Literature Review for Autonomous Cargo Ships

Introduction:

This literature review was generated primarily from the angle of increasing efficiency in shipping lanes through increasing automation – namely, by investing in and introducing self-driving cargo ships – to remove human error caused by fatigued seafarers, to make up for foreseeable continued shortages in manpower and to counter inadequate training that makes human-automation integration unsafe.

It was partly inspired by the results of containerisation, and how part of its success was in increasing the efficiency at port terminals by allowing automation of the loading and unloading of cargo, speeding up the time of transit of between terminals. It also triggered the development of automated terminal infrastructure, such as cranes and cradle straddlers, the building of specialist container ports to cater to container shipping, and provided a case for how international standardisation could lead to the widespread implementation of a single idea.

Looking at containerisation was insightful for considering the pros and cons of automation. I noted that history often mentioned the role of East Asia in popularising containerisation, and also the Vietnam War. Extraordinary situations and backdrops of broader sociocultural upheaval seem to have made it easier to implement new technologies, so highlighting the importance of persuading people to accept them. Advancing to greater automation and reducing human labour, it's easy to lose sight of the real human lives who will be affected. The hindsight perspective, wherein we can look back on previous cases of automation and see, time and time again, the fears automation engendered in people – justified because they'd likely seen similar before, should hopefully contribute to considering increasing automation with humane eyes.

I have divided my literature review as according to resources useful for different themes and histories that could be useful in anticipating and understanding the issues around autonomous cargo ships.

Automation: Much seems to have been written in the context of developing automation to assist a human operator, especially regarding the engine room and bridge controls, however the overall goal of reducing manning on ships seems to be clear. Automation and reducing manning go hand in hand. Two lines of thought seemed to have developed in parallel, with one envisaging the eventual creation of a totally unmanned vessel and the other toying with better enabling automation-assisted one-man bridge operations (OMBO). As I wasn't able to look at the HEC materials beyond their abstracts, whether the latter pertained to cargo ships or not is unclear. OMBO, however, seems to become unpopular in the late 90s after a spate of collisions caused by fatigued officers on watch.

One example is the following: 1997 Cita Collision, Scilly Isles: https://assets.publishing.service.gov.uk/media/54c119bd40f0b6158d000021/MAIBReport_Cita-03-1998.pdf

'OMBO: One man bridge operation or one more banned operation'. Gard. Accessed September 15, 2021. https://www.gard.no/web/updates/content/52615/ombo-one-man-bridge-operation-or-one-more-banned-operation-

Given the choice between a ship operated by one exhausted seafarer and an unmanned vessel equipped to sail itself, the unmanned vessel would appear to be the safer and more humane option. This is in the assumption that trends observed in the literature on the arguments for automation (that it reduces manning, appealing for reasons of safety, costs and efficiency through removing human error) continue and that the industry is incentivised to minimise crew sizes, regardless of crew wellbeing.

There was some research carried out on unmanned oil platforms. These might offer some useful insight into future issues with unmanned ships, given that they experience the same harsh ocean environment and communicate with operators on land, as has been proposed for unmanned ships.

From this literature review it became clear that 'reduced manning', 'automation' and 'increasing operational efficiency' were three significantly linked concepts.

***From the HEC Library Catalogue*:** A search with 'automation' turned up 414 results, the following number of which seemed useful, given the contents of their abstracts. I have summarised the abstracts and added my own comments in bold. These sources are ordered as I found them and my reasoning developed.

1. Kempf, Rudolf. *Automation in ships – Symposium on Automation in Ships.* 1974.
2. (Various) *A Special Survey 'Marine Automation and Remote Control'.* The Motor Ship, 1967.
    a. Covers a brief history of ship automation since the 1961 Kinkasan Maru, the ship with the first automated engine control.
3. Han, H. *Integrated automation system of shipboard engine-room and bridge – the orientation of latest development of modern automation technology and research prospects in China.* 1998
    a. A Chinese perspective on ship automation.
4. (Unknown). '*Automation'.* Marine Engineers Review, 1992.
    a. Examining automation innovations at the time e.g. the intelligent engine designed by Sulzer Diesel; Discussing how to successfully integrate automation and humans.
5. Lough, A. *Marine Automation – Past, present and future.* IMarE Conferences and Symposia. 1999.
    a. Provides a review of marine automation systems from their beginnings to the end of the 20th century. Outlines the historical background of classification requirements for marine automation.
6. Hind, JA. *Automation in merchant ships. A basic manual of control engineering systems and practice in merchant ship operation, supervision and management.* Fishing News International, 1973.
7. Ship Bureau, Japanese Ministry of Transport (edited under supervision of). '*Ship automation in Japan'.* Japan Shipbuilding Industry Foundation, 1966.
    a. Report describes development of automated control of ships. Apparently contained lots of photographs and pictures of 34 vessels. Kinkasan Maru likely mentioned.
8. Crook, J. *The new age of automation.* 1991
    a. Review of problems associated with unmanned oil platforms. Details given of several approaches to automated systems.
9. (Unknown). '*Shipowners move towards full automation'.* (Unknown publication). 1990.
    a. Includes the trend of retrofitting ships with complex integrated automation. Discusses the benefits of doing so e.g. reduced operating costs.
10. Lloyd's Register of Shipping. *'Automation in ships'.* Lloyd's Register of Shipping. 1963.
    a. Has value for being contemporary to what's commonly seen as the beginnings of ship automation.

11. Ziarati, R & Ziarati, M. *'Review of accidents with special references to vessels with automated systems – a way forward'.* The Institute of Marine Engineering, Science & Technology (IMarEST): London, UK, 2007.
    a. Discusses the impact of automation on seafarers and human operators, noting two key issues: 1) Seafarers are often not being trained adequately, if at all, to use alternative systems if automation fails. 2) Human operators rarely understand the weaknesses and limits of the automated systems, which is identified as a cause of major accidents.
    b. **From this, I conclude that there are issues with the human-machine interface that would suggest we are better off fully automating to autonomous vessels rather than maintaining a system of autopilots with human operators.**
    c. **With the current recruitment crisis, it's likely to predict shortcuts in officer training, premature promotion and inadequate seafarer education in general. If we cannot adequately educate seafarers to work safely with automated systems then they are being put at risk of their lives.**
12. Gordon, M. *Retrofitting automation on steamships for periodically unattended machinery space – a US flag operator's experience.* 1989.
    a. Glimpse into a transistion period? Five US flag tankers with steam propulsion systems are retrofitted with microprocessor-based control systems. Aim: To achieve 'economies of fuel and manpower'.
13. MER. *Automation for one-man bridge control.* 1986.
    a. Discussion of NACOS (automatic navigation system). The system is described as expecting to 'provide increased safety, improve fuel efficiency, and reduce manning levels'.
14. Fiorentino, A. *The unmanned ship (if any).* 1998.
    a. Details five operations a vessel will have to be capable to go from one-man bridge operation to unmanned.
15. Bertram, V. *The unmanned ship as a vision – a state-of-the-art review.* 1998.
    a. Describes automation's role in reducing crew size: How in the 1900s, ocean going cargo ships needed a hundred plus men. In 1998, they could go with a few as 15. Concludes that whilst the systems necessary for a highly automated ship exist, the legal framework did not in 1998.
    b. **This issue is still pertinent, in that no authority has the legal framework for handling self-driving cargo ships yet, aside from Norway, which developed them in line with the building of the Yara Birkeland.**
16. Barnett, M., Gatfield, D., Pekcan, C., et al. *The mitigation of human error in the use of automated shipboard systems.* 2007.
    a. Says that automation is beneficial to operators in reducing workload but human errors related to automation use can make automation more hindrance than help to automation.
    b. **This adds to my conclusion that if the industry is unwilling or incapable of adequately training officers to integrate with automation then abandoning integration in favour of fully autonomous ships is a reasonable goal for improving the efficiency and safety of the system.**
17. Nautical Institute. *Ship manning present and future.* 1983
    a. Can see consideration taken here in on the effect of introducing automation into the education and training of seafarers.

18. Lively, KA., Mearman, JF., & Smith, SM. *Next generation platform control – a necessary shift in responsibility from operator to machine.* IMarE Conferences and Symposia. 2002.
    a. Motivation behind manning reduction discussed with the challenges this presents to Platform Management System (integrated vessel control and monitoring systems) design. A historical perspective is taken.
19. MER. *Control of unmanned platforms.* 1988.
    a. An article on unmanned oil platforms – potential parallels with unmanned ships.
20. Chestnut. J, *Globalisation of world trade – history and impacts*. 2000.
    a. This considers the history of containerisation and the subsequent move to 'super-large hub ports' (Singapore, Malta, Rotterdam and Southampton etc.) with an emphasis on 'efficiency through automation'.
    b. **Insight into how new technologies lead to wider changes, such as the character and structure of ports, that impact how humans experience them.**
21. Taylor, GR. *Self discharging alumina carrier.* 1982.
    a. Describes a carrier with a self-unloading system design**. Just an interesting idea**.
22. Smit, J. & Plijcke, AC. *Future ships.* IMarE Conferences and Symposia. 1984.
    a. Interesting from a hindsight perspective how the future was envisaged. Considers the intersection of international safety regulations and automation of machinery amongst other things.
23. Napier, LM. *Modern methods of loading and unloading bulk cargoes from ships.* IMarE Conferences and Symposia. 1985.
    a. Discusses implications of automation in port design and terminal installations.
24. Hatfield, M. *User experience of a computer based watchkeeping and control system.* IMarE Conferences and Symposia. 1974.
    a. An actual user account of an unmanned engine room control and watchkeeping system, which could be useful for insight into the experience of the human-machine interface in the 70s.
25. Gray, D. (Principle Surveyor for Control Engineering and Electrical Engineering, Lloyd's Register of Shipping). *Centralised and automatic controls in ships.* Pergamon Press. 1966.
    a. A general overview of automation on ships (of the 60s).
26. Grool, R. *Examining developments towards the intelligent ship – is the industry ready?* 1995.
    a. Reasons that could justify the development costs of an intelligent ship are looked at. The study concludes that, around 1995, investing in AI technology then on the market is not economically feasible. The aims to do so would have been to 'reduce crew costs and improve ship reliability'.
    b. **I find it interesting that this question was being asked around about the time that OMBO was being questioned.**
27. MER. *Armchair control through integrated bridges.* 1990.
    a. Supplying one-man operated navigation workstations with 'user friendly ergonomic consoles'. Insight into the one-man operation idea.
    b. **That ergonomic consoles were being considered would suggest some knowledge that the experience of being a one-man operator is not a comfortable one.**
28. Munden, A. *One-Man Bridge Operation*. IMarE Conferences and Symposia. 1990.
    a. Review of experimental work being done on the idea of one man acting as both navigator and lookout on the bridge. Risk assessment measures detailed.
29. Sagen, A. *The Second Generation of Maritime Computerisation and Communication.* IMarE Conferences and Symposia. 1990.

    a. **Considering that unmanned vessels would be controlled by a captain on land, I thought the discussion of high-speed ship-to-shore data connections would be of use.**

30. Bouwmann, T. *The unmanned vessel as an objective; the right way or not?.* 1998.
    a. Discusses the implications of unmanned vessels for safety and jobs from the perspective of a shipowner.
31. Vertram, V. *Cyber-ships – science fiction and reality.* 2003.
    a. Explores artificial intelligence technology on ships whilst expressing that the more present issue is 'intelligent ships with reduced crews' over unmanned ships.
32. Malone, TB., Creedon, MA., & Malone, JT. *Human factors engineering for maritime systems.* 1998.
    a. This paper lays out how the 'science of integrating humans into complex systems' can be applied to maritime systems. It says that it is especially relevant for 'reducing human error and the operation costs of maritime system'.
    b. **What this tells us is that issues were being experienced in integrating humans with automation, and that without successful integration we could expect human error to continue and additional operational costs to be incurred by the system.**
    c. **If, however, successful integration was not possible, e.g. seafarers are not being sufficiently trained and are being rushed out to fill shortages, then we would reduce human error and operational costs by separating them entirely from automation. Self-driving ships would be more efficient than the current system.**
33. Ewart, WD. *Reduced manning in Japan – what others could learn.* 1986.
    a. A study of the 'Japanese approach to reduced manning and automated ships' with the aim to increase Australian ship's operational efficiency. Concludes with Australians intending to copy the Japanese ideas.
34. Burrows, A. & England, R. *A vision for an advanced human-machine interface (HMI) for use in future naval platforms.* IMarE Conferences and Symposia. 2002.
    a. This paper looks at studies into Human-Machine Interfaces (i.e. how humans and machines communicate and interact) where a human operator has control of all platform management systems. **This suggests that studies around the 2000 studies were considering human integration with automation, and that the issue of failures in e.g. OMBO were in communications between humans and machines.**
35. Mackay-Camp, R. *From the real world to the virtual world.* 2005.
    a. The abstract starts 'Today's maritime graduate enters one of the most stressful industries'. Mackay-Camp puts the cause of that stress on education, in that, in order to stay on top of technological advancement, a mariner has to be constantly studying. 'Due to an increase in automation, manning at sea has become down-sized and personnel have to be more technically qualified'. However, 'training aboard ship is limited'.
    b. **Therefore, expecting successful human-automation integration is not reasonable. Personnel are not working safely with automated systems or with adequate understanding of them that the automation could mitigate the human errors.**
36. MotorShip. *The 16th International Marine Propulsion Conference – the Intelligent Ship A Commercial Reality.* MotorShip. 1994.
    a. A collection of papers detailing expectations for intelligent ships, where ships are highly-automated but not unmanned, one of which is 'Automation for vessels with minimum crew'.
37. Saanan, Y. *Realising robotised terminals: a simulation supported approach*. 2003.

a. Robotisation is described as in 'serious consideration' as a means of increasing productivity and lowering costs. Describes the 'specific characteristics of the container terminal industry' leading up to terminal automation, and the problems that arise when designing and realising an automated terminal.
b. **Could be useful in being mindful of what else might change with a shift to self-driving ships to accommodate them, such as the building of captain control towers on land, in an ensuing domino effect.**

***In LR Publications*: Code in spreadsheet. Title. Publication. Date.**

1. 273. *Machine controls become centralised*. 100A1, Issue 12. 1963.
    a. The beginnings of automation.
2. 278. *Automation: The Shipowner's Responsibilities.* 100A1, Issue 18. 1967.
    a. The same as 1914 in the spreadsheet.
3. 768. *Science and automatiion goes fishing.* 100A1, Second quarter. 1989.
    a. Typo not my own. Discusses automation in trawlers.
4. 775. *Not just a pretty hull form – but a thinking ship.* 100A1, January Issue. 1989.
    a. Thoughts on how automation is developing.
5. 2682. *Around the world – Denmark.* Annual Report. 1968.
    a. A comment on the degree of automation being incorporated into Danish ships.
6. 2796. *The Brostrom experiment.* 100A1, January Issue. 1981.
    a. An article on a 'revolutionary method' being developed by a Swedish shipowner which will '(cut) operating costs by **minimising manning and maximising automation**'.

From elsewhere:

1. Shipping Heritage. *'Dai-ikkai Funeisan no nintei kekka ni tsuite' (On the results of the first selection of shipping heritage pieces).* Japan Association Society of Naval Architects and Ocean Engineers. Accessed: September 16th 2021**.** https://www.jasnaoe.or.jp/enlightenment/funeisan/01.html
    a. JASNAOE Shipping Heritage (funeisan) project assigning vessels and other shipping-related items as worthy of considering as cultural heritage. In the first round, the Kinkasan Maru, the first automated ship was selected.
2. Glover, FD., 'The Benefits and Pitfalls of Marine Automation for the Ship-handler'. IMarE Joint Automation Conference. 1974.
3. Gray, D. *Marine automation - present and future.* IMAS 69 Plenary Session-paper Control Engineering. P.309 – 315.
    a. Noting that more ships are being fitted out, so that machinery can be left unattended, so that 'operational savings' can be made, Gray notes that **'Although the technical problems will be great, the human problems will be greater'.** 'Wholesale re-education will be necessary'. Gives a table from 1960 to 67 of ships classed with Lloyd's Register with 'control equipment'. (p.309)
    b. Also notes 3 chief ways of reducing costs of shipping operations: 1) bigger ships, 2) more efficient propulsion and 3) reducing manning ('reduction in crew numbers per ton'). (p.309).
    c. In discussing human problems, Gray notes that a 'balanced community' on a tanker with 'stable and happy personnel relations on board' needed a minimum of 30 people on a long-haul journey. (p.315) 30 strong crew on cargo ships these days seems unusual.

4. Evans, AA. *Technical and Social Changes in the World's Ports.* Geneva: International Labour Office, 1969.
    a. Major 1969 study on the impact of new port handling technologies, especially containerisation, on port labour. Notes that obstruction to implementing new technologies occurs when people are afraid of unemployment and loss of income and there's no guarantee that either will be secured for the future. According to Evans, providing a guarantee should then remove the obstacles.

<u>On Seafarer Fatigue:</u> The literature generally agrees that seafarer fatigue is a cause of collisions and human error in the shipping system. Combined with a lack of success in integrating humans and automation, we can conclude that there are serious issues in human-machine interfacing that are creating inefficiencies and an unsafe work environment. Studies from airplane crashes can have value in this area, where it has been shown that a number of accidents have been caused by pilots, lulled into complacency by a long flight, are startled by suddenly being asked to take control by the autopilot in an emergency. This is an issue of the human-machine interface.

***<u>From the HEC Collections:</u>* <u>In bold my own comments</u>**

1. Unknown. *A survey of health, stress and fatigue of Australian seafarers.* 1997.
    a. Examples stress levels as reported by seafarers.
2. Goodwin, S. *Does work keep you awake at night?.* 2006.
    a. Discusses causes of seafarer fatigue explicitly 'not linked to minimum manning', **suggesting that this is a known issue,** such as environmental conditions. Mentions that the UK alone saw 60 vessels run aground indirectly attributed to fatigue between 1993 and 2003.
    b. **That lighting and harsh environments are thought potential causes of fatigue would lead me to suggest that, should traffic in the Arctic Sea Route increase, the ships should be autonomous to handle its unusual light conditions in the summer and winter. Studies, such as the following, have shown that Arctic daylight patterns are disruptive to human mental states, presumably from a sample of those not accustomed to living with them.**
    c. **This would suggest that autonomous ships should also be developed to better safely navigate the Arctic Sea Route.**

<u>From elsewhere:</u>

1. De Blasiis, K., et al., 'Photoperiod Impact on a Sailor's Sleep-Wake Rhythm and Core Body Temperature in Polar Environment*'. Wilderness & Environmental Medicine.* Volume 30. Issue 4. P.343- 350. 2019. DOI:
    a. Study found many circadian and sleep disruptions in sailors on polar sailing expeditions. Future studies will assess risk of accidents.
    b. **However, as general literatures indicate that sleep disruptions contribute to increased likelihood of human errors, so it would be reasonable to assume that the same would be said of Arctic sailing.**
2. 'Fatigue'. ITF Seafarers. 2021. https://www.itfseafarers.org/en/issues/fatigue
    a. A summary on seafarer fatigue.
3. International Transport Workers' Federation Maritime Safety Committee. 'Beyond the Limit: How Covid-19 corner cutting places too much risk in the international shipping system'. ITF Seafarers. 2020. https://www.itfseafarers.org/en/resources/materials/beyond-limit

    a. Details the risk of pushing the limits of 'minimum safe manning' and definitions of 'minimum' and 'safe'. Transport workers' scepticism in their treatment within the system. Risks of fatigue and human error.

4. UK Government's Marine Accident Investigation Branch (MAIB) has also done a number of studies on fatigue and collisions, making it a useful resource in this regard.
    a. MAIB. 'Bridge Watchkeeping Safety Study'. 2004. https://www.gov.uk/government/publications/bridge-watchkeeping-safety-study
        i. Study of accidents from 1993 to 2004. **Around the period where OMBO was being discussed.**
    b. Also from the UK Government via the Maritime and Coastguard Agency. 'Fatigue Research 8 hrs on 8hrs off: Seafarers Watchkeeping System'. 2017. https://www.gov.uk/government/publications/fatigue-research-project-8hrs-on-8hrs-off-seafarers-watch-keeping-system
5. International Maritime Organisation. 'Crew changes: A humanitarian, safety and economic crisis'. *In Focus.* IMO. Updated 2021. Accessed September 16 2021. https://www.imo.org/en/MediaCentre/HotTopics/Pages/Autonomous-shipping.aspx
    a. Details the current situation of crew being unable to return to their homes due to travel restrictions or be relieved by new crew, leading to many being stranded on ships and forced to stay on board well past the expiry of their contracts.
    b. **This situation seems like a prime set-up for creating a fatigued and stressed workforce who are liable, sadly, to human error.**
6. Taylor, A. 'Human-Machine Interaction in the Cockpit and Applicable Design Changes Towards Better Collaboration'. *Advances in Human Factors and Systems Interactions.* P.271-279. 2017. DOI:10.1007/978-3-319-41956-5_24
    a. Includes a literature review on human-computer or human-machine interfacing in the cockpit.
7. Accident accounts of plane crashes and improvements to integrating pilots and autopilot could be an area of research if there's interest in improving seafarer education in working with automated ships, rather than autonomous.
8. Eliot, LB. 'Are Airplane Autopilot Systems the same as a Self-driving Car AI?'. AI Trends. July 21 2017. Accessed September 15 2021. https://www.aitrends.com/ai-insider/airplane-autopilot-systems-self-driving-car-ai/
    a. Handy starter on the difference between autopilot and autonomy.
9. Srinisavan, A. 'New BIMCO/ICS Seafarer Workforce Report Warns of Serious Potential Officer Shortage'. *News and Trends.* BIMCO. July 28th 2021.
    a. Summary of findings from BIMCO's 2021 Seafarer Workforce Report.
    b. **Report highlights a current shortfall of 26240 STCW certified officers, indicating that demand for officers outpaced supply in 2021. Shortfalls expected in total supply of officers by 2026.**

Autonomous Ships

Lloyd's Register

1. 'Cyber-enabled Ships – Deploying information and communications technology in shipping – Lloyd's Register's approach to assurance'. London: Lloyd's, First edition. February 2016. https://cybersail.org/wp-content/uploads/2017/02/Lloyds-Register-Cyber-enabled-ships.pdf
2. 'Cyber-enabled Ships – ShipRight procedure – autonomous ships'. London: Lloyd's, First edition. July 2016. http://info.lr.org/l/12702/2016-07-07/32rrbk

3. Earthy, J. 'Cyber-enabled Ships Assurance'. London: Lloyd's. April 2018.

From elsewhere:

1. The International Maritime Organisation has many good resources if you search 'autonomous shipping' in their website. For example:
    a. 'Autonomous Shipping'. *In Focus.* IMO. Updated 2021. Accessed September 16 2021. https://www.imo.org/en/MediaCentre/HotTopics/Pages/Autonomous-shipping.aspx
        i. This is a good introduction on the current situation of the regulation of autonomous ships, with the IMO completing a scoping exercise in 2021 to assess how current instruments can be applied to ships of 'various degrees of automation'.
2. Kosowatz, J., 'Sailing Towards Autonomy: Future of Self-driving Cargo Ships', The American Society of Mechanical Engineers. September 2nd 2019. Accessed September 14th 2019. ." https://www.asme.org/topics-resources/content/sailing-toward-autonomy-future-of-self-driving-cargo-ships
    a. Includes quote from people involved with Rotterdam's self-driving water taxis: '"Big ports have big issues with traffic, and there are challenges in getting highly skilled officers," said Vincent Wegener, CEO of Dutch startup Captain AI, which partnered with the port to prove the technology. "If you can automate the process you can get a better flow into the port."'
    b. Link made between autonomous ships and improving port flow through operational flow.
    c. Includes summary on Yara Birkeland.
3. Beighton, R. 'World's first crewless, zero emissions cargo ship will set sail in Norway'. *Traders.* CNN. August 27 2021. Accessed September 14th 2021. (https://edition.cnn.com/2021/08/25/world/yara-birkeland-norway-crewless-container-ship-spc-intl/index.html).
    a. Good summary and account. Mentions project cooperation with Norwegian maritime authorities to develop regulations, but the legal liability issues when entering other waters.
4. Yara International. 'Yara Birkeland – animated design and solution'. Youtube video. Posted: October 9th 2017. https://www.youtube.com/watch?v=Y4RTJpxz9hM
5. Maxwell, H. 'What are the regulatory barriers to autonomous ships?'. Safety4Sea. September 24th 2018. Accessed September 14th 2021. https://safety4sea.com/what-are-the-regulatory-barriers-to-autonomous-ships/?__cf_chl_jschl_tk__=pmd_8u192Gbhjgp9etn3hhXb8.0YJRAca6HXPwW1R8kXBMw-1631882705-0-gqNtZGzNAqWjcnBszQh9
    a. Neat overview of regulatory issues.

Cybersecurity: A concern for autonomous ships, but arguably a concern for the shipping system as a whole, as port terminals are already at risk. As part of a bigger picture and part the parcel of participating in an increasingly digitalised world, cybersecurity hazards are not a unique risk of autonomous ships. In terms of historical precedents, the history of telegraphs and telegraph hacking along railway networks could offer us some insight, although I did not have the time to research this myself this time.

Lloyd's:

1. Lloyd's, Cybercube & Guy Carpenter. *Cyber risk – the emerging cyber threat to industrial control systems.* Lloyd's. 2021.
    a. Includes precedents of cyber attacks on railway systems and more. https://assets.lloyds.com/media/542bea95-0d28-4ce1-a603-63db54aa24f9/The%20Emerging%20Cyber%20Threat%20to%20Industrial%20Control%20Systems_Final%2016.02.2021.pdf

From elsewhere:

1. Chalermpong, S. 'Port cybersecurity and threat: A structural model for prevention and policy development'. *The Asian Journal of Shipping and Logistics.* Volume 37. Issue 1. P. 20-36. 2021. DOI: 10.1016/j.ajsl.2020.05.001
    a. Gives a good overview of the extent of digitalisation at ports, showing how autonomous ship security concerns will only be part of a bigger tapestry.
2. Kornwitz, J. 'Hackers vs Cars – the cybersecurity risk of self-driving cars'. *News@Northeastern.* Northeastern University. 2017. Accessed on September 15th 2021. https://news.northeastern.edu/2017/02/15/the-cybersecurity-risk-of-self-driving-cars/
3. Baram, G. & Lim, K., 'Israel and Iran just showed us the future of cyberwar with their unusual attacks'. *Foreign Policy.* June 2020. Accessed September 14th 2021. https://foreignpolicy.com/2020/06/05/israel-and-iran-just-showed-us-the-future-of-cyberwar-with-their-unusual-attacks/
    a. Report of May 2020 cyberattack on Shahid Rajaee Port.

Container History/Port History/Terminal Automation: The history of containerisation played a large part in inspiring this literature review, so I will list a few of the resources used.

From elsewhere:

1. P&O Heritage. 'Container Revolution: 50 years ago'. 2019. Accessed: September 16th 2021. https://www.poheritage.com/features/the-container-revolution-50-years-ago
    a. Mentions the disruption at London Docks of 1968 over fears of unemployment from developing container berths.
2. Port of London Authority Archives: I didn't have time to dig through these myself, but they looked extensive in terms of port and docks history. https://www.museumoflondon.org.uk/collections/about-our-collections/what-we-collect/port-london-authority-archive#:~:text=The%20Port%20of%20London%20Authority,redevelopment%20in%20the%2020th%20century.
3. PEMA. *Container Terminal Automation.* Port Equipment Manufacturer's Association. 2016. https://www.pema.org/wp-content/uploads/downloads/2016/06/PEMA-IP12-Container-Terminal-Automation.pdf
    a. PEMA had a lot of recent market surveys on crane deliveries and port equipment which could give an indication of the character of automation at terminals.
4. Levinson, M. 'Container Shipping and the Decline of New York, 1955-1975.' *The Business History Review* 80, no. 1. 2006. P.49–80. DOI: 10.2307/25097151.
5. Lake, J. & Doulet, J. *Thematic Survey of English Naval Dockyards Summary Report Thematic Listings Program.* English Heritage. 1999.

    a. https://historicengland.org.uk/images-books/publications/thematic-survey-navy/thematic-survey-navy/
    b. Parallels to automation of terminals can be seen in the industrialisation of port towns. This survey offers insight into that.
6. Chung, P., 'From Korea to Vietnam: Local Labor, Multinational Capital, and the Evolution of US Military Logistics, 1950–97'. *Radical History Review*. Volume 133. p. 31–55. 2019. DOI: 10.1215/01636545-7160053.
    a. A 'prehistory' to the 'container revolution' during the Vietnam War, situating it broader contexts. The 'negative impact on workers' is noted.
7. Schober, E., 'Building ships while breaking apart – container economies and the limits of chaebol capitalism', *Focaal.* Issue 89. 2021. DOI: 10.3167/fcl.2021.890102
    a. Just an interesting article on the history of large Korean family businesses in container shipping, spotlighting the Hanjin conglomerate, the impact of their rise and fall on shipping and the impact of container economies on the family.
8. 'Chapter 2 – Woolwich Dockyard Area', in Guillery, P. (ed.), *Survey of London* Volume 48. Woolwich Edition. 2012. https://www.ucl.ac.uk/bartlett/architecture/sites/bartlett_architecture/files/sol-woolwich4-ch2.pdf Chapters made available online from 2018.
    a. An interesting piece on industrialisation and mechanisation and the changing Woolwich dockyard area.

Automated trains: As with planes, accident reports from automated trains can offer insights into where technical failures or issues in human-machine interfacing occur, or other vulnerabilities.

1. Sharples, S., Millen, L., Golightly, D., & Balfe, N. 'The impact of automation in rail signalling operations'. *Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit*. Vol. 225. Issue 2. P.179–191. 2011.
2. Unknown. *AutoHaul Project.* Calibre Group. Website updated 2021. https://www.calibregroup.com/projects/project/autohaul-project
    a. World's first fully-automated self-driving heavy haul rail network with Rio Tinto (2017).
    b. Like maritime automation, it justifies itself through 'improving the safety and **efficiency of rail operations'** and includes an aim to '**minimise in-train forces'**.
3. Unknown. *Driverless trains: On track for a rail revolution.* SNCF. Website certified 2019.
    a. https://www.sncf.com/en/innovation-development/innovation-research/driverless-trains-to-run-in-2023
    b. France's driverless train project, aiming for 2023.
    c. Luc Laroche at SNCF's Autonomous Trains Project says : 'At SNCF, we want to strike the right balance between people and automation. So as we roll out driverless trains, we'll be supporting our employees every step of the way. Our goal is to prepare for the changes this new technology will bring, designing the jobs of tomorrow, developing training programmes, and helping everyone adapt.'
    d. Whether actions will match words aside, the acknowledgement is there that displaced workers will be a challenge to the project.
4. Unknown. 'Automation in railway control – the human factors'. *The Engineer*. 2014.
    a. Provides examples of automation-related railway accidents. Also, Lloyd's own involvement in them.

5. Matsumoto, M. 'Breakthroughs in Japanese Railways 2 – Learning from Past Railway Accidents – Progress of Train Control'. *Japan Rail and Transport Review.* 43/44 March 2006. https://www.ejrcf.or.jp/jrtr/jrtr43_44/pdf/s86_mat.pdf
    a. Contains a brief history of railway signalling. It notes how train collisions used to occur due to misinterpretation or ignored hand signals due to human error, and that new train-control systems were put in place to overcome them and increase operational efficiency. However, with every new train-control system, new types of accidents emerged.
    b. Also an example of active learning from past accidents.
6. Briginshaw, D. 'Rail is on the way to autonomous trains'. International Railway Journal. August 1st 2019. Accessed September 15th 2021. https://www.railjournal.com/opinion/rail-autonomous-trains
    a. An overview of autonomous train projects. Also considers the challenges of retrofitting existing lines, which could be applicable to the prospect of fitting existing ships with autonomous systems.

Legal issues: An interesting aside

From elsewhere

1. Winkelman, Z. et al. *When Autonomous Vehicles Are Hacked Who is Liable?* Rand Corporation. 2019. https://www.rand.org/content/dam/rand/pubs/research_reports/RR2600/RR2654/RAND_RR2654.pdf
    a. Mostly pertains to self-driving covers, but food for thought and has a useful bibliography.
2. King, D., 'Putting the Reins on Autonomous Vehicle Liability: Why horse accidents are the best common law analogy'. *North Carolina Journal of Law and Technology*. Volume 19. Issue 4. P. 127-159. 2017. https://core.ac.uk/download/pdf/214582966.pdf
    a. Why horse accidents are a better analogy for when a human interacts with an autonomous vehicle than autopilot.
    b. **If horse accidents might make a good analogy for self-driving cars then maybe we can look at canal boat horses for liability analogies for self-driving ships.**

Find out more about the Lloyd's Register Foundation's Learning from the past programme