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"Game over" for autonomous shuttles in mixed traffic? Results from field surveys among pedestrians and cyclists on how they interact with autonomous shuttles in real-life traffic in Norway

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Introduction

Automated vehicles (AVs) are entering our roads, and autonomous shuttles (self-driving mini buses), hereafter called AV shuttles, are under development and being tried and deployed in several cities in Europe, Australia, Asia and the USA (Haque & Brakewood, 2020; Heikoop, Nuñez Velasco, Boersma, Bjørnskau, & Hagenzieker, 2020). AVs are expected to improve traffic flow and reduce road accidents. AV shuttles can also lead to lower operating costs for public transport and hailing services.

However, before our roads are solely used by fully AVs, there will be a long transition period where fully AVs, partially AVs and manually driven vehicles, bicyclists and pedestrians must share the roads. For the introduction of AVs into this traffic mix to be successful, the interaction with other road users is critical.

The decision-making and behaviour of humans in interaction with AVs is receiving growing attention in the research community (Domeyer, Lee, & Toyoda, 2020; Ezzati Amini, Katrakazas, Riener, & Antoniou, 2021; Hagenzieker et al., 2020; Heikoop et al., 2020; Lee et al., 2021; Liu, Du, Wang, & Da Young, 2020; Liu, Zhai, & Li, 2022; Parkin et al., 2022; Pokorny et al., 2021b; Rahman, Dey, Das, & Sherfinski, 2021; Şahin, Hemesath, & Boll, 2022; Vlakveld, van der Kint, & Hagenzieker, 2020), and research in this area has for long been called for by experts in the field (Kyriakidis et al., 2019; Rasouli and Tsotsos, 2018; Vissers et al., 2016).

The present paper reports results from field surveys about real-life interactions with AV shuttles among pedestrians and bicyclists in two Norwegian pilots, in Oslo and Kongsberg, where AV shuttles have been introduced in mixed traffic. This is one of several publications from the Norwegian research project "Autobus". Results from video analyses of interactions based on data from the same pilot in Oslo have been presented by De Ceunynck et al. (2022).

Theoretical background

The studies on human response and interaction with self-driving vehicles that exist, have until recently predominantly focused on trust and acceptance of such transport modes (Papadima, Genitsaris, Karagiotas, Naniopoulos, & Nalmpantis, 2020; Roche-Cerasi, 2019), often applying theories and models of trust in technology, such as the Unified

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theory of acceptance and use of technology (UTAUT) or the Technology Acceptance Model (TAM) (Madigan, Louw, Wilbrink, Schieben, & Merat, 2017; Merat et al., 2017; Nordhoff et al., 2017; Vissers et al., 2016).

In addition to technology and the technical performance of AVs, understanding of human factors and trust in technology have been shown to be of prime importance to introduce self-driving technology in society (Kyriakidis et al., 2019).

Recently more and more research is concerned with the interaction of AVs with other road users in real-life traffic (Domeyer et al., 2020; Heikoop et al., 2020; Markkula et al., 2020; Rahman et al., 2021; Rasouli & Tsotsos, 2019; Thompson, Read, Wijnands, & Salmon, 2020).

Perspectives on interaction

Markkula and colleagues (2020) have identified several different approaches to how road user interaction traditionally has been studied, and which are relevant for the study of interactions between AVs and ordinary road users: (i) the traffic conflict approach, (ii) communication and linguistic perspectives, (iii) sociological perspectives and (iv) game-theoretic perspectives.

The traffic conflict approach is an engineering approach to interaction aiming to identify and measure critical time gaps between road users on conflicting paths (Hydén, 1987; Johnsson, Laureshyn, & De Ceunynck, 2018; Laureshyn, De Goede, Saunier, & Fyhri, 2017). By use of video analyses, this approach has gained much attention during recent years, and the big advantage compared to ordinary accident analysis is that conflicts can be seen as a valid surrogate safety measure occurring much more frequently than accidents. The traffic conflict approach is relevant also when studying interactions between AV shuttles and other road users, and can be used to measure how risky interactions are. However, when applied, results often show that the AV shuttles normally stop long before any critical time-to-collision parameter is reached (Johnsson et al., 2022; Pokorny et al., 2021a).

The communication and linguistic perspective has received very much attention in both theoretical and practical studies on interactions between AVs and ordinary road users. The point of departure is the fact that in normal traffic we communicate and apply many informal communication cues, and those cues will normally not be perceived and acted upon by AVs. In addition, AVs do not reveal their own "intentions" in the way that normal road users do. Misinterpretation of the other parts' intention may lead to risky situations and collisions. Much research has been conducted in this area, and results indicate that advanced communication interfaces, that by sound or signs indicate what to expect, can be helpful for normal road users when interacting with autonomous vehicles (Hagenzieker et al., 2020; Lee et al., 2021; Madigan et al., 2019; Merat et al., 2018; Rasouli and Tsotsos, 2019; Rouchitsas and Alm, 2019; Vlakveld et al., 2020; Kyriakidis et al., 2019; Rasouli and Tsotsos, 2018).

The sociological approach to road user interaction is very much associated with the work of Erving Goffman, in particular his seminal book "Relations in public" (Goffman, 1971). Goffman introduced in many ways the strategic element of interaction in traffic and made a point of how different actors could achieve a strategic advantage by for instance not letting another road user catch one's eye to avoid a request to pull out into traffic etc. Thus, signals and signs may be used strategically, an important feature not so much highlighted in the communication and linguistic approach presented above. By emphasizing this strategic feature of communication, Goffman and this sociological and socio-psychological approach very much anticipates the core strategic element of interaction highlighted in game theory.

The game theoretic approaches have gained more popularity in road transport research during recent years, in particular in relation to interactions with AVs (Camara et al., 2018; Fox et al., 2018; Heikoop et al., 2020; Kalatian & Farooq, 2021; Michieli & Badia, 2018; Millard-Ball, 2018; Rahmati, Hosseini, & Talebpour, 2021; Thompson et al., 2020). In this paper our theoretical point of departure is mainly the recent contributions from game theoretic perspectives and models, and thus this approach will be outlined in somewhat more detail in the following.

Game theory

Game-theoretic perspectives were for many years not often used in road traffic research. Nevertheless, road traffic has frequently been used as examples of game-like situations in text-books on game theory etc. (Hamburger, 1979; Schelling, 1960; Sugden, 2005). However, there are eventually quite a number of game-theoretic studies of road user interaction, summed up by Elvik (2014). There are close links between the game theoretic approach and the sociological and social-psychological perspectives on interaction highlighted by Goffman (Goffman, 1971). There are also important links to the above mentioned perspectives on communication and linguistics; an essential element in games and strategic interaction is to communicate a binding commitment to act in a certain way (Frank, 1988; Schelling, 1960).

Evolutionary game theory may be able to explain why certain patterns of interaction develop, are sustained or disappear (Axelrod, 1984; Bicchieri, 2005). This has also been demonstrated in traffic situations, e.g. when road users meet at crossroads and must decide who will yield (Bjørnskau, 1994; Bjørnskau, 2017; Sugden, 2005), when cars meet in the dark and drivers must decide when to dip their headlights (Bjørnskau, 2018), or when two cars approach a traffic light turning yellow and the second driver must decide whether to drive or stop based on the expectations of what the first driver will do. This latter situation has shown to be a key risk factor for self-driving cars: they stop unexpectedly and are hit from behind (Stewart, 2018).

Game theory has been used to predict that over time AVs will meet severe challenges in mixed traffic since other road users will know that they are "committed to" stop and give way in conflict situations, and hence take advantage of that (Millard-Ball, 2018). The final outcome may be that AV shuttles will be severely obstructed in traffic and eventually not able to operate (Camara et al., 2018; Cavoli et al., 2017; Gupta, Vasardani, Lohani, & Winter, 2019; Markkula et al., 2020; Millard-Ball, 2018). The problem has also been addressed in more general terms – that AVs will be "bullied" by other road users (Connor, 2016; Liu et al., 2020; Madigan et al., 2019; Rasouli & Tsotsos, 2019).

The mechanism behind the predicted outcome is that in interactions in road traffic, where road users are on crossing paths, it is assumed that road users in general prefer the opponent to yield and not to yield oneself. However, both actors also have a common interest to avoid a collision. Thus road traffic interactions are mixed-motive games where the actors both have common interests (no collision) and conflicting interests (best not to yield).

There are several well-known mixed-motive games – the most famous being the Prisoner's dilemma, which is normally not so relevant for modelling small-scale road user interactions, but very relevant for modelling traffic congestion (Downs, 1962; Sissons Joshi, Joshi, & Lamb, 2005) and other collective goods problems involving many actors (Elster, 1989). There are however exceptions. Bjørnskau (2018) modelled the decision of when to dip the head lights when meeting an oncoming car in the dark, as a two-person iterated Prisoner's dilemma game.

However, the game that seems best suited to model most small-scale road user interaction problems, is Leader (Bjørnskau, 2017; Hamburger, 1979; Rapoport, 1967; Schotter, 1981; Sugden, 2005), also named as "Crossroads" (Sugden, 2005). This has been used to model how asymmetries between road legs e.g. traffic volumes or between road users can produce yielding behaviour that conflicts with the formal traffic rules (Bjørnskau, 1994; Bjørnskau, 2017; Sugden, 2005).

The more famous game of Chicken is perhaps the game most often associated with car driver behaviour, notably from the classic movie "Rebel without a Cause" starring James Dean. Chicken is quite similar to Leader. Both Millard-Ball (2018) and Camera et al. (2018) have modelled the interaction between pedestrians and AVs as a Chicken game.

Fig. 1 presents Leader and Chicken in so-called normal form, i.e. as a two-person game with simultaneous moves.

When meeting at an intersection, both actors (drivers) have two choices; either to drive or to yield. Each of the four cells in the matrix represents an outcome of the game, giving one payoff to driver A and one payoff to driver B. The number on the left-hand side of each cell represents the payoff to A, the number on right-hand side represents the payoff to B.

For each actor, there are 4 possible payoffs, and the ranking of the payoffs are simply: 4>3>2>1. In both Leader and Chicken, the best outcome is to drive when the other yields and the worst is that both drive. In Leader, the second best outcome is to yield and the other drives (3), whereas this is considered the next to worst outcome in Chicken (2). In Chicken the players are more competitive than in in Leader and rank the stalemate (both yields) as a better outcome than to yield and the other drives. In real traffic, most road users probably have Leader preferences; if both yield, the situation is not solved and must be renegotiated, which takes time.

Regardless of whether one models the game between road users as Leader or Chicken, players have an incentive not to yield, and if they are certain the opponent will yield, they will take advantage of that and go first. Credible information about the other road user's intention is thus crucial, and an important aspect of Leader (and Chicken) games (Guyer & Rapoport, 1969; Schelling, 1960; Sugden, 2005). In interactions with AVs in real traffic, everybody eventually knows the AVs are programmed to stop in case of a conflict, and they will take advantage and drive/go before the AV (Millard-Ball, 2018). Based on game-theoretic logic the result will be that AVs are severely delayed by other road users in real-life traffic. According to Millard-Ball (2018) the final outcome might be that AVs cannot operate in real-life traffic with ordinary road users.

Research questions and hypotheses

The current paper has a particular focus on how road users perceive AVs and how they interact with them. In particular, we want to study whether the predictions based on game theoretic reasoning are supported by the responses from ordinary road users interacting with AV shuttles.

Based on the proposed game theoretic mechanism we hypothesize that ordinary road users' interaction with the AV shuttles will change over time according to three phases:

Phase 1) Initially we expect other road users to be skeptical about how safe AV shuttles are and not to trust that they always will act defensively and stop in case of a conflict. Hence in an early phase we expect road users to be careful and defensive in their interactions with the AV shuttles and generally to yield when interacting with them (Kyriakidis et al., 2019).

Phase 2) According to the game theoretic reasoning, we expect that in a second phase, after perhaps 2–3 months, other road users will discover the very defensive driving style of the AV shuttles and take advantage of this by increasingly go/ride before the AV shuttle at intersections, even when the AV shuttle has the right of way (Bjørnskau, 2017; Michieli & Badia, 2018; Millard-Ball, 2018).[1]

Phase 3) In real life other road users might be more considerate towards the AV shuttles than assumed by the Leader/Chicken games, and there might be another mechanism counter-acting the proposed development of more aggressive behaviour towards AV shuttles in phase 2. The poor negotiating power of the AV shuttle makes it a "weak" road user. Perhaps also the passengers of AV shuttles may be considered to be "weak" (elderly, people with special needs). The weakness of the AV shuttle may elicit traditional norms not to "bully" the weak i.e. not to bully the AV shuttles.

Thus one could perhaps expect more considerate and cooperative behaviour towards the AVs to manifest itself in a third phase when ordinary road users have even more experience with AVs. For the development of social norms and fairness, see for instance Bicchieri & Mercier (2014) and Binmore (2014). Of course, such a third phase will not be manifested if AVs are bullied out of traffic by the mechanism suggested in phase 2.

		B: Drive	B: Yield
A	Drive	1,1	4,3
	Yield	3,4	2,2

		B: Drive	B: Yield
A	Drive	1,1	4,2
	Yield	2,4	3,3

Fig. 1. Leader (top) and Chicken (bottom) presented in normal form with two actors. Each cell includes the payoffs to A (left) and B (right) of the action combinations (drive/yield). Payoffs are valued as follows: $4 > 3 > 2 > 1$.

Materials and methods

Two pilots with AV shuttles were used to empirically test the hypotheses. The pilots took place in Norway, one in the small city of Kongsberg (ca. 22 000 inhabitants) and the second in Oslo (ca. 700 000 inhabitants). At both places data were collected by use of field surveys among ordinary road users, at four different points in time, where the first survey was conducted before the AV shuttle was in operation, both in Kongsberg and Oslo. Three subsequent field surveys were conducted after the AV shuttle was in operation, at both sites (more details presented below).

By repeating the field interviews, we should be able to see if there are changes over time in peoples' opinions and behaviour towards the AV shuttles. Data was collected by interviews with pedestrians and cyclists by use of tablets in the streets along the route of the AV shuttles in Kongsberg and in Oslo. Field interviews did not include car drivers for two reasons:

1) It is difficult in practice to interview car drivers in the streets. To do so, one must either choose those who park their cars, or ask those walking about how they interact when driving (if they do). In either case it is difficult to gain many responses. 2) The route in Oslo was on a stretch of road with extremely few ordinary cars. In Kongsberg, part of the route was through a pedestrian street, and we chose to do interviews there.

For studying the interaction with cars, we used video cameras and the results from these analyses will be published in a separate paper (Johnsson et al., 2022).

Data were analyzed by use of table analysis with standard tests for statistical significance. SPSS version 27 has been used to analyze the

[1] The AV shuttles in these pilots must follow the same traffic rules as normal vehicles; they have the right of way when approaching from the right in intersections without priority signs or traffic signals. Likewise, they have the right of way if pedestrians want to cross outside zebra crossings. If pedestrians cross at zebra crossings, all vehicles must yield.

data. The pilots are described below, followed by a presentation of the questionnaire used.

Pilot 1 – Kongsberg

In Kongsberg, two EasyMile EZ10 AV shuttles started operating on October 15th 2018, on a 900 m route in the city center. The AV shuttle operated on weekdays from 10 AM to 2 PM. The route was extended two times (December 2018, and April 2019) and the final route was a 4.4 km stretch of road from the center to the Kongsberg Technology park.

The shuttle is a SAE level 3 vehicle, initially running with a maximum speed of 16 km/h, but maximum speed increased to 20 km/h from September 2020 when a new generation of Easy Mile EZ10 were deployed. Parts of the route is through a pedestrian street with max. speed at 5 km/h. The shuttle can have up to 12 passengers (6 seated, 6 standing) including the safety steward, but only 6 seated passengers + safety steward was allowed during the Kongsberg pilot.

The AV shuttle was in operation until the end of December, 2021, being the AV shuttle operating for the longest period in Norway. However, it did not operate during the lock-down due to the Corona pandemic (March-May 2020)). Fig. 2 presents pictures of the AV shuttle in Kongsberg in different traffic environments.

Field surveys of people in the streets of Kongsberg were conducted in September 2018 (before the bus started operating) and then in April, June and September 2019. During the winter 2018/19 there were problems with snowfall etc. and frequent stops in the operation of the AV shuttle, so field interviews were not conducted in this period.

Fig. 3 and Table 1 presents the number of respondents in Kongsberg at the different periods distributed by road user group, gender and age. Fig. 4.

Pilot 2 – Oslo

In Oslo, two Navya Arma AV shuttles operated on a 1.2 km stretch of road along the waterfront in the city center from the town hall (Kontraskjaret) to Vippetangen from May 20th to November 1st 2019. The shuttle is a SAE level 3 vehicle, running with a maximum speed of 18 km/h. Near the town hall, which is a shared space area, maximum speed was 5–7 km/h. The shuttle can have up to 15 passengers (11 seated, 4 standing) including the safety steward, but only seated passengers were allowed in the Oslo pilot.

The shuttles ran from 8:00 AM to 8:00 PM every day of the week. Due to numerous events and construction work along the route, the route was sometimes shortened, and during some periods not operating after 6:00 PM. There were also periods when the AV shuttle did not operate at all.

The route consisted of different traffic environments. The beginning of the route, by the town hall, is a pedestrian zone allowing for cycling but not for normal motor vehicle transport. Further on, the AV shuttle travels through a typical shared space area where all types of vehicles are allowed, but traffic is dominated by cyclists and pedestrians. Further south on the route the AV shuttle drives in an ordinary two-way street with cycle lanes and pavements/foot paths. Motor traffic is low, but there are a number of tourist buses here as the route passes the cruise terminal in Oslo. There are also many cyclists here, being one of the busiest cycle commuting routes to the city center.

Field surveys of people in the streets of Oslo were conducted in April 2019 (before the bus started operating) and then again in late May, June and September 2019. Road users were interviewed close to the town hall, i.e. in the pedestrian zone.

Fig. 5 and Table 2 presents the number of respondents in Oslo at the different periods distributed by road user group, gender and age.

It is evident that the Oslo sample is dominated by cyclists, whereas the Kongsberg sample is dominated by pedestrians. There are too few pedestrians in Oslo to provide meaningful statistical analyses of any development over time. Thus we look at the developments over time in pedestrians' and cyclists' interactions with the AV shuttle in Kongsberg, and cyclists' interactions with the AV shuttle in Oslo.

Questionnaire

Although we were mostly interested in how road users viewed the behaviour of the AV shuttle and how they interacted with it, respondents were also presented some general questions about AV shuttles, also used in previous projects, such as the CityMobil2 project (Nordhoff et al., 2018).

We also used "quality ratings" from a questionnaire developed by Van der Laan et al. (1997). This a simple five-points rating scale where respondents are asked to tick their opinion about different characteristics of the AV shuttle e.g. from 1 "useless to 5 "useful".

Given our theoretical focus on game theoretic mechanisms and interactions with the AV shuttles, the results of the general questions will not be presented in the following. The questionnaire included several questions about interactions with the AV shuttle, and the results of these questions will be presented here. These questions are numbered from Q19 to Q34 and presented in the following.

Only pedestrians and cyclists having experienced meeting the AV shuttle more than once a month, were given these questions.

Pedestrians were given the following questions where they should answer on a scale from 1 "Disagree completely" to 7 "Agree completely". They could also answer "Don't know/not relevant".

19. When I am about to cross the street at a pedestrian crossing, the AV shuttle stops too closely so it feels unsafe.

20. I am not sure if the AV shuttle will stop for me.

21. Usually I wait to cross the street until the AV shuttle has passed.

22. I know that the AV shuttle will stop, so I often cross the street before the AV shuttle even if it is not at a zebra crossing.

23. I have become more positive towards the AV shuttle after gaining experience with it.

24. I think one should give the AV shuttle the right of way and not force it to stop.

Question 19 was only given to pedestrians in Kongsberg. In Oslo, the interaction between pedestrians and the AV shuttle mostly took place in a shared space area, i.e. without zebra crossings.

The wording of Q22 was slightly different to cyclists:

22. I Know that the AV shuttle will stop, so I often cross the street before the AV shuttle.

For both pedestrians and cyclists, questions 23 and 24 were only asked in the fourth period in Kongsberg (September 2019), and in the third and fourth period in Oslo (June and September 2019).

Both pedestrians and cyclists were also asked if they yielded more often to the AV shuttle than they did to other vehicles:

25. As a pedestrian/cyclist do you yield more often or more seldom to the AV shuttle than you do to other vehicles?

Respondents were also asked to indicate their behaviour towards the AV shuttle on a scale from 1 "Never" to 10 "Always". In Kongsberg, pedestrians were asked to indicate how often the yielded to the AV shuttle in the following situations by use of this scale:

Think about the times you have met the AV shuttle and wanted to cross its' way. Out of 10 times when you meet the AV shuttle how often do you stop or yield to the AV shuttle in the following situations:

26. In the pedestrian street [*In Kongsberg the AV shuttle also operates in a pedestrian street*].

27. When crossing at a zebra crossing.

28. When crossing when there is no zebra crossing.

Since interactions between pedestrians and the AV shuttle mainly took place in shared space areas in Oslo, pedestrians in Oslo were given a general question about yielding instead:

29 Out of 10 times when you meet the AV shuttle here at Akershusstranda, how often do you stop or yield to the AV shuttle?

Cyclists were also asked to indicate on a scale from 1 "Never" to 10 "Always" how often they yield to the AV shuttle when meeting it in

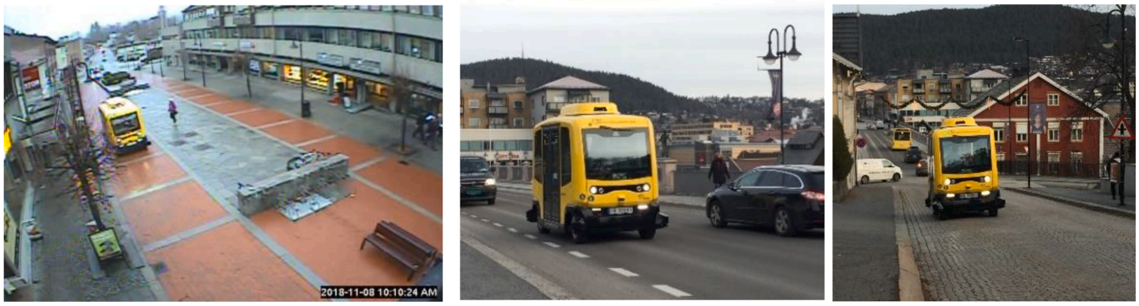

Fig. 2. The different road environments the AV shuttle operates in along the route in Kongsberg. Left: pedestrian street, middle: busy two-way street (bridge) with cycle lanes, right: narrow hilly street with cobblestones.

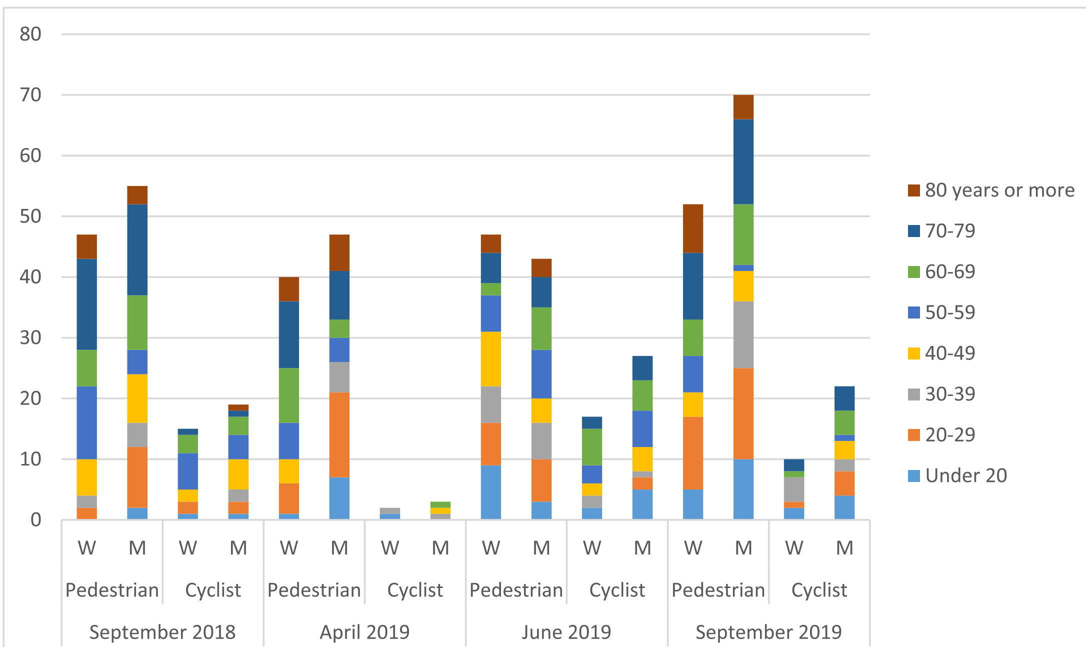

Fig. 3. Kongsberg sample distributed by period, gender (W = women, M = Men), road user group and age group. Actual figures, Total N = 516 (Pedestrians = 401, Cyclists = 115).

Table 1
Kongsberg sample distributed by period, gender (W = Women, M = Men), road user group and age group. Percentages by column. Total N = 516 (Pedestrians = 401, Cyclists = 115).

	September 2018				April 2019				June 2019				September 2019			
	Pedestrian		Cyclist		Pedestrian		Cyclist		Pedestrian		Cyclist		Pedestrian		Cyclist	
Age	W	M	W	M	W	M	W	M	W	M	W	M	W	M	W	M
≤ 20	0.0	3.6	6.7	5.3	2.5	14.9	50.0	0.0	19.1	7.0	11.8	18.5	9.6	14.3	20.0	18.2
20–29	4.3	18.2	13.3	10.5	12.5	29.8	0.0	0.0	14.9	16.3	0.0	7.4	23.1	21.4	10.0	18.2
30–39	4.3	7.3	0.0	10.5	0.0	10.6	50.0	33.3	12.8	14.0	11.8	3.7	0.0	15.7	40.0	9.1
40–49	12.8	14.5	13.3	26.3	10.0	0.0	0.0	33.3	19.1	9.3	11.8	14.8	7.7	7.1	0.0	13.6
50–59	25.5	7.3	40.0	21.1	15.0	8.5	0.0	0.0	12.8	18.6	17.6	22.2	11.5	1.4	0.0	4.5
60–69	12.8	16.4	20.0	15.8	22.5	6.4	0.0	33.3	4.3	16.3	35.3	18.5	11.5	14.3	10.0	18.2
70–79	31.9	27.3	6.7	5.3	27.5	17.0	0.0	0.0	10.6	11.6	11.8	14.8	21.2	20.0	20.0	18.2
≥ 80	8.5	5.5	0.0	5.3	10.0	12.8	0.0	0.0	6.4	7.0	0.0	0.0	15.4	5.7	0.0	0.0
N	47	55	15	19	40	47	2	3	47	43	17	27	52	70	10	22

traffic (in different situations), and how often they overtook the AV shuttle when riding behind it. In Kongsberg they were given the following questions:

30. When you want to cross and you should yield according to the rules.

31. When you want to cross and the AV shuttle should yield according to the rules.

32. When you want to cross and give-way rules are unclear.

Fig. 4. The different road environments the AV shuttle operates in along the route in Oslo. Left: pedestrian zone, middle: shared space, right: ordinary street with cycle lanes and pavements.

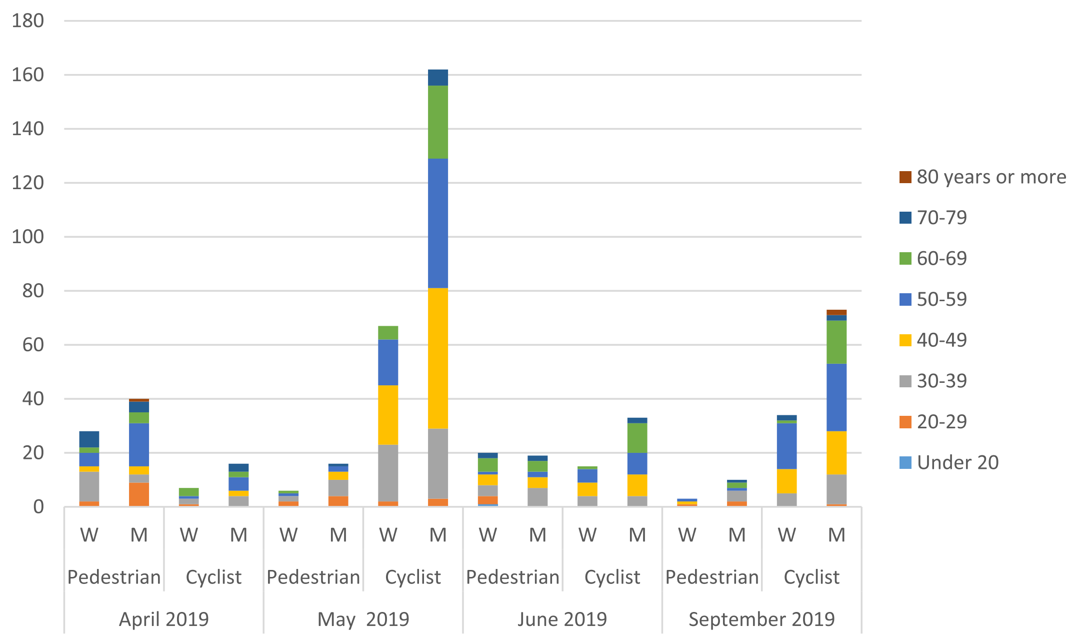

Fig. 5. Oslo sample distributed by period, gender (W = women, M = men), road user group and age group. Actual figures, Total N = 549 (Pedestrians = 142, Cyclists = 407).

33. When you want to cycle over a zebra crossing[2].

34. Out of 10 times how often do you overtake the AV shuttle when it is driving in front of you?

In Oslo, the AV shuttle route did not include many ordinary intersections were cyclists would cross the AV shuttle's path; most crossing situations appeared in the shared space area. Hence cyclists in Oslo were given fewer questions about crossing and the traffic rules. Oslo cyclists were given the same general question about yielding as pedestrians (Q29) and the same question about overtaking as cyclists in Kongsberg (Q34).

Results Kongsberg

Kongsberg pedestrians' perceptions of safety and interaction

Pedestrians in Kongsberg who had experienced meeting the AV shuttles more than once a month, were asked about safety and interactions with the AV shuttle, by use of questions Q19–Q24 listed above. Q23 and Q24 were only asked in September 2019.

Respondents were asked to respond on a scale from 1 "Disagree completely" to 7 "Agree completely". They could also answer "Don't know/not relevant", and this proportion was especially high on Q19. On all these questions there is a consistent tendency that more respondents say "Don't know/not relevant" in June 2019 than in the other periods.

The distribution of responses in each period are presented in Figs. 6 and 7.

In general pedestrians disagree to the statements Q19 "The AV shuttles stops too closely at zebra crossings" and Q20 "I am not sure if the AV shuttle will stop", and statement Q22 "I know the AV shuttle will stop so I cross before it". They tend to agree with statement Q21 "I wait for the AV shuttle before crossing". There are no statistically significant differences between periods on any of the questions Q19–Q22, when measured by a one-way between groups ANOVA, omitting "Don't know"-responses.

Fig. 7 presents the results on questions Q23 and Q24, only asked in September 2019 in Kongsberg.

On Q23 and Q24, pedestrians tend to agree that they have become more positive to the AV shuttle with experience, and that one should give way and not force the AV shuttle to stop. The general picture based on the questions Q19–Q24 is that the pedestrians in Kongsberg behave defensively and considerate towards the AV shuttle, and that these tendencies do not change between periods.

[2] To cycle over a zebra crossing is allowed in Norway, but in that case the cyclists should yield according to the rules. If the cyclist dismounts and walks, the car must yield. The normal practice in Norway is however that cyclists cycle over zebra crossing and get the right of way (Bjørnskau, 2017).

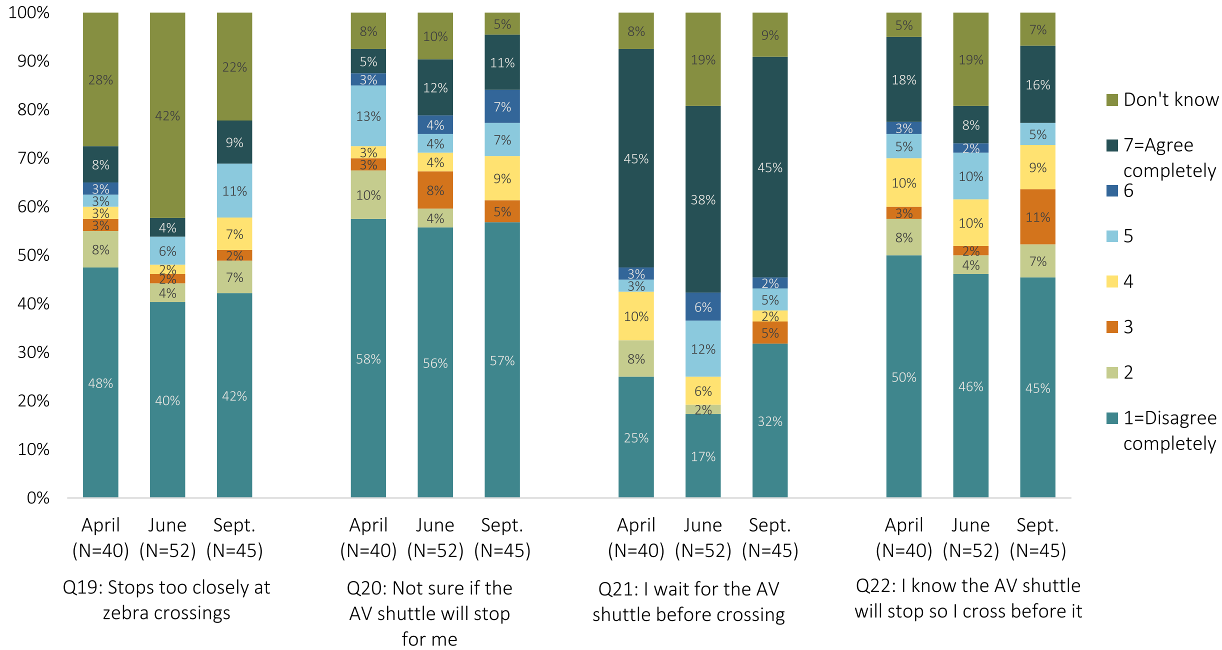

Fig. 6. Kongsberg pedestrians' agreement to statements about the AV shuttle (Q19–Q22) on a scale from 1 "Disagree completely" to 7 "Agree completely" in April (n = 40), June (n = 52) and September (n = 45) 2019. Percent, Total N = 137.

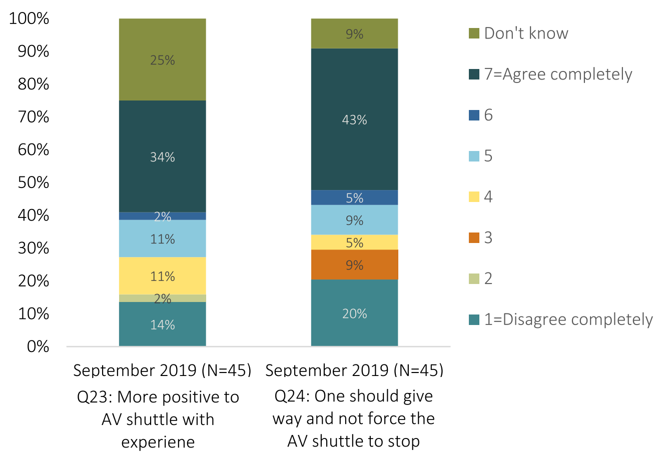

Fig. 7. Kongsberg pedestrians' agreement to statements about the AV shuttle (Q23–Q24) on a scale from 1 "Disagree completely" to 7 "Agree completely" in September 2019. Percent, N = 45.

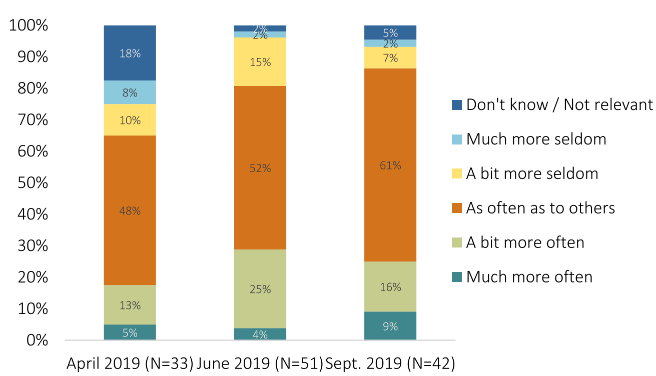

Fig. 8. Kongsberg pedestrians' responses to the question whether they yield more often to the AV shuttle than to other vehicles, in April, June and September 2019. Percent, total N = 126.

Kongsberg pedestrians yielding to the AV shuttle

Pedestrians who had met the AV shuttle at least once a month, were asked how often they yield to the AV shuttle compared to other vehicles (Q25). Answers were given on a scale from "Much more often" (1) to "Much more seldom" (5). They could also choose "Don't know/Not relevant" (6). Results are presented in Fig. 8.

Most respond that they yield to the AV shuttle to the same degree as to other vehicles, however there is a slight tendency towards more yielding towards the AV shuttle. More people say they don't know in April than later, which may be explained by more experience in the later periods. A one-way between groups ANOVA, computed without "Don't know"-responses, revealed no statistically significant differences in mean values between periods.

Pedestrians who had met the AV shuttle at least once a month, were also given direct questions about how often out of ten times they met the AV shuttle on a crossing path, they yielded or stopped for the AV shuttle. Answers were given on a scale from 1 "Never" to 10 "Always" in three different situations: a) in the pedestrian street, b) when crossing an ordinary street without zebra crossing and c) when crossing an ordinary street at a zebra crossing. They could also answer "Don't know/not relevant". Results are presented in Fig. 9.

In all three situations and all three periods most respondents say they yield to the AV shuttle. The only exception is when crossing at a zebra crossing in April 2019 where the distribution is more or less even between "never" and "always". In this situation there is a tendency towards more yielding from April to June and from June to September. To test for statistical significance, a one-way between groups ANOVA for each of the three situations was computed. Respondents answering "Don't know/not relevant" are excluded from the analyses.

For Q28, the one-way ANOVA revealed a statistically significant difference between periods: $F(2, 108) = 4.2$, $p = .02$, revealing more frequent yielding in September 2019 than in June 2019. The effect size, calculated using eta squared, was 0.07, i.e. a medium effect (Cohen, 1988). For questions Q26 and Q27 there were no statistically significant differences between periods.

Table 2
Oslo sample distributed by period, gender (W = Women, M = Men), road user group and age group. Percentages by column. Total N = 549 (Pedestrians = 142, Cyclists = 407).

	April 2019				May 2019				June 2019				September 2019			
	Pedestrian		Cyclist		Pedestrian		Cyclist		Pedestrian		Cyclist		Pedestrian		Cyclist	
Age	W	M	W	M	W	M	W	M	W	M	W	M	W	M	W	M
≤ 20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20–29	7.1	22.5	7.1	22.5	33,3	25,0	3,0	1,9	15,0	0,0	0,0	0,0	33,3	20,0	0,0	1,4
30–39	39.3	7.5	39.3	7.5	33,3	37,5	31,3	16,0	20,0	36,8	26,7	12,1	0,0	40,0	14,7	15,1
40–49	7.1	7.5	7.1	7.5	0,0	18,8	32,8	32,1	20,0	21,1	33,3	24,2	33,3	0,0	26,5	21,9
50–59	17.9	40.0	17.9	40.0	16,7	12,5	25,4	29,6	5,0	10,5	33,3	24,2	33,3	10,0	50,0	34,2
60–69	7.1	10.0	7.1	10.0	16,7	0,0	7,5	16,7	25,0	21,1	6,7	33,3	0,0	20,0	2,9	21,9
70–79	21.4	10.0	21.4	10.0	0,0	6,3	0,0	3,7	10,0	10,5	0,0	6,1	0,0	10,0	5,9	2,7
≥ 80	0,0	2,5	0,0	2,5	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	2,7
N	28	40	7	16	6	16	67	162	20	19	15	33	3	10	34	73

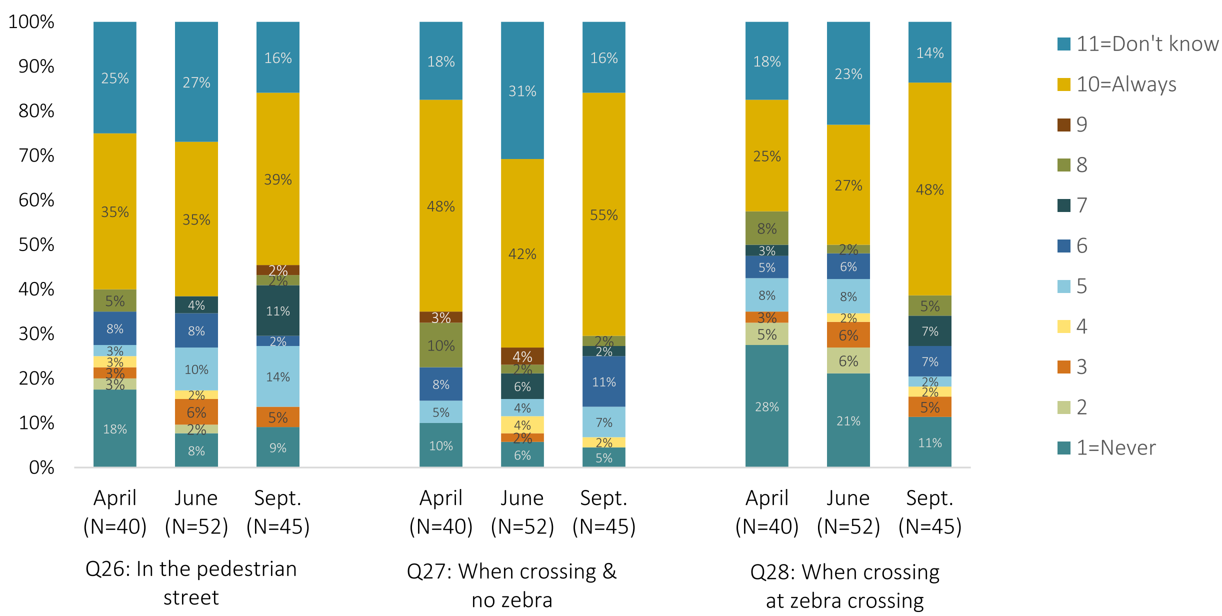

Fig. 9. Kongsberg pedestrians' estimates of how often they stop or yield to the AV shuttle in three different situations on a scale from 1 "never" to 10 "always" when meeting the AV shuttle in Kongsberg, in April, June and September 2019. Percent, total N = 137.

Kongsberg cyclists' perceptions of safety and interaction

In Kongsberg the number of cyclists responding to the questionnaire was rather limited, both because fewer people cycle in general and because interviews were done in the pedestrian street in the town center. In total 81 cyclists participated in the field interviews either in April (n = 5), June (n = 44) or September 2019 (n = 32). Hence it does not make sense to try to distribute responses over all three periods, but we may nevertheless provide results comparing June and September. Cyclists in Kongsberg received questions Q20–Q24 also given to pedestrians (cf. Figs. 6 and 7), however questions Q23 and Q24 were only given in September. Cyclist responses are presented in Figs. 10 and 11.

Cyclists' responses on the questions presented in Fig. 10 are quite similar to those of the pedestrians, given in Fig. 6. However, cyclists are less convinced that the AV shuttle will stop if necessary, on a crossing path (Q20). Cyclists agree more or less to the same degree as pedestrians on Q21, but fewer cyclists disagree. On Q22 cyclists' answers are quite similar to those of the pedestrians. There are no statistically significant differences in mean values between June and September on these questions.

Cyclists are somewhat more divided in opinions on Q23 than the pedestrians, but they are clearly much more in agreement with the statement on Q24 than pedestrians are (cf. Fig. 7).

Cyclists in Kongsberg were asked several questions about their interactions with the AV shuttle, listed in the method section 3.3. Q30–Q33 are questions about how often the cyclist yields when meeting the AV shuttle and wants to cross its path, under varying yielding rules. Q34 is about how often the cyclist overtakes the AV shuttle when riding behind it. Results are presented in Fig. 12.

A clear majority of cyclists yield when they should according to the traffic rules (Q30), both in June and in September, and that is also the case when yielding rules are unclear (Q32). Also, when they intend to cycle over a zebra crossing (Q33), a majority of cyclists say they yield to the AV shuttle, but they do so less in September than in June. To yield when cycling over a zebra crossing is also in accordance with the traffic rules, but not in line with the normal practice which is that motor vehicle drivers usually yield to cyclists at zebra crossings in Norway (Bjørnskau, 2017).

Furthermore, also in situations when the AV shuttle should yield according to the traffic rules (Q31), a majority of cyclists say they yield themselves. However, the proportion who say they never yield increased from 17% to 27% from June to September. The answers to the question whether they overtake the AV shuttle when riding behind it seem to indicate more overtaking in September than in June.

On all questions Q30–Q34 there seems to be a tendency towards less yielding to the AV shuttle, and more overtaking, from June to September

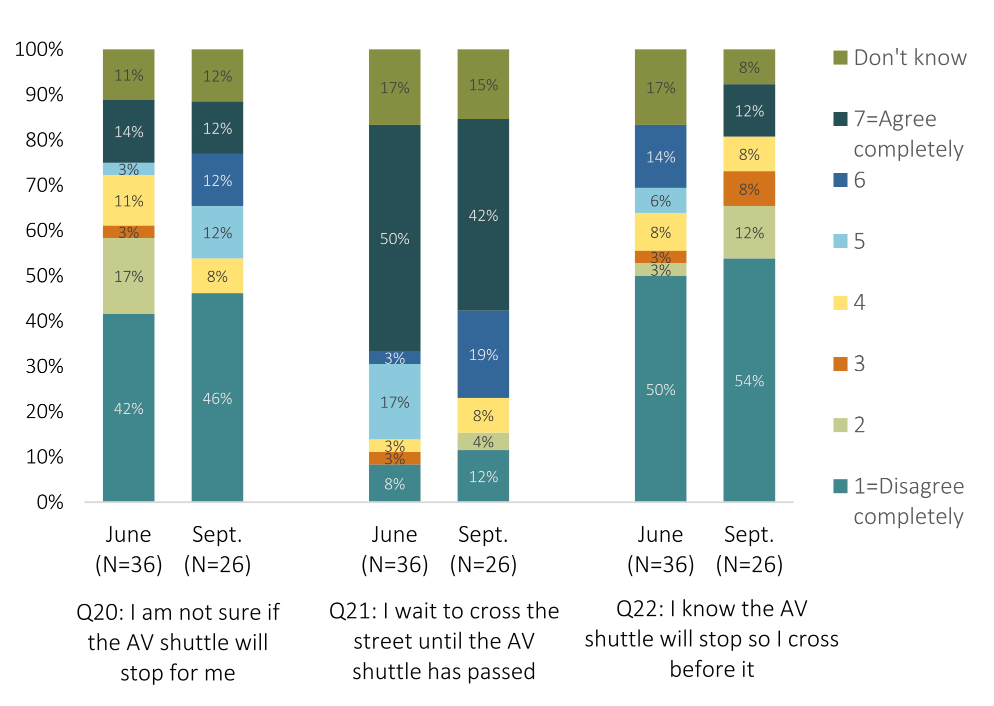

Fig. 10. Kongsberg cyclists' agreement to statements about the AV shuttle, in June and September 2019, on a scale from 1 "Disagree completely" to 7 "Agree completely". Percent, Total N = 66.

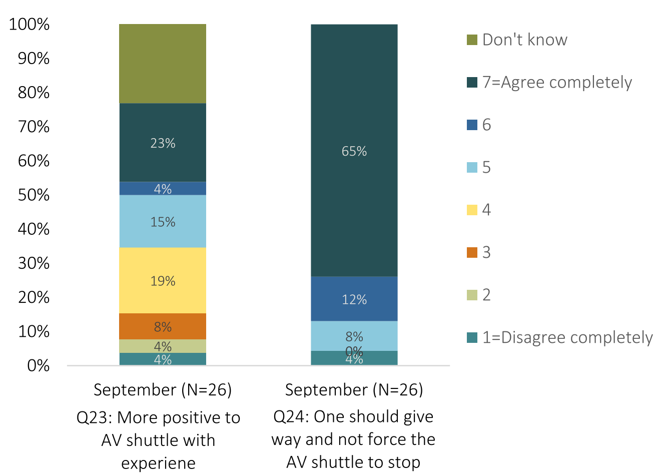

Fig. 11. Kongsberg cyclists' agreement to statements about the AV shuttle, in September 2019, on a scale from 1 "Disagree completely" to 7 "Agree completely". Percent, Total N = 26.

2019. However, a T-test comparing results between June and September, omitting "Don't know"-responses, revealed no statistically significant difference in means between June and September for any of the questions Q30–Q34.

Results Oslo

Oslo pedestrians' perceptions of safety and interaction

In Oslo the sample of pedestrians is limited, not allowing for detailed analyses of changes between periods. In total, 142 pedestrians were interviewed in the streets either in April 2019 (n = 68), May 2019 (n = 22), June 2019 (n = 39) or September 2019 (n = 13). There are too few pedestrians interviewed in Oslo to compare answers between different periods, but we can provide results for the total sample (in June and September after having experienced the AV shuttle).

Pedestrians in Oslo, who had experienced meeting the AV shuttle in traffic at least once a month, were given the same questions (Q20–Q24) about the AV shuttle as given in Kongsberg (Q19 was not asked in Oslo since there are no zebra crossing in the area where the interviews were conducted). Results are presented in Fig. 13.

Oslo pedestrians generally disagree with the statement Q20 "I am not sure if the AV shuttle will stop". Most also disagree with the statement Q22 "I know the AV shuttle will stop, so I cross before it", but on Q22 one in four agrees (ratings 5–7). More respondents agree than disagree to statement Q21 "I wait for the AV shuttle before crossing". On Q23 opinions are divided, and a large share tick the middle value (4). Finally, on Q24 "One should give way and not force the AV shuttle to stop", more than three in four agree (ratings 5–7).

The pedestrians in Oslo were also given question Q25, i.e., if they yield more to the AV shuttle than to other vehicles. Again, there were only 22 responses, but a clear majority (14) say they yield as often as to other vehicles.

Oslo pedestrians were given a general question about how often they yield to the AV shuttle: Q29: "Think about the times you have met the AV shuttle here. Out of 10 times how often do you stop or yield to the bus?" Answers were to be given on a scale from 1 "Never" to 10 "Always". They could also answer "Don't know/not relevant". Note that this question resembles the more situation specific questions given at Kongsberg. As noted, pedestrian responses in Oslo are very few, and on Q29 three answered "Don't know". Of the remaining 19 responses, 8 said "always" and 14 ticked 7–10 times. Thus, even if responses are few, the picture is quite clear: pedestrians in Oslo tend to yield to the AV shuttle.

Oslo cyclists' perceptions of safety and interaction

Only data from June 2019 and September 2019 are suitable for testing whether people behave differently towards the AV shuttle after gaining experience with it.

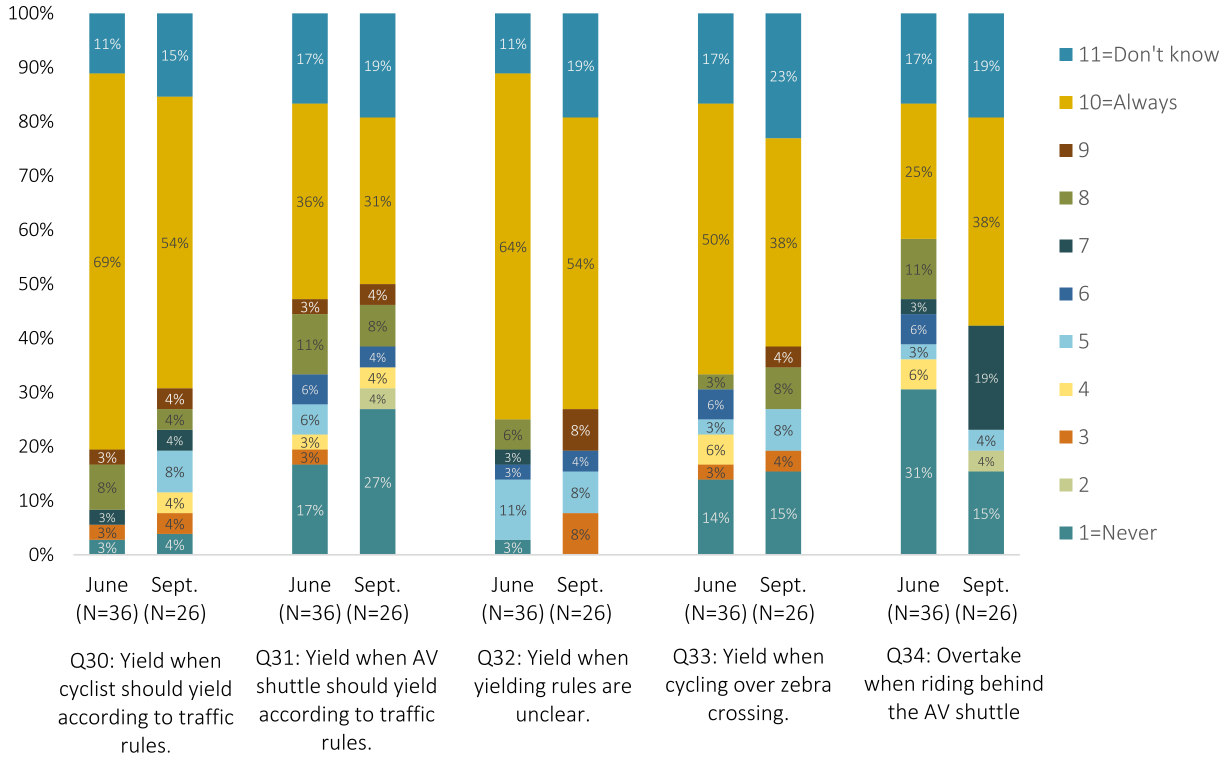

Fig. 12. Kongsberg cyclists' estimates in June and September 2019 of how often they yield to the AV shuttle in four different situations when they cross the path of the AV shuttle (Q30–Q33), and how often they overtake when riding behind the AV shuttle (Q34). Answers are given on a scale from 1 "never" to 10 "always". Percent, Total N = 62, (June = 36; September = 26).

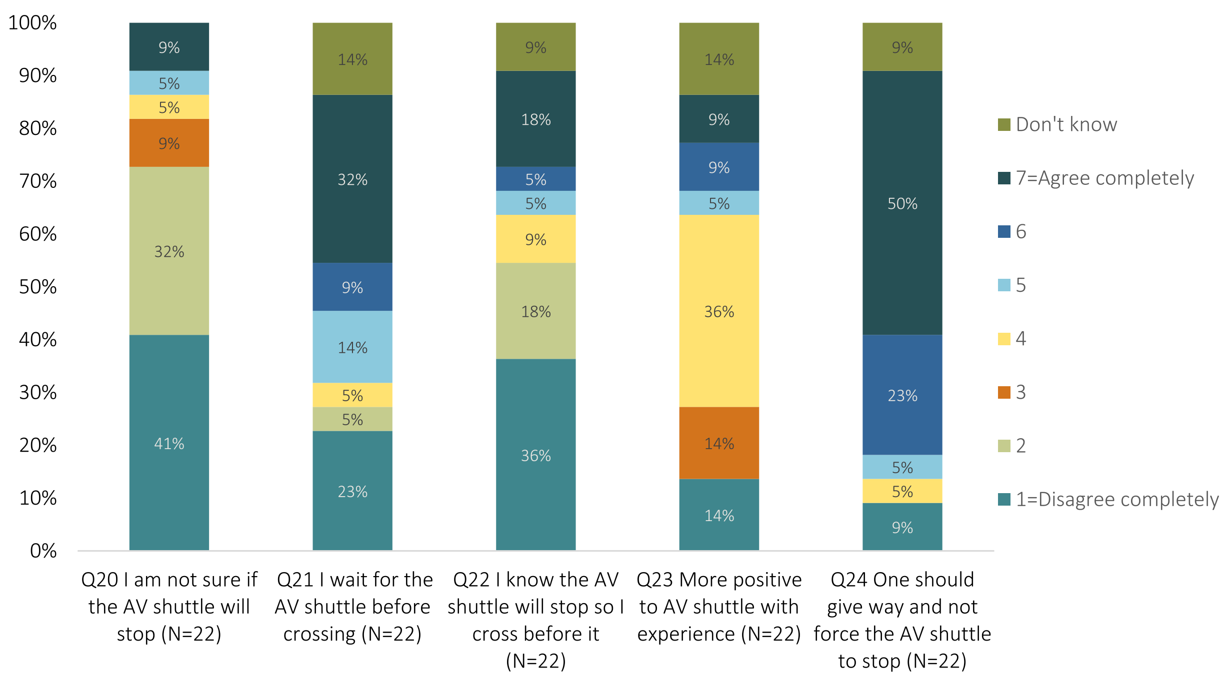

Fig. 13. Oslo pedestrians' agreement to statements about the AV shuttle, on a scale from 1 "Disagree completely" to 7 "Agree completely". Results from June and September 2019.

In June, a total of 48 cyclists answered the questionnaire in the field interview; in September the number was 107. In June, 16 had met the AV shuttle less than once a month; in September the number was 13. These respondents were not asked about their experience with the AV shuttle.

Those cyclists having experienced meeting the AV shuttles more than once a month, were asked about perceptions of safety when interacting with the AV shuttle, by use of the same questions Q20–Q24 given in Kongsberg and to pedestrians in Oslo. Respondents were asked to respond on a scale from 1 "Disagree completely" to 7 "Agree completely". They could also answer "Don't know/not relevant". Results are presented in Fig. 14.

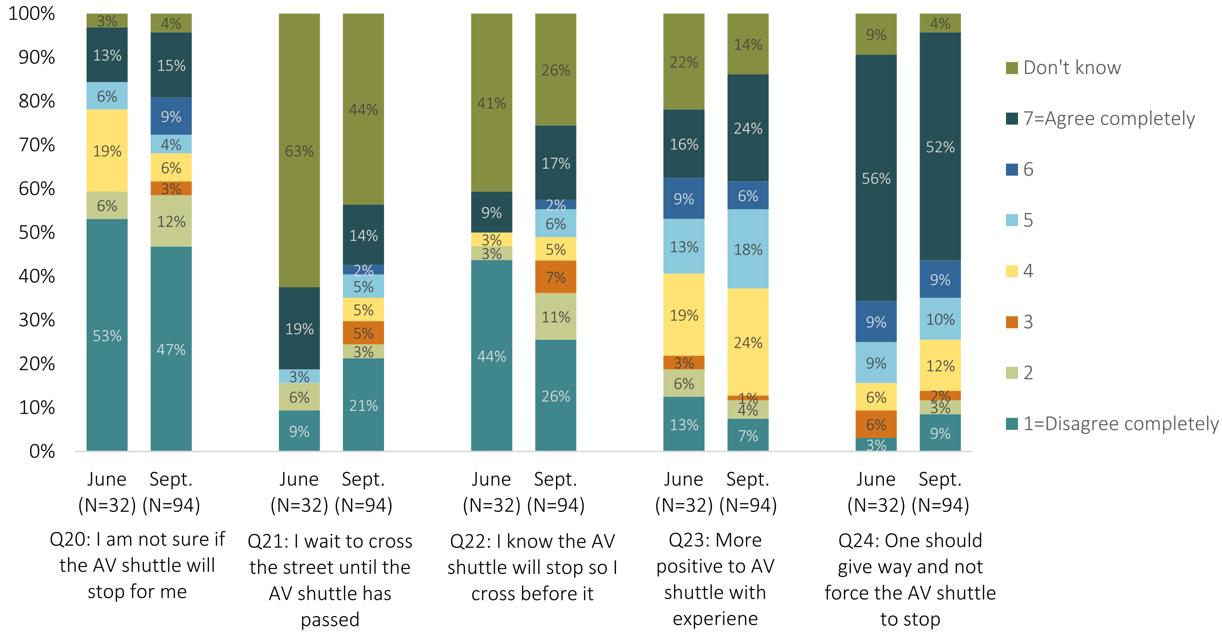

Fig. 14. Oslo cyclists' agreement to statements about the AV shuttle, on a scale from 1 "Disagree completely" to 7 "Agree completely", in June and September 2019. Total N = 126 (June = 32, September = 94).

Oslo cyclists' answers on Q20 resembles the answers from cyclists in Kongsberg and pedestrians in Oslo (cf. Fig. 10 and Fig. 13). However, on Q21 "I wait to cross the street until the AV shuttle has passed" and on Q22 "I know the AV shuttle will stop so I cross before it", there are clear differences. On these questions Oslo cyclists say "don't know" more frequently than Kongsberg cyclists and Oslo pedestrians. In Oslo, cyclists interact more with the AV shuttle in shared space-like areas and don't experience that often to be on a crossing path. On Q23 (about becoming more positive to the shuttle with experience), Oslo cyclists answer similarly to Kongsberg cyclists, but here Oslo pedestrians diverge with larger fractions choosing the mid-category (4). Oslo cyclists agree with the respondents in Kongsberg and the pedestrians in Oslo, that one should give way to the AV shuttle and not force it to stop (Q24).

There is a tendency among Oslo cyclists to be less considerate towards the AV shuttle in September than in June, both on Q21 (more disagree) and Q22 (more agree).

A T-test comparing results, omitting "Don't know"-responses, revealed a statistically significant difference in means between June ($M = 2.16$, $SD = 2.27$) and September ($M = 3.41$, $SD = 2.4$, $t(87) = -0.205$, $p = .044$ two-tailed) on Q22. The magnitude of the difference in means is moderate (eta squared = 0.046). The other differences in means are not statistically significant measured by independent samples t-tests.

Oslo cyclists yielding and stopping for the AV shuttle

The cyclists in Oslo, having experienced meeting the AV shuttle, were also asked whether they yield more often to the AV shuttle than to other vehicles (Q25). Fig. 15 presents the answer distributions in June and September.

There is a clear tendency that cyclists are better able to answer the question in September than in June, probably due to more experience with the AV shuttle in September. There is also a slight tendency that more cyclists say they yield more seldom in September than in June. The difference in mean values between June and September, omitting "Don't know"-responses is however not statistically significant, measured by a T-test.

Oslo cyclists were also asked how often they yield to the AV shuttle: Q29: "Think about the times you have met the AV shuttle here. Out of 10 times how often do you stop or yield to the AV shuttle?" Answers were to

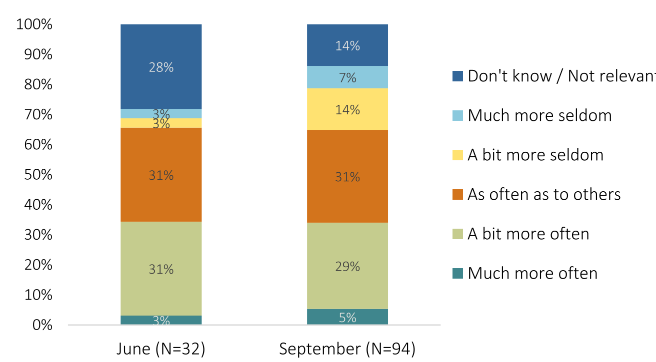

Fig. 15. Oslo cyclists' responses to the question whether they yield more often to the AV shuttle than to other vehicles, in June and September 2019. Percent, total N = 126 (June = 32, September = 94).

be given on a scale from 1 "Never" to 10 "Always". They could also answer "Don't know/not relevant". Note that this question resembles the more situation specific questions given at Kongsberg.

Like cyclists in Kongsberg, Oslo cyclists were also asked how often they overtake the AV shuttle when riding behind it (Q34). Results from June and September are presented in Fig. 16.

The cyclists have gained experience with the AV shuttle during this period, hence less do not know how they interact or behave towards the AV shuttle in September than in June.

To test whether the changes from June to September were statistically significant we analysed mean differences by use of T-test (computed with "Don't know"-responses omitted). This revealed a statistically significant difference in mean values on Q29 between June 2019 ($M = 6.65$, $SD = 3.41$) and September 2019 ($M = 4.31$ $SD = 3.48$), $t(92) = 2.51$, $p = .014$, two-tailed). The magnitude of the difference is moderate (eta squared = 0.064). However, the proportion saying they never yield increased from 3% to 30%.

Results on Q34 reveal a consistent pattern that cyclists tend to overtake the AV shuttle, and there is no statistically significant change from June to September.

The normal speed of cyclists is higher (15–20 km/h) than that of the

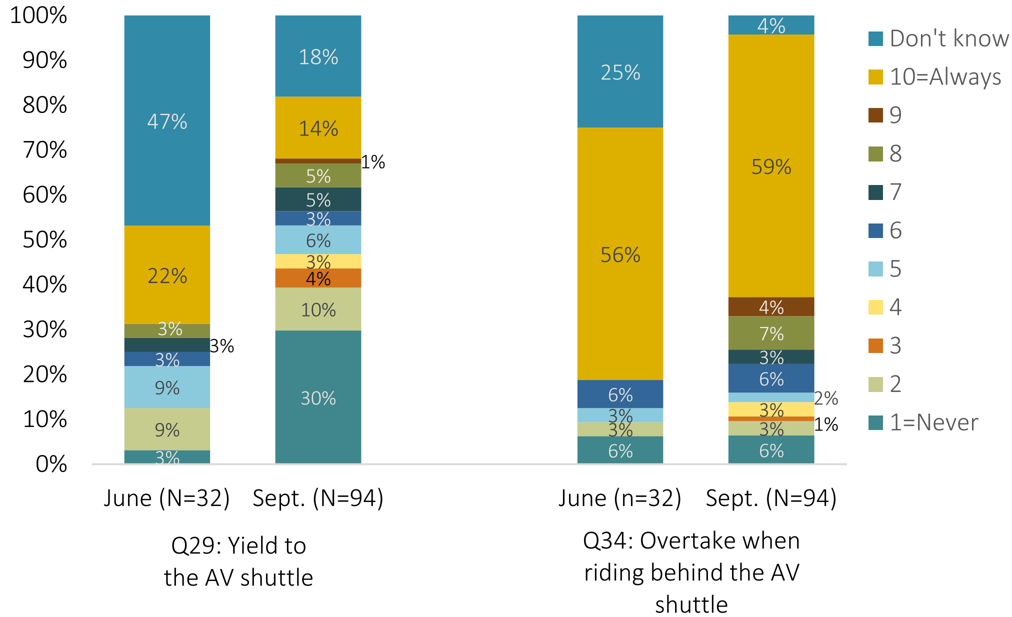

Fig. 16. Oslo cyclists' estimates of how often they yield to the AV shuttle and how they overtake when riding behind the AV shuttle. Answers are given on a scale from 1 "never" to 10 "always". Percent, Total N = 126 (June = 32, September = 94).

AV shuttle on many parts of the route, thus cyclists do have clear incentives to overtake. A problem often encountered when other road users overtake the AV shuttle, is that they cut in too closely after passing, leading the AV shuttle to brake abruptly. The problems involved due to overtaking in these pilots is addressed in a separate article from the same research project (De Ceunynck et al., 2022). The problem has also been reported in other pilots with the same AV shuttles in Oslo (Mirnig et al., 2022; Pokorny et al., 2021b).

Discussion

Pedestrians and cyclists are considerate towards the AV shuttle

Our first hypothesis was that in a first phase, ordinary road users would be uncertain about how safe AV shuttles are, and thus to be careful and uncertain in their interactions with them. We also hypothesized that they would tend to give way to the AV shuttles. Our results from the two pilots studied in Norway clearly show that among road users in Kongsberg and among pedestrians in Oslo there is a very clear tendency that they yield to the AV shuttles. Among road users in Kongsberg and among pedestrians the results are quite consistent. Among cyclists in Oslo the results are more mixed.

Our second hypothesis was based on game theoretic reasoning, and we expected that in a second phase, after 2–4 months when road users were becoming convinced of the safe and defensive driving style of AV shuttles, both pedestrians and cyclists would behave less considerate towards the AV shuttles, and increasingly go/ride before the AV shuttle when crossing paths. In Kongsberg we found no such tendency among pedestrians, (cf. Fig. 6 and Fig. 8). On most questions there were no systematic changes in responses between periods. On Q28, about yielding at a zebra crossing, there was a statistically significant difference between periods in the opposite direction, i.e., pedestrians said they yield more often in later periods (cf. Fig. 9). The reasons for such tendencies we don't know, and it might be due to random variations. Among Kongsberg cyclists, there are some tendencies in the hypothesized direction, i.e., towards less yielding, albeit not statistically significant (cf. Fig. 12).

In general, both pedestrians and cyclists in Kongsberg say they normally yield to the AV shuttle, and they also say one ought to yield and not force the AV shuttle to stop. Interestingly, cyclists seem to be even more considerate towards the AV shuttle than pedestrians in Kongsberg (cf. Figs. 7 and 11).

In Oslo the picture is different. Results indicate that cyclists seem to increasingly take advantage of the defensive driving style of the AV shuttle (cf. Figs. 15 and 16). Over time they both yield less to the AV shuttle, and more cyclists say they cross before the AV shuttle since they know the AV shuttle will stop in case of conflict (cf. Fig. 14). However, although these tendencies are statistically significant, there is still a majority of cyclists that behave considerate towards the AV shuttle also in the last period, and a clear majority say that one should yield to the AV shuttle and not force it to stop (cf. Fig. 14).

We also proposed a third hypothesis, based on the assumption that the AV shuttle always would yield in conflict situations. Hence it would be considered a weak road user that others would be considerate towards. We have seen that other road users are considerate and very much yield to the AV shuttle. Pedestrians in Kongsberg say they yield when crossing at a zebra crossing, i.e., when the AV shuttle should yield according to the rules (cf. Fig. 9). Also, cyclists in Kongsberg say they yield at zebra crossings, which is not normal practice in Norway. Furthermore, both in Kongsberg and in Oslo there is a majority saying that they yield more often to the AV shuttle than to other vehicles, and clear majorities agreeing that one should yield to the AV shuttle and not force it to stop.

These results are very much in accordance with our hypothesis 3, that other road users are particularly considerate towards the AV shuttle. However, the scores on these questions are rather stable over time, i.e., not appearing in a third phase. Furthermore, the findings might be because the road users consider the AV shuttle to be weak, but our data does not enable us to say whether this hypothesis is supported or not. We have also seen that many are uncertain about the behaviour of the AV shuttle, also after having gained experience, and this will also give a strong incentive to yield to the AV shuttle.

Cyclists in Kongsberg and Oslo differ

When comparing the four groups of respondent, pedestrians/cyclists and Kongsberg/Oslo, there is a clear tendency that Kongsberg cyclists are the most considerate towards the AV shuttle. One possible reason for this, that we unfortunately cannot control for, is that there are reasons to believe that the cyclists in Kongsberg to a large degree work or study in the Kongsberg Technology Park. The AV shuttle route runs from the city center to Kongsberg Technology Park, so many cyclists who travel to/from the Technology Park will be the ones who have met the AV shuttle.

There is a very large and important technology environment in Kongsberg, with the Technology Park and the University of South-East Norway as one of Norway's technology hubs, employing thousands of people in various technology companies. One could perhaps expect them to be more positive than average towards new technology such as automated driving, and there is reason to believe that they constitute a substantial share of the cyclists interviewed in Kongsberg.

We do not know if that is the case, but one should be aware of this risk also when evaluating other pilots with AVs. Very often such pilots are located at the campus of technical universities, science parks etc. Also, one of the other pilots that was part of the present project (but not reported here), was situated in such an area (Forus, Rogaland) with many tech companies. A survey among the employees here revealed very positive attitudes towards the pilot with the AV shuttle although very few had used it (Slotsvik, 2019). The point is merely that when pilots are run in such areas/locations, peoples' opinions might me more positive than in a representative population. One of the interviewers also reported that some respondents said it was not okay to show negative attitudes towards new technical pilots and trials in Kongsberg, since the town aspires to be one of the major tech hubs in Norway. Hence there is clearly a risk of social desirability bias in the replies to the questionnaire, in particular the Kongsberg sample.

Limited support for the game theoretic hypotheses

Among cyclists in Oslo, we found some support for the game theoretic hypothesis that after some time road users will become less considerate towards the AV shuttle. In Kongsberg we found a slight, but not statistically significant, tendency among cyclists, but no such tendency among pedestrians. Thus, there is some, albeit limited, support for the game theoretic hypothesis. This is in line with other recent studies on the subject. Pokorny et al. (2022) concluded that ordinary car drivers yield less often towards automated vehicles than towards ordinary vehicles in real-life interactions in a recent pilot in Norway. Similarly, a German study found pedestrians to jaywalk more frequently when faced with AVs (Şahin et al., 2022). Recent Chinese studies also report road users to behave more aggressively towards AVs than towards ordinary human drivers (Liu et al., 2020; Liu et al., 2022).

However, the support for the game theoretic hypothesis in our study is quite limited, and the video analyses of interactions between AV shuttles and pedestrians and cyclists in the Oslo pilot report similar results; pedestrians and cyclists are careful and tend to yield to the AV shuttle (De Ceunynck et al., 2022).

A possible and very important reason for the lack of general support for our game-theoretic hypothesis might be that the assumed mechanism in the game-theoretic logic is not fully met. A precondition for the mechanism to work is that other road users are convinced that the AV shuttle will always yield or stop in case of a conflict. Although most respondents believe this to be the case, there are 15–25% who say they are not sure that the AV shuttle will stop (see Figs. 6, 10, 13, 14), and there is no tendency that cyclists or pedestrians become more convinced over time that the AV shuttle will stop (cf. Figs. 6, 10, 14). Results from video analyses of the AV shuttle in Oslo confirm that the AV shuttle in many cases does not yield to pedestrians or cyclists when it should according to the traffic rules (De Ceunynck et al., 2022; Pokorny et al., 2021b).

This finding is also in line with other studies showing that pedestrians wait longer before crossing in the presence of automated vehicles (Kalatian & Farooq, 2021) indicating that pedestrians do not fully trust AVs. Similarly, Hagenzieker et al. (2020) reported that cyclists were not more confident to be noticed by automated cars than by manually driven cars, and Vlakveld et al.(2020) found cyclists to report to yield more often when interacting with automated cars. The study by (Şahin et al., 2022) illuminates the importance of trust in the behaviour of AVs; when they informed the study participants that the AVs would always yield, the pedestrians tended to show more deviant behaviour, i.e. to yield less themselves.

A second mechanism, that may contribute to explaining why the game theoretic logic seems to be more at work among cyclists in Oslo than among pedestrians in Kongsberg, is the fact that the AV shuttles also operated during rush hours in Oslo and not in Kongsberg. Hence commuters in Oslo have had better opportunities to learn how the AV shuttle behaves. In Oslo there are some indications that those cycling frequently behave less considerate towards the AV shuttle than those cycling less often; the frequent cyclists trust that the AV shuttle will stop more than those cycling less, and they are less willing to wait for the AV shuttle to pass (results not presented above). But the findings were not very consistent, and more research is needed here. If the mechanism assumed in our hypotheses in fact works, we should expect experience with the AV shuttle to be a very powerful explanatory variable.

A third mechanism that may operate, is that pedestrians in Kongsberg are easily recognized by the bus passengers and by other road users (pedestrians), but this is not the case for cyclists in Oslo. Thus, pedestrians may be more victim to norms of polite behaviour (Bicchieri, 2005; Goffman, 1971). Furthermore, Kongsberg is a small, "transparent" town giving ample opportunity to identify subjects who deviate from correct behaviour. Hence social norms may be more easily sustained in Kongsberg than in Oslo. The fact that cyclists are much more mobile than pedestrians may reinforce such a tendency towards more social control among pedestrians in Kongsberg.

Finally, a fourth, and important possible explanation why our game theoretic predictions are not receiving much support, could be that the assumed payoffs of the different outcomes are not as depicted in the Leader (or Chicken) game(s) cf. Fig. 1. In Leader (and Chicken) it is assumed that the preferred outcome is that the other road user waits and that you go first. But in real life, it may not be that important who goes first. In many instances what is important is to coordinate our moves, so we avoid crashes and stalemate situations. For example, it does not matter much which side of the road we drive on, what matters is that we coordinate this and agree to drive on one and the same side (Kuzmics, 2014). It is indeed possible that in some situations the road users interviewed in this study may have such preferences.

Both in Kongsberg and in Oslo we interviewed pedestrians in shared space areas, where there are often many possibilities to adjust one's path if in conflict with another road user. As pedestrians we do this all the time when interacting with each other, and we probably do not consider it a cost to be the one who adjusts the path, and a benefit to be the one that doesn't. Maybe this is also the case when pedestrians meet the AV shuttle in this study. Perhaps they report giving way to the AV shuttle, when the give way maneuver is just a very simple and small adjustment of speed and/or direction without much importance or considerations.

It is perhaps reasonable to suggest that the assumed payoffs in Leader are not correct in some instances in pedestrian areas and shared spaces, and that the interaction here sometime is better modelled as a pure coordination game. But, in other instances in traffic, for instance when negotiating intersections as drivers or cyclists, the preferences assumed in Leader are probably quite well founded.

Strengths, limitations and future research

The strengths of the study presented here are firstly that the surveys have been conducted in real traffic, with real AV shuttles operating ordinary bus routes in mixed traffic together with survey respondents. A second strength is the fact that surveys have been conducted at several points in time, and in two different cities.

There are however also a number of caveats and limitations to the study reported here. The most severe is the limited samples, restricting the possibility to draw conclusions about behavioural changes over time. We used field interviews in the same streets that the AV shuttles operated, which probably contributed to ensuring that people knew which AV shuttle we asked about, but the downside is of course a smaller sample than if the questionnaire was distributed by mail or internet.

An additional challenge is that AV shuttles are often situated at specific locations (science parks, university campuses) and times to ensure an uncomplicated traffic environment with few other road users. For example, in Kongsberg the AV shuttle operated only from 10 AM to 2 PM which is outside rush hours. There are less people in the streets and these operating hours make it difficult to study interactions with ordinary road users commuting to/from work or school.

A third challenge that has limited the possibility to study interactions and to ask people about the AV shuttles, are the frequent interruptions in operations that often happens with the AV shuttles. In the Norwegian pilots, there were numerous stops and pauses in the operations due to weather conditions, road works, social arrangements in the areas and technical problems with the vehicles. Such stops make it difficult to collect data in general, and it makes it particularly difficult to study behavioural adaptations over time. When the AV shuttles do not operate for several weeks on a route, the consequence can be that other road users forget about them and must learn anew how the AV shuttles behave when they again appear. In that case we cannot expect any clear developments in road user interactions over time.

A fourth challenge in doing research on these pilots in Norway, is that the AV shuttles generally appear quite seldom, they are not much used, and very many people in the streets do not have any clear opinions about them. As mentioned in the introduction, we wanted also to do field interviews in a third Norwegian pilot (Forus), but this was not possible since so few people knew about or had experienced any interactions with the AV shuttles.

Such challenges in doing research in the field are often met, but difficult to anticipate and prepare for. In this study, it resulted in rather small samples, and a recommendation for future research would be to allocate more resources to such field surveys to ensure sufficient large samples.

Conclusion

Despite the limitations, some conclusions can be drawn. There are quite consistent results that both pedestrians and cyclists tend to give way to the AV shuttle, at both sites, and that they in general agree that one should give way to the AV shuttles and not force them to stop.

There is also a tendency that cyclists become less considerate towards the AV shuttle over time and yield to a smaller degree in later periods. This tendency is however not very strong and only statistically significant for a few items in Oslo. Thus, the game theoretic hypothesis that normal road users will yield less to AVs over time, receives only limited support.

One important reason for this may be that in some of the study areas the road user pay-offs are not as assumed in Leader; in pedestrian streets and shared spaces it is perhaps not important to pedestrians who goes and who yields, the important thing is to avoid crashes and stalemate situations.

Another important reason why the game theoretic hypothesis receives limited support, might be that the assumed mechanism in the game-theoretic logic is not fully met. A precondition for the mechanism to work is that other road users are convinced that the AV shuttle will always yield or stop in case of a conflict which we have seen is not the case in this study. Hence a somewhat paradoxical conclusion one might draw, is that the more sophisticated and cleverer the AV shuttles become in identifying and automatically stop in conflict situations, the more likely it is that other road users will take advantage of their defensive driving style. This might be an important reason why different studies reach different conclusions about how normal road users react to AVs.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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