MUNIN project – no complete ship design for an autonomous vessel is available, suitable methods might be applied to come up with estimates for weights of individual systems of the ship that are modified for the autonomous bulker. (Simple) approaches to convert reduced weights into corresponding cost savings can be found in literature as well (see for example /50/,/51/). However, it is unclear from what data base the given relationships between cost and weight where derived from in these methods. Naturally, top-down approaches depend extensively on the quality of data and the comparability between the vessels in the database and the current project under consideration. Both cannot be ensured in this context and accordingly an application of top-down approaches for cost estimation has to be treated with caution. Unfortunately, when cost estimation methods were applied to the case of the autonomous bulker to get an estimate of changes in production cost, no sensible results could be obtained. Instead, to give at least an indication how capital cost of the autonomous ship will likely differ from the conventional bulker, typical values for the distribution of the building cost for different technological or weight groups can be referred to. Three cost distributions - for a platform supply vessel (PSV), a cargo ship[5] and a dry cargo ship - are shown in Table 17 and Table 18.

Table 17: Distribution of building cost per technological group for a PSV and a cargo ship /52/

Technological group	Share of total cost for a PSV (in %)	Share of total cost for a cargo ship (in %)
Hull	20-30	20
Machinery and propulsion	25	35
Cargo containment and handling	20-25	15
Ship common systems / ship assembly and systems integration	20	25
Hotel and accommodation	5	5

Table 18: Typical distribution of building cost per weight group for a dry cargo ship /53/

Weight group	Share of total cost
Steel structure (main hull)	24-35
Main engine	8-13
Other elements (superstructure, other machineries, accommodation, equipment and outfitting)	50-60

These cost distribution allow a first approximation of the reduction of production cost. Cost of the hotel and accommodation section represent 5% of the total cost. In case a hotel and accommodation section is no longer necessary the production cost could be reduced accordingly. An estimation of the share the ships deckshouse has in the production cost of the vessel is more difficult. The technological group *hull* represents a rather small part of the ships total cost to begin with. Furthermore, with steel weight accounting for 78 to 85 of the light ship weight overall (see /54/) the deckshouse – even

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[5] Estimates given by a senior naval engineer and general manager of a Korean shipyard

though it has a higher complexity than the main hull which adds to the production cost (see /50/) – is only responsible for a small part of the hull weight (an estimation of the weight of the deckshouse was given in the previous section). Thus, taking into account the higher complexity of the superstructure, the deckshouse might account for a couple of percent of the overall cost at most.

Besides the potentials to reduce the production cost of an autonomous vessel discussed so far, there are certain factors that will undoubtedly increase production cost. Primarily, this refers to new autonomous ship technology and a redundancy of certain technical systems on board for safety reasons. First concepts for autonomous ship technology have been developed during the project MUNIN. Due to the innovative nature of the technologies and the very early stage of development, coming up with a (reliable) cost estimation for these systems is hardly possible at this point. Regarding redundancy induced cost an exact derivation is difficult as well particularly without a detailed ship design. Nevertheless, to get an impression of potential effects on cost the following consideration is helpful. If machinery and propulsion account for 30% of the total production cost of the vessel and additional cost due to redundancy requirements increase cost by one third the overall cost of the ship will (still only) increase by 10%.

The discussion of prevailing cost influencing factors above has shown that it is not feasible to come up with a final estimation of the change in capital cost of an autonomous vessels compared to a conventional ship at this point. Accordingly, reasonable assumptions of potential cost changes have to be reverted to for the business case calculations in the following section. Considering the above it is deemed likely that production cost of the autonomous vessel will be higher but, due to the given potentials to reduce cost, not by a significant extent. Thus, a production cost of 110% is defined for the autonomous vessel as the base case in the financial analysis.

However, some parties have expressed expectations throughout the project that production cost of an autonomous vessel would be even lower than of a conventional manned ship. To take this into consideration production cost are set below those of the conventional bulker in a best case scenario.

3.4 Business case scenarios

In this section the results of several business case calculations are illustrated. To cover a wide range of possible future developments of important input factors the developed model was used to calculate different scenarios. In this context the B0 scenario - which represents an appropriate combination of near-term realizable modules in terms of a reduced crew on board – is discussed as well.

3.4.1 Base scenario

The base scenario represents assumptions and input values that are reckoned to be reasonable. Fuel prices in this scenario follow the medium reference fuel price scenario and the new building price of the autonomous vessel is set at 110% of the new building price of the conventional bulker. Both the autonomous bulker and the conventional bulker use HFO as main fuel.[6] Further, the base scenario considers the effects of reduced crew as well as those of improved fuel efficiency.

Over a 25-year period the MUNIN bulker improves the expected present value by mUSD 7 compared to the reference conventional bulker in the base scenario. Figure 13 shows how the cost structure of the autonomous vessel differs from that of a conventional bulk carrier in this scenario. Reduced crew cost contributes most to the overall positive present value.

Scenario description	
Fuel price:	Medium reference fuel price scenario
New building price	110% of conv. Bulker
Main fuel type	HFO
Considered effects	Reduced crew Improved ship efficiency

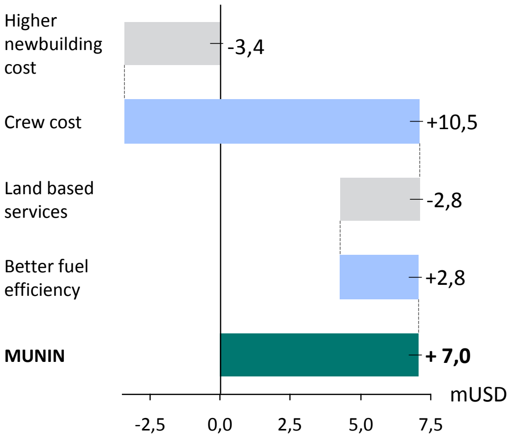

Figure 13: Base scenario: Main assumptions and expected present value over lifetime

In the base scenario average yearly expenses[7] for the MUNIN bulker are mUSD 1 lower than the expenses for the conventional bulk carrier. This corresponds to a reduction of average yearly expenses by 8.6%.

If, ceteris paribus, capital cost of the autonomous bulker are increased to 120% in a modified base scenario the expected present value is reduced to mUSD 3.6 over a

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[6] A requirement from the technical redesign of the Autonomous Engine Room was that autonomous vessel uses MDO as main fuel for technical reasons. The next scenario will address this requirement. An alternative might be pre-processing of HFO on land which is discussed in *New ship designs for autonomous vessels. /9/*

[7] Not considering the time value of money and excluding capital cost.

25-year period. A break even between the autonomous and the conventional bulker in terms of expected present value is reached at a new building price for the autonomous bulker of about mUSD44 (or ~130% of the new building price of the conventional bulker).

In order to evaluate the impact of fuel price on the expected present value over the lifetime of the vessel two additional fuel price scenarios were defined. In a high scenario fuel price was set at 120% of the price in the reference scenario; in the low scenario fuel price was set at 80% of the price in the reference scenario. When these alternative fuel price developments are considered in the base scenario calculations, two things can be observed. First, the higher the fuel price the higher is the expected present value of the autonomous bulker. Second, the expected present value increases (respectively decreases) at a slightly lower rate than fuel price (for an increase in fuel price of 20% the expected present value increases by 17%).

3.4.2 MDO scenario

The second scenario reflects the requirement form the technical redesign of the autonomous vessel to use MDO as a main fuel instead of HFO. The conventional bulker on the other hand continues to use HFO as main fuel in this scenario. Everything else is equal to the base scenario.

It is hardly surprising that the high cost of MDO compared to HFO will have a significant impact on the advantageousness of the autonomous bulker. Accordingly the MUNIN bulker has a negative expected present value of mUSD 29.7 in the MDO scenario compared to the reference conventional bulker. Figure 14 shows how the cost structure of the autonomous vessel differs from that of a conventional bulk carrier in this scenario. In order to put the result of this scenario into context: to break-even regarding expected present value the autonomous ship would need an additional 27% increase in fuel efficiency compared to the conventional ship to make up for the higher fuel price of MDO. Alternatively, the price premium for MDO compared to HFO would need to reduce to about 12% to justify an investment in the autonomous bulker (in terms of a break-even of the expected present value).

Scenario description	
Fuel price:	Medium reference fuel price scenario
New building price	110% of conv. Bulker
Main fuel type	**MDO**
Considered effects	Reduced crew Improved ship efficiency

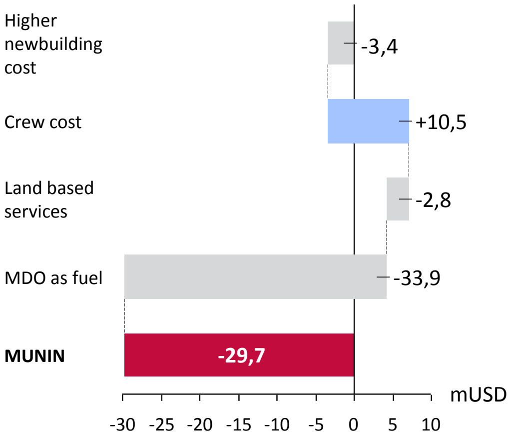

Figure 14: MDO scenario: Main assumptions and expected present value over lifetime

3.4.3 MDO&MDO scenario

The third MDO&MDO scenario represents an imaginable future where the use of HFO as marine fuel is no longer permitted e.g. due to certain environmental regulations, or an operational scenario in pure Sulphur emission control areas e.g. for short sea vessels /5/. Thus, ceteris paribus, both the conventional and the autonomous bulker rely on MDO as main fuel in this scenario

Over a 25-year period the MUNIN bulker improves the expected present value by mUSD 8.5 compared to the reference bulker in the MDO&MDO scenario. Thus the expected present value in this scenario is slightly higher than in the base scenario which was to be expected taken into considerations the findings from the alternative fuel price scenarios discussed above. Figure 15 shows how the cost structure of the autonomous vessel differs from that of a conventional bulk carrier in this scenario.

Scenario description	
Fuel price:	Medium reference fuel price scenario
New building price	110% of conv. Bulker
Main fuel type	**MDO on autonomous & conventional bulker**
Considered effects	Reduced crew Improved ship efficiency

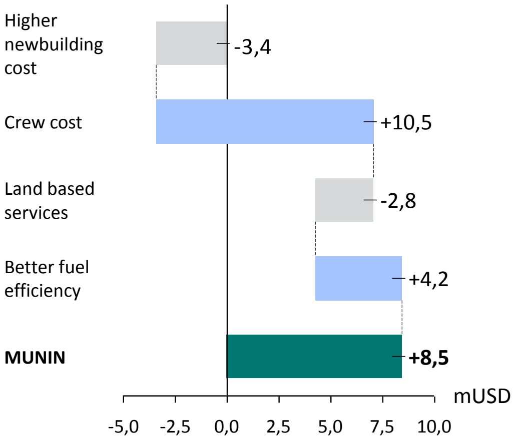

Figure 15: MDO&MDO scenario: Main assumptions and expected present value over lifetime

3.4.4 Reduced crew only scenario

The reduced crew only scenario, ceteris paribus, does not consider the assumed effects of an improved fuel efficiency of the autonomous vessel. Thus, it can be used to identify whether cost savings of shifting the crew from ship to shore as they are estimated in the financial analysis are sufficient to cover assumed increases in new building cost and additional cost associated with new shore and port services.

Over a 25-year period the MUNIN bulker improves the expected present value by mUSD 1.1 compared to the reference conventional bulker in the reduced crew only scenario. Figure 16 shows how the cost structure of the autonomous vessel differs from that of a conventional bulk carrier in this scenario.

Scenario description	
Fuel price:	Medium reference fuel price scenario
New building price	110% of conv. Bulker
Main fuel type	HFO
Considered effects	Reduced crew ~~**Improved ship efficiency**~~

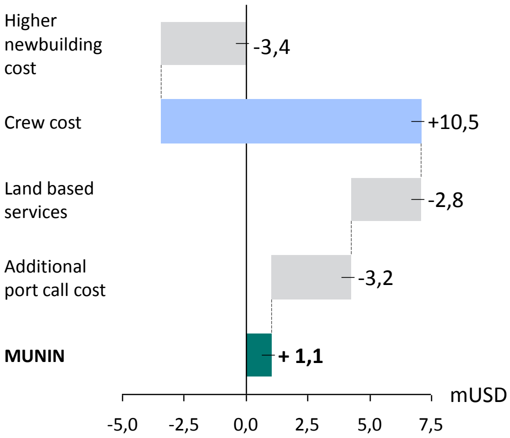

Figure 16: Reduced crew only scenario: Main assumptions and expected present value over lifetime

3.4.5 Best case scenario

The best case scenario combines a number of most optimistic assumptions to produce an answer to the question how large the expected present value of an autonomous is in case everything turns out in favor of the concept. To consider the expectation of some parties that production cost of an autonomous vessel would be lower than for a conventional manned vessel capital cost of the autonomous bulker is set at 80% of the reference vessel. The high fuel price scenario is applied and both the autonomous bulker and the conventional bulker use MDO as main fuel. Besides the effects of improved fuel efficiency and a reduced crew this scenario further assumes that autonomous ship technology will at some point develop to a level that an on-board control team is no longer needed for approach and berthing.

In the best case scenario the MUNIN bulker improves the expected present value over a 25-year period by mUSD 23.3 compared to the reference conventional bulker. Figure 17 shows how the cost structure of the autonomous vessel differs from that of a conventional bulk carrier in this scenario.

Scenario description	
Fuel price:	**High reference fuel price scenario**
New building price	**80% of conv. Bulker**
Main fuel type	**MDO on autonomous & conventional bulker**
Considered effects	Reduced crew Improved ship efficiency **No onboard control team**

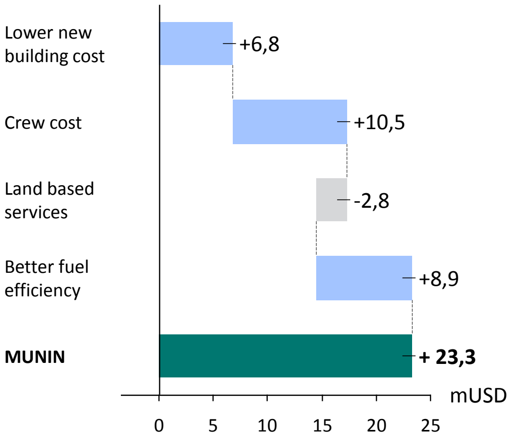

Figure 17: Best case scenario: Main assumptions and expected present value over lifetime

3.4.6 B0 Scenario

B0 was selected as an appropriate intermediate step towards fully unmanned and autonomous shipping (see /55/). It is based on the hypothesis that navigation systems will soon evolve so far, that standard situations can be dealt with automatically. Watch keeping officers are only required to supervise the systems but not necessarily to intervene. Thus, the bridge crew will only be working daylight hours, similar to the engine crew. During phases in which the bridge is unattended, the ship will be monitored by a shore-based entity. In case of an emergency, an alarm will be raised to call the duty officer to the bridge. The parameters for engine room operation are not modified in this scenario and correspond to an E0 operation with a periodically unattended machinery space. /56/

The developed model for the financial analysis of the innovation of an autonomous bulk carrier is only partially applicable for an analysis of the B0 scenario. Thus, it is adapted accordingly. From a cost perspective adopting a B0 operation has three main implications:

- Since the bridge crew will only work daylight hours the number of officers on board can be reduced which reduces the operating cost of the vessel.
- During times where the bridge is unattended the ship is monitored by a shore-based entity comparable to the shore control center developed for the autonomous vessel. The shore control center in a B0 scenario has somewhat reduced functionalities. It conducts “ship sitting” during e.g. night time which has to be paid for and accordingly operating cost of the vessel are increased.
- In order to deal with standard situations navigation systems in a B0 scenario will need to be more sophisticated and feature functionalities not part of conventional navigation systems today (e.g. a surveillance of the ships environment in order to detect objects automatically). Additional functions will likely result in a higher price of such systems which in turn increases capital cost.

As it has been argued above for autonomous ship technology, coming up with a sound estimate of the cost of a “B0 navigation system” is not seen as feasible at this point. Taking this into account the following approach is adopted instead to assess the B0 scenario: changes in the operating cost of the vessel – due to a reduced number of officers on board and “ship sitting” during times the bridge is unattended – are estimated. Resulting changes in operating cost over the lifetime of the vessel are converted into a maximum permissible increase in capital cost at the day of commissioning of a ship equipped with a B0 bridge to break even with a conventionally manned bridge. This maximum permissible increase in capital costs is to be understood as the discounted sum of investment cost and plus operating cost - in terms of e.g. incurred maintenance expenses - of the “B0 navigation system”. In case a “B0 navigation system” costs less than the calculated amount it generates savings for the ship owner.

Reduced crew cost: It is assumed that the number of officers on a B0 equipped vessel can be reduced from four to two at any given time. The number of ratings is unchanged. Cost figures for crew cost used in the financial analysis of the autonomous bulker are sums for total crew on board. Individual pay groups – in this context officers - are not specified. In order to obtain a value how much crew cost are reduced if the number of officers on board is reduced, wages specified for 2014 in the ITF Uniform "TCC"

Collective Agreement are referred to. For an assumed composition of the crew as shown in Table 19 cost for the Chief Officer plus the 3rd Officer account for 12.3% of crew cost. Therefore it is assumed that crew cost of a B0 equipped vessel can be reduced by that amount. Applied to the total crew cost (wages plus crew related cost) as specified in Chapter 3.2.1 the average estimated crew cost reduction per year for a B0 equipped vessel is estimated at about USD 112,000.

Table 19: Assumed composition of the crew on a reference vessel /32/

Pay group	Number	Total salary per month
Master	1	5,786
Chief Off.	1	3,780
2nd Off.	1	3,053
3rd Off.	1	2,946
Boatswain	1	2,001
Able Seamen	3	1,806
Ord. Seamen	1	1,375
Ch. Eng.	1	5,270
1st Eng.	1	3,780
2nd Eng.	1	3,053
3rd Eng.	1	2,946
Electrician	1	2,642
Fitter/Repairer	2	2,001
Fireman/motorman	2	1,806
Chief Steward	1	3,053
Chief Cook	1	2,001
Total	20	47,299

Cost of "ship sitting": The requirements for a control center that carries out "ship sitting" are derived from the set-up of the shore control center for an autonomous vessel as developed in the MUNIN project. Some modifications are made. Situation rooms are not required for "ship sitting" thus no watch keeping engineers and captains are considered. Maintenance and voyage planning is not done in the center either. It is assumed that one "ship sitter" monitors 6 vessels at one time and the center is run as a one shift operation during which 90 vessels are monitored. The number of employees per work station is estimated at 1.9 (to cover vacation, training, absence). Consequently 45 employees work in the "ship sitting" control center in total (see Table 20). Wages are calculated in the same way as for the full scale shore control center in Chapter 3.3.1. In addition investment and operating cost associated with setting up and running the "ship sitting" control center (one-time cost for equipment and annual costs) are estimated. This way cost of "ship sitting" is estimated at about USD 31,000 per vessel per year.

Table 20: Employment plan for the "ship sitting" control center

One shift operation	Per shift	Total number	Equivalent in ITF wage scale
5 operators (1 per 6 vessels)	15	29	3rd Off
1 back up operator (1 per 5 operators)	3	6	3rd Off
1 watch keeping supervisor	3	6	Master
2 admin personal	2	4	3rd Off

Based on the cost estimates for crew cost reductions and "ship sitting" cost above, a present value of USD 859,000 over a lifetime of 25 years is determined. Accordingly the discounted sum of investments plus operating cost of the "B0 navigation system" has to be lower than USD 859,000 for a B0 concept to be favorable form a financial point of view. It has to be noted though, that potential benefits of a potentially increased safety associated with implementing a B0 concept are not considered in this calculation.

3.5 Conclusion

Even though the MUNIN project has provided answers to many of the essential technical questions associated with an autonomous ship the development is still in a very early stage and the project scope was somewhat limited towards a selection of the most severe technical challenges. Accordingly the financial analysis carried out as part of the project had to rely on assumptions to some part and these assumptions might turn out to flawed. Nonetheless an in itself sound assessment of the economic efficiency of an autonomous vessel as conceptualized in MUNIN was conducted with very interesting conclusions and findings.

Based on this analysis it is safe to assume that autonomous ships will have a positive impact on the profitability of shipping companies – but only under specific conditions. (Currently) HFO is unrivalled in terms of price compared to MDO. If going for a completely unmanned vessel requires switching from HFO as main fuel to MDO it is unlikely that such a concept would be financially viable. In future, however, tighter environmental regulations may diminish the difference in price between marine fuel types evident today and thus reduce the disadvantage of using MDO.

If both the autonomous bulker and the conventional bulker use HFO as a main fuel there is good reason to believe the unmanned ship will have an overall lower cost profile over its lifetime. This is for one reason in particular: besides cost savings due to a higher efficiency of land based services in port and the shore control center an autonomous ship makes changes in ship design possible which carry potential to reduce the fuel consumption (and thus emissions as well) of the vessel. Since fuel cost take on such a dominant position in the total costs of owning and operating a ship - typically representing between 50% and 70% - any reduction of the fuel consumption has a strong impact on the financial performance. Reducing crew cost only without achieving better fuel efficiency will most likely not be enough to justify total autonomy. Combining crew cost savings and savings due to autonomous ship designs quite likely will.

Not included in this assessment are potential benefits due to increased safety and interdependencies with other innovation closely related to the intelligent ship (such as optimized (weather) routing or on-board energy efficiency management) that will likely contribute to the favourability of the autonomous ship. Furthermore, the analysis is focusing on the ship-related costs for berth-to-berth-operations and has not further investigated potential of additional benefits in terms of transportation cost for fence-to-fence-logistics. Currently, this is beyond the scope of investigation, but long-term potentials might also exist in the total transport chain, e.g. due to increased flexibility and cost-efficient downsizing.

To achieve a more precise economic assessment of the viability of an autonomous bulk carrier it will be necessary to have a holistic ship design as a basis including e.g. hull, superstructure and auxiliary systems and also continue research on maintenance strategies as well as the concrete design of the SCC and port call procedures. The MUNIN project set out to develop a concept for an unmanned bulk carrier. Thus the economic assessment focused on this particular type of vessel. By now other ideas have emerged and it would be worthwhile to carry out a structured analysis for other ship types and compare expected advantages between them to identify the most advantageous applications of autonomous ships. Further it would be interesting to broaden the perspective of the assessment of the innovation of autonomous vessels to put a stronger emphasis on macroeconomic and societal aspects.

4 Legal & liability in-depth assessment

4.1 Methodology

This lengthy section provides an extensive and in-depth analysis of the most important legal issues arising out of the MUNIN project on unmanned shipping. This work was undertaken in the last few months of the project, when most of all other technical aspects of the MUNIN unmanned ship had been explored by the other partners. On the basis of the work and results of partners, it was decided to structure the liability analysis into the main areas likely to raise legal issues, namely:

(1) The question of navigation without a so-called "human" look out and the related issue of the "automated" and "autonomous" look out as envisaged within the MUNIN project.
(2) The question of manning
(3) The engine room and maintenance issues
(4) The various areas of potential liability
(5) The question of insurance.

For each of these areas, the analysis is based on the findings and results of other tasks and WPs, as they relate to the Autonomous Bridge, the Shore Control Centre, and the Autonomous Engine Room. Every effort has been made to relate existing law to the features that the unmanned ship would have, as proposed by the MUNIN project, and to explain whether the law as it currently stands would be able to encompass an unmanned ship. This has been done by either showing that the unmanned situation would be analogous to a manned situation, therefore not requiring a change, or by proposing a progressive interpretation of the law capable of accommodating the new unmanned situation. Where the analysis shows that it is unlikely, it is indicated that formal changes to the law would be required in order to legally enable the unmanned ship. Reference to the relevant MUNIN reports is provided to show how the legal analysis follows closely the findings of the project.

This section is based on an extensive analysis of international legal regimes relating to the identified areas. In addition, where relevant, examples taken from national legal regimes are provided (mostly from the UK regime). Legal research relating to the unmanned ship would need further exploration if an unmanned ship was actually going to be built and launched. However, this section provides a solid foundation to explore the relevant areas of law, should this be a possibility in the near future. As showed the previous assessment report *Qualitative assessment* (see /57/), the unmanned ship is no longer a mere futuristic possibility, but could well be a reality in a few years. If nation

States and private entities were to engage in this path, it is clear that a few changes to the law would be required, but that the law would in any way not be an obstacle, merely an issue to be resolved. It is also clear the international efforts would be required to secure such changes, and that is why the present section focusses mostly on international regimes, and less so on national regimes. Indeed, it became apparent that a coordinated international effort would be a necessity for any State to allow an unmanned ship to set sails, rather than individual national changes.

4.2 Navigation and the Human Look-out

The unmanned ship can be quite contentious when it comes to navigation. From the discussion in *Impact matrix and report* (see /55/) the position of an unmanned ship cannot be definitively stated with respect to compliance with certain international conventions concerning look-out duties. The technology and equipment employed on an unmanned vessel used to control its navigation may only offer partial compliance with international law as presently drafted and the extent of this compliance can only be measured according to the interpretations given to the regulations within. The first part of the analysis of the MUNIN project highlighted certain areas where navigation of an autonomous vessel could prove problematic. /55/ In that report a tentative and cursory discussion of the issues arising was carried out. Now, in this report, a more detailed analysis can be undertaken in light of the discussion presented in the *Qualitative assessment* of the technology an unmanned vessel will be equipped with. /57/

The MUNIN unmanned ship will be fitted with a Deep-Sea Navigation System (DSNS) as part of its Autonomous Ship Controller. On an unmanned ship this navigation system carries out the navigational functions which would otherwise be undertaken by officers on board a manned ship. The DSNS will perform this task by way of *conduct weather routing* and *conduct collision avoidance*. The DSNS is the crux of the solution to the navigational issues emanating from the operation of an unmanned ship and its compliance with the relevant conventions. It is intended that the DSNS will replace the human navigation element on a tradition ship without compromising on the standards of safe navigation.

4.2.1 Identified legal issues for the unmanned ship relating to navigation

Deep Sea Navigation System

Like a manned ship, the unmanned ship will be capable of navigation but it is conducted in a different way. The Deep Sea Navigation System (DSNS) on board an unmanned ship works in conjunction with the Advanced Sensor Module (ASM) which provides data about the area and environment around the ship and the Automated Engine Monitoring and Control (AEMC) which provides information about the ship itself. /59/ /61/ As noted, the unmanned ship is always subject to the supervision of the Shore Control

Centre which can take over the navigation of the ship at any time should the need arise using the Remote Manoeuvring Support System (RMSS). /59/ /61/ Therefore, just like on a manned ship, the unmanned ship can monitor both the surrounding environment and integrity of the ship and take action accordingly with the SCC available to intervene.

The ASM with its navigational and safety sensors provide data to the DSNS thus enabling it to operate just like a normal ship. These will be complimented by sensors already available on normal sea-going ships. /59/ /61/ Essentially, the unmanned ship is taking the use of and reliance on technology a step further. The ASM will use, *inter alia*, information from daylight and infra-red cameras, GNSS, echosounders, speed logs, NAVTEX, weather forecasts and sea charts. The information garnered from these several sources will then be correlated to give a complete and accurate view of the environment and prevailing conditions.

It was recognised in the project that weather and traffic are the two most important risks to the safety of navigation. The report *Autonomous deep-sea navigation concept* explained how MUNIN autonomous ship conducts weather routing and collision avoidance. (see /58/)

In the report *Autonomous deep-sea navigation system concept* it was noted that an unmanned ship must be able to react appropriately in adverse weather condition by taking both operational counter measures and strategic planning decisions. /58/ On a traditional manned ship, both strategic and operational weather routeing are conducted on board the ship by its master. Current state-of-the-art technology is insufficient to enable an unmanned ship to complete these tasks. Complete sensor data, including motion sensors and wave radar, a connection to the on-board loading equipment and an ECDIS interface are required for the unmanned ship. These are currently not catered for in existing technology.

The DSNS operating on board an unmanned ship is dependent upon metrological data, traffic data, ENC data and when required, manual input by the SCC for collision avoidance. The ASM provides the metrological and traffic data. As it stands, available technology currently employed on manned ships for collision avoidance purposes is inadequate for the purposes of the MUNIN unmanned ship. The installations would only allow partial compliance with the relevant rules and in some instances no compliance at all for example Rule 19 on restricted visibility. The need to conduct further visual assessments may not be possible and difficulties in performing evasive and last minute manoeuvres will present themselves.

In some situations, control of the unmanned ship is taken by the SCC and the strategic and operational plan of the DSNS are overridden to allow for direct remote manoeuvring from the SCC. In these situations the SCC operator is subject to an unavoidable detachment and disconnection for the ship itself and situation occurring due to the absence of a physical presence at the scene to see and appreciate what is happening. In such cases, it is important that the staff in the SCC get a proper sense of the reactions and movements of the ship.

The operational limits for manoeuvring a ship are normally handled by the navigating officer in charge. An experienced mariner will still find it challenging to manoeuvre in difficult circumstances. The absence of a physical presence on the bridge may make manoeuvring more arduous for SCC personnel. To help ameliorate this problem the MUNIN RMSS incorporates a manoeuvring prediction, with state of the art visual interface, to assist the operator in the SCC. /57/ The RMSS therefore provides the prediction of current settings, and also maximum rudder and engine manoeuvres. For example it shows whether stopping would help in a collision avoidance situation, the effects of a full turning circle, or the combination of both.

Having identified these legal issues, it is now necessary to consider in details how the MUNIN unmanned ship proposes to address them from a technical point of view. This will go towards analysing the legal implications of the MUNIN solutions.

4.2.2 The MUNIN Unmanned Ship and the Automated Look-Out

4.2.2.1 *The MUNIN Deep Sea Navigation System*

The MUNIN unmanned ship includes a Deep-Sea Navigation System (DSNS) as part of its Autonomous Ship Controller (see /59/). The DSNS is what replaces the officers on an unmanned ship, to manoeuvre the ship safely, namely by way of 'conduct weather routing' and 'conduct collision avoidance'. It is described in details in *Autonomous deep sea navigation system concept* (see /58/) and the present document points to its critical elements relating to legal obligations. The DSNS is an essential element in understanding how the MUNIN unmanned ship can replace the navigational human functions carried out on board, while ensuring the similar or higher level of safe navigation. This document then connects the analysis of the DSNS to other parts of the project which are linked with the DSNS, such as the important information relating to communication systems and procedures, and the Shore Control Centre.

The DSNS is based on a standard definition of navigation: 'the process or activity of accurately ascertaining one's position and planning following a route' (/58/) whether manned or unmanned, navigation requires information about the ship (technical limitations of the ship, speed, manoeuvrability, responsiveness, etc.) and about its vicinity (weather, sea-state, surrounding maritime traffic, etc.). The MUNIN DSNS is thus connected to the Advanced Sensor Module (ASM), which provides information about the surroundings of the ship, such as floating or submerged objects, ships and environmental conditions. Information about the ship is provided by the Automated Engine Monitoring and Control (AEMC) and by the Remote Manoeuvring Support System (RMSS). This process of autonomous navigation is operationally supervised by the Shore Control Centre, which is manned and may take full control of the ship when necessary, at any time.

The Shore Control Centre has control of the 'operational envelope' of the ship, which consists of the voyage plan and threshold values. The autonomous navigation system updates the waypoints list, and controls rudder and engine with the automatic track pilot. It is designed to function autonomously, within defined parameters. Only when these parameters are overtaken, the SCC by-passes the system to take direct control of the ship (for example when harsh weather creates a critical situation and the risk of delays).

The SCC transmits the voyage plan to the Autonomous Bridge System (ABS), and monitors its implementation via the automated track pilot. The SCC also determines the degree of freedom of the autonomous ship, by setting threshold values regarding acceptable sea state conditions, minimum passage distances, allowable track deviation, etc.

The report *Autonomous deep sea navigation system concept* explains that 'the main function of this module is to maintain lookout by all available means for obstacles as well as for environmental conditions in the surrounding of the ship.' /58/

Navigational and safety sensors provide data. Fusion and correlation of the data thus provided by all sensors improve the quality and integrity of the information used by the ASM and reduce uncertainty. The normal sensors already available on ships are complemented by daylight and infra-red cameras, also providing critical information about the ship's surroundings. The ASM also uses information from GNSS, echosounders, speed logs, NAVTEX, weather forecasts and sea charts.

Here are the main functions of the ASM, which are important to understand how the ASM performs the required lookout function:

- Object detection and identification: input from radar, Automatic Radar Plotting Aid (ARPA) and camera imagery. Also, AIS data is used to identify ships. For

detected objects that the ASM cannot identify, assistance is requested from the SCC.
- Weather observation: meteorological sensors provide information about wind, precipitations, atmospheric pressure and humidity.
- Sea state, ocean surface current and bathymetry: radar and camera imagery data are processed.
- Visibility: continuously assessed by the visual system.

All observations and data thus collected are correlated. According to *Autonomous deep sea navigation system concept*: 'This enables a thorough situational assessment based on robust data to detect and identify potential hazards to the UAS' safe voyage'. /58/

It is recognised that weather and traffic are the two most important risks to the safety of navigation. It is therefore important to explain how the MUNIN autonomous ship conducts weather routing, and collision avoidance. Indeed, it is part of the argument to demonstrate that the MUNIN ship is capable of performing the same navigational functions as a manned ship, in terms of safety.

Harsh weather is known to be the biggest danger to ship navigation. It causes sinking, submerging and foundering. There is a legal obligation on the ship master to ensure safe weather routing, which includes assessing the effects on the ship of current, sea state, waves, wind and sub-zero temperatures (ice). The DSNS must therefore be capable of conducting this assessment so that the DSNS can effectively replace the ship master as regards those functions.

The MUNIN DSNS is designed to circumvent the threats posed by harsh weather, such as induced waves and heavy swells, which can cause surf-riding and broaching-to, reduction of intact stability when riding a wavecrest, synchronous rolling motion and parametric roll motion. Therefore the DSNS must be able to adopt operational counter measures (such as course and/or speed alteration) when adverse environmental conditions are detected. But in addition to the operational counter measures that the DSNS must be able to take, weather routeing also comprises a strategic planning element, to prepare the ship's voyage plan before it departs. This voyage plan has for objectives to ensure safe navigation, including the avoidance of dangerous situations, as well as fuel consumption optimisation. To this effect, it is a requirement that the voyage planned route should be based on: /60/

"1. …the appropriate nautical charts and nautical publications for the area concerned, taking into account the guidelines and recommendations developed by the Organization.".

Also, the route should:
“2.

1. Take into account any relevant ships’ routeing systems;
2. ensure sufficient sea room for the safe passage of the ship throughout the voyage;
3. anticipate all known navigational hazards and adverse weather conditions; and
4. take into account the marine environmental protection measures that apply, and avoid, as far as possible, actions and activities which could cause damage to the environment.”

On a traditional manned ship, both strategic and operational weather routeing are conducted on board the ship, by the ship master. *Autonomous deep sea navigation system concept* reviewed current state of the art equipment being used to assist in this task:

- Weather routeing systems, which may include parameters concerning ship’s resistance, loading conditions and ship motions. These systems assist in determining “real-time assessment of seaworthiness”
- Weather forecasts
- Route restrictions (TSS, islands) and ECDIS

Importantly, the review carried out in *Autonomous deep sea navigation system concept* shows that this state-of-the-art technology is insufficient for the purposes of the unmanned ship’s navigation and weather routing. Complete sensor data, including motion sensors and wave radar, a connection to the on-board loading equipment and an ECDIS interface are required for the unmanned ship. They are currently not catered for in existing technology.

The MUNIN approach is therefore to distinguish strategic routeing from operational routing. Strategic routing optimises the route with regard to duration and fuel consumption. It takes into account the particularities of the ship, its destination and the available weather forecast. Operational routing is concerned with short-term navigation, prevailing weather conditions around the ship and the ship’s position. On a traditional manned ship, this is heavily dependent on the “navigator’s cognitive senses and his subjective sensing”. /58/ On the unmanned ship, the navigator’s senses are replaced by the Advanced Sensor Module (ASM), which provides real-time data about the surrounding environment of the ship, as described above. This data is added to the specifications of the ship, and the limitations imposed by the Shore Control Centre so that the DSNS can optimise the route. The Weather Routeing Module (WRM) of the DSNS also collects information about the ship itself, in order to know and predict the ship’s reaction to her environment and to manoeuvres. Further, a hydrodynamic model allows taking into account the ship's hull to the sea, in still conditions and in conditions where wind and waves are added.

The DSNS is dependent upon, for collision avoidance purposes, meteorological data, traffic data, ENC data and when required, manual input by the Shore Control Centre. The ASM provides the meteorological and traffic data, as explained above, following a sensor fusion process. The legal obligations resting on the ship master as regards collision avoidance are detailed in the Collision Regulations, as explained in *Impact matrix and report* and in A*utonomous deep sea navigation system concept* (see /55/, /58/). State of the art technology to assist ship officers in conducting collision avoidance procedures and manoeuvres currently exist, however, they appear to be insufficient for the purposes of the MUNIN project, and the unmanned ship in general. Either they assist with some of the rules only, and not all of them, or they do not include situations of restricted visibility (Rule 19). The MUNIN approach is therefore based on two strands:

- Analysis of the actual traffic situation, then
- Determination of Collision Regulations- conform counter measures.

4.2.2.2 *Analysis of the traffic situation*

Data is provided by the ASM, and includes AIS, radar and camera data. On this basis, the DSNS can detect objects, and classify them into 3 categories:

- Detected objects
- Classified objects (ship/non-ship)
- Identified ships.

'Detected' and 'Classified' objects normally require further visual assessment by the Officer Of the Watch (OOW), to determine their nature (for example, a floating container). This will obviously not be possible on the unmanned ship, so AIS information will be necessary to identify ships and determine and adopt the appropriate ColReg compliant measure. Therefore as the first analysis indicated, Part C of ColRegs will not be complied with. /55/

4.2.2.3 *Determine ColReg- conform counter measures*

Having assessed the traffic situation, the DSNS must then determine a ColReg-compliant measure. In this respect, a generic evasive manoeuvre strategy is a solution for the unmanned ship. In a multiple-ship situation, it can be impossible to determine whether the unmanned ship should be the give-way or the stand-on vessel. An evasive manoeuvre, leading the ship away from the situation which would otherwise call for a Col-Reg manoeuvre. This evasive manoeuvre must however also take into account required safety levels and economic impacts (fuel consumption). Also, the weather routeing module will provide the relevant constraints so that the unmanned ship does not encounter harsh weather while conducting an evasive manoeuvre.

Rule 17 of ColReg requires a manoeuvre of the last second in certain circumstances. The DSNS includes this functionality, which is based on threshold values set in advance by the SCC:

- Emergency stopping distance
- Time and distance to being off-track (starboard and port)
- Turning circles for a given rudder value (starboard and port)

This Fail to Safe functionality on the DSNS uses those values to safely determine a no-go area around the ship, and identify the last moment at which an action must be adopted. Rule 17 requires identification of the moment the give-way vessel can no longer avoid the collision to determine when the other vessel must adopt a last second manoeuvre. But as this is often difficult to determine, the last moment is also identified on the basis of the unmanned ship's own threshold values.

4.2.2.4 *Remote manoeuvering*

In some situations, control of the unmanned ship is taken over by the SCC, and the strategic and operational plan of the DSNS are overridden to allow for direct remote manoeuvring by an operator or navigator in the SCC. In such cases, it is important that the staff in the SCC gets a 'good sense' of the reactions and movements of the ship. This is normally done by an officer standing on the bridge, but for the unmanned ship, the Remote Manoeuvring Support System (RMSS) will have to conduct equally safe manoeuvres.

The operational limits for manoeuvring a ship are normally handled by the navigating office in charge, and besides the ship's own characteristics, they include the impact of wind on the speed and reactions of the ship, current heading, depth of water, traffic lanes, narrow channels, etc. A well experienced mariner will still find challenging to manoeuver in difficult circumstances. The MUNIN RMSS includes a manoeuvring planner, with state of the art visual interface, to assist the operator in the SCC (see/61/). The RMSS therefore provides the prediction of current settings, and also maximum rudder and engine manoeuvres. For example it shows whether stopping would help in a collision avoidance situation, or the effects of a full turning circle, or of the combination of both.

One issue that investigations in MUNIN have highlighted relate to the problem of time-delay in the ship-shore communications. Time-delay would impact on remote manoeuvring, and further research is necessary to determine the maximum time-delay allowable.

Testing during the MUNIN project showed that the RMSS with predictor effectively helped the operator in the SCC, who was able to direct the manoeuvre better and to reduce the number and amplitude to changes to the rudder.

4.2.2.5 *Telecommunications standards and satellite services*

It is important that the data models and protocols used in the unmanned ship are reliable and internationally recognised. *Final interface description* (see /59/) identified existing standards for the maritime sector:

- IEC (International Electrotechnical Commission) 61162-series, for data contents exchanged between navigation and radiocommunication equipment. IEC-61162-1 was the original standard, with a nominal speed of 4,800 bits per second (bps). IEC 61162-2 has a higher transmission speed (up to 38,400 bps). IEC-61162-3 goes even higher (250 kbps). IEC-61162-4 is a series of standards for Ethernet interconnections. It includes IEC-61162-460 (under development), which will 'provide functionality for safe connections to entities outside the controlled network as well as support redundancy to increase reliability in the network itself'.
- ITU (International Telecommunication Union): standards for AIS, including data transmission formats. These formats are reflected in IEC 61162-1.
- ISO 28005-2, which contains a data model for ship clearance in port, and other operational requirements.

In addition, research within the project kept an eye on the work carried out by the International Hydrographic Organisation (IHO) on S-100, a data standard extended from S-1900 series for geographical data, into hydrographic, maritime and related issues.
Given the complete level of automation required for an unmanned autonomous ship, MUNIN is working on the basis of those recognised and relevant standards developed by IEC, ITU and IHO. This aspect of the project is very important from a point of view of seaworthiness of the unmanned ship, whereby the shipowner must demonstrate, according to established legal standards, that the ship is safe and seaworthy, and that the cargo is also safe. Beside the data standards and models, the issue of automation and safety system networks within the ship are also critical. The report *Final interface description* noted that in this area, there is currently less standardisation, and different manufacturers offer different systems. /59/ MUNIN is taking this into account, and still

working towards the use of IEC 61162-460, including for interface of the automation and safety networks.

As regards ship-shore communication satellite links, VSAT and Inmarsat are the preference, as they are the only two recognised by IMO. Iridium can be used as back up. Finally, AIS standards are crucial, as they are already widely used, and will be necessary for the DSNS. In this respect, the MUNIN report *Final interface description* recommends considering an amendment to Colregs to align Part C with SOLAS V/19 on nautical data sent by AIS, and make sure that nautical data is compulsorily sent through AIS by all ships. Currently, AIS technical specifications are maintained by ITU. /59/

4.2.3 Conclusions on the compliance of the MUNIN DSNS with current navigational legal requirements

4.2.3.1 *Collision Regulations*

The main source of regulation for the navigation of ships is the Collision Regulations Convention. As suggested in *Impact matrix and report* the Regulations are more than likely applicable to an unmanned ship given the use of the term *vessel*./55/ This is a very open term and can conceivably incorporate any vessel including an unmanned one. The Regulations, at Rule 1(e), do however permit deviation in certain circumstances which could be quite helpful considering an unmanned ship constitutes a massive departure from how conventional ships operate. Such a provision could be of great benefit to the MUNIN unmanned ship because it was posited in *Impact matrix and report* that an unmanned ship would be in violation of several navigation rules. /55/

4.2.3.2 *Look out*

Most problematic is Rule 5 concerning the look-out. This requires a human with abilities of sight and hearing. Case law mandates specific characteristics for a look-out but no fixed criteria exist. A relaxation of the rules is evident with respect to ocean voyages which could bolster an argument advancing an unmanned ship’s automated look-out. Courts countenance the use of, and permit reliance on, electronic aids when conducting look-out duties. Notwithstanding, the human look-out is still required and total deference to such aids does currently not have judicial acceptance. It could be said that this is because courts have so far never been presented with a fully autonomous electronic look out system, such as developed in MUNIN. The argument that the need for direct human look out is no longer necessary is yet to be made. In this respect it should be borne in mind that the SCC can at any moment take control of the ship, thus providing an indirect human look out.

Rule 19, *Conduct of Vessels in Restricted Visibility*, may also have a large bearing on this attitude. However, given the advanced systems on board an unmanned ship the argument for a non-human look-out could be cogently made. /57/

Another point raised in *Impact matrix and report* is that look-out functions include manual checking of the ship itself to ensure it is working properly for example steering, equipment, compass, etc. /55/ The look-out must ensure not only that the ship is keeping clear off other shipping paths, but also that it is steering in the right direction and responding to orders satisfactorily. The automations on board an unmanned ship will ensure that the substantive standard of Rule 5 is met. In particular, it is important to note the relationship between the automated bridge and the automated engine room which is always monitored by the SCC. The Remote Manoeuvering Support System (RMSS) developed in MUNIN also goes towards replacing the 'sensations' and direct feel that the navigating officer normally experiences.

4.2.3.3 *Safe Speed*

A safe speed must be maintained by all ships under Rule 6 and Rule 19. Several factors must be assessed in determining what constitutes safe speed at any moment in time: state of visibility, traffic density, manoeuvrability, background light, state of wind, sea, current and proximity of navigational hazards, and draught. Electronic equipment has its limitations and this is particularly pertinent for the unmanned ship, as mentioned in *Impact matrix and report*, which will rely entirely on electronic means for taking decisions as to speed. /55/. However, as explained above, MUNIN uses data fusion to provide an advanced state of information upon which to determine safe speed. Here again, an argument could be made about the reliability and reliability of such data, and the correct speed thus set.

4.2.3.4 *Collision*

Rule 7 on the identification of a risk of collision and Rule 8 on collision avoidance are critical to navigation. Reliance cannot solely be placed on computer software and electronic apparatus to evaluate this risk. Reversion to traditional methods such as plotting should also be used. A lot turns on how the installations on an unmanned ship together with possible SCC guidance can meet the demands of this extremely important rule. Here, the solution to have recourse to evasive manoeuvers for the unmanned ship could be a key element in arguing that the unmanned ship is capable of steering clear of collision risks, thereby not coming within the scope of Rules 7 and 8.

4.3 Manning

This section considers the legal implications as regarding the manning issue, from three points of view. First, it analyses the role of the ship master, and how this role is being fulfilled in the unmanned ship. Second, it looks at staffing issues in the Shore Control Centre. And third, it takes a close look at the specific legal requirement concerning Search and Rescue (SAR) obligations, and how the unmanned ship can meet them. This third aspect was thought to be important in the light of current migration and refugee events taking place in southern Europe across the Mediterranean Sea.

4.3.1 The Master's Responsibilities in the Unmanned Ship

Currently, the ship master is the focus of liability when maritime incidents or accidents occur. The question is how this role would be replaced in legal terms in situation when there would be no master physically present on board the unmanned ship.

This section addresses the responsibilities of the master in maritime law and how unmanned ships propose to meet those responsibilities. The present duties of the master are defined in domestic law, international conventions and safety codes.[8] Most, if not all of these duties, would, in the case of an unmanned ship, fall to be discharged by an automated system which in certain pre-defined circumstances will be supervised by a human controlled operator in the Shore Control Centre. The transition from manned to unmanned ships has, in the eyes of some critics, completely eroded the role of the master. /62/

This section will first summarise the master's current responsibilities as they are stated in maritime law. Then it will examine how these responsibilities are discharged in an unmanned ship. Suggestions are made throughout, where appropriate, as to how these responsibilities should be met or whether some of the master's duties are made redundant by technology.

4.3.1.1 *The Masters Duties and Responsibilities*

The role of the master was once described as "a man of many parts" /63/ which was considered to be the case before technological development. Both as a matter of law, and

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[8] The Merchant Shipping Act 1995 sets out a number of duties that fall to the master to be discharged under UK legislation. Hereafter referred to as "the MSA 1995". See also, the International Management Code for the Safe Operations of Ships and for Pollution Prevention ("the International Safety Management Code") 1987, as implemented by Regulation (EC) No 336/2006 on the 15th February 2006, and The International Regulations for Preventing Collisions at Sea, 1972 and the Merchant Merchant Shipping (Distress Signals and Prevention of Collisions) Regulations, 1996. See also the International Convention for the Safety of Life at Sea 1974 ("the SOLAS Convention").

a matter of fact, the master was "in charge of his crew, part accountant, part lawyer and part navigator". /63/ In addition to this, the master also operated as a servant in law and agent for the ship owner and charter party.

Nowadays, however, much of the legal duties that fall to the master have been either modified or replaced by technological development. Autopilotage, for example, in long route legs, requires minimal human supervision. In addition to technological development, communication with the ship owner has impacted on the decision-making responsibility traditionally within the remit of the master. The master's role might nowadays be viewed as being consigned to making decisions in emergency situations only. /62/ A different view is that the role of the master is still relevant both as "agent of necessity" in an emergency situation in making the final call and in a contractual situation as the person who is entrusted with a large amount of property. /63/

Despite this difference in opinion as to relevance of his role, there is little doubt that technology has encroached significantly, if not superseded his role. Many of the automation functions proposed by MUNIN are already in operation on manned ships, which, as Allen notes, "makes the practical difference between a manned vessel and an unmanned vessel very little". /64/

The present duties of the master can be divided into the three categories. First and foremost is the master's all-encompassing duty of safety of operation and good management, not merely in respect of his own ship, but other ships which may encounter difficulties.[9] /65/ Academic analysis of the MUNIN project suggests that this role will be consigned to history given the technological advances of the project. Secondly, the master of a ship must fulfil certain administrative and reporting duties, which were given less consideration under the MUNIN framework but will be easily adapted by the proposed framework. Finally, the master as agent of the ship owner has certain responsibilities relating to the performance of charterparties.

Duty of Safety of Operation and Good Management

The master has absolute discretion when making decisions in the interests of safe navigation and protection of the marine environment. This discretion is enshrined in the International Convention for the Safety of Life at Sea 1974[10] ("the SOLAS Convention"). /66/ With such discretion, however, comes great responsibility. The master while on board his ship must make sure that he doesn't do anything which causes or is likely to

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[9] These duties are set out in section 58 of the MSA 1995.

[10] Hereafter "the SOLAS Convention".

cause the loss or destruction or serious damage to his ship or its machinery, navigational equipment or safety equipment, or indeed to any other ship. The master must also make sure that he must not do any act which causes or is likely to cause death or serious injury to any person. /67/ Serious penalties in law are in place for omissions of this kind, and are dealt with elsewhere in this research.

Similarly, the master must not omit to do anything required to preserve his ship, safety equipment and indeed persons on board, or omit to do anything that would prevent his ship from causing loss or destruction or serious damage to any other ship or structure. The master and the owner not only have an obligation to ensure the seaworthiness of the ship, but also an obligation to ensure that the vessel is not dangerously unsafe at the time of the voyage or any time during the voyage.

Additional responsibilities are also found in the International Safety Management Code which requires the master to operate his ship in accordance with the safety management system. /68/ The ship owner is required to define the master's responsibility with respect to:

- Implementing the safety and environmental-protection policy of the Company;
- Motivating the crew in the observation of that policy;
- Issuing appropriate orders and instructions in a clear and simple manner;
- Verifying the specified requirements are observed; and
- Reviewing the safety management system and reporting its deficiencies to the shore-based management.

The master also has a number of responsibilities that relate to the good management of the ship. The master is the supreme authority of the ship in the absence of the ship owner and is responsible for overseeing the duties of his staff, including the pilot.

In respect of the pilot, the master has a duty to ensure that he navigates a ship in an area where pilotage is compulsory by virtue of a direction from the Harbour Authority. /69/ If, for whatever reason, the master must use an unauthorised person, he is required to notify the nearest Harbour Authority. If the master seeks a pilot, he is required to display a pilot signal and facilitate the pilot boarding the ship. In addition to this, when the ship is under pilotage, the master must display a pilot signal in a compulsory zone. Assistance in looking out for danger, in guiding the pilot in how to handle the ship and ensuring that the crew carry out the pilot's instructions is expected from the master. /70/

Other obligations that fall under the master's duty of good management can be found in case law. In *the Harcourt* (see /112/) it was accepted that it was the master's responsibility to ensure that proper lighting was used and that the master is required to personally check on responsibilities it has delegated to others. /131/ If the master feels unable to remain, he should not leave until he is fully satisfied that the junior officer understands that it is his duty to avoid a close-quarters situation. /113/ More recently, in the case of *The E.R. Wallonia* /71/ it was held that in conditions of poor visibility the master cannot remain in his cabin. A qualified officer, a helmsman and a lookout are required to be on the bridge.

The master has sole responsibility for the issuing of a distress signal. Regulation 3 of the Merchant Shipping (Distress Signals and Prevention of Collisions) Regulations, 1996 states that no signal of distress shall be used by any vessel unless the master so orders and that the master shall not so order, unless he is satisfied that his vessel is in serious and imminent danger, or that another ship or aircraft or person is in serious and imminent danger and cannot send that signal, and that the vessel in danger (whether his own or another vessel) or the aircraft or person in danger requires immediate assistance in addition to any assistance then available. The Regulations also impose on the master an obligation to revoke any signal of distress by all appropriate means as soon as he is satisfied that the vessel or aircraft to which or the person to whom the signal relates, is no longer in need of assistance.

The master also owes a duty of care to other ships. Under UK legislation the master has a duty to render assistance (as soon as may be practicable) to another ship in the case of a collision between two ships. The master is required to render to the other ship, its master, crew and passengers such assistance as may be practicable to save them from danger caused by the collision and to stay by the ship until the master has ascertained that his assistance is no longer necessary. Furthermore, when so doing the master must also give to the master of the other ship the name of his own ship and also the names of the ports from which it comes and to which it is bound. /72/

The master has a duty to assist vessels in distress both in domestic legislation as well as under the SOLAS Convention. /73/ /74/ On receiving a signal of distress or information from any source that a ship or aircraft is in distress, the master is required to proceed with all speed to the assistance of the persons in distress and should inform them, if possible, that he is doing so. Similarly, where a master of any ship in distress has requisitioned any ship that has answered his call, it shall be the duty of the master of the requisitioned ship to comply with the requisition by continuing to proceed with all speed to the assistance of the person in distress. /75/

The International Regulations for Preventing Collisions at Sea (hereafter "the COLREGS") /76/ were created by the International Maritime organisation in 1972 and set out the "rules of the road" for vessels at sea in order to prevent collisions. Duties relevant to the master include maintaining a proper lookout by sight and hearing, as well as sailing at a safe speed. Rule 5 of the COLREGS requires that every vessel shall at all times maintain a proper look-out by sight and hearing as well as by all available means appropriate in the prevailing circumstances and conditions so as to make a full appraisal of the situation and of the risk of collision.

Reporting Duties

In addition to his role in overseeing the safety of his vessel and nearby vessels, the master also has a number of reporting duties. The master of a ship also has a duty to report under domestic legislation. For example, in the UK, the MSA 1995 Act requires a master of any UK ship to report a meeting with a dangerous derelict or any other direct danger to navigation which could include a ship or ships or cargo which present such a danger consequent upon a collision. /77/ The Master is also required by section 136 of the MSA 1995 to report the occurrence of discharge of oil mixture from a ship in to a harbour in the UK waters, or escape of oil from a ship into any UK waters, to the harbour master or authority. As is noted in section II, much of the reporting duties could easily be replaced by automated communication systems.

The Master of a ship is also required to fly a flag on his ship, a requirement that stems from the High Seas Convention ("HSC") 1958. Article 5 of the HSC requires "a genuine link" between the flag state and its ship. Under this Convention and the United Nations Convention on the Law of the Sea 1982 ("UNCLOS"), the master effectively represents the authority of the flag state on board and is "responsible for administrative, technical and social matters concerning the ship"/78/.

Responsibilities as agent of Ship Owner

The master, in addition to having responsibility for the safety and good management of his ship is also the agent of his owner. The master should have knowledge of the various clauses and provisions of charterparties so that he can make sure they are performed properly. After all, the master is responsible for making sure that the provisions in the contract are complied with.

While the master plays an important contract role on behalf of the ship owner, this does seem to be easily overcome. As Hooydonk notes:

It is difficult to predict how a breakthrough of unmanned merchant shipping will affect the role of the ship's agent. As the contract of the ship's agent is entirely left to freedom of contract in nearly all countries and is moreover governed by international and local standard contractual clauses, the elaboration of new regulations does not appear to deserve priority attention. /62/

The master is agent for the ship owner and is required to sign Bills of Lading as evidence of contracts of carriage. The effect of him signing a Bill of Lading is to bind his owner to the contractual terms and conditions therein. As Hill notes, "a master needs to be particularly careful in the signing of a bill or in the determining of the party to whom he may delegate his authority to sign, since in so doing he is creating a contractual relationship between his owners and the purchaser of the document." /79/ The Bill of Lading is prima-facie evidence of the receipt by the carrier of the goods as therein described.

4.3.1.2 *How does MUNIN provide for the duties of the Master?*

This section addresses the manner in which unmanned vessels will (or will not) discharge the above duties of the master. It is proposed to address those duties in respect of the duty of safety of operation and good management of the ship; the duty to report and the responsibilities of the master as agent of the ship owner.

The basic MUNIN hypothesis is that unmanned ship systems can autonomously sail on intercontinental voyages at least as safely and as efficiently as manned ships. This hypothesis significantly reduces the role of the master who for hundreds of years had absolute authority in respect of the safe operation of his ship. The question arises as to whether the legal duties and obligations that embody the SOLAS Convention, the COLREGS, the International Safety Management Code, as well as other domestic legislation, can be fulfilled by unmanned ships? Can unmanned ships be safely operated and managed without a master?

In order to answer this question, it is useful to understand the various functions of the MUNIN ship which replaces some, if not all of the master's primary responsibilities. The MUNIN-created ship has an Autonomous Ship Controller ("the ASC") that performs collision avoidance, meteorological navigation and stability maintenance. The ASC is supported by an Advanced Sensory Module ("the ASM") which monitors the surrounding of the ship in insuring highly accurate object detection, tracking and identification by means of radar. Both the ASC and the ASS perform most of the navigational and operational duties traditionally assigned to the master. /80/[11] The

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[11] The ship will also have an in-built function whereby it is able to autonomously deviate during certain weather conditions without the requirement for onshore intervention

MUNIN ship is at all times monitored by a human operator in the Shore Control Centre. It is unclear whether the master will be considered the person in charge in the SCC, as both roles do not appear to be entirely similar.

The SCC will control a remote maneuvering system and deep-sea navigation. The remote maneuvering system will incorporate ship-handling simulation. The Remote Manoeuvring Support System will conduct an analysis of 'Ship Feeling', calculate a response and visualize actual maneuvering space. The human element in the Shore Situation Room has direct control of steering and situation awareness. /80/

Therefore the unmanned ship is not strictly speaking "unmanned" and the operator at the SCC can intervene remotely at any stage of the route to take control of the ship if needs be. During berthing and approach as well as in coastal waters, it is anticipated that a crew will be on board.

The ASM has received particular praise in that it copperfastens accurate detection, tracking and identification by means of radar. In addition to this, the ASM performs an automatic crosschecking exercise with other data in outputting relevant information. The ASM fuses the data and provides a single source of information based on this data. /81/

Burmeister et al. (see /82/) view the sensor technology as compensating for the watchkeeping officer, particularly during long and tiring night watches. They state that "enhanced sensor technology will assist watchkeeping officers on conventional ships and help to reduce the number of incidents imposed by human failure." Burmeister et al. further state that if a close quarters situation with another ship is encountered, the sensor will recognize the traffic situation and respond to it "according to COLREGS" in avoiding a collision. [12] There are a number of collision situations, which are pre-stored

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[12] The ASC system basically fuses the information provided by different sensors, like radar, AIS, visual video and infrared cameras and creates a perceived world-model out of it containing the different detected objects, their tracks and navigational statuses, but also an indication about the reliability of the object detection…Using enhanced radar detection algorithms, additional data can be generated that allows further crosschecking with the additional sensor data. This allows e.g. detecting small objects not emitting AIS information, but also false or inaccurate AIS-targets by sensor and feature processing. On board the MUNIN vessel, the autonomous navigation system is thus provided only with data pre-processed by the advanced sensor module, which now only contains one target per vessel including a reliability indication, based on the degree of successful cross-checks between the radar-extracted features and additional sensor data. This module and its detection capabilities have already been successfully tested in Norwegian waters during a voyage of a vessel from the coastal administration.

and analyzed by the ship in advance of deciding what action to take in autonomous mode.

In so far as the safe navigation and management of the ship is concerned, it appears that the operator in the SCC is in a better, more informed position with the assistance of both the ASC and ASM technology. The fundamental reason for this appears to be that the technology outstrips human capacity. As Hooydonk notes, "the safe management of the ship, which falls to the master to be discharged, might credibly be done so [by the MUNIN design] when statistics state the human element accounts for 80 percent of all marine casualties". /62/

The technology appears to perform a more objective analysis by removing the human and sometimes subjective element in decision-making. The opposing argument is that the MUNIN model is highly dependent on the reliability of technology. However, this situation is catered for by a fail-to-safe mode which responds to situations that might undermine the safe navigation of the ship.

While the design of the MUNIN ship incorporates a number of the master's navigational duties, there are certain duties which the master is required to discharge which are not catered for under the MUNIN model. Case law, for example, has created certain legal precedents which place requirements on the master in respect of good management that arguably cannot be fulfilled from the SCC.

For example in *the Harcourt*, it was stated that the master is required to personally check on duties he has personally delegated to others. /112/ Does this decision require the master to physically check the outcome of the duties aboard the ship, or can it be reinterpreted/adapted for the purposes of the masters new role as operated from the SCC? While this might be viewed as an academic distinction, it will have to be decided in defining the master's role in the SCC, particularly where many of his duties are given expression by his physical presence on the ship.

Other responsibilities which are not met by the MUNIN-created ship include the duty to maintain a proper lookout by "sight and by sound" as specified in Rule 5 of the COLREGS. That rule requires the vessel or its crew to make a "full appraisal" of the situation. One could argue that a full appraisal is perhaps less possible, if not impossible, from the SCC. In reviewing the COLREGS, Marsden makes reference to what is known as "the Prudential Rule", i.e., the precautions and duties required by "the ordinary practice of seamen" as referred to in Rule 2 of the COLREGS. The prudential rule, in Marsden's opinion, underlies all of the other rules in the COLREGS. /131/ The question arises as to how the ordinary practice of good seamanship will be assessed from the operator in the

SCC. Hooydonk points out, there is no exemption in the COLREGS for a vessel which is controlled by a shore-based controller as proposed by the MUNIN project. /62/ These types of duties as set out in the COLREGS will need to be reconfigured when human intervention of an autonomous ship will soon be undertaken onshore.

One suggestion made in respect of the COLREGS and the fact that they are directed at human controlled vehicles would be to hold the unmanned vehicles to a different standard. According to one author, unmanned Marine Vehicles should not be made to fit into the COLREGS. As they are written, the COLREGS are too based on human action and thought, and right now technology doesn't have the capability to mimic such foresight. International law cannot work if there is no consideration and respect of rules other than your own, and statutes and conventions are meaningless if governments do not abide by them. /83/

Another suggestion made by master mariners at Chalmers Univeristy was that unmanned ships should avoid getting into a COLREG situation by making an early evasive maneouvre in the time zone TCPA 1 hour to 30 minutes. /84/

Similarly, the requirement in international law that the ship fly the flag of its state is one which will have to be reconsidered by the MUNIN model. The High Seas Convention 1958 requires there to be a "genuine link" between the flag state and the ship which, as Hooydonk notes finds expression in the regulation and control of the officers and crew of the ship, who are by definition absent on an unmanned ship. /84/

Other administrative duties which are assigned to the master include the master's duty to sign the Bill of Lading on behalf of his employer which has not been incorporated at this stage of the MUNIN project. It has been suggested that is likely these will be issued in electronic form, however someone will be required to go through the stock to make sure that it is in proper condition. /62/

The MUNIN framework, and in particular the operations carried out by staff in the SCC, will need to put in place a clear chain of authority in determining the responsibilities that fall to be discharged by the operator in the SCC. As Gogarty and Hagger point out, 'how will fault be determined when a human and computer are sharing the reigns of a vehicle under traffic legislation? Indeed, who will be at fault if the vehicle has an accident when it is clear only the computer AI was in control?' /85/

Though perhaps less pressing, these responsibilities will need to be considered further as they fundamentally tie in with the duties and responsibilities of the master as they appear in maritime law. Analysis of the SCC carried out below, in relation to its crew, will go some way towards this point.

4.3.1.3 *Conclusion*

One of the criticisms leveled at the unmanned ship is that it effectively erodes the role of the master, who will be replaced by the operator in the SCC, and only then, in certain situations. As Hooydonk notes, "the legal powers exercised by the master on board the ship will cease to have any object" (see /62/) in the MUNIN framework. However, as pointed out at the outset, the role of the master for many years has been encroached upon by navigation technology.

The reality appears to be that there is little difference in the difficulties that will face a manned ship that requires onshore assistance and an unmanned ship that calls for onshore assistance. /82/ In other words, whether the master is on the ship or onshore, the reality appears to be that he will encounter the same navigational obstacles. The MUNIN project successfully conveys the point that unmanned ships are in essence safer than manned ships when the majority of maritime incidents are a result of human error. In that regard, the technology in place appears to have fully superseded the role of the master.

A more substantial criticism is who precisely will be tasked with taking over some of the lesser duties mentioned above. Who is the master for the purposes of the flag state of the ship? Who will sign the Bill of Lading? Who will oversee the Pilot and the rest of the crew? These are questions that remain to be seen in so far as the responsibilities of the master are to be transferred to the MUNIN-created ship.

4.3.2 The Crew in the SCC

This section considers manning in the Shore Control Centre, the level that is likely to be required by law, and the type of education and training necessary for the SCC to function adequately.

4.3.2.1 *The Shore Control Centre*

In the SCC, there will be key personnel who will replace the traditional crew members on a traditional manned ship. The role of the SCC is essential, and closely linked to the autonomous navigation system (DSNS) described above. Important definitions are provided in *Organizational lay-out of SOC* (see /30/) which clarify the SCC's input, depending on the different stages the unmanned ship is at:

- **Autonomous execution**: Operation fully controlled by the autonomous system on board and the ship is following a predetermined voyage plan. In case of a hiccup, the autonomous system is able to detect and solve the problem itself by changing to autonomous control mode.

- **Autonomous control**: The vessel is still under autonomous operation, but the autonomous execution is "interrupted" by the autonomous problem-solving in situation such as collision avoidance.
- **Indirect control**: it is an intermediary level of short control between Autonomous control and Remote control. The voyage plan is updated manually with new waypoints. This can be useful for example if the ship is called to participate into a SAR operation, in which it could not perform the traditional rescue operation, but could be very efficient at searching a certain area. The operator in the SCC manually updates the waypoints, and the Autonomous Ship Controller then continues to control the ship, particularly in terms of course keeping and collision avoidance, but following the new manually updated plan.
- **Direct control**: this is the next step towards Remote control. The Autonomous Ship Controller no longer follows the voyage plan but continues to be active as regards course keeping and collision avoidance. The track pilot is disengaged, and the operator controls the course of the ship.
- **Remote control**: IN this case the autonomous system is bypassed. The officer of the watch on duty in the SCC will step in and take the command. He can do that by taking "direct control" (activating the autopilot on a set course and speed) or by activating "situation handling" (remote controlling all actuactors from the bridge-like situation room).
- **Fail-to-safe**: If the communication between the ship and SCC fails, or if technical problems make it impossible for the SCC to solve it, the ship will go into a fail-to-safe state. Depending on the environment, the fail-to-safe state can mean different things: e.g. on the high seas drifting, in trafficked waters the ship with "heave-to", i.e. with engine and rudder stand still, bow to the wind, or close to land, anchoring. In such cases a salvage vessel will be called for or an emergency crew will fly on a helicopter and embark the ship in order to make the necessary repairs.

Two broad points are important for the design and organisation of the SCC. First, as it will be reliant on the use of new technology and software tools, it is critical that communications procedures and organisational aspects are efficient, clear, and based on current guidelines and regulations concerning the human element, and human-machine interface. In this respect, *Organizational lay-out of SOC* points to IMO Resolution A.947(23) on 'Human elements vision, principles and goals for the Organisation'./30/ A further reference is made to ISO 11064 on Ergonomic design of control centres (,/30/). WP7 overall takes care of this aspect of the matter.

Second, the various roles of staff in the SCC need to be clearly defined, so that they can be compared with the roles and functions of a crew on a traditional ship. This is an essential step in identification and analysis of liability issues. *Organizational lay-out of SOC* provides detailed information about this. /30/

The SCC is conceived as closely working with VTS centres, although they would not be identical or tied in with such centres. It is believed that the SCC will be run privately, whereas the VTS centres are publicly operated. The following factors were singled out as part of the elements that the SCC would need (see /30/):

- **Ship owner or manning company**: the most straight forward way of thinking of the SCC is to imagine it as being run by a ship owner or a manning company, or hired by them, in the same way as today owners and manning companies are in charge of providing crews for ships.
- **Ship yards or engine manufacturers**: they would be in a position to know and understand ships best, and would therefore provide important knowledge and experience to resolve problems with the ships or engines.
- **Flag State**: the flag State might have some requirements for the physical location of the SCC.
- **Local knowledge**: the SCC would need local knowledge of specific areas, especially if there is a large ship density.
- **VTS co-location/operation**: the SCC may be located in an already existing VTS space, or near it.
- **SCC daylight work schedule**: a 24/7 coverage and availability is required for the SCC to provide all the necessary services to the unmanned ship. To avoid night shift-work, it may be possible to have SCCs in different time-zones. However, this option would raise other issues of hand-over procedures, which may be even more complex than night shift-work.

Within the context of the MUNIN project, it is envisaged that the SCC would be managed by a ship-owner or manning company. However, the other elements must also be borne in mind, especially with regard to the legal analysis.

Staff in the SCC will be composed of first of all of **operators**, each in charge of up to 6 unmanned ships, working 8 hour shifts. Overlap and hand-over procedures are critical. All operators must have sea-going experience and be watch-keeping certified as per STCW requirements.

The **supervisor** will handle 5 operators (so 30 ships in total). His/her role will be to organise hand-over procedures in the event that one operator needs to concentrate on one unmanned ship, and leave the others to other operators.

The **captain** is legally responsible for all the unmanned ships being monitored and controlled from the SCC. S/he has sea going experience, and experience as an operator, and has the normal qualifications that a traditional captain would have. *Organizational lay-out of SOC* assumes that one captain may be responsible for up to 30 ships. /30/ The SCC captain will also lead the SCC bridge team in the 'situation room' in cases of Remote control of the ship. It is quite clear that the captain is 'Accountable' for all the decisions and modes of functioning for the SCC and unmanned ship. *Organizational lay-out of SOC* indicates that 'Periodic monitoring', 'Operator change', 'Problem investigation', 'Engine problem'. 'Indirect control', 'Direct control', 'Situation room' and 'Weather routeing' are all tasks for which the SCC captain is 'Accountable'. /30/

The SCC **ship engineer** is licensed and experienced like a normal ship engineer. S/he has knowledge and experience with the ship engine, auxiliary power stations, thrusters, steering pumps, etc. S/he will also have to be connected with the maintenance system and database. S/he must have the possibility to investigate matters when called by an operator. Also, s/he will be link with the engine manufacturer and engine optimisation programmes and companies.

4.3.2.2 *Areas of Responsibility in the Shore Control Centre*

This section addresses the areas of responsibility of the operator in the Shore Control Centre and other functions he might be assigned under the MUNIN model. The SCC is an invention of the MUNIN project and aims to cooperate with the ship's own intelligence systems to ensure effective and safe operation. Importantly, the SCC is the only human oversight given to the unmanned ship proposed by the MUNIN project, with the exception of when the ship is on approach or in congested waters. This section addresses the role of the master in the SCC as well as the wider question of whether he can adapt to this role as successfully in the seat of the master/operator in the SCC. While there is overlap between the role of the master and the operator, both in the MUNIN model and for the purposes of this research, he is referred to as the Shore Control Centre Operator ("the operator").

The Role of the Master/Operator in the SCC

Porathe and Costa describe the organizational layout of the SCC as incorporating the following: /86/

- A **Shore Control Centre Operator**, who monitors the ship operation of several autonomous ships at the same time from a desktop cubicle station and controls the vessels by giving high level command like updating the voyage plan or the operation envelope of the autonomous system, and
- A **Shore Control Centre Situation Room Team** that can take over direct remote control of one vessel in certain situations via a shore side replica of the unmanned vessel's bridge including a Remote Manoeuvring Support System that ensures an appropriate situation awareness in direct control despite the physical distance of crew and vessel

The operator in the SCC has similar duties as the master but is no longer in control of the nautical command of the ship or collision avoidance. COLREGS supervision and nautical command will be controlled by the Autonomous Ship Controller ("the ASC"). The ASC is tasked with a lot of the operational functions of the ship, while the operator appears to handle situation awareness and monitoring of data. Both are complimentary but the need for human intervention is intended to be minor. It is hoped that there will be minimal interaction with the ship by the SCC and that the operator will only intervene when something unexpected occurs which is beyond the capacities of the onboard systems.

Project manager, Hans-Christoph Burmeister, describes his role as follows: The primary function of the land-based control is the continuously monitoring of the autonomous system. Of course, they can in case of doubts per remote control intervene, but our target is to minimize this as much as possible. Our target is an unmanned vessel hence it will be monitored continuously on a high level. /87/

On a day-to-day basis, the following information describes some of the analytical responsibilities of the operator. He will be in control of remote monitoring and will receive periodic updates from the ship and ensures safe operation, while also operating maintenance planning and problem solving. /80/ The objective is to communicate enough information to the operator in the SCC so that he has sufficient situational awareness of the conditions in which the vessel is travelling. /88/ The operator can also acknowledge decisions made by the ASC by way of event based data exchange. /89/

There are a number of forms of control which the operator may be required to adopt. When the operator is in direct control of the vehicle, he can adjust the route, while in indirect control the operator can adjust the speed. If there is an obstacle which the ASC system is unable to navigate, the operator will take control of the ship via a bridge simulator, discussed in more detail below. Significant detail, such as the level of people in control of the SCC and the chain of command, have yet to be put in place.

Where there is a failure between ship and shore communication "the ship will be able to carry out certain pre-programmed fail-to-safe modes to respond to arising situations which might threaten safe navigation." /82/ This reduces the reliance on the communication system between the ASC and the operator, particularly when not all systems provide global coverage and oftentimes, ships communication devices can experience signal transit disturbances.

Shore Control Centre Situation Team

The SCC function is used when the Autonomous Ship Controller ("the ASC") is not capable of dealing with a situation or if aspired by the SCC. In that situation, the operator connects the bridge system of the unmanned to a full-mission bridge simulator, where the ship is controlled by a complete bridge team who can override the ASC.

The Remote Manoeuvring Support System will conduct an analysis of 'Ship Feeling', calculate a response and visualize actual maneuvering space. This is undertaken by the operator who will have direct control of steering and situation awareness. /80/

The direct operation of the ship is done by way of a simulated remote bridge in the Shore Control Centre. Burmeister writes that this will be used in "emergency situations where trained bridge teams will work in an immerged environment almost as on the actual vessel, thus utilizing traditional experience." /90/

It has been suggest that autonomous ships will be "dumb" when they are being controlled remotely in that the operator in the SCC will not have an intuitive feel for his surroundings when making decision. However, McLaughlin notes that there is little discrepancy between the information available to the SCC operator and the person physically on-watch on the ship: /90/ They [the operator in the SCC] will have sensors – such as radar – just as manned vessels do, and will be controlled in accordance with the data these sensors reveal. To my mind, there is little distinction between a manned vessel navigating through restricted visibility under the control of an Officer of the Watch (OOW) standing on the bridge with his or her head buried in the radar, and a controller doing the same by reading the radar picture delivered instantaneously to their physically remote control station by the ships sensor suite.

This view is given further support by Allen, who has noted (see /64/): Given present trends, one might soon encounter two watercraft of nearly identical design and equipped with identical sensors and navigation and collision avoidance equipment and programming (indeed, the same watercraft might operate alternately in manned and unmanned modes). Both could be engaged in the same 'work' and both might be equally 'manoeuvrable.' The only difference would be that one still carries a person who monitors a craft that is fully autonomous while the other is completely unmanned. In both cases, control, including navigation and collision avoidance decisions and execution, would be carried out by the installed equipment and their programmed algorithms.

There are a number of legal difficulties still outstanding in respect of MUNIN. It is yet to be decided how many people will be required in the SCC to monitor and directly operate the unmanned ship.

The qualifications required by the operator are not clear. However, the University of Chalmers, who are contributing to the project, has outlined a job description. The operator will be required to have: /88/

- existing experienced-based operational concepts
- to monitor internationally and regionally recognized rules and regulations
- to comply with company-related standards
- operational procedures as process-orientated action orders
- manning and qualifications; good seamanship vs. cognitive skills.

Critical discussion of the Operator's role

One of rewards of unmanned ships is said to be the reduction in human error, however the role of the human operator is still significant in terms of their oversight and responsibility for the ship, particularly in the special circumstances when the ship is unable to navigate autonomously. Others have suggested that the role of the master (and not the operator) has removed most of the traditional functions of the master. /62/

While research in this area tends to suggest that less human control reduces the incidence of mistake, MUNIN proposes human involvement – an irony of the unmanned ship project. In circumstances where the operator is required to take control of the ship, he is expected to operate in a similar environment to his manned vehicle. In this regard, the responsibilities of the operator are akin to the master at sea, except that his awareness and intuitive sense for sea faring is reduced by the lack of visibility in his onshore surroundings, namely in the SCC.

One of the difficulties faced by the operator operating in the SCC is that he will lack his years of accumulated "ship sense". Ship sense can be understood to mean the innate connection between the human and the vessel in its natural environment. This concept initially seems nebulous, but is not underestimated in the role it plays in safe navigation. In fact, the project has worked on a Remote Manoeuvering Support System (RMSS), in order to assist the SCC operator/master precisely with this type of issue (see section above on Navigation). Yet, as Man et al. have written: /91/ Unmanned ship does not mean the resolution of all the problems behind human error or elimination of the human factors; on the contrary, it brings more questions concerning human factors in the SCC, because people need to be able to take full control over the ship at any time…How do operators in the SCC perceive the ship's movements and maneuver the ship without ship sense, if you consider the working environment is totally different in the SCC? There will be no physical connection between the human and the vessel, and no directly perceived information from the ship's environment. Specifically, the visual perception of the environment, a vital sense in ship handling for bridge officers, will be lost. The important questions will arise: Are there going to be new human factor issues? Will the same human factors be applied as they do for the manned ship? If no, what factors behind ship sense onboard needs to be refactored to the shore side? How can we prioritize them to regain the harmony?

Man et al. carried out a focus group interview procedure on 10 master mariners who were students at Chalmers University and with previous sea faring experience. The majority of the students in monitoring and maneuvering a ship onboard stated they would have regard to "feeling"; looking out the window at the waves and experiencing a "sense of balance with the vessel" when navigating at sea. /91/

This was considered, for them, an essential aspect of safe sea faring that would not be available in an unmanned ship. While this has to a large degree been provided for by the bridge simulator, discussed below, it should be born in mind as one of the key distinctions between onshore operation and operation at sea.

Despite this initial skepticism, there are a number of positive outcomes in having the operator in the SCC. One benefit of the operator in the SCC is that s/he will be able to supervise a number of ships simultaneously. While on the one hand, this could be viewed to decrease reliable decision making, the sensor technology operates computer-based data fusion, which is said to produce one single source of relevant information to the operator rather than a number of different sources. /87/ This is believed to reduce the tendency of subjective decision-making among officers. There are, however, risks associated with the multiple operational duties of the operator in that the operator may experience "out-of-the-loop" syndrome when excessive quantities of information is being received. /89/ Out-of-the-loop syndrome is understood as delayed decision making due to the lengthy time it takes the operator to "get in the loop" or process the information.

Porathe has written extensively on this aspect of the interface of the Shore Control Centre. He writes that there is a concern that the duties of the operator will become too "automated" and he will develop what is known as "automation bias". /92/ Relying on the research of Lutzhoft and Dekker, Porathe suggests that automatic systems have to be turned into something more effective. Some of his suggestions directly affect the responsibilities of the operator. For example, relying on the research of Lutzhoft and Dekker, Porathe suggests the necessity for "pattern-based operation whereby operators will be train[ed] to have to quickly scan displays and pick up abnormalities without having to engage in difficult cognitive work" /92/ These suggestions make clear that the interface cannot simply "tell the operator the answer" but will require a measure of engagement from the operator so that in situations whereby they have control of the ship, they haven't lost their navigational confidence.

Conclusions

The responsibilities of the master in the SCC, given expression through the role of the SCC operator and SCC master, are significantly reduced. However, while his duties have been reduced, the legal framework still holds him to account when something goes wrong with the vessel. Therefore key aspects in the MUNIN framework are required to be adapted for the purposes of updating maritime law.

First and foremost, the project needs to address whether the traditional ship master is replaced by the SCC operator, or SCC master, or both, and how. Their duties are no longer the same, but in fact substantially reduced by the autonomous control of the ship. Despite this fact, in some circumstances they will still be required to make decisions onshore based on information communicated them from a ship that could be thousands of miles away. This is an unattractive position for an operator/master who could be culpable in maritime law for acts or omissions outside of their direct control. Hooydonk points out that this will be a complicated task given that in maritime law, the master is defined by his capacity on board a ship. By way of example, the Maritime Labour Convention defines the 'seafarer' as 'any person who is employed or engaged or works in any capacity on board a ship to which this Convention applies'.

Other responsibilties that fall to the master no longer seem to be relevant. For example, the United Nations Convention on the Law of the Sea describes a statutory duty to feature a look-out. The COLREGS require a lookout by "sight and sound". Given that the ASC has replaced a large part of the master's lookout duties, the law will need to be adapted to reflect this, as explained in the Navigation section above.

Other definitional problems will need to be ironed out and in particular, a more detailed framework of the role of the operator will be required. The "special circumstances" requiring his remote intervention will need further elaboration as well as the implementation of a clear chain of command in the SCC.

4.3.2.3 *Training and qualification of staff in the SCC*

The STCW Convention and STCW Code

The STCW Convention has as its objective the promotion of safety of life and property at sea together with the protection of the marine environment. These objectives accordingly give rise to the need for standards in the training and certification of those operating vessels at sea. Thus, the Convention demands that persons on board ships are qualified and fit for their duties. As can be seen from this definitional limitation the Convention as it stands cannot practically be applied to Unmanned Autonomous Vessels (UAVs) and SCCs. Though minimum standards in competence is undoubtedly required of SCC operators it may not be the same as that demanded of those actually on board a vessel.

Application

The Convention's competence requirements apply to personnel on board vessels and not to those ashore. Reference is made throughout to seafarers which is generally understood as referring to the persons on board a ship at sea. The term *master* is defined as a *person* having control of a ship. With regard to an UAV this control function is predominantly undertaken by the ASC and indirectly by the SCC: one is a computer and the other is a person. When the Convention was originally drafted almost 40 years ago the concept of an autonomous vessel would have been considered quite bizarre. Even the subsequent and very recent amended Convention in 2010 made no provision for such development.

Chapter I General Provisions

The application of the Convention to SCCs is unworkable at present. Regulation I/2(1) asserts that certificates of competency shall only be issued by the relevant Administration. At subsection 11 such certificates must be kept on board the vessel on which the holder is serving. To qualify for certification candidates must also have completed, amongst other things, seagoing service. The relevance of this requirement to SCC staff is questionable. Although some exposure to seagoing service may be helpful, it may not necessarily be needed in order to properly execute their duties.

Article X of the Convention states that while in the port of another State, a vessel is subject to control by its agents regarding the verification of certificates held by seafarers on board that vessel. Regulation I/4 elaborates on this. However, framed as it is the Convention restricts a port State's agent to verifying seafarers on board the vessel.

Technically, the regulation has no application to an unmanned vessel. Moreover, no means exists to verify the competence of SCC personnel. The port State agent is also empowered to assess the watchkeeping ability and security standards of seafarers with regard to whether the vessel has been involved in a collision, illegally discharged waste, or the ship has operated in a dangerous manner. Even if an SCC member has allowed such eventualities to occur and evidence is present no action can be taken under this Regulation I/4.

Even if the powers of a port State were expanded to remedy this issue it would only partially solve the problem. Geographically speaking an SCC is likely to be a substantial distance from the port in question and physical inspection of SCC staff's credentials will not be possible. Moreover, the fact that it is contemplated that an SCC operator will be in charge of several unmanned vessels at any one time, each of which could be more onerous to manage, the agent's ability to assess the relevant operator's competence will be curtailed as they will lack a real appreciation of the situation. The proliferation of UAVs will make the role of agents more redundant and some other or additional form of monitoring needs to be devised.

An impartial investigation procedure is mandated by Regulation I/5 to inquire into any perceived incompetence, act, or omission etc on the part of holders of certificates issued under the Convention. Again, any shortcomings or oversight emanating for the SCC will pass with impunity under the Convention in its current form.

The Convention (Regulation I/9) together with the Code (Section A-I/9) stipulates minimum medical requirements for seafarers. However, these are designed to ensure such personnel are able to work safely on board a vessel and have proper speech and hearing. Though SCC operators need a certain degree of medical fitness it can be anticipated such fitness would not need to be to the same standard as the needed for seafarers. The environment they will be operating in and the duties they will be carrying out will not be the same as general seafarers or even bridge officers on board a vessel. An appreciation of the environment in which the SCC personnel will be working is needed.

Certificates issued by an Administration have an expiry. Therefore, those on board a vessel must periodically demonstrate their continuing competence in order to have their certificates renewed (Regulation I/11). The regulation makes specific reference to a ship's master which could, as noted above, cover the person occupying such role in the SCC. Reference is also made to those holding the position of officer which the Convention holds out as a ship's crew but it would not seem to incorporate general SCC operators.

The STCW Convention at Regulation I/13 *Conduct of Trials* makes provision for experimentation with regard to automated or integrated systems. However, as the title suggests the dispensation it grants is ephemeral. Notwithstanding, the regulation does allow indefinite application of the trial system once certain criteria are met. The provision though helpful for research and development purposes would not be enough to cure the incompatibility of the Convention with the concept of the UAV and all that it entails.

The only ashore party the Convention imposes obligations on is the company in ownership of the vessel. Regulation I/14 attributes responsibility for the competent manning of vessels to the company: a duty which should obviously be extended to the personnel is the SCC. But the party responsible for these SCC members might not be the company who owns the AV. It is feasible that SCCs would run be privately and not necessarily by the owner of the vessel but as an independent party. Due to the economies of scale arising from the ability to control several vessels at once this would appear to be an efficient possibility. If this is the case then the responsibility for the quality of the SCC staff should possibly fall on the SCC owner and not the owner of the vessel.

Chapter II Master and Deck Department

This Chapter explains the qualifications required from different ranking members of the crew serving on board a vessel when conducting navigational watch. The standards one must meet all relate back to a prior period of seagoing service a candidate must have completed. Consideration must be given to the skills an SCC operator must have to effectively complete their duties. Like a manned vessel a chain of command will exist in an SCC. Clear guidance will be needed for each individual in this hierarchy especially if the SCC operator is regarded as simultaneously holding two of the highest ranking positions on board a ship, the master and chief engineer, but at the same time, is under the supervision of another. Additionally, the AV's computer system will also play a role in navigational watch. Thus, the structure of the SCC and the position of its staff, particularly in light of the use of the computer software on board the AV, need to be kept in mind when considering implementing new provisions.

Chapter III Engine Department

Chapter III deals with a manned engine room and the requirements for those in charge of such manning. As part of the certification process a prospective candidate needs practical experience. On an unmanned vessel the main actor in charge of this function would be the AV's computer system with recourse to the SCC if problems arise. The SCC operator would have an indirect role in this department. Though practical experience would doubtless be helpful, the same degree of experience might not be needed where

SCC operators are concerned. Standards will also vary according to the position held in the SCC.

Chapter IV Radiocommunication and Radio Operators

This Chapter assumes that radio equipment is physically present on board vessels and that crew members are available to man this communication equipment. Obviously, having radiocommunication facilities on an AV serves no practical purpose. Any communication with the AV would need to be diverted to the SCC. However, once SCCs are covered by the Convention its operators would be required to have proficiency in the operation of this equipment. As it stands the competency requirements contained in the Convention and Code would not give rise any problems for SCC operators and could be directly applied to them.

Chapter V Special Training Requirements For Personnel On Certain Types Of Ships

This Chapter essentially applies to cargo vessels. It lays down requirements for the loading, discharging, care in transit, handling of cargo, tank cleaning or other cargo-related operations. The responsibility for these tasks is placed on the master and other relevant officers on board a vessel.

It is suggested that those in the SCC would assume the roles of crew members and take responsibility for and carry out the duties such crew members would be assigned on a manned vessel. While this might work in the majority of cases, this Chapter may prove troublesome. This is because of the location of the SCC. It is unlikely that an SCC centre, which may be in control of several AVs at a time, could oversee the loading etc of a ship in the same way as a master, for example, who will actually be present on board. It is questionable whether the SCC operator assuming the master's role would need the same degree of knowledge and expertise as a master actually on board a ship. This may be the case for loading and unloading operations but for "care in transit" and "other cargo-related operations" the SCC operator could be subject to the same competency requirements of an actual ship master. Moreover, an additional third party would need to be present while tasks like loading and unloading are taking place due to the absence of a master who will be positioned in the SCC wherever that may be.

The role of an actual ship master needs to be scrutinised and juxtaposed with the practical capabilities of the SCC operator who will act in his stead in order to devise relevant and practical minimum standards of competence.

Chapter VI Emergency, Occupational Safety, Security, Medical Care And Survival Functions

It is axiomatic from the title of this Chapter that it is of no relevance to SCC operators. The qualifications it demands of seafarers have no application to SCC staff. Furthermore, it is redundant when it comes to a consideration of the skills that should be expected of SCC personnel in order to operate an AV safely and carry out their individual duties effectively.

Chapter VII Watchkeeping

Watchkeeping functions are currently carried out by crew members. On an AV the function would be undertaken by its computer system. This situation would accordingly relegate the SCC operator to a more subordinate watchkeeping role in contradistinction to the position envisaged by the Convention and the Code. This might not necessarily be a bad thing and could give rise to a number of benefits.

First, there would be no issues surrounding competency standards of a computer system: once programmed it will continually perform its function. Second, there would be no need to provide for human frailty as a computer will not be impaired by fatigue. Third, there will be no reservations about watchkeeping change-over from one crew member to another, as noted the computer will provide a constant standard. Finally, the current state of technology is such that a computer system can do a more effective job than a human operator.

This, however, does not obviate the need for SCC operators completely. The SCC would function more in an oversight capacity: monitoring the various areas indirectly. To do otherwise and have additional SCC staff specifically designated to individual watchkeeping functions (navigation, radio operations, engineering, and lookout) would not be particularly practical or cost effective. It would serve to undermine the ability of the AV's computer system.

Though there are practical concerns regarding watchkeeping these are not the concern of this section. What is being discussed here are the qualifications necessary for SCC staff. Similar criteria can be drafted for SCC staff as is currently expected of seafarers and enumerated in the Convention and Code however, as with other areas discussed above, an understanding of the environment in which the SCC and AV operate is needed.

Conclusion

Undoubtedly, there should be minimum standards of competence for SCC personnel. However, the standards contained in the STCW Convention and accompanying Code do not adequately deal with the whole concept of an AV and SCC and, as currently drafted, are not capable of imposing meaningful standards on SCC operators.

The extent of the functions undertaken by the AV and its on board computer system need to be considered as it too will need to be able to perform its tasks effectively. Moreover, the functions carried out by the AV and those carried out by the SCC and how each interacts must also be assessed in order implement appropriate certification criteria.

Many areas of operation which would be the responsibility of several different crew members on a ship are now subsumed into one and within the purview of a single SCC operator. However, there will also be SCC operators with specific duties and areas of responsibility. The purpose of Convention is to have on board a crew with a minimum degree of competence to command and operate a ship in a manner that allows for safety of life and property at sea and the protection of the marine environment. This ethos must now be applied to SCCs.

Maritime Labour Convention

The goal of this Convention, as stated in Article I, is "to secure the right of all seafarers to decent employment."The term seafarer in used throughout this Convention which, as noted above, refers to people working on board a ship. From a perusal of the Convention and an understanding of its purpose one can appreciate it is unlikely that it would apply to SCC staff. Life for those working on board a ship is at the opposite end of the spectrum to those working ashore. The work environments are altogether different.

Seafarers are in a more vulnerable position regarding their rights and may not otherwise have the same access to grievance procedures or employment advocates than people working ashore should their rights be impaired. To protect against this the Convention codifies, amongst other things, minimum obligatory rules for the employment of seafarers. Moreover, the Convention sets down minimum standards for medical health and, training and qualification for seafarers. The Convention demands Members to have in place proper recruitment services. The Convention seeks to ensure that seafarers have a fair employment agreement and that wages are paid fairly and regularly. Provision is also made for hours of work, rest and repatriation. Obligations also exist to ensure ships are sufficiently manned. Several other duties are placed on ship owners, regarding accommodation facilities, medical care on board and ashore, welfare facilities, and complaint's procedures.

As noted this Convention refers to seafarers and would not apply to SCC staff. SCC personnel do not occupy the same position as seafarers and as such they may not need, in a new or amended Convention, the same type of protection offered by this Convention. Existing national legislative enactments concerning employment contracts and working condition which are already present on a State's statute book would offer sufficient protection to SCC workers.

The Convention also imposes minimum standards for seafarers' competence and demands that a sufficient number of seafarers are present on board a ship to ensure it is operated safely. Similar requirements are found in the STCW Convention but it does not go so far as to require minimum manning levels. It appears that the Maritime Labour Convention does not permit any derogation from these mandatory manning requirements. Undoubtedly, SCCs would need a certain number of operators present to monitor AVs and a comparable standard could be imposed. If this is not done then ships could be operating at sea which are indirectly controlled and influenced by potentially incompetent operators. To allow a situation like this to manifest would permit double standards: a high degree of regulation for manned ship and almost none for unmanned ship. This is clearly contrary to the objectives underpinning the Conventions discussed here. However, given the Maritime Labour Convention provides for more than just standards in manning numbers it may not be appropriate to interfere with this Convention. It might be the case that the STCW Convention is a better target for reform.

4.3.3 Search and Rescue Obligations

4.3.3.1 *Obligation to Provide Assistance*

International Convention of Maritime Search and Rescue (SAR)

SAR now requires each contracting party to ensure that its rescue co-ordination centres provide when requested, assistance to other rescue co-ordination centres. This obligation goes beyond the provision of specific search and rescue units and extends to demanding assistance from, *inter alia*, ordinary sea-going vessels [3.1.7].

Therefore, there is an obligation placed upon a ship's master to comply with such a request. However, once assistance is rendered, possibly by embarking persons in distress, it appears from the wording of [3.1.9] that the continuing duty imposed on the master is tempered. Contracting parties are required to ensure proper co-ordination and co-operation with one another to ensure that masters of ships providing assistance are released from their obligations with minimum further deviation from the ship's intended voyage provided no further danger to the safety of life at sea is posed by so doing. The delivery to a place of safety must take place as soon as reasonably practicable taking into account the particular circumstances of the case and guidelines developed by the IMO. This aspect of the Convention must be considered in light of the 1951 Convention Relating to the Status of Refugees which asserts that contracting States shall not expel or return a refugee in any manner whatsoever to the frontiers of territories where their life or freedom would be threatened on account of race, religion, nationality, membership of a particular social group or political opinion.

4.3.3.2 *Guidelines on the Treatment of Persons Rescued at Sea*

In paragraph 2 of the recital to the Guidelines ship masters, among other parties, are invited to establish procedures consistent with the Guidelines. Several references are made throughout the Guidelines to a ship's master. The Guidelines echo the spirit of the SAR Convention and at [2.6] recognise the need for flexibility for Governments in determining whether a place of safety is adequate or not but at the same time the underlying need to expeditiously relieve a ship's mater is also emphasised.

The Guideline requires assisting ships to act promptly which should be a top priority for ship masters [3.1]. Ship masters have certain duties that must be carried out in order to provide for safety of life at sea. In fulfilling these duties the Guidelines imposes awareness, planning, and communication obligations on ship masters [5.1].

SOLAS

Chapter V of SOLAS deals with Safety of Navigation. It applies to all ships: any ship, vessel or craft irrespective of purpose or type. There are duties on masters to warn of certain dangers encountered under Regulation 31. Furthermore, Regulation 33 requires a master who receives a distress signal, who is in a position to do so, to provide assistance and any reason for not so doing should be entered into the log book. A ship can also be requisitioned by the master of a ship in distress or by the search and rescue service. If this is done the master of the requisitioned ship must comply.

Finally, under Regulation 7 in Chapter 5 contracting Governments are obligated to ensure that necessary arrangements are made for distress communication and co-ordination within their area of responsibility. Such arrangements warrant the establishment, operation and maintenance of such search and rescue facilities as are deemed practicable and necessary in the circumstances.

UNCLOS

Under UNCLOS Article 98(1) permits every State to require the master of a ship flying its flag, with a consideration of the risks to the ship, crew and passengers, to assist in distress at sea situations. Under Article 98(2) there is an obligation on States to operate and maintain adequate and effective search and rescue facilities.

Analysis of those legal obligations in the context of an unmanned ship

SAR and Guidelines on the Treatment of Persons Rescued
SAR envisages direct communication between SAR centres and ship masters and subsequent compliance with assistance requests by ship masters. Masters must then alter course and proceed to the distress area where practicable. The Guidelines on the Treatment of Persons Rescued at Sea highlight the need to proceed to a distress area as the paramount concern for a ship's master when informed of the situation irrespective of other matters such as maintaining its current voyage trajectory.

Regulation 3.1.7 of SAR makes no reference to a manned ship *per se*. It would seem to apply to an AV's ASC and thus make them amenable to a request for assistance. However, under Regulation 3.1.9 specific reference is made to a ship's master and the obvious inference is that the duty to carry out the requirement imposed under Regulation 3.1.7 would fall on a ship's master. Though Regulation 3.1.7 could apply to an AV in that it could be required to assist it would not have to assist as there is no one on board to which the duty to comply applies. If an AV were recruited to provide assistance there would be no one on board to alter its course or communicate its ability/inability to comply to the relevant party. If an AV has a predetermined course it may not be able independently to change trajectory. Would there be any means of direct communication between the distressed ship or the SAR centre and the AV itself? If so, would the AV be able to respond or would intervention from the SCC be needed. The SCC would have to take control and act as intermediary. If the ASC ignores distress situations those responsible for the ASC would be the culpable party. However, if the SCC fails to take appropriate measure in distress situations the relevant SCC would be accountable *qua* ship master. Given these two instruments place the duty of compliance upon a ship's master it is questionable whether they actually apply to an ASC. Amendments would be needed to incorporate the SCC as the ship's master in such situations and to clarify the application of the rule to AVs taking into consideration the present of the ASC and the SCC.

If survivors are taken on board, under SAR the master must then take a decision as to where disembarkation should be made and whether the chosen area is a place of safety. Again communication is also contemplated under SAR and the Guidelines between the ship master and relevant authorities when determining where the closest place of safety is located. This might necessarily require communication with those rescued. If there are no other vessels available to assist; without direct communication with the ASC and if the ASC cannot impart information concerning those on board it may not be possible to make such a determination without, at least, SCC intervention. Therefore, due to the very nature of an ASC it would not autonomously be able to comply with this requirement no matter how it is framed and responsibility would attach to an SCC to ensure compliance. But again clarification is needed.

SOLAS

Chapter V of SOLAS contains a very broad definition of ship which would encompass an autonomous vessel. This chapter contains manning and awareness requirements, duties to warn and assistance obligations. The assistance requirement contained in Regulation 33 suggests that compliance is mandatory and requires a ship master to proceed with haste to the relevant area. Any reason for not so doing should be recorded in the log book.

Again all obligations are placed squarely on the master of the ship. Here if the ship is in a position to assist it must do so. Even if an AV is in a position to assist no duty is imposed on the ASC because the convention makes reference only to a ship's master which is putatively attributed to the SCC. No consideration is given to the role of the ASC and whether any liability should attach to it in situations of non co-operation or non-response. A decision whether to assist or not is that of the master which must be duly recorded. It would be difficult to draft rules for ASCs if they are limited in their capacity to appreciate their ability to assist it any given situation. Moreover, if response decisions are placed on SCC then it is incumbent upon them to be competent in such decision making otherwise they may be in dereliction of their duty.

Requisitioning under Regulation 33 requires the master of a vessel to relinquish authority to the distressed master. In applying this provision both masters would need to communicate with one another and then the appropriated master would need to alter course and proceed to assist the distressed vessel. The section applies to a person acting as master, but more specifically in his capacity as being in direct control of the vessel at the time the issue arises. Given an ASC is in direct control of the vessel it could be argued that responsibility should attach to the ASC in this situation and not necessarily the SCC. If the ASC is the master in this instance it may not be capable of relinquishing control and if it was how would the distressed ship master control it without the SCC. Moreover, would direct communication be possible with the ASC and could the ASC respond pertinently and intelligibly to a request from a distressed ship's master or would the SCC need to commandeer control and liaise with the distressed ship? Therefore, the ASC should be responsible for failures to relinquish control. However, responsibility would still need to be placed on someone who can react quickly to the situation and take whatever measures are required. Governments will need to engage with this matter to give clarity and certainty to the application of the Convention to AVs.

UNCLOS

As can be seen under UNCLOS an obligation is also contained therein mandating assistance in distress situations. Under Article 98(1) a consideration of certain risks such an endeavour could pose to the ship, its crew and passengers is first needed. These risks are explicitly for the master's estimation. Therefore, this section was drafted with manned vessels in mind. Since an AV has no master there is no one on board an AV to which this section applies as there is no one upon which to impose a duty to assist. If an ASC ignores a distress situation it cannot be said to have breached this convention if the SCC is regarded as master.

Article 98(2) imposes a duty on States to have adequate and effective search and rescue facilities. Such an obligation is heightened with the development of AVs as there will now be fewer vessels in the water to which the convention applies. On the other hand, there will also be fewer lifes at risks if the vessels are not manned. Even if the convention was amended the extent of the assistance an AV could render is questionable.

4.3.3.3 *Ship Reporting Systems and Distress Communications*

SAR and Guidelines on the Treatment of Persons Rescued

Chapter 5 of SAR seeks to promote ship reporting systems. Contracting States when considering whether to implement such a measure should consider the adequacy of other reporting systems or data sources first. The basic requirement of the system is to provide data on the movement of vessels such as sailing plans, position reports and shipping plots.

The Guidelines, with the greatest of brevity, simply state that in order to more effectively contribute to safety of life at sea, ships are urged to participate in ship reporting systems established for the purpose of facilitating SAR operations [5.2].

SOLAS

Regulation 11(1) of Chapter 5 in recognising the crucial role reporting systems play in maintaining safety of life at sea requires the use of such systems in all ships or certain categories of ships or ships carrying certain cargoes in accordance with the provisions of each system so adopted. At Regulation 11(6) the Convention states that any adopted ship reporting system shall have the capability of interaction and the ability to assist ships with information when necessary. And at Regulation 11(7) the master of a ship is obliged to comply with the requirements of adopted ship reporting systems and report to the appropriate authority all information required in accordance with the provisions of each such system.

Chapter 4 Part C discusses the use of radio communications, types of communication equipment and designated communication frequencies which are required on all ships. Regulation 12 goes as far as to require a continuous watch over certain frequencies. Further, Regulation 16 requires the presence on board all ships personnel qualified in distress and safety radio communications.

IAMSAR Volume II

At section 1.3 the manual regards private vessels as constituting search and rescue facilities. The manual further states at section 1.3.4 that masters of vessels should be encouraged to send regular reports to the authority operating a ship reporting system for SAR. Chapter 2 of this volume speaks at length about communication. It notes at section 2.1.4 that private vessels can act as important intermediaries for relaying distress signals to RCCs.

Analysis of those obligations in the context of an unmanned ship

SAR and Guidelines on the Treatment of Persons Rescued

Compliance with the foregoing provisions would involve vessels being manned. Again the ability of search and rescue authorities to communicate with an AV's ASC is brought into question and vice versa. SAR and the Guidelines make no specific reference to personnel with respect to ship reporting systems but the implication is that there would be someone on board to manually operate the system and received and convey information. These rules could be understood as imposing an obligation on ASCs. But clarity is needed on the extent of the information required from an ASC for it to comply with a reporting system. Under the present rules the presumption is that the ship's master would be the person responsible. This duty could be allocated between the ASC and SCC.

SOLAS and IAMSAR

Under SOLAS a reporting system is required which has the capacity to interact with manned vessels and the duty of compliance accordingly falls on the ship's master. IAMSAR, as noted, speaks of the importance of ship reporting systems and communication between various parties, centres and craft.

Though an AV would fall into the category of vessel covered by the above provisions practically speaking such rules were drafted with manned vessels in mind. The presence of a reporting system or communication system that needs human control would be otiose on an AV. With the conventional reporting systems and those contemplated by the foregoing provisions, would an ASC be able to provide any information without SCC intervention and would it be able to relay information between parties?

The reporting obligations fall on the ship's master. Again with no master on board there is no one present for ensuring compliance or held responsible non-compliance with these provisions. The obvious party to attribute this burden to would be the SCC. However, this burden may be abated if a certain degree of responsibility can be given to an ASC. ASCs are capable of transmitting information to relevant authorities. It may be a case of apportioning responsibility. Those responsible for the ASC would need to ensure the adequacy of the equipment and its ability to provide information. But the extent of the responsibility of the SCC could only be discerned after the limits of an ASC's ability to comply with the reporting obligation have been determined.

4.4 Construction, Design & Equipment

This section examines the legal consequences of the unmanned ship as construction, design and equipment standards imposed by the current legal regime. It also includes a discussion concerning the automated engine room, and issues of maintenance of the engine on the unmanned ship.

4.4.1 Construction, Design & Equipment Requirements under International Law

4.4.1.1 *SOLAS Convention*

Chapter I

The SOLAS Convention applies to AVs in respect of Construction, Design and Equipment criteria. Chapter I, Part B, Regulation 12 requires a Cargo Ship Safety Construction Certificate and a Cargo Ship Safety Equipment Certificate for all cargo vessels. These certificates are issued once there has been satisfactory compliance with Chapters II-1, II-2, III and IV of the Convention. Due to the atypical nature of an UAV it may not be able to comply with the Convention's Construction, Design and Equipment requirements. However, Regulation 4 may prove to save an AV from the strictures of the Convention and permit an exemption from irrelevant provisions and permit the operation of its innovative construction without the need for immediate amendment to the Convention.

Regulation 4(b) permits the Administration to exempt any ship which embodies features of a novel kind from any of the provisions of chapters II-1, II-2, III and IV of the Convention. The ethos behind such a provision is to prevent research and development activity from being stymied by a strict application of the Convention. Regulation 4(b) further states that any such ship shall comply with the safety requirements which, in the opinion of the Administration, are adequate for the service for which the ship is intended and are such as to ensure the overall safety of the ship and which are acceptable to the Governments of the States to be visited by the ship. This provision redounds in favour of an UAV and would permit an UAV to operate immediately and before the long process of Convention amendment. However, one drawback is the need to attain consensus from the Governments of the States which an AV will visit.

Regulation 12(vii) allows for the issue of an Exemption Certificate. Regulation 16 mandates that any certificate must be available on board for examination at all time. Even this provision would cause problems for an AV. Some other method of conveying the existence of certificates to relevant authorities would need to be implemented.

Chapter II-1 - Construction - Structure, subdivision and stability, machinery and electrical installations

Chapter II-1, Regulation 3, in particular Regulation 3-3 *Safe access to tanker bows* and Regulation 3-6 *Access to and within spaces in the cargo area of oil tankers and bulk carriers*, lays down provision for means of access for certain parts of the ship. Though not totally relevant to an AV as no crew will be on board compliance with such provisions would be needed for those persons periodically on board for loading purposes, carrying out maintenance and conducting inspections.

Further, Regulations 22 and 25(8) makes provision for inclining and stability calculation. Information concerning same is required to be given to the master who then makes a determination as to the stability of the ship. Moreover under Regulation 23 damage control information must be readily available on the navigation bridge concerning measures for flooding and indicators for the position of doors must also be displayed in the bridge. Regulation 25(9)(2) also requires remote controlling of certain watertight doors in bulkheads and internal decks. The ASC would be able to satisfy these requirements but the definition of master and navigation bridge would need to be broadened to allow for the relaying of such information to the ASC and the SCC and also apportion responsibility for emergency actions.

Regulation 29 concerns the steering gear. Under 29(5) steering gear power units shall be capable of being brought into operation from the navigation bridge, control of the steering gear shall be provided on both the navigation bridge and the steering gear control compartment [29(7)] and a means of communication between the two is required [29(10)]. All of the provisions are cast in mandatory language making it difficult for novel or innovation interpretations. Such requirements would not bode well with the functional design of an AV. In an AV the means of control would be given to ASC and the SCC.

Communication between the navigation bridge and machinery space is required under Regulation 37. Though not essential to an AV, without an exemption or an amendment to the Convention AVs without such systems are in breach of the rules. Periodic entrants in such areas could bring mobile communication equipment and therefore the goal of this regulation would be satisfied.

An engineer's alarm is required under Regulation 38 which must also be audible in the engineer's accommodation. Amendment is needed to appreciate the existence of AVs and the position occupied by the ASC and the SCC.

Part D concerns electrical installations. Any references to installations necessary for habitation on board a vessel would not be applicable to an AV. Consideration would also need to be taken of Regulation 43 concerning emergency power and the duration requirements for lighting and power to certain parts of a vessel. Such supplies of power would not be as essential on an AV.

Part E, Regulation 49 asserts that control of propulsion machinery is from the navigation bridge and provides for indicators and alarms and the like to be displayed and heard in the navigation bridge. Though the ASC would be the predominant ship controller its position and the position of the SCC, which is on land and separate from the putative navigation bridge (the ASC), would need to be accounted for in the Convention.

Regulation 50 is cast in mandatory language and requires that a reliable means of vocal communication shall be provided between the main machinery control room or the propulsion machinery control position as appropriate, the navigation bridge and the engineer officers' accommodation. Such a requirement would serve no useful purpose on an AV. Regulation 51 concerns audible alarms. For the ethos of these provision to purposefully apply to AVs amendment is needed to provide for the absence of a crew and the existence of an ASC and SCC.

Chapter II-2 Construction - Fire protection, fire detection and fire extinction

Chapter II-2 deals with fire protection. Several references are made to manual isolation of tanks and vents together with portable instruments for measuring flammable vapour in Regulation 4. Regulation 5 also speaks of manual operation of vents and the like particularly in accommodation spaces. The purpose of Regulation 6 is to reduce the hazard to life from smoke and toxic products generated during a fire in spaces where persons normally work or live. This Regulation and all that it requires of a vessel like fire patrols for example would have very little relevance to an UAV except for when there are periodic entrants. The same argument can be made for Regulation 7 entitled *Detection and Alarm*. Obviously such measures are needed on an AV but not in the same way as a manned vessel. If an UAV is at sea with no one on board what use is an audible alarm or manually operated call points? Consideration needs to be given specifically to an UAV's fire detection and response system, and whether it should be applied to the SCC instead.

Regulation 8 deals with smoke extraction. Though smoke will not impede an AV as noted, inevitably there will be people on board for whatever reason, therefore the systems in place must be such as to protect these individuals. But the argument can be made for a less rigorous application of these rules to AVs.

Regulation 10 is entitled *Fire Fighting* and its purpose is to suppress and swiftly extinguish a fire in the space of origin. Its functional requirements assert the need for fixed fire-extinguishing systems and fire-extinguishing appliances. An AV would satisfy the purpose of this regulation. However, the requirements enumerated therein would be unnecessarily onerous for an AV and serve to militate against the goals which the regulation propounds. In particular the emphasis for an AV should not be on on-board manually operated fire fighting appliances and installations but more towards those applications controlled by the ASC and SCC. Consideration needs to be taken of the fact that an AV and the fire fighting installations it will have can perform the same functions as the manual ones currently required.

From the preceding discussion of fire safety it is clear an AV will be able to comply with purpose of all of regulations contained in Chapter II-2. It is the individual requirements within these regulations that are not applicable to an AV or are overly rigorous given the state of an AV. What may be required is a re-orientation of the rules. Regulation 17 allows for the use of alternative design and arrangements for fire safety provided that these design and arrangements meet the fire safety objectives and the functional requirements of the Chapter. An AV is not functionally the same as a manned vessel and will have different fire fighting arrangements in place. Regulation 17 will be very useful for an AV and allows for its novel and unique features possibly without the need to amend the Convention.

Chapter III - Life-saving appliances and arrangements

Section I Passenger Ships and Cargo Ships

Regulation 6 requires radio phone and radio transponders on ships, flares must be kept in the bridge and on board communication and alarm systems are also required. These requirements would serve no useful purpose on an UAV.

Regulation 7 is about *Personal life-saving appliances*. It covers lifebuoys, life jackets and immersion suits. There is no detail as to the specific number required so compliance by an AV is required. With respect to life jackets 7.2.1 states that there should be one for everyone on board the ship. However, this is not as simple as it might appear. Does this section apply when the UAV is at sea with no one on board or does it also apply when an UAV is docked and a certain unascertained number of individuals may be on-board. Clarification is needed. The need for immersion suits on an UAV is doubtful but is required under 7.3. Regulation 7 frames these rules as being necessary for the survival of passengers and crew. The need for theses life saving appliances on an AV is questionable as there will be no one on-board to use them. Though they may prove useful for SAR activities they are not required for such purposes under Regulation 7.

Section I also covers manning, embarkation and launching of survival crafts and the like. There is a requirement for trained personnel to be present, emergency training, inspections and servicing. These rules would not be relevant to an unmanned vessel yet given the wording of the Convention such a vessel would nonetheless have to comply.

Section III Cargo Ships (Additional Requirements)

Regulation 31(1) mandates the presence of lifeboats and life rafts on-board cargo ships. This section takes into account the fact that fewer people are present on a cargo ship when compared to passenger ships. A new section should be added to provide for an UAV and its unique manning.

Rescue boats are also required under Regulation 31(2). Cargo ships shall carry at least one. Though quite easy to comply with, its presence on an UAV would be pointless as there would be no one on board to operate it or conduct a rescue.

Also of note is Regulation 32(1) which links the number of lifebuoys required on a cargo ship to its length.

Chapter XI-1 Special Measures to Enhance Maritime Safety

This chapter could cause great hassle for the operation of UAVs. Regulation 4 permits a Port State to prevent a vessel from leaving when there are clear grounds for believing that the master or crew are not familiar with essential shipboard procedures relating to the safety of ships. Given the CDE make-up of an UAV and the impractical application of SOLAS to such vessels absent an exemption and without Convention amendment a pedantic or fastidious Port State could cause great hardship for an UAV.

Chapter XII Additional Safety Measures for Bulk Carriers

Regulation 12 requires the use of water level detectors together with the use of audible and visual alarms in the navigation bridge. Again, the definition of navigation bridge needs to be reconsidered to account for the ASC and the SCC.

Conclusion

SOLAS makes provision for the safety of those on board a ship. Though an UAV has no crew people will invariably be on board at certain times. This would necessitate a certain degree of compliance with the Convention to ensure the safety of those on board. Exemptions can be granted in respect of certain provisions but amendment is needed to give certainty to the law.

All monitoring measures can be undertaken by ASC and SCC and the concept of *navigation bridge* needs to encompass the role of both the ASC and the SCC. The Convention is framed with manned vessels in mind. A relaxation is needed for UAVs. If the CDE requirements were strictly applied to an UAV the installations mandated would serve no useful purpose during a voyage. Consideration needs to be given to the UAV's unique CDE model and how it is capable of satisfying the purposes and goals of the Convention though not in line with the rules expounded therein.

4.4.1.2 *MARPOL*

Annex IV Regulations for the Prevention of Pollution by Sewage from Ships

In the definition section of Regulation 1 of the Annex sewage is defined as drainage and other wastes from any form of toilets and urinals; drainage from medical premises (dispensary, sick bay, etc.) via wash basins, wash tubs and scuppers located in such premises; drainage from spaces containing living animals; or other waste waters when mixed with the drainages defined above. Regulation 2 sets out what vessels are covered by this Annex. Technically speaking the Annex would apply to an UAV as no consideration is given to the type of vessel in question. The criteria for determining whether a vessel must comply are size and/or passenger number. Even though an UAV is unmanned once it is a certain size it must satisfy Annex IV. This would be problematic for an UAV as the definition of sewage refers to waste generated by, for the most part, humans. Such a form of waste will not be present on an UAV and these provisions should not apply. But until the Convention is amended it appears that technically they will.

Annex V Regulations for the Prevention of Pollution by Garbage from Ships

In this Annex garbage covers victual, domestic and operational waste. Again like the definition of sewage in Annex IV the definition of garbage refers to waste generated by human occupation of a vessel. An UAV will not create such waste and will therefore not need a means of disposal for same. Regulation 2 asserts quite brusquely that this annex applies to all ships. There is no scope for adaptation or exemption for vessels like UAVs. Thus, without amendment an UAV will have to comply with the garbage disposal requirements of the Convention.

Annex VI Regulations for the Prevention of Air Pollution from Ships

This Annex does not impede to operation of an AV. Though an UAV will have in place different systems for the prevention of pollution from emissions to those on conventional vessels Regulation 4 of this Annex permits the use of systems different to those contemplated by the Convention provided they are as effective as those required by the Annex. Annex VI has a degree of flexibility, lacking in other areas of the Convention that allows for the operation of an UAV with its unique design structure. Any problems that might arise in relation to an UAV's air pollution in the future can more readily be resolved.

Conclusion

The Annexes pertaining to sewage and garbage are there to cover pollutants and wastes generated by passengers and crew. The design of an UAV is such as to obviate the need for these requirements. A complete dis-application of Annex IV and V will not affect adversely the environment. Annexes concerning pollutants generated by the ship itself such as air, oil, fuel etc are specifically and separately covered by the Convention.

4.4.1.3 *Load Lines Convention*

AVs will have to comply with this Convention. Should an AV have a freeboard lesser than that required by the Convention, Annex 1 Chapter 1 Regulation 2(5) permits a relaxation of the minimum freeboard requirements provided this does not interfere with ship safety.

Chapter II, Regulation 10 mandates the provision of information to a ship's master in order to arrange for the loading and ballasting of the ship. With respect to an UAV it is necessary to clarify the party responsible for this task and, if it is the ASC, how this information will be provided and by whom.

Regulation 25 stipulates measures for the protection of crew with regard to accommodation, freeboards and exposed decks. Given that no crew will be on-board and the regulation is specifically titled *Protection of the Crew* it is arguable that this provision does not apply to an UAV. Crew is a very specific term with a closed meaning. However, compliance would be necessary to provide for the safety of those periodically on-board an AV.

The superstructure on an UAV may not be as large as one on a conventional vessel. The Convention does not seem to lay down any minimum requirements for superstructure size beyond Chapter 3 Regulation 38(13)(b) regarding sheer.

Should doubt or uncertainly arise surrounding the application of this Convention to an UAV several provision militate in favour of an UAV. Article 6 permits the granting of an exemption for a vessel embodying novel features in order to promote research and development. But adequate alternative safety measures are required. Further Article 8 allow for the use of alternative appliances and the like.

4.4.2 Maintenance

MUNIN Engine Room

The Autonomous Engine Monitoring and Control (AEMC) system is part of the autonomous extensions of an unmanned vessel: this is the system that will control the engine related parts of the ship. To carry out its functions the AEMC will interface with the Ship Automation System (SAS) and use data supplied by it to get measuring values and status updates from the SAS. The AEMC will also interact with other autonomous installations on board such as the Autonomous Bridge System (ABS) and forward any control commands to the SAS.

The AEMC controls the systems for machinery operations which include the engine room, stern tube, propeller, rudder, steering gear, and casing with smokestack. Predominantly, the AEMC will have virtually complete control over these components. Little interference can be expected for other systems on board or even from the SCC. It is expected that only the task of starting and stopping the main engine will be controlled by the ABS or the SCC. However, the propulsion system itself is controlled by the AEMC. Power generation is also within the AEMC's domain: this includes the auxiliary engines, the generator and the support systems like lubrication oil, fuel system and cooling system. The bilge system and the steam system are generally under control of the AEMC. The fuel system is also handled by the AEMC but the calculation and the start of bunkering is done by the bridge (see /24/).

From the previous paragraph it is clear any external influence exerted over the AEMC relates to more minor operations, however, there are some instances referred to in *Specification concept of the general technical system redesign* (see /24/) where the AEMC will have limited control. The alarm management system is an example. The AEMC only handles the engine related alarms. The ballast water system is not part of the AEMC, but the AEMC will provide an interface for the bridge to control the ballast water system.

Finally, there are the areas which are not within the sphere of control of the AEMC: cargo management, navigation, manoeuvring, fire fighting, air condition system, aviation system, thruster control including a pump jet and external communication. These systems are generally controlled by the ABS.

Fuel System

In D.62 it was stated that the an unmanned ship could not safely operate in the same way as a conventional ship when it comes to fuel systems due to the need to transition between fuel types for navigation in Emission Control Areas and other areas under special regulation. To overcome this problem that Deliverable recommended a distillate fuel oil system. To implement this type of system for use on an unmanned ship a new type of common rail system is needed, The system proposed for use in *Specification concept of the general technical system redesign* (see /24/) is simpler and less rigorous on components. It is also more environmentally friendly. Moreover, the ability to use inert gas on board an unmanned ship greatly reduces potential environmental pollution caused by fire.

Maintenance System

On board an unmanned ship there will be a need for maintenance just like any other sea going vessel. It is obvious that immediate maintenance at sea is not possible. This gives rise to the need for increased monitoring, fault detection systems, and control functions. *Specification concept of the general technical system redesign* (see /24/) suggested possible solutions to the problems posed. The two most feasible being the use of normal equipment with maintenance and repair taking place in port; or the development of an exchange system where components are used until the assumed end of life without maintenance and then replaced. To permit an unmanned ship to function when things, inevitably, go wrong there will be an increased demand for redundancies on board.

There has been a gradual progression towards the use of unmanned areas on board ships in recent times and now the point has been reached where ships can now be completely unmanned. To deal with this new type of ship *Maintenance indicators and maintenance management principles for autonomous engine room* (see /93/) asserts that new maintenance management systems are now required. The consequences of not designing and implementing an adequate maintenance system for unmanned ships could be severe. The report emphasises the risk of loss of control of the ship, harm to other persons, damage to infrastructure, and capsizing. Therefore, reliance cannot be placed on traditional means of maintenance operation and a redesign is necessary.

The unmanned ship will be reliant on computer systems for updates as to the condition of a ship when at sea and physical inspection will generally only be possible at port. The use of Key Performance Indicators (KPIs) will assist in monitoring various parts of the ship: data will be recorded and measured in order to monitor equipment and the like. The SCC has a central role to play when it comes to monitoring: it will co-ordinate the maintenance plans together with monitoring data received from the ship. /93/

Conclusion

It is envisaged that an unmanned ship will have the same mode of operation as a manned ship but with some additional changes. The majority of these changes will concern the fuel system. Greater emphasis and reliance will be placed on redundancies on board an unmanned ship given the non-existence of a crew to remedy any failures.

4.4.3 Legal Relevance of Maintenance

Compliance with the legal requirements of the several maritime conventions is difficult for an unmanned ship. Maintenance is not different. The relevant conventions are all drafted with manned ships in mind. However, even if a manned ship can comply with maintenance obligations it may not be able to operate. A condition precedent exists. For example, under SOLAS before maintenance obligations arise a ship must first pass inspections and surveys. The maintenance obligation arising thereafter imposes a duty to maintain equipment and the like to the standards expounded in the survey and inspection criteria. Even if an unmanned ship has sufficient maintenance systems in place it may not satisfy the initial survey criteria such that it cannot operate. Maintenance also directly impacts on the seaworthiness of the vessel which is considered further in this section.

Furthermore, the extent of the unmanned ship's compliance with maintenance obligations is unclear as these are legion and suffused throughout all parts of numerous conventions. It can be tentatively stated that an unmanned ship can comply with these to a certain extent but the conventions appear to require measures involving persons physically on board.

The unmanned ship can satisfy the goals of these conventions but not the specific rules. Consideration of the unmanned ship's position is required. The most obvious solution is to introduce specific rules regarding unmanned vessels.

4.5 Liability issues

This section considers the most impotant areas of liability likely to affect unmanned shipping, specifically contractual and tort liability (charterparty, seaworthiness, collision, etc). In addition, it covers the issue of liability specifically from the point of view of the ship master, in some details, with a view to detecting where liability might arise for the unmanned ship.

4.5.1 General issues of liability

4.5.1.1 *Charterparty*

A charterparty is a contract between two parties, generally involving a shipowner and a charterer. Charterparties fall into three broad categories:

A demise charterparty is an agreement under which the charterer literally 'takes over' and has possession of a ship, together with the right of management and control. An important feature of demise charterparties is that the charterer is entitled to engage and pay for the ship's master and crew so that they are his employees for the duration of the charter.

A voyage charterparty is an agreement under which a vessel is to load at one or more named ports a particular specified cargo, which is to be carried to a named discharging port or ports.

Under a time charterparty, a shipowner agrees to place a ship, as well as its Master and crew, at the disposal of the charterer for his use and employment for a defined period of time. The charterer does not, however, at any stage have control or possession of the ship and the master and crew remain at all times in the employment of, and legally responsible to, the ship's owner.

It should also be noted that parties can enter into 'hybrid' agreements known as Trip Charterparties. These arrangements are considered to be 'hybrid' in that they prescribe both the duration and daily rate of hire of the charterparty, and also include a geographical route and named ports. The voyage itself is therefore delineated, along with an estimated time for completion.

Bills of Lading

A bill of lading is a written document signed on behalf of the owner of a ship in which goods are embarked, acknowledging the receipt of the goods, and undertaking to deliver them at the end of the voyage, subject to such conditions as may be mentioned in the bill of lading. The bill of lading operates on three levels:

- A receipt of freight services
- A contract between a carrier and a shipper
- A document of title

Typically, the shipper will sign the bill of lading along with the owner of the cargo at the point at which the shipper takes carriage of the cargo in question. The bill of lading will then be signed by the cargo's recipient once it has reached its destination. In other words, the document accompanies the cargo at all times, and is signed by the owner, shipper and recipient. It will generally describe the nature and quantity of goods being shipped.

4.5.1.2 *Seaworthiness*

The duty of a shipowner under a charterparty to ensure that his ship can perform the contract voyage in safety (with regard to the vessel itself and its cargo) is a fundamental legal obligation. It generally takes one of two forms: either an absolute duty under common law, or a duty merely to exercise due diligence as to the seaworthiness of the ship, which arises where the parties voluntarily incorporate the 'Hague-Visby' Rules.

An absolute duty under common law prohibits a defence of taking reasonable steps to ensure seaworthiness. Exceptions clauses in the charterparty will not apply to unseaworthiness unless explicitly stated. It should be noted that the common law duty, though absolute, extends only as far as the particular cargo and particular voyage in question. Unseaworthiness may be as a result of a physical defect (e.g. a damaged hull) or a non-physical defect (e.g. lacking the necessary documentation as required by law)

Under Article III of the Hague-Visby Rules, the due diligence required of the shipowner has three distinct legs: firstly, the vessel itself must be physically seaworthy; secondly, the ship must be properly equipped, supplied, and manned, and its crew must be sufficient, qualified and trained; and thirdly, the ship must be fit and safe to carry its cargo. Physical seaworthiness would encapsulate a requirement to meet international safety standards as laid down in IMO Conventions.

Crew Incompetence

However, it should be noted that incompetence on the part of the crew may extend beyond ordinary rules of negligence and constitute unseaworthiness. In Hong Kong Fir *Shipping Co Ltd v. Kawasaki Kisen Kaisha Ltd* /94/ , damage done to the ship's engine by an incompetent crew (headed by a chief engineer who was addicted to alcohol) was held to render the ship unseaworthy. Similarly, a failure on the part of a shipowner to inform a crew of the technical or specific knowledge required to properly maintain the boat was held to amount to unseaworthiness in circumstances where the absence of that technical knowledge caused the ship to keel over and sink in calm waters. /95/

When does the duty apply?

The duty (either under common law or Hague-Visby) generally applies at the point at which the ship is delivered to the charterer (under a demise charterparty) or the point at which the charterparty begins (under a time charterparty); however, under a time charterparty, a separate and ongoing duty exists on the shipowner to maintain the ship in a thoroughly efficient state throughout the duration of the agreement.

It should also be noted that, as a general proposition, an initial burden of proof to show unseaworthiness falls on a claimant in a case. Once this burden is satisfied, the burden shifts to the shipowner, who is under a non-delegable legal duty to show that due diligence was properly exercised. Exceptionally, however, unseaworthiness may be presumed by a court from the beginning; for example, in The Torenia case /96/, where a ship sank in weather conditions which were to be expected for that particular voyage.

Legal consequences of unseaworthiness

Where unseaworthiness is shown, the innocent party will be automatically entitled to damages caused by the unseaworthiness under the ordinary laws of negligence, but not necessarily to repudiation or termination of the contract. The contract will only be terminated where the fundamental commercial purpose of the contract is frustrated by the breach - a question which itself is informed by a comparison of the delay caused by remedying the unseaworthiness with the total length of the contract.

4.5.1.3 *Deviation*

In the absence of an express contractual term to the contrary, a shipowner undertakes that the ship will proceed on its route by a usual and reasonable route without unjustified departure from that route or delay. A justified departure from a route or delay may arise where it is undertaken to save lives or cargo, or where it is usual commercial practice to bunker at a particular port off the route.

Article IV(4) of the Hague Visby Rules provides more latitude to the shipowner, in that it permits 'reasonable' deviations – a standard above the common law standard of 'justifiable'. The courts have held that what is reasonable will be determined with regard to the interests both of the shipowner and the cargo. /97/ Separate to the Hague Visby Rules (which, it should be remembered, must be specifically incorporated into a contract), the parties are free to agree specific 'liberty' clauses which gives the shipowner liberty to call at additional ports; these clauses have tended to be construed narrowly by the courts, however. /98/

Legal Consequences of Deviation

Once a deviation is found to be unjustifiable, the common law doctrine of deviation acts to debar the shipowner from relying on any term in the contract. Following a deviation, the shipowner is reduced to the legal status of common carrier, and may only rely on an Act of God, acts of the King's enemies, inherent vice of the cargo or the fault of the consignor as a defence to the claim of cargo damage. /99/

4.5.1.4 *Collisions*

Liability arising from collisions at sea generally arises under the the principles of negligence – that the defendant owed the plaintiff a duty of care, that the defendant did not meet the standard of care owed, and that this failure caused damage to the defendant that was reasonably foreseeable.

The Duty of Care

Legal disagreement rarely arises in respect of whether a duty of care is owed – it is generally accepted that the person in control of a ship owes a duty of care to other ships.

The Standard of Care

The applicable standard of care for the navigation of a ship is known as 'good seamanship' or 'prudent seamanship'. Much of what constitutes good seamanship is set out in the International Regulations for Preventing Collisions at Sea (Collision Regulation), which pertains to, *inter alia*: the use of lookouts; safe speeds; the use of lights; shapes; and the giving of signals by light and sounds. A further analysis of the Collision Regulations is provided elsewhere in this study.

It should be noted that an exculpatory 'in the agony of the moment' clause exists for a crew which has been found not to meet the standards of good seamanship. This may be invoked where the actions of one ship put another ship into a situation of difficulty in which the same standard of skill or ability cannot be expected of a crew. /100/ A shipowner's standard of care extends to compliance with international conventions such as SOLAS and MARPOL, and requirements relating to the equipping and manning of the ship.

Causation

As with all cases under the tort of negligence, causation between the defendant's conduct and the damage suffered by the plaintiff is a necessary ingredient. A common defence under negligence is that a *novus actus interveniens* exists – an event or action which takes place following the defendant's negligence and which absolves him from liability at law by being the operative cause of the damage suffered by the claimant.

Under maritime law, a related rule has arisen, known as the 'last opportunity' rule. Under this rule, the ship that had the last opportunity to avoid the collision shall be held to be its sole cause; often, however, it is impossible to state with certainty which of the parties had the 'last opportunity'. As a result, the rule rarely operates. It finds some application, however, in collisions involving a ship and a stationary object. In *The Kate*

/101/, for example, a ship was held to have had the 'last opportunity' when it collided into a moored barge, notwithstanding that the barge was negligently moored.

Res Ipsa Loquitur

The doctrine of *res ipsa loquitur* – which presumes negligence once the facts of the incident are established – has been invoked successfully in English maritime law cases. /102/ The presumption can be rebutted by the defending party if it can show that the damage was not reasonably foreseeable, or that it was caused by a third party.

Vicarious Liability

A shipowner will generally be held vicariously liable for the negligence of the ship's crew in a collision, unless it can be shown that the negligence constituted a 'frolic of their own', which would take their conduct outside of the boundaries of their employment. This is a very difficult standard for a shipowner to prove, however.

Furthermore, the crew members in question can be held personally liable for their own negligence. In instances where the negligent party is not a member of the crew, the vicarious liability of the shipowner will be determined much in the same way as with a normal employer – the applicable test is whether the negligent individual was a servant or agent of the shipowner, or an independent contractor.

Contributory Negligence

The common law principle of contributory negligence is recognized in the 1910 Collision Convention, which states that liability in a collision shall be apportioned in proportion to the blameworthiness of each party. Although fault is not specified in the Convention, it is widely recognized that a breach of the Collision Regulations would generally constitute a fault. Where death results from a collision, the ships involved are joint and severally liable (but remain free to claim against each other). The liability for property damage, by contrast, is recoverable from each party to the extent of their liability.

These principles are also found in section 1 of the Maritime Conventions Act 1911 and section 187 of the Merchant Shipping Act 1995, and follow from the ordinary rules of contributory negligence under tort law.

The duties of good seamanship are set out in the IRCPS, and form the basis of the assessment for blame in collisions. In addition to broad principles described above, specific rules arise in situations of limited or restricted visibility and in relation to lights and shapes being displayed and sounds signals being given.

Where the owner of cargo is a third party to a collision, he may claim against the non-carrying vessel in tort (with the rules of contributory negligence applying) and/or under contract law against the carrying vessel (which may in turn seek to rely on the Hague or Hague-Visby rules as a defence). It should also be noted that a court will only consider the negligence of a particular crew if that negligence is causative of the collision.

Damages

As described above, damage suffered by the claimant must be directly caused by the negligence of the defendant and must have been reasonably foreseeable. Furthermore, it should be noted that recovery for damages is only possible for physical damage and consequent financial loss; recovery for pure economic loss is not recognized at common law. *The World Harmony* case /103/ is authority for the proposition that a time charterer of a vessel can make no recovery in tort against a vessel with which it collides; this is because the loss is purely and entirely economic in character.

Time-bar

Different time bars are applicable in different jurisdcitions for maritime claims as this is a matter of national law. By way of example, Section 190 of the Merchant Shipping Act 1995 (UK) imposes a two-year time bar on claims arising from maritime collisions, although a court retains residual discretion to extend the time where it has not been reasonably possible to arrest the defendant ship within two years of the collision.

4.5.1.5 *Salvage*

There is no general legal duty to save property at sea; however, various legal frameworks operate within the law of salvage which attempt to protect property on board stricken vessels by encouraging other ships to rescue it. Foremost among the operative legal principles is that providing assistance to a stricken vessel entitles the salvor to a reward. The liability to pay such a reward is shared between the shipowner and the cargo-owners.

Specialised salvage contracts have been developed which outline the obligations and practicalities of salvage. The most prominent of these is the Lloyd's Open Forum (LOF), which delegates the determination of the size of reward to an arbitrator appointed by Lloyd's. This avoids negotiations taking place prior to the cargo being rescued, which might have the effect of delaying the salvage operation. The English law with regard to the law of salvage is outlined in the Salvage Convention, as enacted through the Merchant Shipping (Salvage and Pollution) Act 1994.

The Salvage Convention

The Salvage Convention is applied in all cases brought before an English court or an arbitration panel seated in England. For the convention to apply, the relevant property must be 'in danger', which is defined as sustained damage being reasonably apprehended (though it need not be present at the relevant time, so long as it might arise in the absence of assistance). /104/

Whether the vessel is in danger is to be decided objectively by a judge or arbitrator, regardless of the opinion of the ship's master or any crew members. The salvor must prove that a reasonably prudent and skillful person in charge of the vessel would not have refused the salvor's help. This burden is particularly relevant where the salvage takes place in the absence of a specific request from the shipowner, or in spite of the protestations of the shipowner. The legal authorities suggest the salvor will still be entitled to a reward in such circumstances. /105/ The salvor's duty during salvage includes exercising due care with respect to the cargo and minimizing environmental damage. The owners of the endangered property are also under a duty to cooperate fully with the salvor and to accept redelivery of the property once it reaches a 'place of safety'. If the salvage operation achieves a 'useful result' (a term which is not defined but which would appear to suggest that the property's value or quantity is greater as a result of salvage), a right of reward arises for the salvor.

The Salvage Reward

Where a 'useful result' is achieved from salvage, the '*no cure no pay*' principle is applied – in other words, that a reward is only payable where property is actually salvaged. Article 13 of the Salvage Convention outlines a range of criteria employed to calculate a reward, from the value of the property salvaged to the nature and extent of the danger. In practice, the breadth of these criteria divests a large amount of discretion in the decision-maker. Rewards are payable by the shipowner, the cargo owner and other interested parties in proportion to the value of their interests in the salvage.

An alternative method of reward, known as '*special compensation'*, is calculated under Article 14 the Salvage Convention for salvors who get involved in situations where pollution is threatened and there is little prospect of saving property. Where the salvor is unsuccessful in preventing environmental damage, the shipowner may still be liable for his expenses, and where the salvor is successful, the shipowner may be liable for his expenses as well as an additional payment of up to 100% of his expenses.

Public policy grounds exclude certain categories from claiming a reward under salvage law. Any individual or ship which is responsible for creating the danger in the first place is unable to claim. A reward also cannot be claimed by any party already under a contractual obligation to rescue the cargo (e.g. the ship's master or crew, or pilots or tugs). Salvors employed by the government or state bodies, or the government and state bodies themselves, may also not claim a reward.

Salvage and Time Bar

The time bar for any action relating a reward under the Salvage Convention is two years from the date upon which the salvage operation is terminated.

Salvage Contracts

Article 6(2) of the Salvage Convention permits the master of a vessel to enter into a salvage contract. This will clarify the extent of the obligations on either side and may also facilitate exclusion of many of the terms of the Convention itself. It should be noted that the authority of the master of the vessel to enter such a contract binds both the shipowner and the cargo owner.

4.5.1.6 *Limitation of Liability*

Article 1 of the 1976 Convention on Limitation of Liability of Owners of Seagoing Ships provides that shipowners and salvors may limit their liability to all claims arising from any one incident. The size of the limitation is based upon the tonnage of the ship. Within the convention, the term 'shipowner' is held to include the ship's owner, charterer, manager or operator, and the right to limit is extended 'any persons whose act, neglect or default the shipowner or salvor is responsible for'.

Article 2 of the 1976 Convention provides six heads in respect of which limitation can be claimed:

a. Claims in respect of loss of life, personal injury or damage to property, and consequential loss resulting therefrom;
b. Claims in respect of loss resulting from delay in carriage of cargo or passengers;
c. Claims in respect of other loss resulting from infringement of rights (excluding contractual rights);
d. Claims in respect of raising, removing, destroying or rendering harmless a ship that is sunk, wrecked, stranded or abandoned;
e. Claims in respect of removing, destroying or rendering harmless the cargo of a ship;
f. Claims of a third party in respect of measures taken in order to avert or minimize loss or liability.

Article 3 specifically excludes the following classifications of action from the scope of limited liability:

- Claims for salvage (i.e. claims by salvors, rather than claims against them);
- Claims for contribution in general average;
- Claims arising under a shipowner's statutory liability for oil pollution damage;
- Claims in respect of nuclear damage.

Article 4 states that a person liable shall not be entitled to limit his liability if its proved that the loss resulted from his personal act or omission, committed with the intent to cause such a loss, or recklessly and with knowledge that such loss would probably result.

4.5.1.7 *Classification Societies*

Classification societies are independent private organizations which study the technical elements of ship safety. Importantly, these bodies certify the safety of ships, and these certifications are relied upon by the shipping community, including charterers, traders and insurers.

Certification may either be statutory (i.e. performed by the society under formal authorization by a flag State) or non-statutory (i.e. other contractual work). Statutory surveys expose flag States to third party claims in negligence, which, depending on the domestic laws in question, may entail recourse to the classification society. The liability of a classification society to a claim in negligence in relation to non-statutory work will depend on the wording of the contract.

4.5.2 Conclusion on general issues of liability

Now it will be discussed what is likely to change or will require change for the autonomous vessel.

4.5.2.1 *Charterparties*

The implications of unmanned ships on charterparty arrangements will vary with the type of charterparty involved. However, it should be noted that as charterparties are essentially contractual arrangements between two private parties, the development of unmanned vessels will presumably be dealt with in the drafting of these documents.

The key distinction will arise depending on whether the charterparty is of the type wherein, traditionally, the charterer becomes the *de facto* employer of the ship's master and crew. Under a demise charterparty, it would be expected that the charterer would become responsible for the guiding IT mechanism of an unmanned vessel and become the *de facto* employer of the shore-based controller. By contrast, under a time charterparty, the guiding IT mechanism and the shore-based controller would remain at all times in the employment of the ship owner.

Bills of Lading

A question arises as to how a bill of lading will accompany cargo in the absence of a master or any crew on board the ship. This is a particularly important question given that the Hague rules explicitly envisage a bill of lading being signed by the ship's master. A potential solution to this issue is that bills of lading would be in digital format for cases involving unmanned vessels, following the line of current use of electronic forms of bills of lading.

4.5.2.2 *Seaworthiness*

As highlighted above there is a wider issue regarding the seaworthiness of the AV in terms of it complying with all international regulations such as SOLAS. These conventions and the applicability to the AV is considered in detail in other sections of this report.

In addition on a contractual level, it is envisaged that the term 'seaworthiness' and the related duties imposed by law on ship owners will be adapted and extended by case law to respond to the advent of unmanned vessels. The standard charter forms can be readily adapted to recognise the absence of crew and to deal with the specific practical considerations the unmanned operation gives rise to in contract to manned vessels. For example, in particular, this is likely to concern the competence of the shore-based controller and the adequacy of the guiding IT mechanism. In any charterparty arrangement, the duty will vary depending on whether the parties incorporate the Hague-Visby rules into their agreement (as described *supra*). Due diligence as to the competence of the shore-based controller may necessitate the development and introduction of certifications or qualifications for individuals fulfilling such a role and specific contractual clauses being included within charterparties to reflect such issues.

4.5.2.3 *Deviation*

The transition from manned to unmanned vessels is likely to reduce the scope for deviation from prescribed and agreed routes, on the basis that human error is virtually removed entirely from the navigational process. In the event that deviation does take place (owing, for example, to a failure on the part of the guiding IT mechanism), it appears likely that the ordinary rules of seaworthiness would be a more appropriate framework for recourse than the common law doctrine of deviation.

4.5.2.4 *Collisions*

Among the most significant areas of legal importance with regard to unmanned ships is the law concerning collisions. As described above, the Collision Regulations outline the standard of care required of seafaring vessels. This standard of care includes such aspects as a duty to maintain a proper lookout and a duty to proceed at a safe speed. It is unclear to what extent this standard of care can be adequately satisfied by a shore-based controller who lacks the first-hand exposure and experience of the circumstances at sea as they exist with regard to, for example, a dangerous situation involving proximity to another vessel.

In reality, however, the extent to which 'maritime common sense' is implemented by manned vessels is diminishing with recent advances in technology in areas such as collision-avoidance. Many ships now employ automated navigational mechanisms similar to autopilot on an airplane. Furthermore, and particularly in circumstances of reduced visibility, the experience of a crew or master on board a ship will be broadly similar to that of a shore-based controller. The increasing reliance on technology is reducing the degree to which a ship's crew exercise the principles of good seamanship.

The 1910 Collision Convention apportions fault between ships themselves, rather than between crews or masters. As a result, the Convention is drafted in such a way as to withstand the existence of unmanned ships. No distinction within the terms of the Convention should therefore arise between a collision involving two manned vessels and two unmanned vessels. However, there are still many uncertainties as to who the legally responsible entity for an unmanned ship will be (either SCC as a whole, or operator, or other elements in the SCC, etc), therefore at this stage of the legal analysis it is best to describe the responsible legal entity as 'shore based controller' without specifically pointing to either other entity.

4.5.2.5 *Salvage*

In the first instance, maritime law concerning the salvage of persons at sea obviously has no relevance in so far as unmanned ships are concerned. With regard to salvage of cargo, unmanned vessels present certain challenges to the existent law. For example, in the absence of a master, will an unmanned vessel be capable of being subject to a salvage contract? It may be that the shore-based controller will be vested with the capability to enter such contracts (which are binding on the shipowner and the cargo-owner).

What about a situation in which the shore-based controller loses contact with the vessel due to a technical failure? It may be that a passing ship cannot establish contact with the controller, and must therefore decide whether to attempt salvage. The law outlined above would suggest that the consent of the shore-based controller (acting in a similar capacity to the master of a manned ship) is not strictly necessary for the salvor to claim a reward. The salvor must simply prove that a reasonably prudent and skillful person in charge of the stricken vessel would not have refused the salvor's help. In other words, the test for danger remains an objective one.

4.5.2.6 *Limitation of Liability*

International conventions dealing with limitation of liability are phrased in neutral terms with regard to the presence of a master or crew. In other words, the limitation pertains to the vessel itself, rather than to any person(s) on board. As a result, circumstances in which a ship has no person(s) on board do not appear to undermine the operation of those conventions.

4.5.2.7 *Classification Societies*

The three core pillars of ship safety addressed by classification societies – safety at sea, avoiding human injury and protecting the environment – should remain unchallenged by the development of unmanned ships (albeit that the likelihood of circumstances in which human injury is threatened may diminish). The prospect of unmanned ships should be easily integrated into the existing classification society framework, through safety certification, inspections, and the development of industry standards for technical specification and operating mechanisms for unmanned vessels.

4.5.3 Liability of the ship master in particular

4.5.3.1 *Overview*

The law governing the role of the ship master (in law, referred to as the master) in the UK stems from common law, domestic legislation and international conventions recognized and enforced by the UK Courts. The principal law regulating the Ship Master and his vessel in the UK is Part III of the Merchant Shipping Act 1995. /106/

The Master is subject to both civil and criminal liability. In terms of criminal liability he may be prosecuted by the state and in the event of a finding of guilt, his punishment can include the possibility of imprisonment and/or a monetary fine and in terms of civil liability, he can be held personally responsible to his owners for any injury or loss to the ship or cargo by reason of his negligence or misconduct, or for acting without authority. /107/

In collision-type situations, the Master may be held personally responsible for the collision. There are practical reasons for holding him responsible in collision-type situations, cargo damage and non-adherence to good seamanship, mainly because the master will be the person physically present in the jurisdiction where the incident occurred, making it easy to charge and detain him/her there. /108/

The ship owner can equally be prosecuted by the State but in terms of civil liability the ship owner's liability is likely to be limited under the Hague-Visby Rules[13], which provides that neither the carrier nor the ship shall be responsible for loss or damage arising or resulting from any act, neglect or default of the master in the navigation or in the management of the ship.

It has been suggested that this protection is undermined by the decreasing autonomy of the master who nowadays receives his instructions via onshore telecommunications, where as Douglas points out, *"the corporation can instruct the master in a matter of seconds"/*109*/.* There are a number of duties set down in legislation by which the Master is ultimately responsible while the vessel is at sea. This research addresses the criminal liability, and to a lesser extent, the civil liability of the master under existing UK legislation and common law.

4.5.3.2 *Merchant Shipping Act 1995*

The Merchant Shipping Act 1995 is the primary legislation governing the liability regime of the master. Section 58 (2) of the Act 1995 provides that the master will be guilty of an offence if he (the master or any seaman employed in a United Kingdom Ship), while on board his ship or in its immediate vicinity:

(a) does any act which causes or is likely to cause:

i. the loss or destruction of or serious damage to his ship or its machinery, navigational equipment or safety equipment, or
ii. the loss or destruction of or serious damage to any other ship or any structure or
iii. the death of or serious injury to any person

Section 58, subsection 2(b) goes on to require the Master to preserve the ship from being lost, destroyed or seriously damaged, and to preserve any person on board from death or serious injury, or causing loss or destruction to any other person. /110/ The Master will be guilty of an offence if any of these omissions were deliberate or amount to a breach of neglect or duty, and/or the master or seaman in question was under the

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[13] International Convention for the unification of certain rules of law relating to bills of lading signed at Brussels on 25th August 1924, as amended by the Protocol signed at Brussels on 23rd February 1968 and the Protocol signed at Brussels on the 21st December 1979. Commonly referred to as "The Hague-Visby Rules".

influence of drink or a drug at the time of the act or omission. /111/ The 1995 act also preserves the duty of the master of a UK ship or of a foreign ship in United Kingdom waters in every case of a collision between two ships in so far as he can do so without danger to ship own ship, crew and passengers:

- to render assistance to the other ship, its master, crew and any passengers such assistance as may be practical and may be necessary to save them from any danger caused by the collision, and to stay by the other ship until he has ascertained that it has no need of further assistance; and
- to give the master of the other ship the name of his own ship and also the names of the ports from which it comes and to which it is bound.

The act provides that a failure to comply with this duty does not raise any presumption of fault, as it had in older times. Breach of the duty, however, remains a criminal offence. Breach of the duty by a certified office may result in an inquiry into his conduct being held and his certificate being cancelled or suspended. Where the act or omission was deliberate, there is no defence for the Master. However, section 58, subsection 6 creates a new “reasonableness defence” where the act or omission arises from a breach or neglect of duty. There is a defence that the act or omission could only have been avoided by disobeying a lawful command or lack of reasonable foreseeability or could not have reasonably been avoided. This, however, is a high standard for a master to meet in seeking to relieve himself of liability.

It should be noted that prior to 1995, the former legislation namely the Merchant Shipping Act 1894 and the Merchant Shipping Act 1970 did not have such a defence and so the gravity of a master’s conduct fell to be dealt with, sometimes quite harshly, by the Courts.

In *the Harcourt* /112/, decided prior to the 1995 Act, the master fell ill on approach to his docking at Gunness. The master appointed a pilot on the approach. The weather deteriorated and the so the pilot took shelter in the Hull West Roads, finding a safe anchorage away from the main navigation channel. The mate kept watch but then handed over watch to an experienced deckhand. At sunset the deckhand turned on the navigation lights but omitted to turn on the forward anchor light. By the failure to illuminate the forward anchor light a potentially dangerous collision situation arose. The omission to illuminate was noticed by the authorities ashore. The master was not aware of these events until it was brought to his attention by police officers who boarded the Ship. The Master was found guilty for failing to ensure proper lights were displaced. The Court decided that the master had a non-delegable duty in attending to the navigation lights.

The officer in charge should always be on deck. If the master feels unable to remain, he should not leave until he is fully satisfied that the junior officer understands that it is his duty to avoid a close-quarters situation. /113/

There are serious penalties for failure to comply with the duties in s.58 of the act. If the master discharges his duties under s.58, or performs any other function in relation to the operation of his ship or machinery or equipment, in such a manner as would cause death destruction or injury to another person, or fails to discharge his duties properly, he will be subject to the penalties set out in s. 58 (5) and s. 58 (6) of the Act.

A person guilty of an offence under s. 58 "shall be liable on summary conviction to a fine not exceeding the statatory maximum" or "liable on conviction on indictment, to imprisonment for a term not exceeding two years or a fine, or both" /114/. The definition of duty is quite broad. Breach of duty is understood as meaning "disobedience to a lawful command", while in relation to the master's specific duties, duty is understood to mean the master's duty as it relates to "the good management of his ship and his duty with respect to the safety of operation of his ship, its machinery and equipment" /115/. There are also a number of other responsibilities that can fall to the master to enforce, but are equally the responsibility of the ship owner. For example, s. 49 of the act can result in the master being held liable (on summery conviction, to a fine or conviction on indictment to a fine) where the ship is undermanned.

4.5.3.3 *Duty to Assist*

A duty is imposed upon the master of each ship involved in a collision to assist the other ship. Section 92 of the Merchant Shipping Act 1995 provides that in every case of collision between two ships, it shall be the duty of the master of each ship, if and in so far as he can do so without damage to his own ship, crew and passengers to render to the other ship, its master, crew and passengers such assistance as may be practicable and may be necessary to save them from any danger caused by the collision, and to stay by the other ship until he has ascertained that it has no need of further assistance./116/ If the Master fails without reasonable excuse to comply with s.92, he is guilty of an offence. S. 93 of the Merchant Shipping Act 1995 provides for an obligation to assist vessels in distress. The section provides that the master of a ship, on receiving at sea a signal of distress or information from any source that a ship or aircraft is in distress, shall proceed with all speed to the assistance of the persons in distress and informing them, if possible, that he is doing so. The Master is relieved of his duty if he is unable, or in the special circumstances of the case considers it unreasonable or unnecessary to do so or if he is released from this duty by other provision, i.e., on being informed that assistance is no longer required.

Similarly, where a master of any ship in distress has requisitioned any ship that has answered his call, it shall be the duty of the master of the requisitioned ship to comply with the requisition by continuing to proceed with all speed to the assistance of the person in distress. /117/ If the Ship Master fails to comply with the provisions of this section he is guilty of an offence.

The duty to assist is perhaps one of the original duties particularly associated with the master's role. It stems from older common law and is called into question when one considers the prospect of unmanned ships. The penalties in UK legislation for failing to comply with this are s.93 of the Merchant Shipping Act 1995 are (a) on summary conviction a term of imprisonment not exceeding six months or to a fine not exceeding the statutory maximum or both; or (b) conviction on indictment, to imprisonment for a term not exceeding tow years or to a fine, or both. /118/

The 1995 Act also requires that the master and owner not only have an obligation to ensure the seaworthiness of the ship, but also an obligation to ensure that the vessel is not dangerously unsafe at the time of the voyage or any time during the voyage. Section 98 of the 1995 Act makes the owner and master of a dangerously unsafe ship, or any other person who has assumed the responsibility for safety matters, guilty of an offence and liable on summary conviction to a fine of up to £50,000, or, on conviction on indictment, to imprisonment for up to two years. 'Dangerously unsafe' is defined under s.94 of the 1995 Act as a ship unfit to go to sea without serious danger to human life.

4.5.3.4 *COLREGS*

In addition to criminal liability under the Merchant Shipping Act 1995, the COLREGS have been incorporated into UK law under the Merchant Shipping (Distress Signals and Prevention of Collisions) Regulations 1996. The Regulations make contravention of COLREGS a criminal offence. Regulation 6 provides:

1. Where any of these Regulations is contravened, the owner of the vessel, *the master* and any person for the time being responsible for the conduct of the vessel shall each be guilty of an offence, punishable on conviction on indictment by imprisonment for a term not exceeding two years and a fine, or on summary conviction:
    a. in the case of any infringement of Rule 10(b)(i) (duty to proceed with traffic flow in lanes of separations schemes) of the International Regulations and by a fine not exceeding £50,000; and
    b. in any other case by a fine not exceeding the statutory minimum.

2. It shall be a defence for any person charged under these Regulations to show that he took all reasonable precautions to avoid the commission of the offence.

Compliance with the Rules is strict. Rule 2 (a) of COLREGS states that: "Nothing in these Rules shall exonerate any vessel, or the owner, master or crew thereof, from the consequences of any neglect to comply with these Rules or of the neglect of any precaution which may be required by the ordinary practice of seamen, or by the special circumstances of the case."

Provisions relevant to the role of the master in the UK regulations include Regulation 3 which states that no signal of distress shall be used by any vessel unless the master so orders and that the master shall not so order, unless he is satisfied that his vessel is in serious and imminent danger, or that another ship or aircraft or person is in serious and imminent danger and cannot send that signal, and that the vessel in danger (whether his own or another vessel) or the aircraft or person in danger requires immediate assistance in addition to any assistance then available. /119/

The Regulations also impose on the master an obligation to revoke any signal of distress by all appropriate means as soon as he is satisfied that the vessel or aircraft to which or the person to whom the signal relates, is no longer in need of assistance. /120/

Rules 1 to 36 of the COLREGS /121/ are also incorporated in the UK Regulations, which contain certain requirements specific to the role of the master. /122/ Many duties in the COLREGS could be viewed as falling to the Master. Rule 2 of the COLREGS states that the Master, along with the vessel and the owner, can be held responsible for failing to comply with the Rules or neglecting the precautions which may be required by the ordinary practice of seamen.

For example, Rule 5 of the COLREGS requires that every vessel shall at all times maintain a proper look-out *by sight and hearing* as well as by all available means appropriate in the prevailing circumstances and conditions so as to make a full appraisal of the situation and of the risk of collision. This is a duty which could not be fulfilled by traditional means in an unmanned ship, and which would perhaps be seen as contradicting a standard required by International Regulations.

Rule 6 requires a safe speed so that proper and effective action can be taken to avoid collisions at sea. Rule 8 (b), which deals with the avoidance of collisions at sea refers to the requirement that any alteration of course be readily apparent to another ship either visually or by radar. It is apparent that the COLREGS create standards that rely on human judgment as well as radar signals. This is evident in Rule 7 d (ii). Rule 7 broadly refers to factors which should be taken into account in determining whether there is a risk of collision. An “appreciable bearing change” in the compass may be taken into account in determining the risk. As Rule 7 (c) makes clear, assumptions cannot be made on “scanty radar information”.

Finally, in relation to criminal responsibility, the ISM Code, as implemented by statutory instrument also places responsibility on the Master in creating international safe standards for the operations of ships. /123/ This regulation was enacted in UK legislation by statutory instrument SI 1998/1561 known as the The Merchant Shipping (International Safety Management (ISM) Code) Regulations 1998. /124/ Regulation 7 refers to the duty of the master to “operate his ship in accordance with the safety management system on the basis of which the Safety Management Certificate was issued” /125/. Regulation 19 (3) states that any offence under Regulation 7 is an offence punishable on summary conviction by a fine not exceeding the statutory maximum or on conviction on indictment by a term of imprisonment for a period not exceeding two years, or both.

4.5.3.5 *Corporate Manslaughter*

Failure to obey the collision regulations may also overlap with manslaughter proceedings in criminal law in the UK, as well as the maritime offences already discussed under s. 58 of the Merchant Shipping Act 1995.

Prior to 2011, prosecutions of masters and crew members in the context of a collision for manslaughter generally failed as the “*mens rea*” of the offence was unable to be proven. Normally in a criminal offence, the prosecution is required to prove both the act itself and the intentional or directing mind of the person to intend the consequences of their actions. In the context of sea faring, this is not straightforward where a number of persons on the ship in concert may be responsible for certain actions.

The facts of the case *R v. P & O European Ferries (Dover) Ltd* /126/ are relevant to this. On the 6th March 1987 the P & O European Ferries “MS Herald of Free Enterprise” set sail on its voyage from Zebrugge to Dover. Within 20 minutes of sailing the ship capsized with the resultant loss of 193 lives. An inquiry found that the direct cause of the sinking was a failure to close the bow doors. In October 1987, during the Coroner’s Inquest the jury returned verdicts of unlawful killing. The company, along with five individuals in charge of the ship at the time were prosecuted for corporate manslaughter. However, on appeal, this verdict was overturned.

Where a prosecution of corporate manslaugther is concerned, the English Courts were bound by *Tesco Supermarkets Limited v. Nattrass /*127/*.* That decision makes clear circumstances where the actions of a natural person are attributable to his company. If liability is to attach to a corporate entity, it must be shown that the act or the omission is attributed to the "directing mind" of the corporation. Where a person acts "as the company", his mind will direct his acts as though it is one and the same as the company. This means that his guilt is the guilt of the company and the company is no longer vicariously liable.

In *R v. P & O European Ferries (Dover) Ltd* /128/ the company was not guilty of manslaughter as none of the Defendants could be considered the "controlling mind" of the company such that they were acting as the company. Douglas points out that the identification doctrine is largely replaced by the Corporate Manslaughter and Corporate Homicide Act 2007[14] /129/, which now clearly states that an organisation will be guilty of an offence "only if the way in which its activities are managed or organised by its senior management is a substantial element in the breach" /130/. This relatively recent legislation makes clear that companies can no longer hide behind the veil of incorporation and corporate criminal liability can now result from the acts or omissions of the master.

In 2007, however, the Corporate Manslaughter and Corporate Homicide Act 2007 came into force under which a company can now be successfully prosecuted for manslaughter. The significance of the legislation is that the master of a ship could be construed to be the "deciding mind" of a corporation within the legislation and now subject to this criminal liability. This is particularly so where the responsibility for the seaworthiness of the ship rests primarily with the master.

This legislation is therefore relevant in the context of considering autonomous ships and the potential exposure to those giving remote instructions, although at the time of writing it is understood that a prosecution has yet to be brought against the master of a ship under this act.

4.5.3.6 *Civil Liability in Negligence*

The master in civil law acts as the ship owner's agent. The ship owner therefore remains vicariously liable for any negligence of the master in the execution of those orders. It is therefore reasonable to say that the Master is less exposed under civil law than he is under criminal law. Provided his acts or omissions are within the instructions of the ship owner, he will not be at fault. In *Manchester Trust v Furness*, Lopes LJ stated unambiguously that the master of a vessel is the servant of the owners, i.e. he is an

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[14] Hereinafter "the 2007 Act".

employee, 'they had hired him; they paid him; they alone could dismiss him'. Furthermore, it is more likely that a civil claim will be brought against the master's employer as opposed to the master as the master is unlikely have the requisite insurance such that he could meet any finding of liability made against him. /131/

Negligence in law is the failure to take care with the level of prudence and care that the ordinary man would have used under the circumstances. The master of a vessel is liable for his own negligence but he not liable for the wrongful acts of his crew. One might think that the master has a similar employer/employee relationship with his pilots, but in law he will not be responsible for their negligent acts. However, as in the normal course of negligence, if the master is personally at fault then he will be liable in the normal way. /131/

There are specific situations in which the liability of the master is considered in negligence. In the context of cargo delivery and the issuing of a bill of lading, Girvin states that he is still "fundamental" /132/.

A bill of lading is a document required to be issued by a carrier which details a shipment of merchandise and gives title of the shipment to a specified party. The master should not sign a bill of lading which he knows to be untrue or where he has not given thought to the facts therein. If goods are defective, the master should only indicate what he knows to be the apparent external condition of the cargo.

In the case of *The David Agmashenebeli /*133*/* it was held that the master has to give a reasonable objective view of the cargo and may not decide of his own accord to make an estimation of cargo that is not reflective of the cargo. In simpler terms, the master should not sign a bill of lading where he believes the goods do not meet description or are inadequate.

The Civil Liability of the ship owner is also governed by domestic legislation and international conventions, which have been adopted by the International Maritime Organisation. The International Safety Management Code 1994 has been implemented into UK legislation by The Merchant Shipping (International Safety Management (ISM) Code) Regulations 1998, as amended. This legislation places a specific duty on the Master to operate his ship in accordance with the safety management system.

The ISM Code sets out regulations applying to UK ships wherever they may be; and other ships while they are within UK waters. Regulation 4 of the 1998 Regulations states that every company shall comply with the requirements of the ISM Code as it applies to that company and to any ship owned by it or for which it has responsibility.

However, the importance of the Code is that it also placed certain duties relative to the master on the ship owner by requiring the ship owner[15] to define and document the master's responsibility with regard to:

- implementing the safety and environmental-protection policy of the Company;
- motivating the crew in the observation of that policy;
- issuing appropriate orders and instructions in a clear and simple manner;
- verifying the specified requirements are observed; and
- reviewing the safety management system and reporting its deficiencies to the shore-based management.

Failure by the ship owner to meet these standards will result in them being held vicariously liable for any acts or omissions by the master that relate to these duties, provided the master is operating within their ambit. In deciding to have remotely controlled ships, this relationship would be reconfigured.

4.5.3.7 *Conclusions*

The master has less decision making authority than half a century ago. More often, decisions are communicated to him remotely for him to action. However, despite these remote communications, the master does maintains responsibility for navigational issues while on the ship.

One aspect of the Merchant Shipping Act 1995 worth commenting on is the disparity between the duties that fall to the ship owner and those that fall to the master. These duties infer, if not explicitly require, a higher standard of skill and care from the master in the day to day operation of the vessel. More fundamentally is the on-the-spot judgment which the legislation permits the master to make – an exercise not afforded to the ship owner who is onshore. If this legal relationship were to change, new legislation would be required in the UK to provide for situations, such as those in the COLREGS or the Merchant Shipping Act 1995 that require human judgment and observation in the management of a ship.

Furthermore, there are some curent functions of the master that might be made redundant by the unmanned ship operation. The most obvious is the ability for the master to provide the necessary sea rescue operations detailed above. The obligations in this regard are considered above in this report.

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[15] Owner, manager of bareboat charterer

In the context of liability in criminal and civil cases, for the unmanned vessel it is necessary to consider who the Defendant, i.e., the wrongdoer will be. Who effectively will stand in the shoes of the master.

Given that legislation allows the ship owner to limit his liability where the negligence is that of the master, a question for example arises as to whether those operating the unmanned ships will be able to hide behind their own lack of proximity to the wrong, when and if it occurs. Who will the wrongdoer be when the instructions are extended onshore? Presumably those within the Shore Control Centre?

4.6 Insurance

4.6.1 Introduction

The carriage of goods and/or passengers by sea in the dangerous environment of the sea inevitably presents a number of risks which, in the absence of insurance, would have to be borne either by the person engaged in the business or by seeking compensation against any other party who has caused a loss and is liable for the same. By having in place insurance the risk of economic loss is transferred from the shipowner/operator to the insurer in return for a fixed premium. The risk is in turn then redistributed amongst often a number of parties by investment and reinsurance agreements.

In the early 12th and 13th Century a practice developed whereby merchants agreed in return for payment of a premium to indemnify a party for loss suffered as a consequence of specific perils. In turn the expense of the premium was able to be spread by the merchants by passing on the cost to customers.

By the end of the 17th Century there was an increasing demand for marine insurance in London which had grown as an important centre for international trade. Infamously in the late 1680's Edward Lloyd opened a coffee house on Tower Street in London which became the first marine insurance market. It became a central meeting place for parties in the shipping industry wishing to insure cargoes and ships and for those who were willing to underwrite such risk and it led to the establishment of the insurance market Lloyds of London of today.

The rules governing insurance are a mix of contract, law and practice. A substantial body of common law and judicial precedence were built up in the area of marine insurance which were ultimately codified in the UK in the Marine Insurance Act of 1906. Although originating in the UK the Marine Insurance Act 1906 has had significant international influence and many standard forms utilised in the marine insurance industry are based on the Marine Insurance Act of 1906.

Although it is accepted that there are some differences internationally between the marine insurance promulgated under the Marine Insurance Act 1906, for the purposes of a consideration of marine insurance issues that may arise in relation to the autonomous vessel, a review of some of the key sections of the Marine Insurance Act 1906 is illustrative.

4.6.2 What is a Contract of Marine Insurance?

According to Section 1 of the Marine Insurance Act 1906 a contract of marine insurance is a

> "..*contract whereby the insurer undertakes to indemnify the assured, in a manner and to the extent thereby agreed, against marine losses, that is to say, the losses incident to marine adventure*".
>
> Under Section 3 (2) of the Marine Insurance Act 1906 a "*marine adventure*" is defined as where:
>
> "*(a) Any ship, goods or other moveables are exposed to maritime perils;*
>
> *(b) The earning or acquisition of any freight, passage money, commission, profit, or other pecuniary benefits, or the security for any advances, loan, or disbursements, is endangered by exposure of insurable property by maritime perils;*
>
> *(c) Any liability to a third party may be incurred by the owner of, or other person interested in or responsible for, insurable property, by reason of maritime perils*".

Section 3 (2) further defines "*maritime perils*" as follows:

> "*Maritime Perils" means the perils consequent on, or incidental to, the navigation of the sea, that is to say, perils of the sea, fire, war perils, pirates, rovers, thieves, captures, seisures, restraints and detainments of princes and peoples, jettisons, barratry, and any other perils, either of the like kind or which may be designated by the policy."*

4.6.3 Application of definitions to the Autonomous Vessel and the Shore Control Centre

The first consideration is whether the autonomous vessel and the perils it would face during the proposed sea passage would be considered a marine adventure. Section 3 (2) (a) of the Marine Insurance Act refers to the term ship. The term ship and vessel are often used interchangeably but no recognised definition of a ship or vessel appears to limit a vessel to a requirement for an element of physically manning i.e. a crew on board.

The standard definition of a ship or vessel is more concerned with the ability for use in navigation.

The autonomous vessel seemingly therefore does fall within this definition notwithstanding the fact that the navigation is primarily undertaken autonomously and/or remotely. There equally seems little difficulty of the autonomous vessel and its operation falling within sections 3 (2) (b) or (c) of the Marine Insurance Act.

A secondary issue for consideration is whether the operations of the Shore Control Centre which effectively manifest themselves in the physical hull on the sea would be considered within the definitions. Certainly the actions of the Shore Control Centre could result in perils consequent to the navigation of the sea. There may feasibly however be a number of additional risks that the Shore Control Centre will require insurance from outside of the marine insurance risks.

4.6.4 Seaworthiness and Marine Insurance

Having concluded that the operations of the autonomous vessel would amount to a marine adventure, and the risks of such operation are likely to fall within maritime perils and as such the risks of the autonomous vessel are capable of being the subject of a contract of marine insurance, there is a further very significant issue of consideration: The issue of seaworthiness of the autonomous vessel.

Seaworthiness has been considered earlier in this deliverable. In a contract for marine insurance there is an implied warranty of seaworthiness. There is also under section 18 of the Marine Insurance Act 1906 a comprehensive duty of disclosure on the part of the assured and a duty to act with the utmost goodfaith (or *uberrima fidei)*. An assured must disclose to the insurer any information material to the risk involved. Section 39 of the Marine Insurance Act further expressly implies a warranty of seaworthiness into a voyage policy. Seaworthiness is therefore arguably one of the most important warranties in a contract of marine insurance. The ship must be reasonably fit to encounter the ordinary perils of the sea for the marine adventure. If the autonomous vessel does not comply with relevant international regulations and safety standards such as SOLAS and MARPOL (considered independently in this report), the vessel will not be seaworthy and therefore this would arguably render void any contract for marine insurance and/or arguably make the autonomous vessel uninsurable unless there is legislative change to the relevant conventions to accommodate the autonomous vessel.

4.6.5 Exclusion of loss

Section 55 of the Marine Insurance Act 1906 deals with the issue of what losses will be included and excluded in a contract of marine insurance. Whilst the contract itself will contain more specific wording, the principles enshrined in section 55 are important to consider in the context of application to the autonomous vessel.

Under section 55 (1) of the Marine Insurance Act an insurer is liable for losses proximately caused by an insured peril. Section 55 (2) then provides an insurer will not be liable for loss attributable to the wilful misconduct of the assured, but, unless the policy otherwise provides, he is liable for any loss proximately caused by a peril insured against, even though the loss would not have happened but for the misconduct or negligence of the master or crew.

This raises an issue as to what about loss arising from the misconduct or negligence of the Shore Control Centre? Is that an included or excluded loss? Can the assured rely upon this caveat for coverage irrespective of misconduct or negligence of employees of the Shore Control Centre? This is by no means clear and will require specific contract working. It is not necessary to change the Marine Insurance Act itself when the issue can be dealt with a contractual level.

It can be envisaged that the operations of the autonomous vessel may also give rise to interesting legal arguments as to proximate cause of loss in the event for example of casualty. Is the cause of loss a maritime peril or are for example actions of the Shore Control Centre a direct and proximate cause of loss?

4.6.6 Types of Marine Insurance and perceived impact for the Autonomous Vessel

The general practice in the marine insurance market is to insure ships against specific individual risks. Typically insurance is divided up in to three main types: Hull insurance, P&I insurance and Cargo Insurance. There are other types include insurance of freight, salvage expenses, general average contributions, container insurance, port insurance, shipyard insurance etc. Looking at the first two main types:

Hull Insurance

Hull insurance provides coverage for the physical loss or damage to the vessel, its hull and machinery. Seaworthiness as outlined above will be a critical element to the hull insurance available for the autonomous vessel. In assessing the premium for insuring the autonomous vessel, safety issues will be relevant, perceived additional or reduced risks of collisions etc.

Hull insurance policies will incorporate standard clauses which set out the perils insured against. In the UK insurance market, the standard clauses in use are the Institute

Time Clauses - Hulls 1.10.83 are the Institute Time Clauses - Hulls - 1.11.95. The different clauses provide broadly similar coverage.

In the Institute Time Clauses - Hulls 1.10.83 loss or damage caused by negligence of the Master officers and crew is covered provided the loss has not resulted from want of due diligence on the part of the Assured, Owners or Managers. Obviously with the autonomous vessel there is no Master and crew on board. The clauses as drafted however do not envisage negligence of the employees of a shore control centre or problems arising from the UAV. Also the assured, owners and managers might not encompass the actions of the Shore Control Centre. It might be argued the Shore Control Centre is effectively a manager, but what about the shore control centre that is entirely independent from the assured? This does not readily fall within such clause. The concept of shore based liability for risks is potentially clearer in the Institute Time Clauses - Hulls - 1.11.95 which develop the want of due diligence proviso and extend the responsibility to superintendents or any of their onshore management as well. This would appear to encapsulate possibly the activities of the Shore Control Centre but again there may arguably be insufficient link between the assured and the Shore Control Centre if it is independently operated. It can therefore to be anticipated that there will be a need for new industry clauses for the autonomous vessel.

P&I Insurance

P&I Insurance provides cover to shipowners, operators and charterers for third party liabilities arising from the operation of vessels. The risks covered include:

- Personal injury / illness / death
- Collision
- Wreck removal
- Damage to fixed and floating objects
- Pollution
- Cargo damage/shortage
- Fines
- Stowaways

It is not considered that the liability risks of the autonomous ship will differ greatly from the manned ship save for the obvious exception of there being an eliminated risk of personal injury/illness and death of crew. Stowaway risk could potentially be greater as it will be in theory easier to hide on an unmanned ship but equally less attractive and more harmful for the stowaway with no food etc. access. Risks such as pirate attacks, hostage taking etc. may be reduced or alternatively the unmanned vessel might be seen as a sitting duck for target given the value of the hull and cargo.

4.6.7 Cyber Risk

It is perceived that there is a greater cyber-attack risk for the unmanned vessel. Where its function relies heavily on computer controlled systems ashore, this must be a relatively compelling argument.

Insurance of the risk of cyber-attack is not a new phenomenon however for the maritime sector and therefore the autonomous vessel does not create a whole new creature of unrecognised risk for the maritime industry sector. Vessel navigation and propulsion systems, cargo handling and container tracking systems on board vessels and other automated process by way of example already present a cyber attack risk. Weaknesses in the cybersecurity of navigational systems such as GPS, AIS and ECDIS have already been identified as potential targets of attack.

In marine hull insurance the risk of cyber attack has been generally excluded by the Institute Cyber Attack Exclusion Clause (CL380) 10/11/2003 or a variant on such clause thereby excluding any loss, damage, or liability caused either directly or indirectly by the use of a computer and its associated systems and software. In P&I Insurance there is a special pooling facility with a limit of US$30 million per ship in the aggregate that may respond to such risk unless the attack is an act or war or terrorism.

As one of the potentially greatest risks of the unmanned vessel the practice to exclude cyber-risks in the sector would need to be changed.

4.6.8 Conclusion

Some changes will be required to enable the insurance of the autonomous vessel and to cover the risks it posses. Many of those risks are the same as manned vessel, some risks are greater and other risks are reduced and/or eliminated. Insurance in the autonomous transport sector has however already developed with coverage available already for UAVs and UAS. It can be anticipated that the marine insurance sector will similarly respond to the unmanned vessel subject to the overriding requirement of seaworthiness and compliance with international standards.

5 Summary

This report has discussed results from an in depth study on collision and foundering where the risk of the unmanned ship is indicated to be around 10 times lower than for the manned ship. The incident categories collision and foundering accounts for almost 50% of all total losses in the period 2005 to 2014 and represent clearly highest incident probability category. Also, consequences of these incidents may be very high. Grounding, contacts and stranding will be much more related to how well the SCC can operate the ship and avoid such incidents. One can argue, based on the results from the in-depth study, that risks for unmanned ships are correspondingly lower than for manned, but this is cannot be confirmed at the moment. Risks from engine and other system breakdown should be lower for unmanned ships if proper redundancy is implemented as well as improved maintenance and monitoring schemes. Fire and explosion is a relatively small part of all incidents and with the possibility to use more efficient extinguishing systems in fully enclosed spaces, it is likely that the unmanned ship will be much less risk prone than the manned ship. Finally, risks from cyber-attacks and pirates are issues that cause concern. However, also here it should be possible to design ships and systems that have a very high resilience against such attacks and one could assume that unmanned ships also here are less vulnerable to attacks than manned ships.

Based on a shipping cash-flow model and utilizing a scenario approach potential cost savings associated with the MUNIN concept as well as additional costs of an autonomous bulker were identified and estimated quantitatively in the economic in-depth assessment. This allowed a calculation of the expected present value of cost over the lifetime for the autonomous ship which was compared to a conventional vessel. The financial analysis has revealed that a MUNIN bulker would be commercially viable under certain circumstances. In a base scenario the MUNIN bulker is found to improve the expected present value by mUSD 7 over a 25-year period compared to the reference bulker. Besides cost savings due to a higher efficiency of land based services in port and the shore control center particularly the fact that the autonomous ship makes changes in ship design possible ensures a positive expected present value. Such new innovative autonomous ship designs should make a reduction of fuel consumption (and emissions) possible. While still associated with a high level of uncertainty - due to the early stage of concept development and the limited scope of the project MUNIN – the results indicate that autonomous ships carry the potential to increase the profitability of shipping companies. Future research on the financial viability of autonomous ships should be based on a more detailed autonomous ship design and also take into considerations other vessel types and trades.

This report covers extensively the relevant legal and liability areas likely to affect the unmanned ship. The principal areas concern navigation and manning (the ship master, and SCC crewing): in both these areas, the unmanned ship will significantly alter the practical state of play, with likely legal consequences. Standards in construction, design and equipment of ships will also be concerned. Overall, it appears that the unmanned ship does not pose an unsurmountable substantial obstacle in legal terms. Provided there is reasonable certainty that the unmanned ship can operate at least as safely as a manned ship, in all its functionalities, there is no reason to think that the legal framework cannot be adapted. However, as highlighted in this report, there will be a high number of issues to resolve, particularly relating to the literal application of relevant law, for example where specific human input or standards are required by applicable conventions (the most obvious example concerns the 'human' look out requirement in the Collision Regulations). In terms of liability, this report indicates that the biggest issue will concern the attribution of the existing ship master duties to the relevant and adequate persons involved in the operation of an unmanned ship. It is unclear whether this legal role should be divided between the SCC operators and masters, or attributed in law to a single entity in the SCC. This is an issue which will need to be researched further.

Annex A: Investment and operating costs for the shore control center

Table 21: Overview of investment and operating costs for the SCC

	One-time costs [US$]	Operating Life [y]	Annual costs [US$]	Comment
SCC Equipment				
Situation Rooms	1,050,000	8		12)
Software	765,000			10)
Hardware	117,000	3		11)
Office Equipment	199,800	13		11)
Rent for office space			411,033	9)
Operational Costs				
Power supply			22,624	
Software subscription and support			153,000	
Training costs for employees			287,300	10)
Total	2,131,800		873,957	

Table 22: Parameters for calculation of investment and operating costs for SCC

	Value	Comment
General parameter		
Number Situation Rooms	5	
Number work stations	45	
Number of employees	169	
Number of screens per work station (average)	5	
Number of computer per work station	1	
Cost parameter		
Investment costs per Situation Room [US$]	210,000	1)
Investment costs office equipment per work station [US$]	4,440	2)
Investment costs for software per work station [US$]	17,000	3)
Investment costs per screen [US$]	400	
Investment costs per computer [US$]	600	
Rental costs for office space per each sqm and year [US$]	529	4)
Demand for energy per sqm [kWh]	120	5)
Energy costs per kWh [US$]	0.24	6)
Training costs per employee and year [US$]	1,700	7)
Annual rate for software subscription and support [%]	20%	
Exchange rate [€/US$]	1.11	8)

	Value	Comment
Space requirements parameter		9)
Sum of required space [sqm]	777	
Width of each working station [m]	3	
Depth of each working station [m]	2	
Distance between the two lines of working stations [m]	6	
Per each working station [sqm]	5	
Length of open plan office [m]	68	
Width of open plan office [m]	9	
Number work stations per each sanitary room	10	
Number of required sanitary rooms	5	
Per each sanitary room [sqm]	11	
Kitchen&Lounge requirement per each work station [sqm]	1	
Per each Situation Room [sqm]	15	

Assumption for analysis

It is assumed that the Autonomous Ship is a used and established concept. Among other things this means that there exists a job market for the employees of a Shore Control Center and no special courses are necessary at the beginning of the employment.

Calculation

- Cost of *Situation Rooms* based on Number Situation Rooms and Investment costs per Situation Room.
- Cost of *Software* based on Number work stations and Investment costs for software per work station.
- Cost of *Hardware* based on Number work stations, Number of screens per work station (average), Number of computer per work station, Investment costs per screen and Investment costs per computer.
- Cost of *Office Equipment* based on Number work stations and Investment costs office equipment per work station.
- *Rents for office space* based on Rental costs for office space per each sqm and year and Sum of required space.
- Cost of *Power supply* based on Demand for energy per sqm, Energy costs per kWh and Sum of required space
- Cost of *Software subscription and support* based on Software and Annual rate for software subscription and support
- Cost of *Training costs for employees* based on Number of employees and Training costs per employee and year

Comments and sources

1) The Situation Room includes a bridge and an engine simulator; value for the bridge simulator relates to investment costs for the simulator at Fraunhofer CML; value for the engine simulator relates to a price indication from provider of maritime simulators; The provided price is reduced by 50% because of included training modules which are not necessary for the Shore Control Center. /134/

2) Value for an employee in a company with up to 49 employees. /135/

3) The costs are related to a desktop version for a for an instructor station software. /134/

4) The office rental costs are taken from the city of Helsinki which represents the midfield of costs. /136/

5) Value taken from Energieverbrauch von Bürogebäuden und Großverteilern /137/

6) Value taken from Monitoringbericht 2014. /138/

7) Training costs are related to training costs for a master. /15/

8) Exchange rate from 20.05.2015

9) The operation room is an open plan office where employees work sitting side by side in front of the wall. The walls are covered with screens mostly at eye level. Underneath the screens there is a desk along the wall. Every work station has room for 5 screens side by side (each with 60 cm width). Over the screens additional screens could be placed.

10) It is assumed that a software subscription and support contract is closed and an annual rate has to be paid for this (in percentage of buying costs). This service contract includes new releases and versions as well as technical support.

11) Operating life taken from AfA-Tabelle für die allgemein verwendbaren Anlagegüter. /139/

12) Estimated operating life for computers and screens is 3 years. Due to the fact that Situation Rooms are used only in emergency situations and therefore are far from a 24-7 operation the estimated operating life was raised from 3 to 8 years.

References

/1/ Allianz Global Corporate & Specialty (2015). Safety and Shipping Review 2015. March 2015.

/2/ European Maritime Safety Agency. (2015). Annual Overview of Marine Casualties and Incidents 2014. Updated January 2015.

/3/ Jensen, F. (2015) Hazard and Risk Assessment of Unmanned Dry Bulk Carriers on the High Seas

/4/ European Maritime Safety Agency (2010) First semester 2010 SSN report (January - June), Lisbon, 15 September 2010. Ref: C.2.2/1SR/2010

/5/ Rødseth, Ø., Burmeister, H.-C. (2015) MUNIN Deliverable D10.1: Impact on Short Sea Shipping

/6/ Stopford, M. (2009). Maritime Economics. Routledge: New York

/7/ Corbett, J. J., Wang, H. and Winebrake, J. J. (2009). The effectiveness and costs of speed reductions on emissions from international shipping. Transportation Research Part D 14 (2009) 593–598

/8/ Hummels, D., Lugovskyy, V. and Skiba, A. (2007). The trade reducing effects of market power in International Shipping. NBER Working Papers 12914, National Bureau of Economic Research, Cambridge, MA.

/9/ Rødseth, Ø., Burmeister, H.-C.. (2015). MUNIN Deliverable D10.2: New ship designs for autonomous vessels

/10/ ABS (n.d.). Ship Energy Efficiency Measures Status and Guidance. http://www.eagle.org/eagleExternalPortalWEB/ShowProperty/BEA%20Repository/References/Capability%20Brochures/ShipEnergyEfficiency

/11/ Lineberry, J. (2012). Estimating production cost while linking combat systems and ship design. NPS: Monterey

/12/ Theotokatos, G. and Livanos, G. (2013). Techno-economical analysis of single pressure exhaust gas waste heat recovery systems in marine propulsion plants. Proc IMechE Part M: J Engineering for the Maritime Environment 227(2) 83–97

/13/ MEPC 61/INF.18 (2010). REDUCTION OF GHG EMISSIONS FROM SHIPS Marginal abatement costs and cost-effectiveness of energy-efficiency measures. Submitted by the Institute of Marine Engineering, Science and Technology (IMarEST)

/14/ Atlason, G. F. and Jónsson, Þ. S. (2014). MUNIN Deliverable D6.8: Constant engine efficiency concept

/15/ Neylan, P. (2011). Ship Operating Cost 2011-2012 Annual Review and Forecast. Drewry: London

/16/ Greiner, R. (2013). Ship operating costs: Current and Future Trends. Moore Stephens

/17/ E. R. Schiffahrt (2015). ship & shore 2' 2015

/18/ Ministry of Transport New Zealand (2015) Transport-Related Price Indices : Prices http://www.transport.govt.nz/ourwork/tmif/transportpriceindices/ti008/

/19/ EIA (2015). Europe Brent Spot Price FOB http://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=pet&s=rbrte&f=m

/20/ Insee (2015). International prices of imported raw materials - Heavy fuel oil (Rotterdam) - Prices in US dollars per tonne - FOB - 1% of sulfur http://www.insee.fr/en/bases-de-donnees/bsweb/serie.asp?idbank=001642883

/21/ International Energy Agency (2012). World Energy Outlook 2012

/22/ MAN Diesel & Turbo (2014). Propulsion Trends in Bulk Carriers Two-stroke Engines

/23/ MAN Diesel & Turbo (2014). Marine Engine IMO Tier ll Programme 2nd edition 2014

/24/ Wehner, K., Schmidt, H., Fentzahn, E. (2013). MUNIN Deliverable D6.2: Specification concept of the general technical system redesign

/25/ MAN Diesel & Turbo (2014). L28/32H Project Guide – Marine Four-stroke GenSet compliant with IMO Tier II

/26/ environ (2007) LADCO 2005 Commercial Marine Emissions http://www.ladco.org/reports/technical_support_document/references/commercial_marine_emissions_draft_03_02_07.pdf

/27/ DA-Desk (n.d.). LAURITZEN BULKERS: STANDING THE TEST OF TIME Share this link http://www.da-desk.com/customers/case-studies/lauritzen-bulkers-standing-test-time

/28/ MUNIN (2014). MUNIN Brochure 2014. www.unmanned-ship.org/munin/wp-content/uploads/2014/01/MUNIN_Brochure_2014_Final.pdf

/29/ EquityGate Advisors (2013). Bulk Shipping Market Update

/30/ Porathe T., Costa N., Tjora, Å. (2014). MUNIN Deliverable D 7.4: Organizational lay-out of SOC

/31/ Andersson, P., Ivehammar, P. (2014). Cost-Benefit Analysis of Implementing Dynamic Route Planning at Sea

/32/ ITF (2011). Annex 1 to ITF Circular No. 258/S.104/D.87/SS.12/2011 - ITF UNIFORM "TCC" COLLECTIVE AGREEMENT For Crews on Flag of Convenience Ships 1 January 2012-14

/33/ Arnsdorf, I. (2014). Rolls-Royce Drone Ships Challenge $375 Billion Industry: Freight. Bloomberg. http://www.bloomberg.com/news/articles/2014-02-25/rolls-royce-drone-ships-challenge-375-billion-industry-freight

/34/ MAN Diesel & Turbo (2013). Basic Principles of Ship Propulsion

/35/ Krueger, S. (2006). Umweltbedingte Zusatzwiderstände

/36/ Blendermann, W. (1996). Wind loading of ships - collected data from wind tunnel tests in uniform flow. Bericht Institut für Schiffbau 1953 574

/37/ Schneekluth, H. and Bertram, V. (1998). Ship design for efficiency in economy

/38/ Mikelis N (2012). The Hong Kong Convention and its Guidelines for Safe and Green Ship Recycling

/39/ Günter Mau, G. (1984). Handbuch Dieselmotoren im Kraftwerks- und Schiffsbetrieb. Vieweg: Braunschweig

/40/ Maersk Line (n.d.) Efficient propulsion: the Triple-E's 'twin-skeg'. http://www.shippingpodcasts.com/blog/wp-content/themes/commoditypodcasts/images/Efficient_Propulsion.pdf

/41/ Devanney, J. (2008). The Argument for Twin Screw Tankers. WMU Journal of Maritime Affairs, Volume 7, Issue 1, pp 353-380

/42/ Kim, K. et al. (2014). Hydrodynamic optimization of twin-skeg LNG ships by CFD and model testing Int. J. Nav. Archit. Ocean Eng. 6:392-405

/43/ SSPA (2009). SSPA Highlights - Newsletter 46/2009

/44/ Giles, W. et al. (2013). An Investigation Into Twin Skeg Hullforms In Auxiliary Tanker Design

/45/ MAN Diesel & Turbo (2011). MAN B&W Low Speed Small Bore Engines Now with Electronic Control

/46/ Porathe, T. (2013). MUNIN Deliverable D7.1: Error and human intervention report in the context of autonomous vessels

/47/ Caprace, J.-D., Rigo, P. (2009). Multi-Criteria Decision Support for Cost Assessment Techniques in Shipbuilding Industry. COMPIT'09

/48/ Ross, J. (2004). A Practical Approach for Ship Construction Cost Estimating. 3rd COMPIT, Siguenza

/49/ Bertram, V., Maisonneuve, J.-J, Caprace, J-D.; Rigo, P. (2005), Cost Assessment in Ship Production. RINA.

/50/ Lamb, T. (2004), Ship Design and Construction, SNAME

/51/ Ventura, M. (n.d.). Ship Design I Costs Estimate. Marine Engineering and Naval Architecture Lectrue Notes. Instituto Superior Tecnico

/52/ Shetelig, H. (2013). Shipbuilding Cost Estimation Parametric Approach. M.Sc. Thesis at NTNU

/53/ Papanikolaou, A (2014). Ship Design Methodologies of Preliminary Design. Springer

/54/ Schneekluth, H. (1985). Entwerfen von Schiffen : Vorlesungen. Koehler

/55/ Kretschmann, L. and Bruhn, W. (Ed) et al (2015). MUNIN Deliverable D9.1: Impact matrix and report

/56/ DNV (2011) Rules for classification of Det Norske Veritas Ships Newbuildings Special Equipment and Systems Additional Class Part 6 Chapter 3 Periodically unattended machinery Space January 2011

/57/ Kretschmann, L. (Ed) et. al (2015). MUNIN Deliverable D 9.2: Qualitative assessment

/58/ Hans-Christoph Burmeister et al. (2015) MUNIN Deliverable D5.4: Autonomous deep-sea navigation concept

/59/ Rødseth, Ø J. (Ed) et al (2014). MUNIN Deliverable D 4.6: Final interface description

/60/ SOLAS, Rule V/34

/61/ Krüger, C.-M. (Ed) et. Al (2014). MUNIN Deliverable D 5.5: Concept of a support system for remote maneuvering concept

/62/ Hooydonk, Van (2014) The Law of Unmanned Merchant Shipping, 20 JIML 403.

/63/ Hill, C. (1998). Maritime Law:Lloyd’s Practical Shipping Guides 5th ed., London: Informa,p. 467.

/64/ Allen, C. H. (2012) The Seabots are Coming Here: Should they be Treated as “Vessels”?,The Journal of Navigation 749, at pp. 751-752.

/65/ The Merchant Shipping Act 1995. Section 58

/66/ Chapter V of the International Convention for the Safety of Life at Sea Convention (1974) Regulation 34-1.

/67/ MERCHANT SHIPPING ACT 1995, s. 58 ss. 2.

/68/ International Safety Management Code as implemented by Regulation (EC) No 336/2006 on the 15th February 2006.

/69/ The Pilotage Act 1987, s.15.

/70/ Mandaraka-Sheppard, A. (2009) Modern Maritime Law and Risk Management 2nd ed., Informa Law from Rutledge, London, p. 843

/71/ The E. R. Wallonia (1987) 2 Lloyd's Rep. 485

/72/ Merchant Shipping Act 1995, Section 92.

/73/ Merchant Shipping Act 1995, Section 93

/74/ International Convention for the Safety of Life at Sea (SOLAS Convention). Chapter V, Regulation 33 (1)

/75/ Merchant Shipping Act 1995 Section 93, ss. 5

/76/ The International Regulations for Preventing Collisions at Sea (1972), Rule 2.

/77/ Merchant Shipping Act 1995, S. 91.

/78/ The United Nations Convention on the Law of the Sea (1982), Section 94.

/79/ Hill, p. 468.

/80/ Burmeister, H.-C. (2015). The Munin Project an Overview, Presented at: MUNIN Final Event, 10th of June 2015, Hamburg, Germany. Accessed at: http://www.unmanned-ship.org/munin/munin-final-event-presentations-online/

/81/ Bruhn, W. C. (2015) MUNIN'S Autonomous Bridge, Presented at MUNIN Final Event, 10th of June 2015, Fraunhofer CML,. Accessed at: http://www.unmanned-ship.org/munin/wp-content/uploads/2015/06/MUNIN-Final-Event-B-2-CML-MUNINs-Autonomous-Bridge.pdf.

/82/ Burmeister, H.-C.; Bruhn, W.; Rodseth, Ø.J.; Porathe, T. (2014), Can un-manned ships improve navigational safety?, Transport Research Arena 2014, Paris, in press.

/83/ Vallejo, D. L. (2015) Electric Currents: Programming Legal Status Into Autonomous Unmanned Maritime Vehicles, 47 Case Western Reserve Journal of International Law 417, p. 428.

/84/ Thomas Porathe, T., Man, Y. (2014) MUNIN Deliverable D7.3 Technical Layout of SOC

/85/ Gogarty, B. and Hagger, M. (2008) The Laws of Man over Vehicles Unmanned: The Legal Response to Robotic Revolution on Sea, Land and Air,19 Journal of Law, Information and Science 73, pp. 120-21.

/86/ Porathe and Costa, D 7.4: Organizational layout of SOC. Presentation.

/87/ MUNIN – Unmanned Maritime Navigation: Predicting Future Needs and the Technology Needed for those Needs".

/88/ N.N. (2015) Navigational Shore Support: A new perspective, Presented at: MUNIN Final Event, June 10th to 11th 2015, Chalmers University of Technology, Hamburg, Germany. Accessed at: http://www.unmanned-ship.org/munin/wp-content/uploads/2015/06/MUNIN-Final-Event-B-4-CTH-MUNINs-Shore-Control-Centre.pdf

/89/ Rødseth, O. J. (2014). Control centre for unmanned ships, Presentation given in Trondheim 6th March 2014. Accessed at: http://www.sintef.no/globalassets/project/hfc/documents/munin-scc.pdf

/90/ McLaughlin, R. (2011) Unmanned naval vehicles at sea: USVs, UUVs, and the adequacy of the law, Journal of Law, Information and Science, p. 100–115.

/91/ Man, Y., Lundh, M and Porathe, T. (2014). Seeking Harmony in Shore-based Unmanned Ship-Handling – From the Perspective of Human Factors, What is the Difference We Need to Focus on from being Onboard to Onshore?. Presentation of 5th International Conference on Applied Human Factors and Ergonomics and the Affilated Conferences. Krakow, Poland, 19-23 July 2014, p. 231-239

/92/ Porathe, T. (2014). Remote Monitoring and Control of Unmanned Vessels – The MUNIN Shore Control Centre. Published in the Proceedings of the 13th International Conference on Computer Applications and Information Technology in the Maritime Industries (COMPIT '14), 12-14 May 2014, p. 462.

/93/ Rødseth, H., Brage Mo, B. (2014). MUNIN Deliverable D 6.7: Maintenance indicators and maintenance management principles for autonomous engine room

/94/ Hong Kong Fir Shipping Co Ltd v. Kawasaki Kisen Kaisha Ltd [1962] 2 QB 25, CA

/95/ Standard Oil CO of New York v. Clan Line Steamers Ltd [1924] AC 100, HL

/96/ The Torenia [1983] 2 Lloyd's Rep 210

/97/ Stag Line Ltd v. Fascolo Mango and Co Ltd [1932] AC 328

/98/ Baughen, p. 98

/99/ Hain SS Co Ltd v. Tate & Lyle Ltd (1936) 41 Com Cas 350

/100/ The Bywell Castle (1879) 4 PD 219

/101/ The Kate (1936) 54 LIL Rep 120

/102/ For example: The Merchant Prince [1892] P 179;

/103/ The World Harmony [1967] P 341

/104/ See The Aldora [1975] QB 748

/105/ The August Legembre [1902] P 123; The Jonge Bastian (1804) 5 C Rob 322

/106/ The Merchant Shipping Act 1995.

/107/ Hymers Machay of Clashfern, J. P. and Giffard Earl of Halsbury, H. S. (2008). Shipping and Maritime Law, Published In: Halsbury's Laws of England, Volume 94 Paras 591 – 1254, at 429.

/108 / Grotmol, F.(1995). The Master – Is He Still In Command? Published In: New Law Journal (NLJ) Vol. 145, No. 6716, p. 1541.

/109/ Douglas, T. J. (2008). Master or Servant: A Corporation's Liability for the Activities of a Ship Master, Published In: Journal of Criminal Law (JCL) Vol. 72, No. 6, pp. 496-518, at 500.

/110/ The Merchant Shipping Act 1995. Section 58 (2), ss. (b)

/111/ The Merchant Shipping Act 1995. Section 58 (3)

/112/ Hodge v. Higgins (1980). The Harcourt, 2 Lloyd's Rep. 589.

/113/ The Tenes (1989) 2 Lloyd's Rep. p. 367 at 369.

/114/ The Merchant Shipping Act 1995. Section 58, ss. (5)(a) and (b)

/115/ The Merchant Shipping Act 1995. Section 58, ss. (8) (a) and (b)

/116/ The Thuringia (1872) 1 Asp. M.L.C. 283.

/117/ The Merchant Shipping Act 1995. Section 93, subsection 5

/118/ The Merchant Shipping Act 1995. Section 93, subsection 6

/119/ Merchant Shipping (Distress Signals and Prevention of Collisions) Regulations (1996), Regulation 3(3),

/120/ The Merchant Shipping (Distress Signals and Prevention of Collisions) Regulations, (1996) ,Regulation 3(4)

/121/ The International Regulations for Preventing Collisions at Sea, 1972

/122/ The Merchant Shipping (Distress Signals and Prevention of Collisions) Regulations (1996) Regulation 4.

/123/ International Safety Management (ISM) Code as implemented by Regulation (EC) No 336/2006 on the 15th February 2006.

/124/ The Merchant Shipping (International Safety Management (ISM) Code) Regulations (1998).

/125/ Regulation 7 The Merchant Shipping (International Safety Management (ISM) Code) Regulations (1998).

/126/ P & O European Ferries (Dover) Ltd (1991) 93 Cr App R 72.

/127/ Tesco Supermarkets Limited v. Nattrass (1972) AC 153.

/128/ (1991) 93 Cr App R 72.

/129/ The Corporate Manslaughter and Corporate Homicide Act 2007.

/130/ Douglas, T. J. (2008) Master or Servant: A Corporation's Liability for the Activities of a Ship Master, 72 Journal of Criminal Law (JCL) 6, Section 1 (3) of the 2007 Act.

/131/ Gault, S. (2003) Marsden on Collisions at Sea, Sweet & Maxell, London, ,.

/132/ Girvin, S. (2011) Carriage of Goods by Sea, Oxford: OUP, p. 80.

/133/ The David Agmashenebeli (2003) 1 Lloyd's Rep 92.

/134/ Kongsberg (2010) Price List – GSA Kongsberg Maritime Simulators Effective 28 Sept. 2010 https://www.gsaadvantage.gov/ref_text/GS02F0038K/0IFM2R.27JSKM_GS-02F-0038K_KMSIMODN.PDF

/135/ Franke, Paul J. (2009): Der Bürokostenreport 2008. In: Facility Management (1), S. 36–40. Online available under: http://erfolgsfaktor-buero.de/downloads/m5d2buerokostenreport2008.pdf

/136/ David, B., Can, E. (2014): Office Space Across the World. Hg. v. Cushman & Wakefield. London. Online available under: http://www.cushmanwakefield.com/en/research-and-insight/2014/office-space-across-the-world-2014/

/137/ Eidgenössisches Departement für Umwelt, Verkehr, Energie und Kommunikation UVEK Bundesamt für Energie BFE (2010): Energieverbrauch von Bürogebäuden und Großverteilern.

/138/ Bundesnetzagentur Bundeskartellamt (2014) Monitoringbericht 2014. http://www.bundesnetzagentur.de/SharedDocs/Downloads/DE/Allgemeines/Bundesnetzagentur/Publikationen/Berichte/2014/Monitoringbericht_2014_BF.pdf?__blob=publicationFile&v=4

/139/ Bundesministerium der Finanzen (2000) AfA-Tabelle für die allgemein verwendbaren Anlagegüter http://www.bundesfinanzministerium.de/Content/DE/Standardartikel/Themen/Steuern/Weitere_Steuerthemen/Betriebspruefung/AfA-Tabellen/2000-12-15-afa-103.pdf?__blob=publicationFile&v=1