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Urban mobility at sea and on waterways in Norway

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Abstract. This paper gives an overview of current urban mobility projects in Norway and discusses autonomous short- distance ferries. Five projects are presented, with mobility concepts and timelines. A discussion is given regarding the motivation for and major challenges of autonomous water-based urban transport.

1. Introduction

The use of private cars for general transportation in cities and urban areas contributes to congestion, pollution and safety issues. In addition, there is a growing awareness of the importance of clean energy and energy- efficient mobility solutions in Norway and Europe. Norway's topology, with its interlinked cities and waterways, creates both challenges and opportunities for developing sustainable urban transportation solutions. The recent report on sustainable mobility from the Norwegian ministry of transport [1] now includes a quest for autonomous ferry solutions as a part of the future transportation network of public and goods.

Although autonomous or automated mobility outside controlled environments is still a vision it has attracted R&D investments from corporations as well as government- funded programmes aimed at creating a more efficient, cleaner and on-demand transportation system. The Norwegian government has funded the programmes Smartere Transport and Pilot-T as a part of a NOK 1bn research programme for transport on land and sea. This paper gives an overview of some of the already funded projects for short sea urban transport and some projects affiliated with the joint initiative called "Water Bus" that are pending funding.

Effective ferry solutions for urban areas can facilitate public mobility needs as a supplement to trains, buses, e-scooters and ride-sharing schemes. Ferries could also reduce the need for investment in tunnels and bridges by offering a car-free transportation alternative.

2. State –of- the -art for autonomous vessels in Norway

Autonomous or partly-automated public transport is still a vision. National and international rules regulate all transport at sea and in waterways. To realize the vision requires demonstrating that autonomous transport systems are capable of transporting all kinds of passengers, safely negotiate all obstacles and are environmentally-friendly. Unmanned vessels have been in use for about 20 years, and current examples are the AUVs Hugin and Munin and the surface vessel Odin. These vessels are typically used for mapping the sea bed and searching for objects and explosives. The control systems used in these vessels are designed to work under conditions with a few obstacles, and not in areas with heavy traffic. A public transport system requires a high safety level and functional rescue system to handle all possible incidents, such as collision, fire, grounding, people overboard and water ingress. Public acceptance and comfort are also key demands of unmanned vessels.

Yara Birkeland [1] will most likely be the first autonomous cargo vessel in operation in Norway. This vessel will transport containers of fertilizer from Herøya to either Brevik or Larvik for reloading onto larger ships. The basic development was carried out by Kongsberg Maritime (KM) in collaboration with YARA and other stakeholders. Experiments are still in progress on a model ship (Scale 1:12) run by the University of South-Eastern Norway (USN) and KM. A contract for a full- scale vessel has been signed and the design, construction and fabrication is carried out by the shipyard Vard. Current and forthcoming activities are in progress on a cargo drone (ASKO [1]) and car ferries configured with autocrossing and autodocking systems.

3. Project and activities related to small autonomous passenger ferries

Many cities and urban areas are sited close to or on waterways and historically have relied on water-based transport for public and goods. Many cities, such as Oslo, Fredrikstad, Gothenburg and Wroclaw, still have short distance ferries with daily schedules as part of the public transport system. The number of urban passenger ferries has declined and replaced by bridges and tunnels, which is not necessarily a good solution for either attaining climate targets or for accommodating pedestrians and bikers. The Nordic countries, with their extensive coastlines, have many ferries in operation, but an ageing fleet, strained economy and a preference for bridges or tunnels place the ferry routes at risk of being closed down.

In Norway there are a number of ongoing activities aimed at increasing the number of urban passenger ferries and research is being carried out at different universities, R&D institutions as well as in industry. The list below shows current projects and activities in Norway.

Table 1. Projects and activities in Norway

Location	Project name	Status	Participants	Comment
Tønsberg	Ole IV	Active project	Tønsberg council USN Local industry	Small ferry (12 PAX) Initial research funded by Markom 2020, actively seeking funding and partnership with industry.
Trondheim	Milliampere	Active project	NTNU Amos and other	Small ferry (12 PAX) Funded through the research council.
Kristiansund	RAPP-Sundbåten	Active project	Sundbåt, Kristiansund Municipality, Maritime Robotics, Ulstein, Møre Maritime, NTNU, USN +++	Medium ferry (50 PAX) funded through PILOT-T.
Haugesund	NN	Pilot study	NCE Maritim Cleantech	
Arendal	Kolbjørn	Pilot study	Arendal municipality and Arendal Harbour	Presented at a suppliers conference on 5 June 2019

Fredrikstad	#Byfergen	Active project, procurement of new electric ferry	Fredrikstad municipality with partners	Medium ferry (50 PAX) New electric ferry delivered in June 2019. Evaluating future autonomous operation.
Moss	New traffic solution	User survey	Moss municipality and USN	Establishing user's requirements.
Ballstad	Lofoten Matpark	First report finished. Project application in progress	Lofoten Matpark and USN	Autonomous passenger boat and autonomous harbour for fishing vessels.
Mjøsbyen	Autonomous high speed vessel	Appraisal report completed	Hedmark trafikk and Opplandstrafikk	Identified the need of a new vessel with higher speed and more capacity that can operate in icy waters.
Stavanger	Water bus	A transport analysis has been completed	Nordic Edge, Kolombus and USN/UIS	Smaller vessels with higher frequency.
Bergen	NN	Evaluation of the transport system in progress	Bergen municipality	Idea of floating hubs for interface between high speed vessels and smaller local commuter vessels.
Oslo	NN	Internal discussions	Oslo municipality ++	A large number of medium-sized passenger ferries are in use already
Drammen	New city bridge	Planning was in progress, but is suspended	Drammen municipality	Alternative transport during bridge construction.
Sandefjord	Framnes ferry	Discussions mainly in local newspaper	Sandefjord municipality	
Brevik	NN	New ferry solutions being discussed	Porsgrunn municipality	
Hvaler	NN	Completed pilot study	Hvaler municipality	

4. Cases for in-depth study

Table 1 shows many initiatives for small autonomous passenger vessels in Norway. We will examine some of the active projects, focusing on their status, plans and schedules. The examples cover small and medium- sized ferries, operating under different climate and traffic conditions. Most of these projects are active and have existed over a period of time. The fifth case from our neighbouring country, Sweden, shows probably one of the most exciting areas for a water bus concept. Stockholm is a large city with a large number of islands and rivers.

4.1. Case 1: Tønsberg-Ole4 (Small ferry with a capacity of 12 PAX)
Old historical ferry crossing that has run for nearly 200 years until it was closed down in 2012 due to strained economy. The ferry was re-commissioned in 2017, but the local public and the council want a new efficient ferry, preferably autonomous. A project has been running for 1.5 years devoted to risk analysis and human acceptance of a future autonomous ferry.

4.1.1. Concept. The ferry route has a long tradition and is popular among the residents on both sides of the channel. The municipality funds and operates the ferry (1884 – 2012 and 2017-2019), but the current ferry, Ole III from 1974 (see Figure 1) is not suitable for future operations and will be replaced.

The municipality wants a new 12 PAX, green, autonomous ferry with an electric charging station and operating on a high frequency schedule and on-demand operation. The new ferry shall be able to operate in snow and ice conditions.

4.1.2. Schedule
- 2016: Formal conference with potential suppliers and national authorities
- 2017: The City Council decided to acquire an autonomous, zero- emission ferry
- Acquisition of an autonomous vessel is compromised by national regulations. Due to a lack of advanced technology the project was shelved.
- 2018: The City Council decided to postpone the acquisition and sign a development agreement with USN.
- 2018 Project agreement signed with USN
- Data collection June 6 - August 4 2018
- Risk analysis completed in Dec 2018
- 3 master's theses completed in June 2019
- Design and construction of a new ferry by 2021
- Test and verification 2021-2022

Figure 1 – Ole III ferry in Tønsberg, Norway

4.1.3. Result summary-Risk analysis
- High incident rate (breaches of ColRegs):

  5.8% of all crossings

  8.8% of crossings when other vessels are present in the sound
- No incident led to collision or damage
- Increasing incident rate with increasing traffic (B_{exp}= 1.154, $p<0.001$)
- The results show that human handling is crucial for the prevention of critical incidents

4.1.4. Conclusion. The results of the data recordings and manual observations conducted between June 6 and August 4 2018 did not indicate that an autonomous ferry is unacceptable. However, the observations showed a large number of deviations from ColRegs caused by leisure craft. In all the observed cases, the captain of OleIII resolved the situation by actions such as change of course and speed and by audible signalling. The anti-collision algorithms for a future autonomous ferry must be capable of detecting the ColRegs deviations and show clear intent towards the other vessels.

It may also be necessary to mark the crossing area clearly and even have sound and light signals on the ferry. More research is needed on how leisure craft owners respect and react to autonomous vessels. The safety and security of all passengers must be prioritised in the design phase.

4.2. *Case 2: Trondheim-Milliampere (Small ferry with a capacity of 12 PAX)*

The Autoferry project in Trondheim run by NTNU AMOS and stakeholders has a prototype ferry running (see Figure 2) and will most likely have a full-scale ferry running in the near future. More details will be presented by the project owners, NTNU AMOS.

4.2.1. Concept

- ”On-demand ferry”- push a button to summon the ferry
- Crossing time: 1 minute low latency
- Capacity: 12 persons
- Electric propulsion and automatic charging
- Navigation: High-precision GNSS (cm accuracy) with back-up system
- Anti-collision system

Figure 2 - Milliampere ferry in Trondheim, Norway

4.2.2. Schedule

- Phase 1 (2016): Concept study, student projects. Dynamic positioning system to be tested on board ReVolt from DNV GL in Trondheim harbour.
- Phase 2 (2017/2018): Autonomous pilot ferry for concept testing and to study the behaviour of other boat traffic.
- Phase 3 (2018/2020): Full- scale ferry certified for passengers.

4.3. Case 3: Kristiansund- RAPP-Sundbåten (Medium size vessels with 50PAX)

The main goal of the RAPP-Sundbåt project is to improve the transportation system in Kristiansund. The topology with the town being spread out on three islands requires expensive infrastructure with bridges. A ferry boat has been part of the transportation system in Kristiansund since 1876. The operator and the town council are examining how to increase the schedule and number of ports to better serve the mobility needs.

*4.3.1. Concept.*The R&D project for the new Sunbåt vessel is funded through Pilot-T and the stakeholders come from six companies and two universities, in addition to the ferry operator, harbour authorities, Kristiansund municipality and the county council. The scope of the project is to better serve the mobility needs in a cost-effective, environmentally friendly manner. The list below shows some of the outcomes the project aims to deliver:

- Higher frequency and 24-hour service on demand
- Flexibility in which ports to service
- Reduced manning
- Reduced energy consumption

4.3.2. Schedule

- Data collection, concept development, ship design, docking and charging solution 2019-20
- Ship- and dock construction 2020-21
- Testing and verification 2021-23

4.4. *Case 4: Stavanger (Large and small ferries)*

In the Stavanger region a number of underwater tunnels have been built to connect the local islands to the mainland. This is also a part of Norway’s national transport plan 2018-29 to make a ferry-free coastal highway from Kristiansand to Trondheim [2]. Increased vehicle traffic in the city is one of the results. Smart city Stavanger and Nordic Edge, together with the regional transport provider, Kolombus, have launched a project on smart transport and mobility centres. This includes small passenger ferries called water buses.

4.4.1. Concept. The water bus initiative by Stavanger city could be an important part of a complete mobility solution. Water buses will be an effective mode of transport, particularly for pedestrians and cyclists. The local transportation provider, Kolombus, is also focused on offering environmentally friendly mobility solutions and is particularly interested in multimodal mobility centres as transportation hubs (see Figure 3) that include water buses. In many areas transport by sea will be the shortest distance since there are few problems with congestion and queues. In coastal regions like Rogaland it is natural for the sea to be used for daily transport.

Key concept points:
- Mobility centre, where all available services are connected.
- The old fishing pier will be the new mobility centre.
- Water buses will be a part of a total mobility solution.
- The old fishing pier will be the main hub for all water based transport.

Figure 3 – Mobility centre concept, Stavanger, Norway

4.4.2. Schedule. Planned to be in service by 2022.

4.5. Case 5 - International case - Stockholm
A number of countries and cities around the world have launched projects or activities related to autonomous, zero-emission vessels. Some of these projects are devoted to passenger traffic. The waterways in urban areas are less used for passenger transportation than 50-100 years ago because of the increasing number of vehicles, bridges and underwater tunnels. One example is Stockholm in Sweden.

4.5.1. Concept. In 2017 the Stockholm Chamber of Commerce issued a report with the following recommendations [3]:

- Extend traffic with urban linear ferries to include more routes.
- When planning new infrastructure, critical intersections and nearby park-and-ride facilities must be included.
- Municipalities should be required to plan quays for urban linear ferries when constructing new waterfront residential areas.
- A ticket system that includes traffic via procurement, as well as traffic operated on a commercial basis.
- Political agreement is needed regarding extending Stockholm's urban linear ferry routes, in order to increase housing construction in the region.
- Waterborne public transport solutions should offer a level playing field for private operators.
- Land should promptly be allocated for the construction of two major terminals for ferry traffic, adjacent to the underground network in the city centre.

4.5.2. Schedule. The municipality has started planning a number of new ferry lines in the urban districts.

4.6. Other relevant initiatives - green ships
The Horizon 2020 E-Ferry project [4] is building a medium-distance battery ferry for service in Danish waters between the island of Ærø and the mainland. The objective is to show a viable, feasible solution for energy efficient and emission-free waterborne transportation. In Norway the Ampere battery ferry,

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owned by Norled, has been in operation since 2015. Many new electric battery ferries are under construction and 60 battery ferries will be in operation by 2021 in Norway [5].

5. Level of autonomy

Many of the initiatives listed in table 1 are described as autonomous ferries. The term “autonomous” has to be defined for each of the projects according to the level of autonomy required for the particular ferry. The rules for autonomous vessels, with or without crew members, are not completed, but discussions so far indicate that level 4 autonomy with a remote control centre would be required [6]. The same discussion is happening with autonomous vehicles, where level 4 autonomy is a more realistic scenario for autonomous driving in an urban environment [7].

6. Challenges to address for autonomous water-based transport

There are many ways to improve urban transportation systems by using autonomous water-based transport, but the challenges regarding new untested technology, lack of rules, safety concerns and human-machine related implications must be overcome before widespread use is possible. Table 2 below lists the major challenges common for all the seaborne autonomous mobility projects.

Table 2. Major challenges for autonomous seaborne transportation

Challenge	Status
Scalable solutions	Several ship designers and shipyards (e.g. Damen, Swedeship and Hydrolift) are working on module-based scalable vessel designs that can be adapted to meet specific requirements.
Passenger safety	How will the passengers react to an autonomous ferry with or without crew? Several research projects have been initiated [8] [9].
Internal control system	The navigation system shall function according to the rules of the sea (ColRegs) and in a predictable manner.
Other vessels	The vessel and the control system shall respond in a safe manner to other vessels, kayakers, swimmers and flotsam. Risk analysis and safety management methods for autonomous vessels are being evaluated [10] [11].
Land based infrastructure	Docking infrastructure for automatic docking, charging/bunkering and safe embarking and disembarking of passengers.
Surveillance and control	Traffic surveillance, remote monitoring and control of vessels through a Remote Control Centre [12].
Cyber security	The threat of hacking, software and communication vulnerabilities [13].
Rescue systems	Rescue in case of collision or fire. Learn from other industries such as offshore and aquaculture [6].
Testing	Thorough testing of the vessels over time in realistic conditions [6].
National authorities	New rules must be made to govern autonomous ferry operations. A joint initiative is already underway with the Norwegian Maritime Authorities.

7. Conclusion

Safety in all senses, as mentioned in the foregoing table, is crucial for the future success of autonomous ferries. National as well as international rules and regulations have to take into consideration the new transport concepts. IMO, as well as the Norwegian Maritime Authorities, has task forces devoted to autonomy.

The similarities of the projects shown in table 1 is well suited for collaboration between the stakeholders. Collaboration is needed among users of the transportation services, the service providers (municipalities/public transport companies), shipbuilders, system suppliers, research institutions, universities and national authorities.

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