Automated vehicles to Evolve to a New Urban Experience

DELIVERABLE

D7.9 Final iteration Copenhagen Large Scale Pilot Use Case Demonstration Report

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Acronyms

ADS	Automated Driving Systems
AI	Artificial Intelligence
AM	Automated Mobility
API	Application Protocol Interface
AV	Automated Vehicle
BM	Bestmile
BMM	Business Modelling Manager
CAV	Connected and Automated Vehicles
CB	Consortium Body
CERN	European Organization for Nuclear Research
D7.1	Deliverable 7.1
DC	Demonstration Coordinator
DI	The department of infrastructure (Swiss Canton of Geneva)
DMP	Data Management Plan
DSES	Department of Security and Economy - Traffic Police (Swiss Canton of Geneva)
DTU test track	Technical University of Denmark test track
EAB	External Advisory Board
EC	European Commission
ECSEL	Electronic Components and Systems for European Leadership
EM	Exploitation Manager
EU	European Union
EUCAD	European Conference on Connected and Automated Driving
F2F	Face to face meeting
FEDRO	(Swiss) Federal Roads Office
FOT	(Swiss) Federal Office of Transport
GDPR	General Data Protection Regulation
GIMS	Geneva International Motor Show
GNSS	Global Navigation Satellite System
HARA	Hazard Analysis and Risk Assessment
IPR	Intellectual Property Rights
IT	Information Technology
ITU	International Telecommunications Union
LA	Leading Author
LIDAR	Light Detection And Ranging
MEM	Monitoring and Evaluation Manager
MT	MobileThinking
OCT	General Transport Directorate of the Canton of Geneva
ODD	Operational Domain Design
OEDR	Object And Event Detection And Response
OFCOM	(Swiss) Federal Office of Communications
PC	Project Coordinator
PEB	Project Executive Board
PGA	Project General Assembly
PRM	Persons with Reduced Mobility
PSA	Group PSA (PSA Peugeot Citroën)
PTO	Public Transportation Operator
PTS	Public Transportation Services
QRM	Quality and Risk Manager
QRMB	Quality and Risk Management Board
RN	Risk Number
SA	Scientific Advisor
SAE Level	Society of Automotive Engineers Level (Vehicle Autonomy Level)
SAN	(Swiss) Cantonal Vehicle Service
SDK	Software Development Kit
SLA	Sales Lentz Autocars
SMB	Site Management Board
SoA	State of the Art
SOTIF	Safety Of The Intended Functionality
SWOT	Strengths, Weaknesses, Opportunities, and Threats.
T7.1	Task 7.1
TM	Technical Manager
TPG	Transport Publics Genevois
UITP	Union Internationale des Transports Publics (International Transport Union)
V2I	Vehicle to Infrastructure communication
WP	Work Package
WPL	Work Package Leader

Executive Summary

This deliverable, D7.9, introduces the organisation, the operation and the evaluation of the large scale demonstrator pilot site with

automated vehicles for public transport in the Nordhavn area in Copenhagen, Denmark. The route, homologation of it and the challenges will be presented. This report highlights the reason why the site was shut down and introduces a new AVENUE site, that Amobility will be operating in the project: Slagelse Hospital.

The Norwegian site that was included in the AVENUE project will be described and learnings will be presented. A data summary of the Norwegian and the two Copenhagen sites will be presented with the purpose of showcasing in numbers some of the experience from the sites.

The e-mini bus is operated at low speeds, due to technical limitations and the current risk assessment of the vehicle capabilities and the road conditions for the routes operated by Amobility. The low speeds have shown to be a weighing factor for how people perceive the technology and the service itself. Many of the travellers perceive the e-minibus as too slow to really depend on in daily transport patterns. But sees the technology as exciting and with many potential upsides to society.

A data comparison of the three sites will be presented taking road complexity, data and uptime quality into account - ultimately showing that the Slagelse site is the best site for deployment of Navya vehicles, due to the perfect circumstances for autonomous driving and clear designated lanes for other road participants.

This deliverable will also include learnings from other projects with Automated minibuses conducted by AM

1 Introduction

AVENUE aims to design and carry out full-scale demonstrations of urban transport automation by deploying, for the first time worldwide, fleets of Automated minibuses in low to medium demand areas of 4 European demonstrator cities (Geneva, Lyon, Copenhagen and Luxembourg) and 2 to 3 replicator cities. The AVENUE vision for future public transport in urban and suburban areas, is that Automated vehicles will ensure safe, rapid, economic, sustainable and personalised transport of passengers. AVENUE introduces disruptive public transportation paradigms on the basis of on-demand, door-to-door services, aiming to set up a new model of public transportation, by revisiting the offered public transportation services, and aiming to suppress pre-scheduled fixed bus itineraries.

Vehicle services that substantially enhance the passenger experience as well as the overall quality and value of the service will be introduced, also targeting elderly people, people with disabilities and vulnerable users. Road behaviour, security of the Automated vehicles and passengers' safety are central points of the AVENUE project.

At the end of the AVENUE project four-year period the mission is to have demonstrated that Automated vehicles will become the future solution for public transport. The AVENUE project will demonstrate the economic, environmental and social potential of Automated vehicles for both companies and public commuters while assessing the vehicle road behaviour safety.

1.1 On-demand Mobility

Public transportation is a key element of a region's economic development and the quality of life of its citizens.

Governments around the world are defining strategies for the development of efficient public transport based on different criteria of importance to their regions, such as topography, citizens' needs, social and economic barriers, environmental concerns and historical development. However, new technologies, modes of transport and services are appearing, which seem very promising to the support of regional strategies for the development of public transport.

On-demand transport is a public transport service that only works when a reservation has been recorded and will be a relevant solution where the demand for transport is diffuse and regular transport is inefficient.

On-demand transport differs from other public transport services in that vehicles do not follow a fixed route and do not use a predefined timetable. Unlike taxis, on-demand public transport is usually also not individual. An operator or an automated system takes care of the booking, planning and organization.

It is recognized that the use and integration of on-demand Automated vehicles has the potential to significantly improve services and provide solutions to many of the problems encountered today in the development of sustainable and efficient public transport.

1.2 Fully Automated Vehicles

A self-driving car, referred to in the AVENUE project as **a Fully Automated Vehicle** (**AV**), also referred as Autonomous Vehicle, is a vehicle that is capable of sensing its environment and moving safely with no human input.

The terms *automated vehicles* and *autonomous vehicles* are often used together. The Regulation 2019/2144 of the European Parliament and of the Council of 27 November 2019 on type-approval requirements for motor vehicles defines "automated vehicle" and "fully automated vehicle" based on their autonomous capacity:

- An "automated vehicle" means a motor vehicle designed and constructed to move autonomously for certain periods of time without continuous driver supervision but in respect of which driver intervention is still expected or required
- "fully automated vehicle" means a motor vehicle that has been designed and constructed to move autonomously without any driver supervision

In AVENUE we operate ***Fully Automated minibuses for public transport***, (previously referred as Autonomous shuttles, or Autonomous buses), and we refer to them as simply *Automated minibuses* or *the AVENUE minibuses.*

In relation to the SAE levels, the AVENUE project will operate SAE Level 4 vehicles.

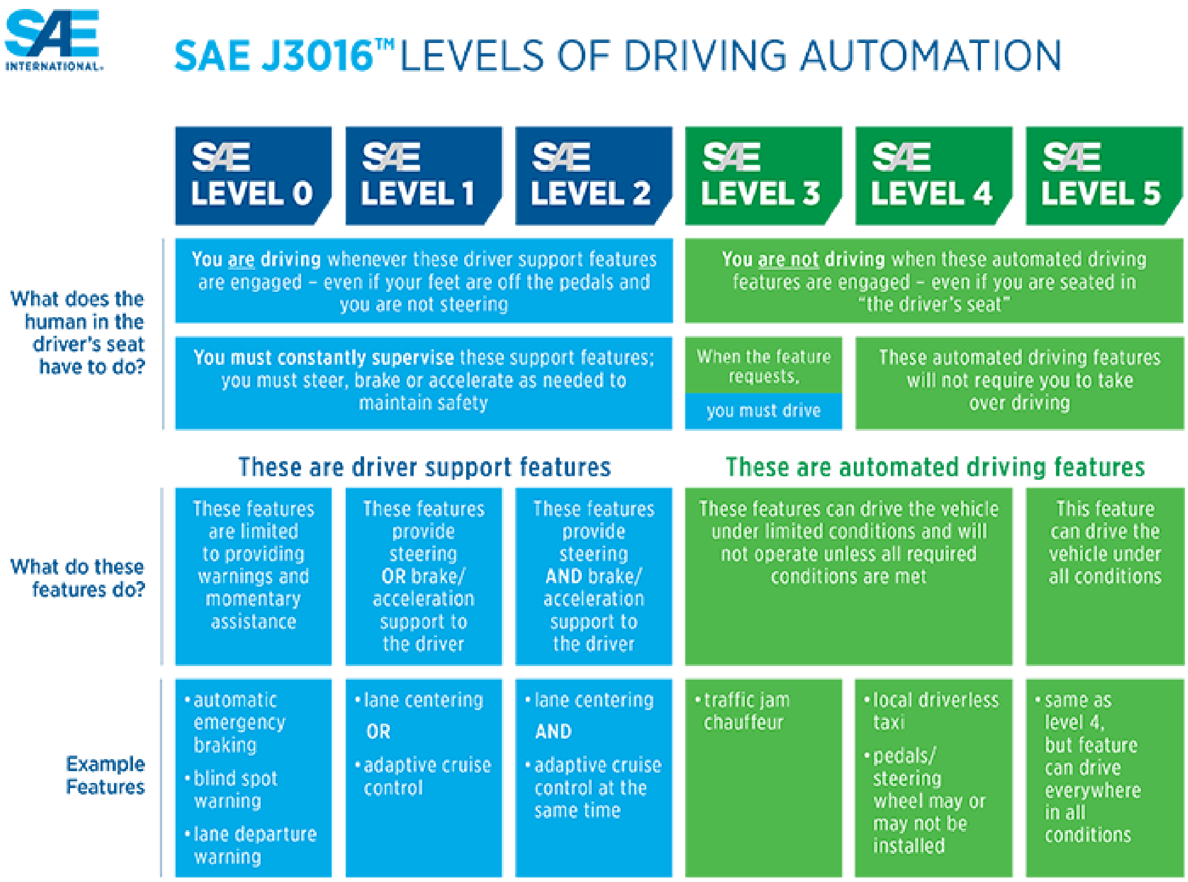


Figure 1.1: SAE Driving Automation levels (©2020 SAE International)

1.2.1 Autonomous vehicle operation overview

We distinguish in AVENUE two levels of control of the AV: micro-navigation and macro-navigation. Micro navigation is fully integrated in the vehicle and implements the road behaviour of the vehicle, while macro-navigation is controlled by the operator running the vehicle and defines the destination and path of the vehicle, as defined in the higher view of the overall fleet management.

For micro-navigation, Automated Vehicles combine a variety of sensors to perceive their surroundings, such as 3D video, LIDAR , sonar, GNSS, odometry and other types of sensors. Control software and systems, integrated in the vehicle, fusion and interpret the sensor information to identify the current position of the vehicle, detecting obstacles in the surrounding environment, and choosing the most appropriate reaction of the vehicle, ranging from stopping to bypassing the obstacle, reducing its speed, making a turn etc.

For the Macro-navigation, that is the destination to reach, the Automated Vehicle receives the information from either the in-vehicle operator (in the current configuration with a fixed path route), or from the remote control service via a dedicated 4/5G communication channel, for a fleet-managed operation. The fleet management system takes into account all available vehicles in the services area, the passenger request, the operator policies, the street conditions (closed streets) and sends route and stop information to the vehicle (route to follow and destination to reach).

1.2.2 Automated vehicle capabilities in AVENUE

The Automated vehicles employed in AVENUE fully and automatically manage the above defined, micro-navigation and road behaviour, in an open street environment. The vehicles are Automatically capable to recognise obstacles (and identify some of them), identify moving and stationary objects, and Automatically decide to bypass them or wait behind them, based on the defined policies. For example with small changes in its route the AVENUE mini-bus is able to bypass a parked car, while it will slow down and follow behind a slowly moving car. The AVENUE mini-buses are able to handle different complex road situations, like entering and exiting round-about in the presence of other fast running cars, stop in zebra crossings, and communicate with infrastructure via V2I interfaces (ex. red light control).

The mini-buses used in the AVENUE project technically can achieve speeds of more than 60Km/h. However this speed cannot be used in the project demonstrators for several reasons, ranging from regulatory to safety. Under current regulations the maximum authorised speed is 25 or 30 Km/h (depending on the site). In the current demonstrators the speed does not exceed 23 Km/h, with an operational speed of 14 to 18 Km/h. Another, more important reason for limiting the vehicle speed is safety for passengers and pedestrians. Due to the fact that the current LIDAR has a range of 100m and the obstacle identification is done for objects no further than 40 metres, and considering that the vehicle must safely stop in case of an obstacle on the road (which will be “seen” at less than 40 metres distance) we cannot guarantee a safe braking if the speed is more than 25 Km/h. Note that technically the vehicle can make a harsh break and stop with 40 metres in high speeds (40 -50 Km/h) but then the break would be too harsh putting in risk the vehicle passengers. The project is working in finding an optimal point between passenger and pedestrian safety.

Due to legal requirements a **Safety Operator** must always be present in the vehicle, able to take control any moment. Additionally, at the control room, a **Supervisor** is present controlling the fleet operations.

An **Intervention Team** is present in the deployment area ready to intervene in case of incident to any of the mini-busses. Table 2 provides an overview of the AVENUE sites and OODs

	Summary of AVENUE operating sites demonstrators							
	TPG		Holo			Keolis	Sales-Lentz	
	Geneva		Copenhagen	Oslo	Copenhagen	Lyon	Luxembourg	
Site	Meyrin	Belle-Idée	Nordhavn	Ormøya	Slagelse	ParcOL	Pfaffental	Contern
Funding	TPG	EU + TPG	EU + Holo	EU + Holo	EU + Holo	EU + Keolis	EU + SLA	EU + SLA
Start date of project	August 2017	May 2018	May 2017	August 2019	August 2020	May 2017	June 2018	June 2018
Start date of trial	July 2018	June 2020	September 2020	December 2019	August 2021	November 2019	September 2018	September 2018
Type of route	Fixed circular line	Area	Fixed circular line	Fixed circular line	Area	Fixed circular line	Fixed circular line	Fixed circular line
Level of on-demand service*	Fixed route / Fixed stops	Flexible route / On-demand stops	Fixed route / Fixed stops	Fixed route / Fixed stops	Flexible route / On-demand stops	Fixed route/Fixed stops	Fixed route / Fixed stops	Fixed route / Fixed stops
Route length	2,1 km	38 hectares	1,3 km	1,6 km	5,5 km	1,3 km	1,2 km	2,3 km
Road environment	Open road	Semi-private	Open road	Open road	Open road	Open road	Public road	Public road
Type of traffic	Mixed	Mixed	Mixed	Mixed	Mixed	Mixed	Mixed	Mixed
Speed limit	30 km/h	30 km/h	30 km/h	30 km/h	30 km/h	8 to 10 km/h	30 km/h	50 km/h
Roundabouts	Yes	Yes	No	No	No	Yes	No	No
Traffic lights	No	No	No	No	No	Yes	Yes	Yes
Type of service	Fixed line	On demand	Fixed line	Fixed line	On demand	Fixed line	Fixed line	Fixed line
Concession	Line (circular)	Area	Line (circular)	Line (circular)	Area	Line (circular)	Line (circular)	Line (circular)
Number of stops	4	> 35	6	6	7	2	4	2
Type of bus stop	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed

Bus stop infrastructure	Yes	Sometimes, mostly not	Yes	Yes	Yes	Yes	Yes	Yes
Number of vehicles	1	3-4	1	2	2	2	2	1
Timetable	Fixed	On demand	Fixed	Fixed	On-demand	Fixed	Fixed	Fixed
Operation hours	Monday-Friday (5 days)	Sunday-Saturday (7 days)	Monday-Friday (5 days)	Monday-Sunday (7 days)	Monday-Friday (5 days)	Monday-Saturday (6 days)	Tuesday & Thursday Saturday, Sunday & every public holiday	Monday - Friday
Timeframe weekdays	06:30 – 08:30 / 16:00 – 18:15	07:00 – 19:00	10:00 – 18:00	7:30 – 21:30	07:00-16:00	08:30 – 19:30	12:00 – 20h00	7:00 – 9:00 16:00 – 19:00
Timeframe weekends	No service	07:00 – 19:00	No service	9:00 – 18:00	No service	08:30 – 19:30	10:00 – 21:00	No Service
Depot	400 meters distance	On site	800 meters distance	200 meters distance	On site	On site	On site	On site
Driverless service	No	No	No	No	No	No	No	No
Drive area type/ODD	B-Roads	Minor roads/parking	B-Roads/minor roads	B-Roads	B-Roads/parking	B-Roads	B-Roads	B-Roads/parking
Drive area geo/ODD	Straight lines/plane	Straight lines/ plane	Straight lines/ plane	Curves/slopes	Straight lines / curves	Straight Lines/ plane	Straight lines/ plane	Straight lines/ plane
Lane specification/ODD	Traffic lane	Traffic lane	Traffic lane	Traffic lane	Traffic lane	Traffic lane	Traffic lane	Traffic lane
Drive area signs/ODD	Regulatory	Regulatory	Regulatory, Warning	Regulatory	Regulatory	Regulatory	Regulatory	Regulatory
Drive area surface/ODD	Standard surface, Speedbumps	Standard surface, Speedbumps	Standard surface Speedbumps, Roadworks	Frequent Ice, Snow	Standard surface, snow during winter	Standard surface, Potholes	Standard surface	Standard surface

Table 1.1: Summary of AVENUE operating site (+ODD components)

1.3 Preamble

Work package WP7 organises, runs and evaluates these large scale demonstrators of the automated vehicle services for public transport, targeting different user groups, and transport models. The goal is to validate a high quality, safe service, which will enhance the acceptance and adoption of automated vehicles for public transport.

The overall aim of task T7.3 is to test and implement the autonomous mobility Cloud – and thereby creating a better connection between selected areas of Copenhagen and existing public transport solutions.

By offering cloud based AM, Autonomous Mobility (AM) aims at providing a transport service to fulfil the changing transportation at the time users need it. The service is shared and on-demand which is more flexible than we're used to. This will provide a customised user experience of a whole new and better way of getting from A to B. When the autonomous mobility cloud is implemented, the activity of the vehicles will be determined by the users' needs. This will not only reduce the number of parked cars by the street side, it will also optimise the use of capacity in each vehicle and on the lanes.

The mobility cloud will be developed and tested to the extent possible in the AVENUE project. The approach is to build and test critical components with the purpose of testing them and establish a better understanding of what it takes to provide the mobility platform in the future. A very important aspect of the mobility platform is to connect and integrate with påublic transport and in this case Amobility will fully integrate with Copenahgen based large PTA Movia on ensuring on-demand shuttle services at Slagelse Hospital.

1.4 The AM Organisation

The city of Copenhagen has an overall goal to become the World's first CO2-neutral capital by 2025. AM and the AVENUE project will support this goal by implementing and operating autonomous electric shuttles in Copenhagen and Slagelse as a green initiative to first-mile last-mile public transport.

The overall goal for AM is to implement and test services under the autonomous mobility Cloud on the Copenhagen and Slagelse site. In order to do so, AM aims at deploying up to four vehicles over a period of four years, while working towards expanding and developing the sites. These routes will create a better connection between selected areas of Copenhagen and existing public transport solutions. On the Slagelse site AM will make a public transport integration with Copenhagen based PTA Movia.

During the AVENUE project, AM wants to further expand the portfolio of vehicles and vessels to create more advanced features and integrations with the Mobility Cloud to the extent possible with the technologies available.. The whole system is planned to integrate with existing PTO solutions in the Copenhagen area - such as Movia.

The Am services should be experienced as "Helpful, Simple & Seamless": When automated vehicles become an integrated part of the cityscape, the user will be able to define her transport needs - and order her solution via AM's autonomous mobility Cloud. Shortly after the user will get picked up exactly at his/her location and will be transported to the end destination chosen. The cloud will also be shaped so that it can move goods and parcels - all in various shapes and sizes - around when needed.

At the end of this project, AM aims to have developed, implemented and tested important components of the autonomous mobility cloud to the extent possible, in an on-demand (door2door) autonomous transport system.

2 Project homologation

In January 2017 a change of the traffic act[1] was put forward, and by May 2017 the law was enacted, upon request from 2 Danish municipalities. The change of law made it possible to obtain permission to carry out pilot projects involving autonomous vehicles on public roads in Denmark. Such permission was not given before 2 years later, where AM was granted approval to operate the first autonomous vehicles on the roads in Aalborg. Since the law was enacted a total of 4 projects has been approved under the current legislation. In 2022 the law is up for review in the Ministry of Transport[2]. AM has been granted 3 of the 4 permits for operating projects with autonomous vehicles, herunder 2 out of the 3 permits are a part of AVENUE.

In the following a descriptive section of the current legislative framework and application requirements in Denmark will be provided.

2.1 Approval process

The Danish approval process for projects with autonomous vehicles is by far the most comprehensive and complex process compared to other Nordic countries, where AM has been granted permits to operate autonomous vehicles on public roads.

A permit is granted by the Danish Road Directorate (hereafter referred to as DRD). However, before an application can be submitted to the DRD an approval of the project must be obtained by both a third party assessor and the Danish Road Safety Agency (hereafter referred to as DRSA). Moreover, applicants must obtain permits from municipalities (road owners) and permits/dispensations from DRSA to conduct public transportation of passengers (Vejdirektoratet).

The following visualisation shows the legislative framework and the process for obtaining permits to conduct pilot projects with autonomous vehicles in Denmark

[1] Folketinget. "L 120 - 2016-17 (oversigt): Forslag til lov om ændring af færdselsloven. (Bemyndigelse til at fastsætte regler om og give tilladelse til forsøg med selvkørende motorkøretøjer)." *Folketinget.dk*, https://www.ft.dk/samling/20161/lovforslag/L120/index.htm. Accessed 12 November 2021.

[2] Ministry of Transport. "Konference om fremtidens transportformer." *Transportministeriet*, 26 October 2021, https://www.trm.dk/ministeriet/ministeriet-artikler/konference-om-fremtidens-transportformer/. Accessed 12 November 2021.

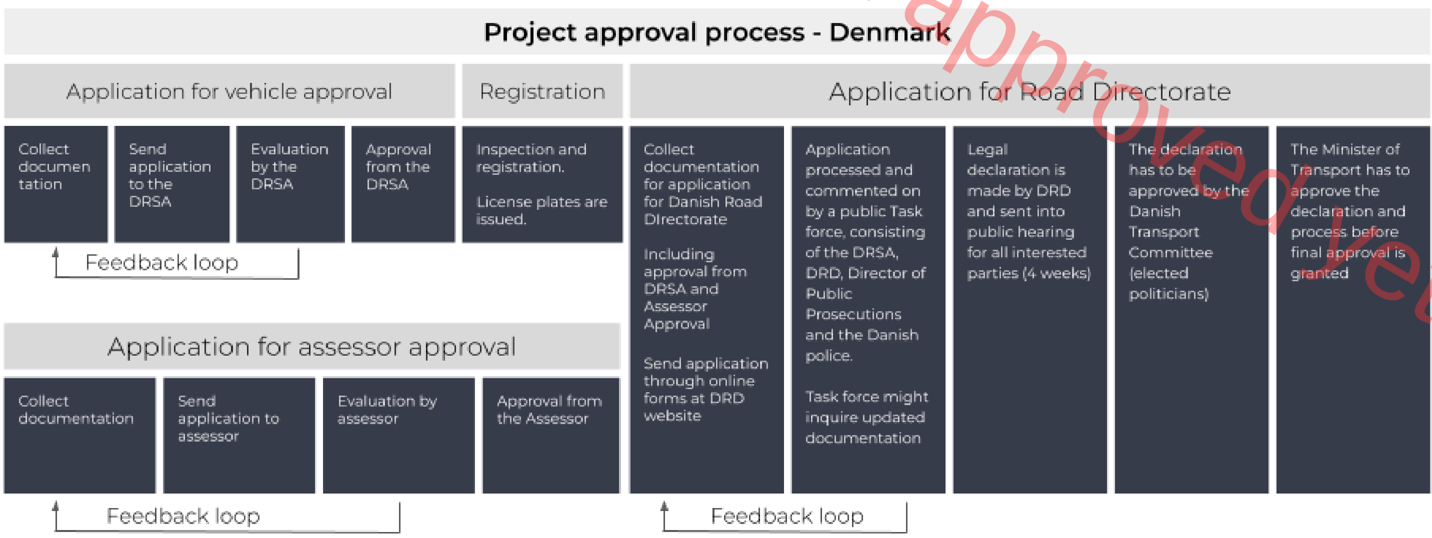


Figure 2.1: Project approval process - Denmark

The project approval process is further outlined in the below steps:

1. A single Vehicle Approval for the AV(s) has to be granted by the DRSA if the vehicle is not EU type approved, which is not yet possible for AVs
2. An impartial third party, called an assessor (appointed by Danish law) has to approve the overall project and write a statement supporting that the traffic risks of performing the project is acceptable
3. The road-owner (typically the municipality) must grant an approval for the project to be carried out on the specified route(s)
4. Once Vehicle Approval, Assessor approval and approval by the road-owner(s) has been obtained an application can be sent to the DRD. An application must include the three (3) above granted approvals and some additional descriptions of the project
5. The material has to be processed and commented on by a public Task force, consisting of the Danish Road Safety Agency, Danish Road Directorate, Director of Public Prosecutions and the Danish police
6. A legal declaration is then made and sent into public hearing for all interested parties, minimum four (4) weeks in public hearing is required
7. The declaration then has to be approved by the Danish Transport Committee (elected politicians)
8. Finally, the Minister of Transport will approve the declaration and permits are granted by DRD

2.1.1 Assessor approvals

In Denmark, the entire project is evaluated by a third party assessor with traffic safety competencies - e.g. a specialised engineering consultancy company. The third party assessor evaluates all aspects of the project in relation to traffic safety. Therefore, if some vehicle technical aspects, or vehicle features, will impact traffic safety in any way, assessors will have the right to question or demand things changed, even though the vehicle has been approved by the DRSA. For example a wheelchair securement solution might be approved by the DRSA because it complies with the national regulations, but the assessor finds that it negatively impacts traffic- or passenger safety - e.g. by increasing the risk of passengers falling. In that case, the assessor will have the right to reject the solution.

Assessors will write a safety assessment report, which must support that the project can be carried out safely, this report will be part of the application for approval to the DRD. Assessors have been given the following areas by the DRD, for review and assessment of traffic safety for the given project:

- General traffic behaviour
- IT and data, herunder how data is logged
- Technical vehicle features/functionalities
- Infrastructure and road technic
- Organisation and resources
- Risk management

Assessors will have to be approved by DRSA before they can fulfil the role of assessor for the specific project. DRSA will evaluate the competencies of the applicant and the method for traffic safety assessment, to ensure that the traffic safety assessment is unbiased and objective (Retsinformation, bekendtgørelse om assessorer).

The company applying for approval of the autonomous project is paying for the third party evaluation, in this case, AM. The law states that the assessor holds the responsibility for assessing traffic risks and safety in the autonomous pilot project. Thereby, a great deal of time has been spent on agreeing with the assessor and the authorities on a sufficient level of documentation. Hence, AM has spent a large amount of time on application material, including defining and documenting standard operating procedures, crisis management processes etc.

There has long been a tradition in Denmark for using assessors in rail projects. And this idea of having experts in the field assessing the risks of an autonomous project might be feasible for high complex autonomous projects. However, it is a time-consuming and expensive setup and it currently does not match well with the low-speed and simplistic projects which are being carried out - with SAE level 3 vehicles.

The following table introduces the parts (chapters and information) necessary in the assessor application for homologation of each routel:

Chapter	Information
Project description	- Introduction - Objectives - Methodology and structure - Partners - Length of project - Operational hours applied for - Method for evaluation of the project
Legal framework	- Description of legal framework - Test-framework
Vehicle description	- Capabilities - Capacities - Technical aspects

	- Feature descriptions: Autonomous driving - Feature descriptions: Manual driving - Vehicle hardware - Safety related software features; localization, object detection, braking and deceleration/acceleration - Implementation processes; commissioning, mapping and validation - Safety validation and third party testing of the vehicle
Vehicle connectivity	- Basestation/N-trip - 4G - Cyber security features
Route description	- Route length - Schedule of operations - Garage placement and route - Depot - Changes to infrastructure
Bus stop description	- Concessions - Positions - Identification
Organisation	- Roles and responsibilities - Trainers & training plans - Job descriptions for Safety operators - Job descriptions for Supervisors - Standard operating procedures - Crisis procedures and crisis processes - CVs of key employees - Project organisational chart
Data description	- Data handling processes - GDPR compliance - API integrations - System descriptions - Data sharing and processes in case of incidents
Risk handling (internal)	- Safety organisation - Risk processes (related to risk assessment) - Compliance - Crisis management
Risk-assessment (external)	- Risk identification - Potential pitfalls - Mitigating actions - Risk process - Evaluation of project risks

Table 2.1: Documentation for assessor application

Aside from providing sufficient documentation in the above areas of interest AM has also spent significant time on implementing the documented procedures and processes. For example AM has had to ensure the accessibility to published standard operating procedures for all AM safety drivers. This also entails training and follow up training in case of changes in procedures. The processes for how follow-up training is done and how changes to standard procedures are evaluated, is another element that has been part of the assessment by a third party assessor.

The application to assessors for AVENUE projects in Denmark (Nordhavn and Slagelse) exceeded a thousand (1000) pages of documentation including appendices.

2.1.2 Vehicle approvals

As demonstrated in figure 2.1: *Project approval process - Denmark*, applicants must provide DRD with a vehicle approval granted by DRSA. This can mean either a EU vehicle type approval or a single vehicle approval granted by the Danish Road Safety Agency. The type approval directive is not yet updated/revised to accommodate autonomous vehicles and thereby a single vehicle approval is necessary for each vehicle used in the AVENUE project. Technical vehicle documentation is provided to the DRSA for Vehicle Approvals, this also includes specifications for wheelchair anchorage solutions, seatbelt and ramps.

The applicant must collect the necessary documentation required to obtain the vehicle approval and send the full package of documentation to the DRSA. The documentation is evaluated and assessed based on the project in question and the compliance with current legislation.

The DRSA is solely responsible for evaluating the technical application. In this application, the vehicle technical aspects are evaluated, mainly based on the compliance with *"Bekendtgørelse om detailforskrifter for køretøjers indretning og udstyr"*; the '*Danish regulatory requirements regarding vehicles layout and equipment'*. This regulation is largely based on the EU Directive 2007/46/EC. The DRSA evaluates the vehicle platform and not the autonomous functionalities or the functional safety of the vehicle. They will, however, base their decisions on the SAE level of automation which is applied for in the project, and the purpose of the project herunder the proposed route/area of operation.

Applications for exemptions regarding the Danish regulatory requirements are evaluated based on aforementioned non-vehicle specific conditions i.e. speed of the vehicle, route complexities etc.

Listed below are the areas of the Danish regulations regarding vehicles' layout and equipment where AM has been granted exemptions for the Navya Arma vehicles. Moreover, the reasoning behind the application for exemption is provided. Applications for exemptions are made for the DRSA and therefore on the basis of the Danish regulation. Danish regulations are however based on UN ECE 2007/46/EC.

Regulation	**Reasoning behind exemptions**	**Terms and conditions (by the DRSA)**
Motorised vehicles must have a steering mechanism with a mechanical link between the control device and the steering wheels.	The vehicle is a self-driving vehicle designed for SAE level 4, thus there are major differences in design and use compared to ordinary cars in category M2 on SAE level 0 to 3. The vehicle does not have a steering column and it is not possible to retrofit this. Any possible risks will be evaluated by the risk assessor associated with the project.	None
There must be a mechanical link for wheels fitted with assisted steering, provided it meets requirements about assisted steering in ECE R79-01	The vehicle is a self-driving vehicle designed for SAE level 4, thus there are major differences in design and use compared to ordinary cars in category M2 on SAE 0 to 3. The vehicle does not have a steering column and it is not possible to retrofit this. Any possible risks will be evaluated by the risk assessor associated	None

	with the project.	
Cars in category M2 must be fitted with ABS of category 1.	The vehicle is a self-driving vehicle designed for SAE level 4, thus there are major differences in design and use compared to ordinary cars in category M2 on SAE 0 to 3. During operation of the vehicle in the project period, there will at all times be an in-vehicle operator present. The in-vehicle operator is trained and instructed in the following procedures: ● The in-vehicle operator must at all times have a clear view when in the vehicle ● The in-vehicle operator must at all times be able to monitor the traffic situation ● The in-vehicle operator must only carry seated passengers ● The in-vehicle operator always has absolute control over the braking system through the control device, and must be aware of possible increased braking distance. When the vehicle is not manned by an in-vehicle operator, the vehicle is at all times surveilled by a supervision centre. This team is able to move out within 15 minutes and has continuous video monitoring and the ability to speak with passengers through a speaker system. The vehicle is not fitted with ABS and it is not possible to retrofit. The vehicle has a top speed of 23 km/h and will in most places drive at speeds between 10 and 18 km/h. Any possible risks will be evaluated by the risk assessor associated with the project.	Maximum speed below 25 km/h
Service braking must be able to produce a deceleration of at least 5,0 m/s^2.	The vehicle is a self-driving vehicle designed for SAE level 4, thus there are major differences in design and use compared to ordinary cars in category M2 on SAE 0 to 3. The vehicle retards at 4,31 and 4,85 m/s^2, giving it a deviation of 13,8%. Since the vehicle is restricted to 23 km/h the increased braking length and risk is limited. The vehicle will in most places drive at speeds between 10 and 18 km/h. Above braking distances will be monitored by a safety assessor.	The vehicle must be limited to a maximum speed of 24 km/h. The speed must be limited in a way that it cannot be changed during operation. Moreover, it is a requirement that the speed of the vehicle is registered and stored in order to be able to document compliance.
EMC	The vehicle is a self-driving vehicle designed for SAE level 4, thus there are major differences in design and use compared to ordinary cars in category M2 on SAE 0 to 3. As the vehicle will only drive SAE level 0 on a predefined stretch of road, the radiation of electromagnetic impulses will be highly geographically limited. The vehicle does not emit electromagnetic impulses at any frequencies reserved by the military, police, rescue services or any other band of frequencies critical for society. The vehicle is approved in 3 out of 4 tests. In one test there is a marginal spike where the vehicle exceeds limits. The exceeded test does not have any high deviations, that it is perceived to be problematic in terms of operation or safety.	None Holo has however obtained statements from the military and a hospital stating that frequencies exceeding the limits does not give any concerns.
Ramp incline	In the first phases of the project, the vehicle will be manned by an in-vehicle operator that is able to assist wheelchair users entering and exiting the vehicle if necessary. A potential increase in risk will be evaluated by the mandatory safety assessor in Holo's general application for the project.	None. The maximum incline of a ramp, according to the Danish regulatory requirements, is only slightly exceeded and consequently the exemption is granted. Danish requirements are the same as 2007/46/EC requirements.

Exit in the rear of the vehicle	In the project period, there will at all times be an in-vehicle operator present. The in-vehicle operator is trained and instructed in the following procedures: • The in-vehicle operator must at all times have a clear view of the traffic situation when in the vehicle • The in-vehicle operator must at all times be able to monitor the traffic situation • The in-vehicle operator must only allow the vehicle to operate with passengers seated • The in-vehicle operator always has absolute control over the braking system through the control device, and must be aware of possible increased braking distance. When the vehicle is not manned by an in-vehicle operator, the vehicle is at all times surveilled by a supervision centre. This team is able to move out within 15 minutes and has continuous video monitoring and the ability to speak with passengers through a speaker system. The vehicle is designed with two emergency exits: manually operated emergency door opener on the inside and outside, as well as left side window with the belonging emergency hammer. Any possible risks will be evaluated by the risk assessor associated with the project.	None, but exemption is granted due to the compliance of size and quantity of emergency exits.
Front screen washing device	The vehicle is a self-driving vehicle designed for SAE level 4, thus there are major differences in design and use compared to ordinary cars in category M2 on SAE 0 to 3. The vehicle will only drive SAE level 0 on a predefined stretch of road, where a front screen washing device will be useful. In this project a distance of fewer than 200 meters. In addition, the vehicle will be driven in SAE 0 in a few manoeuvres along the route. In the project period, there will at all times be an operator present. The operator is trained and instructed in the following procedures: • The operator must at all times have a clear view when in the vehicle • The operator must at all times be able to monitor the traffic situation • The operator must only carry seated passengers • The operator always has absolute control over the braking system through the control device, and must be aware of possible increased braking distance. When the vehicle is not manned by an operator, the vehicle is at all times surveilled by a supervision centre. This team is able to move out within 15 minutes and has continuous video monitoring and the ability to speak with passengers through a speaker system. Any possible risks will be evaluated by the risk assessor associated with the project.	The operator must clean the windscreen manually with a rinsing aid in case the wiper cannot clean the window sufficiently. If the windscreen is covered with mist, snow, rain drops or other things limiting view, the windows must be cleaned before continuing operation.
Mirrors	The vehicle is a self-driving vehicle designed for SAE level 4, thus there are major differences in design and use compared to ordinary cars in category M2 on SAE 0 to 3. The vehicle will only drive SAE level 0 on a predefined stretch of road, where mirrors will be useful. In this project a distance of fewer than 200 metres. In addition, the vehicle will be driven in SAE 0 in a few manoeuvres along the route. In the project period, there will at all times be an operator present. The operator is trained and instructed in the following procedures: • The operator must at all times have a clear view when in the vehicle • The operator must at all times be able to monitor the traffic situation • The operator must only carry seated passengers • The operator always has absolute control over the braking system through the control device, and must be aware of	To ensure an unblocked view for the operator during SAE level 0 driving, standing passengers, or any other objects higher than the lowest point on the windows, are prohibited. Otherwise, the vehicle must have installed a device enabling the indirect view to the sides and in the rear. If the windows are covered with mist, snow, rain drops or other things limiting view, the windows must be cleaned before continuing operation. There must not, in any circumstances, be installed sun

	possible increased braking distance. When the vehicle is not manned by an operator, the vehicle is at all times surveilled by a supervision centre. This team is able to move out within 15 minutes and has continuous video monitoring and the ability to speak with passengers through a speaker system. Any possible risks will be evaluated by the risk assessor associated with the project.	film or adverts on any windows. There must be at least 70% light transmission through windows.
Forward facing reflex devices must be white, rearward facing must be red, and reflexes towards the side must be yellow. If the rear side-reflex device is combined with the rear light or reflex device, this might be red.	The vehicle has a top speed of 23 km/h which lowers the risk significantly. The vehicle is constructed as a two-way vehicle without the option of automated switch of reflexes and it is not possible to retrofit. In the project period, there will at all times be an operator present. The operator is trained and instructed in the following procedures: • The operator must at all times have a clear view when in the vehicle • The operator must at all times be able to monitor the traffic situation • The operator must only carry seated passengers • The operator always has absolute control over the braking system through the control device, and must be aware of possible increased braking distance. When the vehicle is not manned by an operator, the vehicle is at all times surveilled by a supervision centre. This team is able to move out within 15 minutes and has continuous video monitoring and the ability to speak with passengers through a speaker system. Any possible risks will be evaluated by the risk assessor associated with the project.	

Table 2.2: Documentation requirements for vehicle approval

2.1.3 Other relevant authority approvals

As described in the introduction of chapter 2 applicants must include a written statement/permit from the road owner(s) to the area where the project will take place. Applicants must evaluate the route and apply for permission by each road owner, which can both be privately owned areas, such as the hospital parking areas at Slagelse Hospital where AM has conducted part of the AVENUE project, or it can be the municipality owning the roads where the AV will operate.

Typically there will be no standard form to apply for such permits. Applicants can, however, expect municipalities to require a plan for infrastructure changes and signs, meaning detailed descriptions and plans of how bus stops are placed on the route and the specific layout of the bus stop. Moreover applicants should provide information of specific signs placed near and on the route, this could be information of AV operation in the area or specific application to reduce the speed and adjust speed signs in the area of operation.

Permits from road owners must be included in the overall application to DRD.

2.1.4 DRD and political approval process

The application for approval to DRD should be separated and presented in specific sections. All sections together should present the authorities with a holistic picture of the project and serve as the basis for their review (Vejdirektoratet).

The application should contain a description of the pilot, including a detailed plan for carrying out the experiment. The plan must specify which levels of automation (SAE levels) the experiment is to be run under, so that it is clear and distinct where and when the different levels are activated.

Moreover, the application should contain the 3rd party assessor report/findings, description of the organisation behind the pilot, time-wise delimitation, geographical delimitation, description of the involved vehicles, plan for collection and handling of data as well as a plan for information to other road users. All parts of the application should be submitted through DRD's application platform.

The application is then processed by a public task force with members of DRSA, DRD, the Danish police, and the director of public prosecutions. The task force might require more information if they consider that one or more elements have not been adequately addressed. After obtaining all necessary information, the task force prepares a legal declaration of the project, which is sent into public hearing. The public hearing has a duration of minimum 4 weeks, to solicit feedback and concerns from interested parties and citizens.

After being publicly consulted, the Danish Transport committee, consisting of constituted elected politicians, has to approve the declaration internally. Lastly, the Minister of Transport processes the application and eventually passes the declaration resulting in approval from the DRD.

With this process each project is approved as a specific executive order. If any major changes to the declaration needs to be processed after approval has been granted the above process has to be redone. Major changes could be new/changed routes. Moreover, a process for handling changes must also be agreed upon with the assessor. Similarly changes to vehicle and/or other materials shared for the vehicle approval must also be reviewed by DRSA before the changes can be implemented.

2.2 Comparison of legal framework

In the following section a comparison will be presented between the Danish legislative framework for autonomous pilot projects and the legislative framework of other Scandinavian countries; Norway and Sweden. The purpose of this comparison is to illustrate where the Danish legislation differs and to underline the severe differences between the Danish approach and the approach of other Scandinavian countries. Ultimately the consequences of the extensive legislative framework in Denmark will be addressed.

2.2.1 Introduction to legal framework of Sweden and Norway

In order to provide a comparative assessment the legal framework for Sweden and Norway will briefly be presented. AM has conducted autonomous pilot projects in both Sweden and Norway with the same types of vehicles (Navya ARMA) and the comparison and description of legislation will be based on these similar types of applicants for permits.

The Swedish Transportation Agency, hereafter referred to as STA, issues the ordinance on '*Trial Operation with Self-driving Vehicles*' that allows trial operation with self-driving vehicles to take place. A permit may only be granted if the applicant shows that traffic safety can be ensured during the trial and that the trial does not cause any significant disruption or inconvenience to the surroundings.

The Swedish legislative framework for projects with autonomous vehicles is visualised below

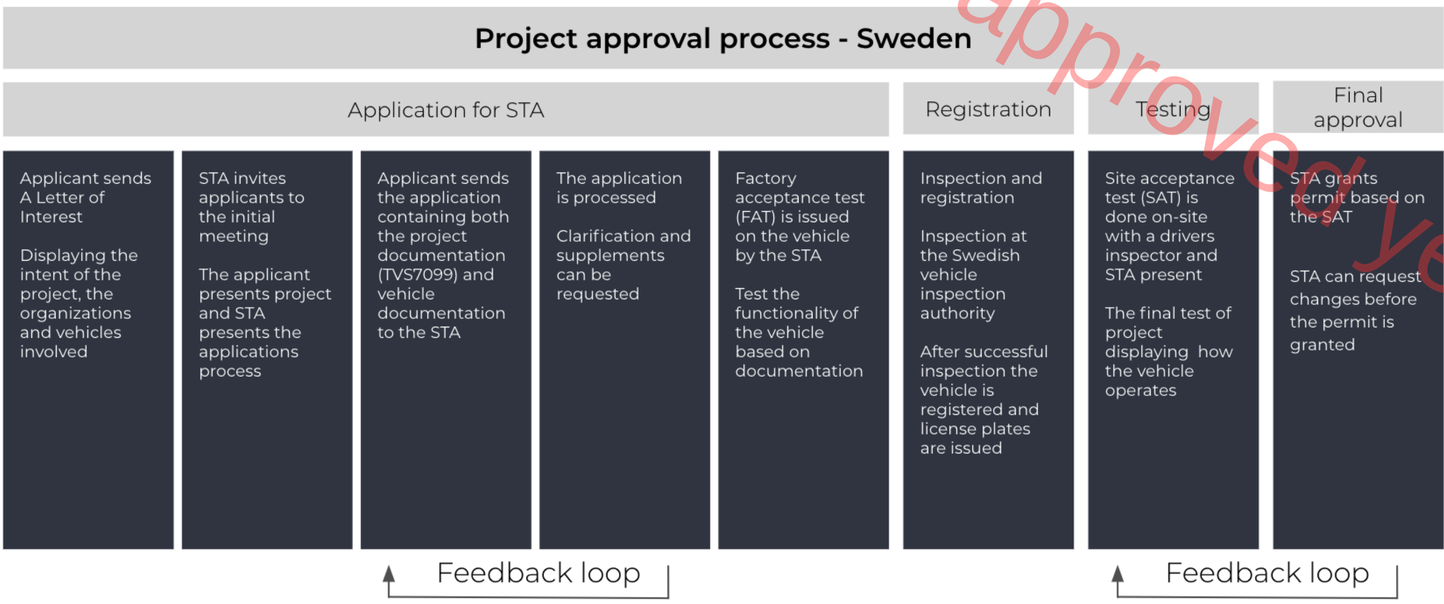


Figure 2.2: Project approval process - Sweden

In Norway approvals to conduct projects with autonomous vehicles are granted as one approval related to the route(s) and time period described in the application. The permit will be granted by the Norwegian Public Road Administration, hereafter referred to as NPRA.

The vehicles are registered and specifically linked to the time and place of the permit and registration runs out when the permit runs out. The Norwegian legislative framework for projects with autonomous vehicles is visualised below.

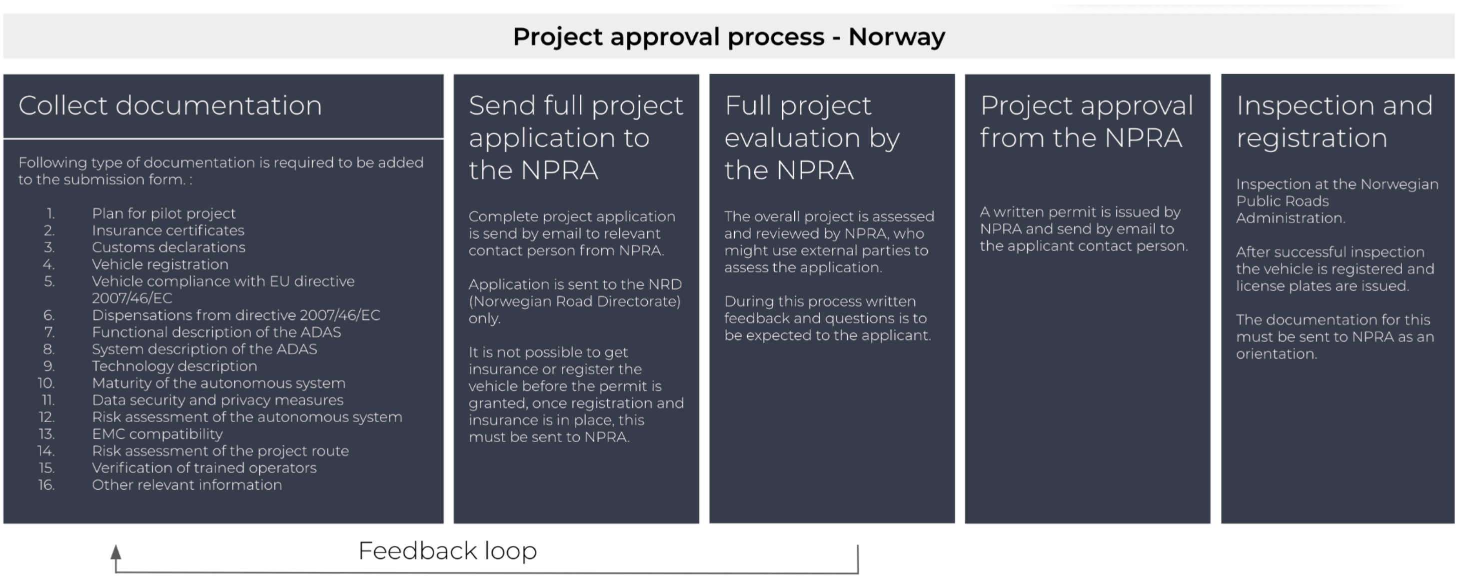


Figure 2.3: Project approval process - Norway

The documentation requirements in Norway are based on the documentation requirements in the Swedish legislative framework, for both countries the following requirements for documentation are set forth to any and all applicants. However, in Norway customs declarations must also be submitted as part of the application to NPRA.

- Plan for pilot project

- Insurance certificate
- Customs declaration (only norway)
- Vehicle registration
- Compliance with technical requirements
- Dispensation from Directive 2007_46_EC
- Functional description of the autonomous system
- System description of the autonomous system
- Technology description
- Maturity of the system
- Data security and privacy
- Risk associated with autonomous system
- Electromagnetic compatibility
- Risk analysis
- Training for operators
- Other relevant information

The above documentation is submitted to the relevant authority (NPRA or STA) for review and approval. In Sweden STA will participate in a Site Acceptance Test on route/site whereas in Norway NPRA assesses either the process for implementation on the specified route or general third party testing of the vehicle.

2.2.2 Comparison of approval process time

The lead time for approving projects across the three (3) compared countries is visualised in the below table. The table is based on AMs experience with Navya Arma DL4 PMR vehicles on public roads. Meaning, the table serves as a comparison of process lead time, in cases with the same type of routes and the same type of documentation available/provided to the given road authorities.

Hence, the visualisation should not serve as a tool to assess how long a different type of project with e.g. another vehicle type would take to obtain permits for.

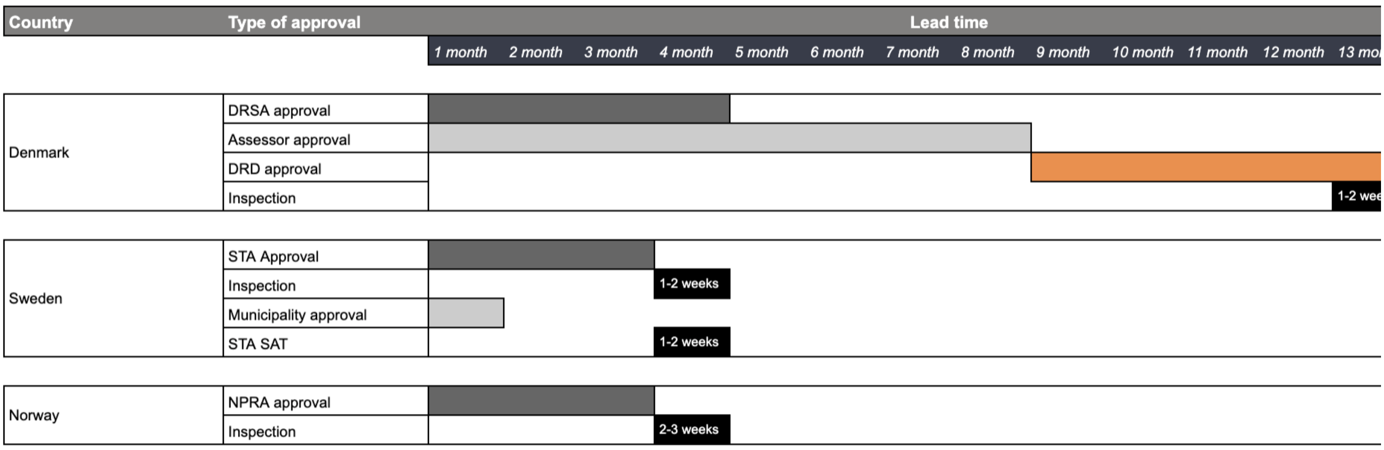


Figure 2.3: Lead time for project approval comparison

The lead-time for approving projects with autonomous vehicles is considerably higher in Denmark than in any of the other countries. Where Norway and Sweden are very similar in lead time of around 3-4 months, Denmark has the highest lead time with an approval time of around 13 months.

The long approval time in Denmark is mainly caused by the multiple authorities and entities who have to approve the project. Moreover, each project needs an independent executive order signed by the Minister of transport, which makes the final part of the approval process in Denmark very sensitive to other matters in the ministry of transportation. For example, Holo experienced a significant delay in the first granted permit, caused by the elections for Danish Parliament in 2019.

In the other two (2) countries, applications are processed by only one authority, who might use other external experts to help with the evaluation, but the overall responsibility for issuing permits lies with the one road authority in both Sweden and Norway. Thereby the lead time for processing applications is reduced significantly compared to the Danish approach to approving projects with autonomous vehicles. Denmark is also the only country in the Nordics where a project needs an independent executive order, signed by the Minister of Transport.

It could be argued that the Danish approach is then more thorough and hence provides a safer approach to conducting projects with autonomous vehicles. However, as described in the introduction the projects compared in this assessment are with the same vehicle type, the same organisation and the same principles applied when conducting risk assessments of the approved route of operation. Thereby, the Danish approach is not necessarily equal to a more safe operation.

For the Nordhavn project specifically AM used 24 months for the approval of the project. The specific timeline is shown below. The timeline would have been even longer if it wasn't for all the work done on the first self-driving project in Denmark that AM got approved in early 2020.

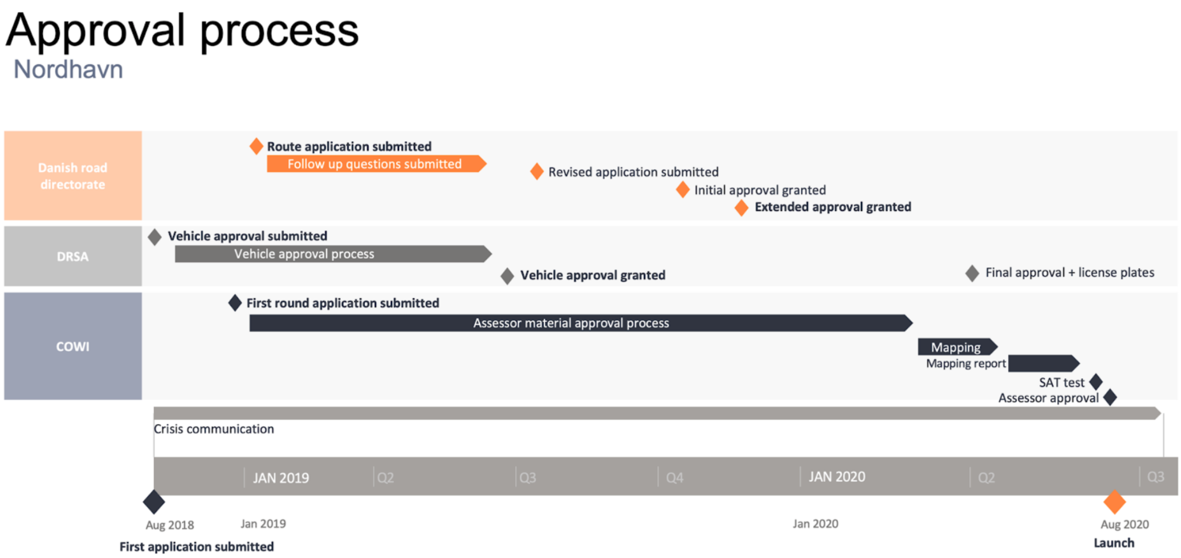


Figure 2.4: Lead time for project approval comparison

In Denmark, the applicant will hold the full cost of the approval process related to an autonomous vehicle project. The Nordhavn project holds high expenses to the assessor, vehicles, operators, consultants, and project management. The requirements set forth in the assessor approval has also led AM to support the project with more resources than necessary in e.g. projects with the same vehicle in Norway and Sweden. This is the case for e.g. the AM compliance organisation to handle changes in procedures and training.

2.2.3 Consequences of the danish legal framework on DK AVENUE Site

The consequence of the long approval process in Denmark has been a closing of the operation in the Nordhavn (Copenhagen) AVENUE route, due to infrastructure changes that required updated permits from DRD. The resources needed for a self-driving pilot in Denmark are enormous both in time and cost, changes during a pilot project are also very time-consuming and costly and timelines for processing are not foreseeable. All of the above makes it almost impossible to make a profitable business case and impossible for most companies or institutions to even apply for a pilot with autonomous vehicles in Denmark, under the current legislation.

In the case of the AVENUE Nordhavn route AM was made aware of infrastructure changes that needed to be executed, forcing the project to close. The changes meant that a new route had to be applied for as the original route would be under construction for the remainder of the AVENUE project. The complications and long lead time for permits in Denmark, ultimately led AM to investigate alternative options, as a new permit was deemed unrealistic within the timeframe of the AVENUE project. Thereby AM integrated the AVENUE project into an existing project with Danish PTA, Movia, at *Slagelse Hospital*, as the route and project was already approved. The decision was made to ensure necessary learnings to the AVENUE project, in regards to on-demand operation and integration. These learnings will be further outlined in the following chapters.

The costly and time consuming approval process in Denmark, has ultimately led AM not to continue with new pilot projects conducted in Denmark, under the current legislative framework for autonomous vehicles. The decision making and process of closing down the AVENUE Nordhavn site is further elaborated in site descriptions in chapter 5.

2.2.4 Effect of approval process on AMs objectives in AVENUE

The approval process has delayed and complicated many of the initiatives that were planned for the Nordhavn site and eventually the site had to be closed down due to complications with the area (construction and no possibility to obtain new approvals within the project period). The approval process has indirectly had a huge impact on the success rate of the objectives of AVENUE for Amobility as an operator. The objectives are listed below with a short status on each, with focus on the impact of the legal framework in Denmark.

Objectives	Status
Public transport (other road users)	**Nordhavn:** The Nordhavn site was fully implemented in public transport and drove in a 30 km/h area with all kinds of road users (bikes, trucks, cars, taxies, pedestrians, e-scooters etc.) **Slagelse:** The Slagelse site was equally successfully implemented on public roads with other road users, integrating with the PTA of Copenhagen area; Movia. The services also integrated with the bus stop at the hospital site, moving passengers from the station to the hospital, hence the shuttle serving as last-mile transportation.
Move actual travellers	**Nordhavn:**

	Being deployed in a residential area the shuttle services moved the residents around the area in a loop of fixed stops. **Slagelse:** Moving patients, hospital staff and visitors between sections/departments of the hospital through on-demand operations
On-demand testing and development	**Nordhavn:** Due to the construction work and delays in the area the route could not be expanded, hence including enough road to test on-demand driving between virtual stops was not possible. Moreover, the legal framework requires a new full assessment and approval for new roads (streets) in the area. With the previous experience of the timeframe (12-14 months) for a new approval, expanding/moving the route away from the construction areas was not possible within the timeframe of the AVENUE project. **Slagelse:** Although at a smaller geographical scale (due to the size of the hospital area) the Slagelse site successfully implemented on-demand solutions, which was developed as an integrated solution through PTA; Movias booking system
Integration with public transport	**Nordhavn:** The plan was originally in the 3rd phase of the Nordhavn deployment to increase the driving area to include the two public metro stations in the area. But again given the legal framework and the timeframe of a new approval, the expansion and relocation of the route was not possible within the project time frame. **Slagelse:** Public transportation to the Hospital main entrance is possible by bus (Movia), from that stop the AV offered last-mile transportation to the other departments at the hospital
Mission integration and adaptation (with PTA and Navya)	**Nordhavn:** As the route was not connected or offered via any public PTA the integration was not possible. The route was integrated with Google Maps allowing people using Google Maps to be redirected to the shuttle when planning a trip in the Area. **Slagelse:** The slagelse site had physical touch screens at each stop, where the shuttle could be ordered, missions was directed through PTA to AM, AM directed the missions to the shuttle through an AM integration with Navya
Dynamic routing (find the smartest way)	**Nordhavn:** As the routing network in Nordhavn could not be extended the dynamic routing was not tested or implemented. Amobility has performed some testing on the test track regarding the mission control and distribution setup between the Navya vehicle and Amobility as an operator. **Slagelse:** The shuttle would always take the shortest route to pick-up point, however the Navya API version did not allow for re-routing once a mission was being executed
Mobility cloud early stage development (SUP portal, data dashboards, operator app, end user app, follow portal, backend API integrations etc.)	**Nordhavn and Slagelse:** One of Amobility's goals of the AVENUE project was to develop the mobility cloud allowing people to seamlessly move from A to B in a geo fenced area (a complete mapped area). The development of the critical components to be able to do this in the future has started and Amobility have developed some of the features necessary to meet the goal. But with the technological barriers and the legal barriers (long approval processes and a very conservative documentation setup) the mobility cloud still needs a lot of work. The experiences from operating in Nordhavn and Oslo have given Amobility knowledge to continue the

	necessary development. AM has instead focused on developing necessary back-end tools, to integrate to the vehicle, to live-monitor the shuttle, dashboards for data analysis and an operator app for additional manual data collection by the on-board operator
Drive without an operator in the shuttle (SAE 4)	**Nordhavn and Slagelse:** The Navya vehicles are currently classified as SAE level 3 vehicles. It will not be possible to drive without an operator in the shuttle before the market can deliver an SAE level 4 vehicle, with sufficient documentation. In Danish applications and approvals Amobility expects requirements for documentation to significantly increase in applications for fully driverless operation and for functional safety assessments of the vehicle to not rely on the safety drivers for any mitigations or stand-by functionalities
Reach higher speeds	**Nordhavn and Slagelse:** The Area in Nordhavn is limited to 30 km/h. The shuttles are currently able to drive a max speed of 18 km/h and have an average driving speed of about 7-8 km/h. If the vehicle vendor (Navya) could provide detailed and accurate documentation for how the vehicle is able to drive faster, with improved braking systems and sensor system. Amobility would be able to apply for higher speeds and feels comfortable that it would be approved within the current approval framework. Documentation and safety validation from the technology provider is necessary in order to apply for increased speed to for example 30 km/h.
Automated wheelchair ramp (+ manual wheelchair seat belts)	**Nordhavn and Slagelse:** This has been approved and tested in both the Nordhavn site and the Slagelse site

Table 2.3: AVENUE objectives

2.3 Recommendations

In the following section recommendations to changes in the legislative framework will be presented. The legislation is currently under review and a new law is expected to be implemented during the fall of 2022. AM has provided feedback through a questionnaire and participated in a workshop held by the Ministry of Transport and Danish Road Directorate.

2.3.1 Review process for DK legislation

In February of 2022 a questionnaire was sent to actors in the AV industry in Denmark, in order for DRD to receive feedback prior to the review of the Danish legislation on AV approval process. The following table presents the questions and answers provided by AM to DRD. The answers to DRD were provided in Danish and have been translated for the purpose of this report.

Question	AM response
Topic 1: Evaluation of legislation	

Assessment of the purpose of the legislation *"The purpose of the legislation is to allow trials with AVs under acceptable traffic safety measures"*	It is AMs assessment that there still is a need to continue trial legislation for AVs. As the market is still maturing towards commercial projects and as we are still awaiting updated EU directives on vehicle (hardware and software) requirements for type approval. A trial legislation is hence crucial for continued development of the technology and adaptation to Danish roads and traffic conditions.
Assessment of the requirements set forth to the applicants organisation	In the application towards DRD the requirements set forth are assessed as appropriate. The requirements from assessors in terms of documenting competencies has been very strict which can hinder and limit smaller organisations and new organisations to enter into projects. AM suggests a higher focus on matching competencies with the complexity of the specific projects applied for, e.g. degree of autonomy, complexity of the route applied for etc.
Assessment of the requirements set forth to applicants financial investment	The project finances have been highly challenged by the long and uncertain approval processes. The insecurity has challenged the project planning and hence the project finances. Likewise the costs of assessors and traffic consultants have been very high, as they have been required for long periods of time during the project and through several iterations. Projects in Denmark would have a hard time becoming profitable or cost-neutral with the current requirements. The requirements of assessment is not a demand set forth by nabour countries (Sweden and Norway). Thereby Denmark could potentially be discarded as a country to conduct AV projects because of these high costs of approvals. It is AMs recommendation to look at both the high cost and the long process time for applications, in order for Denmark to become a more attractive country to conduct trials with AVs in the future.
Assessment of the requirements set forth in the *assessor approval/evaluation*	The requirements provided for assessor approval has been very complicated. This is both true for applicants and for the assessor team(s). In AMs opinion more specific requirements to what assessors should review would be beneficial. AM has experienced that the current process for approval creates double approval of the same material. As the same material is undergoing review by assessors, DRSA and DRD. This increases the lead time for approvals and it is not AMs opinion that this in any way increases traffic safety in the conducted projects.
Assessment of the requirements set forth for *Vehicle Approval*	For vehicle approvals DRSA is following directive w2007/46/EC, which is reasonable. However, in Denmark the requirements for documentation have been significantly higher than in e.g. Sweden and Norway. AM suggests instead focusing on the areas where the vehicles deviate from the directive, this is also a method applied in Sweden, Finland and Norway. Moreover AM suggests implementing a more dialogue based methodology. Long process time can be a hindrance for innovation. With new technology where requirements might be unclear it is crucial to have the possibility for more informal guidance and dialogue instead of traditional ways of application processing.
Assessment of the requirements set forth for: ***Insurement of traffic safety during conduction of AV trial operations***	In this process the responsibility has largely been placed on assessors. AM believes that the requirements had been suitable. It is however, AMs opinion that the process time from Road Authorities must be faster, especially concerning changes which can impact traffic safety.
Assessment of road safety experience	In the 3 projects conducted by AM in Denmark traffic safety has been high. During many months of operations *no* serious incidents or human injuries has occurred. AM has not registered incidents where traffic safety has been worsened.

	AM has experiences that other road users have had to adapt and learn how to interact with the AV.
Other remarks	Overall the long and costly approval process has generated significant challenges for trials with AVs in Denmark. AM hopes that a revised legislation can create better conditions for both private and public actors who wish to conduct projects with AVs. Danish infrastructure is extremely suitable for AV technology and the lack of bus drivers and high wages makes the benefits of introducing autonomous public transportation extremely high.
Topic 2: Suggestions for changes to a revised legislation	
Suggested changes for the purpose of the legislation	AM will recommend that the legislation continues under the current defined purpose, while the technology matures further.
Suggested changes for the organisational requirements	AM does not see it necessary to change the organisational requirements. AM will however recommend that these only be processed by one approver, rather than both having them approved by an assessor and DRD.
Suggested changes for the financial terms for AV trial projects	The industry and market is still not sufficiently matured for there to be any case processing fee from authorities. As projects are currently non-commercial, AM suggests focusing more on increasing PTAs budgets for conducting trials to gain experience and expertise with autonomous technology. As there is still a lot to learn in relation to e.g. ride-sharing, virtuel bus stops, on-demand booking, end-user applications, higher speeds and Level 4 driving. Innovation in this area could be secured through funding or dedicated budgets to projects with autonomous technology as it is the case in our neighbouring countries.
Suggested changes for the assessor approval	It is AMs recommendation to rethink whether all projects need to be approved by a third party assessor. For smaller projects it is an extraordinary high cost which directly limits innovation. Elements from e.g. the Swedish process could instead be adopted where the requirements are dependent on the complexity of the given project. This complexity is determined initially through a letter of intent to the Swedish road authorities. AM would like to see that DRD alone processes applications. This would create more closeness and DRD would have more insights into the technology and road requirements. This is in line with AMs recommendation to ensure more alignment between the nordic countries legislation on AVs. If authorities wish to maintain third party assessment, AM suggests reducing significantly on the remaining elements of the application process by both DRD and DRSA, to eliminate double assessment.
Suggested changes for vehicle approval	By applying the Norwegian or Swedish methodology a taskforce could perhaps be maintained where DRSA supports the process of approving vehicles and assessment of compliance with EU directives. Still it is AMs recommendation to gather approvals under one approving entity at DRD. To shorten the process time for approvals and thereby create a more attractive setup for conducting trials with AVs in Denmark.
Suggested changes for insurance of traffic safety	It is AMs recommendation to maintain the permit holder as the insurance taker and ultimately the responsible party for traffic safety. Moreover AM will recommend to set up systematic reporting for incidents with AVs. This could be a common process or database across the Nordic or EU countries. By this authorities could gain more

	data and greater insights into traffic safety and incidents across AV projects. AM wishes for a closer collaboration and dialogue with authorities in relation to safety data and reporting, among other things in order to compare AVs with regular traffic data.
Suggested changes for the administrative and political processes	AM recommends that the political approval is completely removed and road authorities alone processes and grants approvals. The political approval can cause delays as they are influenced by factors such as elections, change of Minister etc.
Suggested changes for new regulations as a consequence of the AV trial legislation	The technology has developed rapidly since the implementation of the AV trial legislation in 2017. Therefore it is AMs suggestion that changes of other regulations should be of a structural character. The overall strategic ambitions should be to reduce the number of privately owned cars, improvements in public transport and create more shared means of transportation, preferably without a driver as drivers are already a limited resource. The goal should be to create a more effective and sustainable transportation system in Denmark. For example this can be done by supporting PTAs with additional means to conduct trials with AVs. On an EU level it is recommended that the national legislation continues to develop the EU directives for self driving vehicles.
Suggestions to ensure a transparent and applicable legislation	AM would recommend to align the Danish legislation with the legislation of Sweden and/or Norway. Moreover, it could be considered if projects with SAE level 3 vehicles could have an even more simple process for approval, e.g. only approved by DRSA. AM could also recommend the Finnish model for projects with SAE level 3 vehicles, where road authorities grant test-plates, this process creates a faster approval process and makes it easy to gain learnings about e.g. user-interaction and on-demand with still a relatively low degree of autonomy. AM is convinced that an aligned Nordic process would further strengthen the collaboration between Nordic partners and give possibilities for more projects and potentially projects with cross-border routes. Along with even more knowledge sharing across the Nordic countries.
Additional suggestions for changes	AM is convinced that area approvals will be the key to the future efficient public transportation system with autonomous vehicles. The current setup with specific route approval will not be a realistic method in order to cover the many mobility needs. Thereby new methods for risk assessment of areas and methods for granting approvals for areas is necessary for the technology to be able to continue to develop and for PTAs to offer valuable self-driving services.

Table 2.4: Suggestions for revised legislation

In summary AM has provided authorities with the following suggestions for changes in the Danish legislative framework for pilots with autonomous vehicles:

1. When testing/driving in SAE level 3 or lower only approval from the DRSA, local police, and road owners should be necessary. A simple framework for expectations to applicants should be provided, so that requirements for documentation are absolutely clear

2. In projects with SAE level 4-5 operation, AM recommends to have either 1) an approval from the appointed assessor, DRSA, police, and road owner(s) or 2) an approval by the Danish Road Directorate (taskforce), DRSA, police and road owner(s)
    a. If option 1 is used, Amobility strongly recommends that a clear framework is provided to the assessors, to ensure transparency for applicants. In the current framework, there is

no limit to the amount and type of documentation the assessor can request. This makes it hard for the assessor and the applicant to navigate within the framework. Better outlining of the framework would serve both assessor and applicant

3. AM strongly recommends authorities to allow approvals for areas rather than single route approvals. Area approvals require a framework for how to conduct risk assessments for areas which applicants can use and which is acceptable for authorities to grant permits on.

4. Further investments and funding is crucial while the technology matures towards a commercial reliable means of transportation. AM suggests that investments are made through government funded projects for PTAs to conducts trials with autonomous vehicles

5. Ultimately AM recommends removing the political approval process entirely. For each project to have their own executive order is completely diminishing the flexibility and innovation for existing and future pilot projects. Firstly, because the process is highly reliant on the political system. Secondly, changes to executive orders are time-consuming and frequent changes to projects must be expected in these fast-moving and ever-changing environments. Continuing this highly rigid and time-consuming approval process will force companies to seek and pursue innovation outside of Denmark in more agile environments, such as Amobility has experienced in both Norway and Sweden.

3 Vehicles

AM has been testing AV's since 2017 and owned several Navya Arma vehicles before starting up the AVENUE project. In the AVENUE project AM will operate four Navya Arma vehicles, three of them funded by the AVENUE project.

3.1 AM vehicles for AVENUE

AM has 4 Navya vehicles connected to the AVENUE project as follows:

Type	ID (VIN)	Driving	Funded by	Pilot site	Brand foil
Navya Arma DL4	P109	Mono-directional	AVENUE	Nordhavn	Holo branded
Navya Arma DL4	P111	Mono-directional	AVENUE	Nordhavn	Holo branded
Navya Arma DL4	P112	Mono-directional	AVENUE	Ormøya	Ruter branded
Navya Arma DL4	P85	Mono-directional	AM	Ormøya	Ruter branded
Navya Arma DL4	P66	Mono-directional	AM	Slagelse	Movia branded

Navya Arma DL4	P109	Mono-directional	AVENUE	Slagelse	Movia branded
Navya Arma DL4	P111	Mono-directional	AVENUE	Slagelse	Movia branded

Table 3.1: AVENUE vehicle overview

3.2 Navya Arma Technical data

See appendix A

3.3 Options/functionality

3.3.1 Air Conditioning

The Navya Arma shuttles are equipped with air conditioning and heating.

3.3.2 Stickers

Inside the shuttle, stickers are mounted, with the purpose of informing the passengers about hard breakings. This way the passengers are more prepared during a ride.

3.3.2.1 Example of powerful breaking sticker

3.3.3 Seat-belts

The Navya arma shuttle is equipped with seatbelts. Unfortunately, the seatbelts are not approved/allowed in Denmark because the anchorage position is not compliant with standards - hence they are removed from the vehicles. In Norway seatbelts are available in the shuttle and kids and ederly are advised to use them to avoid falling during hard breaks etc. This is approved only because of the low speed of the vehicle.

Based on experience, the Navya Arma vehicles are still experiencing many hard breaks due to close overtaking vehicles, rain drops on the lidars etc. Hence the use of seat belts is encouraged to minimise the risk of falling. Especially elderly and children, who are not able to hold on as tight as other passengers, are exposed to a greater risk when riding the autonomous shuttles.

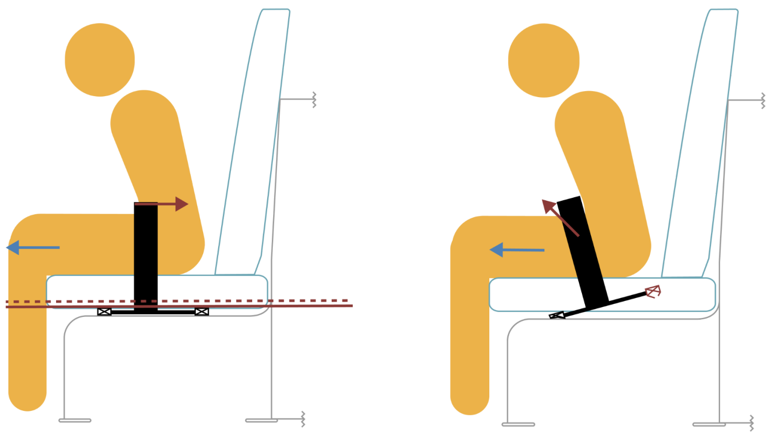


Figure 3.2: The provided seat belt solution from Navya with horizontal anchorage points could lead to the body being "cut in half" by the resulting force applied by the belt (left). Moreover the construction is not fastened to the vehicle's fixed parts, which is not compliant with Danish regulations.

However, the current seatbelt solution provided by Navya for the Arma shuttles are not compliant with the regulations of the countries in which they are driving, meaning they are not allowed in the shuttles. In most countries, however, buses that drive in predesignated routes are exempted from the regulations regarding the mandatory use of seat belts.

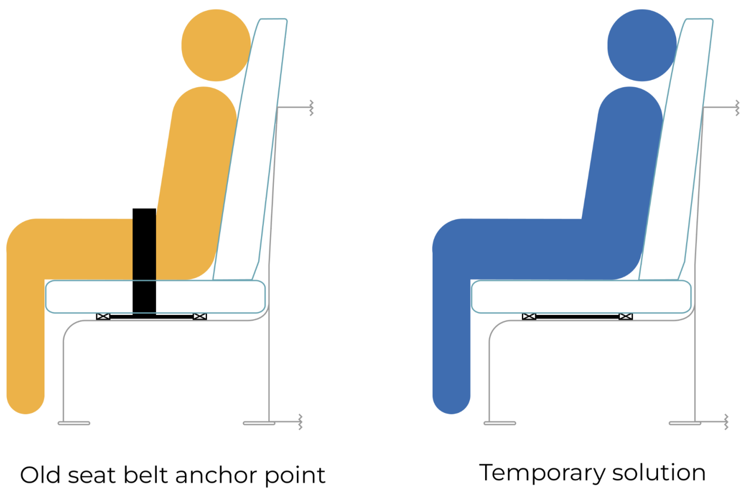


Figure 3.3: The construction of the old seat belt led to its inability to become approved by nordic authorities. The temporary solution was to operate without the use of seat belts.

The primary issue regarding the provided seat belt solution from Navya revolves around the anchoring of the seat belts. Both the anchoring construction which is not properly designed for its exposed traction as well at the angle in which it is anchored. As for now, the anchoring of the belt is done just beneath and on the horizontal plane of the seat, However according to UNECE regulation 14-06[3], the anchoring point should be behind the seat an anto the bearing construction of the vehicle, creating an angle for the seat belt relative to the horizontal plane of the seat.

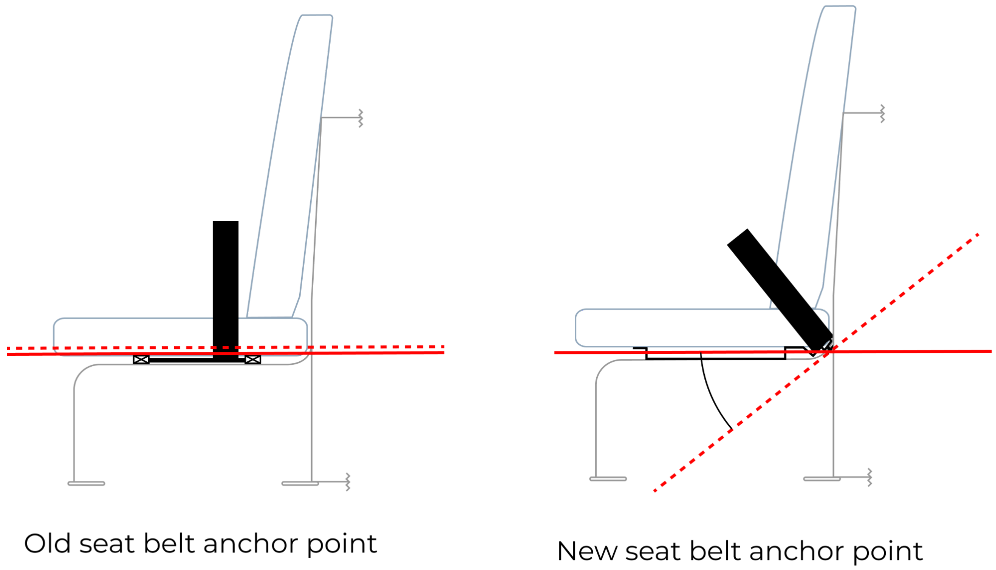


Figure 3.4: Conceptual drawing of displacement of anchoring point resulting in arched retractoring.

As long as the seat belt solution provided is not compliant with the regulations enforced by the UNECE regulation 14-06, the seat belts must be removed from the vehicles, resulting in risks for onboard passengers to fall down from the seat during sudden braking.

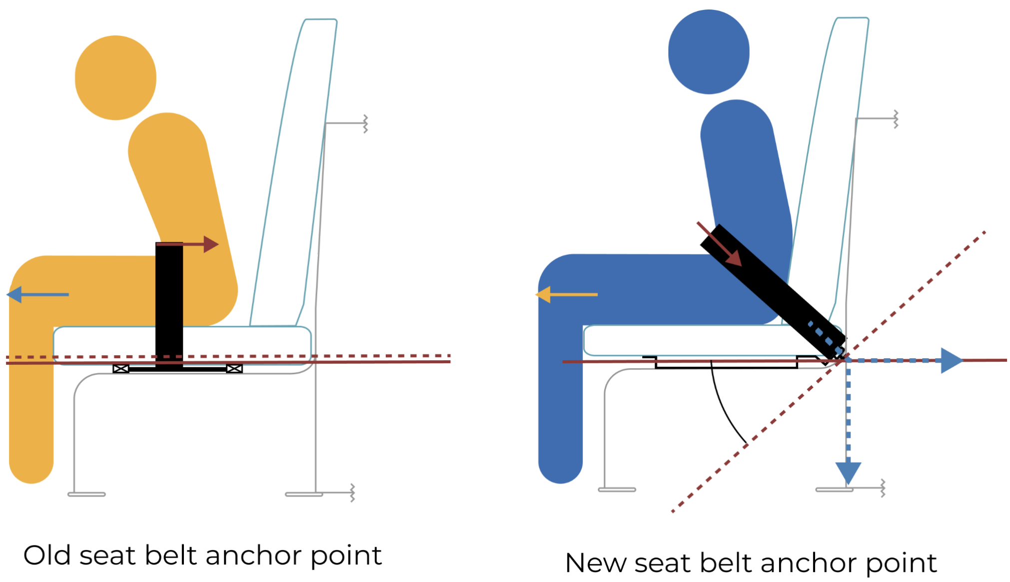


Figure 3.5: Conceptual drawing of displacement of anchoring point resulting in arched retractoring.

To comply with UNECE regulations, the developed solution should ensure both arched retractoring as well as fastening of the seatbelts to the vehicle's fixed parts. A conceptual sketch of the developed

[3] https://unece.org/fileadmin/DAM/trans/main/wp29/wp29regs/2020/R014r6e.pdf

solution can be seen in figure 3.5, where resulting forces applied during hard braking are transferred down and inwards towards the vehicle's frame.

3.3.3.1 Development and approval

To ensure development in accordance with the UNECE regulation 14-06 development was undertaken by Holo's authorised mechanics in collaboration with engineers specialised in automotive retrofit and vehicle approvals from Danish consulting Engineering company AutoConsult[4].

During iterative model fitting and 3-D CAD drawing, a seat frame and appurtenant reinforcement of the cab' bottom was developed to fit the shuttle in accordance with UNECE regulations 14-06. The CAD models were developed in Autodesk Inventor® and were excerted for finite element analyses in Autodesk Inventor®'s simulation environment. The seat frame construction has been analysed in Autodesk Inventor® as a whole, whereas the actual construction is carried out as 2 pieces installed next to each other, but connected on the back of the glass fibre construction to the same steel flat bar. Having the construction carried out in 2 pieces instead of one, decreases the construction span and hence the resulting forces, making the calculation on the safe side. However both constructions are attached to the same steel flat bar on the backside of the glass fibre. The calculations for the seat frame has been done with the support points being as far from the critical points as possible. The support points are fixed supports, meaning they are not able to deform. The size of the applied force to the seat belt anchoring points are set to 3.7 kN under a dispensation given by The Danish Transport Authority. The calculations are carried out as described in "Guidance on vehicle inspection" section afsnit 10.02.001, pkt. 6 (The Danish Transport Authority, 2021), applying a horizontal forward force of 3.7 kN in each anchor point c.f. the dispensation. Figure 3.6.1 and 3.6.2 show illustrations of the applied forces and the resulting stress from the simulation model.

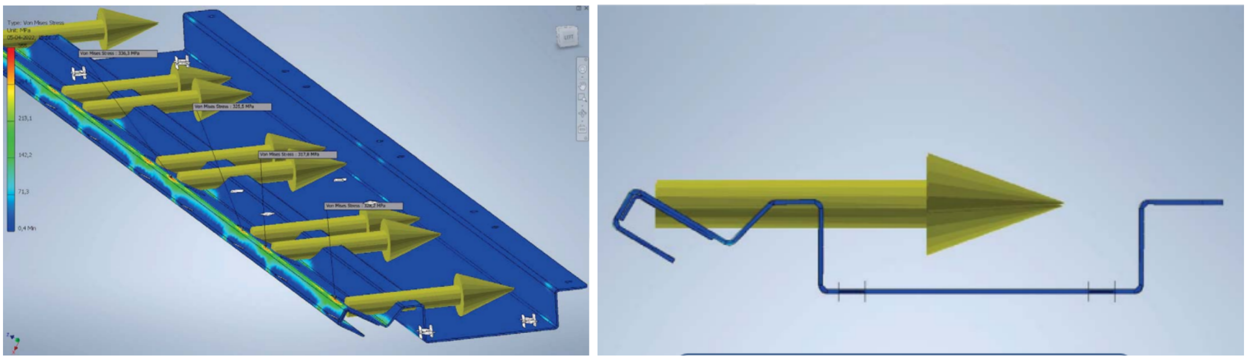


Figure 3.6.1 and 3.6.2: Conceptual sketch of old and new seat- and seatbelt anchor points and constructions.

The simulation software is not able to make calculations concerning plastic deformation in the material, but computes all material stress as pure elastic deformations. Hence the calculations can show stresses exceeding the material's yield point and fracture limit. However, these are manually checked against the material properties by a certified engineer, showing all stresses to be under the allowed limit for the used materials. All components, material dimensioning as well as the simulation model used to determine the stress experienced by the construction is documented in a technical report by AutoConsult (appendix 2).

[4] http://autoconsult.dk/en/

Based on the report an approval of the construction and installation was obtained from the Danish Transport Authority to be installed in the Arma vehicles.

3.3.3.2 Installation

The seat belt anchoring construction should be installed in place of the old seat attachment bars and seat belt anchoring component. The guide for installation of the new construction is provided in the following.

Timeframe: 20 hours depending on mechanical capabilities

Equipment list: What you need to have before starting

- 4 x Special made anchoring construction - 2 for each side. See figure 3.23 and 3.24
- 2 x Steel flat bars, size 60 x 1800 x 5 mm
- 32 x Type M12 bolts, grade marking 10.9
- 32 x Type M12 x 1.5 cm nuts

Introduction:

To install the new seatbelt it is necessary to replace the original seat fastening bars with a new special made anchoring construction. The anchoring construction is put in place to direct any traction to an angled point behind the passenger's hip instead of the original vertical anchor points as seen in figure 4.1.

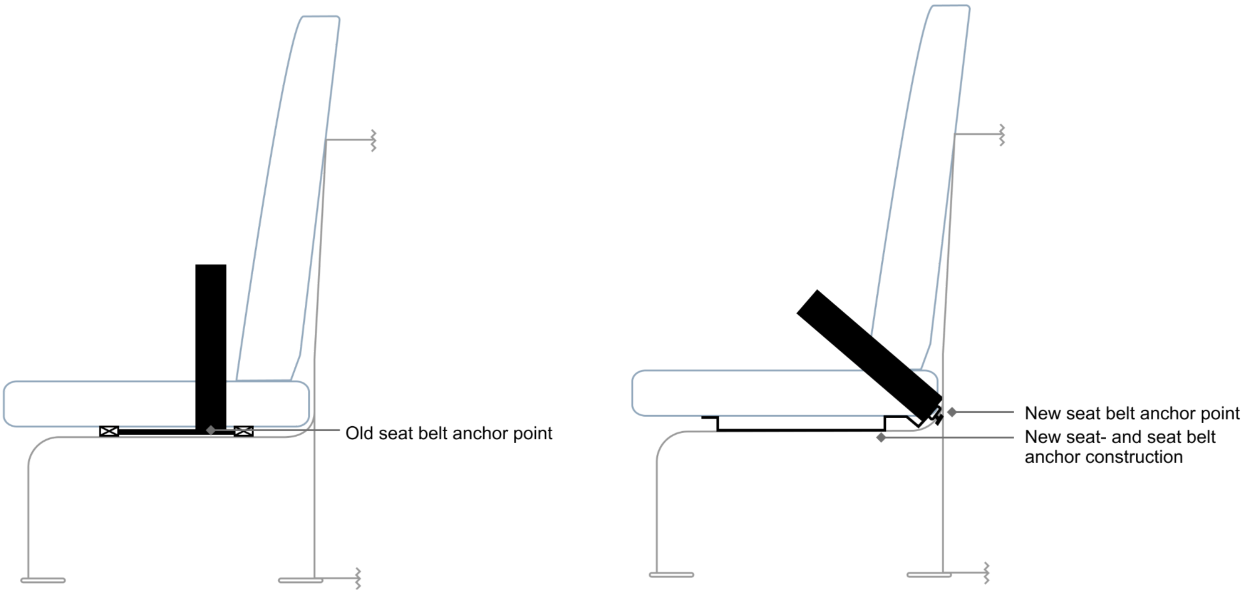


Figure 3.7: Conceptual sketch of old and new seat- and seatbelt anchor points and constructions.

The anchoring construction is supported by a flat bar on the backside of the glass fibre (bus) construction, which distributes the traction horizontally.

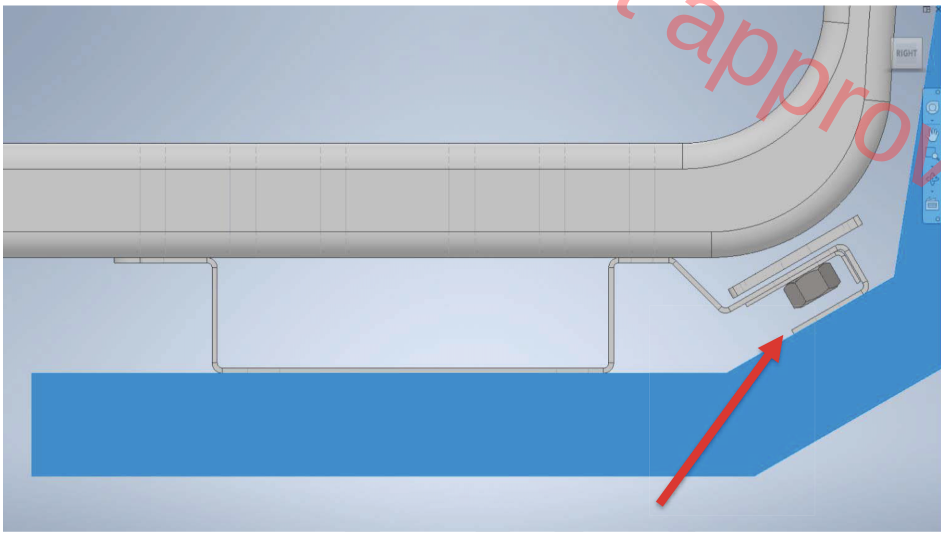


Figure 3.8: Conceptual sketch of new anchoring construction.

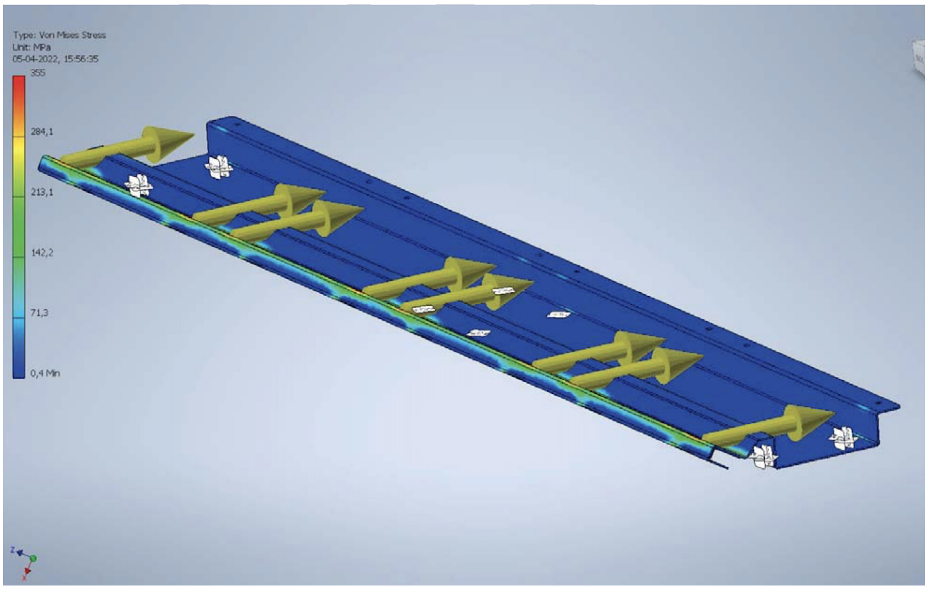


Figure 3.9: Structural analysis of the anchoring construction showing distribution of traction force

The seats are dismounted, but reattached using the same screws. The new anchoring construction is mounted using new and larger bolts to the bottom of the glass fibre construction as well to a flat bar on the glass fibre's backside. To install the flat bar it is necessary to gain access from outside of the vehicle in the front and in the back where the battery is placed.

3.3.3.2.1 Installation Guide

Step 1. Remove seat bottoms, to expose seat fastening bolts, seat belt attachers and seat fastening bars

First, remove the bottom of the seats to expose the seat fastening bolts. Then remove the seats to expose the fastening bars and the seat belt attachers (seen in figure 3.11 and 3.12).

Figure 3.10: Bottom of seats removed. Placement of original seat belt attachers shown in black

Step 2: Remove original seat belts, seat belt attachers and seat fastening bars

After removing the seats, remove the seat belts and the seat belt attachers seen above. Then remove the original seat fastening bars.

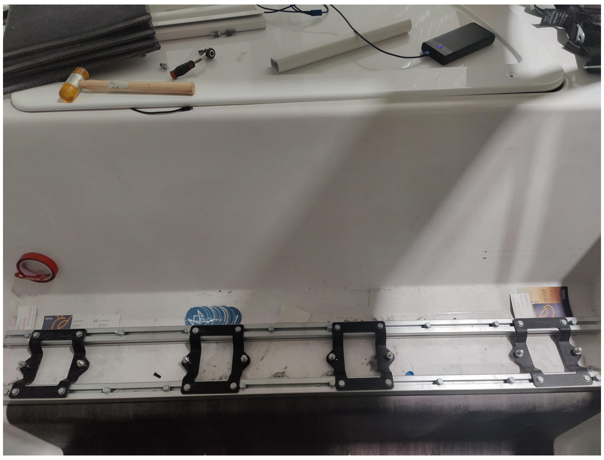


Figure 3.11: Seat belt attachers. Seat belts removed

Figure 3.12: Seats and seat belt attachers removed.

Step 3: Fasten new seat belt- and seat anchor construction

Fasten the seat belt- and seat anchor construction to the glass fibre construction.

The large drilled holes on the bottom are used for attachment to the glass fibre construction. On the slant part, the large holes are for attaching the anchor construction to the flat bar on the backside of the glass fibre and the smaller holes are for attaching the seat belt.

The oblong holes are used for reattaching the seats. Nuts for re-attaching the seats are welded to the backside of the anchor construction to hold them in place.

Figure 3.13 and 3.14: New seat belt- and seat anchor construction

Bolts used for fastening the anchoring construction and photo of nuts welded to the backside of the anchoring construction

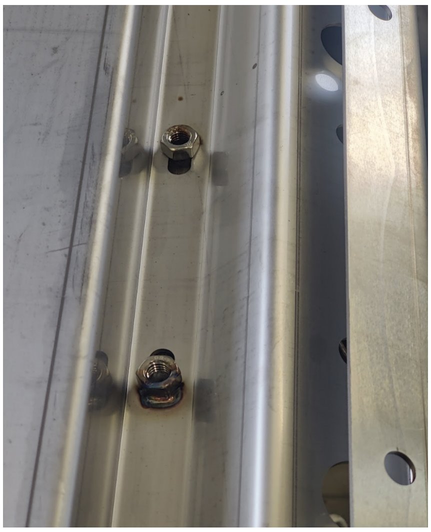




Figure 3.15, left: Bolts used for attaching anchor construction to the glass fibre construction.
Figure 3.16, middle: Nuts welded onto the anchor construction used for attaching anchor construction to the flat bar on the glass fibres back side.
Figure 3.17, right: Nuts welded onto the back side of the anchor construction.

Step 4: Attach flat bar on the glass fibre construction's backside

Fix the flat bar on the angles part of the glass fibre construction and attach it to the bar on the frontside using the holes on the diagonal part of the front bar. The flat bar further supports the original fixtures, as seen on the bottom of the glass fibre construction to the right of the new flat bar.

Figure 3.18: Steel flat bar mounted on the backside of the glass fibre construction and attached to the anchor construction on the glass fibres front. The flat bar distributes possible traction along the entire construction.

Step 5: Attach the seat belt to the anchor construction.

Attach the seat belts to the smaller holes on the slant part of the anchor construction.

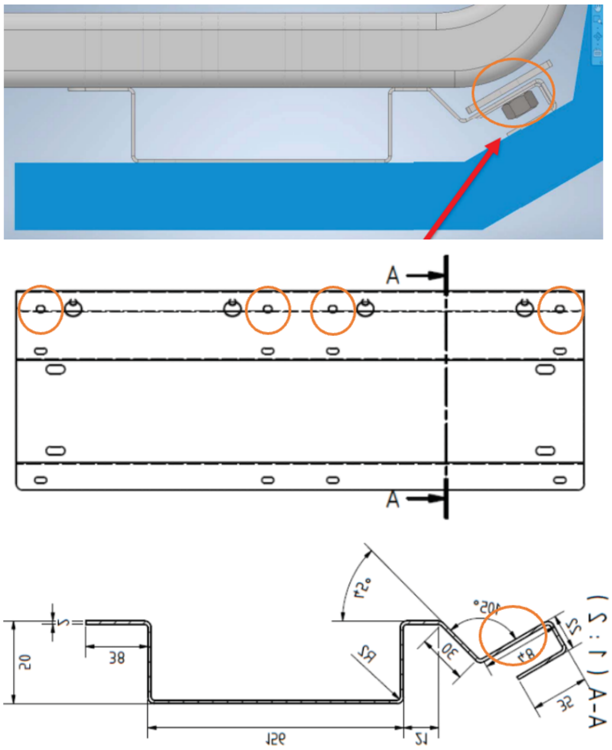
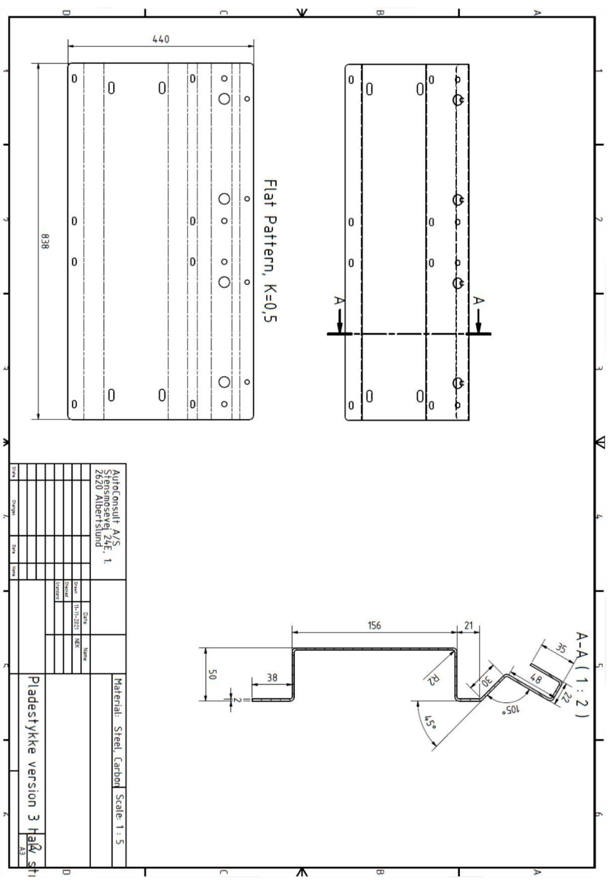


Figure 3.19, 3.20 and 3.21: Point of attachment of seat belt

Step 6: Repeat for the rest of the seat belts and reattach the seats

Figure 3.22.1 and 3.22.2: Reattach all seats to original positions keeping the seat belts over the seats.



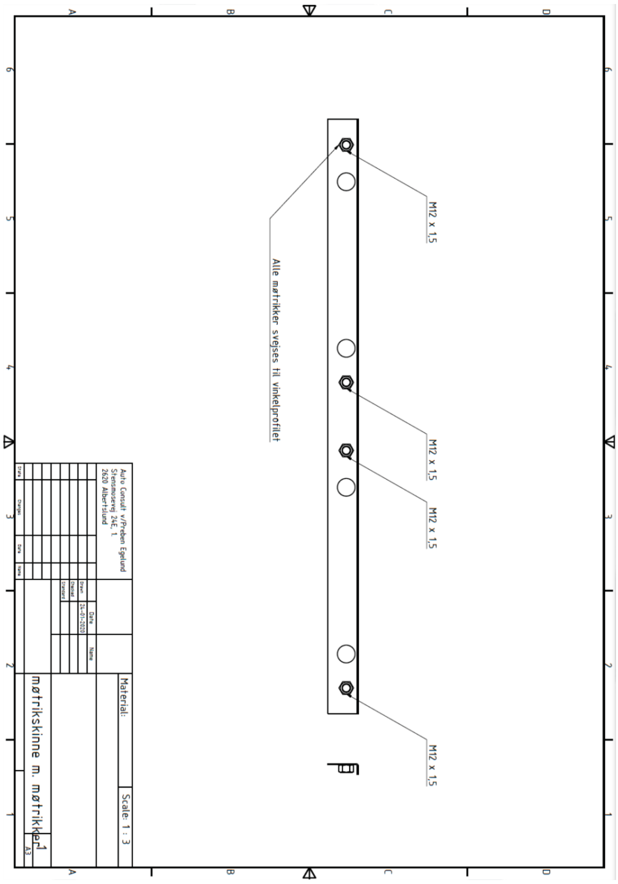


Figure 3.23: Seat anchoring construction layout, part 1 - plate construction

Figure 3.24: Seat anchoring construction layout, part 2 - bar for nut attachment

3.3.4 Wheelchair ramp

If the self-driving vehicles are to be used as part of the public transportation network or in public areas they must be able to carry wheelchair users and thus have a ramp installed or dock to a platform. In case the vehicle is equipped with an access ramp, it must comply with the Danish regulatory requirements regarding vehicles' layout and equipment but there are no requirements to whether the ramp is manual or automatic - as long as it is compliant. Most customers do, however, request as little intervention from operators as possible and therefore an automatic ramp is naturally preferred. Danish requirements for ramps are the same as 2007/46/EC requirements.

The Danish regulatory requirements regarding vehicles' layout and equipment does not state anything about distances between vehicle floor and docking surface - e.g. a platform. The safety assessor associated with a specific project does, however, require the docking to be within certain parameters. When docking to a platform the distance between vehicle floor and platform surface is recommended to be below 7 cm if no ramp is available for wheelchairs. The height difference between the vehicle floor and docking surface is, likewise, defined by the project assessor and must be levelled with the vehicle floor upon entrance without needing a ramp to smooth the transition.

Exceptions might be made, however higher distances will not be allowed without a ramp, when bringing on wheelchairs.

For the Navya Arma DL4 AM has experience in projects with both docking and use of the manual and automatic ramp. The automatic ramp is very steep if used on regular road, hence for specific projects the bus stop platforms have been heightens to approximately 12 cm of the road, to ensure a comfortable entrance via the automatic ramp. In projects where docking has been used the Navya ARMA DL4 has not been able to meet the requirements set forth by Danish assessors, as the gap between the shuttle and the platform is considered too big. Thereby AM has recommended to use the automatic ramp with a raised platform of app. 12 cm as the safest way for wheelchair users to enter the AV.

3.3.5 Q-straint

The vehicles are approved to take on wheelchair users. In order to fixate the wheelchairs Q-straint has been installed in the shuttles. Q-straint works simply by having four mounted points in the floor, with seatbelts, that can be hooked to the wheelchair. The seatbelts retract automatically and locks when necessary. When a wheelchair has to board the shuttle, the Safety driver mounts the four seatbelt heads on the floor. This means that the floor is empty when riding without a wheelchair. When carrying a wheelchair user, the three foldable seats cannot be used, and there is room for 8 additional passengers.

Figure 3.25: Q-straint solution example

3.4 Vehicle foil (branding)

The Navya Arma shuttles are branded differently at the two AVENUE sites. In Copenhagen they are branded with the Holo sub brand and in Oslo they are branded with Ruter colours (the client in Oslo). The following sections show the two vehicle brandings.

3.4.1 Holo branded

Figure 3.26: Holo branded Navya vehicle

3.4.2 Ruter branded

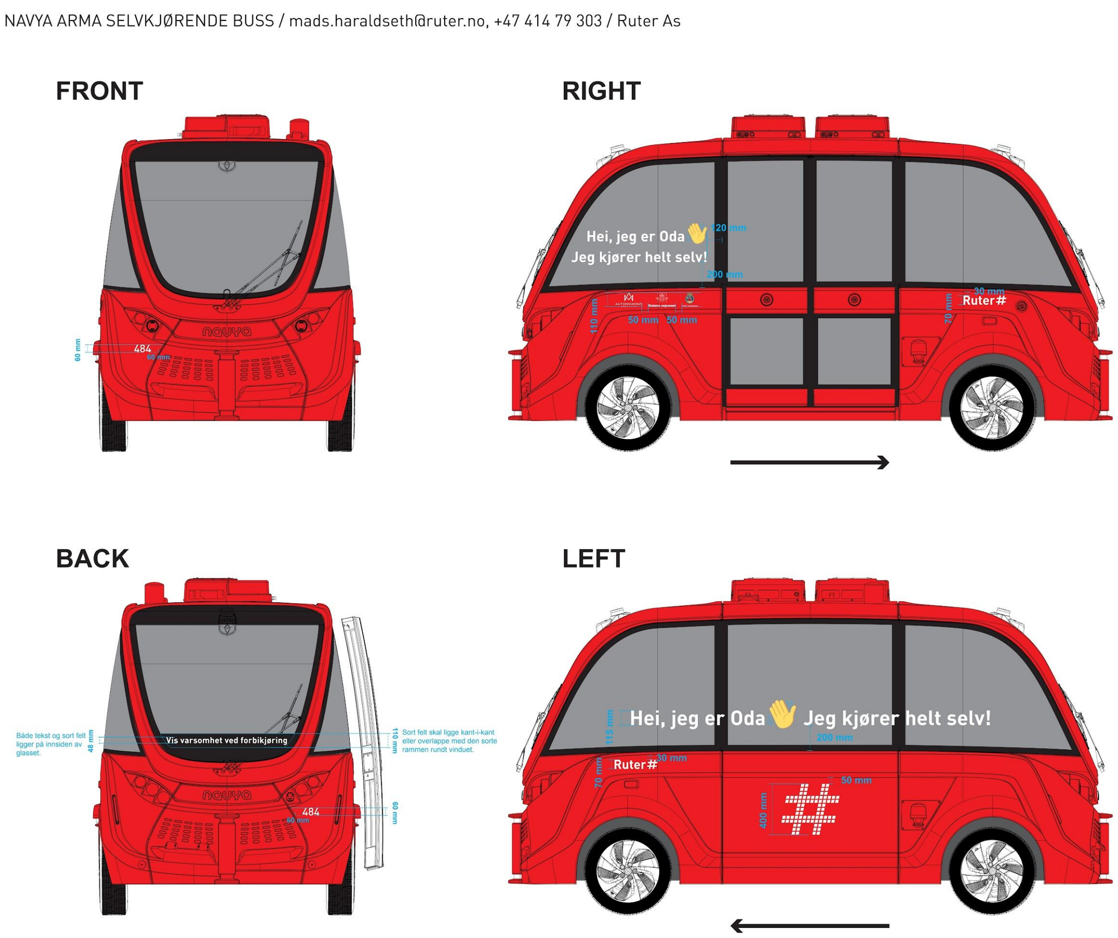


Figure 3.27: Ruter branded Navya vehicle

3.4.3 Movia branded

Figure 3.28 : Movia branded Navya vehicle

3.4.4 AVENUE EU logo

Vehicles in the AVENUE project, hence funded by the EU, are equipped with an AVENUE project sticker/disclaimer in English. The stickers are placed in the front/rear window.

3.4.4.1 English

Figure 3.29 : AVENUE sticker

3.4.4.2 Vehicle example (EU logo)

Figure 3.30 : Placement of AVENUE sticker

3.5 Vehicle inspection

Given the vehicle approval in Denmark and Oslo, the shuttles have to undergo a yearly service/inspection, ensuring safety and quality. Local service agreements have been made with official and approved mechanics. The inspection is focused on the mechanical part of the shuttle with focus on robustness etc. The software inspections are done by Navya as a part of the maintenance agreement.

3.6 Vehicle maintenance

For all Navya Arma DL4 shuttles there is a service agreement with Navya regarding service and maintenance of the shuttles. This includes the entire system enabling the operation, hence base station, commission of the route (ensure efficient operation), the shuttles hardware and software. At AM the Deployment and Maintenance Manager has the highest degree of external Navya Maintenance education, allowing AM to do in-house maintenance on hardware parts to the extent possible. When necessary Navya will send a technician to maintain the shuttles. The state of the vehicles, including service, maintenance and driven kilometres are stored and updated in Fleetio, where standard operating procedures are also attached to each vehicle number. Fleetio is an all-in-one fleet management and maintenance solution for fleets of all sizes.

As a part of the service agreement AM has full access to the Navya Supervision Centre, within the operational hours. The Navya Supervision centre monitors the operation from France and is standby to receive any inquiries from AM's own supervisors.

3.6.1 Sparepart cost

Amobility has driven around 77.000 km in total over the past three years with Navya Arma shuttles. In that time period spare parts have been changed and maintenance of the vehicles have been completed. Amobility has been able to calculate the spare part cost per km driven. The purpose of this is to understand the cost of driving the vehicles but also to be able to compare with other vehicles in the future.

The spare part price per driven km is 3.7 EUR.

The cost per driven km is an average made across all Amobility Navya vehicles during the last three years on all the Amobility routes in Scandinavia.

3.6.1.1 Spare part cost Slagelse

Since starting the deployment of Navya vehicles on the Slagelse site, there has been no major spare part changes to the vehicles. This means that the previously experienced spare part cost per km driven does not count for the slagelse site. There are multiple reasons for this. One Amobility has become better at maintaining the vehicles in collaboration with Navya - predicting and preventing issues to happen. Also the route in Slagelse has the perfect conditions for driving with Navya vehicles, causing less tension on the hardware and software parts.

The performance of the Slagelse route has also been the best of the three AVENUE sites by Amobility, which could also play a part in the maintenance and spare part cost.

The conclusion on this is that, defining, choosing and setting up the right route for the Navya vehicles is very important, taking all the barriers and obstacles of the vehicles into account - hence being able to have a good performance and a high uptime - eventualle also having a lower maintenance and spare part cost of running the operation.

3.6.2 Amobility commissioning

Commissioning process and information regarding the implementation of self driving vehicles in Denmark. The process involves the vehicle manufactura (Navya), AM and public approval authorities.

The commissioning process typically takes 30 days with 14 days preparation and 14 days on site commissioning and costs around 20.000 - 40.000 EUR.

The entire commissioning process with Navya has to be documented and reported to the authorities before an approval can be issued. Major changes to the approved commissioning report have to be approved again by the authorities before implementation. The commissioning process is conducted in collaboration between Amobility and NAvya. The overall process is presented below.

Prep commissioning

1. Pre-study
2. Site analysis
3. Final route decision

4. Garage facilities
5. PO created and signed
6. Preliminary commissioning plan
7. Initial infrastructure changes
8. Route/vehicle/site preparation
9. Final commissioning plan
10. Base station or N-trip setup

On site commissioning

11. Mapping
12. Cartograph (verification and clearing of map)
13. Route setup testing (initial trajectory)
14. Testing and adjusting trajectory
15. Setup of safety - and priority zones, speed limits etc.
16. Navya API setup
17. Formal hand-over
18. Holo IT configuration
19. Holo internal testing
20. Assessor/authority testing (for approval)
21. Final approval

After commissioning

22. Route adjustments (when necessary)
23. Assessor/authority adjustment testing
24. Assessor/authority approval
25. Route adjustment implementation

3.6.3 Amobility Maintenance

Amobility have been trained by Navya on several maintenance courses in France to do maintenance on our operations to a certain level without including Navya. There are three levels of maintenance that an operator can do, the following shows the levels.

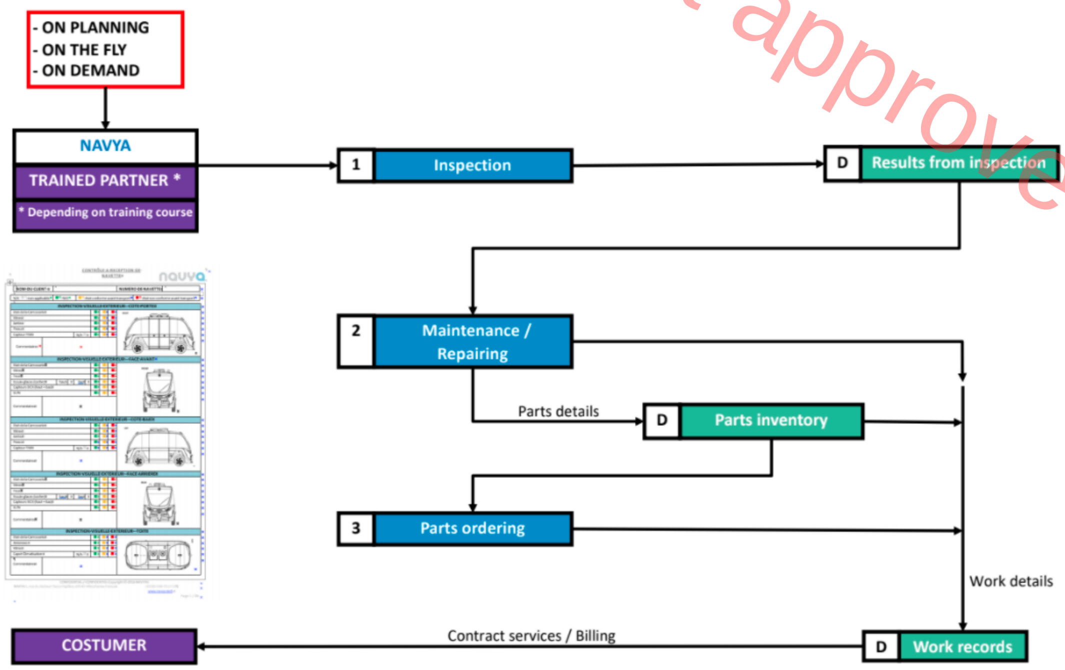


Figure 3.31 : Maintenance organisation and workflow

Amobilitys maintenance team has been trained to do all three levels of maintenance, meaning that Amobility over time has developed predictive maintenance, where data from the vehicles (telemetry) is paired with maintenance data (downtime, reasons for downtime etc.) so that Amobility can maintain the highest possible uptime on all sites.

3.7 AM supporting operational functions

3.7.1 Amobility Supervision

Responsibility and mandate

The supervision team helps and coordinates daily operation with safety operators. They are the link between manufacturers and operators and maintain the bigger picture. Their role is to be proactive to the extent possible and reactive when necessary. Data and learnings are constantly stored to avoid future problems. The daily work of the supervision team can be defined as follows:

- Before operation
  - Coordinate and prepare startup of operation
  - Read handover
- During operation
  - Monitor and assist operators on the routes
  - Troubleshoot with operators and manufactures
  - Communicate with project partners
  - Report issues and register downtime
- After operation
  - Coordinate end of operation
  - Hand over information to next Holo Supervisors

Tools for crisis management

The supervision team has a set of tools they can use when a crisis occurs to ensure that AM handles the crisis to the best possible degree. The process includes securing the site, securing involved parties (safety operator, passengers, other road users etc.) and gathering the required data to understand and analyse the incident, so that AM can avoid making the same mistakes in the future, if the mistake is caused by AM. The following list presents some of the steps and tools used.

- Action cards for incidents
- After action review
- Incident procedures
- Vehicle data analysis
- Incident report(s)
- Final incident assessment report
- Incident interviews
- Incident communication
- Deletion of sensitive personal data
- Incident vehicle assessment

Supervision portal (for monitoring and troubleshooting)

The AM supervision team uses the AM supervision portal to monitor and troubleshoot the vehicles in operation, in collaboration with the safety operators inside the vehicles. The following shows an example of a vehicle in the supervision portal.

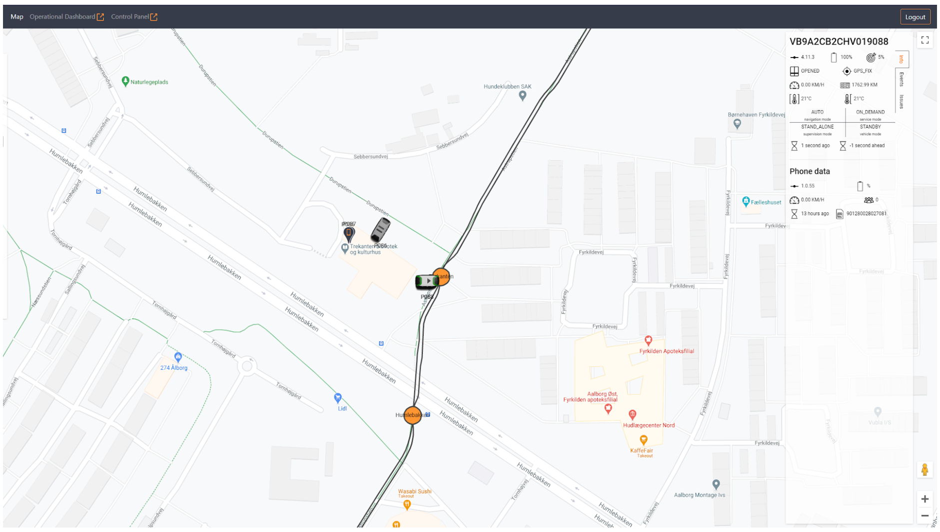


Figure 3.32 : AM supervision portal

The supervision portal is supported by operational data like telemetry, states and events coming from the Navya API and data from the AM operator app.

3.7.2 Amobility training

The Holo training program consists of 5 training blocks that each contributes with important aspects of becoming a safety driver of autonomous vehicles.

The blocks are as follows:

1. Basic knowledge training
2. Vehicle specific training
3. Holo procedure training
4. Holo crisis management training
5. Site specific training

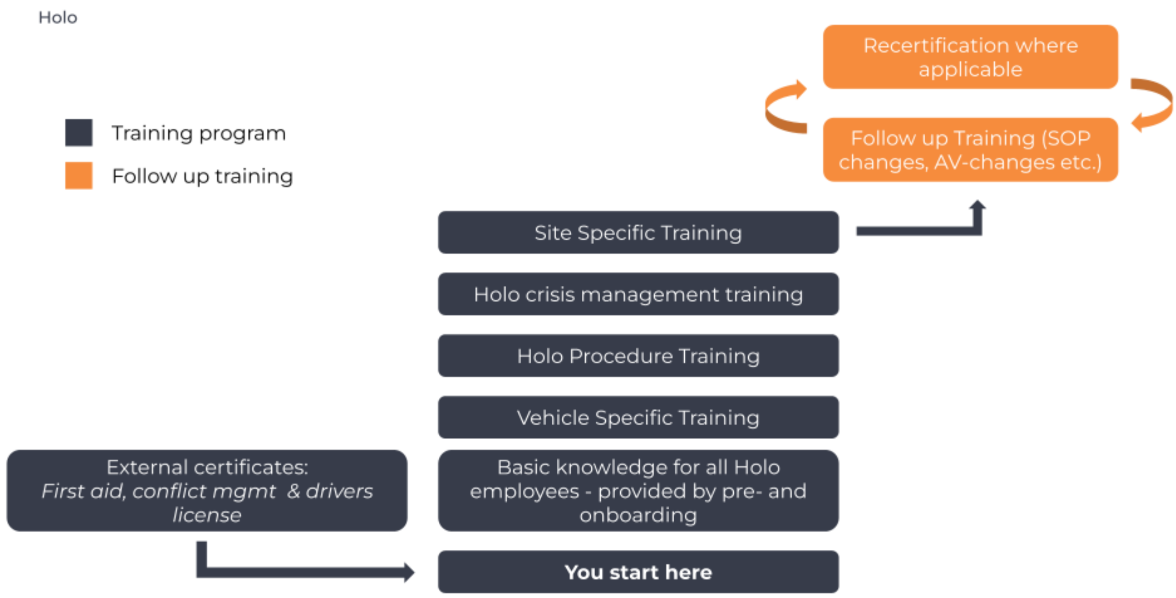


Figure 3.33 : AM training program

Depending on the country of deployment some certificates can be obligatory for operating vehicles on public roads and/or public transport services. These can be driver licences in accordance with the vehicle classification, first aid certificate, conflict management certificates and more.

Equally important to the training program is the follow up training which takes place after the safety drivers are fully educated and out in live operation. The technology behind autonomous vehicles is constantly being developed and new improved features and software updates happen at a rapid pace. Once changes to e.g. procedures or vehicle features happen they will be included into the training program and safety drivers will receive follow-up training in order to ensure the safety profile of the operation.

The ability to conduct efficient and documented follow-up training is crucial for all operators where crucial safety responsibilities are placed on vehicle safety drivers or remote tele operators.

3.7.2.1 Types of training

The Holo training program consist of several formats for learning and the participants will be trained through the following types of training:

- Practical training where the participants will learn by doing and getting to know the vehicle.

- Classroom training, where the participants will receive theoretical knowledge training regarding both the technical aspects but also the commercial aspects of operating autonomous vehicles on public roads.
- Quizzes and tests ensure that the learning objectives are met.
- Video training, allowing the participants to have the most efficient training sessions.

3.7.2.2 Basic knowledge training

The basic knowledge training block consists of two parts, General technology introduction and legal framework and responsibility introduction.

- The general technology training introduces autonomous vehicle Terminology, SAE levels, introduction to different autonomous vehicles, introduction to sensors (lidar, radar, camera etc.) and introduction to the technical routing process.
- The legal framework and responsibility introduction introduces project approvals (both vehicle and route), liability and the role of the safety driver.

The purpose of the general technology training is to ensure that the participant can understand the basis functionality of autonomous vehicles, can understand the technical terminologies, can understand the basic data structure of autonomous vehicles, can understand the basic principles of autonomous hardware, can understand the different SAE levels and understand the role of the safety driver in the ecosystem of autonomous vehicle deployment.

3.7.2.3 Vehicle specific training

This block in the training program is either done by the vehicle manufacturer or via Holo trainers trained by the vehicle manufacturer, where Holos vehicle specialist receives training from the vehicle manufacturer to then be able to train upcoming safety drivers in vehicle training.

Vehicle specific training enables the safety driver to assist the vehicle in both manual and autonomous mode, ensuring safe operation of the vehicle.

Vehicle specific training can be organised as follows, depending on the route and vehicle.

- Introduction to the vehicle
- Demonstration of the vehicle
- Driving and manoeuvring the vehicle in closed area
- Technical troubleshooting
- Extended driving: Driving on route and at night
- Extended driving: Difficult situations, emergency procedures, cleaning and towing of vehicle

3.7.2.4 Site specific information

Site specific training is the last block in the Holo training programme and is executed on route, as the last step to ensure that the participants are ready to operate the autonomous vehicles in real life traffic and open roads.

The site specific training should provide the participant with knowledge, skills and attitude in order to operate safely on the desired route, taking the site specific risk assessment into account.

Before the participant can begin the last block, they have to have completed and passed the 4 previous training blocks including fulfillment of national requirements such as bus-driver's license, certificates etc.

The site specific training depends on the route and traffic circumstances and the following parts are included:

- **Site Specific Information**
  Information about scheduling and operational hours, garage and washing/cleaning facilities, customers and passengers including specific communication instructions.
- **Drive through with Instructor**
  Route/area are driven together with an instructor to go over specific risk areas on the route/area. Holo also conducts this training as site specific video training for experienced operators.
- **Risk assessment identification**
  Identified risks and related mitigations are discussed and explained to operators on site in order to keep high alertness to identified route specific risks
- **Site Specific Actions**
  In cases where procedures have site specific applications these are addressed and training in procedures are conducted in similar ways as general procedure training

4 Operations

The operations of the pilot sites and the different roles are shown in the following organisational chart.

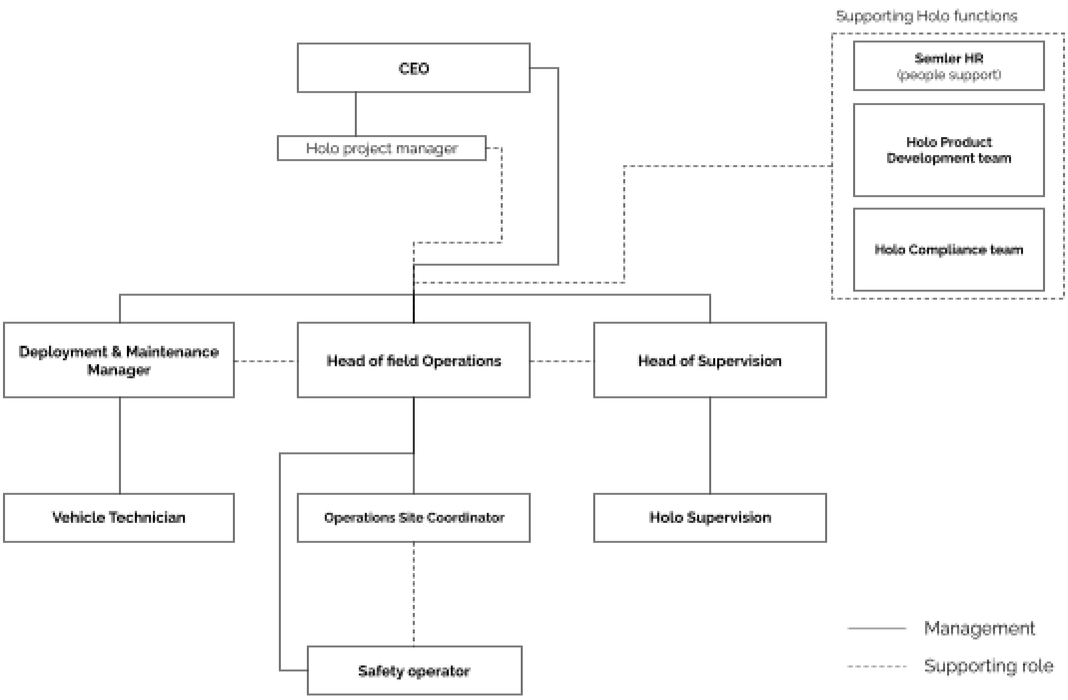


Figure 4.1: Autonomous Mobility's organisational diagram

4.1 Operational excellence and procedures

4.1.1 Procedures

To support the daily operation and ensure safe and compliant operations, all participants in the training programme will have training in standard operating procedures (SOP). The SOPs cover everything from start-up of operation, to shut down and supporting functions. The SOP flow consists of SOPs for both the safety driver, the supervisors and the maintenance team. Besides daily SOPs the flow also contains the crisis management SOPs guiding the operational team through incidents in operations. The SOP flow can be seen below.

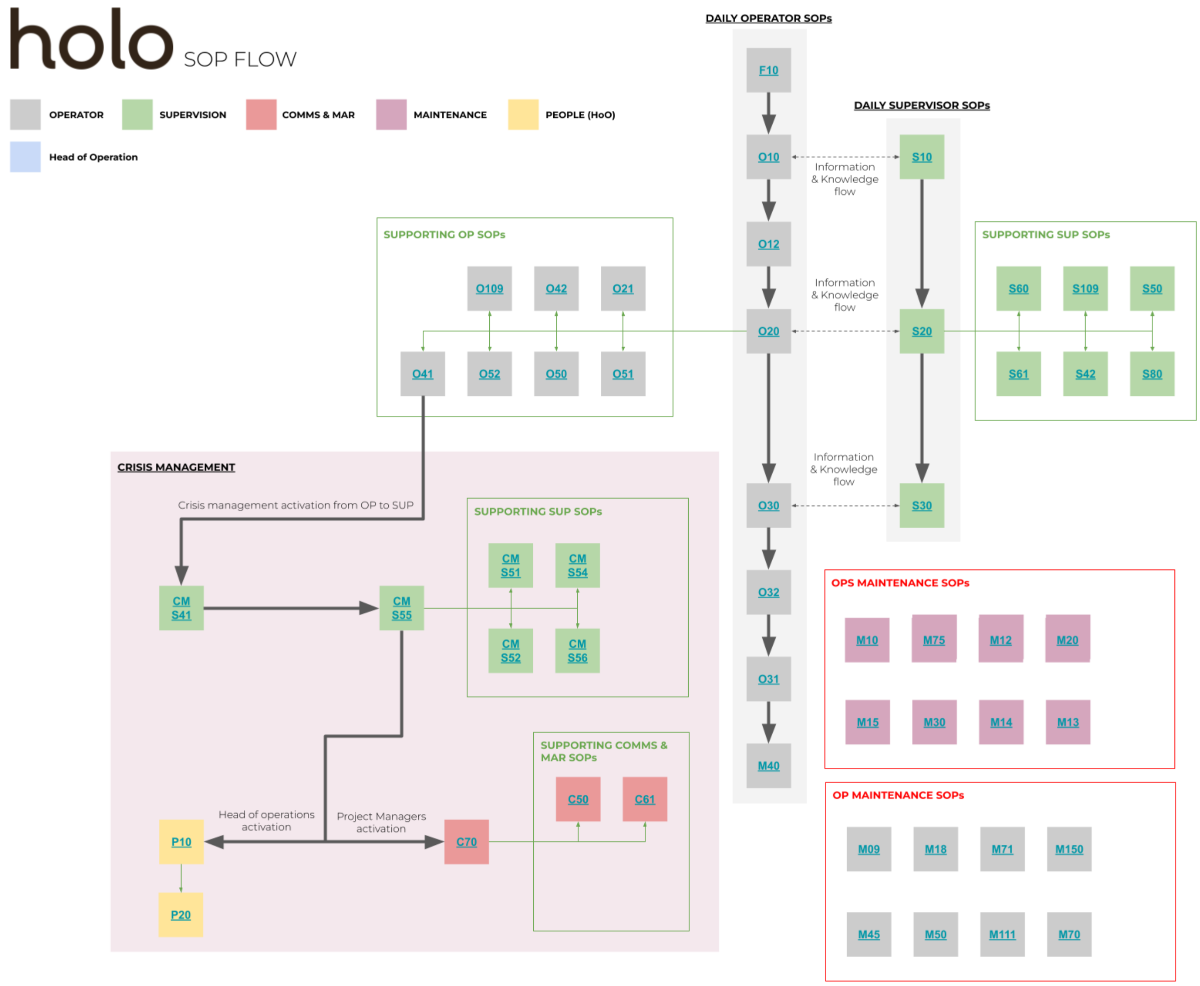


Figure 4.2: Autonomous Mobility's SOP flow

4.1.2 Crisis management

The Holo Crisis management consists of three phases (start, handling and data collection) with supporting tools to ensure a safe and efficient process. Safety drivers are educated in the crisis management process as well they have received a first aid and conflict management certificate, depending on the country of deployment.

Supporting the crisis management process the operators have been trained in using the supporting crisis management tools. The tools are developed to ensure a structured assessment of the incident, collection of data and information, secure handling of involved parties and to safely handle the vehicle. The tools are shown below.

Figure 4.3: Crisis management tools

To ensure good communication during an incident the operators and supervisors are trained in the incident flow chart, defined during the beginning of the project, taking all relevant stakeholders into account. Site specific crisis management exercises are executed every year to ensure that the organisation is compliant with the crisis management processes. One of the important tools is the incident report which is to ensure transparent information across the different roles in the defined flowchart as well as to document information from the safety driver regarding the incident. When an incident occurs, the Supervisor creates a new incident report (from a template) and starts to fill in information from the safety driver.

On the following 3 figures (figure 4.4, figure 4.5, figure 4.6) the flows for incident start, handling and data collection are visualised.

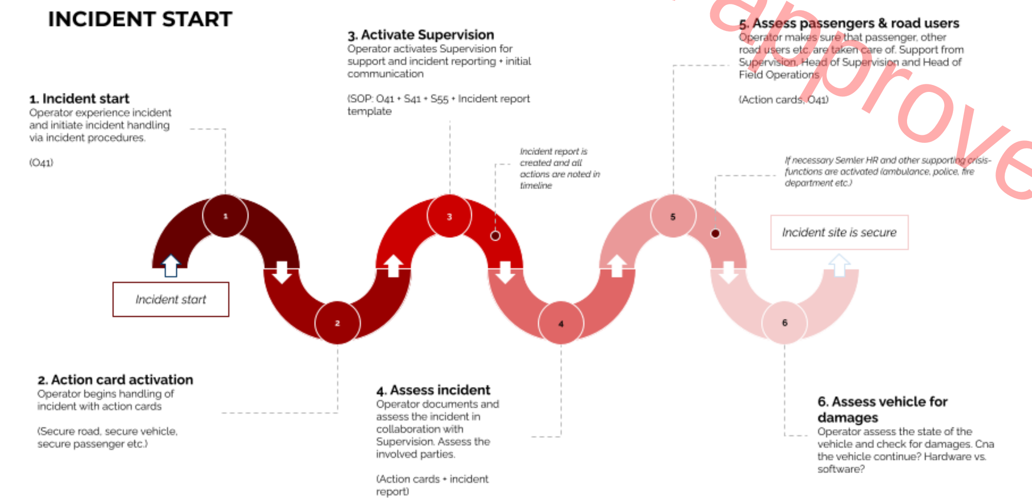


Figure 4.4: Crisis management start

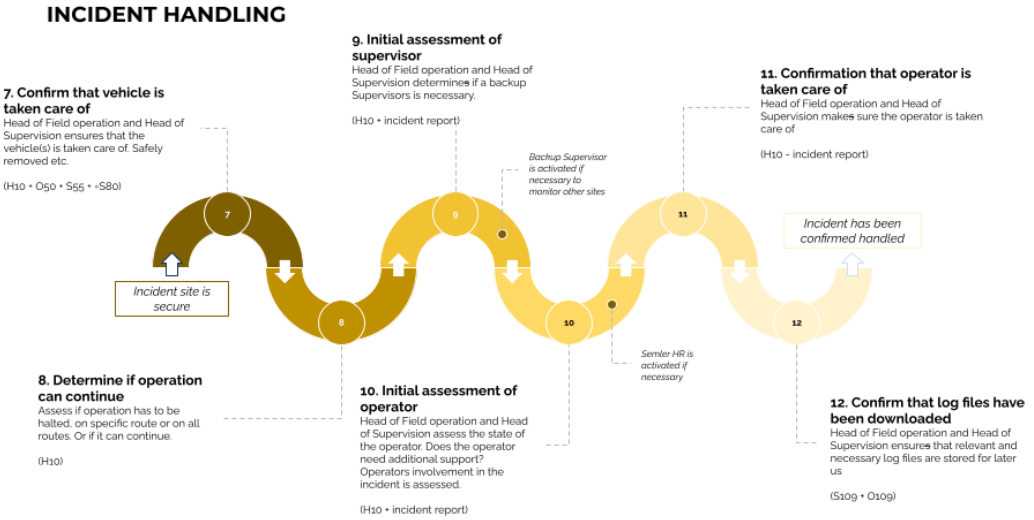


Figure 4.5: Crisis management handling

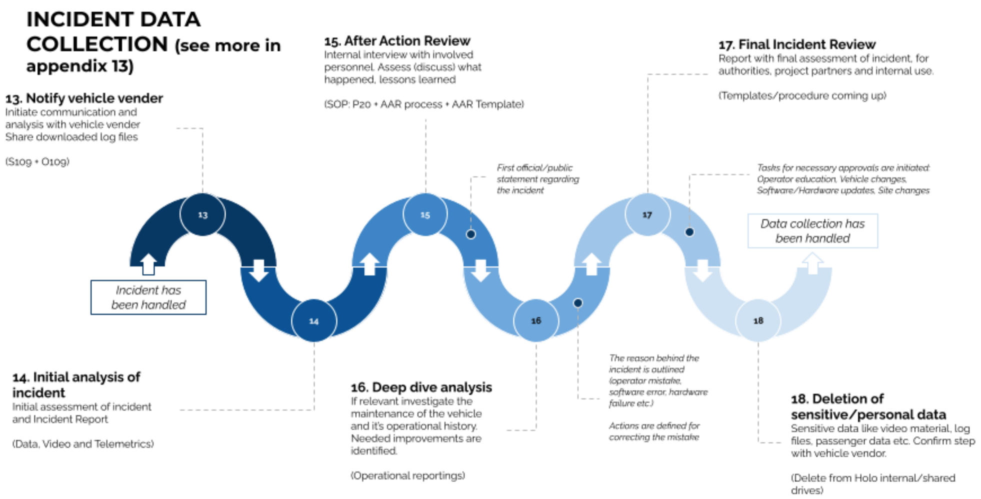


Figure 4.6: Crisis management data collection

5 AM pilot sites

In the AVENUE project, AM will run three test sites:

- Nordhavn, Copenhagen, Denmark
- Ormøya, Oslo, Norway
- Slagelse, Denmark

The Ormøya route was originally initiated without being a part of AVENUE but an agreement has been made to include the site for 5 months to begin with. The Norwegian site ended in December 2020. A new Danish site in Slagelse Hospital will begin in September 2021, with focus on on-demand.

The three routes can be concluded in short as follows:

	Copenhagen	Oslo	Slagelse
Community	Nordhavn (smart city area + residential area)	Ormøya (residential area)	Hospital site
Funding	AVENUE + AM	AVENUE + AM + Ruter	AVENUE + AM + Movia
Start date project	May 2017	August 2019	August 2019
Start date trial	September 2020	December 2019	August 2021
End data trial	March 2021	December 2020	August 2022
Type of route	Fixed circular line	Fixed circular line	On demand - not circular line
Distance	1.3 [km]	1.6 [km]	5 [km]
Road	Open road	Open road	Open road
Type of traffic	Mixed	Mixed	Mixed
Speed limit	30 [km/h]	30 [km/h]	30 [km/h]
Roundabouts	No	No	No
Traffic lights	No	No	No
Type of service	Traditional bus line	Traditional bus line	Flex: On-demand service
Concession	Line (circular)	Line (circular)	Not circular line

Number of bus stops	6	6	6
Type of bus stops	Fixed	Fixed	Fixed
Bus stop infrastructure	Yes	Yes	Yes
Number of vehicles	1	2	2
Timetable	Fixed	Fixed	Not fixed
Operation hours	Monday-Friday (5 days)	Monday-Sunday (7 days)	Monday-Friday (5 days)
Timeframe weekdays	10:00-18:00	7:30-21:30	07:00-18:00
Timeframe weekend/holidays	No service	9:00-18:00	Only for special events
Depot	At 800 [m] distance	At 200 [m] distance	At 200 [m] distance
Driverless service	No	No	No

Table 5.1: AM pilot site overview

5.1 Nordhavn, Copenhagen, Denmark

The Copenhagen pilot site will be situated in an area of the city called Nordhavn. Nordhavn is an active industrial port that is undergoing a transformation – turning into Copenhagen's new international waterfront district offering residential and commercial buildings. When the development of Nordhavn is done, the area will house more than 40.000 residents and 40.000 employees.

Nordhavn aims at being an eco-friendly neighbourhood and contributes to boosting Copenhagen's image as an environmental metropolis. Renewable energy and new types of energy, optimal use of resources, recycling of resources and sustainable transport will help make Nordhavn a model for sustainable development and sustainable design. A vibrant city: Nordhavn should vibrate with life as a versatile urban area with a multitude of activities and a wide range of shops, cultural facilities and sports facilities. The area is becoming more and more populated, and the need for local transportation is expected to keep growing.

Figure 5.1: The Nordhavn route area seen from above

Currently, the Nordhavn area is serviced by a nearby S-train station (app. 1,1 km away) and bus stops located near the train station. There are however no buses or trains running directly in the area – creating a great opportunity for automated vehicles to function as a new public transport solution, connecting the area much better than it is today. In 2020 two new metro stations will have been built – opening in the periphery of the neighbourhoods.

Figure 5.2: Part of the Nordhavn route

5.1.1 Route

The first route is placed in the area called Århusgadekvarteret. This area was the first one finished and residents started moving there in 2015. Since then different squares and the harbour promenade and a rooftop gym have been evolved and taken into use. Furthermore, special attention has been on developing local retail, so today there are supermarkets, cafes, restaurants and different specialised retailers. There are several shared space areas on the route including a bathing zone.

The first route is a circle line around the area (blue line on the map below), making it easier to get around and to enter the area from outside Nordhavn. Our garage is located on the next peninsula close to Århusgadekvarteret (the red line on the below map).

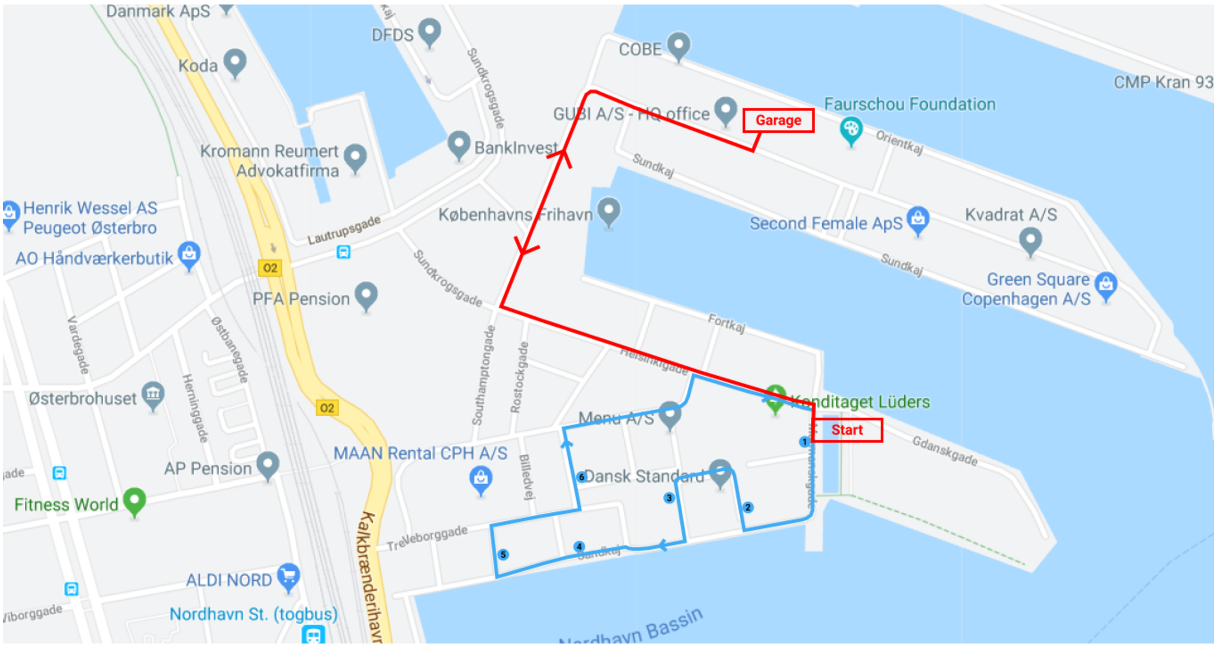


Figure 5.3 : Map showing Nordhavn route

The pilot route is going to be in mixed traffic with cars, pedestrians, bicycles etc. The area is, in general, a low-speed area with 20-50 km/h speed limits on the route, and in the 50km/h limit areas, the recommended speed for cars is 30km/h.

Operation facts:

- 2 AV's running (initially)
- Mon-Fri 10.00-18.00
- Loop route with 6 stops

The main expected users of the shuttle service will be the residents of Nordhavn (including families, children, and elderly), commuters working in Nordhavn, and visitors to the area. Several usage scenarios can thereby be anticipated:

- Ease the mobility within the area for the residents and commuters working in the area.
- Used for the first/last mile from the main road/ entry point to the area to the different stops within the area for residents and commuters working there.

- Provide easier access from the main road to e.g. the harbour pool, restaurants, cultural facilities for visitors and families.

Planned services provided for the end-users:

- The shuttles are free of charge during the pilot project in Denmark, so there is no ticketing yet.
- There are static bus stops providing the position of the bus, relative to the given stop.
- Real-time location of buses can be seen in the mobile application.
- Besides the bus stop signs, users can find information about the pilot project at AM website and AVENUE Mobile Application.

During the project period, it is the aim to test the services developed through the AVENUE project e.g. real-time position of the bus, on-demand booking, accessibility for disabled persons.

5.1.2 Bus stops

Stop name	Picture
Murmanskgade	
Gøteborg plads Ø.	
Gøteborg Plads V.	

Sandkaj	
Karlskronagade	
Bilbaogade	

Table 5.2: Bus stops on Nordhavn route

5.1.3 Timetable

Timeslot	Mumanskgade	Gøteborg plads Ø.	Gøteborg Plads V.	Sandkaj	Karlskronagade	Bilbaogade
A	10:00 10:20 10:40	10:02 10:22 10:42	10:04 10:24 10:44	10:08 10:28 10:48	10:10 10:30 10:50	10:14 10:34 10:54
B	11:00 11:20 11:40	11:02 11:22 11:42	11:04 11:24 11:44	11:08 11:28 11:48	11:10 11:30 11:50	11:14 11:34 11:54
C	12:00 12:20 12:40	12:02 12:22 12:42	12:04 12:24 12:44	12:08 12:28 12:48	12:10 12:30 12:50	12:14 12:34 12:54
D	13:00 13:20 13:40	13:02 13:22 13:42	13:04 13:24 13:44	13:08 13:28 13:48	13:10 13:30 13:50	13:14 13:34 13:54
E	14:00 14:20 14:40	14:02 14:22 14:42	14:04 14:24 14:44	14:08 14:28 14:48	14:10 14:30 14:50	14:14 14:34 14:54
F	15:00 15:20 15:40	15:02 15:22 15:42	15:04 15:24 15:44	15:08 15:28 15:48	15:10 15:30 15:50	15:14 15:34 15:54
G	16:00 16:20 16:40	16:02 16:22 16:42	16:04 16:24 16:44	16:08 16:28 16:48	16:10 16:30 16:50	16:14 16:34 16:54
H	17:00 17:20 17:40	17:02 17:22 17:42	17:04 17:24 17:44	17:08 17:28 17:48	17:10 17:30 17:50	17:14 17:34 17:54

Table 5.3: Timetable for Nordhavn route

5.1.4 Stakeholders and partners

In order to get the demonstration site approved and in operation several stakeholders and partners are involved. Some during the whole project period, others only for specific parts of the project. Besides the below entities there are various public authorities involved in granting the permit, these will be described in part 3.1.

AM:

Is the local private operator and the main applicant of the pilot project. AM has the main responsibility to plan and operate the pilot project. AM is the entity given the permit and thereby has the full responsibility for safety and the vehicles.

Copenhagen Municipality:

Is a member of the steering committee for the pilot project. The municipality is also approving the use of the roads under their jurisdiction where their route is located.

CPH City & Port: Is a member of the steering committee for the pilot project. CPH City & Port Development is in charge of the development of the Nordhavn area and assists in selecting the route, risk workshops, getting road permits from homeowner association as well as being a close dissemination partner.

The homeowner association G/F Århusgadekvarteret:

Is a member of the steering committee for the pilot project. The association provides the permit to use the roads under their jurisdiction as well as ensuring that any concerns from the homeowners are taken into consideration.

The Copenhagen Metro:

Is overall responsible for the operation of Copenhagen's metro and the expansion of the metro system including the line to Nordhavn. The Copenhagen Metro assists with the integration to public transport.

Movia:

Is a public company and is regulated by the law about transport companies. According to the law, Movia handles bus operation, local rail operation and transport of disabled persons. Movia assists with the integration to public transport. Movia is also an operational partner in the new Slagelse Hospital site.

COWI Denmark:

Is a leading consulting group, and two different departments (in order to avoid conflict of interest) are hired to do two different tasks:

One department has been approved as the assessor for this pilot project. The application for a permit to test automated vehicles shall according to the law include an evaluation from an approved assessor.

The other is hired to make a risk assessment of the road safety in the pilot. The assessment is done in close cooperation with AM and is part of the basis for the evaluation by the assessor.

Rambøll:

Is a leading consulting group. A road safety auditor from Rambøll has analysed the below list of conditions in the pilot project. The analysis is part of the basis for the evaluation by the assessor.

- The route and surroundings
- Existing traffic conditions
- The speed on the route
- Handling of other road users
- The conditions to give way
- Traffic at the bus stops

Bech-Bruun:

Is a law firm that is hired to provide legal assistance.

AM supervision:

AMs centralised operation centre (AM supervision) for the route in Nordhavn will monitor the operation all hours of operation.

Navya supervision:

Is Navya's operational monitoring unit, which is contacted in case of difficulties that can be solved on location, or in case of incidents or accidents. Navya's supervision monitors all Navya's vehicles 24/7/365 and AM communicates daily with Navya supervision in connection with the operation of vehicles on other locations.

5.1.5 Status after 32 months in AVENUE

The first 16 months in the Copenhagen demonstration site have been spent on obtaining the permit to drive on the route in Nordhavn. At the same time, AM has tried to get the general approval process changed on a political level, since the current setup is not sustainable to AM.

To provide an overview of the project actions below is listed the highlights from the project timeline. In section 3.1 a more in-depth description of the approval process is provided.

Winter 2017

- CPH City & Port and AM held the initial meeting regarding providing autonomous mobility services to the citizens and visitors in Nordhavn.

Spring 2017

- First inspection of the Nordhavn route

Summer 2017

- On June 1st the law allowing pilot projects with automated vehicles in Denmark was passed
- The compilation of the report for the accessor begins, including obtaining a vehicle approval by the Danish Road Safety Agency. Since this is the first automated vehicle to be approved in Denmark there is not a special type certification for this. According to the law, the Navya bus is then compared to the vehicle type M2, a bus that can have more than 9 passengers including the driver - which means that the applicant has to apply for various dispensations such as not having side mirrors etc.

Winter 2017-2018

- COWI had dialogues with the Danish Road Directorate getting clarifications regarding the role as an assessor.

Summer 2018

- May 1st the AVENUE project begins with Nordhavn as the Copenhagen demonstration site.
- In August COWI and AM host a risk assessment workshop with representatives from CPH City & Port, the Danish Police, COWI and AM.
- In September the final report version 1 based on the vehicles driving SAE 4 is handed to the accessor COWI. The report covered 903 pages including 41 appendixes.

Winter 2018

- In October Navya stated that the vehicles are not able to drive SAE 4 but SAE 3. Due to a blind spot of 30 cm. This meant that AM had to provide revised material for the accessor:
    - Obtain a new vehicle approval by the Danish Road Safety Agency
    - Change the role of the safety operator in the vehicle having to be attentive to the road in the driving direction.

Spring 2019

- 3rd April AM receives the final report from the assessor COWI and thereby closes all 117 questions raised by them.
- 4th April AM hands in the first application for route 1 to the Danish Road Directorate. The application covered 96 pages.
- In May the Danish Road Directorate hosted a meeting with AM, to discuss their first feedback to the application including 11 action points.
- 27th May AM received a formal letter from the Danish Road Directorate, explaining that it will not be possible to perform the necessary political processing of the application. This is due to the announcement on 7th May that the government election will take place on 5th June. During an election period, the parliamentary committees will not hold their ordinary meetings and ministers will not take on new, major political initiatives or decisions in the same period. Originally the first route should follow the blue line on the map below, but due to the time it has taken to get the route approved, new construction work in connection with the Metro station demands that the route be altered a bit from November 2019 (the red line on the map).

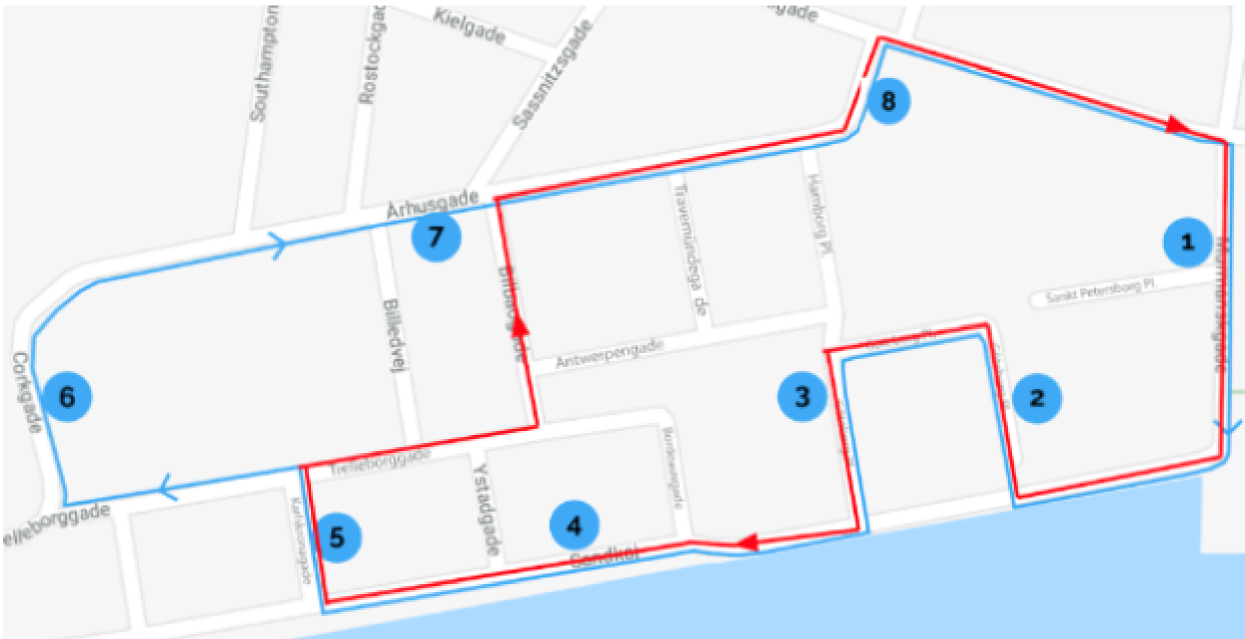


Figure 5.4: Revised Nordhavn route

- In May it was therefore decided that it would be strategically wise to make an application ready for a revised route 1, so when the parliamentary committees are active again, both route 1 and the alternative route 2 can be approved simultaneously. It turned out though that it would be too complex to apply for 2 routes at the same time, and therefore the further application would only be for revised route 2 (blue line on below map). At the same time the traffic assessment for when the construction starts, recommended some changes in the bus stops, so the route now has 6 stops instead of 8.

Summer 2019

- The application for route 2 included that
  - The CPG City & Port, Copenhagen municipality and the homeowner association should approve the new route 2. This had some small difficulties, due to a playground placed next to the new route.
  - A road safety officer looked at the changes and analysed the impact.
  - The risk assessment was adjusted
  - The assessor assessed and approved the new material.
- In July the final report for route 2 was handed over to the assessor COWI.
- 22nd August AM received the final report from the assessor COWI.

Fall/winter 2019

- It is the aim that the final report regarding route 2 can be handed into the Danish Road Directorate in early September.
- Then the Danish Road Directorate will invite AM for a meeting to provide feedback and maybe some action points, they want AM to elaborate. The dialogue with the Danish Road Directorate will continue until they can make a final approval of the application.
- Based on the approved application the Taskforce will make a draft of the order and send it to be processed by the Transport Committee.
- The Authorities have up to 3 months to process the application including 3 weeks for a public hearing.
- It is expected that AM can start operation in Copenhagen late December 2019 or January 2020.

Spring 2020

- In March 2020 the approval from the Danish Road Directorate was granted
- AM started preparation of commissioning with NAVYA
- Due to travel restrictions from France to Denmark commissioning was postponed until Covid-19 restrictions allowed for NAVYA to come to Denmark

Summer 2020

- The Nordhavn route was mapped and commissioned in July 2020
- Site Acceptance Tests were conducted with COWI (assessor)
- AM launched the site for the public on August 3rd 2020

Fall/winter 2020

- AM conducted scheduled operation with 2 vehicles
- Operations was performed with limited passenger capacity due to Covid-19 restrictions
- AM investigated how to expand the route to meet AVENUE objectives
- AM concluded with partners that the route could not be expanded as a result of construction plans for the area
- AM initiated discussions with AVENUE to shut down the site

Spring 2021

- January preparation with CERHT of test of in-vehicle services with camera and sensor technologies.

- February setup of in-vehicle services in Nordhavn on P109 shuttle
- February test within-vehicle services in Nordhavn
- End of february: End of operation in Nordhavn AVENUE

Summer 2021

- Continuously testing CERTH in-vehicle services on test track in Copenhagen (no operation, just test)
- Approval of new AVENUE Amobility site in Slagelse Hospital site.
- Development and preparation of on-demand with Holo operational platform (supervision, remote control centre etc.)

Fall 2021

- Start of new AVENUE site: Slagelse Hospital site (on-demand site with stops)

5.1.6 Operational data summary from Nordhavn

While operating the shuttles, Amobility has been using data from the vehicles and an operational app (developed by Amobility) to improve daily operation and track performance. Data from the vehicles has been received via Navyas API and then categorised and visualised in Amobility Data Analytics tool (Operational dashboards).

5.1.6.1 Data types

The types of data that Amoblity has been collecting are described in the following two chapters; Navya API and Amobility Safety Operator app.

5.1.6.1.1 Navya API

Navya API data sources can be divided into 2 main categories, for simplification, Navya states and Navya events.

Navya states (Telemetry data) contains data indicating vehicle status. This data is received every second as long as the vehicle is turned on. For example this could be: Location, battery percentage, manual/auto mode, door close/open etc.

Navya events (Events) contains data describing events issued by the vehicle at the moment of event occurrence. This could be: Estop button pressed, Arrived at destination, Hard braking occurred, Vehicle is out of path etc.

As seen on the figure, data from vehicles are received and stored in the Holo Platform. From here data analytics tools (ex Operational dashboards) are fetching the data.

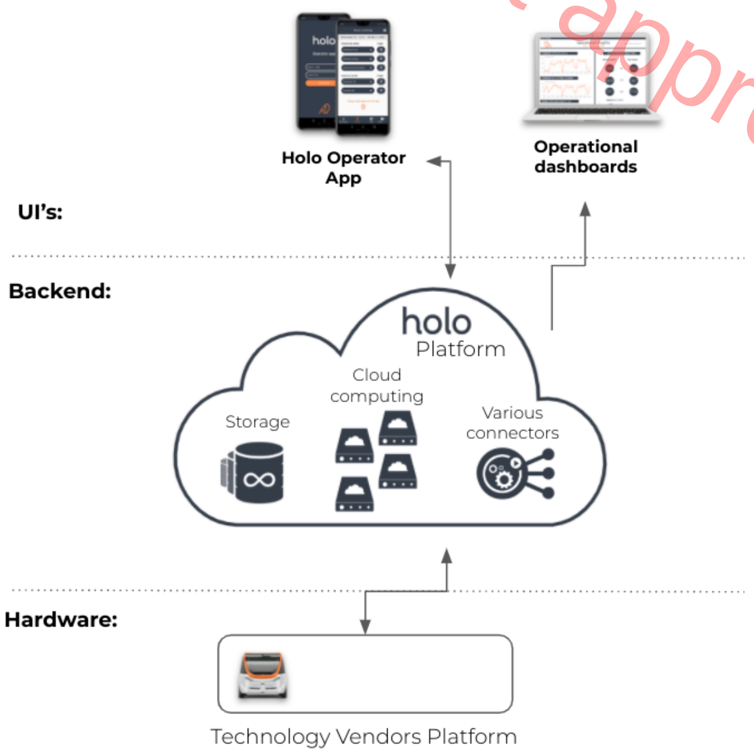


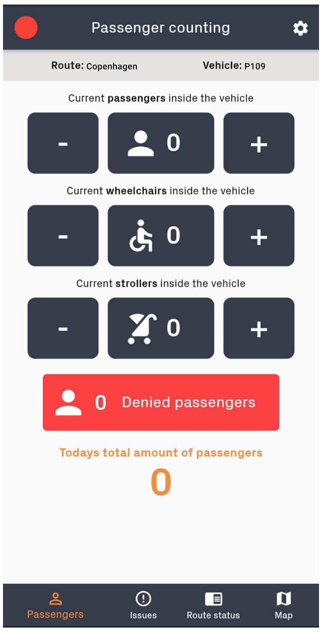
Figure 5.5 : Navya API integration with Autonomous mobility products

5.1.6.1.2 Amobility safety operator app

The safety operator app functions as a support to the data from Navya by gathering several types of data that are not included in the API. As an operator there are multiple things that you wish to monitor and analyse (both technically and based on client needs). Together the Navya API and the Safety Operator app provide the big holistic picture of the daily operation.

The safety operator app is designed to gather two types of data, Issues and passenger counting.

Issues are related to either outside the vehicle (caused by external factor fx. 'Parked car near trajectory') or inside the vehicle (happen in the vehicle ex 'Denied passenger'). Our operators manually register all issues. The application saves timestamp (time taken from phone device and when registering issue), vehicle id (which indicates what vehicle is in use), and location data (geo coordinates also taken from phone devices) together with the issue description chosen by the operator. The safety operator registers issues like Operator fall, denied passengers, dangerous overtaking, parking on road etc. like seen in the picture for issue counting.



Passenger counting is used for manual counting of passengers during operation. The passengers are logged when entering and leaving the vehicle as a plus going in or minus going out. Besides counting the passengers going in and out, denied passengers are also counted as a result of the COVID-19 crisis. The Safety Operator counts regular passengers, passengers with disabilities and strollers, as an attempt to always assess the capacity of the shuttle.

5.1.6.2 Nordhavn data summary

Vehicles on site: P109 and P111

Passengers and distance driven

Passengers we counted every day of operation. In total we have transported 1579 passengers. It is seen that most passengers were transported at the beginning of the pilot, possibly due to route location close by the harbour popular in summer time. Another possible explanation could be that locals got used to the shuttle and as an attraction and as time went by a sense of novelty disappeared.

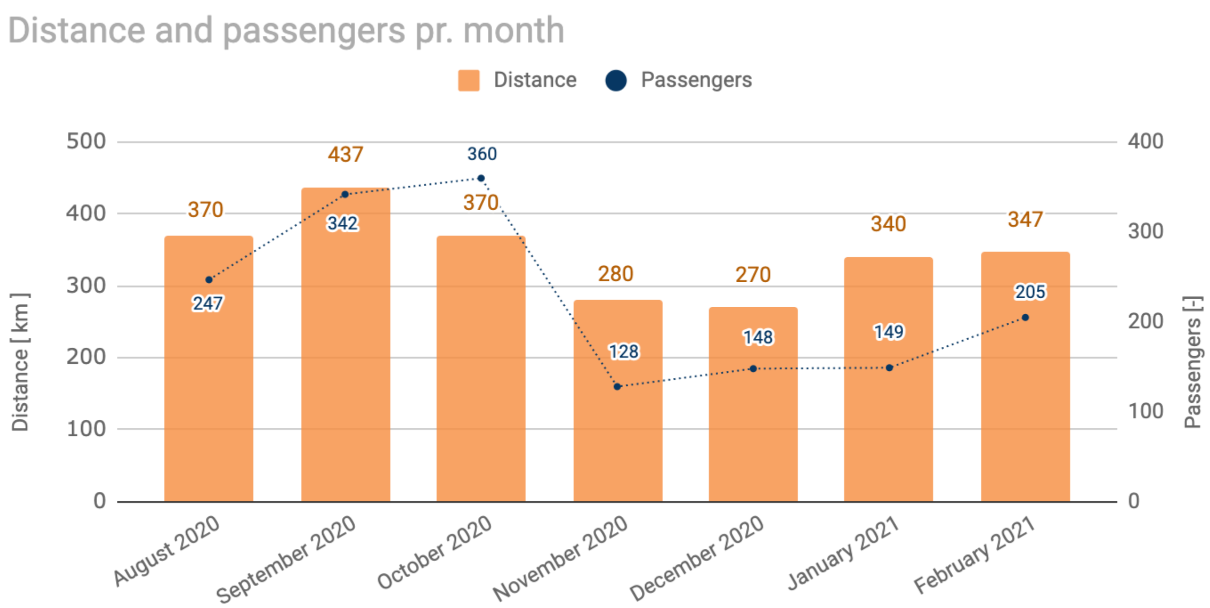


Figure 5.6: distance and passengers pr. month in Nordhavn

A total of 2.417 kilometres has been driven in Nordhavn. The count can be seen increasing in almost linear progress since August 2020.

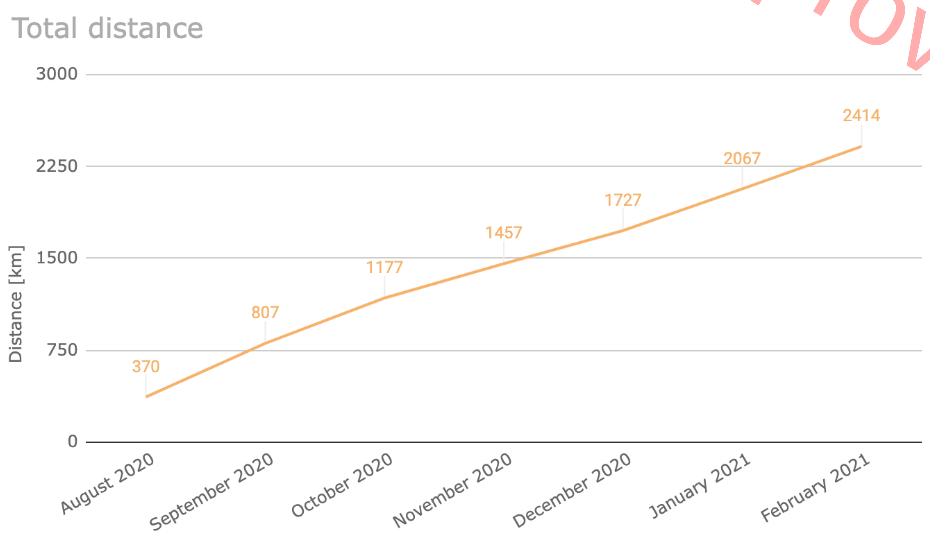


Figure 5.7: Accumulated distance driven in Nordhavn

Driving speed and autonomous vs. manual mode

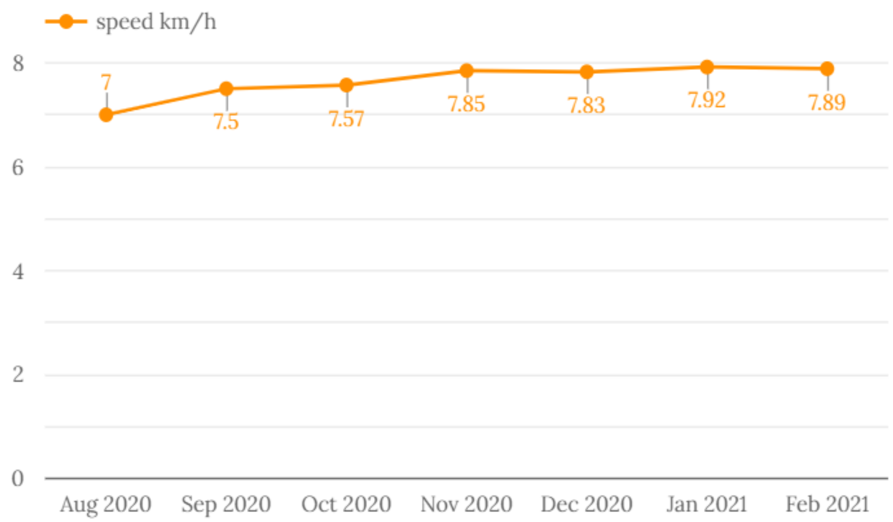


Figure 5.8: Average driving speed (autonomous and manual mode)

The driving speed is seen to be increasing slightly over the operational time period from an initial 7 km/h to 7.89 km/h. This despite an increase in manually driven kilometres primarily related to an increase in parked cars on the route.

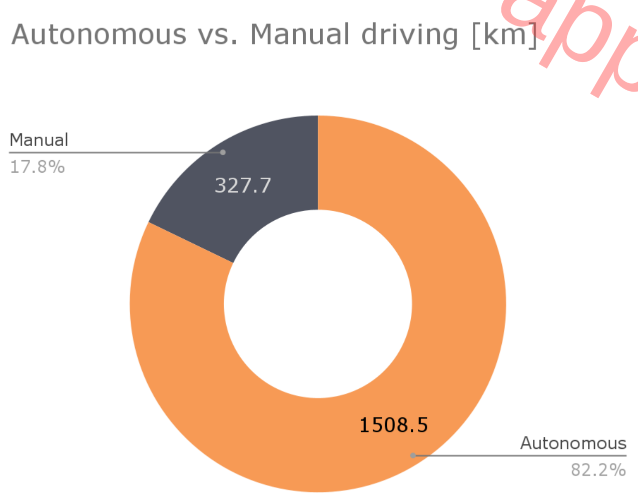


Figure 5.9: Share of the distance driven in autonomous vs. manual mode

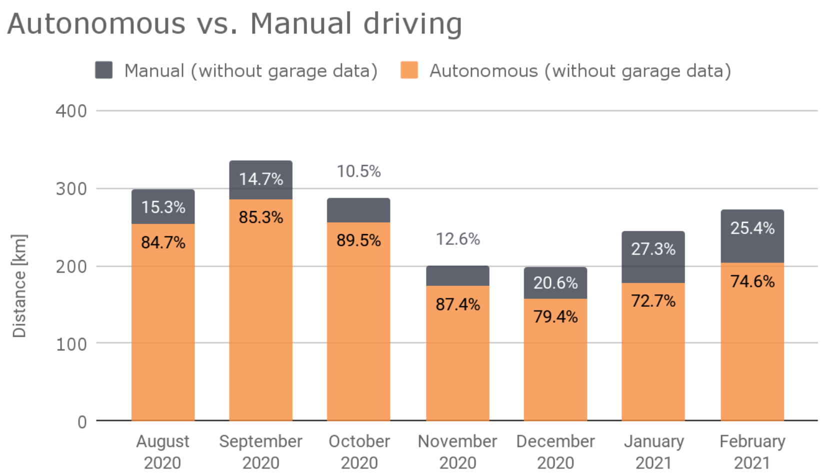


Figure 5.10: Distance driven in autonomous vs. manual mode pr. month

In total, close to 992 hours have been driven during the pilot. In regards to the navigation mode, 82.6% of overall driving on the route was done in autonomous mode. The rest of 17.4% driven in manual mode was mostly due to a large amount of illegally parked cars on the route and due to roadworks. Driving manual to and from the garage is filtered out.

Issues reported on route

The main issue reported through the safety operator app were parked cars on the road. The parked cars disturbs the driving, as the AV is not able to diverge from its planned trajectory, and hence the operator is forced to do a manual take over in order to pass the parked vehicle. In total this has been registered 1995 times.

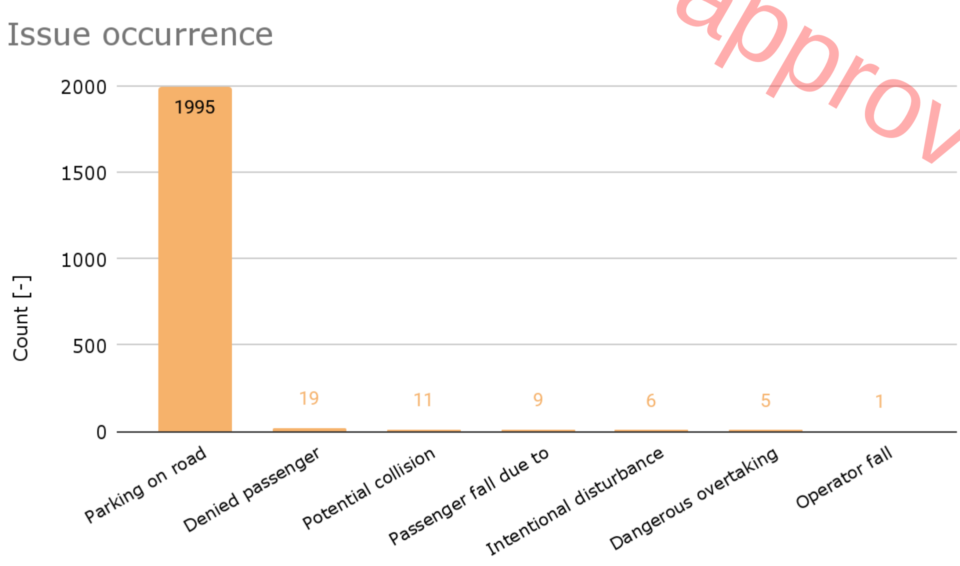


Figure 5.11: Number of issues encountered on the Nordhavn route

The issue of parking on the road has been reported on several locations on the route. Mostly around Århusgade, Sandkaj and Göteborg Plaza. The issues with parked cars in the Nordhavn area was significantly contributing to impeding the operation, finally resulting in its closure.

Figure 5.12: Occurance of issues on the Nordhavn route

Downtime and cancelled operation

The following figure illustrates the distribution of the 5 most common reasons for downtime / cancelled operation per downtime hour it caused. The downtime was primarily due to roadwork on the route, which made driving in the designated trajectory impossible and manual takeover necessary.

Figure 5.13: Causes of downtime in Nordhavn by downtime hours

Support tickets:

The number and share of support tickets created with Navya over the time of the project is seen in figure 5.14. Here it's seen that most of these were concerned with the vehicle's software.

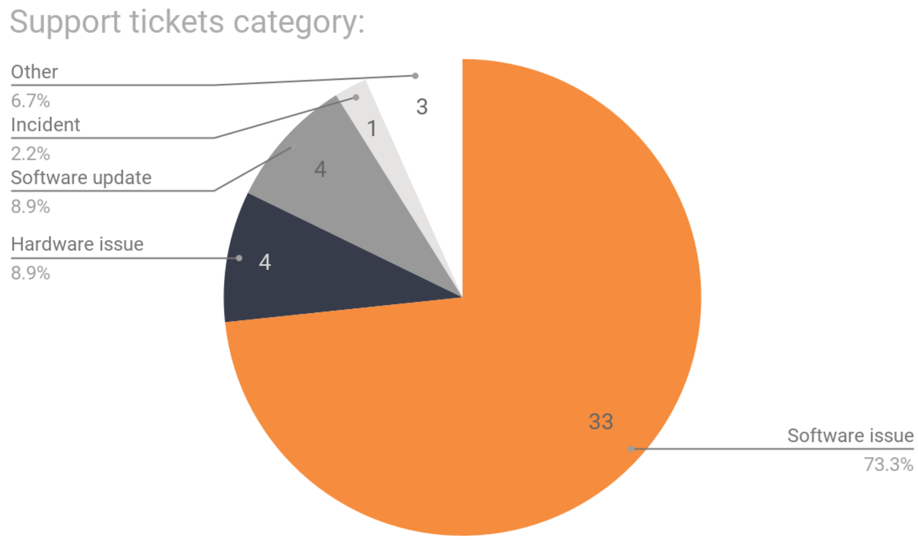


Figure 5.14: Number of Navya support tickets created in relation to the Nordhavn route

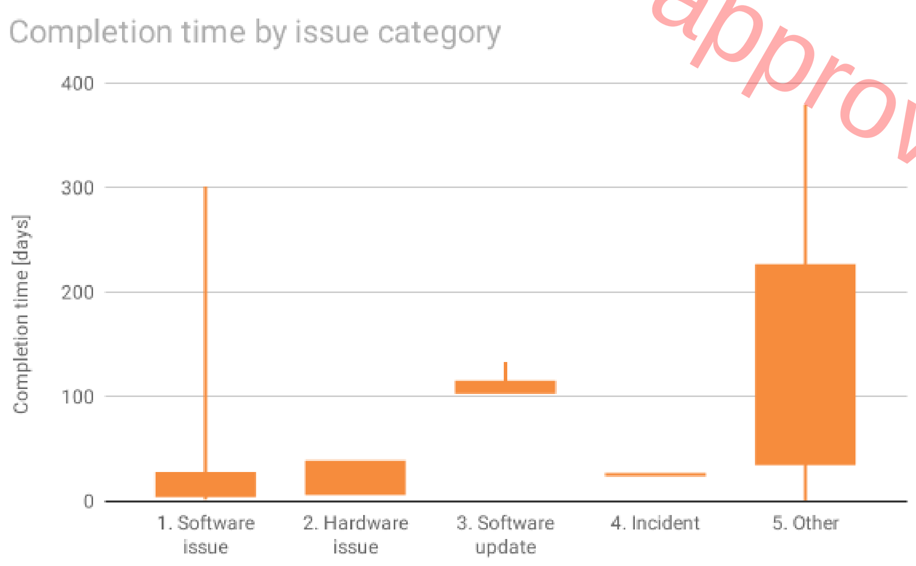


Figure 5.15: Completion time of Navya support tickets created in relation to the Nordhavn route

The completion time of each category of issue is seen in figure 5.15. Here it is seen that most issues regarding software issues, hardware issues, software updates and incidents were resolved before 100 days, but that some issues regarding software issues and other issues were not resolved before 300 and almost 400 days respectively.

5.1.7 The process of shutting down Nordhavn in AVENUE

Unfortunately the route in Nordhavn had to be shut down, and AM has investigated several scenarios to still meet the learning objectives for the AVENUE project. In the following the process and reasoning for shutting down the Nordhavn site will be further elaborated.

5.1.7.1 Complications in Nordhavn

In the fall of 2020 AM started to investigate the potentials for expanding the Nordhavn site. AM investigated several routes which could be added to the already active route in Nordhavn. The selection and evaluation was focused on last-mile transportation from the 2 metro stations and to both residential areas of Nordhavn and various business areas.

In November 2020 all the potential new routes were discarded by *By & Havn*, as construction plans for the area would interfere with the Automated minibuses. The area of Nordhavn is undergoing heavy construction and due to delays in the construction work, several roads are unavailable to use for the remaining period of the AVENUE project.

5.1.7.2 AVENUE scenarios

The above challenges in Nordhavn caused AM to seek alternatives for Autonomous Operation in the Copenhagen area. AM has evaluated several scenarios for how to still meet the objectives of the AVENUE project; these different scenarios will be elaborated in detail in the following section.

5.1.7.2.1 Continue in Nordhavn

AM discussed and assessed if the circle route in Nordhavn could continue to operate. With no expansion to the metro station(s), the number of passengers and last-mile value would remain at a minimum. Moreover, the door-to-door on demand service would not create the crucial value, as only 1-2 shuttles could interact on the route, and the fixed route would most likely not be desirable for passengers.

Based on the above evaluations, AM decided *not* to continue the route in Nordhavn. Because of these very limited learnings to be achieved, AM concluded that the current circular operational route was too far from the learning objectives and continuation could not be justified.

5.1.7.2.2 Find new Norwegian project

After reaching the conclusion to shut down the Nordhavn site, AM initiated investigations to find alternative routes to operate within the AVENUE project.

As the Norwegian approval process for autonomous vehicles has proven more flexible and reliable, AM discussed and investigated possibilities for completing the remaining operational months in AVENUE at a site in Norway. This was done simultaneously as the investigation of potential new sites in Denmark, cf. next section; Find a new Danish project.

Firstly, AM investigated the possibility of finding new routes with an existing customer, the PTA of Oslo, Ruter. However, Ruter and AM had already completed several pilots with NAVYA vehicles. Due to a focus towards new vehicle vendors this possibility was thereby excluded. This decision led AM to discard Norway as a potential place for operating the remaining months of the AVENUE project. The conclusion was based on 1) lack of organisational resources to initiate and pursue new project partners outside of Oslo and 2) establishment of new partnerships and agreements was evaluated to be too time-consuming at such a late stage of the AVENUE project.

AM has continued as an Operator to Ruter and are currently focused on operating new vehicle types from Toyota, equipped with autonomous system setup from Sensible4.

5.1.7.2.3 Find new Danish project

Simultaneously with investigating new sites in Norway, AM conducted several meetings with potential partners for new sites in Denmark. Both discussions with Bispebjerg hospital (Copenhagen) and the municipality of Dragør (near Copenhagen) was immediately very positive towards the project and the potential learnings to be achieved by delivering last-mile on-demand services to citizens. However, both potential sites needed more time, to 1) get political approval to conduct such a project and 2) decide on the actual roads and use-cases for testing.

Ultimately, AM concluded that there would not be enough time to await the decision processes at Bispebjerg Hospital and Dragør Municipality, as the approval process in Denmark easily could take up to a year to get new sites approved. Consequently, AM would not be able to deliver sufficient operational learnings to the AVENUE project, due to a very limited time to operate.

With the aim of achieving a faster decision process with a potential new partner, AM discussed the potential for operating at Copenhagen Airport. AM and relevant stakeholders from CPH Airport conducted a site visit and route inspection. Copenhagen Airport had determined a need for transporting passengers on-demand to and from the main entrance to designated parking areas. However, this route would require operation in a 50 km/h zone with difficult intersections. AM and CPH Airport, quickly determined that adding a low speed vehicle, such as the NAVYA Arma, would not be a good fit, to accommodate the transportation needs for the airport, and thereby the site was discarded as a potential site.

5.1.7.2.4 Use AVENUE shuttles on existing Amobility site

In order to minimise the risk of delaying operations substantially, caused by long approval processes, AM investigated the use of an existing site in Denmark for the remaining months of operations in AVENUE.

AM was granted approval to start operations at Slagelse Hospital (Denmark) in March 2020. However, the project had been paused due to Covid-19. In the 4th quarter of 2020 AM and Movia (PTA) decided to restart the project in August 2021. AM and Movia discussed the possibility of integrating AVENUE as part of the Slagelse Hospital site and agreed to proceed with this possibility.

Even though this alternative only can support operations with 2 NAVYA vehicles, AM has identified several crucial learnings in relation to on-demand and integration with PTA for ordering.

5.1.7.2.5 Stop as an operator in AVENUE (continue as research partner)

If none of the above alternatives was possible, AM would have had to stop as an operator in the AVENUE project.

5.1.8 Learnings from Nordhavn deployment

During the deployment of the shuttles in Nordhavn, multiple learnings were achieved. They are described in the following.

- **Object-detection challenges**

  The Nordhavn area is packed with restaurants, cafes and shops with outdoor seating and displaying areas. Larger parts of the Nordhavn route are shared space areas, where pedestrians, bicycles and vehicles interact in a shared road, rather than separated lanes. This type of city planning causes many situations where the Autonomous shuttles detect obstacles and stops as a consequence. With furniture and other objects crossing into the driving lanes, causing the shuttle to stop and requiring the safety operator to move the objects away from the driving lanes or manoeuvre manually around obstacles.

  For a complete autonomous operation without a safety operator, the area would probably not be ideal because of these shared space areas, at least it would require significant technological break-throughs before an autonomous vehicle would be able to operate in the Nordhavn area without a safety operator. This is also due to narrow roads, where 2 cars can not pass each other without human interaction.

- **Increased mixed traffic in high seasons**

  During the summer period the swimming areas at Nordhavn attract many visitors who arrive by bike. Due to the large number of bikes, bikes are sporadically parked outside of the appointed areas for bike parking. This caused difficult driving conditions and many operational days were shortened as the vehicles were not able to drive due to the many parked bikes and it was deemed impossible to have the safety operator remove the bikes during every round of driving.

- **Consequences of construction work**

  As the Nordhavn area is under heavy construction, the shuttles have had to operate in an area with many trucks and work-related vehicles being parked illegally and shutting off parts of the route. This has caused delays and cancellations of operation for shorter periods of time and sometimes days.

- **Lack of parking spots compared to the amount of cars**

  The Nordhavn area is a very busy area with both local residents, offices, shops and restaurants and has many daily visitors. Some of these visitors travel by car and can during the peak hours find it very difficult to find a place to park the car. This resulted in many illegal parkings on the route - and the safety operators have been taking over manually every day multiple times to overtake parked cars. Driving in an area which requires manual overtakings does affect the total percentage of kilometres driven in autonomous mode.

- **Low speed limit**

  Most streets in Nordhavn have a speed limit of 30 km/h which suits the autonomous vehicles speed capabilities. In general a low gap between the vehicle top speed and the speed limit provides a more safe operation, with less risky overtakings from other road users. This contributes to Holo's general assessment of the Nordhavn area as a safe environment to drive and test low-speed autonomous vehicles.

5.1.8.1 Barriers experienced in Nordhavn

Prior to the implementation of the project, AVENUE conducted user interviews in Luxembourg, Copenhagen, Lyon and Geneva to discover what barriers the project might face. These user interviews contributed to the knowledge on barriers that may affect potential passengers. Hereby, the answers from the user interviews contribute to the learnings on what barriers the implementation of autonomous vehicles can take into consideration when planning and implementing autonomous vehicles as passenger transportation.

During the user interviews the following barriers were identified:

- People prefer to drive their own car
- Users want to talk with a driver
- Users rely on a driver to help them
- Users doubt that the technology is mature enough to be trusted
- Users are worried as a result of stories about accidents with automated vehicles
- Users worry that other road users will not be able to anticipate behaviour of automated vehicles
- Autonomous vehicles in operation will lead to more delays and failures and more traffic jams for other road users
- Users worry about the already complex traffic situations and whether they will be too complex for autonomous vehicles to interact with
- Some worry about the risk of cyber-attacks and the fact that hackers may interfere with the autonomous driving
- Users worry about not having someone to supervise in the autonomous vehicles in case of the need for information, if feeling uncomfortable, robberies or assault, vandalism, or in case of the need for support to get on and off the shuttle.

5.1.8.2 Motivators experienced in Nordhavn

In line with the barriers, AVENUE also identified motivators during the user interviews. More specifically, the motivators are factors that interviewees have mentioned as drivers for implementing and using autonomous vehicles.

During the user interviews the following motivators were identified:

- Presence of a supervisor in the bus to interfere in case of technology fails, to present an authority, and to provide information
- Better coverage of an area with public transport; bus connections where there are none today
- The presence of autonomous shuttles will ensure more destinations and higher frequency of service
- Public transport anytime of the day/night
- Bus on demand: no rigid timetable but instead the possibility to be able to call the bus whenever needed which provides a more reliable service
- More flexibility regarding the stops / door-to-door service
- More affordable tickets
- Sufficient seating and maybe even guaranteed seats for people with special needs
- Better information than today: more accurate and accessible
    - e.g. acoustically understandable announcements, correct announcement of the upcoming stop, information when the bus will actually arrive, information where the bus is at every moment and where it is going (considering flexible routes)
- Expected advantages if the bus is not operated by human driver:
    - A smooth driving style as there is no impatient driver
    - Gentle braking, no more sudden braking manoeuvres
    - Clear announcements that are more understandable

5.2 Ormøya, Oslo, Norway

Due to the delays in launching the Danish demonstration site, it is foreseen that it will take some time before all 4 buses will be in operation. Therefore in May 2019 AM agreed with the consortium to include our subsidiary in Norway as a third party, so that two of AMs AVENUE buses can be deployed on a route there. This way AVENUE would still gain useful insights into the operation while awaiting the launch of the Copenhagen site.

AM is collaborating with Oslo Municipality, the Norwegian Public Roads Administration and Ruter[5] about a three-year self-driving trial project. The project is an important milestone in the process of getting self-driving buses to the Oslo area. Oslo and Akershus wish to have 0% emissions across their public transportation and this project will test if self-driving buses can support these ambitions for a sustainable public transport system. The end goal is for autonomous buses to be part of Ruter's regular offer in a few years.

Originally the plan was to include the two buses on the route Akershusstranda in central Oslo for 5 months beginning in June 2019. This would be a route with 4 buses running and the service fully integrated with existing public transport in Oslo city. However, due to heavy construction this route had

[5] The public transport authority for Oslo and Akershus counties

to be cancelled. It was therefore decided to integrate AMs AVENUE buses on the second route 'Ormøya' just outside Oslo centre. Ormøya is an Island south of Oslo city connected by a bridge to the mainland and a bridge to a second island called Malmøya.

The main purpose of the project was to investigate what self-driving vehicles can mean for everyday logistics in a neighbourhood. By increasing the frequency of public transport by means of small self-driving vehicles the goal was to reduce the need for private cars in the area.

One road leads in and out of the two islands that have a total of around 500 households. The local residents have a 12 metre bus service which departs around once an hour most of the day. On the mainland just off the inland is one of the major through fairs going into Oslo from the south, Mosseveien/E18. This main road has frequent express buses going in and out of Oslo. The autonomous bus service provided a high frequency last mile solution for the residents of Ormøya and Malmøya which connected them to the express service on Mosseveien/E18.

5.2.1 The route

The route is 1,6 km one way (3,2 km round trip) and has 6 bus stops. It runs from Nedre Bekkelaget bus stop which is located near Mosseveien/E18 where users can access high frequency express buses to and from Oslo. Also near this end point is the local area public school which kids from Malmøya and Ormøya attend.

The other endpoint, Malmøya bus stop, is right on the landing on the island of Malmøya where there is a turning place for the vehicles. This bus stop is also located close to a marina, where lots of Oslo residents keep their recreational boats. The four other bus stops are evenly distributed along the two end points. The bus stop Mailand is also located close to a public beach/swimming area and a Marina which attracts lots of visitors in the summer. The route can be seen below with the stops marked.

Figure 5.16: Map of Ormøya route

The speed limit on the entire route is 30 kph and it contains several speed bumps which generally keeps the speed in the area low. The condition and build of the road varies quite a bit along the route. Several places are very narrow, only barely wide enough for two vehicles to pass each other and several stretches have poor asphalt quality. There is also a lot of vegetation close to the route.

In order to be able to offer the inhabitants a valuable self-driving travel service, we must ensure high operational stability along the stretch. This has been challenging due to several elements and we have therefore made ongoing adjustments in the offer to explore what it takes to ensure stable and reliable operation. Operational stability will be a success factor in initiating new, more complex self-driving bus lines in the years to come.

5.2.2 Infrastructure

The route required two major infrastructure adjustments to be operational, a purpose built garage and reflector panels along the road for better LIDAR localization.

5.2.2.1 Garage

It proved impossible to find a suitable garage facility on or near the route and the area is a residential area with strict zoning and regulations on what can be built or temporarily placed in the area. Consequently the project had to construct a garage that would meet strict requirements for sustainability, safety and aesthetics as well as for the operational requirements of Holo.

The solution became a design for temporary wood structure with polycarbonate cladding that could be disassembled and moved if necessary. It was quite an expensive solution, but necessary for operating in an area with no existing facilities and with shuttles that cannot move manually through regular traffic to find a suitable palace further away. See pictures of the garage below:

Figure 5.17: Photos from garage construction in Ormøya

5.2.2.2 Reflector panels

The route contains two bridges, Ormsundbroen and Malmsundbroen. Both contained stretches where there were very few lidar reflecting objects and thus Navya required that Lidar reflecting panels be put up in their site assessment.

However both bridges are protected buildings under Norwegian law and any infrastructure added had to be made to fit their aesthetic. Therefore the project used sails made using 19th century techniques and hemp road as reflector panels. The sails were also printed with old motifs from the island. The sails were tied to railings on the bridges and in total 52 sails were put up to fulfil Navyas requirements. The sails looked as in the picture below.

Figure 5.18: Photo of LiDAR reflection panels mounted on the route in Ormøya

5.2.3 Bus stops

- **Nedre Bekkelaget**

  Was created as a new bus stop in a parking lot near the Mosseveien/E18. existing bus stops could not be used because they are placed on the main road which has a 60 kph speed limit. In addition the shuttle needed a place to turn around and this solution worked nicely for that.

- **Ormsundbakken**

  Is an existing bus stop used by Ruters line 85. It is placed right next to Nedre Bekkelaget Primary school and because of the large numbers of children moving around in the area it has been constructed as a bottle neck so that no other cars can pass while the bus is stopped here.

- **Mailand**

  Is an existing bus stop used by Ruters line 85 and includes a raised sidewalk for easy passenger access. It is laced right next to the public beach and Holos garage facility. Used as the spot where the shuttles entered and exited autonomous operation

- **Kirkebakken**

  Is an existing bus stop used by Ruters line 85. It has no curb but lots of room for the shuttle to pull to the side and for passengers to enter and exit the shuttle without interfering with traffic.

- **Malmøysundet**

  Is an existing bus stop used by Ruters line 85. It is placed at a narrow part of the road which has no curb and very little room for passengers to enter and exit the shuttle. As a result the shuttle would stop traffic while stopped here in both directions.

- **Malmøya**

  Is an existing bus stop used by Ruters line 85, it includes a raised sidewalk for easy passenger access. It has a small roundabout which enabled the shuttle to turn around

5.2.4 Operational hours

Weekdays: 6.30 to 20.30

With departures every 10 minutes during rush hour in the morning and afternoon and every 20 minutes in off peak hours

Weekends: 10.00 - 17.00

With departures every 20 minutes

5.2.5 Learnings from Ormøya deployment (AVENUE shuttles)

5.2.5.1 Public transport in Oslo

The Service at Ormøya functioned as an integrated part of Ruters public transport offerings in the general Oslo area. This meant that the bus required a standard ticket which gives access to the entire network and that the service was included in Ruters overall route planning tools for users. Neither Holo nor Ruter performed checks of valid tickets.

By all indications users did not complain about the ticket requirement, but viewed it as natural for a service in Ruters network.

5.2.5.2 User experience

During the final quarter of operations, Ruter conducted a user survey around the shuttle. The survey was conducted by interviewing people walking or moving around the general area of Ormøya. In total Ruter collected 107 interviews each lasting 5-8 minutes during the weeks 38,39,41 and 42 in 2020. The main purpose of the survey was to evaluate what users and local residents think of the self driving bus service

In general respondents were positive towards the tests and felt that it was safe. However the survey also showed clearly that the service was not providing a valuable mobility solution. 82% of passengers took the bus merely out of curiosity while only 12% used the service for their daily commute. And when local residents at Ormøya and Malmøya were asked why they didn't use the autonomous bus for their daily mobility needs, two of the top answers were the low speed and that the bus did not go where they needed to go. Furthermore low reliability was also noted as a reason why the service was not used for their daily mobility needs.

5.2.5.3 Vegetation and snow

The narrow road on Ormøya makes this site especially challenging when it comes to vegetation. There is little to no margin on growth of vegetation. Both vegetation on the sidewalk and overhanging bushes and branches are stretching into the safety zones interfering with smooth operation.

Another issue at Ormøya are the high and low overhanging branches interfering with the GNSS signal. The contact from the vehicle to our base station at Nedrebekkelaget. When the GNSS signal is low or even completely out the vehicle relies on Lidars for obstacle detection and localization.

In the picture below the overhanging branches are within the safety zone, these are then detected by the vehicle causing it to brake or slow down.

Figure 5.19: Photos showing the vegetation close to the vehicle trajectory on the route in Ormøya

The rapid growth of vegetation in the summer months has led to constant interference with operations. In periods operations have been halted until the vegetation has been properly cut. In the summer months, April to September, we have seen the need to cut vegetation up to every second week.

Vegetation related issues have heavily impacted the stability of the operation on this route. Comparing this site to other routes with less vegetation, clearly shows a negative impact on performance of the vehicles. And furthermore sudden brakes caused by vegetation is a major safety concern as well. The sudden braking can cause cyclists, pedestrians and following cars to potentially collide with the vehicle when it makes unexpected and seemingly irrational decisions like braking hard for a small branch near the trajectory.

In the winter months snow and ice proved a similarly big challenge. The ODD for the Navya Arma vehicles states that they cannot operate when snow is falling or when the route is covered in snow. Falling snow proved quickly to be unsuitable for operation. With snow in the air the vehicles makes continuous false obstacle detections and every snowfall resulted in a halt of operations.

2020 did not see very much snow at the Ormøya site and only on a couple of occasions did snow on the ground cancel operations and mainly because snow clearing was not done well enough to clear the vehicles trajectory as highlighted in the image below.

Figure 5.20: Photos showing snow and snow banks in and close to the vehicle's trajectories on the route at Ormøya

5.2.5.4 Major safety issues

Already in the risk analysis of the route before operation commenced, the major safety concerns were identified as other road users behaving dangerously around the shuttle due to low speed, slow reaction to clear road or similar. Also passengers and operators getting hurt inside the shuttle due to sudden and hard braking were highlighted along with intentional disturbances. These safety concerns proved to have been correctly assessed from the beginning and they were the major safety concerns throughout the operation.

Through the Holo operator app Holo was able to collect data on these most potentially dangerous situations that occurred on the route. The four most important categories that data was collected on are dangerous overtakings of the vehicle, intentional disturbance, operator fall and passenger falls.

These categories were defined in the following way:

Passenger fall

If a passenger falls inside the vehicle due to hard braking, risky overtaking or similar driving behaviour.

Operator fall

If the operator falls inside the vehicle due to hard braking or similar driving behaviour.

Dangerous overtaking / Potential collision

Dangerous or hazardous events directly caused by our vehicle or indirectly by the presence of our operation.

Example: A car overtakes our vehicle in a dangerous and/or illegal manner (e.g. overtaking by using the sidewalk, passing on a zebra crossing, risk of hitting a cyclist coming in the opposite direction).

Intentional disturbances

If another road user intentionally attempts to test the behaviour of our vehicle or intentionally disturb our service.

Example: A bicycle overtakes our vehicle and drives immediately in front only to provoke hard braking - in this case, the operator must be confident that this is done intentionally.

Issue count from January 1st 2020 through December 20th 2020			
Passenger fall	Operator fall	Dangerous overtaking / Potential collision	Intentional disturbances
9	59	189	34

Table 5.4: Issue count generated from OP app in Ormøya

No serious injuries were recorded as a result of these safety concerns, but on two occasions dangerous overtakings of the vehicle caused minor collisions and on several occasions operators were bruised by falls inside the shuttle. Therefore two major safety concerns that remain with an operation like the one on Ormøya is:

- The operators of Navya Arma vehicles do not have ideal working conditions. Sudden and hard braking has resulted in several mild injuries because of the lack of proper seating and suitable working positions.

- The low speed of the shuttle does cause other road users to act irresponsibly and attempt overtakings in areas that are not suited for overtaking like areas with bad overview or near pedestrians crosswalks

5.2.6 Operational data summary from Ormøya

While operating the shuttles, Amobility has been using data from the vehicles and an operational app (developed by Amobility) to improve daily operation and track performance. Data from the vehicles has been received via Navyas API and then categorised and visualised in Amobility Data Analytics tool (Operational dashboards).

5.2.6.1 Data types

Described in section 5.1.6.1

5.2.6.2 Ormøya data summary

Passengers and distance

In total, 6637 passengers were transported and 22.984km driven on the Ormøya route. During the one-year pilot there were over 5233 hours of operation (total number when all 3 vehicles are added together). That is equal to approximately 395 operational days or 131.67 full operational days with 3 vehicles (1 operational day = 13.25h).

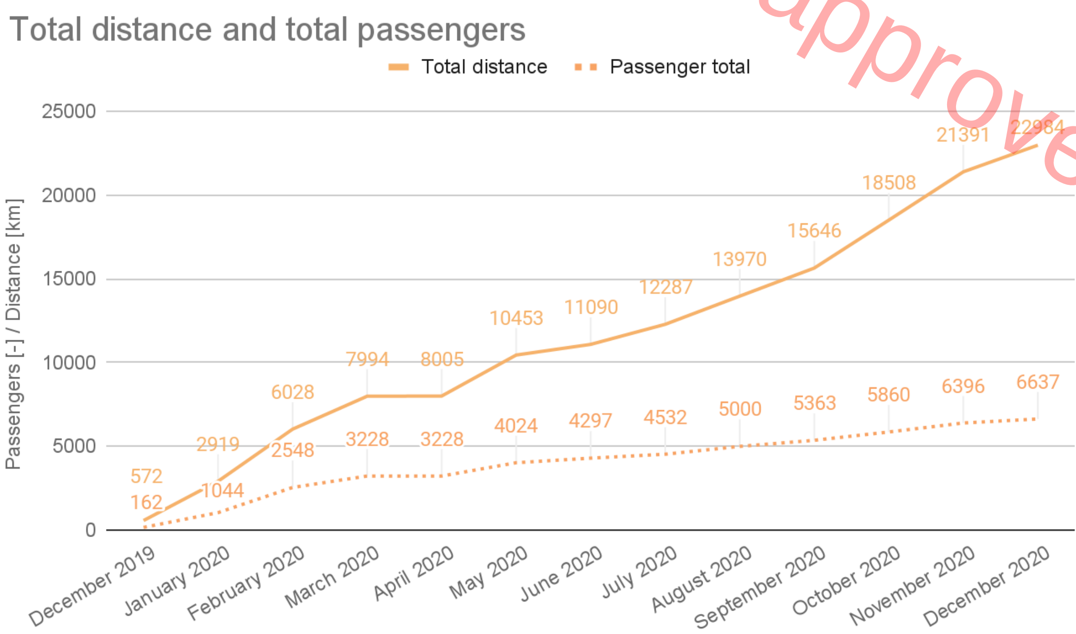


Figure 5.21: Accumulated distance and passenger count at Ormøya

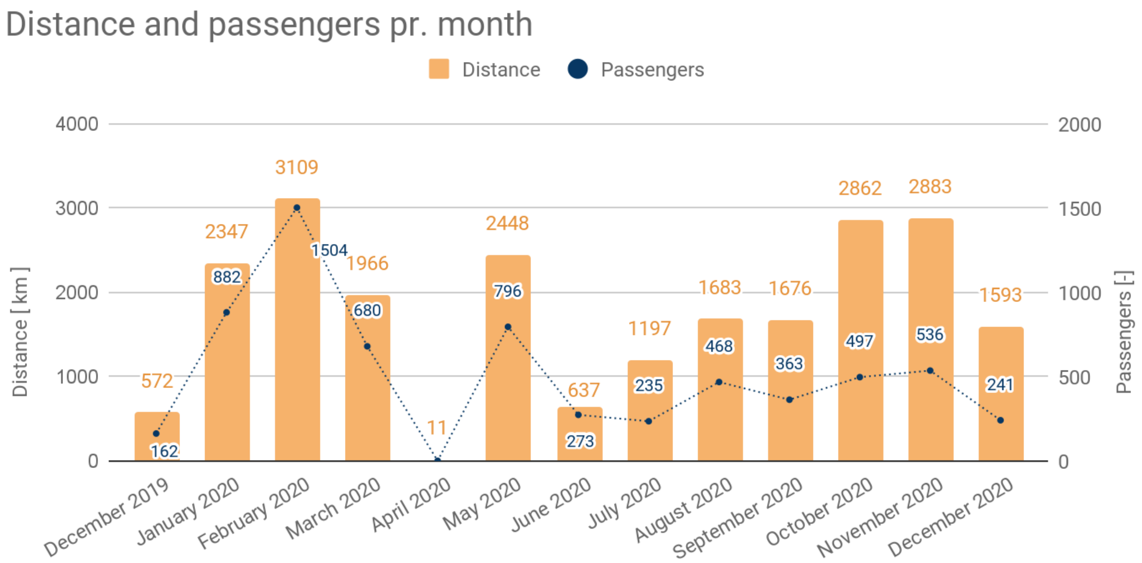


Figure 5.22: Distance and passenger count pr. month at Ormøya

The route in Ormoya was severely impacted by operational challenges and Covid-19 lockdowns in some months during the project period. This resulted in some periods with few passengers and distance driven.

In terms of passenger distribution, passengers were using the shuttle service for transport on every day of the week. However, from figure 5.23 a somewhat higher number of passengers during the weekday than weekend.

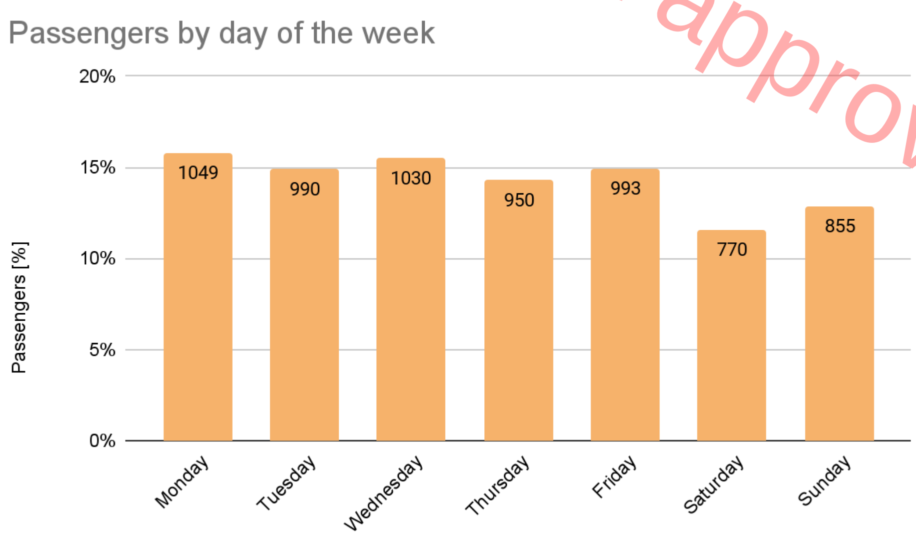


Figure 5.23: Passenger distribution on weekday and weekend

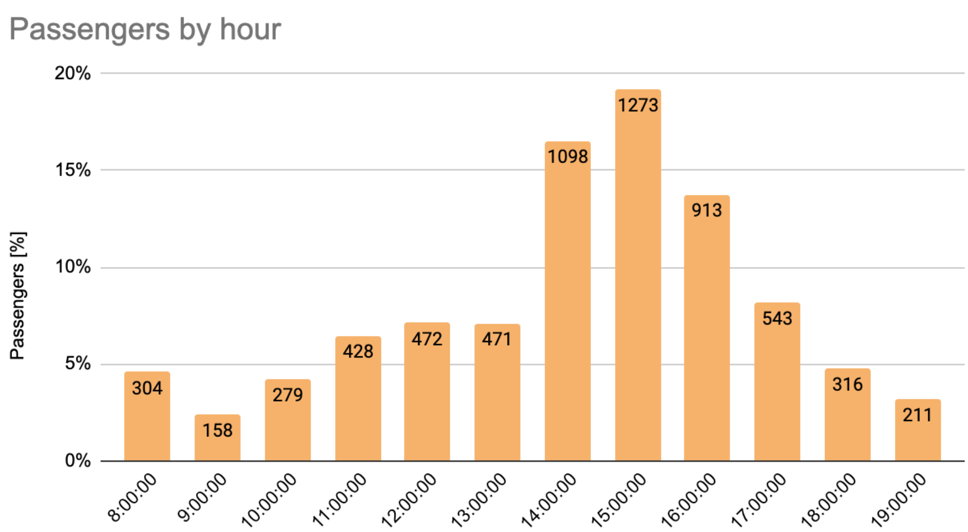


Figure 5.24: Passenger distribution pr. daily operational hour

Autonomous vs. manual driving

In regards to the navigation mode, 93.8% of overall driving on the route was driven in Autonomous mode. The rest of 6.8% driven in Manual mode was mostly due to technical issues. Driving to and from the garage is filtered out.

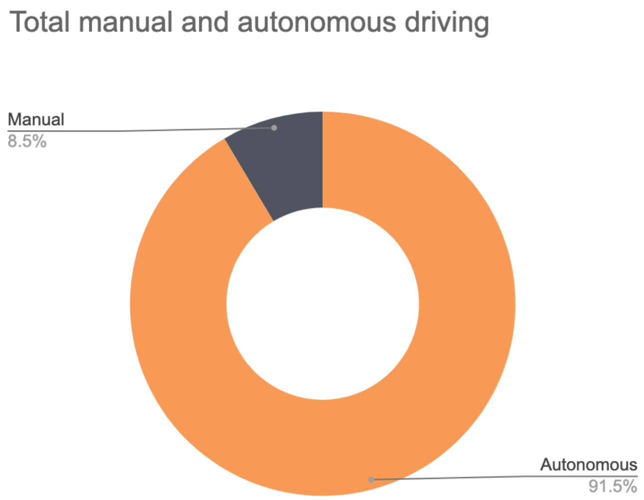


Figure 5.25: Share of manual vs. autonomous driving

Driving speed on the Ormøya route was between 9.44-10.53km/h. The overall average speed was approximately 10 km/h. By summer of 2020 a recommissioning was done to improve driving in areas of the route

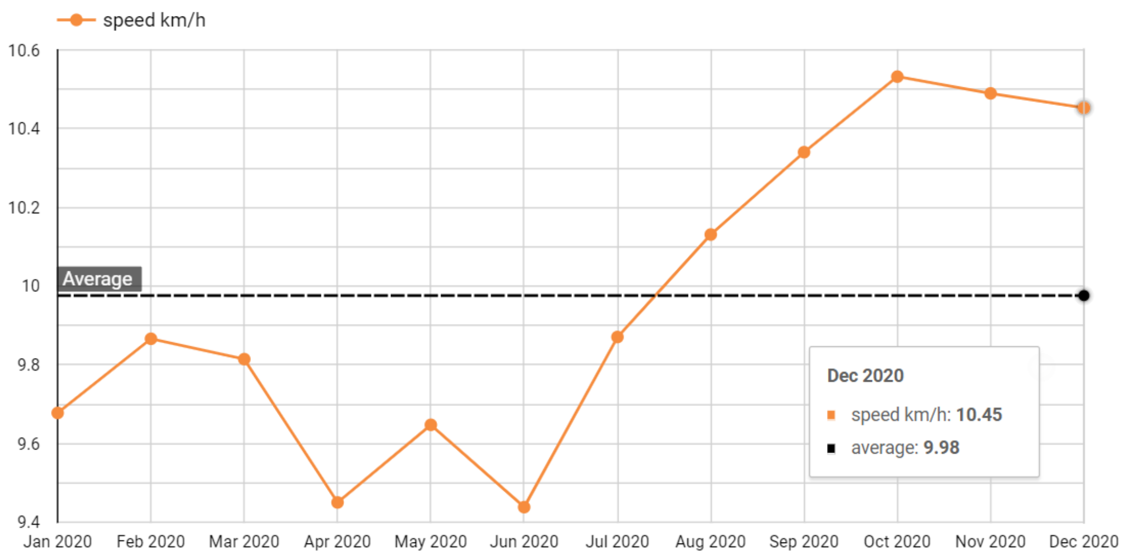


Figure 5.26: Average driving speed pr. month

Issues encountered on route

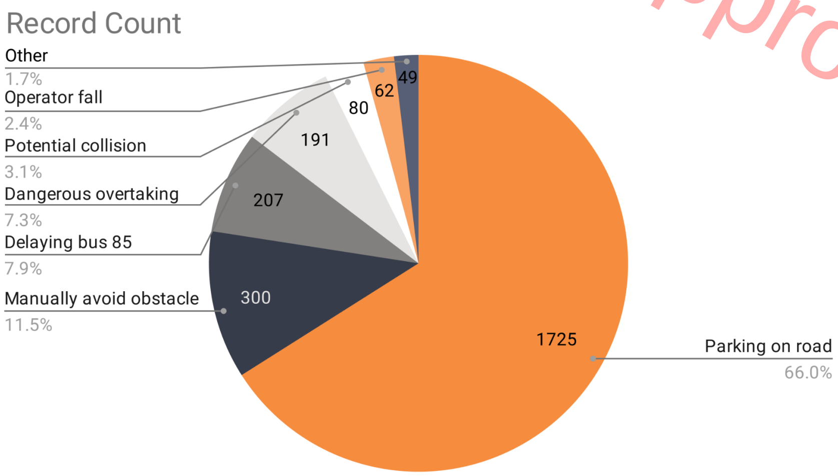


Figure 5.27: Issue distribution at Ormøya

When looking at the distribution of different issues reported by the safety operator. Again for this route the 'Parking on road' is the most frequent issue occurring. With a total occurrence of 1786 times. Passenger-fall 15 times. Operators fall as many as 69 times, signalling a safety issue in the working position of the operators.

Support tickets and feature requests

In the project support tickets and feature requests were used to actively communicate with Navya regarding operational issues. Support tickets were concerned with issues that needed immediate attention and solution, whereas feature requests worked as a suggestion tool to push for updates and features that would improve the operations.

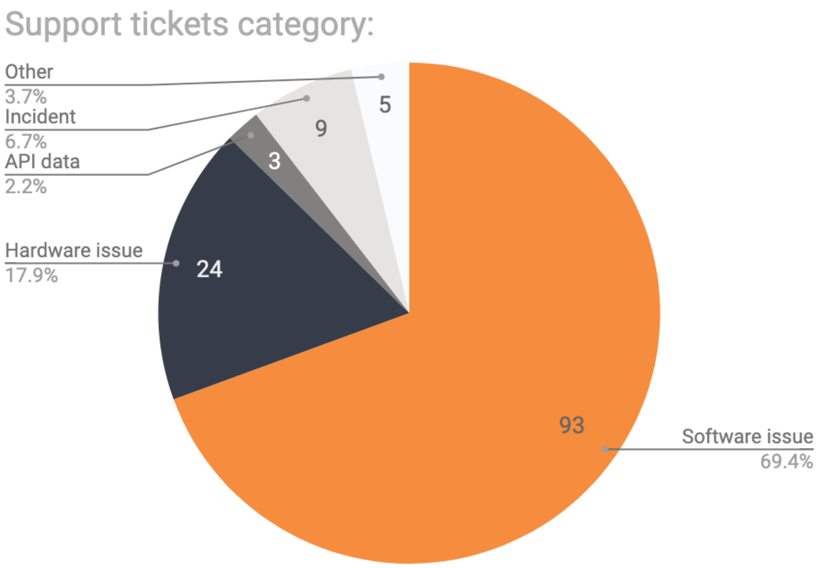


Figure 5.28: Support ticket distribution at Ormøya

During the project a total of 134 support tickets were created with Navya, distributed on issues with software, hardware, API data, incidents and other issues. Most issues were raised within the vehicles software not working properly

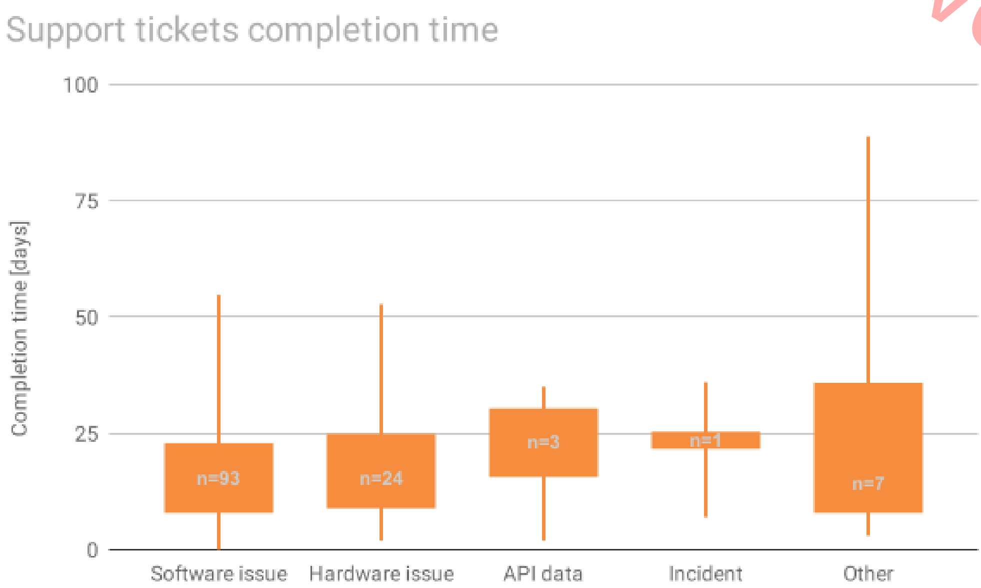


Figure 5.29: Support ticket completion time at Ormøya

13 requests for new features were created during the project regarding autonomous software and API endpoints. Most API requests were resolved within 10 days, whereas requests regarding autonomous software mostly took around 20-60 days.

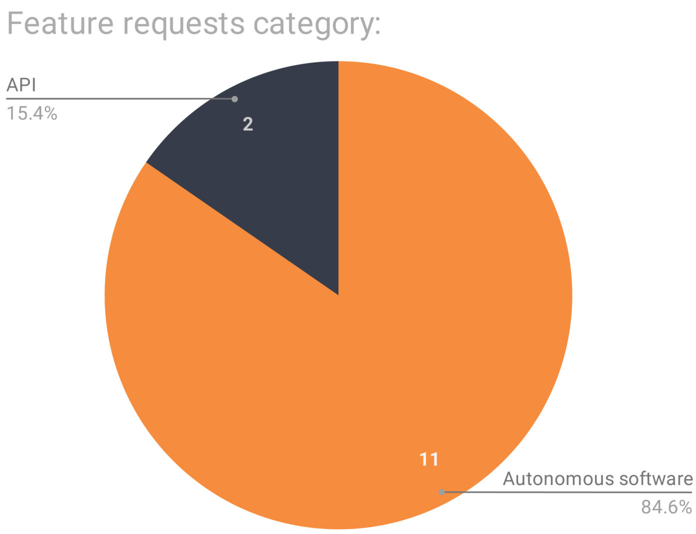


Figure 5.30: Feature request share at Ormøya

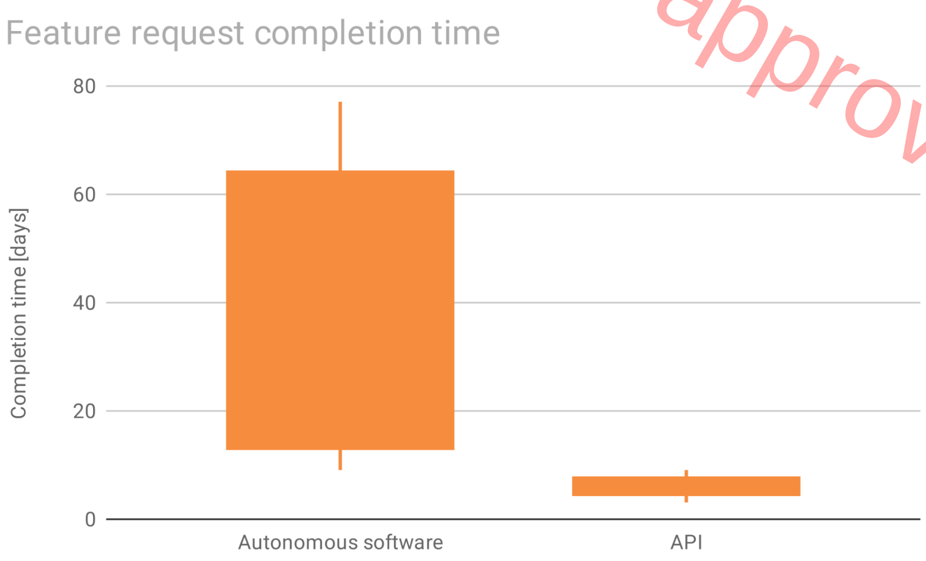


Figure 5.31: Feature request completion time at Ormøya

5.3 Slagelse, Copenhagen, Denmark

The Nordhavn area should originally have been finished in 2020, but due to major delays in construction plans parts of the Nordhavn route (streets) was closed down permanently for longer periods of time during the remainder of the AVENUE project in that area. Hence AM and Copenhagen area PTA Movia agreed on introducing an AVENUE shuttle on the 2 shuttle project at Slagelse Hospital. Here the main learnings were aimed at on-demand driving and integrations with public transport PTA Movia, their client systems etc.
The Slagelse site was an interesting case, as the distances between the departments in the hospital are too long for patients to walk between them and a shuttle moving between different departments and connecting parking lots would improve the mobility in the area.

5.3.1 Route

The shuttle will drive on a 770 m long stretch on Fælledvej at Slagelse Hospital. Besides driving on Fællesvej, the shuttle will drive in 5 parking areas, with multiple stops, to turn the shuttle and reenter the stretch of Fælledvej. The route and the stops can be seen below. Besides the stops placed on the parking areas, the shuttle also stops at the west part of Fælledvej, in both directions.

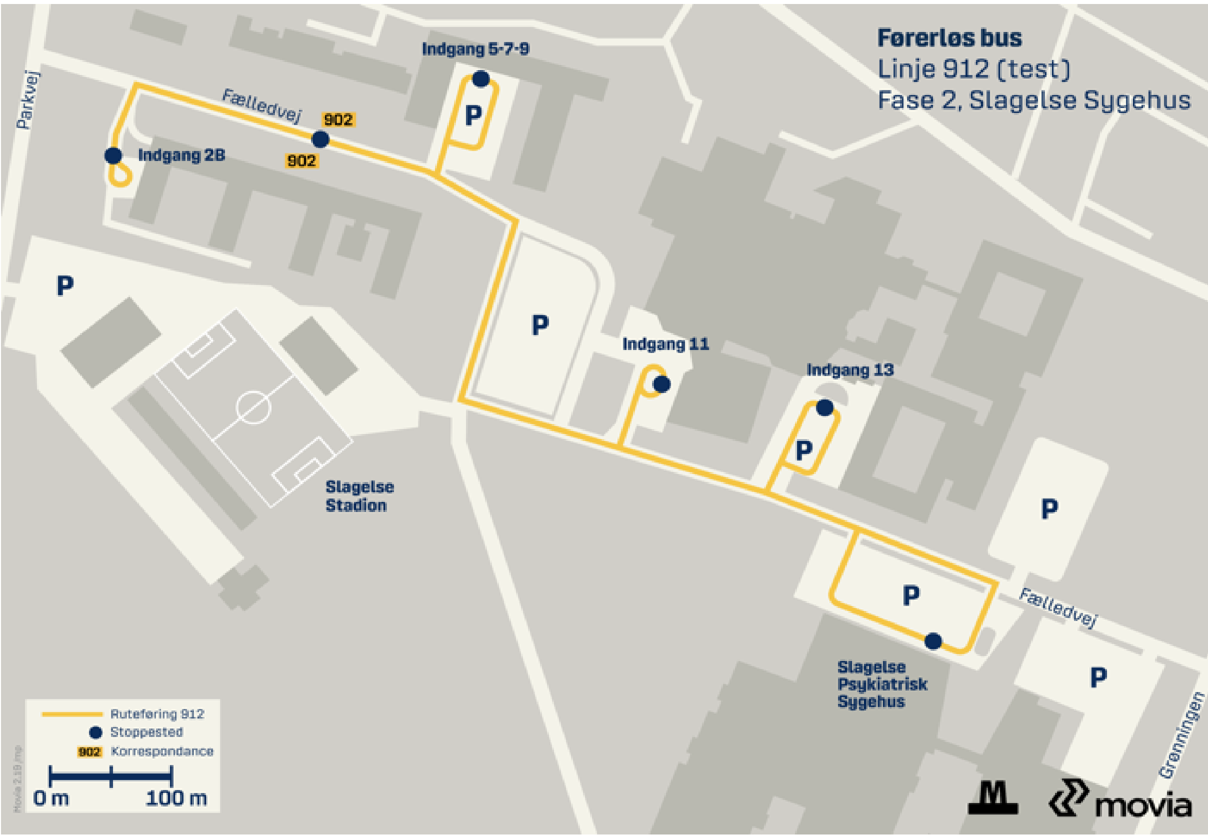


Figure 5.32: Map showing the route at Slagelse

When driving on Fælledvej, the shuttle will drive on sections of the road with different infrastructure settings. These different sections are shown in the following picture and further described below.

Figure 5.33: Map showing the route sections at Slagelse

Red section

The red section is a 240 m stretch with parking spots longside the road on the south side, parking booths between the two driving lanes and a double edged bicycling lane on the north side of the stretch. There is a sidewalk for pedestrians on both sides of the road and no facilities for scooters in the eastbound direction. Meaning, scooters and to some extent bicycles must use the road in the eastbound direction. The speed limit for the stretch is today 50 km/h and the red section has a width of 6 m. On the red section there are 3 road connections with an unconditional right of way for the road users on Fælledvej. The municipality of Slagelse has approved the speed limit to be decreased to 30 km/h during the Hospital Pilot Project.

Green section

The green section is a 300 m stretch with parking booths between the two driving lanes and a walking path in the west - and south side of the road, as shown in the picture below. There is no sidewalk on the north side of the stretch (meaning that it is assumed that pedestrians may walk on the roadway on the north side). On the green section there are no implemented facilities for scooters or bicycles, meaning that they will drive on the roadway on the green section. The speed limit for the stretch is today 50 km/h, but it is assumed that the driving speed is lower because of two sharp curves on the stretch, with a small turning radius, which cannot be driven with 50 km/h. The green section has a width of 6 m. On the green section there are 5 entry roads for parking facilities. From the parking facilities to Fælledvej drivers have an unconditional obligation to give way. There is a road connection in one of the sharp curves, where drivers have an unconditional obligation to give way to drivers on Fælledvej. The municipality of Slagelse has approved the speed limit to be decreased to 30 km/h during the Hospital Trials.

Blue section

The blue section is a 230 m stretch with road separating barriers and newly implemented speed signs, recommending 20 km/h on the stretch. There are walking paths for pedestrians on both sides of the stretch. There are approximately 35 m of biking paths on both sides by the exit from entrance 11. On the remaining part of the stretch the road is shared with bicycles and scooters. The driving lane has a width of 3,25 m in both directions and there are 5 cross sections with an obligation to give way for the traffic on Fælledvej. Slagelse municipality has approved speed limits of 30 km/h during the Hospital Trials.

A regular Movia bus (line 902) operates on Fælledvej with 30 min intervals during weekdays. The line has two stops (for each direction) on the part of Fælledvej, that the shuttles will be driving on. At the main entrance of Slagelse Hospital, a patient-bus of the same size as Movia's regular bus, will depart a couple of times during the day. The patient-bus has a marked parking area in front of Slagelse Hospital, that is placed outside the self-driving shuttle's route. During entry and exit to/from Slagelse Hospital, the self-driving shuttle and the patient-bus can lock. This will require the safety driver to manually take over and give way for the patient-bus.

Parking conditions

The area of which the Automated minibus will be operating has a high density of parking areas. There are parking facilities on Fælledvej, where drivers will dismount their cars directly onto the road. Further, there are marked parking booths on these parking facilities, which the Automated minibus has to drive past. Besides parking areas defined by regulation or signs, there is a high degree of parking outside these designated areas, as seen below. Based on this, it is uncertain how much effect the parked cars outside of designated areas will have on the operation of the shuttle. Unwanted stops and brakes may occur if parked cars are blocking the route of the shuttle.

Figure 5.34: Photos showing parking conditions at Slagelse

Garage

The following map shows the route including the location of the garage, where the shuttle will be parked overnight. The distance from the garage to the route is approximately 500 metres. Driving from the garage to the route is manually in SAE level 0, with a maximum speed of 15 km/h.

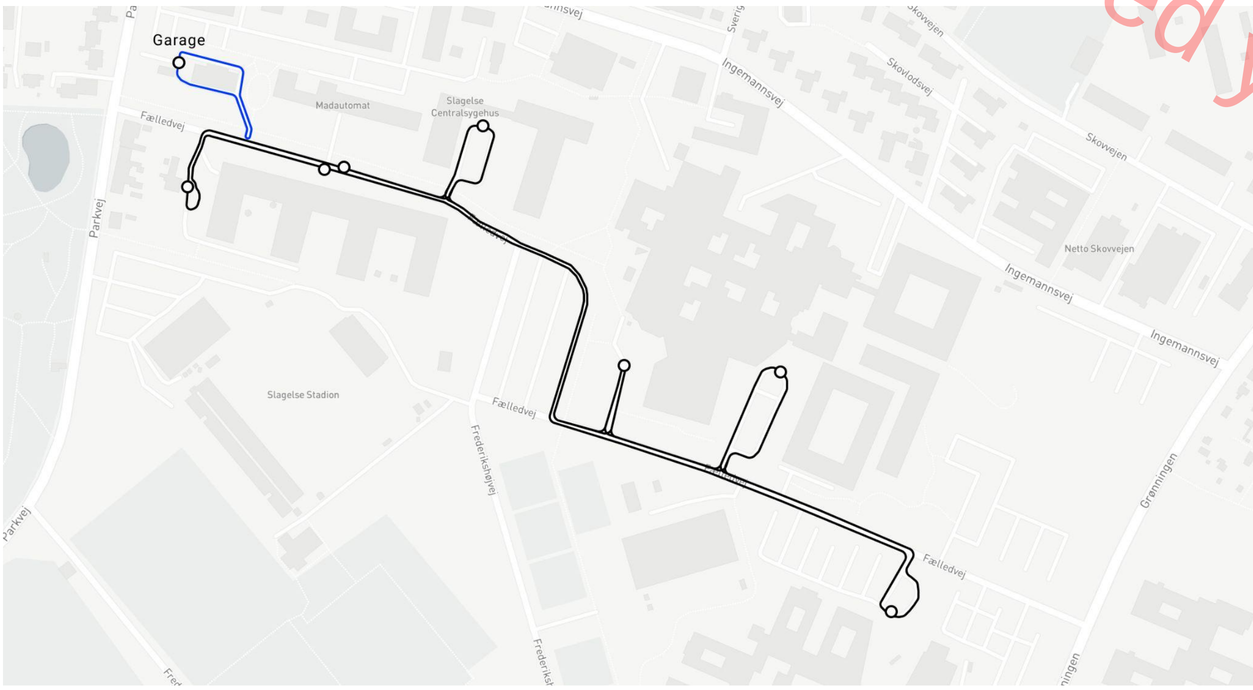
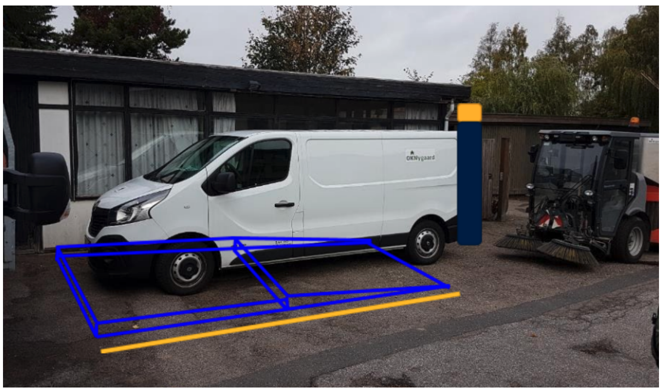


Figure 5.35: Map showing the route and drive to garage at Slagelse

5.3.2 Bus stops

Pictures, on-demand virtual stops

Stop name	Picture
Stop 1: Fælledvej 2B	

Stop 2Ø: Fælledvej Øst	
Stop 2V: Fælledvej Vest	
Stop 3: Fælledvej 5-7-9	
Stop 4: Slagelse Hospital, Entrance 11	

Stop 5: Slagelse Hospital, Entrance 13	
Stop 6: Slagelse Psychiatric Hospital	

Table 5.5: Bus stops in Slagelse

5.3.3 Project timeline

The Slagelse Hospital project is already approved. The following months will be spent on preparing the site for the operation of two Automated minibuses. Both infrastructure changes and preperational work regarding the deployment has to be done. User surveys and observations have been conducted with the purpose of ensuring the most optimal and user friendly way of ordering a trip. Speed limits are being adjusted by the municipality, on-demand is being tested on the Amobility test track and much more. The following timeline underlines the ongoing and coming steps in order to reach the launch in August/September 2021.

- March 2021
  - Slagelse Hospital site approved in AVENUE
  - Preperational meetings with Movia
- April 2021
  - Certh and Amobility in-vehicle services tested and perfected in Amobility offices
  - Integration test with Movia Planet (being able to receive a mission/trip)
- May 2021
  - On-demand testing with Navya on Amobility test track
  - Certh and Amobility in-vehicle services development and testing on Amobility test track
    - Use case testing
- June - July 2021
  - Integration test with Movia Planet (booking trip → receiving mission → Deploying vehicle)

      - Testing of cancellation of trips, rerouting during trips etc.
    - Integration test with Movia interactive stops for ordering of trips including haptic feedback tests
- August 2021
    - Commissioning with Navya (4 week process)
    - Final on-demand tests
    - Final on route testing of in-vehicle services (Certh / Amobility)
    - Final route test drive (approval for assessor)
    - Project and route communication (Movia / Amobility)
- September 2021
    - Launch of Slagelse Hospital site project
    - National communication about launch (Movia / Amobility)

5.3.4 On-demand testing (technical perspective)

The goal for the on-demand service is 1) hospital staff can book trips for patients and visitors and 2) patients and visitors can book their trip . Transportation between parking lots and other entrances makes good sense because of the large distances in the hospital area. The status of the trips booked will be updated through the tool used by hospital staff, hereby passengers can get info when to expect pickup time. Safety stewards will greet passengers when the vehicle arrives at the pickup point. Without any direct input from the safety steward, the vehicle will begin its trip once doors are closed.

The on-demand service will initiate with 1 vehicle. The second vehicle will be included in the on-demand service as soon as possible. If the on-demand service performs well, it is the goal to service both vehicles in on-demand as much as possible.

At this stage, there are some technical activities that needs to be performed in order to prepare the service:

- Update Navya vehicle software to 6.1
- Integrate Holo system with Navya API
- Integrate Holo system with dispatcher at Movia
- Movia to develop UI for booking

There will be full focus on the technical integration and stability/performance in the service created. In order to gain the full learning experience in trying to service a robust on-demand service.

There will be less focus on development of apps and screen content, hereby limiting the investigations into the whole Automated minibus customer journey. This is in order to favour the technical development and achievement on back-end software - customer interfaces are owned by Movia.

This priority is possible because the user who is booking the trips will be hospital staff and the passengers via the Movia interfaces. The passengers will receive the necessary info needed from the hospital staff and the interfaces. Furthermore the safety operator still has to be present in the vehicles, and will be utilised to give the needed information to the user.

The practical test process will look like this:

- Outline vehicle behaviour in all possible on-demand situations on Holos testtrack in Copenhagen. SW version 6.1. Holo internally dispatches missions to vehicles.
- Outline vehicle and integration behaviour in all possible on-demand situations with missions received from Movia. Still on Holos testtrack.
- Move to Slagelse and perform similar tests on the real route. Reach a satisfactory level of performance before servicing passengers.

5.3.5 Software integrations

In the illustration below the technical components are presented. A main software component is the dispatcher, which matches passenger request and vehicle capacity, by dispatching missions and thereby fully controlling the destinations of vehicle movement.

The dispatcher used is a piece of software that currently is being used for manual driven transports. From Movias point of view, this is a key point to test and learn about. That is, including self driving vehicles into existing software architecture

A couple of existing Holo products will be used to support the on-demand service.

- Holos operator app in order for the safety operator to be informed about the incoming mission and passengers. But also to report issues manually for data analytics purposes.
- The Supervision portal for remote monitoring and assistance.
- And potentially the End user app for public information about the service and the project.

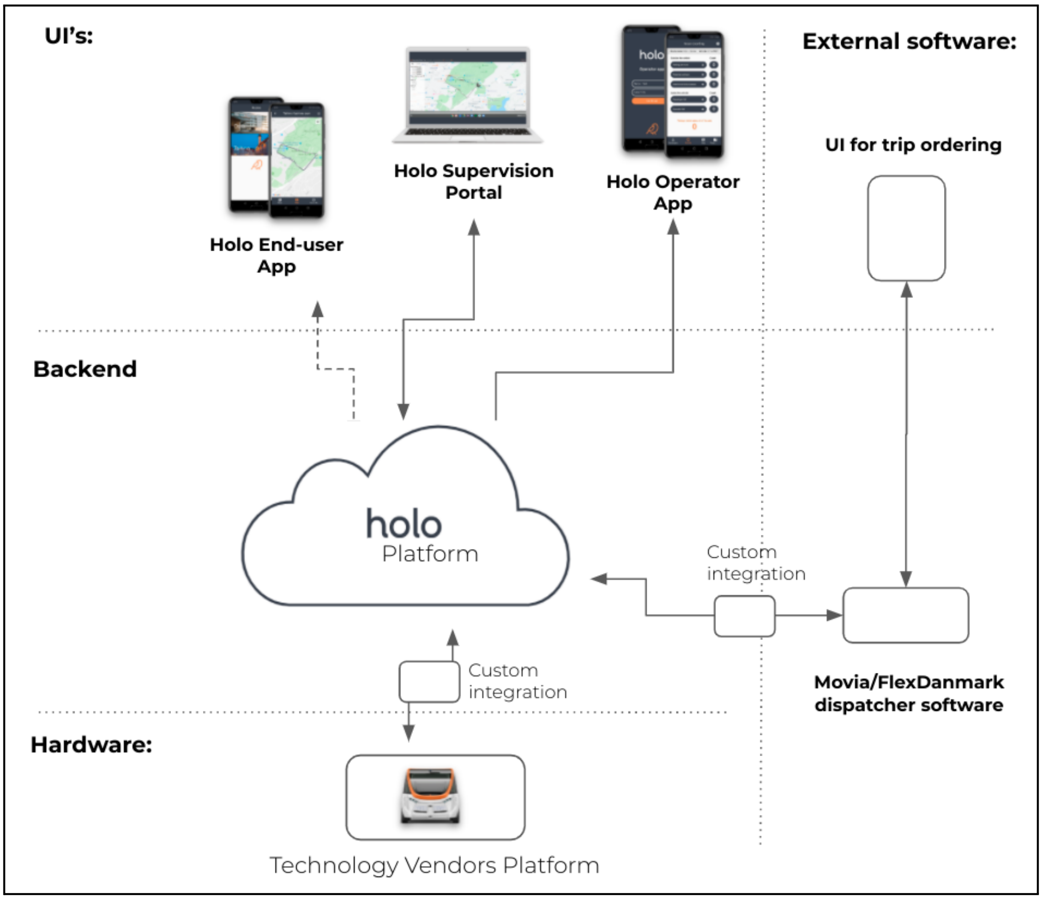


Figure 5.36: Systems and software integrations done in the Slagelse project

In the illustration two integrations are shown. This is where most of the development work will take place.

- Navya API <--> Holo Platform
- Movia <--> Holo Platform

The task of coupling an on-demand service to a vehicle demands a series of integrations. A middle layer is in this case added to support and works as a translator. A general purpose dispatcher is used where the missions are translated into vehicle specific language on Holos Platform. Also the support function is placed at Holo, which makes sense as it has the info from all components.

There are many learnings that will be created from this technical setup:

- Introduction of AV's into standard dispatchers. What limitations will be met?
- Outlining the content and dependencies of the integrations?
- With this set up of an on-demand service, how well can it be operated?

Notes: Receive a mission (demand) → forward mission to vehicle → Vehicle execution

5.3.6 Stakeholders and partners

Movia, Region Zealand, Capital Region of Denmark and the Copenhagen Metro have initiated a strategic partnership with the purpose of promoting and shaping the development of self-driving vehicles in Denmark. Movia functions as the operational partner in the strategic partnership.

The four partners and supporting stakeholders are described in the following section.

AM:

Scandinavian operator of autonomous vehicle systems. AM has the main responsibility to plan and operate the pilot project in collaboration with Movia. AM is the entity given the permit and thereby has the full responsibility for safety and the vehicles.

Movia:

The client in the project and an operational partner. Amobility and Movia will integrate systems in order to deliver the on-demand driving experience at the Slagelse Hospital site. Movia is a public company (PTA) and is regulated by the law about transport companies. According to the law, Movia handles bus operation, local rail operation and transport of disabled persons.

Slagelse Hospital

The Hospital where the pilot project will take place.

Region Sjælland (Region Zealand)

Strategic partner in the Slagelse Hospital project. Region Zealand is one of the five regions in Denmark. Comprising 17 municipalities. Region Zealand performs two main tasks: Regional development and an operational enterprise in the area of healthcare and social affairs. Region Zealand's vision is to create the best framework for sustainable growth and quality of life for its citizens.

Region Hovedstaden (Capital Region of Denmark)

Strategic partner in the Slagelse Hospital project. The regions are responsible for the transport to and from the stations and for patient-transport internally and to and from the hospitals.

The Copenhagen Metro:

Strategic partner in the Slagelse Hospital project. Is overall responsible for the operation of Copenhagen's metro and the expansion of the metro system. The Copenhagen Metro assists with the integration to public transport.

COWI Denmark:

Is a leading consulting group, and two different departments (in order to avoid conflict of interest) are hired to do two different tasks:

One department has been approved as the assessor for this pilot project. The application for a permit to test automated vehicles shall according to the law include an evaluation from an approved assessor.

The other is hired to make a risk assessment of the road safety in the pilot. The assessment is done in close cooperation with AM and is part of the basis for the evaluation by the assessor.

Rambøll:

Is a leading consulting group. A road safety auditor from Rambøll has analysed the below list of conditions in the pilot project. The analysis is part of the basis for the evaluation by the assessor.

- The route and surroundings
- Existing traffic conditions
- The speed on the route
- Handling of other road users
- The conditions to give way
- Traffic at the bus stops

5.3.7 Operational data summary from Slagelse

Distance and passengers

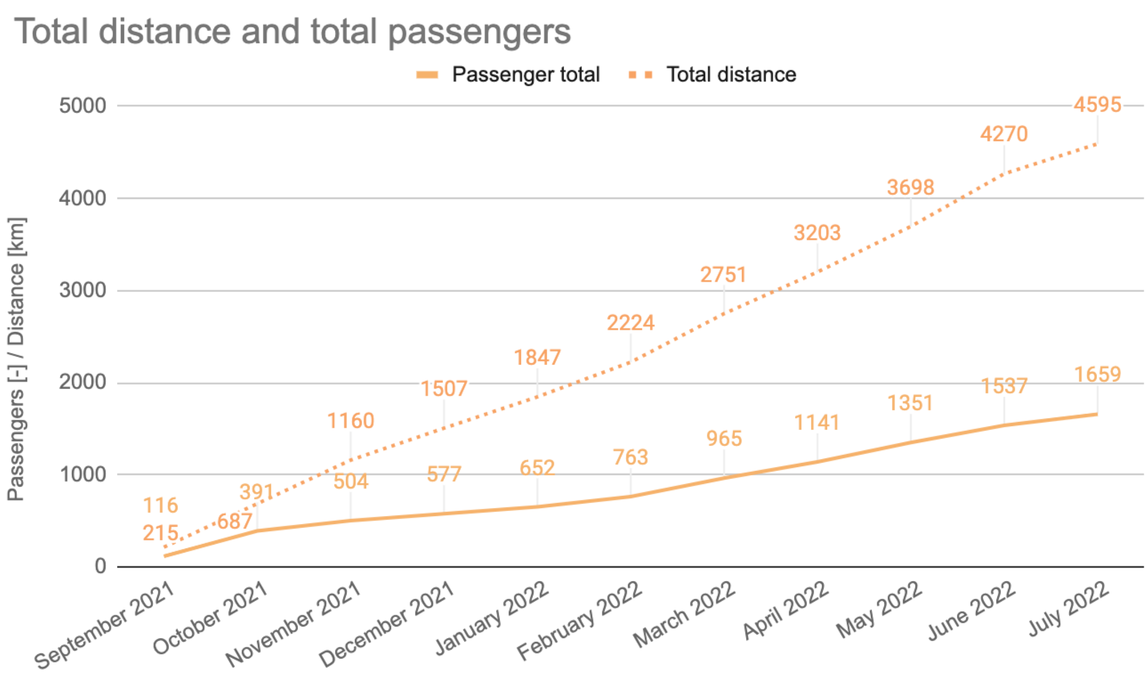


Figure 5.37: Total number of passengers and distance driven in the Slagelse project

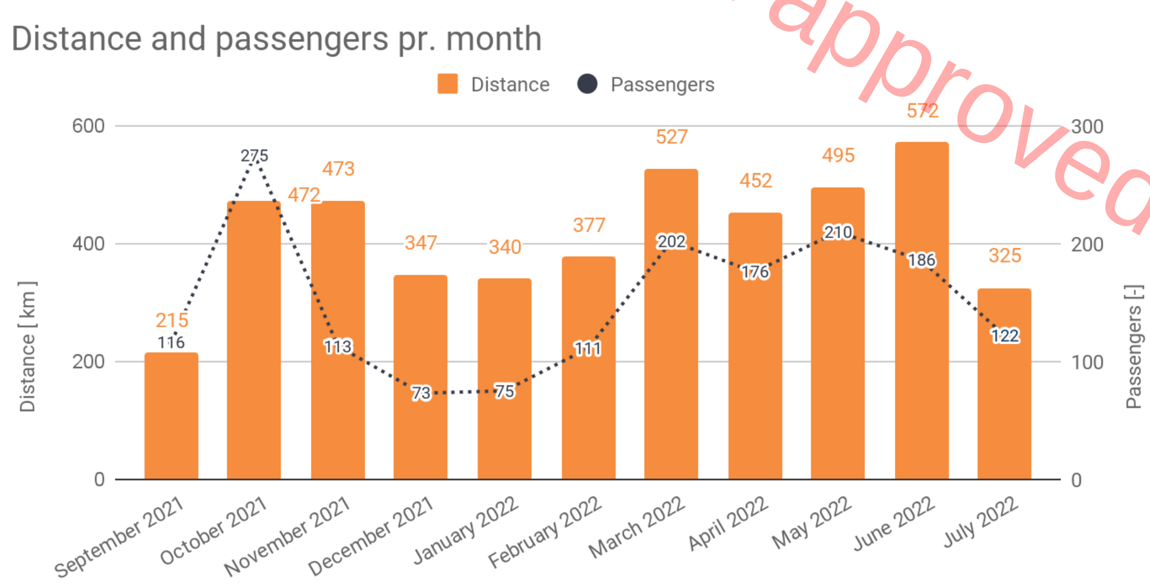


Figure 5.38: Distribution of passengers and distance driven pr. month in the Slagelse project

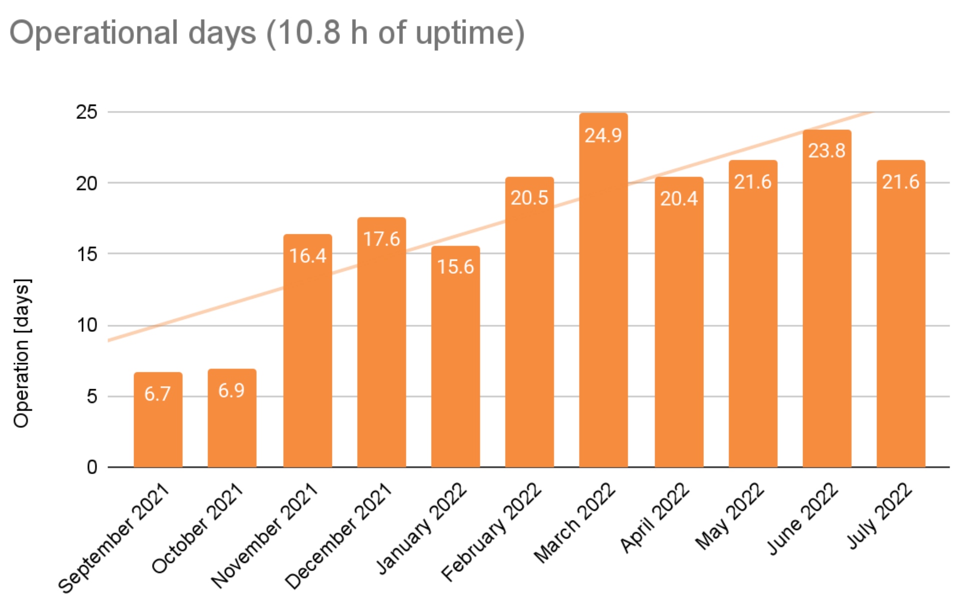


Figure 5.39: Number of operational days measured in active operational hours pr. month in the Slagelse project

Autonomous vs. manual driving

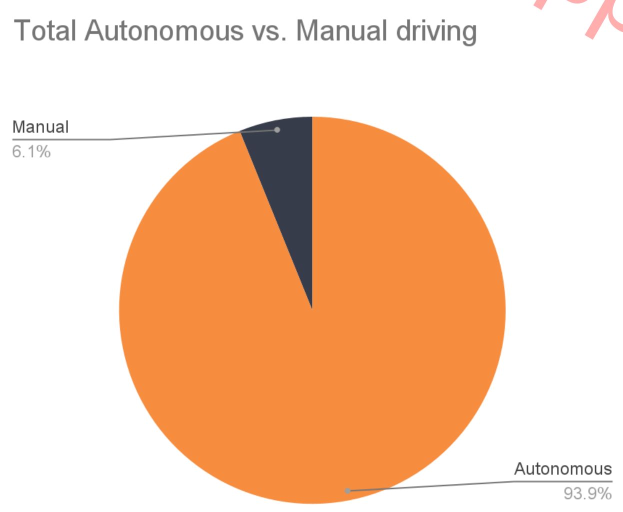


Figure 5.40: Share of autonomous vs. manual driving in Slagelse

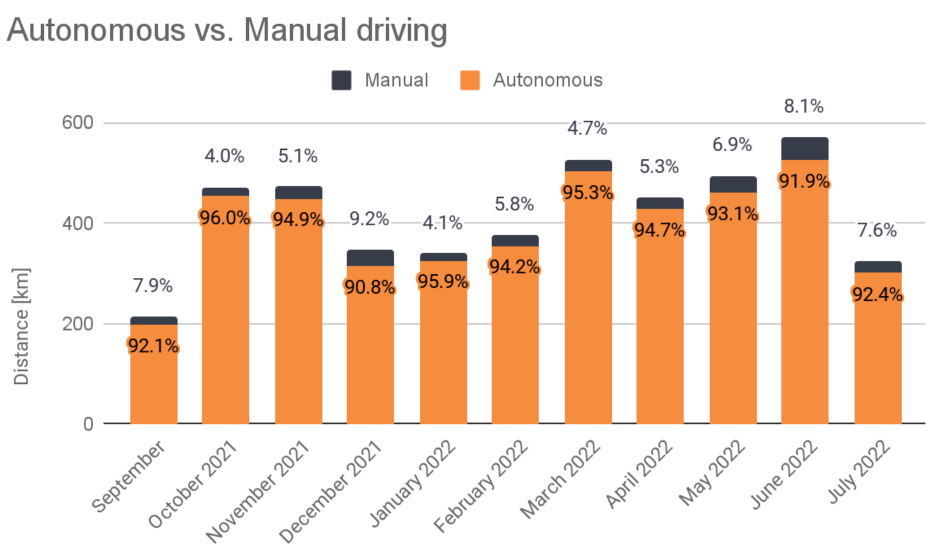


Figure 5.41: Development of share of autonomous vs. manual driving in Slagelse

Support tickets and completion time

In the Slagelse project it was decided not to create feature requests toward Navya, as no new projects involving that vehicle platform are being undertaken by AM. However support tickets and their completion time was continuously monitored throughout the project..

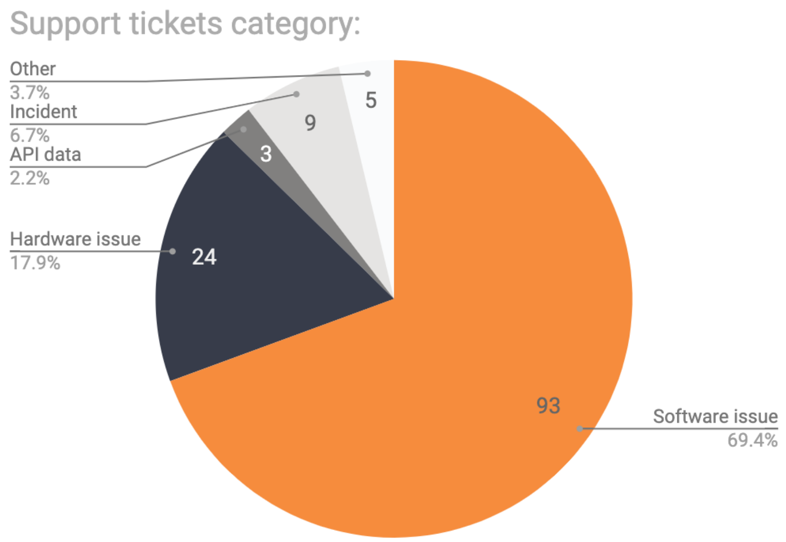


Figure 5.42: Share of support ticket categories in Slagelse

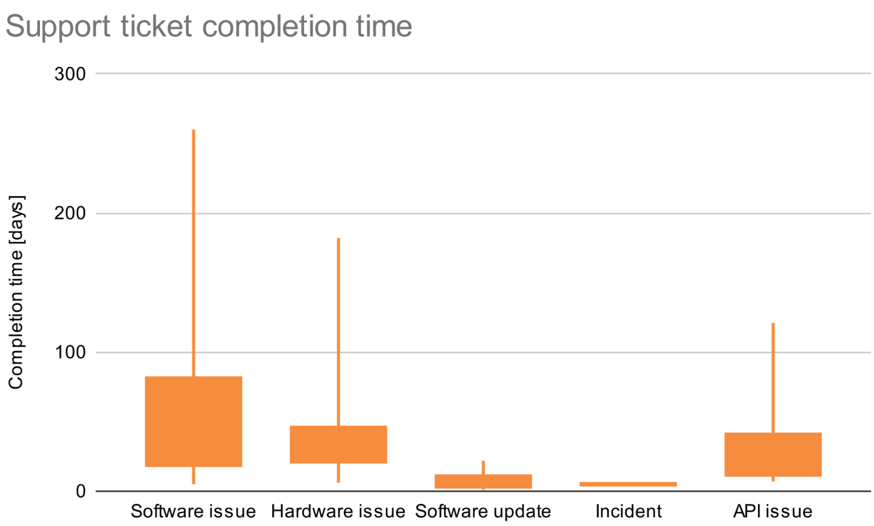


Figure 5.43: Support tickets completion time in Slagelse

Issue count

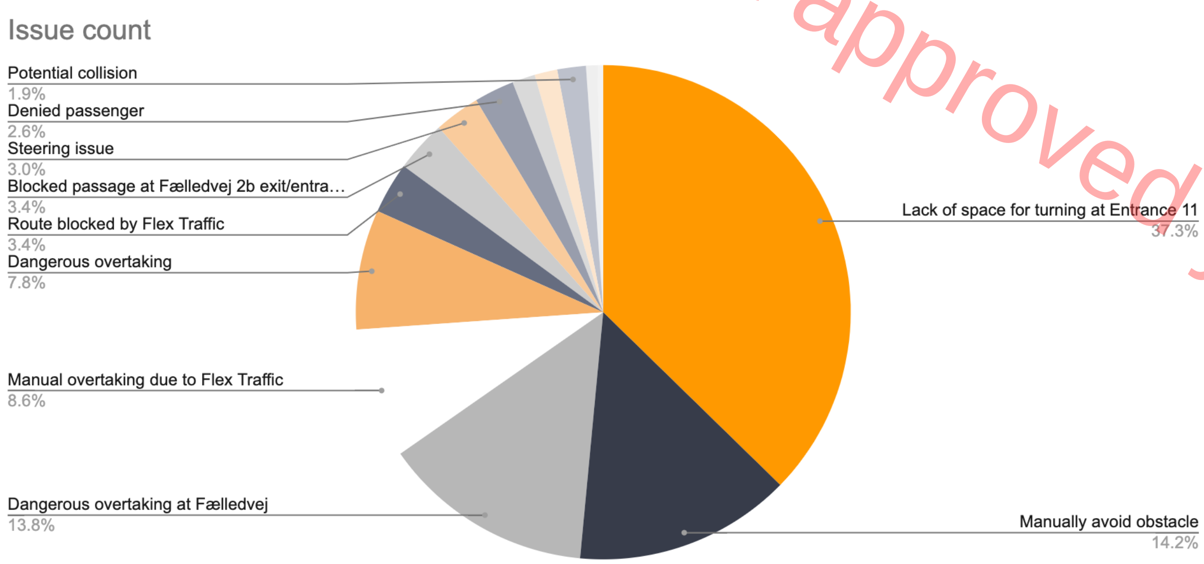


Figure 5.44: Share of issues experienced on the route in Slagelse.

From the data collected on issues experienced on the route in Salgese, it is seen that mostly Movia's own flextrafik vehicles' illegal parking caused "lack of space for turning at entrance 11", "manual overtakings due to flex traffic" and "route blocked by flex Traffix". This data was actively used and presented to Movia in an attempt to bring down the number of issues obstructing the operation on the route.

5.3.8 Learnings from Slagelse deployment

5.3.8.1 User experience learnings

- **Patients**
  Moving patients from A to B on a hospital site has proven to be a very good use case for the Navya vehicles, as patients often do not need high speeds but rely on comfort and the ability to be moved. This means that even if the shuttle's top speed is 18 km/h the patients still experience high value, as the alternative would be to walk or wait for local flex taxis etc.

- **Relatives/visitors**
  Being a relative at a hospital site is often associated with difficult parking conditions and lots of walking on the hospital sites. WIth the service provided in the AVENUE project, relatives and visitors have had the opportunity to park in large parking areas away from the hospital entrances, but then being carried by the shuttle to the entrances. Meaning less coingestion and car hassle at the entrances of the hospital - allowing the emergency vehicles to have more space and less reckless parking from visitors.

- **Employees**
  As for the relatives and the visitors, the employees have used the shuttle service to get from larger parking areas to the entrances of the different departments - but also to accompany patients from one department to another - cutting off time from walking and waiting on flex taxis.

5.3.8.2 Technical On-demand integrations learnings

5.3.8.2.1 Navya integration

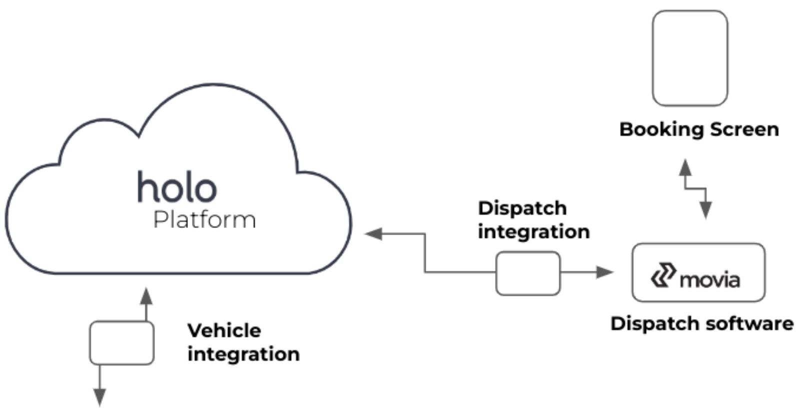
The key takeaways for on demand integrating with Navya are:

- Until mid/late 2022 Navya did not share the mission state/progress. Meaning it was not possible to see if a mission was in execution state, deleted or finished. At Holo we needed to estimate the mission state based on location and door state. This overcomplicated things
- Lack of Navya API stability at random times. Not possible to scaleup when no agreement on API uptime and API support
- The safety stewards did not fit very well into the workflow of sending a mission/destination to a vehicle. In a best case scenario, the vehicle starts driving without any notice inside the vehicle. Making it slightly uncomfortable for the safety stewards to use the on demand mode, which technically is called the Partner mode in Navya language
- Navya needs a lifelike simulator to build and test the on demand integration. Not sure what the present state of this is at Navya. But in Holo we had to test basic things on a real vehicle, which under normal circumstances should have been tested in a simulated environment
- Despite the challenges and the immaturity of Navyas on demand possibilities throughout the project, it has been extraordinary learningfull for Holo to be the middle layer/integrator putting the puzzle together to make everything possible

5.3.8.2.2 Movia integration (planet)

The dispatch management system in use by Movia is called Planet and is delivered by Flexdanmark. It is a widely used product that can serve many purposes. It is as most dispatch management systems able to dispatch trips from booking requests including many sorts of parameters like amount of passengers, luggage, special needs etc.

An interesting thing about integrating with Planet is that the communication is based on the SUTI (Structured Unified Transportation Information) protocol. It's a nordic standard for demand responsive transportation. However it was built and targeted for manual driven vehicles. A simple illustration is shown below.



The key takeaways for integrating with Planet using SUTI are:

- When using a protocol like SUTI, where we are challenging its intended usage. Movia should involve Flexdanmark to a high degree for support and for Flexdanmark to take part in the learnings. Often the Planet system had behaviour that Movia was not able to explain, due to the different application of autonomous vehicles.
- With Holo as a middle layer, abstracting the communication from Planet to the vehicle. It has been great to work with a standardised communication protocol. This is really the way forward for the dispatch software suppliers. However there is a long way to go and if the SUTI protocol is not modified/updated it is not in its present form easily able to include autonomous vehicles. The main reasons are:
  - Content of messages are meant to be human readable. A much more stringent and limited amount of content in the messages is needed
  - Ability to publish the state and progress of the vehicle back into the system
  - SUTI and Planet to take some of the limitations of autonomous vehicles into account. Such as u turns are a problem and only a limited roadgrid is being operated on
- Holo as an operator need possibility to look into Planet to see the booking requests made on the booking screens
- Need for a support hotline that Holo can contact when the autonomous vehicles are not behaving like the Planet system is expecting

5.3.8.2.3 Booking screen integration (MultiQ)

The booking screens are physical touch screens placed at each stop. Here any passenger can order a trip from the stop the are at and to the destination they choose. The trip is confirmed and an eta for pickup is shown to the passenger.
The software running on the screen belongs to MultiQ, a partner of Movia, who chose this supplier for the route in Slagelse.

The key takeaways from the projects experience with these ordering screens:

- Do not use an experimental setup for a pilot project. Enough challenges are present in a project like this to begin with. Using well known/tested equipment
- As Planet does not know the exact progress of the vehicles, the eta presented on the screen are too un-precise. It's not the screens or the supplier fault, but as a waiting customer you want precise info.

5.3.8.3 Navya utilisation/performance learnings

- **Low speed environment**
  The Slagelse Hospital site has shown to be a very good fit for the deployment of the Navya vehicles. Being the site in Amobility' history with the highest autonomous uptime percentage; 93,9 percent of the planned operation has been delivered in autonomous mode. The environment at Slagelse Hospital is low speed (20-30 km/h) zones. Passengers, employees and relatives visiting the Hospital with cars drive slowly and are in general not in a hurry - meaning less dangerous overtakings and reckless driving around the shuttle.

- **Low complexity environment**
  The roads on the Slagelse Hospital are public with low speed zones. The roads are wide and have designated lanes for both pedestrians, bicycles and cars. This has provided a good environment and level of complexity for the deployment of the Navya vehicles. Historically Amobility has experienced many issues with bicycles sharing the roads with the cars, resulting in many overtaking close to the vehicle causing severe and hard brakings of the vehicle - a huge risk for the passengers inside the vehicle. Having this environment, more suited for the Navya vehicle, has had a huge impact on the high uptime in a positive direction.

6 AM data comparison and discussion

6.1 Road complexity comparison

The complexity of the route used for autonomous driving has shown to be of crucial importance for operational performance. Based on the following derived complexity factors, the total score indicates the combined complexity of the driven route.

Road complexity indicators

1. **Area type**
   3: city centres, 2: urban areas, 1: sub-urban and public/private areas
2. **Service type**
   1: Line service (or circular but metro mode), 2: On-demand service (complex driving pattern)
3. **Separate lanes**
   0: yes, 1: no
4. **Segregated road users (**bicycles, pedestrians and cars are separated)
   0: yes, 1: no
5. **Traffic type**
   3: heavy traffic (buses, trucks etc. disrupting the flow of traffic), 2: easy traffic (visitors in cars, no major public transport, bicycles etc.), 1: public/private site (hospitals, airports, campuses etc.
6. **Vegetation and surroundings for LiDARs**
   3: high, 2: medium, 1: low

Road complexity comparison							
	Type of area	**Service type**	**Separate lanes**	**Segregated road users**	**Traffic type**	**Vegetation & surroundings**	**Complexity score**
Nordhavn, DK	3	1	1	1	3	1	**10**
Ormøya, NO	2	1	1	1	2	1	**8**
Slagelse, DK	1	2	0	0	1	3	**6**

Table 6.1: Road complexity comparison between AM AVENUE routes

6.2 Data summary comparison

Data summary and comparison

	Nordhavn	Ormøya	Slagelse

Passengers [-]	1579	6637	1659
Distance [km]	2414	22984	4595
Passengers [km^{-1}]	0.86	0.29	0.44
Autonomous driving [%]	82.2%	91.5%	93.9%
Operational hours [h]	1015	5234	2117
Avg. speed (km/operating hours) [km/h]	1.8	4.4	2.3
Issues [km^{-1}]	8.32	0.11	0.07
Severe brakings in auto [km^{-100}]	0.37	0.12	1.7
Switches to manual [km^{-1}]	2.15	0.55	3.1

Legend: Perfect — Bad

Table 6.2: Operational data summary comparison

6.3 Data comparison conclusions

Tha Navya vehicles have been performing best at the Slagelse site, offering higher uptime and lowest maintenance cost. Looking at the road complexity comparison it stands out that the Slagelse route has the best circumstances for operating the AVs. There are segregated lanes for each traffic participant (pedestrians, bicycles and cars/buses). The data summary comparison also confirms this and it can be seen that Issues per km driven is much lower for Slagelse than the other two routes - especially in Nordhavn Issues per km driven is a factor 900 higher than Slagelse. This can be explained by the complexity of the area Nordhavn, with one shared space including all types of traffic participants - besides that the area is in the city centre and has stores, shops, supermarkets, cinemars and so on, causing much more unpredicted trafik in the area. At the same time the area has very few parking spots but many cars - eventually leading to illegally parked cars everywhere - causing the shuttle to stop constantly.

The Slagelse route also has the highest autonomous driven percentage, again indicating how the route is more suited for the Navya vehicles. Looking at Switches to manual the numbers contradicts the previously mentioned points and is higher than both Nordhavn and Ormæya - this can be explained by the FlexTrafficDenmark vehicles that often park illegally in front of the hospital department entrances to drop off sick patients. In these situations the safety operator has to drive manually around, but only for 10-15 metres. Finally the amount of severe brakings per km driven is also higher at the Slagelse route than the other two, which can be explained by the huge parking lot around entrance 11 and 13, where the vehicle often is stopped by cars driving recklessly in front of the vehicle. The number has been decreasing from day one and forward, due to communication and signs in the area, and it is expected that the number will be even lower when the project is finalised at the end of August 2022.

In conclusion the data summary comparison and road complexity comparison indicates the importance of choosing the right route with the right circumstances to operate, taking both the transport need and demand into account but also the environment, road complexity and traffic patterns. Finding the right balance means a route with high uptime and stable operation.

7 AM learnings from other pilots

AM has currently four non-AVENUE Automated minibus pilot projects running in Finland, Norway, Sweden and Estonia, where in total across all sites have driven 25.000 passengers by now. Furthermore we await approval of three pilot sites in Denmark.

Tallinn (Estonia) 2019 - Done

The route in Tallinn was part of the Sohjoa Baltic project that researches, promotes and pilots automated driverless electric minibuses as part of the public transport chain, especially for the first/last mile connectivity. The operation will last 5 months and start at the end of August 2019.

Details:

- Vehicle: 1 Navya Autonom Shuttle
- Route: Fixed route and fixed stops, 1 km one way
- Passengers: Students, university employees and local commuters.
- Operating hours: Tuesday-Friday: 10.00-16.00, Saturday-Sunday 09.00-20.00
- With an safety operator on board (required by Estonian Road Authorities)
- Pricing: Free of charge

Oslo (Norway) 2019-2021 - Done

The pilot project in Oslo ran for three years and was a collaboration between Oslo Municipality, the Norwegian Public Roads Administration, Ruter and AM. Oslo and Akershus wishes to have 0% emissions across their public transportation and this project testet if self-driving buses can support these ambitions for a sustainable public transport system

The first route was launched in May 2019 in Akershusstranda. It runs on a route from Vippetangen, to the town hall, city square and back again. This takes the shuttle service past the cruise-terminal and along the harbour front.

Details:

- Vehicle: 4 Navya Autonom Shuttle
- Route: Fixed route and fixed stops, 1.3 km one way
- Passengers: Local commuters, tourists
- Almost 19.000 passengers during the first 4 months

- Operating hours: Monday-Sunday 8.20-21.15
- With an safety operator on board (required by Norwegian Road Authorities)
- Services: Fully integrated with the public transport in Oslo e.g. in the RuterReise App and digital time schedule at the two major bus stops.
- Pricing: Same tickets as for other public transport in Oslo are needed to use the ride.

Helsinki (Finland) 2019 - Done

The route in Helsinki was part of the Sohjoa Baltic project that researches, promotes and pilots automated driverless electric minibuses as part of the public transport chain, especially for the first/last mile connectivity. It takes place from June to September 2019.

Details:

- Vehicle: 1 Navya Autonom Shuttle
- Route: Fixed route and fixed stops, 2,5 km one way
- Passengers: Students, university employees and local commuters.
- Operating hours: Monday-Friday: 09.00-15.00, Saturday-Sunday: 12.00-18.00
- With an safety operator on board (required by Finnish Road Authorities)
- Pricing: Free of charge

Gothenburg (Sweden) 2018-2019 - Done

The pilot project in Goteborg was divided into two phases. The first phase of the pilot project took place from May until September 2018 in the Chalmers university area for a duration of 6 weeks.

Details:

- Vehicle: 1 Navya Autonom Shuttle
- Route: Fixed route and fixed stops, 1,8 km one way
- Passengers: Students, university employees and local commuters.
- Total passengers: App. 1500.
- Operating hours: Monday-Friday 07:00-18:00
- With an safety operator on board (required by Swedish Transport Agency)
- Pricing: Free of charge

The second phase took place from April - October 2019 at Lindholmen Science Park for a duration of 6 months. Around 25.000 people travel through the area daily. At one end of the route is a parking area, where the monthly parking permit fee has been reduced, in order to encourage motorists to park there and take the shuttle for the last part of their journey.

Details:

- Vehicle: 2 Navya Autonom Shuttle
- Route: Fixed route and fixed stops, one roundabout, 1.8 km one way
- Passengers: employees at international companies and national authorities, students, scientists and residents.

- Operating hours: Monday-Friday 7-18
- With an safety operator on board (required by Swedish Transport Agency)
- Pricing: Free of charge

Learnings: Driving in mixed traffic provides many learnings regarding how the other road users act, and what obstacles and challenges that occur due to this. How much interference with the service arises when a cyclist or a car overtakes the shuttle. Does the interest in this technology keep interests among citizens; how long does it take for the locals to accept the service as a natural integrated part of the transport services, etc. Furthermore, many technical details regarding operation and the safety operator's functions are obtained.

Køge Hospital (Denmark) 2018-2020 Done

The pilot project at Køge Hospital is divided into three phases. The first phase of the project took place from May until August 2018 in the Køge Hospital for a duration of three months.

Details:

- Vehicle: 1 Navya Autonom Shuttle
- Route: Fixed route and fixed stops
- Passengers: Patients, relatives and hospital staff. Total passengers: > 6500.
- Operating hours: Monday-Friday 7:30-15:30
- With an safety operator on board
- Services: In the non-peak hours on-demand stops on the fixed route were tested, based on the fixed bus stops. The visitor could order the bus through the screen at the bus stop sign post, and then the bus would come to pick them up without stopping at the other stops unless others had made a demand.
- Pricing: Free of charge

Learnings: Gained important learnings about passengers with special needs, e.g. walking frames, wheelchairs, and elderly. The users expressed gratitude and relief due to the service provided, and the hospital experienced the impact of the service and the size of the need among their patients. The on-demand trials indicated the need to find the common denominator when communicating the how-to messages - so that all types of users are able to interact with the service. Furthermore, many technical details regarding operation and the safety operator's functions were obtained.

Aalborg East (March 2020 - December 2021) Done

The pilot project in Aalborg East is a two year project designed to show how Automated minibuses can provide public transport services in a fastly developing area. The route is on an enlarged bike lane where only self-driving vehicles are allowed to drive alongside with the bikes and pedestrians.

- Vehicle: 3 (2 in operation, 1 spare) Navya Autonom Shuttle
- Route: Fixed route and fixed stops
- Passengers: People in the area around Astrupstien. Still running.
- Operating hours: Monday-Friday 7:00-21:00
- With an safety operator on board

- Pricing: Free of charge

Learnings: Running the vehicles on a tight path with limited space meant that overtaking bicycles constantly caused the vehicle to perform a hard brake, making the rides uncomfortable. After a while the local municipality was involved and put up signs to warn the bicycles. Did help quite a bit. Furthermore the route had stop platforms allowing people in wheelchairs to access the vehicle, meaning that the vehicle had to approach the platform with high precision in order to avoid a gap that passengers could trip/fall over. This caused huge issues for the shuttles as they did not have the ability to approach the platform with enough precision causing issues for the passengers. During the project more than 20.000 passengers used the service to go between the two city areas.

Ski (Jan 2021 - Jan 2022) Done

The pilot project in Ski is a 2 year project, designed to integrate on-demand last mile services across and around Ski Central Station. Ski Station is located approximately 30 min. outside of Oslo. Residents in the area use the Ski train station for daily commuting to and from Oslo.

- Vehicle: 2-4 Toyota ProAce retrofitted with Sensible4 Autonomous system
- Route: Fixed, but undergoing expansion currently. On-demand functionality will be introduced in Q4 2021
- Passengers: Residents in Ski Municipality
- Operating hours: 11-19, 7 days a week
- With an safety operator on board
- Pricing: Same tickets as for other public transport in Oslo are needed to use the ride.

Learnings: Running with another vehicle than Navya, provided the opportunity to compare vehicle performances both in terms of hardware and software. The Toyota Proace vehicles, retrofitted with Sensible 4 software, performed well at speeds up to 35 km/h. The vehicle build proved to be more solid as Toyota has been building cars for centuries. In terms of the software, Sensible 4 is still not ready to perform SEA level 4 driving, but did show promising driving in higher speeds.

8 Conclusions

The main conclusions that can be drawn from the Amobility efforts in the AVENUE project and the implementation of self-driving vehicles in Nordhavn, Copenhagen, Ørmoya, Oslo and Slagelse, Copenhagen are summarised in the following points.

- The approval process in Denmark has been a slow start where multiple stakeholders in the approval process had to learn the basics of self-driving vehicles, resulting in and approval process with inspirations from the railway approval systems - hence a documentation level out of the ordinary, seen from the perspective of the self-driving vehicles industry, where the technology is still at a low maturity level. A new approval is on average considered to take between 9-14 months in Denmark and the adjustments and changes to an already given approval is rigid and requires a new approval in most cases.
- The entire approval process in Denmark with multiple approvers is very expensive and requires a huge amount of work from Amobility, in terms of documentation, separate approvals, tests, risk assessments and so forth.
- The approval process in Norway is structured in a very different way, allowing for a more dynamic and communicative approach. It is Amobility's experience that the Norwegian system is more agile and ready to adjust to the rapid development of self-driving technologies. A new approval is on average considered to take between 3-5 months in Norway and the adjustestments and changes to an already given approval is seen as dynamic and innovative.
- Based on the experiences and knowledge that Amobility has gained so far, recommendation for the Danish legal framework has been provided, with both direct and indirect changes that can be made to ease up the approval process.
- Amobility have suggested that when testing/driving in SAE level 3 or lower only approval from the DRSA, local police, and road owners should be necessary. Furthermore in projects with SAE level 4-5 operation, AM recommends to have either 1) an approval from the appointed assessor, DRSA, police, and road owner(s) or 2) an approval by the Danish Road Directorate (taskforce), DRSA, police and road owner(s). AM also suggests authorities to allow approvals for areas rather than single route approvals. Also AM recommends that the Danish Authorities target public funds more towards AV implementation. Ultimately AM recommends removing the political approval process entirely. For each project to have their own executive order is completely diminishing the flexibility and innovation for existing and future pilot projects.
- Inspiration and know-how from the Norwegian approval system has been recommended to the Danish authorities as a comparison - aiming at showcasing the potential loss of innovative projects in Denmark, if the approval system does not adapt to the innovative and rapid developments of self-driving technologies.
- From a technical perspective Amobility has experienced that the technology and industry in general has developed at a slower pace than anticipated and the objectives of AVENUE have been difficult to meet.
- The Navya vehicles are not able to drive in SAE level 4 as there are still many aspects of the safety related features that need to mature before Amobility can take out the Safety Operator from the vehicles. As a part of the risk assessment in Denmark there are certain jobs related to risks in traffic that the Safety Operator has to perform to verify and support the vehicle in public transport.

- During the project of AVENUE, Amobility have deployed Navya vehicles at three different sites in both Norway and Copenhagen, Denmark. Experience has shown that the route in Slagelse offers the best circumstances for operating Navya vehicles with the right amount of complexity still ensuring the opportunity for high uptime. The maintenance cost is historically low in Slagelse and major breakdowns and issues have not been experienced. At the same time passengers on Slagelse Hospital have been very happy with the service moving patients from department to department. This highlights why the use case in Slagelse is better than the other sites, as the patients do not demand speed, but comfort and the ability to avoid walking. They are not in a hurry, as Amobility experienced passengers in Nordhavn to be - due to the city centre position having both residents, employees and tourists.
- To be able to reach higher speeds with the shuttles the sensory systems have to be improved allowing for a larger safety net of lidars etc. Given the Amobility experience in Nordhavn and Ormøya, the average speed is still as low as 7-8 km/h. The top speed of the Navya vehicle is currently 18 km/h. Is it Amobility's opinion that the average speed is more important to increase than the speed of vehicles as the most important improvement for the operation is to move the passenger faster from A to B and not at the highest top speed. The objective is to try to raise the average speed to 14-16 km/h.
- Driving in snow and heavy rain in Oslo has turned out to be quite the challenge for the Navya shuttles. The big snowflakes are often confusing the lidars and tricking the system into thinking that there is an object that the vehicle has to avoid, hence usually a severe braking causing the passengers and Safety Operator to fall.
- The map of the vehicle (from the commissioning process) does not take into account that vegetation changes from season to season - even from the day the commissioning was executed to the day the operation begins. This has caused many problems for the vehicles that have performed many hard - and severe brakings. Often the branches are seen as obstacles in front of the vehicle in the safety zones. Amobility and the clients have spent both time and resources on keeping the vegetation to a minimum (preferably exactly as it was during the commissioning).

Appendix A:

Technical data Navya Arma DL4

Description	Value
Capacity	
Passengers	11
Sitting	11
Standing	Not included in Denmark & Norway
DImension	
Length	4.75 [m]
Width	2.11 [m]
Height	2.65 [m]
Clearance	0.20 [m]
Tyres	215/60 R17
Wheels	Steel wheel rims
Empty weight	2400 [kg]
Gross weight	3450 [kg]
Engine	
Drive wheel	2
Engine	Electric
Power	15 [kW] nominal
Maximum speed	45 [km/h]
Operating speed	25 [km/h]
Maximum slope	12 %
Energy	

Battery	Battery pack liFe P04
Capacity	33 [kWh]
Average theoretical autonomy	9 hours
Charge duration for 90 %	8 hours at 3.6 kW, 4 hour at 7.2 kW
Charging technology	Induction / plug
Charging temperature	0 to +40 degrees
Operating temperature	-10 to +40 degrees
Direction	
Steering wheel	2x2
Turning radius	less than 4.5 [m]
Equipment	
Air Conditioning	Automatic
Heating	Central
Doors	Double wings
Body	Polyester
Windows	Glass
Visual information	15 inch touchscreen
Sound information	Speakers
Lighting	Unidirectional
Sounds warning	Buzzer/claxon
Safety	• Handholds (4) • Supporting bar (2) • Emergency hammer • Triangle • Safety vest • First aid kit • Fire extinguisher • Interior camera
Wheelchair access	Manual ramp
Localisation & object detection	

Lidar 1	Two 360 degree multi-layer lidar
Lidar 2	Six mono-layer lidars
Cameras	Front stereo vision cameras
Odometry	Wheel encoder + inertial unit
Safety2 buttons	
Emergency stop button	
SOS intercom	! button / vi supervision
Emergency brake	Automatic
Parking brake	Automatic