Assessing Business Cases for Autonomous and Unmanned Ships

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Abstract. Public interest in autonomous ships has grown rapidly since 2012, when the MUNIN project started its investigations. In 2017, the first project, Yara Birkeland, was published and other projects are under development. The business case for autonomous ships is not obvious: Benefits are no crew cost and simpler ship structures. However, it needs expensive shore infrastructure, it needs more redundancy and more expensive fuels than heavy fuel oil, and the approval process may be costly. This may be the reason why projects are not initiated by the ship owners, but by other parties in the supply chain, i.e. the fertilizer manufacturer Yara. Thus, an unmanned ship is an integrated part of a transport system and not an ordinary ship as we know them today. This paper will go through the most important benefits and cost factors for autonomous and unmanned ships and assess what business cases may be suitable for this technology: "An unmanned ship is not a ship without crew – it is a new factor in waterborne transport."

Keywords. Autonomous ship, Connected and automated transport, automation, supply chain.

1. Introduction

The concept of autonomous or unmanned ships is not new. Japan investigated remote control of ships in the "Highly reliable intelligent ship" project from 1982 to 1988. Other transport modes have researched autonomous vehicles since the 1970s. One can even argue that the idea may originate from Nicola Tesla's demonstration of a "radio-controlled" model boat in New York's Madison Square in 1898 [1].

The first large scale study on unmanned and autonomous merchant ships was the EU-project MUNIN, running from 2012 to 2015 [2]. The purpose of the study was to assess the possibility of converting a Handymax dry bulk carrier into an unmanned ship. It turned out that this was unrealistic from a commercial point of view, but that a fully unmanned and autonomous vessel would be feasible in other operations. Since then, there have been a steadily increase in new investigations and concept studies. *Yara Birkeland* is at the forefront and is planned to demonstrate autonomy in 2021 [3].

Autonomous literally means self-governed. For a mobile robotic system like an autonomous ship, this means that the ship systems can sense the environment, avoid obstacles and sail without human assistance. Even then, autonomy will take many forms and often including a human in the loop, e.g. in a Shore Control Center – SCC.

A major benefit of autonomy is that the ship can be unmanned. This saves crew cost and allows new and innovative designs of the ship. An unmanned ship need not be autonomous, it can also be directly controlled from the SCC in remote control mode. However, in most cases it will be useful to give the ship some level of autonomy to allow more efficient manning of the SCC. Typically, the ship may be given the capability to sail in uncongested waters without direct control from the operator, e.g.

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partly and constrained autonomy [4]. In the following, the term **unmanned ship** will be used for a ship with no crew and a relatively high level of autonomy.

This paper will discuss the pros and cons of unmanned ships. The paper will also discuss how the unmanned ship represents "disruptive technology" and how this will change the way we think about future ship transport systems. The main point is that an autonomous ship is *not a conventional ship without a crew*! It is a completely new component of the transport system and requires a new frame of mind, both for developing new concepts and for the implications of the use of autonomous ships.

The paper is a qualitative assessment of the benefits and challenges related to unmanned ship operation and will not do a quantitative cost-benefit analysis. A quantitative analysis for the MUNIN project ship can be found in [5] and [6].

Section 2 will provide an overview of the main benefits of unmanned ships, including also crew cost reductions. Section 3 will look at cost increasing and other complicating factors. Section 4 will provide an overview of typical characteristics of the viable business cases and section 5 will give some examples of the possibilities. Section 6 provides a summary and conclusion.

2. What are the benefits of unmanned ships?

2.1. Improved working conditions

Autonomy and automation is first and foremost applied in tasks that are "3D": Dirty, Dangerous or Dull. One can question what on-board jobs fall into this category, but it has been shown that working on a ship is often much more dangerous than working in similar jobs on land. This is mainly due to work related accidents on board, including exposure to harmful substances [7].

2.2. Lower damage related costs

It has been argued that the human factor is responsible for a majority of the incidents and accidents that happen at sea. Most of these are relatively small and, e.g. associated with allisions with port structures. However, repairs and off-hire will still be costly.

Whether it is it is human errors or rather the effects of poorly designed control systems, fatigue due to little rest and boring work, that cause these incidents can be argued [8]. Regardless, it is good reason to believe that improved automation will help to avoid many of these incidents.

2.3. Reduced crew cost

One generally accepted benefit of unmanned ships is that crew cost will be reduced. This is a truth with some modifications that will be returned to in section 3, e.g. as more shore maintenance and the need for a SCC. However, crew related cost reductions are very relevant for smaller ships. This supports a transition from today's very large ships that are driven by the benefits of larger scale, to smaller transport units and more flexible transport systems.

2.4. Slow steaming

An interesting issue related to operational cost is to operate at lower speeds to save fuel costs, i.e. slow steaming [5]. This requires a trade-off between time dependent costs such as capital expenses and crew and the speed dependent cost of fuel. Unmanned ships reduce crew dependent costs, but the balance depends heavily on the costs of fuel and capital. For smaller and less expensive vessels, it may be a good business case. Again, defeating the "economy of scale" is an important part of the picture.

2.5. Lower structural costs

An unmanned ship will not need a hotel section and most of the deck house. It does not need any life support or personal safety systems, such as galley, laundry, heat and ventilation, water, sewage, life boats and many other costly sub-systems. The removal of these systems will also reduce the light-weight of ship or can be used to increase cargo capacity. If a ship can be built for completely unmanned operation, there are obvious benefits in construction costs and increased cargo capacity of the ship.

2.6. Better environmental performance

Reduction in light weight or increase in cargo capacity will increase energy efficiency. The removal of the hotel section and associated power drains will further increase the efficiency. Removal of deck house will also decrease air drag and general optimizations of the hull may also contribute to better energy efficiency.

2.7. New ship designs

The removal of the deck house and other crew related features allow for more innovative designs of ships. Unmanned ships will in particular lend themselves to smaller, more flexible and more efficient ship designs that may defeat the general "economy of scale" thinking, which today is pervasive in the industry.

3. What are the additional costs and limitations?

3.1. No maintenance on technical system during voyage

One of the main challenges for an unmanned ship is that the technical systems cannot be maintained during the voyage. This has two consequences:

1. The ship will need much increased redundancy so that a single technical failure does not stop the ship. This increases design and operational costs.
2. The systems cannot be maintained during voyage and should not need much more off-hire for repairs. This may require costlier technical solutions.

The severity of this issue can be expected to increase with the voyage length. Large ocean-going ships may have to install two smaller main engines rather than one large, which will be more expensive, but may increase efficiency [9]. For smaller ships, consequences are less severe and one may get benefits from hybrid diesel-electric/battery systems to do power regeneration, peak load shaving etc.

3.2. No use of heavy fuel oil

Heavy fuel oil (HFO) is the most common fuel for large and medium sized ships due to its low cost. However, HFO requires heating, filtering and other manual intervention. Changing from HFO to lighter fuels in emission control areas is also complicated. Thus, it is not expected that unmanned ships can run on HFO without some new technology. Alternatives, which may be marine gas oil or LNG can be up to twice the price of HFO and will have a serious impact on the cost of operation of the ship. For ships, e.g. in coastal trade, that are already using low Sulphur fuels, this is not a problem.

3.3. Port and fairway infrastructure

The unmanned ship will also be dependent on port and fairway infrastructure. This can be automatic mooring or automatic cargo handling, high precision positioning system for berthing, improved and more secure communication systems etc. This is a significant cost factor as well as a limiting factor in where the unmanned ship can operate: It is highly unlikely that unmanned ships will be used in voyage charter trades until most ports have the necessary infrastructure.

3.4. Shore control center

An unmanned ship is a type of “industrial autonomous system”, where high requirements to cost-benefit, reliability and security is prevalent [11]. For unmanned ships, this will normally mean that the ship will never be left unattended, but will be supervised by a shore control center (SCC). This is expected to increase safety, reduce complexity and simplify adaption of rules and regulations for unmanned ships [15]. The SCC comes at a cost, which will depend on how many ships the center serves.

3.5. Additional accidents and societal acceptance

As noted in section 2.2, unmanned ships are expected to reduce accidents and insurance costs. This is illustrated as the center circle in Figure 1, but this is not the full picture.

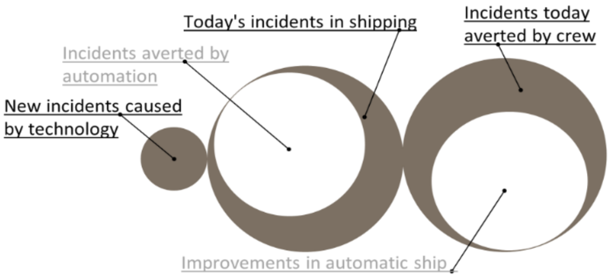

Figure 1: Aggregated accident picture for unmanned ships [8]

We will have to handle situations that may escalate into incidents as no crew can intervene to do corrective actions (right circle). Not much is known about this subject and understanding the nature of the problem and finding automation solution to fix it will be demanding[10]. There will also most likely be new accident types related to the introduction of the new technologies (left circle).

It is a tendency that the public acceptance of new technology is lower than for known technology with an equivalent objective risk level [16]. A new unmanned ship must therefore be designed to be significantly safer than a conventional ship. Likewise, a serious accident in an early phase may result in even wider public resistance against its use. In other words, significant efforts and costs must be dedicated to ensuring that the unmanned ship is safer than its manned counterpart.

3.6. More advanced ICT systems and higher security

An obvious cost factor is more advanced ICT-systems. Better sensors, new types of collision avoidance and higher redundancy will add to system costs. ICT systems for the unmanned ship must also be built to withstand cyber-attacks, which further may increase costs. As no persons on-board can take corrective actions, the communication and control systems must be made as secure as possible. This also applies to the SCC. However, the ICT systems do not represent a large proportion of the total ship costs, so it is expected that this factor has limited impact.

3.7. License to operate

International shipping is a heavily regulated business with a large volume of international legislation to satisfy. The move to unmanned shipping will require changes in legislation, but there seem to be no long-term show stoppers [13]. IMO starts a scoping exercise to determine what parts of the various IMO instruments that needs to be amended at MSC (Maritime Safety Committee) 99 in May 2018 with a target completion date in 2020 [14]. After that, it will take many years to do the necessary amendments or to develop a new code. As the first unmanned ships are expected to be operational from 2021 [3], the legislative issues need to be handled on a national and regional level until international regulation is in place.

It is believed that this is a viable approach, also for international operation of unmanned ships, but it will require agreements between the flag state of the ship and the respective port and coastal states that are involved. This means that unmanned ships in the foreseeable future will be limited to operate in "liner mode", between ports and in national waters where the authorities have approved the use of the technology.

4. Expected trends for autonomous shipping

The two above sections have discussed main pros and cons for unmanned ships. These define four very specific possibilities and constraints for near-future unmanned ships.

4.1. Liner type shipping only

Unmanned ships will operate between a small number of pre-defined ports, either in liner mode or as part of an industrial shipping system, such as *Yara Birkeland*. Legislation, infrastructure and other factors make it almost impossible to do other types of operations, e.g. to ports that have not been thoroughly cleared for an unmanned ship call. Unmanned ships will be part of a well-planned operation and will have to involve all parties, including ship operator, ports, flag and coastal state authorities.

4.2. Integration into transport systems and supply chains

The cost of an unmanned ship, including necessary infrastructure and SCC, can be expected to be higher than for a conventional ship in most cases. This means that unmanned ships cannot compete directly in conventional shipping operations. However, the unmanned ship will be more scalable due to no penalty in crew costs and they can be designed differently and be more automated than conventional ships. This makes unmanned ships much more interesting in an integrated supply or transport chain, such as *Yara Birkeland.* The cost of ship transport is very low to start with, so increased flexibility can cancel out the increased ship leg cost in lower overall logistics costs. This also means that new parties may build and operate unmanned ships, as is the case with Yara. This is one typical effect of a disruptive technology.

4.3. Defeating economy of scale

In general, the factors described above will increase the relative benefits of unmanned ships with reduced ship size. An important potential of unmanned ship is to reverse some of the developments related to economics of scale in the shipping sector, where ships grow increasingly larger and less flexible in terms of ports they can call on. This is particularly interesting in short sea and inland shipping where economy of scale has made ships less competitive with trucks on the shorter distances.

4.4. Towards zero emission

The technical systems on unmanned ships needs to be of high quality and the ships will use cleaner fuel than many conventional ships, including fully electric and diesel-electric solutions. Together with reduced energy use for same cargo volume and a much-improved competitiveness towards truck transport, the unmanned ship is a very interesting contribution to zero or low emission transport. This may also mean that unmanned ships will be used in transports where they are more expensive than conventional ships, if the cargo owner is sufficiently interested in a green profile.

It may be difficult to reach the goals of reduced greenhouse gas emissions from the shipping sector without using unmanned and autonomous technology.

5. Some known business cases

5.1. Industrial shipping

Yara Birkeland is a very good example of several of the possibilities and constraints discussed above. It is a transport system commissioned by a fertilizer manufacturer as part of an integrated product export system. It is industrial shipping where the transport is an integrated part of the production and supply chain system.

Yara Birkeland is designed to operate in a specific transport route and will not in general be used for other operations. The way the ship was commissioned is completely different from conventional ship deliveries and adds credibility to the statement that this is disruptive technology: New stakeholders appear and new business models are established.

5.2. *More flexible and higher frequency waterborne transport systems*

A new waterborne transport system is being investigated in the Trondheim area through the ASTAT project (Autonomous Ship Transport at Trondheimsfjorden) [17]. This project looks at a number of industrial shipping operations as well as a more general waterborne transport system.

Trondheim Port Authority is owned by thirteen municipalities in Mid-Norway and operates several smaller ports and terminals in the Trondheimsfjorden area. Today, container feeders have about 2 hours sailing from the coastal fairway to the main container terminal. One possibility is to establish a new port near the coastal fairway and use a number of small unmanned shuttles to connect to smaller terminals and ports in the area. This could, e.g. be operated by the port authority as part of the port services.

5.3. *On-demand low volume passenger services*

Norway is a country with many fjords and small islands. Building bridges and tunnels are costly and cannot always be offered to the smaller communities. They will then be dependent on ferry services which, due to cost constraints, have limited service.

One interesting proposal is to use unmanned ferries that can be called and used on demand. As passengers are transported, this requires special precaution, but this can be solved by training a number of the regular users to operate safety systems and requiring that at least one of them accompanies the ferry during use.

5.4. *More flexible intercontinental traffic*

Crew costs for a large container ship of around 20 000 TEU is on the order of a few percent of operating costs [18]. Thus, it does not make much sense using costly technology to reduce crew on these ships, although removing the deck house may be beneficial to increase loading capacity.

On the other hand, most large container ships call on many ports to discharge and load cargo and this may not always be the best solution in an overall logistics perspective. It could be interesting to look at replacing one large ship with four or five smaller ships. In this case, cost savings associated with unmanned operation will become much more important. As the sea leg cost of a container transport is low compared to the complete logistics chain cost, more flexible shipping routes may make sense in an integrated logistics perspective.

6. Summary and conclusions

This paper has tried to show where unmanned and autonomous ship can be used and where it does not make sense to use them. The main messages are:

1. Unmanned ships are *not conventional ships without crew*. It does not in general make sense to replace a conventional manned ship with an unmanned.
2. Unmanned ships have an immense potential as a *new component in completely new transports systems* with much higher integration into logistics chains.

3. The previous point also means that unmanned ships *will not suddenly appear in a foreign port*. They will be components in a well-defined transport operation where all parties, also authorities, need to be involved.
4. Unmanned ships will be a major contributor to the future *low or zero emission transport* systems.
5. Unmanned ships represent a *disruptive technology* in that it will enable new business models and introduce new parties into the maritime transport area. It can also replace existing transport systems with completely new ones.

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