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Framing Intelligent Transport Systems in the Arctic: Reindeer, Fish and the Engineered Road

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ABSTRACT

The article explores the relationship between humans and other animals, technology, and engineering practices in a project testing Intelligent Transport Systems (ITS) in the arctic. Generally, roads are engineered to promote efficiency and predictability for transport. However, in the arctic northern region of Norway, animals sometimes challenge these virtues. Using Goffman's notion of frames and Callon's concept of overflow as theoretical starting points, the article explores how transport engineers develop intelligent transport infrastructure and envision ways of including animals and other non-humans in the engineers' framing of the road. The engineers first and foremost implement new technological artefacts, which allow them to survey the road in a manner which makes nature's overflows onto the road more manageable. However, these artefacts do not merely contain nature in the engineers' frame—the engineers also envision humans, in this case, motorists, to change their practices. As such, the engineers' attempts to contain animals in a particular frame entail using technology to assemble a new relationship between nature and culture. Taking nature into account when planning and developing infrastructure means reassembling a particular nature-culture relationship. Thus, the article points out that in order to engineer nature, it is also necessary to engineer culture.

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1. Introduction

Modern transport systems are increasingly made up of a combination of physical and digital infrastructures, in configurations often referred to as Intelligent Transport Systems (ITS). Proponents of ITS argue that combined physical-digital infrastructures might help reorganize the transport sector in a manner which makes roads safer, more efficient, and more predictable. The emergence of sociotechnical systems such as ITS represents an opportunity to understand how engineers attempt to construct future societies, including particular conceptions of how humans and non-humans might coexist.[1] The role of technology in shaping society and vice versa has long been a central concern within Science and Technology Studies (STS).[2] However, despite the observation that humans have not separated nature from culture, relatively little attention has been paid to the role of *non-humans* in

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the construction of sociotechnical futures.[3] This is noteworthy, considering the fact that the development of the built environment and associated infrastructures cuts through and alters animal habitats, threatens biodiversity, and decimates invaluable landscapes.[4] As such, there is a need to consider how technologies and technologists—such as engineers—deal with nature and its critters.[5]

In this article we look at how transportation engineers' practices take animals and other non-humans into account when developing and testing an ITS. Do engineers consider how animals will or might interact with roads, now and in the future, or are these interactions simply left to chance? This question is crucial to consider: while roads (and, in the case of ITS, associated technologies) are engineered to facilitate human activities, humans are not the only beings who traverse the road. Roads are also part of environments where animals cross, graze, find shelter, and are transported. Hence, in order to create sustainable environments, it is crucial to take animal-human interdependence seriously.[6] Cross-disciplinary thinking between STS, environmental history, and animal studies can provide fertile ground for epistemological inquiries into the role experts have in constructing boundaries between the environment and human-built infrastructures.[7] While road infrastructure relies heavily on the knowledge, skills, and expertise of engineers, transport planning practices have often ignored or overlooked animals, or relegated them to some less important domain.[8] However, the current development and implementation of ITS (including sensors, communication systems, and new materials) is giving rise to new epistemic practices in which there might also be carved a place for animals.

Transportation systems can be conceptualized in a multitude of ways.[9] Through the emergence of telecommunications in the 1990s, a new understanding of transport systems arose, allowing for viewing transport systems 'as the combination of physical and informational inputs that allow a transport activity to take place.'[10] ITS may be considered an extension of this development. By pairing remote sensing with information and communications technologies, new opportunities for surveying and controlling traffic flows arose.[11] As the cost and size of computer hardware and sensors continue to decrease, engineers can develop new tools for charting movement within cities or along highways. By extension, the amount of data collected provides both new opportunities for modeling transport and new tools for surveying and controlling movement.

The development and implementation of ITS is also postulated to be a prerequisite for the realizing of autonomous vehicles (AVs). While recent narratives on AVs have tended to focus on vehicles rather than infrastructures, there is reason to believe that it will be necessary to develop both physical and digital road infrastructures to accommodate such vehicles.[12] AVs are posited to have wide-ranging implications for society, including aspects such as safety, environment, urban development, and transport planning.[13] As such, ITS are tied to a development which at least is posited to initiate comprehensive sociotechnical transformations.[14]

Development and implementation of new technologies is often associated with both unintended and unwanted consequences, and therefore warrants critical scrutiny.[15] In this article, we study one such project, where the Norwegian Public Roads Administration (NPRA) installed ITS technologies on a road located in the arctic reaches of Northern Norway. As we will show, a multitude of human and non-human actors shape and are impacted by the development of such new transportation systems. However, engineering is often conceived of as a purely technical practice, which ignores or downplays the social aspects of the profession.[16] Even less attention has been given to the more-than-social aspects of engineering, such as the place of (other-than-human) animals. This is our concern in this article. Engineers play an important role in defining what a road should be, how it is supposed to be used, and by whom. In doing so, engineers employ a set of methods which embody a particular approach to knowledge production. This outlook impacts the extent to which animals are considered when practicing engineering—for example, when developing road infrastructure. Hence, a closer look at the methods and epistemology of engineers is warranted.

1.1. Engineering knowledge

The engineering profession is curiously hard to define. This is evident not least when attempting to articulate the profession's epistemological basis.[17] Whereas engineering often involves the application of scientific knowledge, as reflected by the oft-used labeling of engineering as 'applied science,' engineers are generally not scientists.[18] Still, much of modern science relies upon the operation and interpretation of technological apparatuses, which often results in technical and scientific competences being collapsed into a more general techno-scientific epistemology.[19] This comes with an associated bracketing of the epistemological particularities of the engineering profession, as well as engineering knowledge as a distinct kind of knowledge.[20] Whereas the above implies a close relationship between science and engineering, there are some aspects where the two approaches visibly diverge.

Kant and Kerr argue that engineering should be considered separate from the sciences as engineering methods 'are not the product of disinterested inquiry.'[21] Unlike scientists, who ostensibly embark on a quest for answers regarding the nature of reality itself, engineers are expected to produce satisfactory *solutions*, often from incomplete knowledge and in the face of limited resources.[22] Whereas the *perceived* universality of science stems from its frequent disengagement from the context of its production, engineering happens in an explicitly sociotechnical context.[23] Engineering work is both conducted within sociotechnical systems and geared towards the construction or modification of such systems. As such, engineers are faced with demands regarding funding from employers—such as governments, the military and large companies—and expectations from society at large.[24] Because of these constraints, engineers strive to make the best from available resources and knowledge in a given timespan—with the quality of the chosen solution depending on these factors. Accordingly, 'engineering methods do not attempt to produce accurate … models of the phenomena they study.'[25] Rather, engineers only describe reality to the extent that is necessary for solving the problem at hand.[26]

Transport systems engineering processes are situated in complex networks of knowledge, involving multiple disciplines, like geography and economics.[27] With engineering knowledge being built on shifting sands, engineers are concerned with 'knowing when or why to search for new knowledge or update existing knowledge.'[28] This, we argue, also means that engineers are concerned with what aspects of the world may be reliably identified at any given time. As existing technologies are improved or new technologies are introduced, new aspects of the world can—or may need to be—surveyed. Consequently, engineers are both given and produce new tools for knowing. If we consider engineering tools to be tools that both describe and shape society, the emergence of new tools might have social impacts, as they facilitate new ways of organizing the world through engineering methods. This may have ramifications beyond the social: as human activities intrude on animal habitats, engineering tools are sometimes used to manage the reciprocal intrusion of nature into the realm of the sociotechnical.[29] This warrants an exploration of the relationship between the social and the natural, and the role of technology in constituting this relationship.[30]

1.2. Technology, nature and culture

Although transport engineering thematizes nature and wildlife, it is often as an afterthought.[31] The way in which animals are considered when developing technology-based infrastructure is seldom spelled out or problematized. Generally, animals are seen as something that can be dealt with, as external to the road localization. In this article, we question this perspective and seek to explore how animals are taken into account when developing ITS.

Examples of animals being affected by human activities are numerous, as reflected by numbers indicating world-wide biodiversity loss.[32] An often-cited example of technological activities affecting animals is the industrial melanism observed in industrial England. Moths with dark wings blended better against smog-blackened trees and were thus eaten less frequently than their paler siblings. Over time, this shifted the moth population toward darker colors, meaning that coal-fired industry affected natural selection.[33] Norwegian reindeer provide a grimmer example of animals being affected by technology. Through their lichen diet, Norwegian reindeer are still exposed to radiation stemming from the 1986 Chernobyl nuclear accident. Consequently, the radioactivity levels in reindeer meat may still exceed the levels permitted within the European Union.[34]

However, animals are not only inadvertently affected by human technological activity. They are also regularly and actively made part of human affairs. For example, fish have generally been placed at the nature side of the nature-culture divide, perhaps due to the 'difficulties of building affective relations with fish.'[35] However, with the advent of gene-editing in the 1980s, the introduction of salmon infused with a human growth gene launched a heated debate in Norway, with the acceptability of particular nature-culture relations being discussed and (re)defined at the national level.[36]

The salmon population of the Deatnu River in Northern Norway provides another example of how nature-culture relations might differ within the nation state. The dwindling salmon population of the Deatnu has been made an object of national regulation and recipient of governmental care. Overfishing has been diagnosed as the cause of the population's decline; as a result, strict regulations have been put in place to conserve the population. [37] However, the Sámi people living by the Deatnu have contested the state's actions, as the regulations 'prevent them from fishing in the same ways that they have for generations.'[38] To the Sámi, care for the salmon is closely connected to care for the continuation of Sámi culture near the Deatnu. Such an expression of care emerges from a less pronounced nature-culture divide than that of the state: rather than being part of nature, the Sámi consider the salmon part of their culture. The state's expression of care, on the other hand, sees (a monolithic conception of) human culture disturbing the fragile balance of nature, necessitating state intervention. This shows how different groups construct the relationship between nature and culture in their own distinct manner.

The above examples show how human actions do not merely affect animals or take them into account, but also shape and reshape both nature and culture in a manner which makes the stark nature-culture divide of modernism hard to uphold.[39] While human activities affect and are inextricably linked to non-human actors, these actors are to a varying degree considered and/or incorporated into new and emerging sociotechnical systems. In this article, we aim to understand how engineers take non-human actors into account when planning or developing transport infrastructures and by which means animals are included in their framing of the road.

2. Framing and overflowing

If the primary task of engineers is to establish satisfactory solutions, it stands to reason they need to actively demarcate the situation at hand: what is the problem, what is the desirable outcome, and what aspects are necessary to take into account in order to produce a satisfactory solution? With this as a starting point, we find the concepts of framing and overflow to be helpful in elucidating our case study.[40]

The concept of framing originates with Erwing Goffman and refers to the (usually implicit) rules of interaction in particular situations.[41] Goffman distinguished between two primary frameworks: natural and social.[42] When assessing a situation, a person first tries to ascertain whether the situation is the result of guided or unguided doings. Consider a truck grinding to a stop on an icy slope. The truck would be subject to the unguided doings of nature: weather, temperature, and downpour have conspired to bring the truck to a halt. However, to the subsequent motorists for whom the truck is blocking the road, the frame changes: the situation is now subject to social standards and human judgement. The whole situation might even depend on whether weather conditions or the truck driver are considered to be at fault.[43] In its most general sense, the concept of frames refers to the social framework we interpret a situation in light of, regardless of whether the situation originates with guided or unguided doings.

Whereas Goffman distinguished between natural and social frames, his writings dealt almost exclusively with social frames.[44] These are characterized by an (again, usually implicit) agreement or mutual understanding of the proper ways of interacting. Upon approaching a situation, people mobilize their cognitive resources and past experiences in order to interact without having to think twice about the situation. However, cognitive resources and past experiences are only part of what allows for frictionless interaction: frames are also profoundly shaped by the material and organizational devices surrounding a situation. Upon entering an art museum, for example, one will act and interact differently than when entering a shopping mall. However, as most of our daily interaction takes place within surroundings where known elements are assembled into familiar patterns, the familiarity allows us to bracket our links to the surroundings and act unencumbered.[45]

While a frame structures interaction, the frame is not total. Frames depend on the material and organizational surroundings as well as a mutual understanding of the situation at hand. Frames can also be misinterpreted, intruded upon by external actors, or even actively challenged. Even though a frame allows for the surrounding world to be bracketed, the links to the surroundings are not severed. Thus, there is ample room for (guided or unguided) doings to intrude on the frame. Michel Callon termed such instances 'overflows.'[46] In many instances, overflows can be adapted to without substantially altering the frame in question. However, the existence of overflows raises questions regarding the completeness of frames and whether overflows are the exception or the norm. If overflows are the exception, this implies that framing is an outcome that is easily achieved. If overflows are the norm, this suggests that framing takes a considerable effort. Callon suggested that the latter is the case: establishing and maintaining framings requires substantial and often continuous effort. Upon inventing new (material or organizational) devices for establishing more complete framings, 'each of these elements, at the very same time as it is helping to structure and frame the interaction of which it more or less forms the substance, is simultaneously a conduit for overflows.'[47] Attempts at containing overflow only serve to introduce further linkages to the world outside the framing.

Transport infrastructures such as the road may be seen as a frame encompassing both formalized and informal elements. Road conduct is governed by the traffic code and its associated infrastructures (for example, signs, road markings, traffic lights).[48] Further, the road is associated with certain norms and assumptions, such as being predictable, safe, and efficient—all aspects dealing with guided doings. However, the road which is the subject of this article is a site where multiple overflows originate in the (ostensibly) unguided doings of animals and weather.[49] One could argue that the road is a site where the natural and the social meet, but this would suggest that the natural-social distinction can easily be made.[50] This is not the case. As pointed out previously, the nature-culture distinction differs between groups.[51] As such, the exact character of this distinction will depend on the identities of the involved actors.[52] This also applies to professional identity, which profoundly shapes the framing of a situation.[53] Hence, rather than positing any pre-existing distinction or relationship between the social and natural elements, our analysis focuses on how engineers reassemble a particular nature-culture divide in relation to the road.

3. Method

This article explores the Borealis project, an ITS project initiated by the Norwegian Public Roads Administration. The origin of Borealis can be traced to 2016, when the Finnish Transport Agency (FTA) initiated the Aurora project. In Aurora, the FTA equipped a 10 km stretch of the E8 road with digital infrastructures. The NPRA was inspired to conduct a complementary project on the Norwegian side of the Norwegian-Finnish border and struck up a partnership with the FTA. The Norwegian project was initiated in 2017 and was named Borealis. Together, the two projects spell *aurora borealis*, Latin for the northern lights. For Borealis, a 40 kilometer long stretch of public road was designated as the test area. The stretch reached from Skibotndalen in Troms and Finnmark County to the Norwegian-Finnish border (see Figure 1). After enlisting a group of nine partner companies and institutions, a 10-kilometer section of the E8 was equipped with electricity and communications infrastructure and a variety of technologies, with testing of these commencing in March 2019.[54]

The E8 was chosen as test site both due to the combination of demanding weather conditions and its socioeconomic importance. In terms of climate, most of Northern Norway is located in the arctic region, characterized by long, snowy winters that are mild in coastal areas but cold inland. The E8 starts in Tromsø, where the coastal climate is relatively mild,

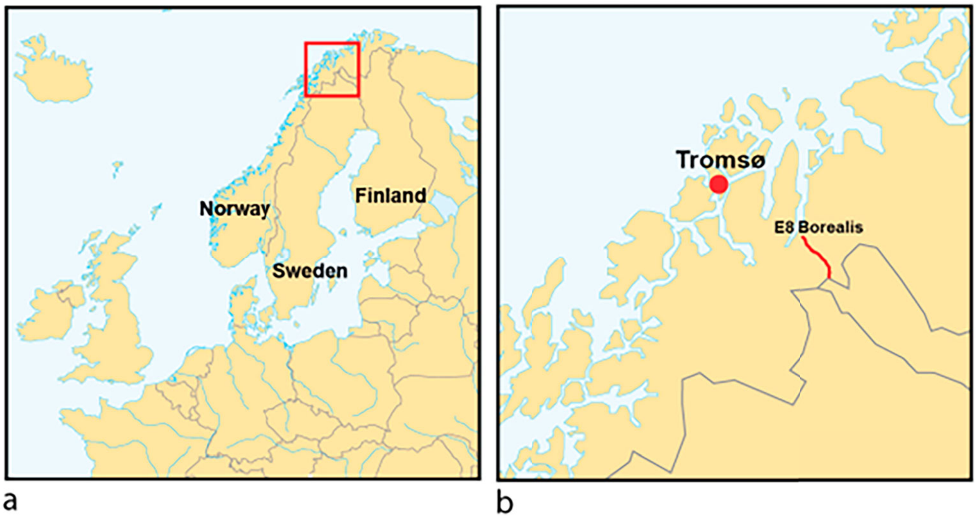

Figure 1. Location of the Borealis project. a: The location of the Borealis site in Northern Europe. b: The location of the Borealis project in relation to the regional capital Tromsø. (© Kartverket under a CC BY 4.0 license, modified by the authors.).

runs along fjords, before turning inland towards the Finnish border. Hence, the E8 is characterized by a relatively broad range of climatic conditions, especially in the winter. The socioeconomic importance of the E8 is also related to its coastal proximity, in particular fish, which is Norway's third largest export good (approx. EUR 9,500 million/year) after crude oil (approx. EUR 25,700 million/year) and natural gas (approx. EUR 26,200 million/year). The E8 acts as a transport corridor for freight trucks carrying fish from the coast of Northern Norway to airports in Finland, where the fish is flown to European and Asian markets.[55] The growing market for Norwegian fish has led to a significant increase in heavy transport along the E8 (according to the NPRA's websites, a 70% increase since 2010), with freight trucks now making up 26% of the road's total traffic. In order for the fish to reach European and Asian markets, trucks first need to safely carry the highly valuable but often time-sensitive cargo along a road where temperature and weather conditions change rapidly, from relatively temperate coastal climates to freezing inland temperatures.

Whereas the E8 is increasingly trafficked by fish-carrying freight trucks, these are not the only denizens of the road. The road is also populated by private motorists, public transport, tourist buses, and local fauna, as well as herds of semi-domesticated reindeer. These four-hoofed mammals are bred by the indigenous Sámi people within Sápmi, the cultural region of Fennoscandia traditionally inhabited by the Sámi. As with the aforementioned Deatnu salmon, reindeer are a central part of Sámi culture, as well as an important means of economic sustenance for the Sámi population.[56] Given that the reindeer herds graze over a considerable area, domesticated reindeer frequently interact with transportation infrastructure. Figure 2 shows reindeer suddenly emerging on the E8 as we approached the Borealis test site for our fieldwork. Thus, the E8 is a site where vehicles meet both animals and weather, elements that make the road prone to overflows.

Our analysis is based on observations and qualitative interviews with stakeholders and participants in the Borealis project, mostly conducted on site. We conducted 11 interviews

Figure 2. Reindeer emerging on the road. (© The authors under a CC BY 4.0 license.).

with key stakeholders involved in the Borealis project, including representatives of the Norwegian Public Roads Administration (including civil engineers and project managers), technology developers whose products were being trialed, regional politicians, and industry actors from transportation and goods procurement. The interviewees were selected as they held key roles in the shaping of the new ITS systems and the road. The interviews were recorded, anonymized, and transcribed verbatim. We also draw on policy documents, white papers and gray literature. Our collective data material was inspired by a Grounded Theory approach, allowing the empirical basis to shape the direction of the research.[57] The combination of open-ended interviews and an analytical approach where the central actors were not defined beforehand allowed us to identify a variety of actors as implicated in the Borealis project—including reindeer and fish. These unexpected actors emerged during our coding process, piquing our interest: as these actors seldom show up in scholarly discussions regarding ITS, they seemed to offer an interesting entry point for studying the relationship between animals, technology, and engineering practices.

4. Analysis: nature, technologies and ways of knowing

The engineers working in the Borealis project argued that in order to solve problems, one needs to understand both the available technology and the local culture. Hence, when preparing the Borealis project, the NPRA sought out the views of local actors such as public transport companies, the customs office, road maintenance companies, and the fishing industry, as to identify particular challenges facing the E8 road and possible ways of solving them. In terms of perspectives, however, this list had some notable gaps: reindeer herders and Storfjord Municipality, the municipality hosting the Borealis project, were merely kept informed, rather than being consulted. The list, then, suggests a particular focus: the NPRA appears to primarily have sought out the perspectives of those whose business and/or logistics rely upon an efficient and predictable road, rather than actors whose connection to the road was less obvious—including other-than-human animals, such as reindeer and fish.[58]

The NPRA's elicitation of local perspectives, however partial, was grounded in a belief that the problems of the road might be solved by other means than technology. Whereas the funding and development of Borealis relied upon the construction of technology-informed visions, the NPRA did not believe technology to be the sole solution to the problems they had identified: cultural change might be another option.[59] As one engineer put it, by way of analogy: 'you cannot ask the French to stop drinking alcohol and driving afterwards—but it would be more cost-efficient for society if people quit driving when drunk than to invent cars that allow people to drink and drive.' The engineer's statement suggests a distinction between cultural and technological change, in which technology is seemingly a neutral (though expensive) means of solving problems, whereas changes in culture might be more efficient but harder to achieve. The distinction between technological and cultural change lacks precision, though, as the implementation of new technology often requires an associated change in culture and, in our particular case, even the reconfiguration (or reengineering) of the nature-culture relationship.

4.1. *Fish and timing*

One example of overflow stems from the Norwegian fishing industry. The E8 road where the Borealis project was located is a route used for the transportation of fish from the coast of Northern Norway to Finnish airports, where the cargo is flown to Euro-Asian markets. This cargo is time-sensitive, especially when the fish has not been frozen. However, a common problem in the winter is freight trucks grinding to a halt on slippery uphill slopes, blocking traffic. One of the NPRA's partners attempted to mitigate this problem by equipping the road with repurposed parking sensors capable of identifying the magnetic signature of trucks coming to a stop:

> It's a challenge that large trucks filled with fish have problems in slippery slopes, stopping everything behind them. The alternative route is extremely long in comparison, so that's it for the cargo, the value is lost. Now, we are testing the detection of trucks driving up this problem hill, which send out warnings if [a truck] slows down or stops. We then send warnings to the road central, and alternatively also to the smart signs. (Interview, technology developer)

Upon identifying a truck experiencing difficulties, the sensors would alert the traffic authorities through a dedicated communications infrastructure. This would allow the authorities to rapidly deal with the situation and re-open the road. Paired with an alert sent to the smart signs in the region, the sensors would also be able to communicate to truck drivers, allowing them to choose a different route long before reaching the blocked road. The sensors, if working properly, would help make the road more predictable and decrease the chances of a spoilt cargo. The importance of efficiency and predictability along the E8 was also stressed by an NPRA engineer:

> You've got 18 h to get to Helsinki, with maximum two hours to spare. If loading is slow at Skjervøy, you lose one hour, you use 45 min for installing and removing snow chains, which leaves you 15 min to spare. If someone gets stuck in a slope, then, your cargo is spoiled, you'll miss the flight to Asia from Helsinki, and lose the 'rigor mortis' in the sushi. Alternatively, you could freeze the cargo and lose 75% of the value. (Interview, engineer)

Due to its specific biological composition, fish is a highly perishable good. The combination of perishability and the E8's unpredictability means that the fishing industry is faced with a choice: either transport fresh fish and risk losing the cargo in case of unforeseen events or freeze the fish and lower its retail value in order to avoid this risk.[60] However, by equipping the road with ITS technologies, the Borealis partners sought to improve predictability and ease time-management, thus possibly reducing the need to deal with a specific animal characteristic of fish, namely its perishability. By establishing an overview of when, where, and what goods and people are on the road, overflows would become more immediately identifiable and thus also quickly manageable. Curiously, reducing the need to freeze the fish would possibly also alleviate an already existing overflow in the engineers' frame of the road, which we turn to next.

4.2. Reindeer on the road

The semi-domesticated reindeer of the Sámi can often be seen walking leisurely on the roads of Northern Norway, where they run the risk of being hit by motorists. This problem has been exacerbated by the fishing industry: during transport, frozen fish sees a slight temperature increase, which causes ice to melt and spill saline fish water onto the road. As reindeer seek nutrition in the winter, the salt brings more reindeer to the road. In neighboring Finland, motorists deal with reindeer through the mobile application (app) Porokello (Finnish for 'reindeer bell'). The app allows drivers to report real-time reindeer observations via their smartphones. When other app users approach the same area, they are alerted by a sound notification. However, Norway is more restrictive than Finland regarding the use of mobile phones in cars, precluding the implementation of such an app. The implementation of an ITS, however, could help manage the reindeer.

One NPRA engineer suggested that by equipping reindeer with GPS trackers, one could reduce the number of such reindeer being killed by drivers.[61] Using data from GPS trackers, it would be possible to communicate the presence of reindeer on the road to cars in the area through dedicated communications infrastructure—so-called infrastructure-to-vehicle (I2V) communications. For example, the vehicle could play back a pre-recorded voice message warning the driver that there are reindeer ahead. However, the engineer expressed some concerns regarding the prospect of drivers taking the necessary care after being alerted:

> You can begin to alert vehicles. Not necessarily the driver… In a car, the weakest link sits between the steering wheel and the seat… But if we can communicate with the car and have it act differently, if the navigational system communicates that there are reindeer ahead, rather than merely alerting the driver with a reindeer icon. Or if the driver is routed around [the reindeer], without even knowing that there was trouble on that road. They are merely recommended an alternative route or to lower their speed. (Interview, engineer)

Rather than merely 'alerting the driver with a reindeer icon,' the engineer suggested that upon receiving a reindeer alert, the car's functionality could change. One of the engineer's suggestions was to have the car's navigational system redirect the current route as to avoid the reindeer altogether. Another suggestion was to have the car's system change the inflection point of the gas pedal. Such a change would cause the car to decelerate, forcing the driver to apply more pressure to the pedal to maintain the (too high) speed. Through this functionality, the driver would have to make a conscious decision to continue to drive at a high speed after being alerted to the presence of reindeer. These suggestions demand the driver to exert different degrees of agency and show how the inclusion of reindeer in the frame of the road demands a certain control over the agency of motorists. In this case, the engineer envisioned changes in the relationship between the driver and the car.

The Borealis project also tested pole-mounted LiDARs pointed toward the road. This technology uses laser pulses to measure distance and was implemented to assess whether it could be used to identify trucks coming to a stand-still in steep uphill slopes. One NPRA engineer, however, envisioned a possible alternative use. He suggested that pole-mounted LiDARs might also be used for identifying quadrupeds on the road and subsequently communicating their presence to cars in the vicinity. However, he argued, moose do not 'walk like a catwalk model in front of you': they move unpredictably, which makes it complicated to produce a useable LiDAR signature. However, the engineer suggested, a potential solution would be to place a LiDAR device at a farm and use horses to produce a LiDAR signature for large quadrupeds. Rather than correctly identifying the *species* of quadruped, this signature would allow the LiDAR to identify the presence of *any* large quadruped on the road. This reflects the practical approach characterizing engineering methods: rather than correctly identifying the quadruped, the aim was to reduce its chances of becoming roadkill.

4.3. New ways of knowing, new overflows

In our last example, we no longer deal explicitly with animals. However, the example still warrants inclusion because it succinctly illustrates the problem of constructing a comprehensive sociotechnical system to contain overflows, regardless of whether they originate from nature or culture. Also, the example still relates to the nature-culture divide, with the northern lights representing nature. The previous examples we have discussed show how the engineers dealt with *known* problems. However, their attempts at dealing with the known problems also revealed new, hitherto unknown problems. One such problem originated with the northern lights. Since the late 2000s, Northern Norway has seen a steady increase of so-called northern light tourists, lured by the prospect of seeing the northern lights, going reindeer and dog sledding, and feasting on salmon, reindeer, and other local delicacies. To properly be able to see the northern lights, tourists seek out areas without light pollution, such as the rural stretches of the E8. This, it turns out, has unexpected ramifications for road safety. In Borealis, the NPRA installed cameras to survey certain stretches of road. To their surprise, the cameras showed tourists stopping their vehicles and laying down in the middle of the road to better take in the view of the northern lights. This practice could obviously lead to dangerous situations, should a loaded truck pass by at the wrong moment. Whereas the engineers did not present any specific solution for addressing the problem, the example still illustrates how technologies not only create new overflows, as in the example of saline fish water, but may also expose existing, though previously unknown, overflows.

While the NPRA engineers sought to use technology in order to create a comprehensive frame for the road, technologies may also expose existing overflows, as exemplified by the novel practice of stargazing in the middle of the road. While the practice leaves few material traces, it became knowable (and known) through technological means. The implementation of new artifacts did not only allow for the inclusion of new elements in the engineers' frame, it also gave the engineers new knowledge of the road, which introduced them to a new overflow. Whereas engineers need to decide when and where to search for new knowledge, this example shows how new knowledge might also be the by-product of new engineering practices.[62] Through the engineers' attempt to contain overflows, the camera technology produced a new overflow by making a novel, chiefly immaterial socio-cultural practice known and thus eligible for inclusion in a future expansion of the engineers' frame. Whereas this example does not deal with animals per se, it still demonstrates the challenge of using technologies to establish control: these technologies produce new knowledge and may thus also introduce new actors, human or non-human, that have to be dealt with in order to retain control over the road.

The above examples show how the engineers invested significant resources in attempting to contain known overflows. Whether through repurposed parking sensors and smart signs or I2V communications and GPS-tracked reindeer, the Borealis partners envisioned a future in which technology would help contain an ever-increasing number of actors in their framing of the road. Reindeer, for example, were thought of as just another variable. By providing the road with the possibility of sensing them, they could also become manageable. Still, the examples also show how attempts to contain certain overflows demand further expansions of the current framing in order to contain new overflows. For example, the attempt at engineering away risk by freezing fish resulted in saline fish water attracting reindeer that subsequently have to be managed. The risk associated with transporting fresh fish, on the other hand, necessitates another kind of engineering where time constraints are negated through the establishment of a predictable, controlled road. In both these instances, new technological solutions are envisioned or added to contain any currently unmanageable elements. As the introduction of new elements also introduces new links to the world outside the frame in question, the engineers' frame extends far beyond the fishing industry and reindeer herds, possibly even influencing motorists' control over their own car. Simultaneously, the expansion of the frame through technological artefacts revealed new overflows. However, the new problems (for example, stargazers) might be negligible compared to the ones that have been (prospectively) contained. This suggests that rather than *solving* problems, frame expansions *change* what problems are present, for better or worse.

5. Discussion: engineering nature, engineering culture

Through Borealis, the NPRA engineers sought to take stock of what ITS technologies currently existed and how mature these technologies were. The engineers emphasized that they were not invested in any particular technology.[63] Rather, they sought to assess whether the technologies they tested might help solve the transport challenges facing the region. In terms of framing, the NPRA engineers held a position where both framing and overflow was the norm: framing was the desirable norm, but overflows were statistically predominant.[64] The epistemic culture of the NPRA engineers was characterized by a problem-solving mentality: wherever there was overflow, there was an associated prospect of concocting a technological artefact which might contain it.

Engineers 'use knowledge primarily to design, produce, and operate artefacts.'[65] In Borealis, the engineers and developers sought to create new or deploy extant technological artefacts capable of containing known overflows.[66] Some of the technologies were tailor-made for Borealis, while others were simply adapted from previous uses, pointing to a certain interpretative flexibility in terms of area of application.[67] Whether tailor-made or repurposed, the technologies in question were tested due to their potential for rendering the world surrounding the road knowable: in order to reliably contain overflows, the technologies would have to be (sufficiently) adept at identifying their surroundings. As such, the engineers used Borealis to explore how new artefacts might allow new elements, among them animals, to be surveyed through an ITS and, by extension, to be included in the engineers' framing of the road.

The E8 road acts as a meeting place for animal species that do not 'naturally' intermingle. The NPRA chose the E8 as a test site due to its socioeconomic importance, not least for the fishing industry. The NPRA and the fishing industry shared similar concerns regarding the efficiency and predictability of the road. The current lack of predictability led some industry actors to freeze fish in order to reduce the economic risk posed by overflows such as reindeer or weather-bound trucks. When frozen, the perishability of the goods—itself a characteristic of the fish's biological composition—is reduced, but its value as a commodity can be more easily controlled. However, even after being slaughtered and commodified, the fish are still a source of overflow: trucks carrying frozen fish drip saline fish water onto the motorway, water that attracts reindeer which then risk being hit by other vehicles. The engineers saw the reindeer as a problem to be managed, whether through a Finnish mobile app or a future I2V system encompassing tracking devices, LiDAR, smart signs, and communications devices in cars. Through such a technological system, the reindeer could be contained within the engineers' framing, which would help them uphold the virtues of the road: freedom of movement, efficiency of time and cost, and predictability. However, as exemplified by the northern light tourists stargazing in the middle of the road, the implementation of new technologies may also make new overflows visible, thus highlighting the challenge of using technologies to establish control.

Terje Finstad has argued the importance of 'investigating the ways in which animals are integrated into society.'[68] Adding to this, one should also ask *why*—for what reasons and by what means are animals brought into which cultures? Consider the NPRA engineers' work to help reindeer and salmon migrate from nature to culture: the same animals have been an integral part of Sámi culture for centuries.[69] In the case of Borealis, the engineers seek to make fish and reindeer part of culture for particular purposes, whether it is the fish being frozen to mitigate the risk of spoilt cargo due to unforeseen events (overflows) or the prospect of integrating reindeer into an ITS to make the E8 more predictable.

To contain nature is to change culture. Whereas the NPRA engineers sought to contain overflows originating from fish and reindeer, such containment would often rely upon the reconfiguration of culture. Consider the reindeer alerts. The engineers envisioned different concepts: voice alerts urging the driver to slow down, the GPS suggesting a different route to avoid problem areas, and changing the inflection point of the gas pedal. All three concepts rely upon changing driving practices, whether by having drivers comply with technology (the two former) or actively counteract it (the latter). As such, the engineers presupposed that humans will accept to have their actions controlled or at least influenced by technology. Hence, the prospect of including reindeer in the ITS also constructs a frame where guided and unguided doings are entangled—through an ITS, the unguided doings of reindeer are quite clearly transposed into guided doings by (ideally) influencing the actions of motorists.[70] The successful containment of reindeer in the engineers' frame depended entirely upon changing the overall culture surrounding the road.

The NPRA engineers are but the latest in a long line of actors seeking to facilitate co-existence through controllability. Similar efforts have been exerted by city physicians toward pests, local governments toward pigs, and nation-states toward salmon.[71] In our case, the engineers' efforts to facilitate co-existence focused on the construction of an expansive ITS consisting of technologies that were capable of knowing the world (to the extent that the world needed to be reliably knowable in order to solve known problems). This suggests that the NPRA engineers did not merely solve problems: they concocted comprehensive systems that would make the world knowable in a certain manner, in order to make it manageable or, ideally, solvable. Accordingly, one could argue that the engineers in question only took nature into consideration insofar as it could be made predictable, and thus ignored views of nature which consider it to be more than just something to be folded into culture in service of predictability, controllability, and (perhaps inadvertently) profit.

John Law has argued that no unified reality exists. However, through the establishment of standards and procedures for measuring and identifying certain aspects (or concepts) of the world, one reality is given privilege. This reality is further institutionalized through the use of technologies that survey the world in specific scientific terms.[72] While this description appears to mirror the practices of our engineers, we argue that it is something quite different to survey the world in *engineering* terms. Rather than attempting to establish the strict unity and exclusivity often associated with and strived for in science, our engineers appeared more open to multiplicity.[73] The engineers constructed a frame of the road where their frame was at the top of a hierarchy, rather than being the only one: the engineers' frame could co-exist with other nature-culture configurations, as long as the doings of (for example) reindeer and drivers did not actively challenge it.

To our engineers, co-existence was a question of animals' submitting to a technological worldview. The engineers' worldview emphasized controllability, although not the strict controllability yearned for by science. There was room for uncertainty: as long as an overflow was readily identifiable as such, it did not matter if it was a horse, a moose, or a reindeer. Our engineers were adept at coming up with concepts for containing overflows. However, these concepts often entailed reconfiguring both nature and culture. Hence, the prospect of successfully implementing or expanding the engineers' framing of the road depended on both humans and animals accepting to first and foremost become denizens of engineering culture upon entering the road.[74]

An issue remains: if animals are expected to submit to the engineers' technologies, do the proposed concepts help facilitate a meaningful mode of co-existence? While the concepts entailed a reconfiguring of the nature-culture relationship, possibly including human agency over their vehicle, nature was generally given the short end of the stick: animals were first and foremost expected to adapt to the needs of human society. Whereas the implementation of new technologies might render the presence of animals more tolerable, the accompanying reconfiguration of the nature-culture divide still promoted a mode of co-existence which skewed toward culture rather than nature. While the engineers left room for other understandings of the nature-culture relationship, their worldview still implies a future in which humans retain dominion over the animals. However, our study still offers hope: if the relationship between nature and culture can be reengineered, there exists a possibility of constructing nature-culture relationships which emphasize co-existence over subjection.

6. Conclusions

In Euro-American thought there is a 'foundational division of nature from culture.'[75] However, we are all entangled in nature, even in what appear to be explicitly human endeavors—for example, road development.[76] In this article, we have explored how engineers had to consider animals—both dead and alive—when implementing, developing, and testing a combination of physical and digital infrastructures in a so-called Intelligent Transport System. In their attempt to frame the road as a predictable, efficient, and safe environment, the engineers in our study had to deal with overflows such as reindeer and fish. Rather than treating these actors as external to the road itself, the engineers sought to make them part of society. By concocting and implementing a variety of technological artefacts for surveying and knowing the road and its surroundings, the engineers sought to retain control of the road. These artefacts would give the engineers new ways of surveying and knowing the road and its denizens, and possibly new methods for controlling or managing the relationship between motorists, technologies, infrastructure, and animals. However, it is worth noting that these new ways of knowing did not require a fully accurate representation of the road and the events surrounding it. Rather, the engineers exhibited a certain pragmatism, in which the containment of overflows trumped an accurate representation of reality: whether the animal on the road is a horse or a reindeer did not matter, the identification of *some* quadruped was sufficient. This suggests that the engineers' overall priority was to render nature manageable or controllable.

Whereas the engineers envisioned or sought to implement artefacts through which non-human actors would become manageable, the inclusion of actors such as reindeer in the ITS would also entail changing the relationship between motorists and reindeer. Digital infrastructures capable of sensing reindeer and alerting vehicles of their presence would be of little use if motorists do not act accordingly. Hence, the engineers also sought to influence the motorists, either by having them adapt their driving practices or by rerouting their vehicles upon being alerted to the presence of reindeer, or by changing the gas pedal's inflection point, thus forcing motorists to actively counteract the vehicle's technology if they do *not* want to take the alert into account. To use Goffman's terms: as the presence of reindeer is communicated through the ITS, the reindeer's unguided doings would (ideally) be turned into guided doings on the part of the motorist, with the ITS essentially transposing a natural frame into a social one. Hence, the engineers did not merely seek to contain particular elements of nature in their frame of the road. Rather, they sought to constitute a new relationship between nature and culture. Whereas the engineers' frame left room for cultures with a different conception of the nature-culture relationship (for example, the Sámi), subjection to technology (that is, the engineers' frame) was considered a prerequisite for human and non-human co-existence on the road.

A final, very different example may remind us that engineers, like most humans, regularly must consider animals. Upon our visit to the Borealis site, the NPRA engineers recounted how it is crucial to seal the base of ITS control centers: if left unsealed, mice will intrude and gnaw away at electrical insulation, causing short-circuits. This mundane example, in combination with the ones elaborated upon throughout this article, suggests that engineers deal with animals more often than one would expect. The intersection between engineering studies and animal studies is currently under-explored but as this article shows, the two may be combined fruitfully. As engineers direct their problem-solving capabilities toward combinations of technologies (broadly defined) and animals, they often come up with novel configurations of natural and social elements. Hence, inquiries into how engineers take animals into account are also inquiries into the (historical, actual, or future) reconfiguration of nature and culture.[77]

Engineers seek to produce workable solutions with limited resources and within a given timespan.[78] As such, their profession is characterized by problem-centered frames, pragmatic choices and a continually evolving knowledge base. This sets engineering apart from the rigidity of science 'proper.' Still, engineering appears to prioritize sorting nature and culture in ways that make the resulting world manageable. Considering engineering's flexibility toward other frames, however, a control-focused, technology-enabled frame might not be the only frame in which guided and unguided doings can productively coexist. To engineer nature, one also needs to engineer culture: within this observation lies the prospect of constructing new ways of relating to the so-called natural world.

Notes

1. Finstad, "Naked Gene Salmon"; Haraway, *Staying with the Trouble*.
2. Bijker, Hughes, and Pinch, *Social Construction*; Callon, "Society in the Making"; Mackenzie and Wajcman, *Social Shaping of Technology*; Jasanoff and Kim, *Dreamscapes of Modernity*.
3. Latour, *We Have Never Been Modern*; although consider, e.g., Haraway, *Staying with the Trouble*.
4. Jasanoff, *The Ethics of Invention*; Pimm et al., "Biodiversity of Species."
5. Haraway, *Staying with the Trouble*; Jørgensen, "Rethinking Rewilding."
6. Brown, "Animal-Human (Co)Agency."
7. Jørgensen, "Rethinking Rewilding."
8. Andrews, Priya, and Riley, *Roads and Ecological Infrastructure*.
9. Button and Hensher, "Introduction."
10. Ibid., 3.
11. Rodrigue, Comtois, and Slack, *The Geography of Transport Systems*, 241ff.
12. On the recent narrative of autonomous driving, see Stilgoe, "Machine Learning, Social Learning." However, historically, infrastructures have played an important role in visions of vehicular automation, see for example Wetmore, "Driving the Dream" and Kröger, "Automated Driving." For recent studies discussing AVs and infrastructure, see Stilgoe, "Seeing Like a Tesla" and Haugland, "Changing Oil."
13. Milakis, van Arem, and van Wee, "Policy and Society Related Implications of Automated Driving"; Legacy et al., "Planning the Driverless City."
14. Haugland and Skjølsvold, "Promise of the Obsolete."
15. Stilgoe, Owen, and Macnaghten, "Framework for Responsible Innovation."
16. Trevelyan, "Reconstructing Engineering from Practice," 175.
17. Grimson and Murphy, "Epistemological Basis of Engineering," 161.
18. Indeed, historically, the notion of applied science has played a particular role in drawing up the boundaries between science and engineering; see Gieryn, "Boundary-Work," 791.
19. Latour, *Science in Action*; Layton, "Conditions of Technological Development."
20. Kant and Kerr, "Taking Stock," 690.
21. Ibid., 716.

22. Merton, "The Normative Structure of Science."
23. On the universality of science, see, for example, Knorr-Cetina, *The Manufacture of Knowledge*; Traweek, *Beamtimes and Lifetimes*.
24. Kant and Kerr, "Taking Stock," 715.
25. Ibid., 715–6.
26. Simon, *Sciences of the Articifial*.
27. Cvetinovic, Nedovic-Budic, and Bulay, "Decoding Urban Development Dynamics"; Eräranta and Mladenović, "Networked Dynamics of Knowledge Integration."
28. Grimson and Murphy, "Epistemological Basis of Engineering," 176.
29. Kant and Kerr, "Taking Stock."
30. Latour, *We Have Never Been Modern*.
31. See for example Glista, DeVault, and DeWoody, "Mitigation Measures"; Rytwinski et al., "Reducing Road-Kill."
32. Pimm et al., "Biodiversity of Species."
33. Knorr-Cetina, "Evolutionary Epistemology."
34. Skuterud et al., "Chernobyl Radioactivity Persists in Reindeer"; see also Wynne, "May the Sheep Safely Graze?" for a different perspective on animals, radioactivity, and risk.
35. Finstad, "Naked Gene Salmon," 98.
36. Ibid.
37. Joks and Law, "Sámi Salmon, State Salmon."
38. Ibid., 163.
39. Latour, *We Have Never Been Modern*; Haraway, *Companion Species Manifesto*.
40. Goffman, *Frame Analysis*; Callon, "Framing and Overflowing."
41. Goffman, *Frame Analysis*.
42. Ibid., 20f.
43. Brewster and Bell, "The Environmental Goffman," 51f.
44. Ibid., 48.
45. Here, we draw upon the language of Latour, *Reassembling the Social* as well as Goffman, *Frame Analysis*.
46. Callon, "Framing and Overflowing"; see also Goffman, *Frame Analysis*, 26.
47. Callon, "Framing and Overflowing," 254.
48. However, road conduct is not exclusively shaped by the formalized rules, it is also shaped by (more or less) shared outlooks on what rules are permissible to bend or break; e.g., Haugland and Skjølsvold, "Promise of the Obsolete," 42.
49. On the question of agency in animals, Goffman supports 'some perceivedly basic distinctions within the social sphere, such as that between human and animal purposiveness.' In our interpretation, this suggests that Goffman relegates animals to the realm of the natural, meaning their doings are considered unguided; Goffman, *Frame Analysis*, 23.
50. Such dualisms are not uncommon in engineering practice, see, e.g., Faulkner, "Dualisms, Hierarchies and Gender." However, we contend that situations generally are hybrid, that is, made up of combinations of social and natural elements which cannot easily be untangled; Callon, "Sociology of Translation." Indeed, often we deal with *natural fabrications*, that is, 'deliberate attempt[s] at making a contrived event or environment appear natural'; Brewster and Bell, "The Environmental Goffman," 53.
51. Joks and Law, "Sámi Salmon, State Salmon"; Finstad, "Naked Gene Salmon."
52. E.g., van Hulst and Yanow, "From Policy 'Frames' to 'Framing,'" 102–3.
53. Fyhn, Søraa and Solli, "Energy Retrofitting"; Lagesen and Sørensen, "Walking the Line?"
54. For an in-depth look at the technopolitical aspects of the Borealis project, see Haugland, "Changing oil."
55. Because of the limited capacity of nearby Norwegian airports, fish cargo is often carried by trucks to Finland and then flown from airports there.
56. Joks and Law, "Sámi Salmon, State Salmon."
57. Charmaz, *Constructing Grounded Theory*.

58. For another example of the NPRA's ambivalent treatment of local expertise, see Solli and Ryghaug, "Assembling Climate Knowledge."
59. For example, the NPRA has been relatively successful in striving toward realizing Vision Zero; Elvebakk and Steiro, "First Principles, Second Hand." On the use of visions in Borealis, see Haugland, "Changing oil."
60. On the construction of value-chains for frozen fish and the establishment of Norway's domestic frozen fish industry, see Finstad, "Familiarizing Food."
61. One example of active geo-fencing using virtual herding technology can be seen in the case of Norwegian goats; Søraa and Vik, "Boundaryless Boundary-objects." However, the technology being used for goats is still being tested, and, as of writing, testing on reindeer has not been approved in Norway.
62. Grimson and Murphy, "Epistemological Basis of Engineering."
63. For example, the NPRA used A/B testing of both different technologies and variants of the same technology; for an in-depth description, see Haugland, "Changing Oil," 6.
64. Here, we paraphrase Callon, "Framing and Overflowing," 250.
65. Vincenti, *What Engineers Know*, 226.
66. On the relationship between technology and engineering knowledge, see Kant and Kerr, "Taking Stock," 706ff.
67. Bijker, Hughes, and Pinch, *Social Construction*.
68. Finstad, "Naked Gene Salmon," 116.
69. Joks and Law, "Sámi Salmon, State Salmon."
70. On the question of whether animal doings should be considered unguided, see note 49.
71. Finstad, "Rottereiret"; Jørgensen, "Running Amuck?"; Joks and Law, "Sámi Salmon, State Salmon."
72. Law refers to this process as routinization; Law, *After Method*, 33.
73. Here, we refer to the overarching ideal of science, rather than the heterogenous work taking place within disciplines and subdisciplines; see Kant and Kerr, 'Taking Stock,', 686, 691ff. As previous STS studies have shown, there is considerable work involved in making scientific knowledge claims generalizable; e.g., Knorr-Cetina, *The Manufacture of Knowledge*.
74. The geo-fenced goats referenced in note 61, for example, would actively challenge the perimeter defined by the technology; Søraa and Vik, "Boundaryless boundary-objects."
75. Lien and Law, "Emergent Aliens," 65; Latour, *We Have Never Been Modern*; Haraway, *Companion Species Manifesto*.
76. Haraway, *Staying with the Trouble*; Latour, *We Have Never Been Modern*; Law, *After Method*.
77. There exists a considerable literature dealing (implicitly or explicitly) with the construction of animals as natural or cultural subjects: Jørgensen, "Running Amuck?", Finstad, "Naked Gene Salmon" and Lien and Law, "Emergent Aliens" are merely some of the examples. However, less attention has been paid to how engineers deal with animals—and, not least, how animals deal with engineers. For recent studies of how animals deal with technology, see Finstad, Aune, and Egseth, "Domestication Triangle" and Søraa and Vik, "Boundaryless Boundary-objects."
78. Grimson and Murphy, "Epistemological Basis of Engineering," 176.

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