# How automated shuttles handle regular urban traffic?

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**Summary**

Researchers at TØI have been exploring different aspects of the implementation of automated shuttles in public transport services since 2018. In this text, we summarize the safety knowledge TØI has gained from several Norwegian pilot projects, wherein the shuttles have been operating in regular traffic. In these pilots we carried out external video observations with the goal of exploring the interactions between the shuttles and other traffic participants and also with a traffic signalling system. We identified several potentially risky types of behaviour, such as unexpected and abrupt stops of the shuttles in certain situations, or other road users dangerously overtaking or not giving way to the shuttles. Such knowledge is essential for ensuring smooth future operation of these shuttles in regular traffic.

***Definition***

*The automated shuttles are low speed, electric minibuses, currently operating mostly at SAE automation level 3 (i.e. there is a human operator presented on board, ready to take over operation if a situation requires it). There have been numerous deployment pilot projects of these shuttles carried worldwide, typically in urban environment or during a specific event (such as Olympic games).*

*Figure 1- The automated shuttle Navya Arma operating in Oslo in summer 2020 (photo by P. Pokorny)*

## The automated shuttles in Norway

Norway is among the most innovative countries when it comes to the application of new technologies. The Autonomous Vehicles Readiness Index, which measures the level of preparedness for automated vehicles, ranked Norway 3$^{rd}$ among 30 evaluated countries and jurisdictions, both in 2019 and 2020 (1). The recent introduction of automated shuttles into the public mobility services in several Norwegian municipalities strengthens this position.

Since 2018, thirteen automated shuttle pilot projects have been carried out in ten municipalities in Norway. This makes Norway one of the pioneering European countries in implementing these shuttles, together with France, Germany and The Netherlands (2). The pilots have had a variety of aims, such as testing V2X communication between the shuttles and a traffic signalling system, studying the effects of the shuttles on travel behaviour of residents, evaluating the interactions between the shuttles and vulnerable road users, and testing the performance of the shuttles in winter conditions. Most of pilots took place under regular traffic conditions on public roads, which make them rather unique. They were deployed in low-speed environments, such as a shared space, a sea promenade, a pedestrian zone and a residential area, typically in places without any previous public transport services. Figure 2 provides the timeline of all Norwegian pilots from 2018 to August 2021.

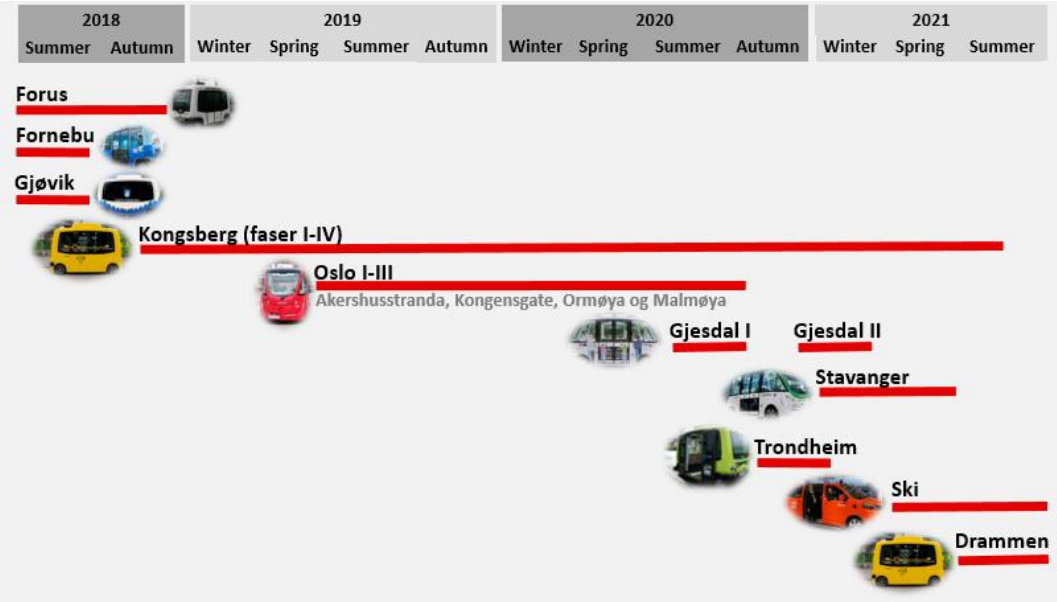


*Figure 2 – The timeline of Norwegian pilots*

Almost all Norwegian pilots used French shuttles Navya Arma (Figure 3) or EasyMile (Figure 4). Only in one project (Ski), retrofitted Toyota Proace vans were used.

*Figure 3 – Navya Arma shuttle drives along a seaside promenade in Oslo (photo by Ruter#)*

*Figure 4 – EasyMile shuttle operating in winter condition in Kongsberg (photo by T. Bjørnskau)*

In all pilots except one, the shuttles operated at SAE automation level 3, which means there was a human operator inside the shuttle, ready to take over operation if a situation required it (3). The only pilot that operated at automation level 4 (i.e. without a human operator on board) in regular traffic was conducted in Kongsberg during summer 2021.

## How automated shuttles work?

Each deployment of an automated shuttle service is a multi-step process. First, every pilot project must meet the Norwegian national legal requirements for testing of automated vehicles in public spaces. Second, it is necessary to programme the shuttle on how to drive, behave and react along the particular route. This "teaching" consists of several tasks, such as a site assessment, a mapping (i.e. creating Lidar maps to define traffic lanes, road elements and trajectory to adopt) and a manual pre-learning driving.

At the end, the shuttle is equipped with pre-trained models which must solve a variety of traffic situations in a way that allows the shuttle to follow the pre-defined trajectory. These models are not self-learning yet. Therefore, they could fail if facing a traffic situation they have not been trained for (4).

The following set of detecting/measuring components provides the shuttle with the data necessary for its operation:

- cameras and LIDAR sensors for detecting objects, obstacles, and landmarks within an established radius around the shuttle
- an inertial measurement unit (IMU) which measures acceleration, orientation, angular rates, and other gravitational forces
- a Global Navigation Satellite System (GNSS) for providing positioning, navigation, and timing
- an odometer for measuring the distance travelled

Several computer units are constantly analysing the inputs from these components to understand the surrounding environment and the position of the shuttle in this environment.

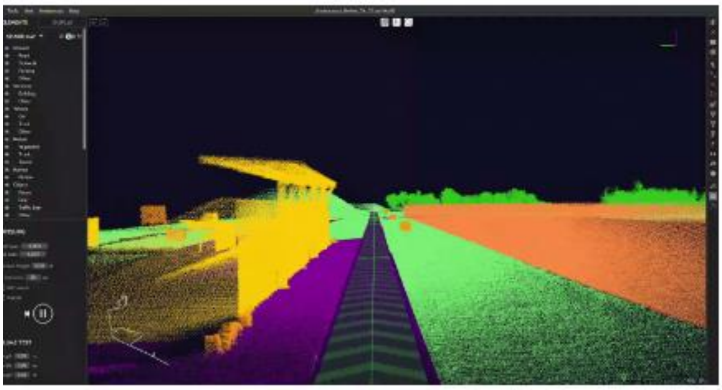

*Figure 5 – How the shuttle (Navya Arma) "sees" its surrounding (source: https://navya.tech)*

If there is a risk of collision, deviation from the trajectory or violation of a safety zone/priority area around the shuttle, the Object and Event Detection and Response technology (OEDR) calculates the appropriate trajectory and deceleration. In order to adjust the trajectory and deceleration, the shuttles are equipped with several independent braking systems, such as regenerative, hydraulic and electrical calipers, and fail-safe brakes.

## How the shuttles perform in regular traffic?

Introducing the automated shuttles into regular urban traffic leads to the emergence of new types of operational and safety challenges, including those related to: the sensitivity of sensors; the correct interpretation of traffic situations and intentions of others; and the potential behavioural adaptation of other traffic participants. Particularly pedestrians, cyclists and e-scooter users require increased attention, as they are the most vulnerable and challenging traffic participants to deal with (5). For example, according to EasyMile, a pedestrian walking alongside the shuttle and suddenly crossing in front of it, is considered as worst-case scenario for the shuttles (6).

The Norwegian pilot projects have been carried out in regular traffic, which presents a unique opportunity to pursue deeper understanding of how the shuttles handle the above mentioned challenges, and how other traffic participant react to the shuttles. TØI has been providing its research know-how in four pilot projects so far. An overview of these projects is presented in Figure 6.

| Project and duration | Funded by | Studied site(s) | Main research aim of the project | Methods |
|---|---|---|---|---|
| **AUTOBUS**<br>2018-2021 | Norwegian Research Council | Forus<br>Kongsberg<br>Oslo | To study how road users and passengers respond to the introduction of automated shuttles into road traffic in Norway, how they will interact with such vehicles and how these interactions will change over time. | ▪ Review of current knowledge<br>▪ Several types of surveys<br>▪ Video recording (cameras outside the shuttle) |
| **AUTOLYSKRYSS**<br>2020 | Norwegian Public Road Administration | Oslo | To study how the shuttles perform when driving through signalized intersections under real-life traffic conditions in city center area. | ▪ Video recording (cameras outside the shuttle) |
| **Drive2theFuture**<br>2019-2022 | EU programme Horizon 2020 | Oslo | To collect experience with the performance of the shuttle under real-life traffic conditions, particularly with right-turning maneuver of the shuttle over a bicycle lane and overtaking behaviour of other road users. | ▪ Surveys among road users<br>▪ Video recording (cameras outside and inside the shuttle) |
| **AUTOPIA**<br>2020-2022 | Norwegian Research Council | Ski | To evaluate a MaaS-solution (Mobility as a service) that includes automated shuttles operating in a residential area (sharing the road space with pedestrians) | ▪ Surveys among road users<br>▪ Video recording (cameras outside and inside the shuttle |

*Figure 6 - Overview of the pilots in which TØI has been involved since 2018*

In all these projects, TØI conducted the exploratory analysis of several hundred hours of video recordings, using the method of video observation. The aim was to identify risky or peculiar types of reactions and behaviour, both of the shuttles and other traffic participants. The analyses covered different traffic environments, such as a residential area, a road with signalised intersections, a pedestrian zone, a downtown area, and a road with a bicycle lane.

## *How the video observation works?*

*Video observation has three main steps. First, the location of interest is recorded with a camera. Second, the shuttles are detected in the video and short video clips containing a manoeuvre of each shuttle are cut. Third, these clips are viewed and analysed by a road safety researcher.*

*At TØI, we use two types of cameras to collect the video data. The first type is a static external camera, usually located on a lighting or a traffic sign pole along the shuttle's route. It records a selected area during a predefined time, typically for several weeks (Figure 7 - left). The second type is an internal dashboard camera, which records the road in front and/or behind the shuttle (Figure 7 - right).*

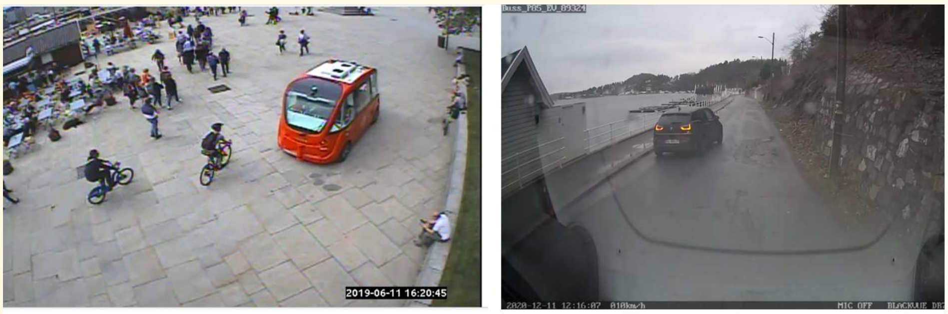


*Figure 7 – Views from the external (left, video 1) and from the front internal camera (right, video 2)*

*We process and analyse the video data with several tools, such as a software for detecting moving objects in the video (RUBA), a software for analysing traffic conflicts (T-Analyst, Figure 8), and common video/image viewers. We also gather the data from the shuttle's sensors, such as speed, deceleration, or time of disengagement.*


*Figure 8 – An example of the analysis conducted in T-Analyst (here, the shuttle stopped hard to give way to a cyclist – video 3)*

*When analysing the video clips, a researcher briefly describes the observed situation and collects a set of variables (such as maneuverer of the shuttle, intensity of its reaction, compliance with traffic rules, types of other traffic participant, their positions etc.). These data enable to categorise the interactions between the shuttles and other traffic participants, and identify risky or peculiar behaviour.*

The shuttles performed well in the majority of observed traffic situations, and there was no accident recorded. However, we identified several risky or peculiar types of reactions and behaviours. The main findings are summarised in the following:

- The automated mode of the shuttles is characterised by a defensive style, slow speed, stereotypical trajectory and strict adherence to traffic rules. When encountering such cautiousness, some car drivers engaged in hazardous behaviour. We observed two such examples:
  1) Car drivers were overtaking the shuttle at locations where it was potentially risky or illegal (*videos 2, 4 and 5*). At one location in Oslo (Vippetangen), 14 percent of drivers who had the opportunity to overtake the shuttle did so, despite it being illegal at that location (crossing double yellow line). We have been conducting more detailed analyses of this risky behaviour within EU project Drive2TheFuture. In this project, we designed and evaluated a sign that was placed inside the shuttles operating in residential area Ormøya. The sign advised drivers to carefully overtake the shuttles.
  2) Car drivers were not giving way to the shuttle at intersections with right-hand yielding rule (*video 6*). In the residential area of Hebekk in Ski, 50 percent of drivers were not giving way to the shuttle at T-intersections.
- The shuttles often hesitated when entering a signalised intersection at the moment of traffic signal change from green to red (*video 7*).
- The shuttles reacted exaggeratedly in relatively simple traffic situations, when another traffic participant was in a proximity of the shuttle's predefined trajectory/priority zone (*videos 1, 8 and 9*) or was placed in an "untypical" position *(video 10 – a cyclist waits for the green light inside the intersection)*. The shuttle usually stopped (often hard) in these situations. Sometimes, the shuttle stopped even without any obvious reasons or reacted to non-traffic related situations *(video 15 – the shuttle reacts to a bird)*. After a hard stop, the shuttle often had a problem with restarting (*video 11*) and the operator had to take over the driving. These unexpected and hard stops can surprise other drivers in traffic and increase the risk of rear-end collisions. Furthermore, hard stops can be uncomfortable and even dangerous for passengers inside the shuttle. Additionally, such behaviour limits the smooth operation of the shuttles. This was well demonstrated in the residential area in Ski. At this particular site, in order to avoid the unnecessary stops caused by pedestrians walking too close to the shuttle's trajectory, the operators were proactively taking over the driving when they saw a pedestrian ahead.
- We observed a few instances in which the shuttle did not give way to a pedestrian who was crossing a zebra crossing from the left (*video 12*).
- We observed situations, when the other traffic participants hesitated in the proximity of the shuttle. Most likely they were not sure about the intentions of the shuttle. This sometimes resulted in a "stale-mate" scenario, when both the shuttle and other traffic participant stopped, unsure about who should go first (*videos 13 and 14*). In these situations, the operator inside the shuttle typically took over the driving to solve the situation.
- The shuttles were mostly driving in automated mode, however, sometimes they were driven manually. Despite these two modes being visually distinguishable, some traffic participant can misjudge the shuttle's mode and her/his expectations

regarding the shuttle behaviour/reactions might not be accurate. This especially affects the people who encounter the shuttle frequently and have some expectations regarding the shuttles' behaviour.

**Conclusion**

Safety is obviously the biggest concern when implementing the automated shuttles in traffic. Because of low mileage driven by the shuttles so far and specific characteristics of the environment they operate in, only very few accidents have occurred worldwide. These are typically slight accidents involving another road user hitting the shuttle. However, each of these accidents attracts considerable attention from the media and reinforces scepticism regarding the suitability of these shuttles in regular traffic. The latest reported accident occurred at the Tokyo Paralympic games. It was different from other accidents, because a Toyota shuttle drove through a pedestrian crossing and hit a visually impaired athlete. The athlete was walking across, while the shuttle expected him to stop (*such scenario is reminiscent of the conflict situation captured on this video from* Oslo). In response to the accident in Tokyo, the president of Toyota declared that "*autonomous vehicles are not yet realistic for normal roads.*"

The successful full implementation of automated shuttles in regular traffic will not be possible without a deeper understanding of their interactions with other traffic participants. The limited number of accidents means that researchers must evaluate safety of the shuttles using observational types of studies. In the Norwegian pilots, we observed that the shuttles were reacting oddly in a variety of traffic situations and a human operator was needed to solve many of these situations. It was obvious that we are still long way from the shuttles operating smooth in regular traffic without a human operator (SAE level 4 and more). Furthermore, the shuttles' defensive driving style was associated with dangerous behaviour of some road users.

However, the pace of the technology development is enormous, and the existing problems will probably be solved in a very near future. Public transport operators and municipalities are eager to add the automated shuttles into their regular public transport services, especially in areas without existing public transport services. In addition, the public is generally positive towards the shuttles, despite occasional spikes in skepticism. The safety research must, therefore, closely follow the rapid development of these shuttles and their deployments into traffic. As for the shuttles, the crucial technological and software challenges are the correct detection and interpretation of traffic situations (especially in interactions with pedestrians, cyclists and e-scooter users), intensity of braking, and communication with other road users. The research must focus not only on the shuttles, but also on how other traffic participants perceive them, how they behave when encountering the shuttles, and why they behave in such ways.

Readers can find the complete results of TØI projects on automated shuttles in the following reports and research articles:

- TØI report 1822/2021: Performance of automated shuttles at signalised intersections.
- Final seminar of AUTOBUS project
- Automated bus systems in Europe: A systematic review of passenger experience and road user interaction (2020). *Heikoop, Velasco, Boersma,*

*Bjørnskau, Hagenzieker.* Advances in Transport Policy and Planning, vol. 5, pp 51-71.

- Video observation of encounters between the right-turning automated shuttle and other traffic participants at a non-signalised T-intersection in Oslo (2021). *Pokorny, Skender, Bjørnskau, Hagenzieker.* Manuscript accepted in European Transport Research Review.

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