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Regulating connected and automated vehicles: How do drivers experience being automatically regulated by digital traffic rules?

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ABSTRACT

Digital traffic rules using geofencing can be communicated to Plug-in hybrid electric vehicles (PHEVs) offering possibilities for both national and local authorities to regulate traffic in an efficient and environmentally sound manner. This real-traffic study provides novel results of attitudes towards being automatically regulated in low emission zones (LEZs) in Norway and Sweden. Drivers with updated software were surveyed about their experience with the functionality, and the acceptance of being regulated by such a system, and further compared to a scenario of geofenced speed zones (SZs). Findings show the difference in attitudes between the two use cases – drivers are much more positive to LEZs than SZs. And further that those that had noticed the function were more positive than those that had not noticed the function. The study demonstrates the importance of experience with the technology in vehicles and how LEZ can be more compatible with existing values, while SZ can create feelings of infringement of freedom. The study is novel in that it focuses on attitudes to regulation. Voluntary use cases demonstrated in this study, show a promising example of adaptive policymaking and nudging that could help authorities mitigate uncertainties on the way towards a more efficient, safer and environmentally friendly transport system.

Introduction

Vehicles are increasingly becoming connected and automated, which opens new opportunities in terms of how transport authorities can inform road users or regulate driving behaviour. There is a need to explore how digital traffic rules can be communicated to the vehicles, which by no means is standardised across different countries (Hansson, 2020), and explore how this is received by the drivers. Geofence for traffic regulation can be an important instrument in this regard and can be applied to a variety of different use cases. It enables digital zones defined on a map containing information on traffic rules or other traffic information to be communicated to the vehicles and drivers based on the position of the vehicle (e.g., Arnesen et al., 2020).

This is important information for OEMs which develops sensors, algorithms, and cloud services for increasingly more advanced cars and AVs, as the regulations will have implications for design requirements (Lee and Hess, 2020), as for the authorities in their work on traffic challenges.

An interesting example in this regard, is the 2019 ruling approved by the European Commission to make Intelligent Speed Assistance (ISA) mandatory on all newly manufactured models, set to start from 2022. This new ruling also requires all vehicles to incorporate event data recording, which means logging driving that potentially could be used to determine if a driver were overriding the ISA system in the event of an accident. Different versions of the system have been approved, but most critically is the ability of the driver to switch it off, as this could aid public acceptance (European Commission, 2021). User acceptance is among the most important barriers against the introduction of such new technologies (Bezai et al., 2021), but we argue that the attitude towards regulation is equally important.

There is a strong need for more knowledge on how these digital traffic laws are perceived by drivers. Several instruments are available for policymakers and practitioners, but geofence can be an instrument which allows the driver or the car, depending on the level of self-driving, to be informed, assisted, or forced to follow the traffic rules. Depending on the degree of regulation, this could narrow the freedom of the driver (also argued regarding AVs – see Sweet and Laidlaw, 2020). The research question of this paper is thus: What are drivers' attitudes towards being automatically regulated by digital traffic rules, and what are the main explanatory variables for these attitudes?

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This is an important subject to investigate as the public's opinion of digital traffic rules might affect the future of the transport system. To the best of our knowledge, no studies so far have focused specifically on drivers' attitudes towards digital traffic rules, and particularly investigated this among drivers that have experienced this in their everyday life. This is an important addition to the research field as experiments under strictly controlled conditions could imply limited real-world validity (Walker and Marchau, 2017). Using a questionnaire, we have collected experiences from drivers in Norway and Sweden who have experienced being automatically regulated within a low-emission zone (LEZ), that is where the PHEV switches automatically to electricity within certain zones. Furthermore, we compare the findings from the experienced LEZ with a scenario use case of speed zones (SZs). For both use cases we divide the sample into those that have noticed the functionality and those that have not.

The remainder of the article is structured as follows: In Section 2 we give an overview of previous research focusing on digital traffic rules, the role of regulation, and an overview of the acceptance literature on ADAS and AVs, followed by further literature presentations of eco-driving and speed management, followed by acceptance studies of each respectively. In Section 2.2. We present the main expectations for the analysis. In Section 3 we provide the research setting and use cases as well as descriptions of the sample and statistical approaches. In Section 4 we present the results divided into two main parts, before providing the discussion in Section 5 and conclusion in Section 6.

Previous research

Developments in automotive technology have accelerated (Taeihagh and Lim, 2019) and as vehicles are becoming more automated and connected, the need for regulation of traffic will change. For instance, in terms of responsibility, which tasks should the driver be responsible for, and which tasks could the vehicle be in control over? These questions are at the core of the SAE (2018) scale where a gradual increase of automated driving features is described across level 0 to level 5. While level 0 to 2 include driver assistance technology, level 3 includes conditional driving automation where the driver must take over control when asked. In level 4 and 5 the driver will not be asked to take over control as long as the vehicle is inside the operational domain. Hence, when reaching the higher SAE levels, the responsibility in terms of interpreting and following traffic rules will be left to the vehicle. While the current system of regulating traffic is developed with a human driver as the responsible actor, the future with increasingly more advanced vehicles will need to be adjusted to also accommodate vehicles as the responsible actor.

Making an adjustment in terms of responsibility of interpreting and following traffic rules is not straight forward. One issue is that policies tend to lag the introduction of new technology, a development that characterizes multiple sectors, including for instance biotechnology (Mordue et al., 2020). Policymakers balance the governance of risks associated with the technology with the societal and industrial benefit of the underlying innovation (Mordue et al., 2020). This could according to Wiener (2004) be seen as a tension between regulatory policy and industrial policy, which could imply that regulation can hamper innovation and development. "Technology symbolizes markets, enterprise, and growth, while regulation represents government, bureaucracy, and limits to growth" (Wiener, 2004, 483). Policymaking often takes a reactive attitude in response to uncertainties, which could slow down the implementation of innovative transport solutions (Walker and Marchau, 2017). Hence, there is a need for understanding peoples' attitudes and acceptance towards digital traffic rules, which could be helpful in assisting implementation of these.

Digital traffic rules could be an immense help for authorities, in regulation of vehicle traffic, both in terms of pollution and speed, but also for steering traffic away from road works and accidents. They can also be used as pure nudging tools, instead of hard regulation (Thaler and Sunstein, 2008). As vehicles and regulation allow for increasingly higher SAE levels, the digital traffic rules will be at the core of the future transport system. Already some interesting parallels exist where digital traffic rules are implemented in enclosed areas, such as ports, or for a certain type of vehicles, such as e-scooters. These examples are already in use or being piloted several places in Europe and the USA (Hansen et al., 2021).

However, as long as SAE level 4 and 5 is not realized, human drivers and vehicles will have a shared responsibility. Even though it could be argued that SAE levels 4–5 represent the most fundamental shift in society (Taeihagh and Lim, 2019), it is just as interesting to investigate how authorities can make use of the technology implemented in vehicles at lower SAE levels. The process of introducing AVs is likely to be a gradual transition, and it will take time before vehicles are fully self-driving. For instance, the average car in the US is 11,8 years old (USA Today, 2019), indicating that the phasing out of manual vehicles will be a long process.

During this period the acceptance of drivers will be important. While digital traffic rules for e-scooters or within confined areas has already been introduced, using it in private vehicles introduces a higher level of complexity. The privately owned vehicle is far more than only a means of transport. It represents something much greater for many car owners, such as power, freedom, status, and superiority (Gardner and Abraham, 2007; Beirão and Cabral, 2007).

However, with the emergence of vehicles at higher SAE levels this could change how users and owners of vehicles perceive the car (Sweet and Laidlaw, 2020). A car owner stated in the Beiaro and Cabral (2007: 484) study that "the car gives the perception of freedom, of being more in control and being able to keep their personal timetable and thus enhance autonomy." Other studies also emphasize the car as an important symbol of freedom (e.g., Sandes et al., 2019). A related literature investigating consumers perception of the disposal of their car, shows that they re-signify the concepts of freedom, comfort, safety, and status (Sandes et al., 2019). A similar process may also occur as connected automated vehicles (CAVs) are becoming increasingly more advanced, making the affective motivations related to car-use likely to change during this process (Sweet and Laidlaw, 2020). When the affective motivations of drivers change, this could have important implications for policymakers when introducing regulations for CAVs.

Several new developments could be mentioned demonstrating the large potential that new technology could have in terms of improving the transport system: optimization of fuel consumption and methods for handling so called conflict zones in traffic, e.g., at ramps, intersections or in work zones (Yao et al., 2020), and methods for studying the influence of CAVs on mixed traffic flows, taking the vehicles' driving behaviour in platoons into consideration (Jiang et al., 2021). However, these are simulations or models, and not tested in real traffic yet. Further new research shows the possibility of applying geofences as moving geofences, e.g., Eom et al. (2020) created "mobile geofences" using Smartphones, with the zones following the vehicle itself, where geofences intercepting and under certain other restrictions (directions etc.) were set to communicate V2V message. This was tested in real traffic, and points to a wide area of use for such technologies. However, many of these technologies, would mean less control for the drivers themselves, and to be controlled or assisted by external entities, such as authorities. Our interest lies with the attitudes and acceptance of the drivers, which is particularly interesting in the period where both the driver and the vehicle have responsibility for the driving process.

Automatic digital traffic regulation and attitudes

While no other study has investigated attitudes to digital traffic rules in general, there is a plethora of studies on the acceptance of advanced driver assistance systems (ADAS) and AVs. From acceptance of fuel-efficient gear shifting (Staubach et al., 2014) to driver acceptance of the different levels of automation (e.g., Hartwich et al., 2019; Strauch et al., 2019), and others investigating specific use cases (e.g., Reagan et al., 2020). We start with introducing the two traffic regulation cases our study is based around, before turning to the literature on acceptance within these areas.

Low-emission zones and eco-driving assistance systems:

LEZs are areas within a city where there are restrictions on the operations of polluting vehicles (Oltra et al., 2021; European Commission, 2021). LEZ is implemented in several European cities with the aim of reducing air pollution to meet the European Union Air Quality Standards. Several analyses of various LEZs show that emissions are reduced, and air quality increased after implementation of the LEZ in the city centre (e.g., Lebrusán and Toutouh, 2021; Zhai and Wolff, 2021; Santos et al., 2019). However, there are many ways of implementing these, where geofence is one and a quite recent one. As already summarised in the study of Seter et al. (2021) the literature on various aspects of acceptance of eco-driving is large and growing. This includes studies of everything from technical measurements of compliance, e.g., (Fors et al., 2015), evaluations of different HMI (Human Machine Interface) solutions (e.g., Dahlinger, et al., 2018), fuel-saving potential (Staubach et al., 2014), and glance behavior (Li et al., 2019). Also, lately eco-driving behavior among electric vehicle users have gained attention (e.g., Wang et al., 2020). The findings from these eco-driving assistance systems found there to be high acceptance among users. However, Staubach et al. (2014) discovered feelings of distraction and restriction of the systems giving recommendations to participants concerning fuel-efficient gear shifting and acceleration/deceleration behaviour. In this recent study by Seter et al. (2021) geofenced low-emission zones, and acceptance of these were compared, in both an integrated and retrofitted version (Seter et al., 2021). The study found the acceptance of LEZ with the integrated system, where electricity shifted automatically, considerably higher, than with the retrofitted case, where drivers only received information and notification about the LEZ in the HMI of an installed Smartphone (which was connected to a OBD-II dongle via Bluetooth), as well as an award incentive (see also Arnesen et a. 2021 for further description of case).

Speed management

Most studies on speed focuses on Intelligent Speed Adaptation (ISA). ISA systems include different technical systems that help drivers keep the right speed. For example, satellite technology to register the speed of a vehicle and compare this to the speed limit on the section of a road at hand, and/or speed sign-recognition video camera (see e.g., Jenssen, 2010; ETSC, 2021). They can include visual, auditory, and haptic systems, and they could have varying levels of intervention. The study of Jenssen (2010) on ISA divides such systems intro three main variants: Informing, assisting and controlling. Different systems then issue warnings in different ways, through alerting drivers via the sense of sound (acoustic or verbal), light (visual display) or touch (haptic). Several studies have documented the positive effects ISA technology can have on reducing speeding and improving traffic safety, e.g., one study suggests that a simple mandatory ISA system would reduce injury accidents by 20% and fatal accidents by 37% (Carsten and Tate, 2005). The European Commission decided that from 2022 ISA will be mandatory for new models sold in the EU (ETSC, 2021), which highlights the importance of more knowledge on this particular use case. But there are still work to be done, e.g., harmonization of speed limit maps by European, national and regional authorities.

Most studies on acceptance of ISA were conducted in the early 2000s (e.g., Adell et al., 2008; Adell and Várhelyi, 2008; Vlassenroot et al., 2007; Young et al., 2010). In the recent literature review on acceptance and effectiveness of ISA by Harkin et al. (forthcoming) informing and assisting ISA systems were found more accepted than controlling systems. However, as pointed out, such controlling systems are also the ones shown most effective.

Acceptance of speed management zones were also compared in the study of Seter et al. (2021). In the integrated version, the drivers were notified in the vehicle HMI prior to entering the zone, and after the entering the electric engine of the car gradually decelerated. The functionality adjusted the mapping of the gas pedal to require more effort from the driver to override the functionality. For the retrofitted test, the drivers were simply informed in the HMI. Findings showed that the drivers found the integrated version easier, more comfortable, and informative, as well as more intuitive to use, and also less distracting. Further the integrated version was considered more useful for increasing traffic safety when compared to the retrofitted system.

These studies however, did not look at acceptance of being regulated, they give some hint to how acceptance of the technology, could be an influencer on being regulated.

Main expectations

Our analysis is dedicated to i) uncovering what the drivers' attitudes towards being automatically regulated by digital traffic rules are, and ii) describing what could be the main explanatory variables for their attitudes. It is likely that drivers will have different attitudes towards different use cases, even though the technology used may be the same (Seter et al., 2021). Some studies find that the trust and use of technologies in vehicles vary across different implementations of the same system (i.e., for different car brands), and that the attitude also varies for different use cases (Kidd et al., 2017). Hence, we expect the drivers' attitude towards having their driving behaviour automatically regulated to vary according to different use cases.

Another important issue is that it is likely to be a difference in how drivers evaluate advanced driving assistance systems before and after experiencing the system. For instance, both Beggiato et al. (2015) and Pereira et al. (2015) find that acceptance and trust of an adaptive cruise control (ACC) system changes over time as the drivers learn to use the system. This highlights that one can expect that there is a difference between those that have experienced and used the technology, and those that have not. Hence, we expect there to be a difference in the attitudes between the drivers that have experienced the technology and those that have not.

Turning to the explanatory variables describing differences in the attitudes toward being automatically regulated, we rest on the existing literature on acceptance of AVs and advanced driving assistance systems. Many previous studies have found that socio-demographic attributes are related to the acceptance of AVs. In particular, it seems that young men, who are well-educated and wealthy, and live in urban areas are the ones that are most accepting of AVs (Nair and Bhat, 2021; Milakis and Müller, 2021). Furthermore, many studies also argue that a positive attitude towards technology use in general could also be an attribute that make drivers more positive towards AVs (Nair and Bhat, 2021).

Travel patterns has been found to be an important explanatory variable for attitudes toward LEZ (e.g., Mehdizadeh and Shariat-Mohaymany, 2021; Tarriño-Ortiz et al., 2021). Those who are most affected by the LEZ, such as commuters, are often those that are most negative towards the LEZ.

Environmental awareness has been argued to be an important explanatory variable for support of climate and environmental policies, which is supported by empirical studies (e.g., Mehdizadeh and Shariat-Mohaymany, 2021).

Trust is in general argued to be one of the most important explanatory variables for the acceptance of AVs (Nordhoff et al., 2021), and is argued to be a strong predictor of its use (Kidd et al., 2017).

Perceived usefulness could be an important explanatory variable of the drivers' attitudes toward being automatically regulated. This concept is close to the term "perceived effectiveness" (e.g., Kim et al., 2014) which was found to have a positive effect on acceptability of sustainable transport policies such as carbon taxation, and transport pricing strategies (Schade and Schlag 2003). As found by the recent study by Morton et al. (2021), how effective LEZs are considered to be at improving air quality seems to promote positive attitudes for these measures. Further, following Rienstra et al. (1999), we expect to find a difference in the effect of usefulness of the measure regarding one's own driving, the "individual usefulness", and usefulness for society in general, the "social usefulness".

Method

For answering the research questions, we use a questionnaire survey approach to capture the experience and opinions of the drivers driving cars with geofence technology used for low-emission zone regulation. First, we explain more about the research setting, including initiation of the project, geofence and use cases in Section 3.1, before presenting the recruitment approach and sample, followed by the approach to answer the research questions and the survey questions used. Lastly, we present the respondents and discuss representativity.

Research setting and use cases

Through a collaboration between BMW and The Norwegian Public Roads Administration and the Swedish Transport Administration, volunteer LEZs have been defined in Norway and Sweden. The purpose of this collaboration is to investigate the possibility of using geofencing for regulating traffic. The LEZs are not publicly adopted zones in the cities in this project, but represents volunteer trial zones issued through the national authorities in the following cities in Norway: Oslo, Stavanger, Bergen and Trondheim, and the following cities in Sweden: Stockholm, Gothenburg, Malmö and Uppsala. In the geofenced LEZs the cars' engine automatically switches from fossil fuel to electricity. The drivers were informed by a message in their dashboard when this happened. The drivers had the option to switch off the function.

The LEZs are communicated directly to the car using the national road databank. One definition of geofence is "a virtual perimeter for a real-world geographic area. A geofence could be dynamically generated as in a radius around a point location, or a geofence can be a predefined set of boundaries" (Sadler 2021), 127). Using geofence enables digital zones defined on a map containing information on traffic rules and information to be communicated to the vehicles and drivers (e.g., Arnesen et al., 2020). The respondents of the survey are owners of BMW PHEV cars registered in 2019 and 2020, more specifically: BMW X5 xDrive45e, BMW 745e xDrive, BMW 330e/330e xDrive, BMW 330e Touring / 330e xDrive Touring.

The other use case of interest in this study is SZ, but as a scenario use case. Here we ask about the expected attitudes to being automatically regulated with speed zones. However, a version of such a case is described in Section 2.1.2., in the study of Seter et al. (2021). Both informing and assisting geofencing was trialled as well as an integrated version with breaking through the engine. This use cases is further discussed in Section 5.

Recruitment and sample

The respondents were drawn from the central registers of motor vehicles in Norway and Sweden, where information about vehicle owner, address and type of vehicle is registered. The names of the vehicle owners were then matched with publicly available phone numbers, and the survey was distributed to the vehicle owners by SMS. The sample also included vehicles registered to sole proprietorships and businesses.

While the total contacted population in Norway and Sweden were 1416 and 1285 respectively, there were some errors either in phone number information or with the send out, giving a survey distribution of 1367 and 1042 respectively. Of those who responded and completed the whole survey, the sample for Norway ended on 581, giving a response rate of almost 43 percent, and for Sweden 82, giving a response rate of almost 8 percent. See Table 1 for an overview. The diverging response rate for the two countries could be likely to be due to that a Norwegian research institute was listed as the sender of the SMS, which one could expect is less known to the Swedish respondents.

Table 1
Overview of population and sample size.

	Population	Survey distribution	Survey sample	Response rate
Norway	1416	1367	581	42.5 %
Sweden	1285	1042	82	7.87 %

Operationalisation and statistical analyses

For operationalisation of attitudes to being automatically regulated, we used the question *What is your opinion on authorities using automatic low-emission zones to regulate the way you drive?* For operationalising attitudes to regulation through geofenced speed zones, we used the question *This technology can be used for several purposes. For example, for speed regulation. How do you feel about the authorities using this type of technology to regulate speed, so that you cannot drive over the speed limit in speed zones?* Even though the drivers had not experienced SZs, the opinions of these are particularly interesting as they have relevant experience from automatic LEZs where the car takes over tasks of the driver. E.g., with the way we phrased this question, it would in this SZ case mean that the car cannot be driven over the speed limit. Although both the question for LEZ and SZ are phrased similar, none of the cases question actually mentions anything about the drivers' possibility to oversteer the functionality. Although that was actually an option in the pilot of the LEZ. Both questions were measured on a 5-point Likert scale from 1 = negative to 5 = positive.

For investigating what the attitudes to automatic LEZs and automatic SZs as regulating tools are, we used univariate descriptive analyses. First with calculating the mean for the two main variables and comparing them. Next, we show the distribution, as well as the mean, between those that had noticed and not noticed the functionality of the cars, and between Norway and Sweden. We compared the means using paired t-tests to identify if they were statistically different. A paired (samples) *t*-test is used when you have two related observations (i.e. two observations per subject). The same procedure was done to compare across those that had noticed and not noticed the functionality and across the two uses cases. This is described more thoroughly in the next section.

The second set of analyses applied nested multiple multivariate analysis to identify explanatory variables for positive or negative attitudes toward being automatically regulated. These two analyses were run for both those that had noticed and not noticed the functionality. The analysis was nested using blocks of predictors, where the next block contained all the terms of the previous block, and a new block of at least an additional term. The analyses included altogether six blocks or themes, presented in the table below: 1) Socio-demographic background, 2) Driving experience, 3) Attitudes to technology, 4) Problem perception (Importance of driving environmentally friendly transport means), 5) Trust in the functionality, and 6) Usefulness. The full question phrasings and their answer categories are included in Appendix A.

Respondents

In our sample we see an overrepresentation of men, as much as 94 percent were men, while only 6 percent women. The average age was 53 (Mean = 53, SD = 11.93), while the average education level was college or university up to 3 years (Mean = 3.24, SD = 0.83). The sample further contains drivers who have had their driver's licence for a long time, around 35 years (Mean = 34.79, SD. = 11.86). The average driving distance for the sample is between 12 001 and 30 000 km in a year (Mean = 3.12, SD = 0.88, based on scale question from 1 to 5).For how much time the drivers estimate to drive on electricity in a day, the average is 64 percent of the time (but SD = 26.50).

When it comes to general attitudes to technology in the sample, the drivers on average rate this high, results shown in Table 3. The recently published paper on user acceptance of driver assistance systems with geofence (see Seter et al. 2021) also asked the same questions as found in Table 2. Interestingly, that (Seter et al., 2021) sample has a lower mean and a lower standard deviation on question 2 than our sample. This shows that our sample of BMW PHEV owners are particularly interested in driving cars with the latest technology, and as such, regarding the representativity discussion above, goes to show that drivers of these vehicles have a somewhat different profile.

Related to that, it is important to note that the sample is not a representative sample of the total population of PHEV owners. The specific sample of cars in our study can be argued to be in the higher price range, especially some of the models (Nesheimv, 2020). Another point is that drivers with certain characteristics or pre-existing attitudes can be more likely to choose certain brands of cars. For instance, see Brustad (2020) or Skogstad (2017) for examples from Norway. As such, it could be that BMW drivers specifically has a certain profile that differs from the overall PHEV owner profile.

Results

We start with an overview of the sample, before moving to the attitudes to being automatically regulated in Section 4.1., and then the regression analyses in 4.2.

Not everyone in the sample had noticed the update in the car's software. This could be due to several factors, for instance if the person has not been driving within the cities where the LEZs are defined. As we can see from Table 4, over 60 percentage of drivers noticed the update, while approximately 40 percent did not.

Attitudes towards being automatically regulated

The means for the attitude toward being automatically regulated by LEZs and SZs are presented in Table 5. When comparing the means, we find a more positive attitude towards LEZ when compared to SZ. We also performed a paired t-tests to compare the means, finding as expected LEZ and SZ are significantly different.

Based on the numbers this gives us a foundation for comparing how the attitudes toward being regulated varies for the two use cases between those that had noticed and not noticed the function Comparing horizontally in Table 6, we see that for LEZ the drivers that had noticed the functionality are more positive than those who did not. For SZ, it was opposite – those that had noticed the function had a slightly lower mean than those that did not. A paired *t*-test showed statistically significant difference for both. Comparing the means across the two use cases (vertical comparison), we also found a clear statistical significance, indicating a more positive attitude towards being regulated by LEZ compared to SZ. Hence, we see clear differences in the attitude towards being automatically regulated both in terms of the two use cases, and in terms of those who noticed the function and those that did not.

We also compared the means between the Norwegian and the Swedish samples to check for any country-specific effects. We found that the Swedish sample had a statistically significant higher mean for both use cases both for noticed and not noticed the function (See Table 1, Appendix B). We also found statistically significant difference within the countries, between the two use cases, similar to the analysis above. However, when comparing for those that had noticed and not noticed the function across the countries, there is some variance. For LEZ, for those that had noticed the function, the country difference was not statistically different, while for those that had not noticed the function, the difference was statistically significant, being higher for Sweden. For SZ, the country difference for those that had noticed the function was statistically significant, again slightly higher for Sweden. While for those that had not noticed the function, the finding was not statistically significant.

Explanatory factors-regression analyses

To compare more closely the difference between attitudes towards LEZ and SZ, nested multiple multivariate regression analyses were

Table 2
The themes and explanatory variables making out the analyses, based on main expectation in 2.2.

Factors	Variables
Socio-demographic background	Age Gender (Male) Education
Driving experience	Driver's licence Driving distance per year E-driving in everyday Often driving in cities with zones
Attitudes to technology	Testing new technology Important drive car with newest technology
Problem perception	Important with environmentally friendly transport means
Trust in the functionality	Trust in car to make shift to electricity
Usefulness	Usefulness for oneself Usefulness air quality

Table 3
Attitudes to technology and means of transport.

	Mean	Std. Dev.	Obs.
I am interested in testing new technology.	4.40	0.715	662
I think it is important to drive a car with the latest technology.	4.23	0.828	663
It is important for me to use means of transport that are environmentally friendly.	3.80	0.890	662

Table 4
Proportion of drivers who had noticed the functionality. 'Have you noticed that the car switches to electric operation in the automatic low-emission zone?' Answer categories: Yes/No.

	Freq.	Percent
Noticed that the car switches to electricity	405	61.09
Not noticed that the car switches to electricity	258	38.91
Total	663	100

Table 5
Descriptive statistics for attitudes towards being regulated by automatic low emission zones and speed zones.

	Mean	SD	Obs.
Regulating by automatic low emission zones	3.98	1.28	661
Regulating by e.g., automatic speed zones	2.16	1.34	660

Table 6
Means for the two use cases, for those who had noticed and not noticed the function. Std.dev. in parantheses.

	Noticed the function	Not noticed the function
Regulating by automatic low emission zones	4.11 (1.24)	3.79 (1.31)
Regulating by e.g., automatic speed zones	2.08 (1.31)	2.28 (1.38)

performed, for those who had noticed and not noticed the functionality, for the two use cases. The values next to the variable names refer to the unstandardised beta coefficients. Further, the tables show the Adjusted R^2, the explanatory power (adj r2), and F change, a test that determines if the variable additions significantly improved the model. The results are divided into two sections, which refer mainly to the final blocks. Full results of the regressions are found in Appendix B, Tables 2 and 3.

Explanatory variables for attitudes towards low emission zones

Summarizing the findings from the final block, Table 7, we find that for both drivers who have noticed and not noticed the function, they are more likely to be positive to being regulated by LEZ if they also drive more on electricity in the everyday, find it important to drive a car that is environmentally friendly, they trust the car to make the shift to electricity, find the functionality to be helpful in driving more environmentally friendly, and that it is useful for improving air quality if everyone has the function in their car.

The adjusted R^2 gives some nuance to the findings and the strength of the variables (Appendix B, Table 2). While the block adding important to drive environmentally friendly transport means, showed an adjusted R^2 as high as 13 percent explanatory power, for those that had noticed the function, and 17 percent for those that had not, it was especially in block 5, with adding trust in the functionality, that adjusted R^2 increased substantially. It was almost 20 percent for those who had noticed the function, and 24 percent for those that had not noticed the function. The block with the usefulness variables also had a substantial increase, to 30 percent for those who had noticed the function, and 28 percent for those that had not noticed the function.

Explanatory variables for attitudes towards speed zones

In this section we describe the results for attitudes towards being regulated by automatic speed zones. Only the last block is shown, in Table 8. Interestingly, socio-demographic variables (age, gender and education) are significant only for those who had not noticed the functionality, similar for driver characteristics. The variable important with environmentally friendly transport means was positive and statistically significant for both noticed and not noticed. Trust in the functionality is not significant in the last block, while the variable measuring usefulness for improving air quality if everyone had the function in their car, is positive and statistically significant for both those who had noticed and not noticed the function.

In general, the adjusted R^2 is much higher across the blocks for those who had not noticed the function, with 25 percent in block 6. Comparing LEZ and SZ, we see a much lower explanatory power of the regression for SZ than LEZ, notably for those that had noticed the function. This could naturally be because the actual geofenced zones that were used in the cars were for LEZ. For those that had not noticed the function, adjusted R^2 for SZ was closer to LEZ.

Table 7
Results from block 6 of nested multivariate regression analysis – attitudes towards being regulated by automatic low emission zones as dependent variable. Full regression analysis can be found in Appendix B, Table 2.

	Block6	
	Noticed B	Not noticed B
Age	0.01	0.02
Gender (Male)	0.33	0.13
Education	0.002	0.05
Driver's licence	0.01	-0.02
Driving distance per year	-0.04	-0.09
E-driving in everyday	0.004*	0.01**
Often driving in cities with zones	-0.03	0.01
Testing new technology	-0.04	0.10
Important drive car with newest technology	0.04	-0.01
Important with environmentally friendly transport means	0.16**	0.22**
Trust in car to make shift to electricity	0.24**	0.38***
Usefulness for oneself	0.11*	-0.07
Usefulness air quality	0.41****	0.30***
ADJ R^2	0.31	0.28
F Change	29.66****	6.24***

*p <.10, **p <.05, *** p <.01, ****p <.001.

Table 8
Results from block 6 of nested multivariate regression analysis – attitudes towards being regulated by automatic speed zones as dependent variable.. Full regression analysis can be found in Appendix B, Table 3.

	Block6	
	Noticed B	Not noticed B
Age	0.02	0.05*
Gender(Male)	−0.04	−0.57*
Education	−0.10	−0.21**
Driver's licence	−0.003	−0.05*
Driving distance per year	−0.11	−0.41****
E-driving in everyday	0.002	0.002
Often driving in cities with zones	−0.006	0.06
Testing new technology	0.01	0.05
Important drive car with newest technology	−0.03	−0.04
Important with environmentally friendly transport means	0.33****	0.37***
Trust in car to make shift to electricity	−0.03	0.20
Usefulness for oneself	−0.01	−0.07
Usefulness air quality	0.19**	0.22**
ADJ R^2	0.09	0.25
F Change	3.18**	2.58*

Discussion

The analysis focused on drivers' attitudes towards being automatically regulated by digital traffic rules for two use cases: LEZs and SZs. Our study finds a clear difference in attitudes towards the two use cases, with more positive attitudes for automatic LEZs than automatic SZs. This confirms the expectation that the drivers' attitudes towards having their driving behaviour automatically regulated varies for different use cases. This finding is also supported by previous research (Seter et al., 2021; Kidd et al., 2017). However, while previous research has focused on the acceptance of the technology itself, we focused our analysis on the attitudes of being regulated This is important for the transport sector as a separate research question because policies and regulation tend to lag the introduction of new technology (Mordue et al., 2020), and new technologies in vehicles are offering many new opportunities in terms of improving safety, efficiency, and environmental performance in the transport sector. Digital traffic rules, offer immense possibilities for municipalities, regions and even governments, to control or nudge traffic or make traffic flow more smoothly, safely and with less local emissions. For these societal benefits to be achieved, road authorities must start deploying policies, and the drivers' acceptance of these policies is critical for realizing this.

One possible explanation for the finding that the attitude towards being automatically regulated varies according to the use case could be that the car traditionally has represented freedom for car owners (Gardner and Abraham, 2007; Sandes et al., 2019). When the vehicle takes over an increasing number of tasks, the freedom of the driver is challenged. Determining the speed of the vehicle is one of the most critical tasks that the driver is responsible of, both in terms of manoeuvring the vehicle on the road when reacting to obstacles and road users, and controlling the vehicle during steering, acceleration and deceleration (Storsæter et al., 2021). Hence, speed is a use case that defines much of the labour executed by the driver, and automatic handling of speed could therefore be a particularly challenging use case to gain acceptance for. This has important implications for policymakers when introducing regulations at different SAE-levels.

However, it could be that LEZ use case may be more compatible with the drivers existing values, needs, and behaviour than SZ, an argument referred to as the compatibility argument. Nordhoff et al. (2021) find compatibility to be the strongest explanatory variable for behavioural intention for using automated shuttles. Since PHEV owners usually utilize their electric capacity in cities already (Arnesen et al., 2021), the LEZ use case may fit well with these drivers' existing behaviour. This is also in line with our finding of a positive relationship between how much drivers drive on electricity in the everyday and attitudes to LEZ. The compatibility argument could be an argument for road authorities to start deploying the use cases for increased use of digital traffic rules that are as close as possible compatible with values of current use of vehicles, first. Such use cases are more likely to be accepted in the public, and most likely to be implemented successfully by policymakers, before moving to more challenging use cases.

We also find support for the expectation stating that there is a difference in the attitude towards being automatically regulated between those drivers that have noticed the functionality and those that have not. For LEZ we found a clear difference, in that those that had noticed the functionality were more positive than those that had not noticed it. This is also supported by previous research, finding that changes in driving behavior and attitudes toward the technology will develop as the driver is getting to know the system (Pereira et al., 2015). This shows the importance of large-scale real-traffic studies. If the participants only try the technology for a short period, their attitudes could be expected to change as this develops over time. For instance, Jia et al. (2017) study license plate restriction policy in Tianjin, China, and find in their analysis that although drivers may be negative before implementation of this policy, the same drivers are more positive towards the policy after implementation. The authors hypothesize that the increased level of support after the implementation was due to that the drivers experienced the positive effects of the policy.

The more negative attitudes found towards speed zones, and more negative attitudes among those that had noticed the LEZ functionality contra those that had not, could be a fear of what such a control of the vehicle would entail when it comes to speed. Or that you had to switch off the function each time it happened, with no possibility to switch off permanently, making it annoying. Because of this, it will likely be beneficial to include clear oversteering possibilities if SZ are to be implemented. The testers of this study never got to see how an automatic SZ could function with oversteering and/or voluntary use, so it would be pertinent to include fully as a test use case. SZ would entail a much more visible and felt change for the driver, than the shift to electricity in the LEZ case. As mentioned, it affects the driving task to a much larger degree. However, it could also be related to the specific sample, which is not representative of the entire population of PHEV drivers since only owners of one brand is represented. The important difference between the LEZ and the SZ cases is that the drivers have not actually experienced using SZs, which could be a reason why the drivers are less positive towards this use case. They do not know how it would be enforced. When ISA becomes mandatory on newly manufactured models, this will be an opportunity to gather data and experiences from drivers that have experienced using this or similar kinds of technology.

Turning to the explanatory variables, we find that for both use cases, the variable measuring the drivers' perceived importance of using environmentally friendly transport means, has a positive impact. This could relate to the term "problem perception" and in this case environmental awareness as we measure this with a general question on environmentally friendly transport means. For the LEZ use case, those who see the problems for the environment with car use, are more likely to accept regulations to mitigate these issues (Schade and Schlag, 2003). Following this logic, transport authorities could start to investigate what drivers perceive as the largest problems within the transport sector to determine what use cases for automatic regulation would be the easiest to start with. The European Strategy on Cooperative Intelligent Transport Systems (C-ITS) follows a strategy where they have identified ITS services that are considered mature in terms of technology and highly beneficial, referred to as Day 1 services. In this strategy, the drivers' attitudes are not a key emphasis. Based on the findings made in this analysis, we would argue that the drivers' attitudes towards and acceptance of the specific services should also be an important indicator for determining which services one should start deploying first.

However, perceived importance of using environmentally friendly transport means, had an especially high effect on attitudes to SZ. While this is a topic for debate, e.g., dependent on how you calculate it (Lejri et al., 2018) some studies indicate that driving with low engine speed has proven efficient in order to reduce fuel consumption (e.g., Van Mierlo et al., 2004). If drivers believe this is the case, this could explain why problem perception has such an effect on attitudes to being automatically regulated with SZ. The findings, both for LEZ and SZ can be linked to what can been termed pro-environmental identity and how it can influence adopting environmentally friendly technologies (Axsen et al., 2012).

Another important explanatory variable that contributed to positive attitudes towards regulation in both use cases is related to the perceived effectiveness of the technology, or what we label usefulness. We found usefulness related to helping oneself drive more environmentally friendly of positive significance only for those that has noticed LEZ, which again could be linked to the compatibility argument. However, interestingly usefulness related to usefulness for improving air quality if everyone had the function in their car had a significant positive effect throughout the analyses. This can be argued to represent social usefulness. Following Morton et al. (2021), Kim et al. (2014) and Rienstra (1999) we find support for the expectation that social usefulness has a greater effect on attitudes toward vehicle being regulated automatically than individual usefulness. This comparison can also be related to the well-used NIMBY argument "Not-in-my-backyard" (Dear, 1992), which fittingly could be termed "Not-in-my-car" in this case, as we see that drivers are more positive to LEZ when they also consider the functionality as useful if others have the functionality, compared to the usefulness for themselves.

Following this observation, the question then is how to increase the experience of individual usefulness. More communication to the public can be key here, and information campaigns in an early stage have been found to influence acceptance (Bögel et al., 2018). Communicating the benefits for urban pollution and health, could be promoted as specific effects of such zone regulations. One interesting point regarding this was the findings of a difference in attitudes to the use cases in Norway and Sweden. In general, the Swedish sample was more positive overall. One reason for this, could come from the Swedish Government's action plan regarding geofence specifically (Government assignment 2018) thus providing more direction and perhaps more knowledge about this in the general public. The action plan pointed out that there is no regulation demanding geofence but provides a list of steps to assist in the implementation of the geofencing concept, as such referring to a general guideline. A similar action plan and government vision specifically regarding geofencing lacks in Norway, although it is part of the Intelligent Transport Programme (NPRA 2021). As both the countries implemented this volunteer use case with the same digital infrastructure and HMI, an interesting research question continuing forward could be to look deeper into the differences in socio-demographics and cultural explanations between the two countries, however, the scope and resources did not allow it for this paper.

Trust in the functionality to make the switch to electricity was another relevant factor for the use cases, however only in the LEZ use case. This could again be explained by the fact that the trust question was related specifically to the LEZ use case. However, the coefficient for trust was lower for those that noticed the functionality than for those who did not. It could be that they experienced that the functionality actually did not work at times. However, we cannot confirm this with the data we have. This is an interesting finding, showing again the importance of real-traffic experience, and the importance of having ADAS equipment that is reliable for achieving positive attitudes to regulation through such a measure. However, there could also be technology-specific mechanisms in play: for LEZ, one can expect the shift from the combustion engine to electricity to not be very noticeable for the driver in terms of for instance sound.

The demographic factors showed a clear tendency in the SZ use case. The analysis showed that the older you get the more positive to being regulated, education reduces acceptance of being regulated and males are more negative. This is in contrast with previous literature on acceptance of AVs (Nair and Bhat, 2021; Milakis and Müller, 2021). This highlights that the acceptance of a technology and the acceptance of being automatically regulated by technology should be investigated in separate analyses.

When it comes to SZ, driving experience was negatively influencing attitudes towards being automatically regulated. The longer the drivers had had their driver's licence, and the longer they drive in a year, the less positive they are to being regulated. This was however only statistically significant for those who had not noticed the functionality of LEZ. But this attitude could be related to anticipated feelings of infringement on their sense of freedom while driving if such a speed regulating zone is applied. Infringement of freedom is a possible determinant of attitudes towards being regulated, following e.g., Kim et al. (2014) and Schade (2003 in Kim et al., 2014) who found it to be negatively influencing acceptability. However, the recent paper by Morton et al. (2021) who studied a similar concept but for LEZ, perceived behavioural control, (which measured whether an individual considers a LEZ to have consequences for their mobility patterns), found it not to influence acceptability. The influence on SZ seems to be opposite. This is a topic that needs further investigation, and to investigate feelings of freedom as a determinant for attitudes.

The findings of the difference between LEZ and SZ indicate the need for differentiation on regulation, depending on the use case. And that with future introduction of more digital traffic rules or higher SAE-levels, we need flexible tools to do this. Geofence could be a tool for implementing different types of traffic management zones and could be used as a tool for regulation for authorities. They can be used for informing or assisting the driver, as well as enforced or controlling versions of for instance ISA. Since the geofences are digital they can also be used as a more flexible system with dynamic changes of zones, or to indicate more vulnerable zones, according to the regulatory needs of authorities. E.g., it is currently being tested as part of a road user charging instead of the more used toll system in the project GeoFlow (see also the paper by Arnesen et al., 2021 on this topic).

Digital traffic rules, such as with ISA or geofencing when being used as a voluntary enforcement, are a type of nudging, instead of hard regulations. As argued by Lehner et al. (2016) nudges can be considered a complement to traditional policy instruments, rather than a substitute for regulations – which is also something you can do with geofencing, all depending on the regulation level. The seminal work of Sunstein and Thaler (2008) argued how one can nudge humans towards making better decisions, either through information, product placements, warnings about weather etc. A nudge is meant to steer individuals in a particular direction, without imposing any regulatory or financial sanctions. As such, a speed limit is not a nudge, as a regulatory sanction would (normally) follow (Ranchordás 2019). The definition of nudging is "any aspect of the choice architecture that alters people's behaviour in a predictable way without forbidding any options or significantly changing their economic incentives" (Thaler and Sunstein, 2008). They are policy interventions, that must be designed in a way that makes it easier for people to decide. If the car itself brakes with the engine, the driver will have to make an active decision and perform a task – like e.g., pressing the gas pedal harder, to override the slowing down, as such it makes the driver perform something to end the assistance, thus making the choice easier. As such, implementing SZ in a similar way as with LEZ, where you can override the functionality, but you have to make an active decision to do that, could be a more accepted use. Although, it needs further research.

Limitations

As already touched upon, the main limitation of this study is that the test se case was LEZ, while the SZ use case was a thought scenario presented to the participants. That means the drivers and participants of the survey had a better qualification for judging the LEZ use case than the SZ. However, we believe this is a worthwhile comparison, considering the resources of the project. In this sense, it could be argued that we were able to measure acceptance of being automatically regulated, but also acceptability – that is the " prospective judgment of measures to be introduced in the future". In this case – what could be introduced.

Another obvious way of improving such a study, is to do another large-scale real traffic study with geofenced SZ functionality in the car, however, with the increasing number of vehicles holding some type of ISA, this could be an interesting follow-up study to this, and to study if experience with such solutions improve the acceptance. Another way to do a similar study, is explaining in the survey questions explicitly what type of control or functionality such a use case could have. However, we believe we have captured a general attitude, that is worthy of investigating further, with different versions of control and nudging.

Another limitation also concerns the framing of the survey questions, especially of the explanatory variable "perceived importance of using environmentally friendly transport means". This is a very general question – and does not capture the general variety and degrees of what can be considered environmentally friendly. However, the way it has been used in this paper, is as a way to capture the general problem perception of environmental problems, which we believe this could be one good measure for. Future research could benefit to create a scale based on several attitude questions, to make out a more nuanced measurement variable.

The last limitation we would like to discuss is the sample. As mentioned in Section 3.4, this is not a representative sample of the total population of advanced PHEV owners. It would demand more resources, and collaboration with several OEMs to facilitate such an experimental study of other brand drivers. However, in Section 3.4. We presented the attitudes of these drivers and compared to a previous study with another type of PHEV. The comparison showed that this sample might be representative of so-called "early adopters" of technology (Rogers, 2010) as they are particularly interested in driving cars with the newest technology. Such drivers could be especially useful not only for their knowledge with technology and thus more accurate technology evaluations (Hardman et al., 2019), but also for considering more the pros and cons of digital traffic policy interventions, such as here. However, as with the SZ discussion above, with increasing ISA vehicles in the private car fleet, it might be possible to soon achieve a more representative sample of the general population.

Conclusions

This paper started out by asking: What are drivers' attitudes towards being automatically regulated by digital traffic rules, and what are the main explanatory variables for these attitudes? The main findings shows that the drivers' attitudes towards having their driving behaviour automatically regulated varies for different use cases. While they were quite positive to the LEZ, they were not very positive to the scenario of being automatically regulated by SZ. We argue the experience with use cases, such as SZ, and further, what degree of regulation it is implemented with, matters. The voluntary LEZ use case is an example of how cities and national authorities can start planning and deploying early policies for implementing digital traffic rules in the private car fleet. This demonstrates that it is possible for authorities to make use of the technology in advanced vehicles at lower SAE-levels by defining the use of these to be voluntary and by allowing the drivers to switch off the functionality. By exploring the technology in a voluntary use case, it is possible to gather experiences from the drivers based on their use of the system in their everyday life, enabling a large-scale data collection.

Trials or piloting studies are often conducted under limited circumstances – such as time or location. Even though not all drivers use the functionality in our sample since it is voluntary, more drivers will experience learning, and this will over time influence how they experience being regulated automatically by digital traffic laws. This argument is supported by the fact that the most support for automatic regulation of LEZ were among the group that had noticed the functionality. Hence, authorities around the world should try to identify use cases where they could realize societal, environmental and industrial benefit, to among others avoid the so-called "regulatory vacuum" (Mordue et al., 2020) where the issue of accountability of the vehicle continues to be solely with the driver. Voluntary use cases are examples of how authorities could move forward in terms of using adaptive policymaking, since voluntary policies are more flexible and easier to adjust over time as experience and knowledge about the use case is brought forward. Using such flexible approaches could allow policymakers to better cope with uncertainties (Walker and Marchau, 2017).

Research on ADAS and AVs so far has been mainly focused on the technical and less on the societal dimension of the transition (see e.g., Milakis and Müller 2021). Societal implications of this study include understanding the driver's attitudes toward being automatically regulated by digital traffic rules. This could be useful for local and national transport authorities in considering what traffic management solutions they could implement, and what type of regulation is feasible for the specific challenges they face in both urban and rural areas.

CRediT authorship contribution statement

Lillian Hansen: Conceptualization, Writing – original draft, Methodology, Formal analysis, Writing – review & editing. **Hanne Seter:** Conceptualization, Writing – original draft, Methodology, Writing – review & editing. **Ørjan Mørner Tveit:** Conceptualization, Funding acquisition.

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.

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Appendixes. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.trip.2022.100611.

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