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Automated shuttles and negotiation in motion – an inductive study of interactions with human road users

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Abstract:	Since automated vehicles were first introduced in public imagination, the stated goal of developers has been to develop vehicles that would eventually operate in diverse contexts like any other vehicle. To understand what this entails in real-life traffic interactions, data was collected from three separately run trials of automated shuttles in diverse low-speed socio-spatial contexts with vulnerable road users in Denmark. We analyzed notes from field observations, interviews with road users, geolocalized real-time event registrations, video tracking data, and response to open-ended survey items. Findings regarding 1) dynamic negotiation of space and timing, 2) handling of situational and traffic system ambiguity, and 3) human road user learning, go beyond what should simply be attributed to a transitory immaturity of the underlying technologies. The analysis shows how road users expect other road users to engage in an ongoing dynamic negotiation of space and timing. When AVs fail to negotiate, traffic flow is interrupted, and road users express confusion and impatience, until they develop strategies to obstruct or move around the shuttles. We discuss possible planning implications and potentials in low-car environments.

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ABSTRACT

Since automated vehicles were first introduced in public imagination, the stated goal of developers has been to develop vehicles that would eventually operate in diverse contexts like any other vehicle. To understand what this entails in real-life traffic interactions, we analyzed notes from field observations, interviews with road users, geolocalized real-time event registrations, video tracking data, and response to open-ended survey items. Data was collected from three separately run trials of automated shuttles in diverse low-speed socio-spatial contexts with many vulnerable road users in Denmark. Findings regarding 1) dynamic negotiation of space and timing, 2) handling of situational and traffic system ambiguity, and 3) human road user learning, go beyond what should simply be attributed to a transitory immaturity of the underlying technologies. The analysis shows how road users expect other road users to engage in an ongoing dynamic negotiation of space and timing. When AVs fail to negotiate, traffic flow is interrupted, and road users express confusion and impatience, until they develop strategies to obstruct or move around the shuttles. We discuss possible planning implications and potentials in low-car environments.

Key findings:

- Qualitative inductive cross-case study of interactions with driverless shuttles
- Interactions are negotiated and dynamic even when with automated vehicles (AV)
- Distinction between *spatial awareness* and *social awareness* in traffic is proposed
- Planners must know AVs' specific demands to plan proactively for public good

1. Introduction

It has up to now generally been assumed that AVs would eventually be seamlessly included in traffic and would then make no special demands on societal behavior or road infrastructure at the vehicle level (Fagnant and Kockelman, 2016; Sparrow, 2017)). If this assumption was to materialize, it would from a planning perspective make little sense to examine their traffic characteristics in the current phase of technology development, as the vehicles can currently only be deployed within delimited contexts and with comprehensive support systems in the form of preparatory digital mapping, the availability of suitable physical reflectors, data networks and security personnel inside or outside the vehicles (see Tennant and Stilgoe, 2021). In other words, in the current state of technology AVs are highly dependent on their attachments to actors and structures that create exceptions and demarcations in order for the vehicles to operate, something that would need to become obsolete prior to implementation at scale in what we label a 'same-as-any-other-vehicle' scenario. However, a growing literature argues that AVs are better understood as a technology with characteristics and attachments that will inevitably make demands on its surrounding world (Legacy et al., 2019) and that a promise to "change the world without the world needing to change" (Tennant and Stilgoe, 2021) is unlikely to become reality.

The current requirement to delineate operational design domains suitable for AV operation and the sliding timeline of fully autonomous mobility has gradually shifted the outlook for automated vehicles from a question of *when* to a question of *where* (Marsden, 2018; Tennant and Stilgoe, 2021). That is, from an expectation that AVs will eventually function everywhere, to an expectation that automation features will take over driving in specific operating conditions and that fully autonomous vehicles will in the foreseeable future only be an option within delimited and digitally mapped geographical areas. Such descriptions of conditioned use invite a retelling of the narrative of road transport automation and highlights a need for knowledge about AVs' specific dependencies and implicit and explicit requirements regarding the behavior of other road users and the design of the physical infrastructure.

In practice, it is hardly possible to unambiguously characterize the full set of dependencies that unfold between a technology and its context in an open social system, but some factors seem to be agreed upon in the literature. Several studies indicate that from an urban planning perspective, it is preferable if self-driving cars are introduced as rideshared or public transport, as AVs as a replacement for private cars and low occupancy rides are likely to increase transport volume and exacerbate congestion (Soteropoulos et al., 2019) to the detriment of the environment (Grindsted et al., 2022), urban liveability (Soteropoulos et al., 2021) and efficiency (ITF 2015). Mainly transport companies and local authorities have been initiating tests of AVs which have resulted in publicly available and peer reviewed research (Heikoop et al., 2020), something that is mirrored in the fact that available vehicles on the market for urban innovators to consider has thus far been limited to driverless shuttles (DS) whereas detailed data from independent sources regarding the realized autonomous performance of other types of AVs has been hard or impossible to come by (Tennant and Stilgoe 2021; Marat 2017). Heilkoop et al (2020) point out that there is only limited knowledge about interactions with other road users, just as descriptions of the specific characteristics of the socio-spatial contexts are sparse. in recent trials DSs have had a set maximum speed of approximately 15 km/h (Heilkoop et al. 2020) due to safety and regulatory concerns.

In the empirical section of this paper, we draw on inductive qualitative evidence to identify aspects of how ASs interact with road users within specific socio-spatial contexts in three separate and different test beds. We propose that some findings go beyond what should simply be attributed to a transitory immaturity of the underlying technologies by documenting traffic interactions as social in nature even when one party is an AV. By adopting a cross-project approach this study identifies similarities in interactions across socio-technical contexts that could inform an aggregate understanding of phenomena and challenges specific to the interaction between low-speed DS, human road users and spatial planning. The authors propose that such aggregate knowledge is a valuable starting point both for assessing the potentials of automated transport in specific socio-spatial contexts, for assessing industry claims for software updates and new vehicle models, and contributes to the empirical foundation for discussions about autonomous vehicles in urban planning.

2. Research design and Methods

For this study qualitative evidence of the interplay between DS and other road users based on data from three separately run projects conducting tests of autonomous shuttles in Denmark between 2018 and 2022 was examined. The shuttles were implemented in specific and varied socio-spatial contexts and the projects engaged two different brands of shuttles. In the three trials distinct user groups were targeted in tests situated in different types of low-speed testbeds and with different project owner motivations. What connects the projects is a common focus on automated busses in their early implementation and an aim to provide a knowledge foundation for the involved municipalities and transport authorities' evaluations of automated vehicles as a way forward for sustainable public transport. As a result, the research designs applied to the three projects departure from the same open-ended inductive question: what occurs in the meeting between passengers, a specific socio-spatial context and automated shuttles?

The three projects were launched, implemented and evaluated separately and with their respective teams of technicians, project managers and researchers[1]. The projects were the first, second and fourth of their kind in Denmark and the research was organized based on a desire to document experiences in a broad and descriptive way in the absence of localized empirical and theoretical knowledge about the vehicles' expected performance in the specific contexts. Across projects research was rooted in a socio-technical approach, which is why both the technical deployment of the vehicles, road user experience and interactions were subjects of study.

Project venue and duration	Project owner	Traffic context and users	Project goals	Data collection methods
Trial 1: Hospital lobby Duration May–Aug. 2018 (4 months) 	Movia – Regional transport authority, Region Seeland	• Route: Indoor in 350 meters long central lobby at hospital. • Informants: Patients, visitors, hospital staff and stewards • Steward on board (SAE 3) • 1 Navya Arma DL4 shuttle • Max 3,6 km/h • 5 days/week; 7:30am-3:30pm	Focus: Building knowledge base for future public transport: • First experiences with AVs as public transport • First operational experiences	• Field observations • Informal travel along interviews • Questionnaire survey
Trial 2: University Duration Apr.–Oct. 2021 (7 months) 	Albertslund Kommune - Municipality, Capital Region	• Route: 3 km roadway at a university campus with mixed traffic of cars, vans, cyclists and pedestrians. • Informants: Students, staff and stewards • Steward on board (SAE 3) • 3 EasyMile eZ10 shuttles • Max 15 km/h; Avg. 5,4 km/t • 5 days/week; 5.30am-7pm	Focus: Future first-last mile solution for Copenhagen light rail: • Study user experience and interactions with other road users. • Study integrations with context aware digital support systems	• Field observations • Informal travel along interviews • Focus group interviews • Geo-localized registrations of events in steward-app • Questionnaire survey, user panel • Video analysis
Trial 3: Suburban path Duration Mar. 2020–Nov. 2021 (21 months) 	Aalborg Kommune - Municipality, Region North Jutland	• Route: 2.1 km redeveloped local path open to vulnerable road users, mopeds and automated shuttles. No motorized vehicles on the path pre-trial. • Informants: path users and stewards. Many children and young people. • Steward on board (SAE 3) • 2 Navya Arma DL4 shuttles • Max. 18 km/h; Avg. 8,6 km/t • 7 days/week; 7am-9pm	Focus: Urban development: • Internal and external mobility in suburb • Better urban mobility structure by upgrade of local pathway • Local image boost with innovative technology	• Field observations • Informal ethnographic interviews • Focus group interviews • Workshops • Daily logging of events by stewards

Table 1 Project overview

2.1 Vehicle characteristics and implementation

[1] First author has been associated with all three projects, while second and third author have mainly studied trial 3

Two different vehicle brands with some common functional characteristics were deployed (see Table 1): Both types of shuttles were designed for public transport and could accommodate up to 11 and 15 passengers respectively[2]. They were operated on fixed routes which had been mapped and analyzed in detail, then driving protocols had been prepared in collaboration with safety professionals and with requirements for subsequent final authority approval. The vehicles could not deviate from the preapproved route when operating in automatic mode, but could when necessary be controlled manually with a joystick by a certified person (steward) who was on board the vehicles during the entire operation period.

The shuttles used various sensors including 3D mapping (LiDar), camera stereovision and GPS to orientate and detect physical objects in its surroundings. If an unmapped object e.g., a person or vehicle, was detected within the shuttle's immediate safety zone, the vehicle would stop. This zone is programmable and adaptive to shuttle speed. The preprogrammed operation protocol included speed as well as trajectory, but unlike the trajectory shuttle speed was adjusted autonomously based on proximity to unmapped objects. Stewards were sometimes (depending on situation and vehicle type) required to reset the system after an emergency stop before autonomous operation could be resumed. Stewards were responsible for traffic safety, daily operation and provided information and welcomed passengers onboard.

2.2. Data collection and dataset

Data from the three trials was collected through a combination of several qualitative methods. In trial 2 and 3 data was collected in stages covering pre-implementation, initial operation and fully implemented operation. In trial 1 data was collected mid project.

2.2.1. Fieldwork - In-situ observations in trial 1, 2 and 3

Across projects fieldwork amounted to a total of 23 full days of observations (Trial 1: 2 weekdays; Trial 2: 10 weekdays; Trial 3: 10 weekdays/weekend days). Additionally, more than 600 images were taken, and testbeds were documented in terms of physical properties, traffic types/density and interactions on and along the routes. Observations were recorded in the form of initial *jottings* and *proper fieldnotes* (rich and detailed narratives) written in-between observations (Bernard, 2006). Observations include shuttle functionality, stewards' reactions and reactions of passengers and non-passengers who encountered the shuttles.

2.2.2 In-situ informal interviews in trail 1, 2 and 3

During fieldwork informal ethnographic interviews (Bernard, 2006) were conducted with more than 200 informants in and around the shuttles. Informal interviews were documented in fieldnotes with some direct quotations of central statements. Interviewees represent a diverse group including children, elderly, cyclists, pedestrians, wheelchair-users, motorists and stewards. Interviews differ in terms of the exact questions asked (how they experience the project, shuttles, the area etc.) and duration of the interviews (between one and ten minutes). The inductive nature of the research required a continuous change of focus with new findings (Hannah and Lautsch, 2010) and as a result not all informants have had the opportunity to discuss all themes. For these reasons, no quantitative analysis was attempted (e.g. how many people mentioned a particular theme).

2.2.3 Further data collection specific to trial 2 and trial 3

In trial 2 an on-line user panel consisting of >500 students, staff and regular visitors was convened and send regular updates and questionnaires. Questionnaires included open-ended exploratory questions regarding experiences with the automated shuttles as pedestrians, cyclists, motorist and passengers. Furthermore, in order to record stewards' experiences, a mobile phone app for stewards' use was developed, allowing stewards to categorize, locate and describe notable events in real-time. Categories were defined and adjusted in collaboration with the stewards during co-researcher training and in a follow-up focus group interview. The categories were: 'physical obstructions', 'pedestrians', 'cyclists', 'motorists', 'abrupt stops', 'road works' and 'extreme weather'. Finally, based on initial findings, a central intersection was chosen as the location for one full day of video-tracking shuttles' and road users' trajectories and interactions.

In trial 3 twenty further informants were interviewed in eight semi-structured interviews3. Group interviews are useful to gain insights into a specific case, by letting informants share knowledge between each other and reveal context-specific themes that might be unknown to the interviewers (Hammersley and Atkinson, 2007). Due to Covid-19 6 group interviews with residents, local children and stewards were conducted outdoor as Go-along interviews; Go-along interviews involve the informants and interviewer walking (or driving) together, and are well-suited to capture informants' experiences of social structures and phenomena situated in physical surroundings (Kusenbach, 2003). Also, Three workshops were held with children from a local school, asking the children to draw and explain their expectations for and experiences with the shuttles. The workshops were audio-recorded and photographed. Finally, the stewards in trial 3 filled in a daily log prepared by their employer, with various questions regarding technical issues, driving patterns and behavior from passengers and other road-users.

2.3. Data analysis

Strategies for data analysis diverged between projects and in the following a short overview of the three approaches will be given and a description of how the data was combined and analyzed in the results section of this paper is presented.

2.3.1 Trial 1 – hospital lobby

[2] Due to coronavirus restrictions, there have been periods of restrictions on the number of passengers that could be included in trials 2 and 3
[3] interviews involving 20 informants; 14 residents, four workers in the area, and two shuttle-stewards.

Data from trial 1 was analyzed focusing on predetermined themes: 1) How users interacted with the shuttles when boarding and alighting; 2) Interactions and behavior in vicinity of shuttles and in lobby; and 3) Users' and non-users' perceived safety and intention to use. Analysis of theme 1 and 2 was based on field observations, theme 3 was based on a questionnaire survey[4].

2.3.2 Trial 2 – University campus

Analysis of interactions with other road users was stated as an explicit focus of data collection and method development in trial 2. Qualitative and quantitative data was used to triangulate results. Analysis was based on a coding and categorization into six predefined broad areas of interest: 1) Interactions with pedestrians; 2) Interactions with cyclists; 3) Interactions with motorists; 4) Passengers' evaluations and feedback; 5) Stewards' role, behavior and impact; and 6) Geographical distribution of challenging events and relation to route characteristics.

2.3.3 Trial 3 – Suburban path

Data from interviews and fieldnotes was coded using a general inductive approach in order to explore themes generated from the raw data. (Thomas, 2006) Descriptive codes were assigned e.g. "stewards' social role", "shuttle too slow", "cyclists interaction" etc. Codes were grouped in 10 larger categories, e.g. "community of Aalborg East", "roles of stewards", "traffic interactions" etc. which guided the final phase of data collection in 2021, where similarities or contradictions within these categories were explored. Data from 2021 was coded separately using the same process. In this paper only data identified as pertaining to traffic interactions has been included.

2.3.4 Methodology for combining results across projects

When reviewing results from the three trials separately results regarding interactions seemed bound to specific properties in the socio-spatial contexts, e.g., the layout of routes and stops or the preexisting social patterns of interactions between different modes of transport. When results were reviewed across the three trials common features in observed interactions and their associated infrastructural characteristics, situational conditions and testimonies from users and non-users emerged. To capture such common features the underlying data on traffic interactions was revisited. This resulted in a further layer of themes: 'cyclists overtaking shuttle', 'shuttles overtaking pedestrians', 'road user impatience', 'unusual traffic management arrangements', 'ambiguous mutual timing', 'assessment of relevant distance to shuttle', 'habituation over time' and 'new negotiated coexistence'. These themes were subsequently grouped in three overarching phenomena:

- Distance and timing in interactions
- Interpretation of intent in ambiguous situations
- Repeated interactions and road users' learning over time

In section 3 examples of observed interactions, informants' assessments and experiences from the three trials are presented and discussed.

3. Findings

3.1. Distance and timing in interactions

In all three testbeds field observations recounted situations where delays and stops occurred when road users entered shuttles' safety zone. Some informants reported that they were mindful of the shuttles detection of their presence and tried to adapt their behavior to the distances that the shuttles required to operate smoothly. Despite this, braking and emergency braking was regularly caused by other road users in situations, that were not perceived by road users in the vicinity of the shuttle as posing a risk:

> (Fieldnote - trial 1) "Patients queuing at the hatch near stairway 13 [where the hallway is narrow] exceed the lines marking the shuttle lane slightly. There is enough physical space for the shuttle to pass but it stops until people have moved further back. Steward uses the bell so that people discover that "they are in the way" – they don't seem to realize why the shuttle has stopped. It stops some meters away and does not approach further."

> (Comment from pedestrian - trial 2) "[The bus] slowed down even though I was walking on the side of the road. It was not uncomfortable for me, but it was apparently uncomfortable for the security man driving it. At least, he indicated that I should keep my distance. I thought afterwards that it is not me who has to keep my distance. Ordinary cars just bet that no one jumps out in front of them."

> (E-scooter rider - trial 3) "And then, like, when we need to pass [the bus] – because it's going so slow - when you're about to pass it, it just stops out of the blue."

Challenges in timing and assessment of distance resulted in unplanned stops and delays in the flow of traffic, something that tended to be enhanced once normal flow was interrupted. Below (Example 1) is a series of still photos from a video capturing how one close passage resulted in multiple stops and further mutual mistiming.

[4] Questionnaire data and findings are not included in this study

Example 1: Distance and timing: Shuttle stopping several times

1. The shuttle is turning right. An oncoming pedestrian (A) slows down, to let the shuttle pass, but a cyclist (B) driving on the inside of the shuttle triggers emergency braking. The shuttle hesitates for several seconds before starting again.

2. Meanwhile, the waiting pedestrian decides to cross the road. The shuttle stops again, to comply with its obligation to give way. Behind the shuttle, a cyclist (C) is approaching.

3. While the shuttle is giving way to the pedestrian, a further cyclist (D) waiting to turn tries to stay upright, even though he is almost stationary. The cyclist (C) on his way up the hill passes behind the shuttle, at a large distance.

4. As soon as the cyclist (C) has passed, the waiting cyclist turns, passing close by the shuttle, which thereby stops again. Now a car and several pedestrians have joined the small traffic jam.

5. After all the other road users have moved on, the shuttle can finally finish the turn.

Stewards in trial 1 and 2 describe such situations as problematic and try to predict, avoid or mitigate them by interfering with the shuttles' automated features. Multiple instances were observed of stewards manually overriding automated operation e.g. by preventing the shuttle from leaving a bus stop because there were another road user approaching:

> (Fieldnote - Trial 3) "[The steward] stops the bus manually a couple of times to make space for cyclists and someone in an electrical wheelchair. [The steward] explains that it's a bit easier to just halt the bus to avoid confusion and sudden braking."

Stewards in trial 3 also note situations, where they are manually driving around slow-walking pedestrians or halting the bus as exemplified below.

> (Steward log - trial 3): "Just before you enter the tunnel going north - if you here meet a handicap scooter, they often have to move up on the pavement to make room for the shuttle, or we have to stop the shuttle to make room."

Anticipation of road users' impatience was also reported to prompt stewards to interfere. This was especially pronounced in trial 2 where cars and other busses were at times held back by the shuttle:

> Steward (trial 2): "Especially at [the stop by] Netto, there are many problems. Sometimes there are many who wait. The shuttle drives back and forth, back and forth, but just can't find the melody. Then I sometimes switch to manual so we can get on our way. They get impatient, of course. They are friendly, they wait – and then nothing happens! We do not drive! Then they think: "What?!?' [steward gestures incredulity]"

In these instances, stewards are seen to intervene in consideration for other road-users, and in order to make traffic run smoothly and convenient. Stewards are predicting or evaluating traffic-situations from the perspective of other road users and their comfort – something the shuttles are not (yet) equipped, or programmed, to do.

3.1.2 Road-users passing the shuttle

In outdoor trials 2 and 3 the shuttles where run at speeds that caused bikes and motorized traffic to need to overtake the shuttles. Road users point to two types of challenges when overtaking the shuttles: 1) assessment of how and when to overtake and 2) timing of when to pull into own lane after passing. During fieldwork in trial 3 overtaking cyclists and scooters were observed to pull in within three meters of the bus, causing the bus to brake instantly. This is also described by stewards and cyclists. For example:

> (Steward - trial 3) "[cyclists] can be a problem when they pull in too close in front of [the bus]"

> (Cyclist - trial 3): "And we've also gotten used to actually having to be quite far in front of the bus before we can pull in again without it stopping. And that's more because we don't want to inconvenience the bus because it'll do an emergency stop."

Despite going in the same direction, and the cyclist portraying no obvious risk to a human observer, the shuttles respond to other road users as close-proximity obstacles. The distance required by the bus seemed unclear to other road users and some described that they keep what they regard as a "good distance" to the shuttle, however they still experience that they make the shuttle brake. This tendency to keep extra distance was also described by cyclists in trial 2:

(Cyclist - trial 2): "I just drive in a big arc around it. It's easier as a cyclist because you ride much faster than it does."

(Cyclist - trial 2): "It can be a little difficult sometimes to overtake it – either around it, or if there is room, to dare to pass on the inside. You hold back more for it than for other vehicles."

A video analysis from trial 2 (Example 2) shows a situation where a cyclist overtakes a shuttle and cause an emergency stop.

Example 2: Cyclist overtaking and causing emergency braking

1. A cyclist (A) is riding away from the camera at a speed close to the 30 km/h limit. Another cyclist (B) is behind the shuttle, waiting for it to turn right at a speed of 0.7 km/h.

2. The shuttle drives forward and the cyclist (B) pulls out to the left before turning. The cyclist (7.8 km/h) is already moving faster than the shuttle (5.6 km/h).

3. The shuttle makes the turn at a stable speed. The cyclist reaches a speed of 22.1 km/h and passes the shuttle, maintaining a large distance from it.

4. The shuttle accelerates. It has reached a speed of 12.7 km/h when the cyclist pulls in front of it after overtaking. The cyclist's speed is now 28.2 km/h.

5. The overtaking is completed, from the cyclist's perspective. He slows to 14.6 km/h immediately after pulling in front of the shuttle. This activates emergency braking; within a few meters shuttle speed is reduced from 13 km/h to zero.

3.1.3 Shuttles passing pedestrians and physical obstacles

In all three test beds it was observed that shuttles due to their predetermined trajectory could not easily overtake pedestrians obstructing the shuttles' lane. Sometimes pedestrians were not aware that the shuttle was trapped behind them, e.g. when they walked in a group on the side of the lane. Some pedestrians found this awkward:

(Pedestrian - trial 2): "Strange that it does not overtake, but stays behind me."

Depending on how fast the pedestrians were moving and how flexibly the system allowed stewards to switch to manual mode the stewards either alerted the pedestrians and gesticulated to them to make room, stayed behind them at a low speed, or shifted to manual mode if the set speed in manual mode made it possible to overtake pedestrians. Stewards would assess this based on the situation as these examples show:

(Steward log - trial 3): "An old man with a [walking frame] was going very slowly. I passed him manually, so I didn't stress him."

(Steward - trial 2): "It rarely makes sense to shift to manual to overtake pedestrians because the switch takes time and [the shuttle] only goes 5 km/h in manual. They'll be long gone… I just wait for them to notice or I'll use the horn."

In trial 2 inaccurately parked and waiting cars frequently caused shuttles to stop prompting time-consuming shifts to manual mode and low-key conflicts with motorists. During 1.740 hours of operation stewards in trial 2 reported to have switched to manual mode due to an obstacle at least 1.718 times mainly due to irregularly parked cars and ad hoc road works. No parking signs and information boards had been erected in preparation of the trial. In trial 1 the shuttle moved at walking pace resulting in fewer situations where the shuttle had to overtake, but in these conditions more people were observed to apparently expect the shuttle to allow closer distance to pedestrians or did not notice that they were the reason the shuttle stopped:

(Fieldnote - trial 1): "Patient in a wheelchair waiting in line. The wheelchair is positioned so that the handles enter the shuttle's marked lane. Bus stops and steward rings the bell. Not clear if the person realizes that there is not enough space for the shuttle to pass. I bystander steps in and the situation is resolved."

In sum, road users inexperienced with automated shuttles struggled to get an accurate sense of the required distance and the logic that determines it. Generally, the shuttles were perceived to be "very sensitive" or "overly sensitive" by other road users. As a result, road users regularly ended up obstructing the shuttles' path or causing them to stop abruptly by mistake or inattention.

3.2 Interpretation of intent in ambiguous situations

Some informants describe the shuttles as exceptions to normal traffic or as something they have to deal with in an especially attentive manner:

> (Cyclist - trial 3) "[…] but our children may get a bit confused, because when we've been out practicing their biking [skills], it's like, "oh, the bus is coming", and so the rules change a bit, so we need to either pass it or stay behind it."

Descriptions of perceived ambiguity form a recurring theme in the data. The shuttles are described by some informants as difficult or unfamiliar to decode and stewards' logs, interviews and observations confirm situations where road users are more hesitant and seem less able to predict the shuttle's decisions and behavior than that of conventional vehicles. Stewards in trial 3 noted in their logs during the test-period that they have been asked by other road users how they are expected to overtake the shuttles, and that road users had expressed confusion in terms of how to act in different situations.

> (Steward log - trial 3): Bicycles and scooters have a hard time figuring out if they should stop or drive past us when we exit the tunnel while going north. So a lot simply drive up on the path for pedestrians

> (Steward log - trial 3): It's hard to figure out. Because when you overtake the bus you pass it on the left, and that in normal traffic isn't legal, so it causes some confusion on how to behave.

The traffic code actually does allow cyclists to overtake on the right in situations where there is not enough room to pass on the left. Cyclists in trial 2 and 3 overtook the shuttles both on the left and right side.

3.2.1 Effect of unusual traffic management designs

In Trial 3 the route runs from north to south however bus stops are only placed on the west side of the path, meaning that when the shuttles drive north in right-hand traffic, they have to cross the path when docking and leaving stops, as illustrated in figure 1. This has led to uncertainty, potential risk and patterns of traffic behavior from other road-users that slowed down the flow of traffic. On multiple occasions cyclists were observed to overtake between the shuttle and the stop (ramp), meaning that they enter the front-sensors within 3 meters and the bus brakes, as illustrated in Example 3. These situations are also recorded frequently in field notes, and described by other road users and stewards, for example:

> (Cyclist - trial 3): "Let's say that the bus is coming (heading north) and pulls in to the left side heading for the bus stop, and I approach on my bike. I can't of course just continue into the bus, and I can't quite go around it because there isn't enough room because it takes up a lot of space."

> (Steward log - trial 3): Once again nearly collided [with] a moped, [because] it was going between the shuttle and the ramp

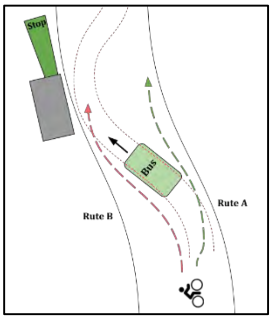
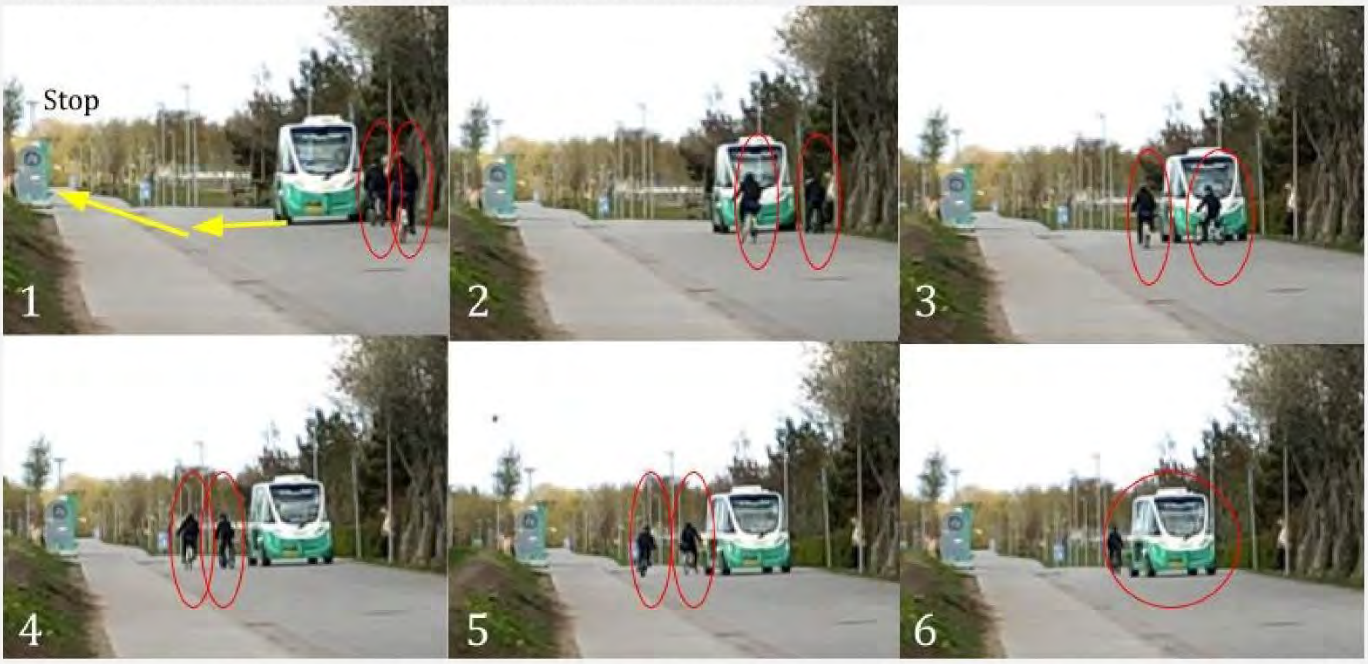


Fig. 1 Stops situated on one side of path only; cyclists overtaking on both sides of bus

Example 3: Cyclists overtaking between the shuttle and the stop



The automated shuttle is driving away from the camera and turning left (yellow arrows) towards the bus stop located on the left side of the path [1]. Two cyclists are riding behind the shuttle in the same direction [2] The cyclists overtake the shuttle on the left [3]. They are now registered by the bus sensors [5] and the bus brakes [6].

Some road-users express uncertainty as to whether they are expected to wait for the bus to make the turn and pass it on the right, or if they allowed drive between the shuttle and the ramp. In trial 2 and 3 cyclists were observed to overtake the bus on the left in situations where the steward expected them to have seen that the shuttle was about to turn. In trial 2 some informants found it difficult to ascertain when the shuttles were preparing for a turn. Some describe that they experience that the shuttles signal late:

> (Motorist - trial 2): “I cannot understand why it does not start signaling until it reaches the turn. It only starts signaling when it is ready to turn. It’s annoying that you cannot see which way it will go.”

In trial 2 interactions assessed by stewards as problematic, seemed to be amplified when the normal operation of traffic was interrupted. During an unplanned road work on the shuttles’ route a temporary roadblock was set up for cars while bicycles and pedestrians could pass via a narrow path on one side. The signage was provisional and ambiguous. At this location, the stewards reported many problematic interactions in the days after the roadblock was put up. Other densifications of events were recorded around lunchtime at a location where students often stood in line on the road outside a food truck and at a busy bus stop, which due to road work had been moved close to the shuttles' turning area with no clear separation of road and sidewalk.

The difficulty of interpretating the shuttles’ intent combined with atypical situations, where formal traffic rules do not fully describe how the individual road users should act, seemed to create particularly challenging situations. This was supported by some comments where informants described that uncertainty was linked to the complexity traffic situations, e.g., one pedestrian in trial 2 who describe how multiple usages of an area effect the interaction:

> (Pedestrian - trial 2): “Many of the uncertain experiences have taken place at the turning point on Diplomvej by Scion, as the place is also used as an entrance to the building”

Informants described that in these situations the steward may gesture intent in order to manage standoffs and uncertainty. Some informants explicitly commented on the general absence of a human being expressing intent:

> (Pedestrian - trial 2): “What is a bit different [is that] there is no driver you can look at and read the body language. This makes it a bit unclear sometimes... “

The stewards in all three trials report that road users’ lack of knowledge as to what the shuttle will do, and/or how to act in its vicinity creates ambiguous situations. For example, a steward in trial 3 note in their log that because of uncertainty other road users will at times stop near the shuttle, which also causes the shuttle to stop, and the steward reports: ‘So we are holding back for each other’.

3.3 Repeated interactions and road users’ learning over time

In all three trials both informants and observations confirm that a learning process took place where road users learned to anticipate how the shuttles move and react. Informants in trial 3 explain that despite some initial confusion, they had learned how to correspond and “got used to” the bus.

> (Cyclist - trial 3): ”now I’m thinking that now, we just coexist somehow. We’ve gotten used to [the bus] being here.”

> (Steward -trial 3): ”I also think by now people have gotten used to [the bus] being here as part of the traffic.”

> (Cyclist - trial 3): ”[…] and then there are some [cyclists] who get really angry and swear at the bus, but I think that might be people who don’t ride here very often. But you soon get used to what it does”

The stewards in trial 2 distinguished between motorists who "come here more often" and motorists whom they perceived as outsiders. Regular visitors were perceived to be more patient and offer more space for the shuttles. One steward described how contractors who often visited the campus drove less aggressively over time, so that the shuttle’s safety system would not cause it to stop: “They know that once they stop us, it will take time before we are running again.”

3.2.1 Effect of DS’s defensive safety protocol

It has been hypothesized (Millard-Ball, 2018) that the defensive safety protocol of autonomous vehicles would be taken advantage of by other road users who learn that autonomous vehicles will always give way when obstructed. In all three trials stewards report situations that can be interpreted as examples of this asymmetry in available strategies – especially in situations where road users appear impatient or frustrated with the shuttles inability to predict traffic situations and give space or in situation where road users – predominantly young people - find it amusing to challenge the shuttles’ operation. Pedestrians were observed crossing immediately in front of the shuttle, or walking slowly in front of it despite the shuttle signaling for them to move, as exemplified below.

> (Fieldnote – trial 3) “Young guy crosses right in front of the bus on foot, causing it to brake. On the other side he stops and nonchalantly ties his shoelace.”

> (Steward log – trial 3) “Had a near miss at [the] sandwich [bar]. A guy on a bike (not a kid) drove directly in front of the bus. It stopped hard and was about 20 cm from the guy. He smiled; I think it was on purpose.”

> (Steward log – trial 3): “Had a bicycle cross right in front of the shuttle when it was docking, and he was well aware of what he was doing. I stopped the shuttle manually.”

The stewards experienced road users deliberately stepping out in front of the shuttles, and they interpreted this to signal a high degree of trust in the technology, as a display of road users growing understanding of the shuttles defensive programming, and in some cases as deliberate provocation. In trail 1 hospital stewards reported that hospital staff moved in the lobby “as if the shuttles were not there”:

> (Steward - trial 1): “It is especially the staff who almost rely too much on the technology ... e.g., nurses who seem a little overconfident and pass quite close by. They seem to forget that people fall on their asses in here when the bus suddenly stops.”

The same observation regarding the behavior of some of the road users most experienced with the shuttles was made in the other tests:

> (Steward - trial 3): ”Some of those who are really familiar with the area, they just walk out in front of it. […] But you do feel that they are aware that it’ll stop.”

> (Steward - trial 3): “I think it’s just because they are aware that they don’t need to wait for it. But that’s actually pretty understandable, because people get used to how it reacts. When they realize it’ll give way, then people are aware they have the right of way […] But if it [should happen] that it doesn’t work properly, we would run them down, so it’s a bit … People wouldn’t just jump in front of a city bus, and that also ought to stop, you know.”

What stewards experience as road-users’ trust in the technology is expressed differently by some children who described that they could tease the stewards by stepping out in front of the shuttles, because they “know it will stop”. The unvaried track line and limited behavioral repertoire also meant that returning road users learned to predict how to avoid disturbing the shuttles. In places where there was sufficient space, the majority of other road users tended to find ways to keep their distance and braid in and out of the shuttles’ track-line. This type of interaction was less successful on route sections where the shuttles made turns, where many types of road actors intersected or where the allocation of space was contested due to multiple usages or poor road design. Part of the redeveloped path in trial 3 was designed with shared space characteristics. This section had a wide paved surface in an environment with multidirectional non-car traffic. Observations indicate fewer problems with overtaking bikes in this context than on the nearby more linear section where the path width was divided into a sidewalk and a narrower separate lane for bicycles and shuttles. In trial 2 road users who had joined a user panel were given the opportunity to indicate to which extend they found that automated shuttles challenged their patience. Results indicated that the informants felt comparably more inconvenienced by the shuttles when driving a car than when walking or riding a bike. This was supported by observations of cars affected by trial 2 having fewer opportunities than cyclists and pedestrians to pass the shuttles fluently due to their width.

4. Concluding discussion

Difficulty adjusting distance and timing was pervasive when the DS was introduced in the three test beds and has also been noted in other trials (Boersma et al., 2018; Brown and Laurier, 2017; Madigan et al., 2019; Rehrl and Zankl, 2018). This can be interpreted as an expression of technological immaturity, but may alternatively prove to be an indication that DS and possibly AVs more generally will have a different behavior than vehicles driven by humans and exhibit other basic characteristics in interactions from the point of view of road users. The collective narrative of vehicle automation has created the expectation that AVs will be better at navigating in traffic than vehicles driven by humans (Janatabadi and Ermagun, 2022; Kacperski et al., 2021). The underlying assumption for this rests on a prevalent preconception of traffic as a system of formal rules that people sometimes break either intentionally or as an expression of their limitations in attention and computing power (Noy, 2018; Hilgarter and Granig, 2020). The analysis of field observations and interviews in the three Danish trials shows a picture of traffic, which does not confirm this description. In the light of the disturbances that DSs introduce to the existing socio-spatial system in the three test beds, a picture of traffic emerges, consisting of dynamic interactions in a negotiated arena where formal traffic rules form the skeleton for a continuous adaptation of behavior and speed based on different forms of mutual reading and signage between road users. Such an understanding of traffic can also be found described outside the self-driving literature (Haddington and Rauniomaa, 2014; Endsly, 2019), labelled by Jensen (2010) as “negotiation in motion”.

The DS's behavior is objectively predictable, but findings from the three trials indicate that DSs are at the outset perceived as unpredictable. This is particularly observed in situations where DSs are involved in interactions where the ordinary behavior presupposes a foreseeing of other actors’ behavior - ie. interactions where the relevant behavior is informed by a partial or presumed knowledge of the other road users' options for action and expected preferences. Precisely DS's inability to participate in this dynamic - and objectively less predictable - social interaction seems to make it more difficult for the other road users to interact with the DS as this interactive reading, prediction and signaling characterizes the behavior that the informants exhibit and expect. We find that the observations highlight the analytical benefits of a conceptual distinction between an advanced sensing and handling of *spatial context*, which the vehicles largely master (within the set operating conditions), and an advanced sensing and handling of *social context*, which the vehicles in the experiments do not master. The results of this study suggest that seamless same-as-any-other-car interaction in complex negotiated traffic contexts presupposes not only a knowledge of how movement in traffic unfolds statistically, but also the ability to engage in a real-time negotiation of how, when and by whom the road space is occupied in different situations and cultural contexts.

Experience from the three trials in low-speed areas with many pedestrians shows that the other road users in these design domains get used to the DS and get to know their driving patterns, but that they do not consider them same-as-any-other-car. They develop strategies for dealing with DS, which are very much about leaving them alone, so that they follow their preprogrammed protocol as much as possible. This presupposes sufficient space in the road layout for other road users to walk, ride or drive around them at a certain distance (A strategy that was also recorded by Madigan et al., 2019), but DS did not deter road users in situations with less space available. The DS are vulnerable to other road users' breach of the duty to give way, due to their defensive safety protocol, but generally such behavior was the exception in the trials. In the vast majority of interactions, road users avoided stopping the DS - provided that they experienced that there was sufficient space for both the DS and other traffic to operate.

In line with the literature referenced in the introduction of the paper we find that self-driving vehicles is best understood as a technology with characteristics and attachments that make demands on the surrounding world. The trials show how these dependencies integrate with existing socio-spatial patterns and establish pressures or demands that can either be absorbed or challenged by the surrounding social and material context. A better understanding of AV-road-user interactions can inform choices of locations and applications where AVs are likely (or unlikely) to support planning goals. According to Tennent and Stilgoe (2020), there is a reluctance among developers of AVs to develop technologies that presuppose societal change and changes to infrastructure based on an assumption of the existing socio-technical system's insurmountable inertia. At the same time a number of urban design concepts that reshape transport infrastructure to accommodate liveability and sustainability have been proposed (Hamilton-Baillie, 2008; Eggimann, 2022) in an urban planning reorientation which opens up opportunities to redefine space allocation in cities and reconsider the framework conditions for AVs and other vehicles (Vitale Brovarone, 2021; González-González et al., 2019)). One possible line of analysis could be whether the undeviating and defensive safety protocol of DSs can fulfill specific needs and objectives in walkable low-car environments and sustainable mobility and urban planning contexts.

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