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Micro-*meso*-macro assessment of drivers and barriers to implementing geofencing for sustainable transport

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ABSTRACT

Transport is in need of innovation to reach the goals set for social and, more importantly, environmental sustainability. However, in transport, innovation rarely goes from pilot to large-scale implementation, as various barriers create blocking mechanisms to implementation. This paper focuses on the technology of geofencing in transport management, with the aim to contribute to the understanding of actors' perceptions of drivers and barriers to the technology and how these perceptions impact its implementation. A qualitative approach, based on 34 interviews, helped identify drivers and barriers to geofencing, with the focus on Sweden. The drivers and barriers were then analyzed at different institutional levels (macro, meso, and micro). Drivers could be identified for actors at all levels, indicating that geofencing can contribute to transport sustainability. However, there are also barriers at all levels that hinder implementation. Closer collaboration is necessary to reduce knowledge gaps, develop policies, and establish viable business models.

1. Introduction

Within transport, especially urban, innovation is considered central to increasing sustainability. Smart urban mobility has recently been introduced as a concept that seeks to reduce the negative effects of mobility, but, at the same time, ensure that people and goods can move efficiently around cities (Butler et al., 2020; Golbabaei et al., 2021; Lyons, 2018). The smart mobility concept entails both technical and behavioral changes needed to ensure safe and equal accessibility for people and goods, with a low or zero impact on the environment (Chen et al., 2017). However, it has often proven difficult to implement innovative transport solutions aimed at increasing sustainability (Lindkvist and Melander, 2022). The solutions either do not live up to the expected positive effects or do not encompass all three parts of the triple bottom line to be considered sustainable. The reasons are manyfold: innovative transport solutions consist of complex networks with many different actors and unclear roles (Lindkvist et al., 2022), there are restrictions in the regulatory framework (Smith et al., 2019), there is a lack of viable business models (Li and Voege, 2017), and in some cases there is user resistance toward the new solution (Tsakalidis et al., 2020). Innovation in transport is becoming increasingly dependent on collaboration between several actors, and, more recently, with the increasing focus on sustainability, there are more cases in which public and private actors collaborate (Bushell et al., 2022; Küffner, 2022; Smith et al., 2019; Weber et al., 2014). The growing use of digital tools, automation, and electrification has also led to more actors becoming involved in the development of the transport system (Docherty et al., 2018). Factors influencing the development and implementation of an innovative transport solution can also be

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identified at different institutional levels, which further increases the complexity of implementing innovative transport solutions (Karlsson et al., 2020).

This paper focuses on a case study of the technology of geofencing in a transport-related setting. The choice to focus on geofencing is based on a number of reasons: (i) it has attracted growing attention in urban transport and traffic management; (ii) it is not a particularly advanced technology (in contrast to autonomous vehicles), but has the potential to contribute to lower emissions and traffic safety; (iii) like many other potential sustainable transport solutions, geofencing relies on public–private collaboration. Studying geofencing more closely can provide new insights into why other solutions are difficult to implement. Geofencing enables traffic-related applications by ensuring certain vehicle behaviors when a vehicle enters or exits a geographically defined area by triggering some kind of action in the vehicle, such as switching off the powertrain in a hybrid vehicle, warning signaling, or adjusting the speed (Foss et al., 2019). It relies on connected vehicles and, in some cases, connected infrastructure that can communicate through digital interfaces. In many use cases, geofencing is heavily dependent on public–private interaction and perceived as having the potential for societal, environmental, and business improvements. Several cities and national governments have increasingly included geofencing in their strategic planning toward more sustainable transport systems. Although it is a proven technology and has the potential to increase sustainability in transport management, geofencing is not yet widespread, and testing has mostly been limited to a number of small-scale pilots and demonstration projects. The technology has therefore not contributed to the desired effects of the governmental strategic guidelines for sustainable transport. While there are drivers for developing and implementing the technology, there are barriers that hinder large-scale implementation. There is a need to better understand these drivers and barriers at different institutional levels to overcome the barriers and reap the benefits.

The aim of this paper is therefore to contribute to the understanding of actors' perceptions of the drivers for and barriers to the innovative transport solution of geofencing and how these perceptions impact the implementation of geofencing. In particular, (1) we identify drivers for and barriers to geofencing at the macro, meso, and micro levels, and (2) we analyze how the barriers can be overcome to reap the benefits of implementing geofencing.

The paper is structured as follows. Section 2 describes geofencing and past initiatives in more detail and looks at previous research on innovation, innovation in a public–private context, and the different institutional levels, macro, meso, and micro, in which drivers and barriers can be allocated. Section 3 describes the methodology of the paper. Section 4 goes through the results of the interviews of the case study in detail, and Section 5 discusses the results in relation to previous research. We conclude with managerial and policy implications and suggestions for future research.

2. Literature

2.1. Geofencing

Although geofencing is an old technology, it is fairly new in transport management. Reclus and Drouard., 2009 mention that there is strong potential for geofencing in transport and traffic management, especially in relation to safety and security, such as preventing terrorist attacks and avoiding bridge collisions. Applications and use of geofencing are expected to increase, as navigation systems improve over time. Several projects have already been conducted, for instance, related to logistics (Oliveira et al., 2015), automated vehicles (Ma et al., 2019), differentiated road charging (Arnesen et al., 2021), and management of electric scooters (Liazos et al., 2022). One study shows a 31 % reduction of NO_x emissions when busses use optimized geofencing for environmental zones, meaning that busses switch to electricity when driving in designated areas (Fussey and Dalby, 2022). The same study showed a reduction of NO_x emissions by 10 % and PM_x by 23 % when taxi drivers used a similar system. Furthermore, the geofencing system created a behavioral change among the drivers, who became more environmentally aware (*ibid.)*. In a literature review within a project focusing on geofencing, Hansen et al. (2021) concluded that geofencing can be used, in particular, in four areas of traffic management: safety, environment, efficiency, and tracking and data collection. The review pinpoints several projects, mostly located in the Nordics or the UK, where geofencing has contributed to lower emissions, positive acceptance from drivers, and regulation compliance.

However, the technology is still not widespread in traffic and transport management. Studies show difficulties in GPS accuracy and a lack of regulation for some use cases (Hansen et al., (2021). Uncertainties by actors in the geofencing network of their roles, stimulated by public and private interaction, in developing and implementing geofencing is considered another challenge (Lindkvist, Lind and Melander, 2022).

2.2. Innovation in public–private interaction

Innovation is key to sustainable development. Goal 9 of the Sustainable Development Goals (SDGs) explicitly encourages innovation and relates directly to several other SDGs. An innovation is defined as a combination of new and/or old resources (e.g., products, materials, knowledge) or old ideas put to use in a new context (Van de Ven et al., 1999; West and Bogers, 2014). Innovation includes the process of developing a new idea and implementing it. However, innovation entails a few challenges. Silvestre and Ţîrcă (2019) mention the fundamental characteristics of innovation as complexity, dynamism, and uncertainty, while West and Bogers (2014) state that a core issue of innovation is adaptability with regard to how it can be integrated into specific contexts and established processes and routines.

Innovation increases in complexity in public–private settings due to the inherent differences in objectives and value perceptions among the actors (Munksgaard et al., 2012). While public actors have an objective to serve and protect the well-being of inhabitants, private actors have an objective of economic growth and to serve their stakeholders. Public actors base themselves on regulatory frameworks decided by political forces that systematically organize resources and activities carried out by departments (Håkansson and Axelsson, 2020). Laws, regulations, and added bureaucracy affect speed and agility among public actors and are potential barriers to collaboration and interaction in a public–private context (Smith et al., 2019). Previous research in public–private innovation contexts has shown that there is a lack of understanding of the private sector perspective in the development, implementation, and commercialization stages of an innovation (Evald et al., 2014). From the public sector perspective, there is also a lack of understanding of the implementation and commercialization stages (*ibid.*). The balance between drivers and barriers influences the implementation and commercialization of an innovation.

Drivers and barriers can be studied with a multi-level approach. For instance, Leviäkangas and Öörni (2020) studied cooperative intelligent transport systems (C-ITS) from a business ecosystem perspective, including views of the end-user, business models of a firm, business value of a supply chain, and, ultimately, societal value. Karlsson et al. (2020) made a macro, meso, and micro analysis of Mobility as a Service (Maas), and Melander et al. (2022) analyzed uncertainties at the macro, meso, and micro levels by investigating drivers for and barriers to using electric freight vehicles. The macro, meso, and micro concepts have also been used in other scientific fields, such as economics (Dopfer et al., 2004), technology (Cunningham and O'Reilly, 2018), and social sciences (Serpa and Ferreira, 2019). The macro level represents society as a whole, in which regulations and policies can induce both drivers for and barriers to an innovation. Macro-level drivers include overall positive effects for society and the environment (Garcia et al., 2019). The meso level represents a network of actors and organizations that either collaborate or co-create. Barriers can include a lack of collaboration or coordination within networks, while drivers can include knowledge sharing and new business models (*ibid.)*. The micro level refers to individuals or individual organizations. Here, barriers include attitudes and acceptance among users (Karlsson et al., 2020), a lack of resources, and conflicting internal goals (Garcia et al., 2019). Drivers, on the other hand, include new value propositions (Leviäkangas and Öörni, 2020), reduced costs, and better prerequisites for the staff or business.

The macro, meso, and micro levels are highly interlinked, where drivers and barriers at one level affect drivers and barriers at other levels, as displayed in Fig. 1. While there are interactions between the different levels (a, b, and c) there are also downstream and upstream factors that influence each other. Downstream factors include regulatory frameworks, policies, and funding, while upstream factors are the economic, societal, and environmental contributions that are created at the micro and meso levels. The macro, meso, and micro concepts are considered an effective analytical tool to gain a better understanding of complex subjects with many variables as well as the relations between different levels (Javaid et al., 2019).

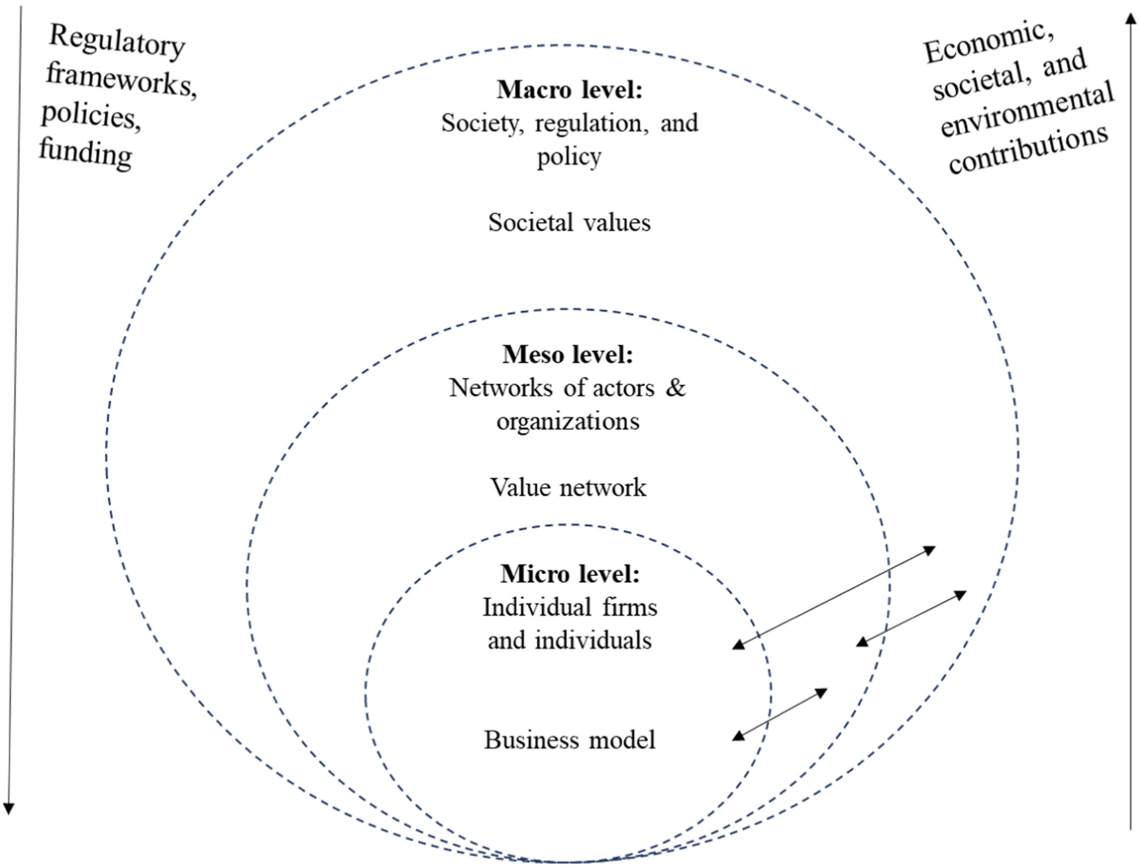


Fig. 1. Multi-level perspectives and interactions between levels, developed from Garcia et al. (2019).

Table 1
Type of organization and participants in the interview study.

Actor category	Type of organization	Number of interviews (number of respondents)	Roles in organization	Experience of geofencing	Use case (if high level of experience)	Abbreviation
Authorities	Local road authorities	6 (7)	Project manager	High	Speed zone Emission zone	LRA1
			Traffic strategist	High	Speed zone Emission zone	LRA2
			Freight strategists (3)	Medium/High	Speed zone Emission zone	LRA3-5
			Smart city coordinator	High	Speed zone Emission zone	LRA6
			Senior advisor business transport	Medium		LRA7
	National road authorities	2 (3)	Head of development of geofencing	High	Speed zone Emission zone Prevent/allow access zone	NRA1
			Head of unit road user	Medium		NRA2
			Project manager	Medium		NRA3
Geofencing service providers	Vehicle manufacturer	6 (11)	Senior manager R&I	High	Speed zone Emission zone Fleet tracking	VM1
			Business consultant	Medium		VM2
			Technical consultant	High	Road charging Fleet tracking	VM3
			Market/sales (2)	High	Speed zone Emission zone Fleet tracking	VM4 & VM11
			Technical development (2)	High	Speed zone Emission zone Fleet tracking	VM5-6
			Product planner	High	Speed zone Emission zone Fleet tracking	VM7
			Service owner connected services	High	Speed zone Emission zone Fleet tracking	VM8
			Safety and connected solutions	High	Speed zone Emission zone Fleet tracking	VM9
			Road map developer	High	Speed zone Emission zone Fleet tracking	VM10
	Third-party service provider	1 (2)	Sales	Medium		TPSP1
			Business unit manager for fleet management	High	Speed zone Emission zone Fleet tracking	TPSP2
	Map service provider	2 (2)	Sales	High	Speed zone Emission zone Fleet tracking	MSP1
			Senior project manager	High	Speed zone Emission zone Fleet tracking	MSP2
Transport service provider	Freight operators	3 (3)	CTO	High	Speed zone Fleet tracking Battery optimization zone	FO1
			Fleet manager	Medium		FO2
			Operations manager	Low		FO3
	Haulage depots	1 (1)	Environment and quality manager	Low		HD1
	Freight forwarders	1 (1)	Environment and quality manager	Medium		FF1
Buyer of transport service	Retailers	4 (4)	Business developer	Low		R1
			Sustainability developer	Low		R2
			Development manager transport	High	Scheduling truck traffic and unloading	R3
			Head of transport	Low		R4
	Raw material producers	1 (1)	Strategic purchaser of transport	Medium		RMP1

(*continued on next page*)

Table 1 (*continued*)

Actor category	Type of organization	Number of interviews (number of respondents)	Roles in organization	Experience of geofencing	Use case (if high level of experience)	Abbreviation
Enclosed or specified areas	Ports	2 (2)	IT manager	High	Access control	P1
			Head of innovation	Medium		P2
	Roadworks	1 (1)	Business developer	High	Speed zone Work zones	RW1
Influencing actors	Insurance companies	3 (5)	Researcher	Medium		IC1-5
			Product manager vehicle insurances	Medium		IC2
			Researcher traffic safety	High	Speed zone	IC3
			Group leader motor products	Medium		IC4
			Business and product developer	Medium		IC5
	Trade organization (transport)	1 (1)	Industry representative	Low		TO1

3. Method

A qualitative case study approach was chosen, as it provides depth, detail, and richness of data and has proven a useful approach for studying phenomena in business networks (Dubois and Araujo, 2007; Easton, 2010) as well as problems in settings with unclear boundaries (Dubois and Araujo, 2004). The case study relies on expert interviews with respondents from multiple organizations involved and/or interested in geofencing applications. An interview guide was developed that started with questions about the respondent's background and role in the organization. There were questions about geofencing, such as how the organization used geofencing and which drivers and barriers would be related to its implementation in the future. Sampling was done by first identifying geofencing-related actor categories. Types within each actor category were then identified. This process was conducted in collaboration with the Swedish research and innovation program for geofencing, a collaboration platform that has operated since 2018. The program involves and coordinates national and international projects and initiatives related to geofencing and encompasses a large network of contacts. The identified actor categories and types of actors to be interviewed were accepted by a steering committee of the R&I program for geofencing. Following this process, we reached out to available contacts or found contacts to interview through Internet searches. A snowballing process also resulted, as respondents were asked about other organizations they thought should be interviewed. A total of 36 organizations were reached out to, of which 28 ultimately participated in the study. A total of 34 semi-structured interviews were conducted within these organizations, sometimes there were several interviews with different people in the same organization and sometimes several respondents participated in the same interview meeting. Hence, there were a total of 44 individual respondents. Interviews were conducted with people working in organizations related to the development and use of geofencing, including freight transport operators, public road authorities, service providers, transport buyers, service users, and insurance companies. The actor categories and actors are specified in Table 1.

The respondents were asked if they were familiar with geofencing and the concept, as their experience might have influenced which drivers and barriers they thought affected the development and implementation of the technology. All the participants were familiar with the term and had some knowledge of what geofencing can do, albeit at different levels. Some respondents had been directly involved in projects with geofencing for specific use cases, while others had heard or read about it. The authors rated the respondents' experience of geofencing on a scale of low to high, with *low* being no real experience working with geofencing, *medium* being indirectly involved in or following its development, and *high* being involved in geofencing activities. Respondents with a high level of experience have been associated with main use case they were working on.

The interviews were conducted during 2020–21. They were all conducted digitally due to Covid-19. All the interviews were recorded except one, as the respondent did not want to be recorded. Detailed notes were taken in this interview. All the recorded interviews were transcribed. The interviews lasted approximately 60 min with a few up to 80 min. A couple of interviews were shorter, approximately 30 min, as they were with people specialized in a specific topic, and others in the organization had recommended that we interview them to obtain more in-depth answers.

Additional data was collected through observations and participation in various workshops, seminars, and meetings within projects and initiatives related to the development and implementation of geofencing in Sweden and Europe. The participants in these meetings, workshops, and seminars were aware that the researchers were involved in investigating the development and implementation of geofencing and that the notes taken at the meetings could be for academic use.

The initial data analysis was made using the Gioia (2013) method, dividing the data on the drivers for and barriers to geofencing into first order concepts, second order themes, and aggregate dimensions (Gioia et al., 2013). The first order concepts were respondent centric, focusing on finding categories within the data. The second order themes were more researcher centric, including theory to categorize and understand the phenomenon being observed. Lastly, the aggregate dimension further distilled the emergent themes into manageable and overarching units for discussion (Gioia et al., 2013). In the process, the two researchers first individually coded the first order concepts, the second order themes, and the aggregate dimensions. The results from the individual coding were then compared. The individual results differed slightly in the sense of the wording or the way the first order concepts were organized into second order themes, but, after mutual discussion, only minor adjustments were needed. For instance, one researcher combined the first order concepts of “increased safety” and “improved traffic conditions”, while the other researcher divided these into the second order themes of “traffic safety & security” and “traffic management”. The end result of this process for the aggregated macro, meso, and micro levels is presented in Fig. 1-3 in the appendices.

The first order concepts are directly extracted from the data and what the respondents expressed as being drivers for and barriers to geofencing development and implementation. For example, the second order themes were derived from the data and previous research in transport innovation research, including drivers such as *improved urban environment & planning, environmental benefits,* and *traffic safety & security*. Barriers included items such as *regulation, security,* and *data quality*. Lastly, the aggregated dimensions encompassed both drivers for and barriers to second order themes. Here, the micro, meso, and macro level concepts were used.

4. Results

4.1. Actors’ understanding of geofencing

The interviewed actors were all involved in the transport system in different ways. They had all come across the idea of geofencing as a future resource. However, they had also formed slightly different ideas of what it is, how it could be used, and how it could benefit (or not) their own operations. This, of course, also depended on the respondents’ differing levels of experience of working with geofencing. Since the range of ideas and experience impacts how they perceive geofencing, a brief description of their different views is given below.

First, some of the actors focused on what geofencing is and how it can be used, rather than on specific “use cases”. Geofencing is described as a geographical limitation, something that is drawn on a map (MSP1). In relation to transport management, most respondents described geofencing as a technology to enforce the behavior of a vehicle. *“I think it can be condensed to the fact that it is a matter of digital regulation, primarily linked to speed, access, and the environment”* (LRA1). This definition requires some kind of connectivity in the vehicle that can receive map information and details of what should happen within the geofenced zone. However, others had a slightly different definition. One respondent who managed a harbor perceived geofencing as a physical zone (like the harbor) within which certain driver behaviors could be affected by, for instance, signs (P1). This actor had taken some measures to manage the traffic in this physical zone by integrating data from the vehicle registry with ferry bookings, so that trucks could enter the harbor zone more efficiently without stopping to check in and directing all incoming trucks to the right lanes while waiting for boarding. Similarly, another actor saw geofencing as a future resource to manage traffic within storage areas (R2). In other cases, the geofenced zones were as large as cities or inner-city zones. Others had a wider scope, such as whole fleets of trucks rather than specific geographical areas (VM2). Adding the possibility to integrate the technology into the vehicles by OEMs, all traffic could be managed everywhere—considering zones characterized by different regulations.

Furthermore, the ideas about what geofencing might entail with regard to managing traffic varied among the interviewees. Some focused their ideas on monitoring rather than controlling traffic (MSP2), while others considered geofencing a tool to guide drivers or vehicles (LRA2). A related question was who would manage the traffic, e.g., road authorities, “zone managers” or fleet managers.

Some of the actors related their ideas of geofencing to other technological developments. Some perceived geofencing a prerequisite for autonomous traffic systems (NRA1), while others saw it as a tool for more energy-efficient vehicles and as playing a part in the transition to fossil-free transport (WM8). Their ideas about the uses of geofencing thus related to the benefits of combining geofencing with autonomous and/or electric vehicles. Yet others saw limited use for and value of the technology, as geofencing was not considered to provide any direct value to them (FO3).

Below, we look at the specific benefits and barriers that have been identified at macro, meso, and micro level.

4.2. Macro level

Our findings revealed a wide range of drivers for implementing geofencing at macro level, as shown in Appendix 1. The identified aggregated benefits at macro level are *Improved urban environment and city planning*, and *Increased knowledge.* There are also benefits for *Policy implementation*, *the Environment*, *Traffic safety & security,* and *Traffic management*. For *Improved urban environment and city planning “Geofencing will be central to ensuring quiet and slow vehicles in city centers, not just controlling what types of trucks and busses are driven but also cars”* (LRA7). Geofencing could thus reduce noise and speed, which would improve traffic safety and lead to an improved psychosocial environment. There would also be less need for controls and physical barriers. Speed bumps would be redundant, as the technology would ensure that vehicles travelled at safe speeds. *“Geofencing could ensure traffic rules are followed, which would result in less need for police controls, speed bumps, and physical barriers on our roads, which would save a lot of money”* (LRA3). Furthermore, geofencing could allow more dynamic use of the existing infrastructure, as different regulations could be effective on a street during a day. *“If we do not require physical obstacles to control the city environment, then we have much more flexibility in the way we use that space. We can use it differently depending on the time of day or year. It will be much easier to regulate, and we can have a dynamic city. For example, around lunch time, when there are many people out walking, we can make pedestrian streets or create temporary squares for food trucks”* (LRA3).

Another benefit of implementing geofencing is that it provides *Increased knowledge* that can be used for policymaking and improvements. Geofencing could provide data on roads that need to be improved and research on accidents to improve regulations where this is needed (IC1). Public transport buyers could also use public procurement as a way to push for a standard in the development of geofencing. Authorities act as big procurers of construction transport and, as such, they can have a large impact on the environment, if stricter requirements can be checked using geofencing (HD1).

Many of the respondents in our study pointed to the *environmental benefits* that could be reaped from implementing geofencing. Examples included regulation of emissions and control of alternative fuels, providing incentives for electrification of vehicles, and enabling a more sustainable city environment. The respondents also pointed to the potential for emission reductions, which would result in better air quality. Geofencing could facilitate the enforcement of environmental zones and dynamic environmental zones. *"Geofencing could enable us to divert some transport to nighttime, and then have better environments for public transport, bikes and other types of transport. But then we would like to have quiet vehicles. Here, geofencing can ensure that hybrid vehicles switch to electricity in the right place and at the right time"* (LRA6). Other examples of environmental drivers included assisting the transition to fossil-free transport in cities, enabling more sustainable speeds (lower speeds result in lower emissions), and allowing heavier truck loads on vulnerable roads if reduced speeds are enforced through geofencing (fewer trucks would then be needed).

At macro level, drivers also mentioned *traffic safety and security*. An important aspect of geofencing, mentioned by several respondents, was to control speed in urban areas. *"Ensuring that vehicles are driven safely and at the right speed is a benefit"* (R2). Geofencing could provide safer traffic environments for vulnerable road users, as infrastructure is not always adapted for walkers or cyclists (IC4). Geofencing could also be used to prevent attacks in which vehicles are used as weapons (such as those in Nice, Berlin, and Stockholm). *"Geofencing can be used to prevent terrorist attacks, such as the one on Drottninggatan in Stockholm. If the vehicle had been limited to, say, 10 km/h then the consequences may not have been fatal. So, there are benefits for city centers where traffic could be restricted"* (IC2). Other applications could be to ensure lower speeds near accidents, provide alerts to approaching vehicles in emergency situations, stop high vehicles on windy bridges driving too fast, or use geofencing to prevent a vehicle from driving into certain tunnels and viaducts (LRA3). It was also suggested that geofencing could be suitable in areas where the experienced speed is higher than the actual speed. Other ideas included geofencing forming part of certification and/or labeling for safe and sustainable transport (TO1).

A clear driver for geofencing is the potential for improved *traffic management*. This includes better routing of dangerous goods, enabling temporary road closures and re-routing at accidents, better compliance with road closures, and improved traffic flows using real time data to control traffic. Geofencing could also be used to allow quiet vehicles to make off-peak deliveries or heavier vehicles than are usually allowed (LRA2).

The findings at macro level also revealed some barriers to implementing geofencing. These included *Regulation, Lack of relevance, Lack of demand, Security* and *Data quality*. *Regulation* has repeatedly been mentioned as a barrier. Issues raised included possible integrity infringements, and the need to change national and international laws for some applications, which is a slow process. There is also a lack of standards for geofencing (technical, data formats, etc.). At macro level, there are difficulties related to different geographical regions. One suggestion was that standardization would drive development, but that needs to happen at European, if not global, level. Another barrier was the different interpretations of international road laws within Europe (which makes interoperability difficult). There is a hierarchy for regulations in Europe (local, national, and international), and taking Sweden as an example, there are different regulations for state-owned and locally owned roads. *"There are different regulations for state-owned roads and regional roads, with national roads following national laws, which take a long time to change if required to adapt to the use of geofencing"* (LRA7). The respondents in our study argued that there are regulatory difficulties moving from informative geofencing to controlling geofencing. One example is the difficulty of checking the compliance of some geofencing applications, as there needs to be a feedback loop, which is difficult due to regulations. Finally, there is little political will to introduce stricter regulations.

Some respondents questioned the *relevance* of geofencing as a technology for sustainable transport. It was argued that the problems that geofencing is intended to solve are not that great, and that they are only relevant for large cities. There also seems to be no sense of urgency, as other things are deemed more important (e.g., fossil-free vehicle development). *"I think you can come up with an incredible number of cool ideas [with geofencing] that sound very good, but then in practice and in reality, they do not really add any value"* (FO3). Furthermore, *"there is a lack of agreement on the direction and goals by governmental agencies related to the technology"* (RW1). Our respondents pointed out that politicians prioritize other investments. Other issues included difficulty showing the positive effects and getting unions and drivers to accept the technology.

Closely related to this barrier was a recurring mention of *lack of demand*. *"But you don't know the benefits clearly enough. Geofencing is a technique that is quite fun to look at on a screen and regulate the speed of the vehicle. But it is probably the benefit that must be concretized first, and that is probably also why it is not obvious for everyone to use it today"* (R3). Another respondent argued that: *"From our point of view, there is no need for geofencing solutions. If the idea is to use geofencing for access restrictions, then there needs to be a good reason for such restrictions"* (R1). A number of barriers were raised, such as that other solutions are available, that it would take a long time to renew vehicle fleets to be compatible with the technology, and that it was seen as an expensive investment.

Security issues were raised as a barrier, in particular, cyber security and the risk of someone hacking the system and creating their own zones and attributes. *"Security is an issue, such as hacking. During the terrorist attack in Stockholm, someone stole a truck. But what if we have connected vehicles and there was someone who could hack the system and control lots of trucks?"* (R3). There is also the risk of too much surveillance and possible integrity infringements (GDPR).

The final barrier concerns the need for high *data quality*. Today, the data quality is sometimes not good enough to be useful. *"..., if you also want to geofence speed, for example, the speeds that are available digitally need to match what is on the signs, for example, and we know that this is not entirely true today"* (NRA1). There are positioning errors (GNSS/GPS incorrect) and it is difficult to ensure/validate data quality (OEMs need to be sure the geofences are correct). Hence, there needs to be reliable and updated data from authorities. It was argued that the only way to have some quality assurance is if the data comes from public authorities. *"Our challenge was more about data on roads, roadworks, and different zones not being centralized in Sweden. The Swedish Transport Administration cannot provide it, and we cannot go to each city separately and pick up Stockholm's rules and Gothenburg's rules. Then it would be hopeless"* (WM5).

4.3. Meso level

At meso level, which drivers for and barriers to a confined network of actors, two clustered drivers were identified, *efficiency* and *compliance control,* as shown in Appendix 2. *Efficiency* includes drivers for geofencing, where actors consider it to contribute to better use of existing resources, such as vehicles, charging stations, and local road infrastructure. One example is electric charger allocation and predicting the usage of the chargers (TO1). Another example is allowing heavy truck loads by enforcing a reduced speed. As heavy vehicles cause more wear on the road infrastructure, it is possible to mitigate the damage by reducing the speeds of these heavy vehicles: *"In practice, it could be that we let a vehicle travel a route that may have a bridge that cannot really handle the weight of the vehicle in combination with the speed. But if we could put a 'fence' right on the bridge where you might go down to 30 or 50 [km/h], the vibration damage on the bridge would be much less*" (NRA1). This application creates a driver not only for the owner of the infrastructure but also for the transport operators that can reduce their travel distance if they are allowed to use a certain road with the assistance of geofencing.

Some actors mentioned using geofencing as a tool to better guide vehicles carrying dangerous goods and make sure that those vehicles do not use roads that are unsuitable for safety reasons. Furthermore, as mentioned earlier, several respondents mentioned geofencing in relation to off-peak deliveries, which creates drivers for several actors, both public and private. The technology could also assist in other areas of off-peak deliveries: *"I would have liked to have used the geofencing technology to perhaps unlock a door during an off-peak delivery, for example"* (R3).

Other ideas that were mentioned were to use geofencing to allocate certain lanes or parts of infrastructure for prioritized vehicles or transports, such as buses or freight vehicles. It could be a way to incentivize more sustainable transport by allowing, for instance, electric vehicles to use a bus lane, and to use existing infrastructure more efficiently by using empty space in existing priority lanes. Geofencing would be used to ensure that only those vehicles that were allowed used the allocated roads or lanes.

Another area where geofencing could be used is at port entrances. One respondent saw geofencing as the current solution to their port entrance problems. With the help of sensors and cameras, they made the entry of freight vehicles more fluent, reducing the number of stops. *"As soon as you don't have a steady flow of traffic without it starting, stopping, starting, stopping. That creates an environmental problem. A lot of emissions.* […] *This will avoid queues, collisions, ships won't cross each other and everything can be started and stopped at exactly the right time, just in time. And then the ships can be loaded in the optimal way"* (P1).

The next driver that is identified is *compliance control*, i.e., how to better ensure that regulations or requests are followed. On example is at roadworks. *"[…] we still have not solved the biggest risk—and that it [the traffic] almost always goes too fast past roadwork sites. And that's why geofencing is incredibly interesting, if you can create a geozone when there are roadworks and control the speed, much would be gained* (RW1). Examples of the compliance control mentioned in the study include making sure that vehicles that have obtained a permit to drive longer or heavier vehicles than are normally allowed comply with their permits. These vehicles are often only allowed to use certain roads, and geofencing can be used to report vehicles that have gone outside these allocated roads (NRA1).

However, several barriers at meso level were mentioned. They were *roles, interoperability, functionality, business models,* and *technical system/data exchange*. A barrier mentioned by several actors within the *roles* concept was uncertainty about which actor was responsible for providing what kind of data and quality. The same applied to what the digital procedures should look like and who was responsible for activating a geofence and where. *"I think about who manages which road area. So, we have someone who manages streets and things like that in the cities, and the Swedish Transport Administration a little outside, etc. There is a lot that is split up, and where the responsibility lies and so on"* (IC3). The interviews also showed that the respondents had different understandings of geofencing and the best way to use it in their respective operations, amplifying barriers of functionality and roles.

With regard to *interoperability,* the risk was mentioned that different cities develop different solutions. While cities develop, procure, and operate possible geofence systems separately, vehicle manufacturers and service providers operate on national or international markets. They therefore want solutions that work similarly in all cities and countries. *"This is where we are likely to see that these types of new functions are a challenge, because they are very local, even though we try to come up with something here in Sweden or Stockholm or the Nordic countries, but we do not work at European level"* (VM6). To mitigate this problem, many respondents mentioned the importance of standardization. However, there is currently a lack of standards for geofencing, and they will take time to implement. It is not clear what the standard should cover. This also spurs concern that service providers will develop individual solutions that are not interoperable with similar services from other service providers. For instance, one transport operator has many different brands of vehicles, and if they all have individual geofencing solutions it could be difficult to handle. *"[…] similar functionality exist, but it is very much tied to the particular brand of vehicle"* (TPSP1).

Another barrier is considered to be the *functionality* of geofencing. On this theme, several aspects of the technology's objectives and operation are questioned, such as the level of control desired by the technology, how the desired effects can be achieved with other measures, how the technology can be integrated into already established structures and routines, and how to align the development of geofencing with other emerging technologies. *"Will the urban environment need to be rebuilt? Should we allow ourselves, or maybe have, to change the design of the urban environment for the [geofencing] to work as well as possible. The fact that it kind of works as a system, the design of the traffic environment and the system itself could be a drawback"* (IC1). In relation to integrating a new technology into already established routines and systems, a respondent from a haulage depot mentioned the difficulty of that integration.

A major part of the barriers at meso level is the *business model*. This often recurs in the interviews. *"From our side, of course, there are things we have to think about. How do we profit from this? What will our business model be? Should we sell data or functionality or services?* (VM1). As one transport operator mentioned: *"There is low willingness to pay for new solutions among transport buyers"* (FO2). The margins in the transport market are also low, which makes it more difficult to invest in new technologies. However, a couple of the interviewed transport buyers were positive, to some extent, to pay more for transport if it led to good effect: "*We are not worried, if we see that there is profit in it and that it is a good thing from a security perspective or that there is some other kind of profit, economic or* *environmental aspects or something like that, and it is enough for us to invest, then we absolutely will. That is the mentality with all good solutions"* (R2).

The barrier *Technical systems/data exchange* refers to challenges of accuracy, connectivity, and processes of sending and receiving data. Although some actors mentioned that technical systems were not the barrier to implementing geofencing, many respondents still said that there was some way to go on technical development. *"It depends on the connection. In some places it is quite good. In Sweden, we have a pretty good connection here in Stockholm and in Gothenburg, but if you are in Germany, some places only have 2G on the highway and then it can take a little time when you have no connection at all"* (VM6).

4.4. Micro level

At micro level, which refers to drivers and barriers for individual actors, considerably more drivers than barriers are identified, as shown in Appendix 3. The drivers *Safety issues, Monitoring and positioning, Analyze and increasing knowledge/performance, Cost saving, PR,* and *Work environment* have been identified. Themes identified as barriers are *User issues* and *Knowledge/awareness.*

Safety issues include drivers contributed by geofencing by increasing safety for drivers or workers or reducing the risk of theft or damage of goods and vehicles. *"You can limit the speed of the cars or where they are allowed to travel so we can perhaps reduce the number of thefts* (IC2). This could be a valuable application for expensive cars. Similar aspects are mentioned from a vehicle manufacturer: "*I think it is good for all parties. They drive their cars a little more carefully and there are less accidents, the cars do not need to be repaired, less money… so it is good for everyone as well"* (VM2).

Geofencing also allows for better monitoring of vehicles and drivers to see where they are and how they are operated. "*Above all, we have concentrated on making it efficient for those who have large fleets to allow them to monitor their fleet and improve the efficiency of the operation and fuel costs"* (VM4). A better understanding of how vehicles are used can improve the way they operate and reduce fuel usage. By using positioning data combined with other data, geofencing can provide helpful insights for vehicle owners as well as drivers: *"There are customers globally interested in follow-up on, for example, speeding violations, in order to create a safer driver environment or surroundings"* (VM4). This leads to the next identified theme of *cost savings*. Geofencing can reduce the amount of damage to vehicles, decrease insurance costs, and make transport more efficient, thereby reducing the number of vehicles needed.

In this sense, geofencing can also be good *PR,* as the transport company can brand itself as a more sustainable business by increasing safety for drivers, reducing the traffic risks, and making transport more efficient. *"Good advertising about these things in this zone, let's say an environmental one, you raise awareness…"* (HD1). It could also be good PR for transport buyers: *"Now, I am not saying we do, but we could use it for PR purposes. And, above all, we can answer reporters and others who ask us questions about how we manage these parts. So, we could definitely pay more for that, because it sounds absolutely fantastic"* (R4).

Lastly, *work environment* is identified as a driver, as several respondents mentioned how geofencing could assist drivers to comply with the mandated speed, reduce the stress of the drivers, and simplify administrative tasks. *"Today, we have a solution [that uses geofencing] with tolls. […] They may not complain about it [paying road tolls], but it creates quite a lot of administrative work"* (VM3). Others mentioned how today's traffic situations are often stressful for drivers and that geofencing helps the drivers do the right thing. It is easy to miss a sign, and here geofencing supports the driver. *"But if you look at the transport operators, I think there should be value in, for example, adhering to the speed limit and helping your drivers to keep the speed. So, of course, you contribute to increased traffic safety, but I also think it should contribute to reduced wear and tear on vehicles"* (LRA1).

Barriers at micro level are summed up as *user issues* and *knowledge/awareness*. Many barriers are related to *user issues*. These entail useability of the system, issues the drivers might have with geofencing, and problems that arise when using the technology. Several respondents mentioned the issue of drivers feeling exposed or monitored if geofencing was used in the vehicles. *"One negative would be if you went into this with personal integrity and you connect this to that driver and this to that driver. That you can check up on them, so to speak"* (RMP1). In some sense, the technology could take away the right, as an individual, to make your own decisions. *"The industry will not demand further monitoring of the transport; it is big brother sees your problem* (R1). In relation to these aspects, some respondents mention that the drivers should or must be able to turn off the system when necessary. This, in turn, to some extent diminishes the purpose of the technology. At the same time, to avoid geofencing, you have to use older vehicles that do not have the technology. One person mentioned that *"the drivers could also have better or more useful experience than the technology"* (FO3). Setting up the geofences could also be problematic. The systems in which you set up a geofence and its attributes can have flaws, or the person setting up the zones could set them up badly, creating substantial problems.

That last barrier identified is *knowledge/awareness*, indicating that there is not enough knowledge about geofencing among some actors and the potential to start working with it. *"[…] it is often difficult to explain to customers compared with other commercial solutions and explain the value. It is a little challenging, especially when it [geofencing] is not so widespread. Because it is quite early, there are few vehicle manufacturers who do this today, as far as I am aware* (VM4). This problem also occurs within city authorities to start working with geofencing: *"one problem, if you work in development in any way, is that you need the understanding and insight of decision-makers for this problem, but since it tends to be technically complicated, legally complicated. and so on, there is a risk that it goes further down on the interest and agenda so to speak"* (LRA6).

5. Discussion and implications

5.1. Drivers and barriers

In this study, we identify a wide range of drivers for and barriers to the implementation of geofencing. We categorize these into macro, meso, and micro levels, which have been used in other transport-related studies (Karlsson et al., 2020; Leviäkangas and Öörni, 2020; Mattioli et al., 2016; Melander and Lind, 2022; Melander et al., 2022). These studies attest to the necessity of taking a multi-level perspective when implementing new and innovative solutions in the transport system. Geofencing is an established technology that can enable future transport modes, such as automated vehicles (Bin-Nun and Binamira, 2020) and shared mobility services (Nikiforiadis et al., 2023). Hence, while the technology is not new per se, its implementation can enable and support new and emerging transport solutions.

The study finds that at macro level, drivers for implementing geofencing included an improved urban environment and city planning, increased knowledge that could result in policy implementation, environmental benefits, traffic safety and security, and improved possibilities for traffic management. Barriers included regulatory difficulties, limited relevance of using geofencing, limited demand, fear of security risks, and problems related to data quality. At meso level, drivers included improved efficiency and possibilities for compliance control. Barriers encompassed uncertainties around roles and responsibilities, interoperability, limited functionality, uncertainties around viable business models, and limitations in technical systems and data exchange. At micro level, drivers for implementing geofencing included safety issues, monitoring and positioning, the possibility of analysis and increased knowledge and follow-up on performance, cost savings, possibilities for improved public relations, and improvements in the work environment. Barriers included risks around user issues and low levels of knowledge and awareness of the technology and its potential implementations.

The study points to many uncertainties around business models and the roles of different actors. Hence, the implementation of geofencing faces similar barriers to those of implementing other new transport solutions, such as MaaS, sharing charging infrastructure, or hydrogen fuel cell technology for heavy-duty vehicles (Karlsson et al., 2020; Küffner, 2022; Melander and Wallström, 2022). The actors' perceptions of the drivers for and barriers to different features of geofencing also call attention to how geofencing may be perceived as interfering when managing traffic. In addition, the issue of who will have responsibility for managing the zones may induce different actions and reactions among the various actors that become affected as involuntary users.

Furthermore, there is not a unified definition of geofencing among the actors. This may affect the expectations of the technology as well as how it can be used and how actors perceive their roles in relation to the development, implementation, and usage of the technology (Lindkvist et al., 2022). Another aspect that can affect the implementation of geofencing is how different actors perceive the technology itself and its use. The variety of use cases of geofencing creates a vast number of drivers and barriers. These drivers and barriers can be both use case specific and overarching for geofencing as a whole. Furthermore, different actors, for instance, public actors, service providers, or transport service providers can acknowledge different drivers and barriers with the technology. While some actors, primarily public ones, may gain big benefits with the technology, private actors, especially potential customers of geofencing services, may to a greater degree find geofencing unnecessary at this point in time. This is exemplified by both transport operators and potential developers of geofencing. Exceptions are direct economic values, mainly through reduced costs as a result of increased monitoring and positioning, of geofencing services. There can be several reasons why potential customers perceive geofencing as providing limited value. 1: Few transport service providers or retailers have been involved in geofencing-related projects and, hence, have not experienced the benefits, and they mostly consider different barriers to using it. 2: Due to their diverse operations, actors consider different use cases for geofencing with different drivers for and barriers to implementing it. 3: Studies of projects with geofencing focus on the societal and environmental benefits of geofencing and not on the business opportunities and business models.

It can further be discussed that individual backgrounds and strategic or operational roles of people within organizations generate different perspectives on drivers for and barriers to geofencing. The individual views contribute to a wider understanding of implications and opportunities within different contextual settings where geofencing can be used. It also contributes to difficulties to formulate a unified definition of the technology and the drivers and barriers. Herein, the experience of the people involved affects the definition of drivers and barriers. People with more experience can better pinpoint the different drivers but are also better at describing the actual barriers.

5.2. Implementation at micro, meso, and macro levels

The study identifies a wide range of potential benefits of implementing geofencing at different levels of the transportation system. Implementing geofencing at micro level requires limited external interaction, as it is often related to local zones, e.g., in-house geofenced areas, such as storage facilities or loading zones. However, the implementation at the meso level requires interaction between various actors in the network. Here, public actors (such as road operators) need to become part of the network, resulting in a need for public–private interaction. Hence, to achieve the benefits identified at macro level, the transportation system, including multiple public and private actors, needs to interact and share data. We know from previous studies that public–private interaction can be difficult to achieve (Andersson and Mattsson, 2018; Guercini et al., 2020; Munksgaard et al., 2017). However, to achieve the potential values that geofencing can bring at societal level, public–private interaction needs to be facilitated and stimulated.

At micro level, actors have primarily captured specific values, making their operations more efficient and/or safe. Beyond the rather local use cases, there are expectations of more generic geofencing solutions that could contribute to traffic and/or vehicle control in all kinds of zones. To develop such solutions, however, there is a need to develop standards and protocols for communication between vehicles and infrastructures of different kinds. Herein, not only private actors but also public ones need to be involved. Since vehicles and vehicle OEMs operate across cities and national boundaries, agreements on national and/or international standards and interfaces would be needed to make such solutions viable.

5.3. How can barriers be overcome to reap the benefits of implementing geofencing?

While there are barriers of a technological and regulatory nature, these can be overcome by investments in digitalization and regulatory adjustments. Technological investments and development of standards within and across national borders would facilitate communication and sharing of information, which is needed to implement geofencing applications. Regulatory bodies, between regions as well as nations, need to converge on issues such as control, data sharing, and compliance. At the same time, several use cases for geofencing could be implemented without regulatory changes, although several actors seem to be convinced that that is not the case. There seems to be a knowledge gap in what is required to increase the use of geofencing. Therefore, to reap the benefits of geofencing, such as improved safety, a better environment, and improved planning and traffic management, many actors, both public and private, need closer collaboration to clarify and overcome the hindering factors for large-scale use of geofencing. Such multi-actor collaboration requires much coordination. While some actors see clear benefits from implementing geofencing, others see few. These differences in perspectives need to be addressed to ensure commitments from actors, such as getting unions and drivers to accept geofencing applications. Such barriers need to be overcome before implementing geofencing.

There is a knowledge gap and information asymmetries between actors that needs to be overcome. Outside actors need to build relationships with actors in the transport network, going beyond their business and supply chain partners. Hence, there is a need for multi-level collaborations, from micro and meso levels toward macro levels. Activities are needed for the diffusion of the technology and implementation of geofencing solutions. Users, government representatives, and citizens need to be convinced of the benefits of using geofencing. Here, the social dimension becomes important to reach acceptance in cities from these groups. Resources (technological, organizational, and financial) need to be combined and mobilized. Collaboration is needed, as different resources are controlled by different actors. Hence, there is interplay between actors, activities, and resources at micro, meso, and macro levels.

Business models for different applications need to be developed, tested, and implemented. The lack of business models for private actors makes it difficult for transport operators to see any added value from geofencing, and OEMs have low incentives to develop it, and transport buyers view it as an increased cost. These viewpoints from different actors need to be addressed when developing new business models. Roles and responsibilities need to be established, and the behavior of both professionals and the public may need to be adapted to facilitate the implementation of geofencing solutions. Viable business models at micro levels could be developed by multiple decentralized actors for each specific need. However, for implementations at macro levels, a central actor needs to take a prominent role to enable it. Moving beyond micro success cases toward meso and macro level implementations is challenging. These business models require multi-actor and multi-level collaboration between public and private actors as well as social acceptance from citizens.

Today, there are several implementations at micro level, such as in warehouses or within an actor's premises. There are also pilot projects and larger demonstration projects of geofencing applications. However, it has been difficult to go from these small local solutions to large-scale commercialization. The only geofencing solutions that are used on a larger scale today are use cases that have clear cost reduction for the users, such as fleet tracking. However, use cases that support more societal and environmental values, which are the main drivers for public actors, induce more barriers. These barriers are found more often at meso level, such as uncertainties around roles and responsibilities, lack of viable business models, and technological uncertainties. Geofencing solutions with drivers that are prominent for public actors need more collaboration between a wide range of actors, and additional driving forces for interest among private actors. For instance, it could be requirements in public procurements or policies that enforce the use of geofencing.

5.4. Managerial implications

The study points to a number of managerial implications. Managers need to be aware of the multi-level aspects of geofencing solutions and multi-actor collaborations. Small-scale and local geofencing implementations are needed for actors to gain value from the technology as well as for testing it. Managers should also be aware of the possibilities of geofencing applications at meso and macro levels, where each actor needs to consider its role and responsibilities in the transport network. While barriers of a technological and regulatory nature are difficult for individual firms to overcome, managers should, instead, focus on adapting the behaviors and attitudes of individuals, showing that there are benefits to be had from implementing geofencing once the main hurdles had been overcome. Business models for different applications need to be developed and tested, and demonstrate added value to organization and its customers and users.

5.5. Policy implications

The study shows the need for regulations and policies to support the implementation of geofencing solutions on a larger scale. In some cases, there can be a need for regulatory changes, but many applications can be realized without slow law changing processes. Instead, the focus should be on policies and overall advancement in digitalization and knowledge of geofencing among local, regional, and national authorities. These and international governmental bodies need to collaborate to facilitate the implementation of geofencing applications. Private actors have key roles to play, but they need to be joined by public actors that have wider control of roads, cities, and traffic management. Furthermore, as actors can interpret geofencing differently, it would be beneficial with structured definitions for geofencing for different use cases. This would decrease risks of misunderstandings and clarify the various roles of actors.

5.6. Limitations and future research

This study is limited to a Swedish context. Sweden is a country that is a forerunner in many transport-related developments, having incumbent transport actors such as Volvo and Scania as well as start-ups, such as Einride, pushing for technological developments in the transport network. For future studies, it would be interesting to compare a number of countries that are testing geofencing solutions. Another useful venue of research could be to conduct a scenario study, investigating potential future scenarios of geofencing implementations.

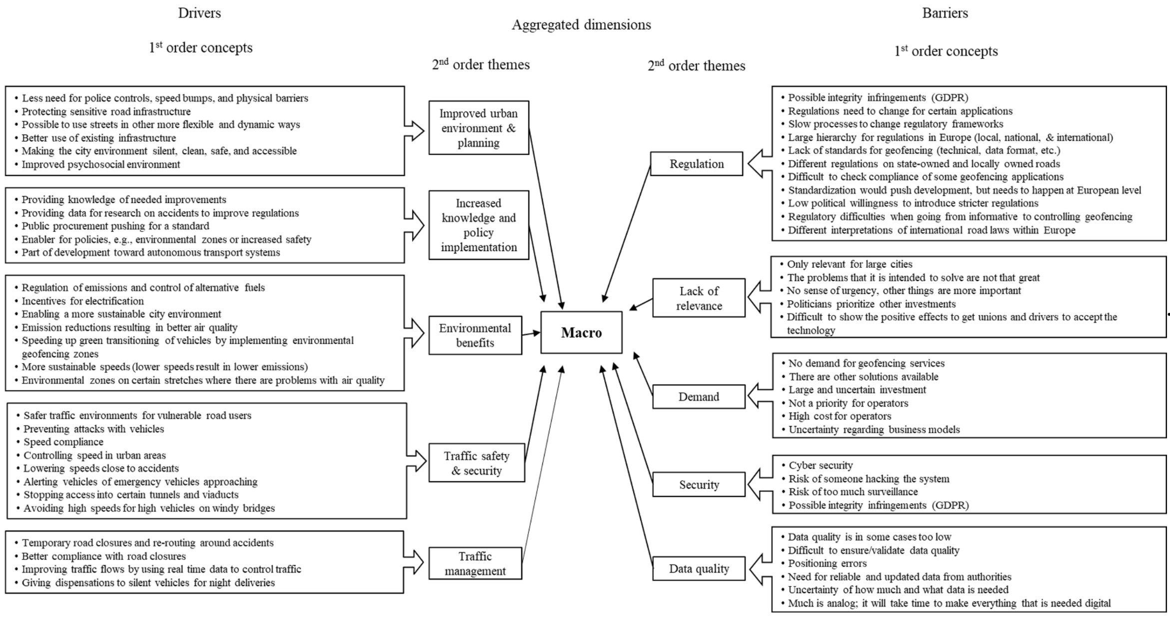
CRediT authorship contribution statement

Hannes Lindkvist: Conceptualization, Data curation, Formal analysis, Writing – original draft, Writing – review & editing. **Lisa Govik:** Conceptualization, Data curation, Formal analysis, Writing – original draft, Writing – review & editing.

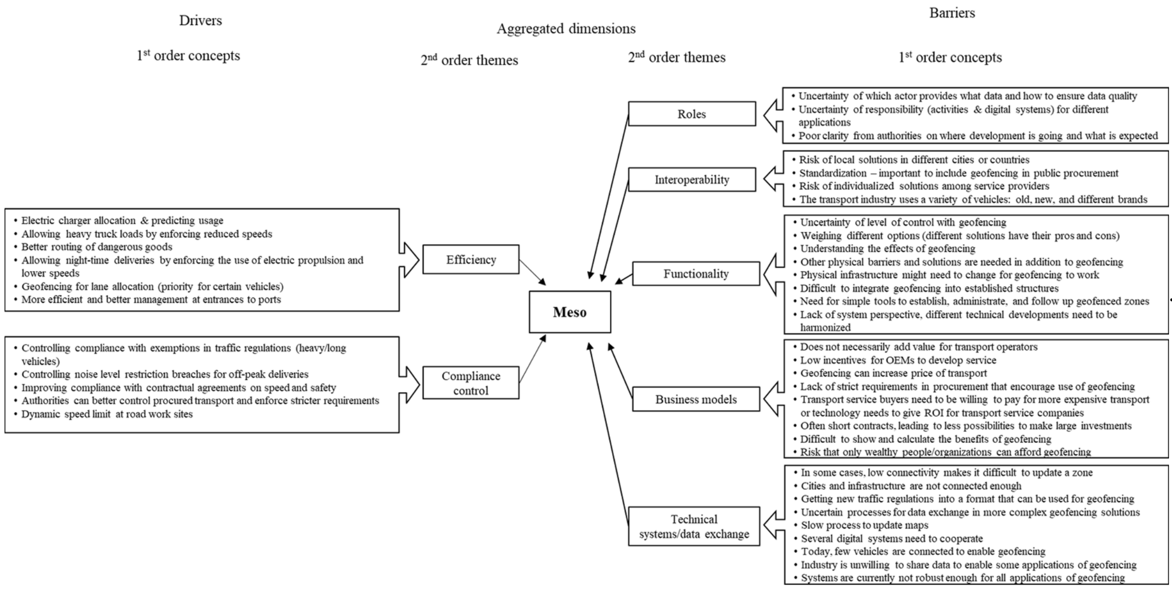
Declaration of competing interest

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

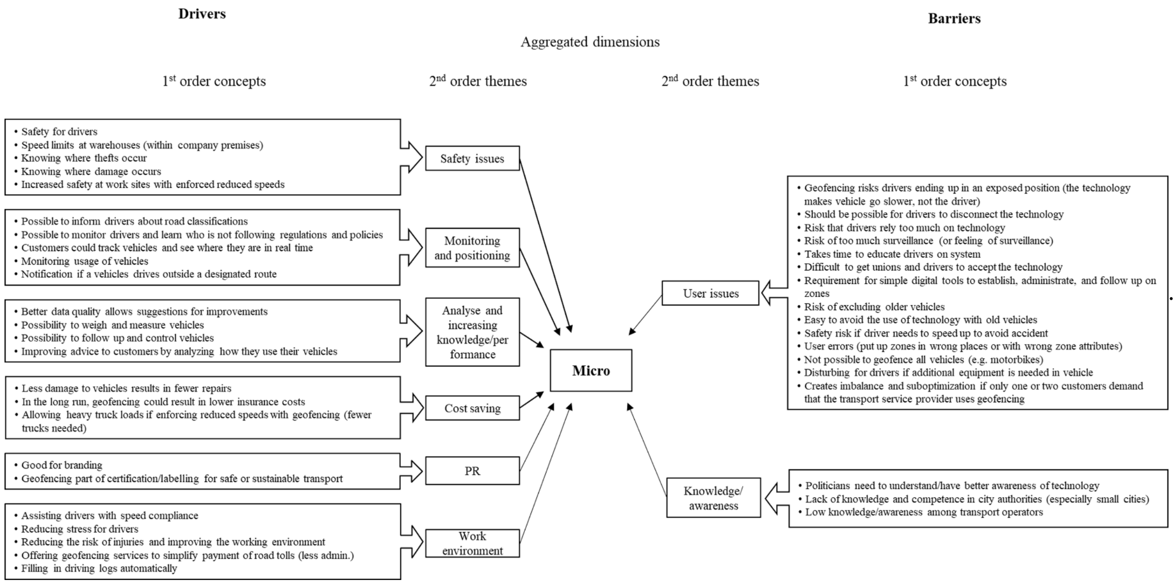
Appendix 1. . Driver and barriers on macro level



Appendix 2. . Driver and barriers on meso level



Appendix 3. . Driver and barriers on micro level



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