Testing Emergent Technologies in the Arctic: How Attention to Place Contributes to Visions of Autonomous Vehicles

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Abstract

There are great expectations around the future of autonomous vehicles (AVs). Such visions often picture vehicles that work *everywhere* without human interference. In this article we use empirical data from a pilot project taking place in the Norwegian Arctic to explore the place-specificity of such technologies. The case study is used to demonstrate how new configurations of emergent technologies are shaped by the places where the trial unfolds; and how insights produced through working on and with this site contribute to changing visions of AV technologies into questioning issues of transferability and scalability. In this way, the paper contributes to discussions of how pilot projects and testing of emergent technologies in the real world relates to the re-configuring of visions and expectations. The paper highlights how emerging technologies might transform societies, infrastructures and vehicles towards more computerized configurations in ways that are not anticipated or discussed in public and therefore seldom governed.

Keywords: automated vehicles, testing; place; Arctic; scalability, connectivity, Intelligent Transport System

Introduction: Transport systems, infrastructure and the impacts of autonomous vehicles

The globalization of food markets and associated food-chains has resulted in vast demand for long-distance transport of livestock, meat and fish (Anderson et al., 2018). These transportation activities depend on large technical systems such as road infrastructures and large fleets of vehicles to transport goods from production sites to markets. The transport of salmon from fish farms on the coast of northern Norway to high-end Asian markets is a good example. Large volumes of fish are brought to shore by boat, transported on trucks through Norwegian landscapes with rough roads and challenging driving conditions, before reaching Finnish airports where the cargo is flown to Japan.

Today, policy makers and goods transport actors are working to transform transportation practices to improve environmental and climatic performance and to increase profit margins. Amongst these actors, there are strong visions and expectations for the role of emerging technologies in such processes of change (Mladenović et al., 2019). Technologies like ´connected´ or ´autonomous vehicles´ (AVs) and Intelligent Transport Systems (ITS) are examples of innovations that many believe are likely to transform the transport sector in the near future (e.g. Sovacool et al., 2019; Stilgoe, 2018; Mutter, 2019), providing seemingly universal solutions to diverse challenges associated with transportation. While actors such as the European Commission claim that we are only a few years away from a reality where autonomous vehicles are the norm (EC, 2017), and industrialists have argued that it is only a matter of months until the most important technological challenges facing full AV implementation are solved (Duarte and Ratti, 2018; Koetsier, 2020), the potential social, economic, environmental and practical implications of autonomy, automation and digitalization in the transport sector are contested (Haugland and Skjølsvold, 2020).

Innovation within this field is often conducted through demonstration projects, test beds, field trials and pilot projects. Such projects[1] are at the centre of our approach in this study, as we zoom in on one site where intelligent automotive technologies are being developed and tested under arctic conditions in the north of Norway. Through this, we seek to gain new insights about how visions of intelligent automotive transport futures are enacted, but our ambitions are also broader. Pilot projects do not only discretely test new technologies. These sites are places where 'visioneering' is transformed into materiality (Engels et al., 2017), potential sites of 'anticipatory governance' (Guston, 2014) and milieus where the ethics of invention (Jasanoff, 2016) are shaped in rapidly evolving fields. These sites constitute important geographical locations for studying emerging technologies, as well as the shaping of knowledge claims and visions about future societies.

Actors involved in the case we study, mobilize the characteristics of the place to lend credibility to the tested technologies. Compared to Silicon Valley and other sites associated with artificial intelligence and driverless vehicles, northern Norway provides an altogether different set of challenges for AVs. Hence, if successful, the test site might become somewhat of what Gieryn (2018) calls a truth-spot for AVs. Interesting questions for us are how studying pilot projects may contribute to our understanding of current innovation practices and how pilots relate to visions of technology introduction, scalability, and place? By investigating such questions, we bring to the surface otherwise marginalized debates and alternative visions of technological pathways for automation and digitalisation of large technical transport systems.

Studying emergent technologies: the role of experimentation and pilots

In recent years, a scholarly interest in a ´sociology of experimentation´ has boomed. Research in this field studies societal experimentation and testing in real-world social environments (van de Poel et al., 2017; Marres, 2019). Studying experiments beyond the laboratory have been flagged as central, as they clearly constitute places where new forms of governance, economy and subjectivity are invented (Engels et al., 2019; Van de Poel et al., 2017; Marres and Stark, 2020; Gross and Hoffmann-Riem, 2005). While experimental development of new socio-technical configurations provides opportunities for experimenting both with new socio-political orders and technology (Marres et al., 2018; Marres, 2019), some scholars have noted that it is quite rare that pilot projects do more than test technologies under standard societal conditions (Schot and Steinmueller, 2018). However, AV performing tests in public streets have recently prompted STS-scholars to raise new questions concerning the relationship between such innovation activities and the social. Many of these real-world intelligent vehicle tests explicitly focus on social phenomena and thereby, do not comply with the "social deficit" associated with testing reminiscent of older STS accounts of testing (Marres, 2019; Pinch, 1993). Actors conducting AV testing, for instance, often highlight that improving the understanding of vehicle-pedestrian interaction is a key element of the test (Haugland and Skjølsvold, 2020; Marres, 2019).

Thus, while these tests operate with rather narrow understandings of sociality one cannot claim that they are void of social concern. Our point, however, is that we should not only see these occasions as attempts of transferring the tests from laboratories to social environments such as public streets. We should also explore the relations *between* real world sites of testing, their relations to the environments they are part of, and focus on how such a move can illuminate social change, more broadly.

Many assumptions about the future of AVs and ITS are based on what we might call technological hype produced by media actors, policy makers, consultants, and companies promoting AVs (Stilgoe, 2020). Hype, however, does not mean insignificance. STS scholars have illustrated the 'constitutive' nature of promises, e.g. within literature on technology expectations. Visions, expectations, and technological hype are not only predictions of the future, they also produce futures (Van Lente and Rip, 1998; Borup et al., 2006; Skjølsvold, 2014; Pollock and Williams, 2010; Stilgoe, 2020). This makes such predictions interesting research objects. It also points to the importance of scrutinizing who predicts what and why and the importance of studying emerging technologies at an early stage, "before they become just another fact of life" (Stilgoe, 2020: 5), both in the quest to govern technologies, and to be able to understand the transformative power of technology in order to be able to resist, stop, slow down or redirect technological trajectories (Jasanoff, 2016).

Pilot projects, trials and experiments are important sites, where the discursive elements of expectations are made concrete and material (Engels et al., 2017). They represent an approach to innovation which signals ambitions of making technologies that function when implemented in society (Skjølsvold et al., 2020; Ryghaug and Skjølsvold 2021b) and tend to have a dual set of ambitions: On the one hand, they seek distinct and localized lessons. On the other hand, there is often an outspoken ambition of scaling up and to apply what has been tested in one setting universally (Naber et al., 2016; Ryghaug et al., 2019; Engels et al., 2019). Classic STS-accounts note how technologies become shaped by their social surroundings (e.g. MacKenzie and Wajcman, 1999; Williams and Edge, 1996) or through the work of relevant social groups (Pinch and Bijker, 1984), which is echoed in accounts of how pilot projects for technologies are often shaped by a combination of local concerns (Skjølsvold and Ryghaug, 2015; Ryghaug and Skjølsvold, 2021a) and wider repertoires of interests, understandings and competence circulating through international networks (Bulkeley et al., 2014; Engels et al., 2019). In this paper, we build on such perspectives from STS, and aim to contribute to discussions of how and in what ways pilot projects, experiments and testing of emergent technologies in the real world relates to the re-configuring of visions and expectations.

Social implications of AVs and different levels of automation

In the discussion above, we mainly engage with the enactment and materialization of expectations in concrete trials. However, there are also strong visions for how AVs will affect life on the roads more broadly. This is visible in the increasing media- and scholarly interest in AVs (Stilgoe, 2020; Duarte and Ratti, 2018; Shladover, 2018; Sperling et al., 2018), in part shaped by vehicle development, but also wider transport and mobility developments, e.g. Mobility-as-a-Service, traffic management, and IT applications for transport in smart cities. Important interactions have also been established between automation and innovations in modes of ownership and fuels (Hopkins and Schwanen, 2018). Today, new cars can automate tasks that until recently have had to be performed by the driver through technologies such as automated and adaptive cruise control and lane assistance systems. Fully automated – or popularly called “driverless” or “self-driving” cars – have arguably gone from being interpreted as highly unlikely, to becoming what many think are an inevitable part of our near future, soon to be found driving down every street (Sperling et al., 2018; Stilgoe, 2017; 2020).

The hype and expectations both in terms of technology development and how AVs might change societies, have led social scientists and others to critically engage with such visions, and to reflectively probe potential societal implications of AVs. Examples include questioning whether AVs will lead to safer environments for pedestrians (Combs, 2019), increased vehicle miles travelled, (negatively) impact public transport, reduce the overall number of vehicles and parking spaces (Duarte and Ratti, 2018; Soteropoulos et al., 2019) and if AVs would demand more or less road infrastructure; contribute to increasing urban sprawl, or rather attract more residents to city centres if they are freed from congestion and pollution. Loss of social safety and privacy have also been identified as potential social implications (Blyth, 2019). AVs may potentially impact many aspects of our lives.

Through reviewing the literature on the effects of automated driving, Milakis et al., (2017, 2018) divided the implications of AVs into: (i) day-to-day usage impacts (travel costs and choices), (ii) impacts to long-term decisions (vehicle ownership, sharing, residence choice, land use and infrastructure), and (iii) overall societal impacts (energy, environment, equity and health). Others have discussed the potential implications of AVs by simplifying them into extreme future transportation systems scenarios, such as the “Heaven” and a “Hell” scenario described by Sperling et al. (2018) where the Heaven scenario focuses on effects such as improved safety, accessibility and equity among travellers and a Hell scenario characterized by further entrenchment of private vehicle ownership and negative effects such as increased vehicle use, suburban sprawl, fossil fuel usage and less use of public transit and active travel modes.

While all the above tend to be discussed as impacts, or effects of technology, they are in reality parts of the societal visions and expectations for how AVs will change the world. Hence, a move from the study of pure discourse to the study of materialization, is also a move towards studying consequences and implications in the making. Not long ago, laboratory tests were the norm for AV development (Leonardi, 2010), but a rapid rise in real-world testing to learn and to proceed to higher levels of intelligence has ensued (Stilgoe, 2017). To us, this also entails the making of sites that on the one hand tests technologies and social aspects, but which on the other hand also contributes to the production of new visions and expectations. One practical consequence of the move from laboratory to street, is that the different levels of automation have become omnipresent in discussions of AVs. These levels serve as a solidification and standardization of certain technology expectations. As one can read on the website of the US National Highway Traffic Safety Administration (NHTSA, 2020):

> Fully autonomous cars and trucks that drive us instead of us driving them will become a reality. These self-driving vehicles ultimately will integrate onto U.S. roadways by progressing through six levels of driver assistance technology advancements in the coming years. This includes everything from no automation (where a fully engaged driver is required at all times), to full autonomy (where an automated vehicle operates independently, without a human driver).

Here, the NHTSA refers to the J3016 Levels of Driving Automation standard developed by the Society of Automation Engineers (SAE). This standard divide driving automation into six distinct levels, ranging from level 0 (no automation) to level 5 (full automation).[2] At level 5, automated features allow the vehicle to “drive everywhere in all conditions” (SAE International, 2016). The SAE standard, originally developed to elucidate the challenge of automating the driving task (Stayton and

Stilgoe, 2020), has come to define level 5 automation as the singular goal of transport automation (Ganesh, 2020; Hopkins and Schwanen, 2021). This suggests that, at some unspecified point in the future, self-driving vehicles will be capable of operating within any environment without needing support from 'smart' infrastructures. Such a future is promoted by Tesla, as well as other AV proponents (Stilgoe, 2018). For a vehicle to operate without concern for its specific environment, however, it is crucial that the technology learns how to drive in different environments.

Street trials with AVs on public roads are said to provide the variety necessary for learning vehicles how to drive under every single circumstance. Testing under real-life conditions is important in order to benefit from machine learning. Such testing allows the technology to learn from unexpected situations that would be difficult to simulate (Stilgoe, 2017; Marres, 2019). If most road automation trials are about displacing innovation activity and experiments from the laboratory to the real world to do experimental innovation (Laurent and Tironi, 2015) in line with the logic of data-intensive machine learning which requires learning from as many and varied situations as possible, it should be important that these trials are not always "displaced" to very similar environments. On this basis one should expect that real-world AV trials were conducted in very different environments (arctic, tropical, etc.) with different characteristics (urban, rural, road topography and geometries) and under different conditions (weather, traffic, pedestrians etc.) in order to ensure successful operation in all possible contexts.[3]

The early history of AVs had prominent plans for integrating car innovation and road infrastructure (Stilgoe, 2018). From the 1950s until quite recently it was assumed that, in order to get self-driving cars to operate well, they would require communication with equally intelligent highways and road infrastructures (Wetmore, 2003). However, in the last couple of years, innovations experimenting with intelligent road infrastructures such as responsive traffic light systems or concepts of fleet steering and truck platooning[4] (like we focus on in this article) have not been given equal weight. Current field tests focus mainly on cars and associated automotive technologies driven by platform companies such as Google, Uber and Tesla (Stilgoe, 2018). Early trials were also typically done in remote and confined spaces, such as the Mojave Desert and Nevada Desert, although AV trials in cities and urban areas have become more common (Hopkins and Schwanen, 2018; Marres, 2019). Such urban AV trials have, however, typically been configured in specific parts of the city, such as new residential and/or commercial developments (e.g. Greenwich Peninsula in UK) and sites characterized with lower traffic flows and less complex road configurations (Hopkins and Schwanen, 2018; Haugland and Skjølsvold, 2020).

Many of the test sites that have already been studied in Europe also have been heavily prepared and facilitated to curtail interaction between intelligent vehicles and other road users (Marres, 2019; Haugland and Skjølsvold, 2020). Thus, there is clearly an ´unevenness of laboratorization´ going on (Hodson and Marvin, 2009).[5] This deserves more attention when trying to anticipate the futures that could surround self-driving cars, which futures such cars might enable, what futures those advocating such technologies might push for, and likewise what future transport scenarios become disfavoured by increased focus on AVs (Haugland, 2020).

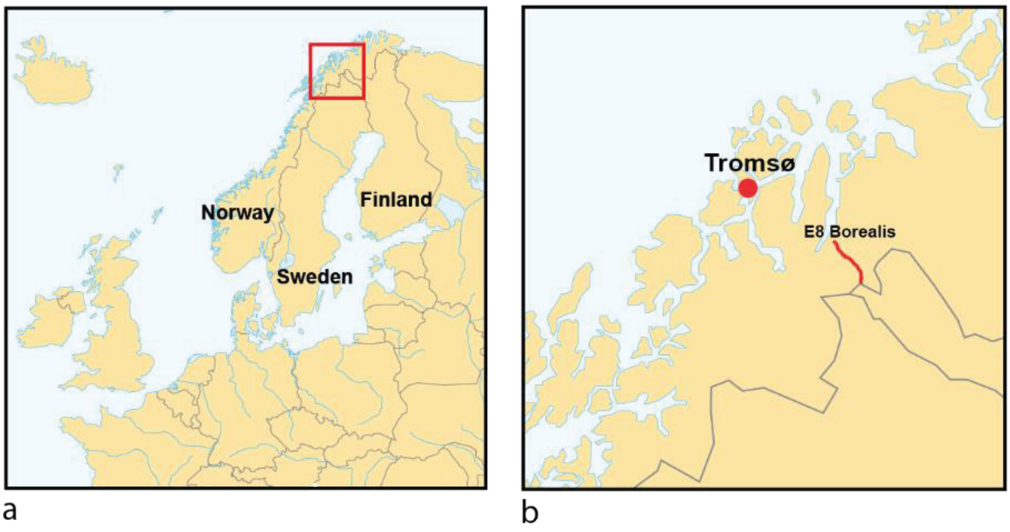
Testing emergent innovations in different environments and under particular hash conditions is obviously important for both technical and non-technical reasons, as we also need to empirically examine different ways in which road trials of intelligent automotive technology contribute to the production of new visions and expectations and configure relations between society and innovation in new ways. Thus, in this article we have chosen to focus on a case study representing a test site for intelligent transport technologies that clearly stands out from typical urban test sites in warmer climates: a test site along a long road stretch in a remote area north of the Arctic Circle.

Infrastructures and other elements of the built environment in polar regions have traditionally been given little attention in the literature (Schweitzer et al., 2017). The particular "laboratory" reputation of the Arctic, as a technology-intensive locality that renders tensions between human and technology in these settings unavoidable (Usenyuk et al., 2016) should however be acknowledged. For instance, it has been shown that continuous modification, tuning and even redesign of technology *in situ* have been necessary for humans and machines to function in these extreme settings, often leading to new design principles (Usenyuk et al., 2016) and new insights highlighting the contextual relevance of design, innovation and policy implications of developing technologies for extreme and uncertain environments (Usenyuk et al., 2020). Others have focused on the important role of the state in building infrastructure in the polar regions (Schweitzer et al., 2017).

In the following, the Borealis test site on European route E8 will be analysed – a case that does not focus primarily on vehicle technologies but may represent a particularly hard case when it comes to testing intelligent transport technologies and road infrastructures in rural and remote settings. By zooming in on one particular field site where intelligent automotive technologies are piloted we are able to articulate more precisely not only *what* is being tested and how this relates to the place, but also how these innovation practises can question the whole narrative of "placelessness" that characterize the current vision of AVs (Hopkins and Schwanen, 2021). Thus, the case study is used to demonstrate how new configurations of emergent technologies are shaped by the places where the trial unfolds; and how insights produced through working on and with this site contribute to changing visions of AV technologies into questioning issues of transferability and scalability. The pilot test under scrutiny in this article, also contributes to illuminating some unforeseen glitches in the technology at hand. Consequently, and indirectly, it also points towards questioning the transferability of knowledge gained through other AV test sites and field trials, acting as truth spots (Gieryn, 2006) for claims about AVs.

The case study: Developing and testing intelligent transport technologies in the Arctic

The Borealis project, chosen as case study for this paper, has been described as both a research and development programme and a national test laboratory for new technology covering a 40-kilometre-long stretch of the European route E8 in Skibotndalen, 69 degrees north in the Arctic reaches of northern Norway.[6] E8, which stretches 1,410 kilometres from Tromsø, Norway to Turku, Finland and goes through Skibotn to Kilpisjärvi is one of five Norwegian road sections selected as pilots for the development and testing of ITS solutions in Norway. While the pilot project in Norway from Skibotn to Kilpisjärvi has been named Borealis, it also has a Finnish counterpart project running from Kilpisjärvi to Kolari, named Aurora. However, in this article we will mainly focus on the



Figures1a & 1b. 1a Norway's placement in Northern Europe. 1b The location of the Borealis project (© Kartverket under a CC BY 4.0 license, modified by the authors).

Norwegian part of the project run by Norwegian Public Roads Administration (NPRA).

The paper is based on observations and qualitative interviews of key actors of the Borealis project, including a site visit by three of the authors to the Borealis test site during the first on-site testing in the winter of 2019. During the site visit we also took part in several meetings between different actors operating in the project, mostly consisting of (chief) engineers and leaders responsible for conducting the testing on behalf of NPRA, as well as representatives from several technology developers engaged in different subprojects of Borealis. In these meetings and during the on-site activities, status, progress, challenges, and ways forward were topics that were discussed. In addition to these participations and field-observations, our main empirical data material consists of eight semi-structured interviews with key participants of the Borealis pilot project. These actors consisted of senior engineers, planners, test-leaders, and test-conductors, companies involved, and local government.[7] The interviews, ranging from 25–85 minutes in length, were conducted by the authors and subsequently transcribed verbatim. In addition, written sources, and updates on the project in meetings and seminars and more informal briefs given to us by the NPRA as part of a larger project in which Borealis was picked as one of the cases, contributed with additional insight about the pilot activities after the visit. These additional sources, as well as our interview data, provide us with a rich material for thoroughly analysing the pilot project and its operation. In the next sections we will zoom in on the innovation strategies that have governed the pilot project and how place specific concerns are raised through the implementation of this project setting out to test intelligent transport technologies in the Arctic.

Innovation strategies of the Borealis pilot activity and test site

The Borealis test site was organized by the NPRA to test and develop Intelligent Transport Systems (ITS). ITS is an umbrella term that covers technology and computer systems in the transport sector. In an ITS system communication can flow from one vehicle to another, from the vehicle to the roadway or from the roadway to the vehicle. Examples of such technologies are real-time information about weather, road surface conditions and traffic accidents, automatic scanning of the vehicle's brakes, and warnings of wildlife or other obstacles on the roadway. According to the NPRA, ITS combines technology and computer systems with a dual goal: For road users and transport operators, ITS can make the drive safer, more efficient, and more environmentally friendly. For those who operate and maintain the road, ITS can make it easier to implement the right measures at the right time.

In the start of the project, the NPRA enlisted the help of the interest group ITS Norway to host a workshop and an idea-competition. Subsequently, the NPRA received 36 ideas of which they chose 16 concepts they deemed interesting, before ultimately selecting 8 projects for funding. Table 1 gives an overview of most prominent technologies that were tested within the Borealis project and related concepts discussed by test side organizers and participants during our visit to the test site and in interviews.

The NPRA organized the innovation process so that these firms could implement their technologies alongside the road chosen to be a test site. However, before doing so, they needed to know the real problems in this north region. They therefore organized dialogue meetings and interviewed different stakeholders and users of the roads such as local industry (customs, fishing industry, businesses) and those using the road (like truck and bus drivers) to identify their needs and what their problems were. These insights were fed back to technology developers in and after these meetings.

According to the NPRA, this road was selected for its socio-economic significance, especially with reference to the road's high importance in exporting fish from fish farms by the Atlantic Ocean to European and Japanese markets. Thus, its importance as a corridor for transporting fish from the Norwegian coast to an airport in Finland cannot be overstated. Time is a complicating factor in this regard. The fish should be at the Finnish airport no more than 18 hours after being loaded onto the truck. Driving the stretch takes 16 hours, giving the truckers no more than two

Table 1. The Borealis project: concepts and technologies that were tested

Technology	Description
Truck platooning	Technology for linking of two or more trucks in a convoy. Combining communications technology and advanced driving support systems allows the vehicles to maintain a pre-determined distance, reducing air drag and thus also fuel consumption.
LIDAR technology	LIDAR technology uses a pulsed laser to determine the distance from the LIDAR and to an object. In the Borealis project, LIDAR was mounted on poles, to judge the technology's merit in identifying trucks coming to a stop in slippery uphill slopes.
Parking sensors	A set of parking sensors were dug into a stretch of the road. The sensors use the magnetic field generated by the mass of a passing vehicle to identify the vehicle type. Like the LIDAR, these sensors may also identify vehicles coming to a stop.
Smart signs	Digital signs placed along the road. The text on the signs is editable, and the signs are connected to communications infrastructure. These signs are capable of displaying alerts received from other infrastructure, such as the aforementioned LIDAR, as well as information about road and weather conditions.
I2V and V2V communications	Different solutions for facilitating communication between infrastructure and vehicles (I2V) or between vehicles (V2V). These technologies include both software for processing and distributing alerts and hardware for passing these alerts from infrastructure to vehicles or between vehicles.
Distributed acoustic sensing (DAS)	Acoustic cables cast into the road. When a vehicle passes over the cables, noise is introduced to the signal passing through the cables. This signal noise might then be used to identify the kind of vehicle passing or follow the vehicle's trajectory.
Roadside cameras	Combining Bluetooth, wi-fi, and cameras, these cameras were intended to contribute to the estimation of travel-time, counting vehicles, and give the proper authorities an overview of an unforeseen situation, e.g., an accident.
Clocking-app	An app surveying and suggesting adjustments in vehicle speed to avoid waiting time and traffic jams. As Northern Norway has multiple locations with narrow tunnels and bridges, this app would allow these sites to be traversed in a problem-free manner by avoiding oncoming traffic at these narrow sites.
Travel-time estimation	A set of algorithms combining available data, for example weather data, road conditions, previously registered travel times, etc., to predict travel-time
Relevant Concepts	
Smart roads	Umbrella term for ITS technologies, for instance technologies mentioned here are technologies that detect vehicles moving upwards, and then different alerts are set if the speed is declining or it stops completely. It is also sent back to the Road Traffic Centre, possibly also directly to the smart signs.
Communications infrastructure	A general communications infrastructure was established along the road. This would enable the above technologies to communicate with each other or with, for example, the Road Traffic Centre or road maintenance providers in the case of unforeseen events.
C-ITS	Cooperative intelligent transport systems and vehicle-to-vehicle and vehicle-to-infrastructure communication which is seen as one step towards more autonomous or automatic vehicles, and cooperative awareness messaging

hours to spare for unforeseen events with potentially big economic losses in the case of delay. The two hours margin could easily be "eaten up" by for instance, a bit of trouble, or a slow loading process at Skjervøy (the largest fish landing in the area), and weather conditions. With icy roads an additional 30 minutes fitting chains on the tires, and another 15 minutes removing them, leaving only a 15 minutes margin for travelling the whole road stretch. Thus, getting stuck on the notoriously difficult to drive road stretch of the E8 road in Skibotn, would result in serious trouble. The cargo would risk decay in both taste and value, the plane would be lost, the sushi would lose its 'rigor mortis' and the Japanese would not be willing to pay a premium price for the fish. The alternative would be freezing the fish, reducing the market value by seventy-five percent. Thus, improving solutions for when to slaughter the fish, when to send the trailers and on to which route, may have significant importance for fish farmers and the local economy.

Thus, the Borealis test site was chosen both because of its important role in the local community and for its difficult test-site environment, as the E8 road had very demanding winter conditions and a large share of heavy vehicles and trucks trafficking the road. The fact that the road stretch itself was nick-named "the road from Hell" and considered a terribly difficult stretch of road to drive as the weather in the area often caused chaotic situations: trailers sliding off the road, trucks with difficulties getting up the long and quite steep hill of the Skibotn valley, the road getting blocked for hours by trucks in need of vehicle assistance, was seen as an advantage for experimenting. From the point of view of the test organizers, it was considered a particularly tricky place for demonstrating intelligent automotive technologies. As one of the NPRA project leaders noted: "If you think of self-driving vehicles in terms of the school system, then Arizona is kindergarten", the flat and confined trials of the Netherlands as elementary school, driving on European roads as secondary school and driving in Finland, as high school as you will have to deal with snow. However; "if you manage to drive the Skibotn valley down, then you are at the PhD level". Thus, by operating tests in this harsh environment the NPRA was deliberately striving to test technologies under difficult circumstances. The harsh winter conditions and demanding road infrastructure were considered as advantages and something Norwegian research communities could capitalize on. According to one of the NPRA engineers,

> the special challenges we face in relation to positioning, communication, and that they do winter testing in Norway – If you manage to attract foreign companies to do so, then we have succeeded because we get technologies that are more robust and more beneficial. Our goal is not that Norwegian industry will make the cars (…) but they have to function in Norway.

Here, we clearly see how field scientists, or in this case, the engineers strived to justify their choice of the specific place and the research site as being analytically strategic (Gieryn 2006) in that it uniquely displayed certain forms of process with great interests for technological advances.

The NPRA saw the trials as a way of showcasing the difficult circumstances that intelligent automobile technologies must be able to operate under, highlighting that the harsh winter conditions are an opportunity for Norwegian innovators, who could attract foreign companies by using the circumstances to develop more robust intelligent automotive technologies. However, this argument was not always easy to convey to other actors working on automation and ICT solutions. The argument that, for the technology to work, it had to handle all kinds of situations, was often met with pointing to the peculiarities of the place: that it is not like that everywhere. However, for the NPRA engineers the question should be the opposite: how many days of snow the European economy would be able to handle if everyone was driving their own AVs. Thus, we see that the peculiarities of the site played a double role; both as a credibility-enhancing geography (Gieryn, 2006) that was required in order to develop reliable technological solutions that could work 'anywhere', but at the same time contested by some of the IT and automation industry experts because Norway was not exactly 'anywhere' – hinting towards the fact that other sites were perceived as more naturalized 'anywheres' or 'placeless places' that could enhance the credibility of scientific claims.

According to the engineers involved in making the smart signs and communications solutions, the Borealis project was exciting because it would give answers on how far one could get regarding self-driving vehicles by using existing technology and what new technologies were needed to make it work. Following this line of reasoning, it was important for the Borealis project to be open about *the limitations* of the technology and what possibly could be tested in the trial. However, this kind of critical remarks about limitations of the technology were sometimes sanctioned by the IT and automation industry actors in the project, who were afraid that such remarks might harm them.

Thus far, this article has focused on conditions that are important for the NPRA to consider when setting up the trial and some of the rationale for creating a test site under such difficult conditions. The position taken by the NPRA seemed to strive towards more robust technology, but also creating more socially robust knowledge (Nowotny 2003; Stilgoe 2017) about self-driving and AV technology; to manage technological expectations so that they better aligned with societal needs and urgent challenges to be solved.

Another result of this was that the NPRA deliberately worked to keep the trial relatively small and to minimize the complexity by reducing the number of technologies being tested and to manage expectations and visioneering. While some of the industrial partners from the IT and automation industry wanted to “conquer the world” by designing a comprehensive digital platform capable of handling all the data gathered and processed in the Borealis project, the NPRA worked to keep the test site focused on solving local pertinent issues. Thus, instead of buying into the bold visions around big data and machine learning associated with AVs they decided to focus on small use-cases concerning how to use existing intelligent automotive technologies to improve the building and use of tunnels. This they saw as something that could potentially add value both for NPRA and the local community as it would keep them from having to build new tunnels.

Thus, technological solutions used to showcase the project, such as platooning, were not really something that was tested out, although these concepts featured prominently in the public accounts of the projects. This, however, did not mean that platooning and self-driving vehicles did not play a role in the project. Platooning self-driving trucks and AVs seemed to play a role in allowing for particular ways of operating the innovation process. It was seen as crucial for branding the project and had created a lot of media attention and political support. This type of big and shiny visions was regarded as important tools to give NPRA engineers finances and leverage: as “building blocks needed to be able to work undisturbed”. Thus, the innovation process was deliberately set up with the inherent duality: to, on the one hand upholding big shiny visions about self-driving cars and technological advances, on the other hand pushing for technological sobriety and realism within the project team in order to be able to push the development forwards realistically and stepwise.

Place-based challenges of the trial site

There were several issues concerning correct positioning of vehicles in the area. Some of these problems related directly to the positioning of the site near to, and at, the border to Finland. For the technology to work properly it was important that technology developers could use correct maps. However, at the borderline between Norway and Finland, an unanticipated problem was identified: Gaps in the Global Positioning System (GPS) maps between the national borders. As one of the engineers explained:

> One thing is to find out where you are going, but it must be connected to a map. And that link between the position and the map is made a little bit differently in each country. We have a small gap of ten centimetres where there really is nothing! On Norwegian maps there is nothing, and on Finnish maps there is nothing. But, of course, there is something there! But it is these systems that make it wrong.

Although the digital maps showed a non-existent area, this area was of course very real in the physical world. Thus, the engineers working in the project clearly found challenges that needed to be addressed for the intelligent automotive technologies to function accurately in this type of environment.

Tectonic plate movement represents another challenge to the accuracy of GPS. As explained by one of the engineers: The GPS and the associated Global Navigation Satellite System (GNSS) refer to a fixed position on the *globe*, not the Earth’s *surface*. As the tectonic plates imperceptibly drift over time, this means GPS positioning will not match the maps of the actual terrain. In one instance, the NPRA found that a GPS map produced in 1989 consistently positioned all the marked road signs incorrectly, by approximately 0.5 metres. This was after some time discovered to result from continental plates drifting 46 centimetres north-east since the maps were made. This made the engineers question the prospect of using GPS for AV positioning, as this would require a positioning accuracy of at least ten centimetres for the vehicles to drive safely. As tectonic plate activity influences GPS positioning, this would require maps to be updated regularly.

The above challenges would be present across the globe. The upper reaches of the northern hemisphere, however, came with their own set of problems in relation to GPS. First, GPS relies upon a set of four satellites for accurate positioning. As most of the satellites are located to the south-west of Northern Norway, geometry dictates that accurate positioning is harder to achieve as the angles from the satellites and onto the globe flatten. To achieve accurate positioning in these areas, one would need satellites in hyperelliptic orbits.

The prospect of accuracy was challenged further by the quite frequent natural phenomenon of Northern Lights (Aurora Borealis in Latin) made driving by GPS signals difficult as well, as one of the interviewees explained:

> Everyone says the Northern Lights are terrific! Let's send all the Asian tourists with autonomous vehicles to look at the Northern Lights! But what does the Northern Lights do to satellite navigation? It is a living hell for GPS signals, it destroys them! So, then the uncertainty increases, and we start driving the tourists into the ditches (…)

The amount of Northern Lights in the area is considerable, thus this would lead to a huge challenge. But also, the latitudes would reinforce this as the challenges related to GPS positioning mentioned above. Altogether this makes it difficult to have a good positioning fixed in the high north.

We find this to be an interesting juxtaposition concerning Norway's dual identity as one of the foremost countries both on natural phenomena as the Northern Lights, and as a frontrunner in emerging AV technology testing. As noted above, interviewees deemed navigating AVs in the north as problematic due to lacking GPS accuracy. Within positioning, one usually went by "three meters, 50% of the time" as the standard rule, which was considered fine for landscape measurements. A similar standard of levels of accuracy would however be fatal for positioning AVs that would require much more accurate positioning to be considered safe. This kind of inaccuracy of using GPS also led to discussions about other types of inaccuracies that the engineers struggled with within the automation projects.

When talking about intelligent automotive technologies, one of the things that puzzled the engineers in the project was the accuracy and myriad of signals that would be going to and from, and in between vehicles and the road infrastructure. They felt very unsure about the prospect of every problem being solved by local sensors, as was often presented as the answer when raising questions about the inaccuracy of GPS positioning. They would not get any good answers from industry partners about what levels of accuracy they could expect regarding sensor technology. According to the NPRA engineers, local sensors might also fail. Without a proper distribution of signal wavelengths when using LIDAR technology for local positioning, an automated vehicle might experience 'sensor blackout' when interpreting an outgoing signal from another car as a returning signal from its own sensor. This points to both the importance and limitations of back-up systems and made the ITS developers aware of the importance of making technologies that communicate across different domains, and the importance of adapting and/or upgrading infrastructure in order for self-driving vehicles to work.

Furthermore, there were the more mundane problems relating to winter conditions, such as snow and ice, which influenced the effect of sensors tested in the Borealis project. Snow on the sensors meant you could no longer get much information from them. Therefore, building infrastructure that also could help with the positioning was important. Sensors are well-known to have serious problems during difficult weather conditions, and the project therefore focused on infrastructure (for instance in signposts) along roads and in tunnels that could help with the positioning of AVs.

In fact, massive investments and technologies were built into the roads and infrastructures in order for the technologies tested at this site to work. Examples were costly broadband cables in the ground that ensured communication and connectivity on the test site and 120 sensors installed in the asphalt to detect and send signals back to the traffic centre if vehicles stopped in the hills. Consequently, the vision of AVs being able to navigate the world's complexity using only its sensors and processors seems far-fetched. In addition to the webs of social and technical connectivity so-called autonomous vehicles rely upon in order to work (Stilgoe, 2017), their implementation also appears to demand expensive and comprehensive infrastructure upgrades which are unlikely to be undertaken indiscriminately across the nation's road network, as illustrated well by this case.

Cross national cooperation and different innovation cultures

The agreement between Finland and Norway which was initiated on a high departmental level to develop innovations and think anew regarding freight transport in this particular pilot, also seemed to have some significance for the focus of the project. The Finnish part was carried out by commercial actors and therefore governed by more price-concerned thinking. The Norwegian side of the project was on the other hand, run by a public body, the NPRA with a different innovation approach to this kind of project. The fact that Norway still has a lot of engineers employed in the Public Roads Administration, compared to other European countries that have replaced many of their transport engineers and with procurement officers also play a role and had consequences for the division of labour between the two test sites.

The technologies tested also had national imprints that aligned with cultural standards around safety and risks. For instance, communicating directly to the driver by mobile phone was unheard of in the Norwegian context, in contrast to the Finnish. This was, according to the NPRA engineers, rooted in cultural differences: In Norway where traffic security was higher up on the agenda than in other countries, engineering strategies were accordingly risk averse. This also impacted who were regarded as important players to cooperate with. If you designed systems that communicated directly to the car (for instance telling the car to slow down because of an incident on the road ahead) consequently car manufacturers were considered more important. This was one reason that Norwegian Borealis actors considered cooperation with car or truck manufacturers more important than on the Finnish, Aurora, side of the border where one designed systems that communicated with the driver.

These examples clearly indicate how innovation activities were shaped by different engineering cultures and standards related to risks and safety. Technologies developed were shaped by their social surroundings, by local concerns and wider repertoires of interests, understandings and competences.

Conclusion

Most research on autonomous vehicles (AVs) focuses on vehicle technology or seek to anticipate the societal impacts of autonomous vehicles (Milakis et al., 2017). We have argued that to understand the direction of innovation, its potential consequences, and to reflect on the governance of these emerging technologies, we need to study the sites where they are currently developed and tested. Today, such innovation increasingly unfolds in real-world environments such as in test beds, street trials and pilot projects.

In this paper, we have used empirical data from one such pilot project situated in the Arctic to point out the place-specificity of testing and its consequences for visions of autonomous vehicles. The paper challenges some of the dominant visions about AVs and ITS, especially related to the often-overlooked networked aspects of these emerging technologies. Thus, the analysis reveals several challenges associated with digitalization of the transport sector and intelligent automotive systems which today are being ignored in most scholarly and public debates about self-driving cars and intelligent transport systems that deserves further attention.

First, we establish that the development and testing of intelligent automotive technologies is shaped by the place in ways that have serious consequences for the trustworthiness of current AV and ITS visions. The analysis of the Arctic test site demonstrates that testing of intelligent transport systems is tied to geographically specific needs and problems such as unreliable GPS signals and sensors related to inadequate maps and positioning systems, influence of Northern Lights, and difficult weather conditions. Thus, we point out several technological challenges usually ignored when discussing the future of AVs. Visions of AVs as able to navigate the complexity of the world using only its sensors and processors is likely to be misleading. 'Placelessness' is however, an important feature of level 5 automation, with vehicles being expected to work without any human interference *everywhere* and under all conditions. It should be noted though, that the placelessness of AVs is about adaptability of technology to different circumstances, not about universalism as such. Referring to the Borealis site, an NPRA engineer argued that "if [a technology] works here, it will work anywhere". This statement suggests that the particularities of place can be taken into consideration, to the extent that a technology might work anywhere. Theoretically, placelessness is achievable. However, as suggested by our case study, it can only be approached by focussing intensely on the particularities of places. This also means that placelessness can only be imitated, and not truly achieved: in order to give the impression of placelessness across vast geographical swathes, a wide variety of place-specific factors have to be compensated for, whether through further technological development or additional, supporting infrastructure. This means that although placelessness might be possible in theory, it is both hard-won and improbable in practice, as both AV infrastructure and automated driving is highly place specific.

Second, this points to the fact that achieving full automation would require substantial work and sizable infrastructure investments, to such an extent that an indiscriminate implementation across the globe is entirely unlikely – one need only consider the substantial number (and complexity) of environmental factors which would have to be adjusted for at the Borealis site studied here, to make this point. If intelligent automotive technologies were made to work in difficult geographical areas such as the Arctic, heavy infrastructure developments would be required for fully autonomous vehicles to operate. As the case study reveals, AVs and ITS will have to rely on webs of social and technical connectivity and require vast investments in infrastructures and communication networks to function properly. This is also shown in other studies of autonomous vehicle street tests (Marres, 2019; Hopkins and Schwanen, 2018). However, this type of work and investments are often underplayed in the current narratives of AVs futures.

This points to a third challenge relating to the fact that not all places in the world would have the same capability to develop these required infrastructures. For instance, it is known that the agency of infrastructures and built environments in Arctic and polar regions have more easily been overlooked, partly because these regions are less densely populated (Schweitzer et al., 2017). New additions to communications networks and infrastructures in such areas may however have more profound social implications and maintenance may be more demanding in terms of financial and human resources, thus pointing to the need for governmental support in order to build and maintain these infrastructures. Thus, we see pertinent challenges related to both scalability and justice concerns.

This brings us to conclude concerning the question: what does the analysis reveal about what it means to transform societies, infrastructures and vehicles towards more computerized configurations and how to govern future intelligent automotive technologies? So far, visions and innovation activities in the field of AVs have been dominated by market-driven, expert-focused discourses that may limit the range of alternative AV futures (Hopkins and Schwanen, 2018). Street and roads testing have often been associated by a lack of engagement with societal contexts and concerns. They have been identified as having profound limits to responsiveness in innovation related to inadequacies in social learning, the inability to involve diverse sets of actors in testing and by a lack of accountability towards the populations enlisted in tests (Stilgoe, 2017; Marres, 2020).

In the Borealis pilot some efforts were made to include local stakeholders, such as the fishing industry and road users when developing the test site. The site was chosen because of its role as a socio-economically important stretch of road, as a key transport corridor for seafood export from Norway to European and Asian markets. Thus, while there are clear commercial interests and market logics at play, the fact that the pilot was governed by public sector actors and engineers committed to solving real societal problems shaped the innovation activities in a different direction than most AV and ITS pilots.

The pilot was framed as a test site that may situate Norway as an innovation centre with regards to automation, in the same way as many other countries trying to attract business by showing off industrial strengths and ambitions in this area. However, those involved in the Borealis pilot strived to deconstruct more established truth spots (Gieryn, 2006) that previously had lent credibility to claims about AV and ITS futures in Europe and the US. For instance, when AVs have been tested on the roads in San Francisco or in London, these testing sites have been portrayed as both anywheres – placeless places with underlying patterns that can be found in most cities – while at the same time being field sites with strategically important qualities (such as Lombard street in San Francisco, being called "the crookedest street in the world" by one of Google's founders (Stilgoe, 2020: 21). By conducting, developing and testing AV and ITS innovations in remote areas in the Arctic, it also become evident that not all test sites easily represent such lab-like anywheres. This has made us ask, whether certain truth spots may be able to displace knowledge claims from other (less truthful) places?

'Truth-spots' have traditionally been related to scientific or other knowledge claims and not, as in our case, claims within engineering used to demonstrate that technologies work. However, interpreting a truth spot, as a proof of concept, thus more in line with a 'proof-spot', which lends credibility to knowledge claims about the workability of technologies, demonstrates the importance of developing knowledge and experiences outside more traditional (often urban) truth-spots. We argue that such proof-spots are crucial for understanding how vehicles, self-driving or not, may drive in more extreme environments. However, it remains to be seen if new proofs from the Arctic in the form of challenges to level 5 automation can displace well established visions and expectations of autonomous driving based on work elsewhere.

Through the in-depth exploration of a large scale intelligent automotive technology pilot project that seek to structure and stimulate innovation by piloting new sociotechnical arrangements *in situ*, undertaken here, our ambition was to explore how place contributes to and challenges the credibility of knowledge claims, visions and expectations about AVs and ITS more generally. We regard the evaluative capacities of this road test as modest, but not without merit, as we see evidence of new and interesting articulations of social, cultural and political aspects related to intelligent automotive technologies being developed by the involved actors. However, seeking to understand how testing and the social relate by investigating how testing "operates *on* social life, through the modification of its settings" (Marres and Stark, 2020: 423) should be an important endeavour for future Science and Technology Studies also in other areas.

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Notes

1 Although we are aware that pilot projects, test beds, experiments, demonstration projects and field tests and trials have distinct features and can be defined more precisely, they are often used interchangeably depending on empirical focus and disciplinary backgrounds (Engels et al., 2019). We have therefore chosen to try to use the term "pilot project" consistently throughout this paper, as this is how the project that we are studying are most often labelled, without drawing sharp boundaries to other similar terms.

2 In between levels 0 and level 5 this categorization gives the following levels: *one*, features which provide warnings and/or momentary assistance; *two*, when some functions respond using information about the driving environment, but the driver must be ready to take control; *three*, when cars are fully autonomous under certain traffic conditions; *four*, when cars also perform all safety-critical driving functions within a certain number of driving scenarios (SAE International, 2016).

3 The possibility to reach level five autonomy has been disputed (Stilgoe, 2018). Still, if the goal is level four autonomy, we would expect that a thorough and diverse testing is necessary in order to enable the technology to essentially bracket the context in which the vehicle is embedded.

4 A configuration where two or more trucks are linked in convoy, using connectivity technology and automated driving support systems (so that vehicles automatically maintain a set, close distance between each other).

5 Some cities are also viewed as more worthwhile experimenting on than others, for reasons related to economic, regulatory, cultural bearings or other aspects pertaining to how they are structured and what significance they are thought to have nationally and internationally.

6 https://www.vegvesen.no/Europaveg/e8borealis/inEnglish downloaded 22.10.19

7 The pilot project was tied to several other smaller trial projects in the region, where our interviewees reported having included public consultations. Our empirical material also includes a focus group interview with users (truck drivers that used the road, the truck drivers' association as well as the Mayor of the municipality). Road users and representative organisations were not the primary target for the focus in this article.