It’s not all about the COLREGs: a case-based risk study for autonomous coastal ferries

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Abstract. Whilst the maritime world is preparing for autonomous vessels or Maritime Autonomous Surface Ships (MASS), as defined by IMO, we suggest an approach to investigate the risks involved with introducing such ships into service. This case study investigates the risks regarding other surface vessels that the MASS can encounter on their voyage between two berths used by coastal ferries in Norway. The ferries in this case, operate within a fjord declared as testbed for autonomous operations. Albeit the technology is available and declared ready, the area of operation is not. This paper seeks to address some of the remaining obstacles with regards to the risks involved.

1. Introduction

The development of Maritime Autonomous Surface Ship (MASS) is a focus area for maritime developers, regulators, and researchers. Despite such focus for several years, no commercial MASS concept is operational. As autonomous vessels will coexist with conventional vessels, it is necessary to have a common set of rules for navigation. As such, all vessels, including the future autonomous vessels, are expected to follow the Convention on the International Regulations for Preventing Collisions at Sea (COLREGs). One major challenge for maritime autonomy is to coexist with conventional vessels and how to ensure safe navigation when no navigators are left on the bridge.

A large part of the COLREGs is prescriptive on how traffic conflict situations should be solved, however, the COLREGs also opens for the navigator making decision on how to resolve a situation based on seamanship. The ordinary practice of seamanship allows the crew to take action to avoid a collision that may not comply with the COLREGs but is necessary in particular circumstances to avoid a collision. While a set of prescriptive rules can be programmed, the human aspect, or seamanship, cannot be included in a pre-programmed solution. Consequently, following the COLREGs is a challenging task for conventional vessels, but even more challenging when autonomous and conventional vessels will have to coexist.

In this study, a geographical area with a large variation of traffic was monitored for a period of 30 days to identify how often conventional vessels deviate from the prescriptive rules of COLREGs to avoid potentially dangerous situations in overtaking, head-on, and crossing situations.
2. Background

The convention on the International Regulations for Preventing Collisions at Sea (COLREGs), 1972 as amended, regulates the behavior of vessels in marine traffic situations. The COLREGs states that the risk of collision should be carefully assessed at an early state, and if there is a risk of collision normally one vessel is the give-way vessel and the other is the stand-on vessel. However, this is not the case in head-on situations where both vessels are expected to give way. In this it is implied that the officer on the stand-on vessel needs to trust the officer on the give-way vessel and wait for him to conduct an evasive maneuver. The COLREGs do not provide detailed information on when and how an avoiding maneuver should be performed. This leads sometime to uncertainties [1]. According to the COLREGs the stand-on vessel shall maintain her speed and course until she finds herself so close that collision cannot be avoided by the action of the give-way vessel alone. How to determine when this is the case, is up to the navigator on the stand-on vessel. This introduces the human role into the assessment of what and when appropriate action, although sometimes seemingly in contradiction to the COLREGs, should be taken. Porathe, [2] discusses the confusion about which rule is applicable in certain situations. Arguably the COLREGs are a trade-off between safety and efficiency. The rules are open for interpretation with wordings like an evasive maneuver should be carried out in “ample time”. What ample time is, is dependent on the state of one’s own vessel, the state of other vessels interacting, weather conditions, the condition of the waterways among others. How the navigator perceives these variables will affect the action he chooses.

The Convention on the Regulations for Preventing Collisions at Sea (COLREGs) regulates the behavior of vessels in marine traffic situations through rule 1-19. Depending on the relative bearing between the vessels, different rules describe appropriate action, see Figure 1. In this paper we choose to focus on rules 13 to 17. Rule 13 covers overtaking (vessel D) and states that an overtaking situation is when one vessel is coming up with another vessel from a direction more than 22.5 degrees abaft her beam. This means that the overtaking vessel can only see the other vessel’s stern lantern. Rule 14 describes head-on situations (vessel B) and states that this is the case when two power driven vessels are meeting on (or nearly) reciprocal courses. This means that each vessel could see both starboard and port side lanterns and both masthead lights in (or nearly) in line. Rule 15 covers crossing situations and states that the vessel which has the other on her own starboard side (vessel C) shall keep out of the way and shall avoid crossing ahead of the other vessel. Rule 16, action by give-way vessel, states that a every vessel which is directed to keep out of the way of another vessel shall, as far as possible, take early and substantial action to keep well clear. Rule 17, Action by stand-on vessel states that when one of the vessels is to keep out of the way, the other shall keep her course and speed (vessel A).

Figure 1: Categorization of situations depending on the relative bearing
The exact time or distance for an avoiding action is not stated. The COLREGs do address this in vague terms in rule 8 “Action to avoid collision”, but these discussions lie outside the scope of this paper. This has been discussed on several occasions, among others by Olinderson et. al, [3].

2.1 Maritime autonomy
Autonomous, unmanned vessels are expected to play an important role in future maritime industry. To date, autonomous shipping appears to primarily have been about a technology push rather than considering and providing sociotechnical solutions including re-design of work, capturing knowledge, and addressing human factors in modern shipping, [4]. Several research projects are underway, among others the Autoferry, a small passenger ferry which is expected to be in operation in the near future, [5]. The general idea with this autonomous passenger ferry is to incorporate automatic anti-collision features with detection and identification of other objects in the area, such as leisure boats, kayaks, or drifting debris. The ferry itself is expected to follow the rules of the road stated in the COLREGs.

2.2 Automatic Information System (AIS)
Today it is possible to analyse vessels’ actual track with information from the Automatic Information System (AIS), used onboard almost all merchant vessels and many leisure crafts, but not nearly all of them. Messages from the AIS system are sent out with short time periods 2-360 seconds. This interval is depending on the vessel’s status (underway, moored, anchored etc.), speed and course change. The accuracy and integrity of positions derived from AIS has been debated earlier, see [6]. Still it is used in many studies as the best way of measuring the track of vessels at a low cost. In this study, in addition to AIS we used a radar tracking system combined with a pan-tilt-zoom (PTZ) camera to also track the vessels without AIS. To our knowledge, this has not been done before. This projected is limited to look at rules 13 to 17 which dictates appropriate actions by both stand-on and give-way vessels in overtaking, head-on situations and crossing situations. These were the situations most easily recognized with regards to the limitations our equipment represented. The goal was to identify exception to those specific rules. A Maritime Autonomous Surface Ship (MASS) will need to able to recognize such situations warranting deviations from the rules.

2.3 Objective/research question
The aim of this study has been to identify the traffic situations that occurred in a ferry crossing in the north-western part of Norway during a period of 30 days, in the late summer of 2018. The traffic was recorded and during playback, relevant situations were analysed and how they related to the COLREGs were assessed and traffic conflict situations between the ferries and other vessels were identified. In the conflict situations, the study identifies if the evasive actions carried out in were compliance with COLREGs or not. The study is limited to assess the situations against COLREGs rule 13-17, and do not consider if other means, such as the use of radio communication, were used.

The research question is:

How often are the COLREGs apparently breached when making evasive actions to resolve traffic conflict situations in a ferry crossing?

3. Method
Storfjorden, located in the north-western part of Norway see Figure 2, is a designated test area for autonomous vessels. At the point of this ferry crossing, the fjord is more than three nautical miles wide. Therefore we do not consider this as a narrow channel. In this fjord there are several ferry connections as parts of both national and local roads. At the end of the fjord lies Geiranger, listed on the UNESCO world heritage list. As such, Geiranger is a popular destination for cruise vessels who use the Storfjord enroute to Geiranger.
Selecting the best location for monitoring purposes was based upon three criteria: Firstly, the crossing should be in the most vessel congested areas of the Storfjorden. Secondly, we needed access to electrical power and thirdly the length of the crossing should be within the range of both the camera and the radar. Based upon these criteria, it was decided to install the monitoring equipment at “Klubben” light located at the “Solavågen-Festøy” ferry crossing, a three nautical miles crossing. Klubben light, in position N 62° 24.5’ E 006° 19.28.0’ see Figure 2, is a lantern with indirect illumination and has available 220V power as well as a separate storage space in the foundation itself. This storage space was utilized for the monitoring equipment.

3.1 Monitoring equipment
The monitoring equipment should be able to record and document the traffic in the ferry crossing area. Our aim was to identify the vessels with Automatic Identification System (AIS) installed, as well as the smaller vessels, i.e. kayaks, leisure boats and small fishing vessels that do not have AIS installed on board. In order to do this, a 360° pan-tilt-zoom (PTZ) camera was chosen. In conjunction with a solid state radar with Automatic Radar Plotting Aid (ARPA) and an AIS receiver, this setup would give an almost complete picture of the marine traffic in the area. The complete set-up as installed, and the ferries’ normal crossing route is illustrated in Figure 3.
The information from these units was integrated, presented and recorded by “Timezero” software. “Timezero” is a coastal monitoring system delivered by Furuno Norway. For further specifications of the equipment used, see Feil! Fant ikke referansekilden.

Table 1: Specifications of the installed equipment on-site

| Instrument       | Producer | Type               |
|------------------|----------|--------------------|
| Radar            | Furuno   | DRS4D-NXT          |
| Camera           | Axis     | Q6054E PTZ         |
| AIS receiver     | Furuno   | FA-30              |
| 4G LTE Router    | D-Link   | DWR-921            |

Albeit the equipment was installed on-site, it was possible to remotely access the installation via TeamViewer software. This access allowed for fine-tuning of radar parameters and adjusting the alarm zones and tracking parameters for the targets. All data was logged on the computer hard drive meaning that when data collection period ended the computer was collected and brought to the NTNU premises for further analysis. A screendump from the Timezero software is shown in Figure 4.

Figure 4: Left, Radar/ARPA. Right, ECDIS with AIS overlay.

3.2 Procedure
To categorize the vessels monitored the area was divided into zones. An area within which any targets entering would necessitate attention from the officer onboard the ferry as well as to tell the camera to focus on this target was defined. This is represented by the pink area in figure 3. The ferry’s route was also divided into zones of transit and docking/undocking. In the transit zone the ferry was expected to maintain full speed, whereas in the docking/undocking zones this was obviously not the case.

The sampling period from 21st August to 19th September 2018 was chosen as this period would represent a peak in leisure fishing of crabs as well as it was still within the high season for the cruise vessels transiting the area. The risk of encountering bad weather with reduced visibility, which would reduce the applicability of the camera, was still low.

3.3 Analysis
The actions analysed were done so with no knowledge of what information was available to the navigators, what clues in the environment they searched for and what prospective arrangements they have done with other vessels, i.e. by VHF radio.

The playback of the recordings was reviewed by two licensed Master Mariners. During the laborious review of the playback from the Timezero recordings, targets were identified and
categorized. Only targets entering the fairway utilized by the ferries were registered. Targets outside of this would not cause any concerns for the navigators onboard the ferries. The targets within the fairway were all targets which the officer onboard the ferry had to assess whether they would represent a concern for the ferry’s transit. These targets were then categorized by what kind of marine vessel they represented and by what source they were identified, either by radar or AIS. Furthermore, where they appeared within the fairway, whether it was in the docking/undocking area or in transit zone, were recorded. Finally, and crucially, the evasive manoeuvres, executed by targets or by the ferry itself, were assessed whether they were conducted in accordance with the COLREGs or not.

3.4 Limitations of the study
Our approach to this project was to identify situations concerning the safe passage of the ferries crossing this fjord. Our installed equipment did not allow us to get the full picture of what information was available to the navigator onboard, neither the ferries nor the targets. Information such as CPA, TCPA and BCR could in hindsight be estimated using the playback function of the Timezero software, this laborious effort could have somewhat complimented our data. The fact that evasive manoeuvres were observed, indicated that the navigators performing these found their threshold limits breached, whether it was CPA, TCPA or BCR. Notwithstanding Part A and B section 1 of the COLREGs, which always should be taken into account, we focus solely on what we could observe with the equipment available to us. This led us to evaluate the manoeuvres solely against rules 13-17 described earlier.

3.5 Reliability and validity
The situations were identified, and the actions analysed by triangulation of sources. The AIS, ARPA and the PTZ camera would all give separate pictures of the situations. I.e. if the AIS indicated a speed reduction as an evasive manoeuvre, this was crosschecked with the speed input from the ARPA. If a course alteration was detected by ARPA, this again was confirmed by AIS and the PTZ camera.

Both analysts had a background as licensed master mariners. Drawing on their experience, situations were rapidly discovered and assessed. Their background as officers on merchant vessels could give them a predisposition to favour the merchant vessels over the leisure vessels though, interpret and criticize their actions differently than say an experienced fisherman onboard a small fishing vessel operating in this area would do.

This study chose a ferry crossing representative of others in Storfjorden. There are at least three similar crossings within a relative short distance. They all have almost similar features, 20-30 min departure intervals, two or three different ferries assigned to the crossing. One could also question the time of year this study was conducted. There were still cruise vessels transiting, albeit the numbers decreasing towards the end of the monitoring period. The leisure boat activity was undoubtedly also on decline as the summer season nearing its end, but the crab fishing season had begun and there were still quite a large number of leisure vessels involved in this.

Even though it was late summer/early fall, the occasional rain shower and wind gusts did reduce the camera’s ability to enable us to identify what kind of vessel the ARPA picked up. This was especially the case with vessels appearing near to the end point off the crossing, almost three nautical miles away. At night, targets without AIS could have slipped by without being noticed. As mentioned earlier, one of the analysts has previously worked onboard a ferry operating this crossing. He knows the conditions under which the navigating officers onboard the ferry work. He knew the options available to them with regards to both path selection and speed reserves. This could have affected the study. The other analyst lives nearby and therefore knows this particular area very well. However, we did see this as a representative area and not one where we knew situations would occur more frequently than others.
4. Results and discussion

A total of 1010 targets were identified and categorized as influencing the ferries’ transit during the 30-day sampling period. Based upon the analysis criteria and COLREGs (13-17), evasive manoeuvres were performed 85 times (8.42%). The evasive manoeuvres were performed by both the ferry and targets respectively. 925 situations that the target(s) who were crossing the fairway, required no avoiding manoeuvres. Of all the targets tracked, only 41% had AIS installed. Table 2 summarizes the results of the identified evasive manoeuvres.

Table 2: Summary of identified evasive manoeuvres.

| Evasive manoeuvres                                      | By ferry | By targets |
|--------------------------------------------------------|----------|------------|
| According to COLREGS (13-17)                          | 49       | 24         |
| Not according to COLREGS (13-17)                       | 8        | 3          |

Further analysis of the manoeuvres not according to COLREG showed that these were either course change, speed change, a combination of the two or delayed departure. To illustrate this, two selected cases will be displayed in detail. These cases are representative of the manoeuvres done by the ferry which, in our opinion was not according to COLREGs.

**Case 1:** Ferry alters course to starboard and increases speed for a give-way vessel. In this case according to COLREGs the ferry, as the stand-on vessel, should maintain course and speed, and the give-way vessel should alter course and/or speed to resolve the situation. This is not what occurred in this instance.

The ferries have scheduled departure times and in this case the ferry departs at 08:30 LT from Sølevågen. It was observed that the ferry increased speed above normal cruising speed and at the same time altered course to starboard in order to increase the CPA. Figure 5 shows a screenshot of the above-mentioned situation.

![Figure 5 Left: Camera view of give-way vessel. Right: Radar and AIS overlay with give-way vessel and ferries. Note the heading and speed vector of ferry located to the top left in the picture.](image)

**Case 2:** Ferry alters course to port and at the same time deviates from its normal route for a give-way vessel. Similar to case 1; the ferry, as the stand-on vessel, alters course. However in this case, the ferry
also deviates from the normal route to avoid give-way vessel. Normal route for the ferries is west of the “Solevagsfluda” located as a small yellow area top-middle in figure 6. This time the ferry alters course and passes “Solevagsfluda” on the east side to allow passage for the give-way vessel.

Figure 6 Left: Radar and AIS overlay showing ferry that alters course to port and deviates from its normal route. Right: AIS and ARPA plots of ferry and give-way vessel. Note the ferry located top-middle close to shore and give-way vessel in blue.

Case 1 and case 2 are examples of situations that are identified in COLREGs and in both cases the ferry was the stand-on vessel but acted as give-way vessel.

5. Conclusion/further work

The goal of this project was to show that even though the COLREGs are universally accepted as the rules of the road, they are not always strictly followed. Rule 2 in the COLREGs, “Responsibility”, also called the seamanship rule, introduces an opening for this. The ordinary practice of seamanship allows the crew to take action to avoid a collision that may not comply with the COLREGs but is necessary in particular circumstances to avoid a collision. Seamanship is not a fixed standard, but a product of factual circumstances. A MASS will have to recognize these circumstances warranting deviation from the COLREGs.

As this study has shown, instances where deviation from the COLREGs appear, are quite frequent. 14% of the evasive manoeuvres done by the ferries were not according to the rules. If MASS are to coexist with conventional vessels, both merchant and leisure, they must demonstrate an ability to recognize and act as expected to these kinds of situations.

It is quite possible, or maybe even likely, that the evasive manoeuvres by the ferry described above were agreed upon, that the action was planned between the give-way vessel and the ferry. This could have been done by VHF. The cruise vessels all have pilots onboard when sailing in this area. It is not abnormal that the pilot calls on the ferry and asks the ferry do give way as it might be easier for the ferry to delay the departure a couple of minutes, or choose a more easterly route when departing Solevågen, than the cruise vessel to reduce its speed or alter course of 300+ meters long ship. Even so, this arrangement needs to be done by someone.

Further studies are needed to verify our findings as we do not know whether they are replicable on other traffic congested areas.
References

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