GeoSence - geofencing solutions aiming at improving urban traffic management and planning.

GeoSence Report on Impact Assessment and Evaluation

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Abstract

This report presents the impact assessment and evaluation of geofencing solutions developed and tested during the GeoSence project from 2021 to 2024.

The objective of the GeoSence impact studies is to answer two key research questions: firstly, what are the quantitative and qualitative benefits obtained when performing a pilot or a use case of a geofencing application in a city? Secondly, what are the management lessons learned, barriers and success factors to a future wide-scale implementation?

This report shows the results and analyses of the evidence, data collection and information obtained in the GeoSence trials. It is intended to serve as a reference for the preparation of future government and business activities, pilots, trials and applications. It publishes the key information obtained, from the most strategic level down to the most practical quantitative data.

This report forms part of a series of final reports on the three-year GeoSence project. It focuses on the results and impacts of the use cases, mainly based on the experiences in the cities of Gothenburg and Munich. Consequently, it includes multiple aspects such as regulations, managerial approaches, technological solutions and market studies that have the potential to be connected when developing geofencing in future.

Keywords: *Geofencing, trial, impacts, speed, parking, micro-mobility*

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List of Symbols, Abbreviations & Acronyms

%	Percent
&	and
ACC	Adaptive Cruise Control
CO_2	Carbon Dioxide
DOI	Digital Object Identifyer
e-bike	Electric bicycle
e-scooter	Electric scooter
e-truck	Electric truck
Fig.	Figure
GeoSence	Geofencing strategies for implementation in urban traffic
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
i.e.	id est (latinum for “that is”)
ISA	Intelligent Speed Assistance
km	Kilometre
km/h	Kilometres per hour
KPI	Key Performance Indicators
l	Litre
mph	Miles per hour
NHTSA	National Highway Traffic Safety Administration
ODM	On demand services
PESTLE	Political, Economic, Social, Technological, Legal and Environmental (factors)
pkm	Passenger-kilometre
$PM_{2.5}$	Fine particles with a diameter of 2.5 micrometres or less
R&D	Research and Development
STA	Swedish Transport Administration
SWOT	Strength, Weaknesses, Opportunities and Threats (analysis)
tkm	Tonne-kilometre
US (U.S.)	United States
UTA	Urban Transport Administration (of the City of Gothenburg)
WP2	GeoSence Work Package 2 - Acceptance Studies
WP3	GeoSence Work Package 3 - Legal studies
WP4	GeoSence Work Package 4 - Potential and impact studies
WP5	GeoSence Work Package 5 - Guidance

1 Introduction

1.1 Objectives

Evaluating geofencing is not easy. Main challenge to be tackled when looking at tangible effects in the frame of urban transport policy and transportation business management is the lack of data on the various costs, benefits, traffic and environmental changes triggered by the use of geofencing applications. The key questions are: what are the quantitative and qualitative benefits obtained when performing a pilot or a use case on geofencing application in a city? What are the barriers and success factors to a future wide-scale implementation? Answers to these questions are presented in this report.

One of the objectives of GeoSence is to deliver evidence to decision makers on the benefits of different types of geofencing solutions, thus enabling future scale-up of technologies with demonstrated effects. This report contributes with background and evidence to this guide.

1.2 Purpose and ambition of this report and of Work Package 4 (WP4)

The purpose and ambition of this report is to present an impact assessment that is successfully isolating the geofencing effect from other effects, comparing data with and without the solution. Due to the large operational differences in the trials, a unified data collection methodology was not really feasible, so it remains difficult to analyse and compare different projects and facilitate knowledge exchange among cities. This report is the main report for GeoSence Work Package 4 - Potential and impact studies (WP4).

As initial ambition, the GeoSence project design stated that WP4 would “deliver evidence with an assessment of the effects of different geofencing solutions on the transport system and the environment as a whole, and for specific cases in partnering cities. WP4 will study these effects using a full range of state-of-the-art methods of urban mobility research, such as field surveys, multi-actor assessments, Costs & Benefits Analysis, scenario building, and data processing. Main KPI units and interview data will be collected with and without (before/after) the use of the application, enabling a comparison of what if scenario and business as usual. The final list of quantitative KPI will include at least: distance, units (passenger numbers/tonnes/parcels delivered), vehicle types and modes, number of trips/day, fuel use and emissions. The design of the GeoSence case studies will be influenced by the WP4 data collection as it will be possible to include field experimentations that match the agreed data quality, disclosure and public openness requirements”.

At the end of the project, most of this initial ambition could be reached, and the report presents these results and outcomes.

1.3 Main challenges and problems to be overcome in WP4

Problem 1, methodology difficulties leading to a lack of robust data:

The lack of robust data giving evidence on the difference between a situation without geofencing and a situation with geofencing application in use.

Problem 2, difficulty to isolate the beneficial effect of the geofencing solution:

Either as a pure technology or a more strategic and regulatory solution, the success in obtaining good quality, robust data lies in the ability to design trials that are capable to isolate the beneficial effects from the impacts of other origins.

Problem 3, early stages of technology and bottom-up approach:

All trials are prepared and organised rather independently by local actors, with their own time plans and local resources. GeoSence is a management research, not a technology development project, so all technological changes need to be supported, run, and funded, by local stakeholders and local actions.

1.4 Structure of this report

After the introduction (section 1) we present the main definitions (section 2) and the state of the art for the methods in use (section 3). The major chapter 4 is about the impact assessment of the use case of geofencing for speeding, based on the use case in the City of Gothenburg, Sweden. This is followed by Chapter 5 on the impact of the use case of geofencing for micro-mobility achieved with the use case in the city of Munich. In conclusion, Chapter 6 answers the initial research questions, and presents future possible steps.

2 Definitions and Design of Use Cases Enabling Good Data

Definitions and key terms for impact studies

The definitions and key terms used in this report are based upon those stated in the GeoSence report on "Current state of the art and use case description on geofencing for traffic management" (Hansen et al., 2021). Few elements of clarification were added.

Geofencing

According to Hansen et al. (2021), the working definition of geofencing for traffic management and planning is defined as: "Creation of a geofence for monitoring, informing, and controlling traffic (mobile objects/vehicles) located within, entering or exiting the geofence, using electronic communication technologies or pre-defined geofences embedded into the mobile objects/vehicles", where a geofence is defined as: "a virtual geographically located boundary, statically or dynamically defined".

Geofencing can offer several objectives in traffic management, including:

1. Traffic analysis: Geofencing can be used to monitor traffic flow and congestion levels in specific areas. This can help traffic managers identify problem areas and optimize traffic flow.

2. Parking management: Geofencing can be used to manage parking areas, including monitoring occupancy levels and enforcing parking regulations. This can improve parking efficiency and reduce traffic congestion.

Use Case, or Case Studies

An application, demonstration or testing of a geofencing solution in a real business, public transportation, or individual mobility purpose, including real traffic situations corresponding to day-to-day activities by generic actors, and characterised by the absence of pure simulation exercises. In this report we use the terms "Use Case" for an entire city demonstration of geofencing, and the terms "Case Study" for a specific subset of applications tested.

Scenario

Characteristics and specifications for a new scenario situation are designed to provide the most robust evidence for the calculation of a difference between a test situation and a business-as-usual situation. The content of a scenario can include different elements such as area, duration, actors, technology, vehicles, management, service level etc. The scenarios are defined by the project managers and decision makers responsible for the testing.

Assumptions

Theoretical assumptions should be avoided as much as possible. But most of the time, in transportation trials, it's proven impossible to collect the entire spectrum of data for 100% of vehicles, situations and people. For example, if a public transport company testing a solution is employing 2000 staff, the trial interviews can only be performed with a very small sample of few dozen people, and assuming that all the other staff would be acting similarly.

Use Case Design

Design in this trial context means defining all the elements necessary for setting up a pilot, a new regulation or a geofencing management solution.

Impacts

All negative or beneficial effects generated by the geofencing solution, pilot or regulation.

Examples of such effects could be economical benefits or costs (higher or lower costs), transportation efficiency (less km for the same service level), transport safety (lower speed, less accidents), environmental (excluding dirty vehicles from a geofenced zone) or health related (cleaner air and more active mobility). The effect could also be managerial, with the geofencing solution allowing municipality to adapt the geofenced area to the specific needs, for examples new speed limits during construction works, remote control of speed levels, etc. The effects could also be legal, with new rules being developed and applied city wide.

Impact data

Due to the holistic approach chosen in GeoSence, the relevant data is not only about numerical information on impacts, but also includes a lot of additional information made available about a wide range of effects. Data can be quantitative or qualitative, for example in form of quantitative time series about speed, qualitative interviews, technology specifications, management solutions etc.

KPI – Key Performance Indicators

In transport research, there are some well-known indicators, such as mode share (%), distance (km), time (day/hour/min/sec), speed (km/h), load factor (passenger/vehicle, tonne or transport unit loaded/journey etc.), number of complaints, number of infringements, accidents (fatalities/year), fuel use (l/100km), fuel efficiency (l/pkm or l/tkm), emissions ($PM_{2.5}$/km), emissions intensity (CO_2/pkm or /tkm).

Every Use Case defines and selects the KPI and derives the most relevant ones according to the objectives and the methods applied during the trials.

3 Methods for Impact Assessment of GeoSence Use Cases

3.1 Overview of approaches, methods and steps used for planning and testing cases

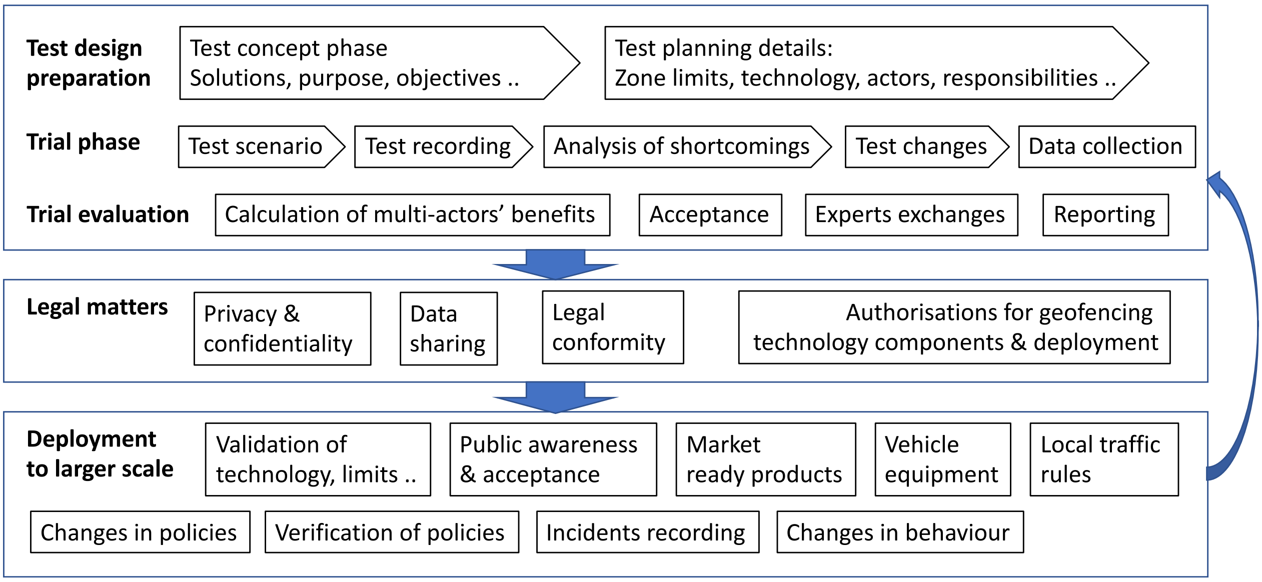
Following methodology is an overview of the impact assessment and the different elements involved in testing, trials, and pilot demonstrations for transport research purpose. This combination of steps was developed by Dörr (2021) for tests of automated driving technologies and solutions, and is being adapted to our geofencing use cases.

In innovation research, especially those linked with automation technologies for transportation, it is essential to get an overview for the preparation of a use case (Fig. 1).

The upper part of the graph is the one showing the relevant steps for the preparation of the test design, with the concept phase and the test planning details as major steps.

The trial phase is starting later, but it is important to acknowledge the longer-term effort to be performed until the practical test can take place, and even longer timescale until the larger deployment phase can start.

Figure 1: Strategic planning steps and data management in testing, implementing, and deploying geofencing solutions in the GeoSence project, 2021-2024



Source: Adapted from Dörr, 2021.

For example, at the beginning, GeoSence was going through all the steps of trial preparation, test design and evaluation for several use cases about speed, parking, driving and Municipality zones. At the end of the project, GeoSence underwent a thorough check of regulation and legal matters and has now arrived at the stage of deployment to larger scale for the case of e-scooter parking and e-scooter ride hailing process.

Overall, GeoSence research was in the lucky position to have relied upon excellent Municipality services, actively involved in the day-to-day development and running of trials, and very successful outcomes, so that all steps described in Figure 1 could be observed and considered in this report.

The holistic view of GeoSence was reflected in its organisation. WP4 Impact Studies deals mostly with trial evaluation tasks but were already involved at the trial preparation and trial monitoring stages. Acceptance was surveyed and assessed in WP2 as an integral part of the trial preparation, monitoring and trial evaluation. Legal matters were the subject of WP3 investigations. Possible future deployment to larger scale were researched and are analysed and presented in the WP5 report, the guidance document D5.3.

The trial phase was run by local authorities and the trial preparations were a collaborative effort of all partners in GeoSence.

3.2 Background research on impact assessment of transport policy options is focusing on geofencing applications

As academic and practical preparation steps to the trial, extensive literature review (Hansen et al. 2021), survey of city management representative (Hansen et al., 2022) and check of effectiveness and soundness of various practical technologies, managerial and legal solutions were performed, with direct consequences for the impact evaluation.

Only limited additional GeoSence research is needed for specific cases, as most background knowledge available can be considered fully validated for the policy making of the field researched.

For example, background knowledge on impacts, key principles and well-known effective policies for speeding and road safety were not reviewed in general, only in detail, when devising how best develop geofencing to influence speeding, because there is a full compendium of reliable evidence on general effectiveness of various speeding limitation policy, as stated by the recent US safety report on "countermeasures that work": "The effects of maximum (…) speed limits on speeds, crashes, and casualties have been studied extensively over the past 40+ years. In general, there is significant evidence that when limits are raised, speeds, crashes, and injuries rise, and when they are lowered, speeds, crashes and injuries usually decline" (NHTSA, 2023).

As another example: The satellite based geospatial technologies of GNSS and GPS were made available long ago to the transport operators, and the knowledge how to derive speeding information from these types of data is well established (Soole et al., 2023).

So, the full body of literature available on geofencing was reviewed first in the project beginning, and the necessary assessment steps, methods and framework became obvious and easy to develop.

As a consequence, about safety and speeding, the differences in effectiveness are evaluated according to an impact scale from very high to very low only for very specific options, not for the overall safety policy (Section 4 below).

For e-scooter, parking and micro-mobility management, there is a similar decision to bypass reviewing all the general policies on mobility, car, public transport, and road traffic, and focus instead on the impacts of the very special cases of geofencing use for mobility service providers and micro-mobility policy options (Section 5).

3.3 Analytical methods of management science were applied after completion of trials

Due to their usefulness, a number of classical, additional standard methods of management science and transportation science were used for this impact assessment, such as Effectiveness and Efficiency analysis, SWOT, PESTLE and Sustainability Analysis. These analytical steps were performed after the completion of the trials.

4 Gothenburg Use Case

4.1 Background and state-of-the-art of Intelligent Speed Assistance (ISA) technology and geofencing use in urban traffic management

Purpose of the Gothenburg trial is to demonstrate what happens when adding geofencing to a speed limit functionality, such as Intelligent Speed Adaptation (ISA) and beneficial effects when used in Special transport vehicles. In this report, the focus is on the impacts.

Because geofencing is applied on policy actions, first, we clarify the state of the art and principles of the technology, before presenting the geofencing application itself. This update reflects literature as of May 2024, for example using the recent effectiveness review of the safety technologies presented by the US National Highway Traffic Safety Administration (NHTSA, 2023) and the report of the European Commission on Traffic Safety (EC, 2021).

State of the art about speed policies and the impact of using Intelligent Speed Assistance (ISA)

Table 1: Speed management policy options

Intervention	Proven	Promising	Insufficient evidence	Ineffective	Potentially harmful
Establishing speed limits appropriate to the road users (see Section 2.2.1)					
Setting speed limits for new and existing roads based on Safe System principles	✓				
Implementation of 30 km/h zones	✓				
Setting speed limits based on the 85th percentile					✓
Building or modifying roads to include features that reduce speed (see Section 2.2.2)					
Increasing travel speed without improving quality of infrastructure					✓
Speed humps and chicanes	✓				
Lane narrowing	✓				
Refuge islands and kerb extensions	✓				
Footpaths and cycling lanes	✓				
Raised pedestrian crossings	✓				
Pedestrian bridges					✓
Pedestrian fencing			✓		
Raised intersections	✓				
Roundabouts	✓				
Gateway treatment at entrances to towns and villages	✓				
Enforcing speed limits (see Section 2.2.3)					
Manual speed enforcement	✓				
Automated speed enforcement	✓				
Point-to-point enforcement ("section control")	✓				
Using in-vehicle technologies (see Section 2.2.4)					
Speed limiters (SL)		✓			
Intelligent speed adaptation (ISA)		✓			
Autonomous emergency braking (AEB)		✓			
Raising awareness about the dangers of speeding (see Section 2.2.5)					
Stand-alone public campaigns (TV, newspapers)				✓	
Public campaigns supporting enforcement initiatives		✓			
School-based education on speeding				✓	
Driver skills training					✓

Source: Speed management, 2023

There is an internationally recognised range of interrelated policy interventions relevant for speed management, as analysed and presented in the Red Cross guidance document on counteracting speeding. In this report, it is noticeable that all in-vehicle technologies are considered “promising” and none actually “proven” (Speed management, 2023) (Table 1).

Among the safety technologies for road transport, Intelligent Speed Assistance (ISA) refers to a set of hardware and software systems belonging to the purpose: counteracting speeding, and speed management.

A principle of speed management actions for local authorities and transport administration is that drivers must at all times and places be aware of the speed limit, to comply with it while driving and navigating in traffic.

Given that transport policies encourage minimal placement of speed limit signs, or no posting in areas under statutory limits, drivers need support for knowing the speed limit.

Intelligent speed assistance, or intelligent speed adaptation (ISA), is a digital system of hard- and software using in-vehicle GNSS (GPS) technologies, connected with accurate geospatial data, including digitally mapped speed limits of the road network. ISA can also include a vehicle-based digital system of speed limit sign recognition. ISA can vary from minimal systems that provide information, to active speed limit control. Such system could be mandatory or voluntary (for example using manual on/off switches for speed control mode activation).

4.1.1 Description of functionalities and legislation status

ISA systems can:

1. Provide information only (display the speed limit and changes)
2. Provide visual or audible alerts when the speed limit is exceeded, but the driver can decide how to react
3. Provide accelerator resistance to make speeding more difficult, but still possible. This system is like cruise control, except the speed limit (not the driver) determines when to engage speed resistance. Drivers may be able to turn off the system with a switch
4. Automatically prevent speeding above the speed limit (mandatory speed compliance) (Table 2)

Table 2: ISA systems in use

5.

Assistance level	Type of feedback	Feedback
Information	Mainly visual	The speed limit and changes to the speed limit are displayed
Warning (Open)	Visual/auditive	The system alerts the driver if he exceeds the local speed limit. The driver decides what to do with this information and whether to adjust his speed.
Intervention (Half-open)	Haptic pedal (medium/light feedback)	The driver feels resistance in the accelerator pedal when trying to exceed the speed limit. If sufficient force is applied, it is possible to drive faster than the limit.
Automatic control with speed limiter (Closed)	Haptic pedal (powerful feedback) and off pedal	The maximum speed of the vehicle shall be automatically limited to the local speed limit. Attempts by the driver to drive faster are simply ignored.

Source: EC, 2021

ISA helps potentially control speed of all motor vehicle types according to the limit at a location.

In 2019, the European Union passed legislation requiring all new vehicles sold starting in 2024 to be fitted with ISA (EC, 2021a, EC 2021b). European ISA will work much like cruise control to prevent the vehicle from travelling in excess of the regulated speed limit by limiting engine power. Unlike automatic braking, this will not involve the vehicle braking automatically in response to a speed limit violation. The systems will be equipped with on/off switches in order to encourage public acceptance. However, the default status will be "on" each time the vehicle is started. Furthermore, the systems can also be overridden by the driver, who remains in control of the vehicle speed. The commission also updated other vehicle safety measures, including a requirement for event data recorders to show whether the system was being overridden at the time of the crash.

4.1.2 Effectiveness impact assessment of ISA

ISA has been found to lower speeding among drivers using the systems. Varied types of systems have been widely studied in European countries for acceptability and effects on driver behaviour (Graupner et al. 2024).

According to NHTSA (2023) in Europe, the effects on speeding have been dramatic for both warning and control type ISA systems, decreasing the amount of speeding and narrowing the speed distributions while the systems are being used. Like other speed control measures, there seems to be little potential for a lasting educational benefit or "training" of drivers to control their speed once the systems are in place. In a long-term study of 284 drivers using an active accelerator pedal, Várhelyi et al. (2004) found that while driver speeds increased somewhat from initial drops, speeds remained lower over the long-term (5 to 11 months), remained lower when the systems were active, and were significantly lower than that of other drivers. Furthermore, emissions were reduced, and travel times were not significantly increased.

Based on relationships between speed and safety, substantial crash savings are expected (NHSTA, 2023). The European Transport Safety Council has estimated that the forthcoming installation of ISA in all cars, vans, buses, and heavy goods vehicles will result in a 20% reduction in road deaths across the European Union countries (EC, 2021).

In U.S. trials involving young drivers and repeat speeding violators, results have also found reductions in speeding and compliance with speed limits. Researchers developed and pilot-tested a half-open system (increased accelerator counter pressure) when the limit was exceeded by young drivers 18 to 24 years old—22 in the experimental group (with system on for half the drives) and 22 in the control group with no ISA. The experimental group showed less speeding on drives when the ISA was activated compared to not activated and compared to the control group. The researchers also assessed user perceptions of the performance and "likability" of the system. In general, performance was rated more highly than likeability-related factors.

There is a need to provide current and accurate maps of speed limits (NHTSA, 2023)

Adaptive cruise control (ACC) works similarly to standard cruise control, except that, in addition to maintaining a speed set by the driver, a radar system in the front of the vehicle detects and responds to other vehicles in the lane ahead to maintain a safe following distance. A set of US trials involving 40 Boston area drivers found that drivers using ACC were more likely to speed on interstates and freeways, and by a higher degree than when manually controlling the vehicle's speed (Monfort et al., 2022). The vehicles permitted the drivers to readily modify their speed by 5 mph faster or slower, via a toggle control, which may have contributed to the observed results. These findings underscore the importance of detail and driver adaptation to the manner in which systems are designed, as well as voluntary efforts to control speeding behaviour.

Nevertheless, designers, evaluators, and policymakers should be aware of the potential of ISA for other unintended adaptations or effects.

For these reasons, the effectiveness of ISA on speeding is not considered as high or as fundamental as other solutions such as lower speed limits, increasing penalties, camera enforcement, or dynamic speed display signs (NHTSA, 2023).

At the same time, these somewhat inconclusive findings means that more research is needed on behaviour and driver response to existing ISA, or to an improved ISA.

4.1.3 Intermediate lessons learnt and derived next step: testing geofencing for ISA and speed management

As intermediate deduction about what to do next, these successful past ISA trials were very much compatible with the current trends in geofencing technology, notably it was soon clear that setting geofenced speed zones could potentially contribute to the improvement of the ISA effectiveness and counteract more successfully speeding and be potentially useful to future related transport policy developments. For these reasons, the GeoSence team in Gothenburg decided to focus its trial on using geofencing for speed management.

4.2 Design and run of the Gothenburg Use Case

Special Transport Services is a department within the Urban Transport Administration in Gothenburg. The department offers public transport services to passenger groups with special needs, i.e. trips to daily activities for people with functional limitations or cognitive disabilities and school trips for children with special needs. The Special Transport Services is a part of public transport (Fig. 2).

A certain permission is needed for using the special transport services. The trips must be booked in advance, either by calling the ordering central or by using a web page or a mobile application. The special transport service may also be used by city employees for certain work trips/missions.

Every year, over a million special transport trips are made in Gothenburg and surroundings. The mission is to offer safe and secure trips, which is followed up and checked with regular feedbacks from customer surveys.

The fleet of vehicles is divided into two parts:

1. Traffic operators specialised in this kind of trips. From February 2022, when the new contract period started, there were two operating companies. This part represents approximately 85% of the overall contract sum. The operators are contracted to be available a certain amount of time every week/day. They get paid for this time, regardless of how many trips they conduct. These vehicles are painted green and have a special striping and information on the sides of the vehicles. There were 243 vehicles (106 vehicles fitted for wheelchairs and 137 ordinary passenger cars. 73 of the passenger cars were battery electric).
2. Ordinary taxis. These are a complement to the ordinary fleet at peaks/periods of higher demand. The taxi companies are paid per trip.

Figure 2: Special Transport Service vehicle in operation in Gothenburg, 2022

Source: own picture, 2022

The fleet consists of electric vehicles, biogas- and HVO100-driven vehicles.

Use of ISA-system: The traffic operators use ISA systems that **inform** the driver of the speed. The national road data base is the source for the legal speed data. The systems log the actual speed for each vehicle.

Different operators use different ISA systems.

Sometimes, drivers disconnect the ISA-function since they find it irritating.

Problem description: Some **passengers complain about the speed**, that the driver speeds and/or goes to fast. Because of that, the trip does not feel safe and secure.

Complaints per year:

- 2018: 54
- 2019: 31
- 2020: 20

This is a relatively small number when one considers that one million trips are made annually. It is important to note that not all thoughts or comments regarding a trip result in a complaint. The city engages in regular dialogue with associations representing passengers (for example, the National Association for the Blind) and they convey their members' experiences of using the Special Transport Services.

The city also gets **complaints from citizens.** The green-painted cars are easy to recognise and the public notices their driving behaviour (for example speeding). In case of speeding and complaints, the reputation of the city is impacted.

Hypothesis – what causes the problems?

- The driver's support to not override the speed is not good enough.
- The drivers may feel stress to be on time, or to be able to handle as many trips as possible (depending on which business model the company uses).

Possibilities and policy options for counteracting speeding

The Urban Transport Administration (UTA) of the City of Gothenburg does not have a mandate to handle or prosecute speed violation. Only the police authority is authorized to do that. Therefore, we are looking for functions that can give better support for the drivers to keep the speed.

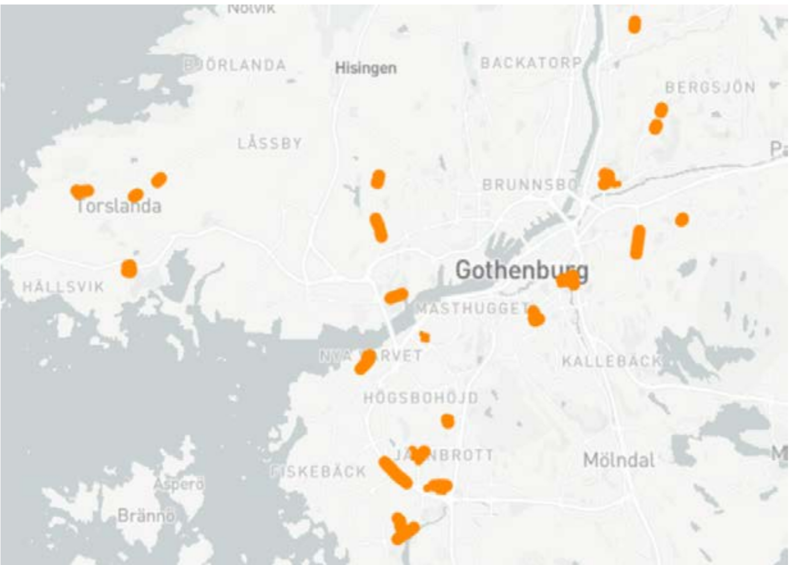
The city wants to have the possibility to set lower speed than regulated at certain areas/parts of the roads, for example where there are complaints, and where there is a higher risk for incidents.

UTA also thinks that the traffic operators are interested in helping the drivers keeping the speed. This could mean less damage and wear of the vehicles, which in turn would decrease costs and increase safety in operation.

Selection, design, identification criteria and location of the geofences zone

Geofences were initially considered for the whole city area, but a selection took place down to about 50 lower speed zones in a more limited extension, including the city centre (inner city), industry areas and suburbs in the North, West and South-West (Fig. 3).

Figure 3: Location of the geofenced speed zones in Gothenburg



Source: UTA, 2022

Tests were carried out in these selected areas. Regulated speed is mostly 50 km/h in urban streets, sometimes 70 on faster roads or 80 km/h on urban motorways (Figure 4).

Figure 4: Regulated speed map, inner city of Gothenburg, 2022

Source: UTA, 2022

The main selection criteria for the limits of the geofences were that lower speed should be tested in zones with higher risk for accidents and/or places with a lot of vulnerable people.

The geofencing zones for the trials were designed based on inputs from the operators and experience and statistics from the Urban Transport Administration, combined with the test drivers "driving areas". The exact number, places and setup for the zones were decided when the drivers were recruited.

All geofences were located in zones near schools and strategic places where safety issues and accidents were the most likely.

In some housing area, multiple zone entrances and exits were possible, and multiple speed limits of 20 km/h and 30 km/h were set-up (Figure 5).

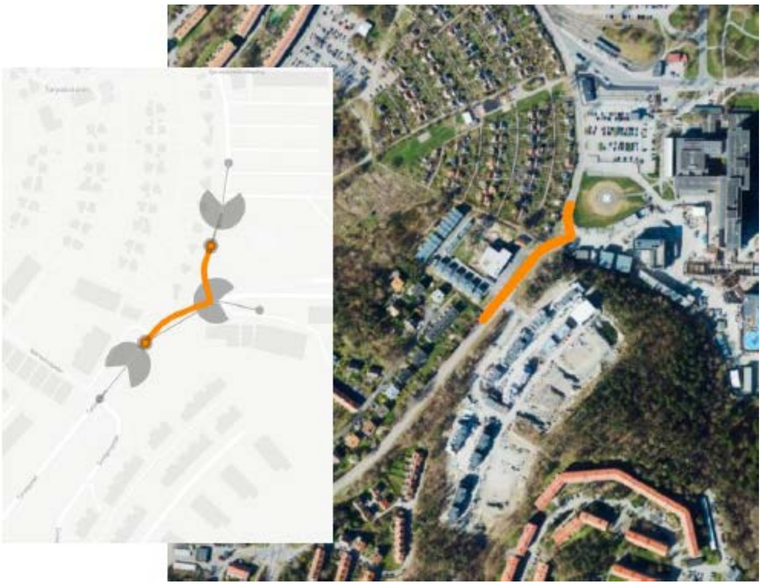
Figure 5: Complex zone set-up with multiple streets and two speed limits in housing area

Source: UTA, 2022

A “safeguarded” buffer radius for entry point procedure was created to enable the vehicle systems to trigger the speed limiter functionality before entering the zone. The trigger entered in the system acts to reduce the vehicle speed accordingly, so that it would comply with the speed limit right at the entrance of the zone, and thus avoid starting decelerating too late. When the speed limit was reduced along the route, for example from 70 to 50, it was visible, prior to the trial start, that drivers were continuing braking and decelerating after entering the lower speed area, thus were over-speeding for a very short time, mostly less than one second, while entering the lower speed zone.

Having set-up these “buffers” in the system for the use case of mandatory speed limit, the geofence limit was already recognised about 20 metres in advance (Figure 6).

Figure 6: “Buffers” around the entry and exit points of the geofenced lower speed zone



Source: UTA, 2022

Description of use case options

In these service trips, passengers belong to a vulnerable group. The use case investigates how public procurement can be used to ensure that speed limits always are respected and thereby strengthens the passengers' right to safe transport.

Test were made to evaluate technical aspects and user acceptance.

During the trials, the devices were fitted to the vehicles so that a gas flow reduction was noticeable, when entering a lower speed zone, but it could be overridden by pressing hard, thus avoiding forcing the drivers to speed compliance at all costs. That’s why we evaluated the drivers’ experiences and behaviour when combining optional ISA for regulated speed (i.e. information about the legal speed) with mandatory ISA for the test areas with contracted lower speed (i.e. geofences).

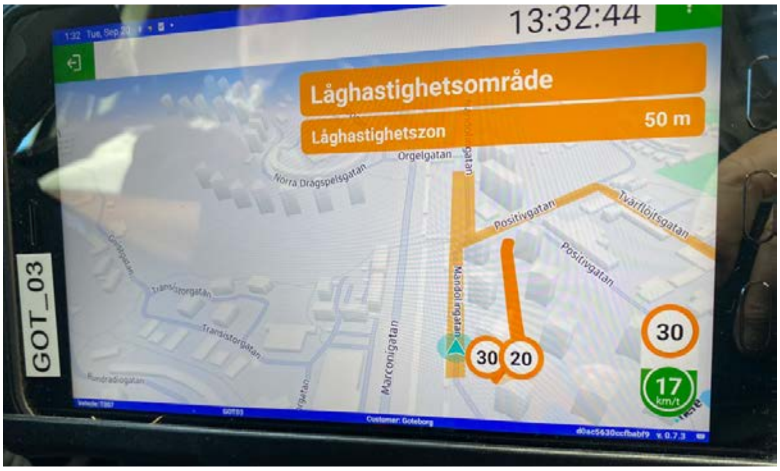
An important issue to analyse is if the drivers accelerate after passing a mandatory geofence to make up for possible time loss.

Technical setup

20 vehicles were equipped with speed limiters. This equipment including a tablet was leased during the test period and the vehicles in the trial were retrofitted with ISA technology including added geofences. “**Retrofit**” means here equipped with new materials, parts and

devices that were not available previously in the vehicle. Geofenced areas were all imported into the fleet management system to impact the test vehicles. An app on a tablet was used to inform each driver of the current speed when entering a geofenced area. It used different sound options, including a pre-recorded voice message, when entering a geofenced zone (Fig. 7). The tablets were plugged into the vehicle systems and compatibilities with existing hard and software were the most time-consuming adaptations.

Figure 7: Tablet fitted in the passenger van during trial operations, with display of geofenced zones and recommended speed limits



Source: own picture, 2022

The vehicle equipment and access to the fleet management system was leased from a third-party supplier and used in the test vehicles during the test period.

The driver could see the entrance of the zone, but attention was limited due to the positioning of the tablet in a place where there was some free space left (Fig. 8).

Figure 8: Geofencing trial Gothenburg: Retrofitted equipment with tablet position in the passenger van

Source: own picture, 2022

Initial questions that the Special Transport Services department wished to get more knowledge about:

1. Can temporary/dynamic speed recommendations, lower than legally regulated, be used to support the driver in driving in a way that the travellers find safe and secure?
2. What drivers' support is needed to make it easier to comply with recommended speed (i.e. lower than legally regulated)?
3. What routines and ways of working must be established to use geofencing in daily operations? From the purchaser's point of view (the Urban Transport Administration) and from the providers' (the traffic operators)?

Initial aim was to test/validate if the geofencing technique

- supports the mission to achieve safe and secure trips (by complying to speed regulations)
- is accepted by the drivers

Learn what is needed to implement geofences for special transport services.

Initial intended outcome

The tests have been carried out and the results have been documented.

Potential issues to be considered

Main prerequisites for preparation and planning

Need to have:

- Vehicle equipment and back-office system to monitor geofences. A supplier was selected, and procurement of devices and software was actioned.
- Test drivers. Continuous dialogue with two operators. Driver recruitment (for the tests) started when the new contracts were valid in February 2022.
- Speed data from trials. The collected data records informed if the test drivers have driven faster than allowed after passing the geofenced zones.

Good to have:

- Speed information from drivers from ISA log files. This data was helping to compare the driving behaviour (regarding speed compliance) of the drivers in the trials with the "normal" driving behaviour.

Limitations due to GDPR:

- The Urban Transport Administration is not allowed to handle information about speed violations. The data that were logged during the trials were made available in the system.
- All speed violation data were anonymized, so it cannot be associated with a certain vehicle or driver.

Time plan: The trials were carried out during summer and autumn 2022.

4.3 Speed limiting geofencing trial: data and results

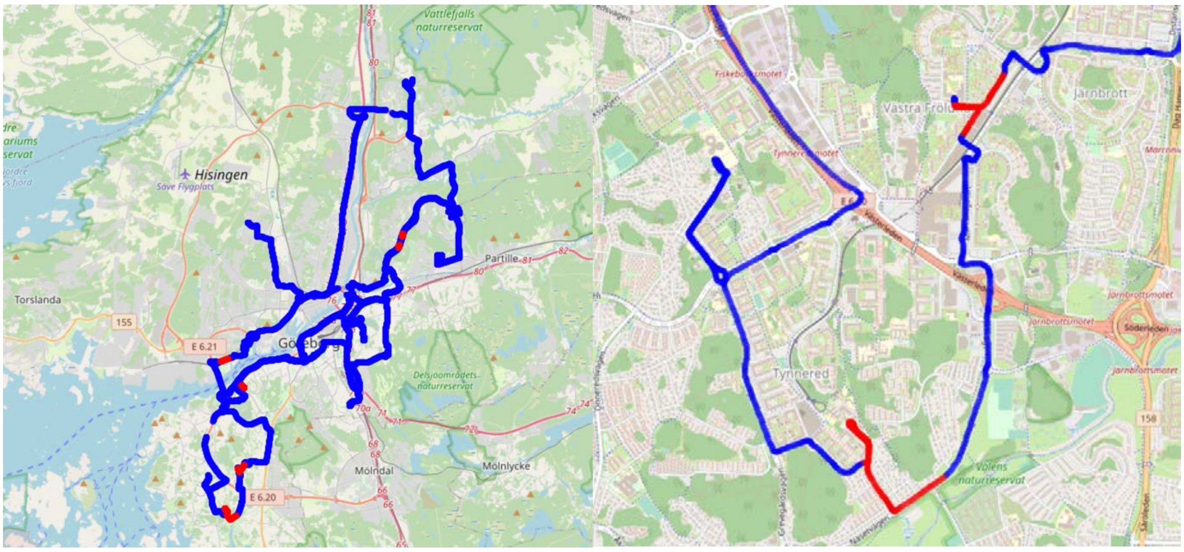
The test vehicles, all passenger vans, provided data for the three stages:

- Stage 1, scenario 1, baseline: No speed limiter, driving as usual, recording trips, speed and behaviour

- Stage 2, scenario 2, indicative: Speed assistance, signal triggered when entering the geofenced lower speed zone
- Stage 3, scenario 3, mandatory: Speed limiter, gas pedal restricted before entering the lower speed zone

A typical journey consisted in driving the customers from the residential area to the schools or institution destination in the morning, and then driving them back home in the afternoon, with the entire duration of the trips spent in urban area. The trip data were recorded by Scantech hardware and software, stored on a server and the data made accessible for project partners for each vehicle (Fig. 9).

Figure 9: Trip of a passenger van driver for full day (left), extract (right) 20 Sep 2022

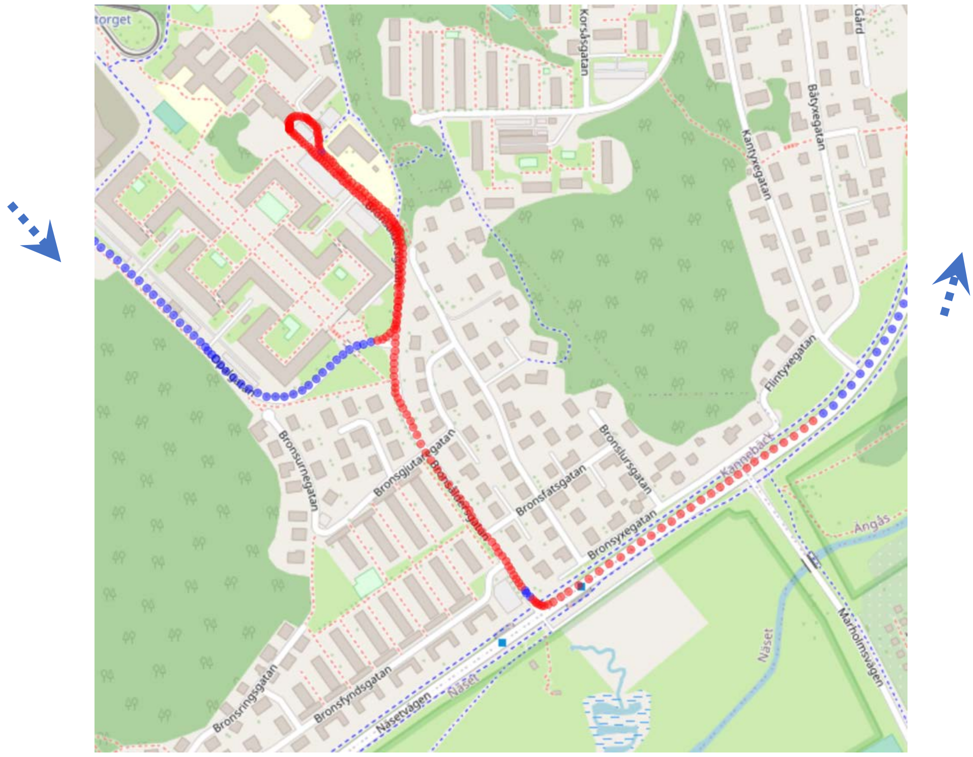


Source: Skantech GNSS trip data, 2022

Visible are the geofenced lower speed zones in red, and the location of the stopping points in streets already effective for counteracting speeding by design, with no through traffic (dead end/cul-de-sac streets). Many of these streets were nevertheless identified as prone to accidents due to the high number of vulnerable pedestrians during peak times in mornings and afternoons.

Further detail of the trip speed with a stop at a school, entering the zone from the left and departing to the right, is presented in Figure 10.

Figure 10: Entry and exit of a lower speed zone, during the phase one



Source: Skantech GNSS trip data, 2022

4.4 Impact assessment and analyses

4.4.1 Effectiveness impact assessment of geofencing use during trials

Objective of the effectiveness impact assessment is to determine how well the technology performs, if the original research questions were answered and the targets attained during the different phases of the trial.

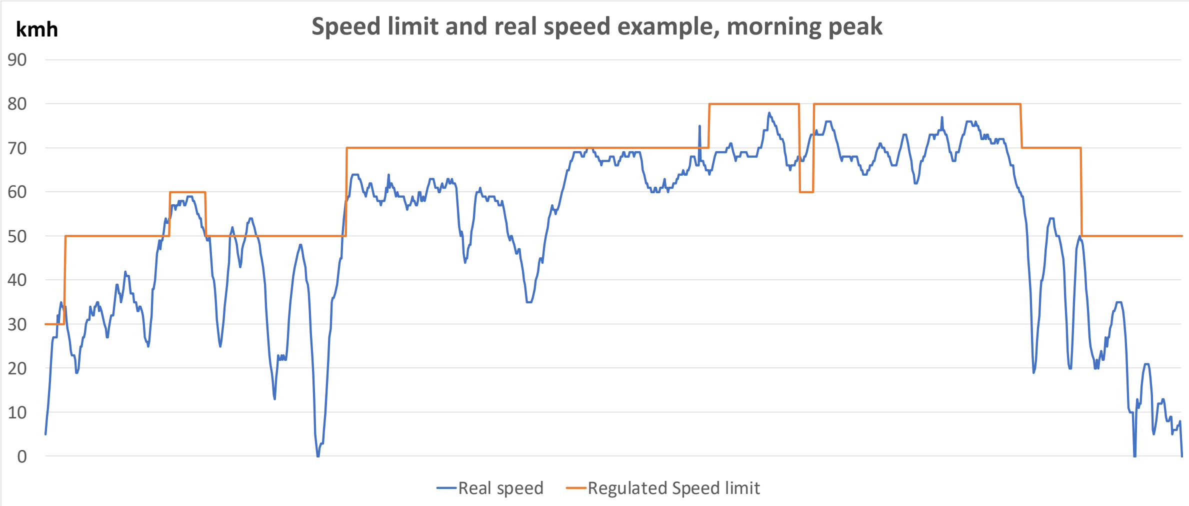
The concept "effectiveness" is defined in the context of transport research and transport applications, whereby an effectiveness improvement occurs when using the same resources than the baseline, but achieving a higher level of output, performance, quality of service, or benefits for users and citizens. Often, the focus of the definition of effectiveness is on the even more fundamental question, if the business effectively attained its set objectives.

The concept "efficiency" is very similar, but has a slightly different perspective, because an efficiency improvement occurs when achieving the set mobility target while using less resources, time, costs, distance or generating less traffic, inconvenience or negative externalities, than it was the case before, in the baseline situation. Often, the terms effectiveness and efficiency are used together for assessment and analyses of public transport policies and innovations (Daraio et al., 2016).

As can be seen in the series of Figures 11 to 13, the effectiveness of the speed limiting devices associated with a triggering technology activated when entering a geofenced lower speed zone, and deactivated when leaving the zone, was demonstrated in its feasibility and practical countereffect on speeding.

The main indicator observed here is: if the real speed line (Fig. 11, in blue) is crossing the regulatory speed line (in orange) or the geofenced zone speed line (Fig. 12, in green).

Figure 11: ISA speed (regulated speed) and real speed (vehicle speed) outside zones, 22 Sep 2022, trial stage one

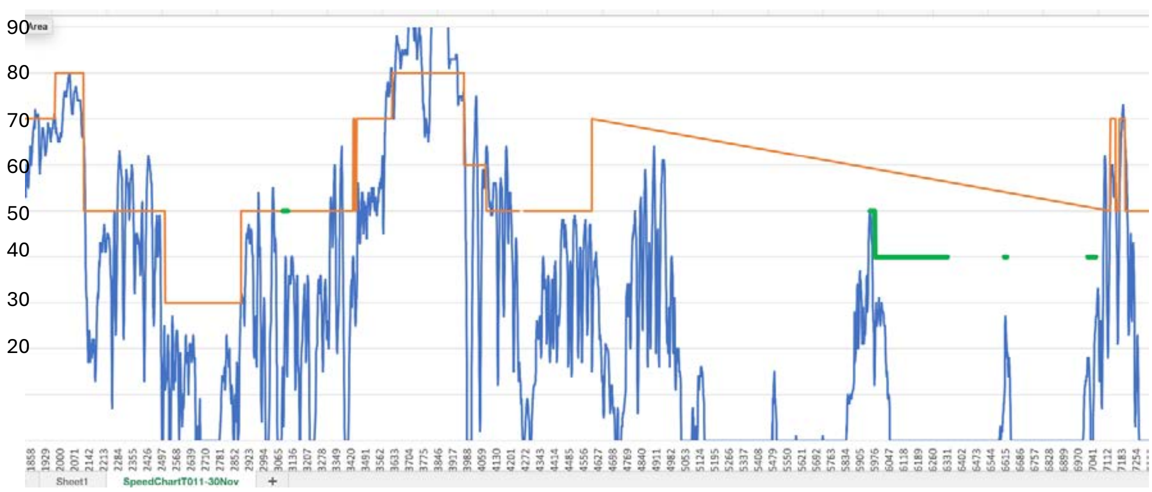


Source: Skantech speed data, 2022

Figure 11 shows typical speed pattern of driving in the morning peak, during the first stage of the data collection, in which the speed limiting systems were inactive, the maps of the zones were not visible for the drivers. The system recorded the location and speed of the vehicles and also logged the regulated speed limit on that street. Visible is a rather frequent occurrence of “slight” speeding, for a short period, most of the times only few seconds or less. This pattern of drive speeding behaviour was characteristic and did not change for the entire test duration, even when using the speed limiter, there were still very short periods of speeding observed during deceleration phase.

On phase three, all speed limiting systems were activated and functional. The speeding was still occurring, but outside the mandatory lower speed zones. A data extract is presented in Figure 12, in which the blue line represents one dot per second over a period of about 120 minutes. The green lines are the geofenced lower speed zones, in this case set at 50 and 40. The orange line is the local regulated speed limit.

Figure 12: Stage 3: Mandatory set limit is correctly enforced in geofenced lower speed zones, observation from 30 Nov 2022



Source: Skantech speed data, 2022

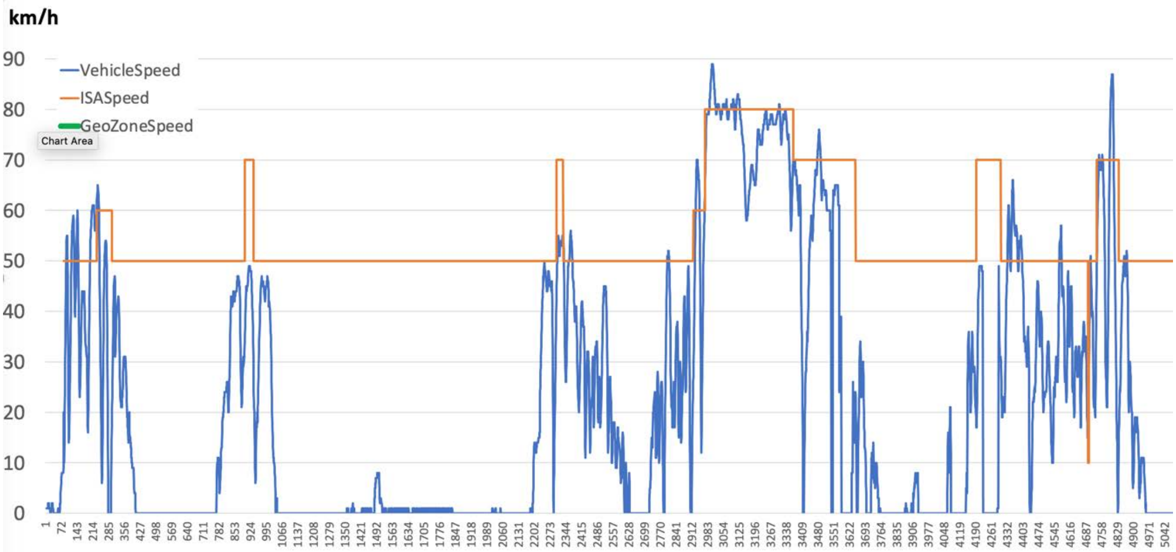
Visualised are the many occurrences of speeding outside the zones, notably on the motorways with a speed limit of 80 km/h, where no mandatory zone was set. It was possible to accompany a driver for one trip and indeed, the passenger bus only followed the normal traffic flow at the same speed than all other vehicles, who were in that case all speeding on the urban motorway.

Occurrences of speeding were not observed when a researcher went on a live round trip during the Stage 2 (Fig. 13) and Stage 3 phases.

The data collected over a longer period from June to October 2022 show that during the three phases of the trial, the speed limit was exceeded on few occasions inside of the lower speed zone, mostly during deceleration and for a very short time (Fig. 14). The reason was that the system was not fitted with braking, only with more resistance on the gas pedal when accelerating, so that the speed limit could not be exceeded. The total occurrences of speeding inside the compulsory zone in Phase 3 were representing far less than 0.1% of the total time spent inside the zone. The exact values for average speed could not be determined with enough confidence for Stages 1, 2 and 3, due to the variability, the very low number of speeding occurrences, the extremely short time of less than few seconds for the speeding observed, and the very low speed in all zones.

One of the possible explanations for the observation of speeding, in some cases, is the time lag of the GPS signal, leading to inaccuracies in the route speed, for example when another street nearby has another speed limit. Also possible is that the current vehicle speed was slightly slower or faster than the record shows, due to the time lag, for a very short duration of less than one or two seconds. Most speeding occurrences were observed for very short time, with the few speeding cases observed exemplified in Figures 14 and 15. There was not much speed difference observed on all three phases. In all phases, the over speeding duration was short, in the geofenced zones not more than the magnitude of few seconds per day. Outside of these zones, the speeding was rather frequent.

Figure 13: Speeding trial data Stage 2, situation without geofenced speed limited tech activated, but with warning system, visualisation and acoustic signal



Source: Skantech speed data, 2022

Figure 14: Detailed of a second-by-second speeding observation in Stage 2 geofenced zone.

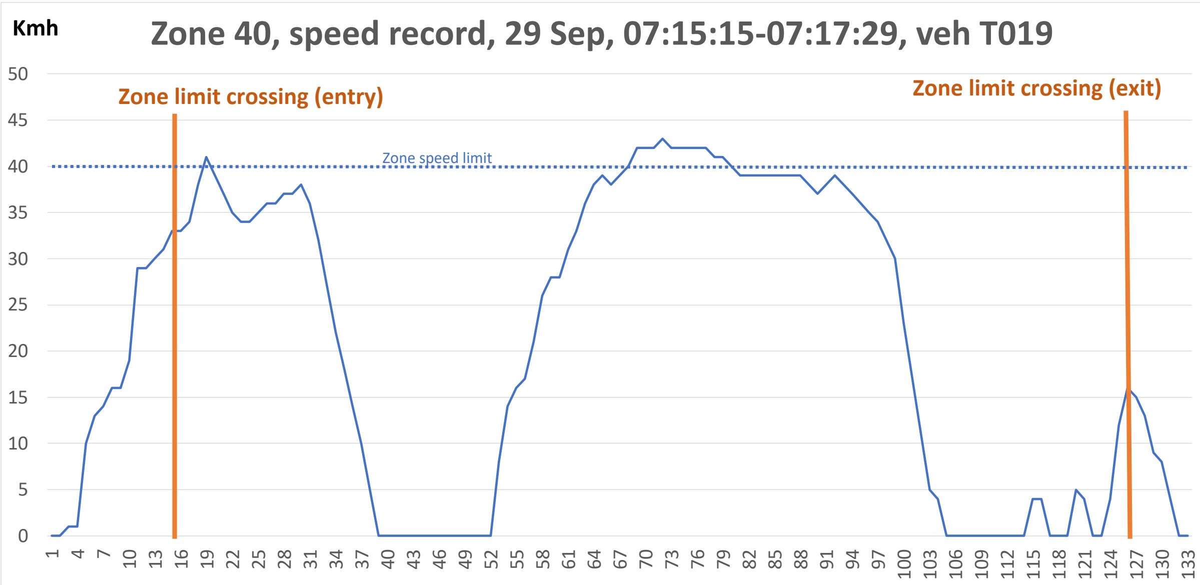
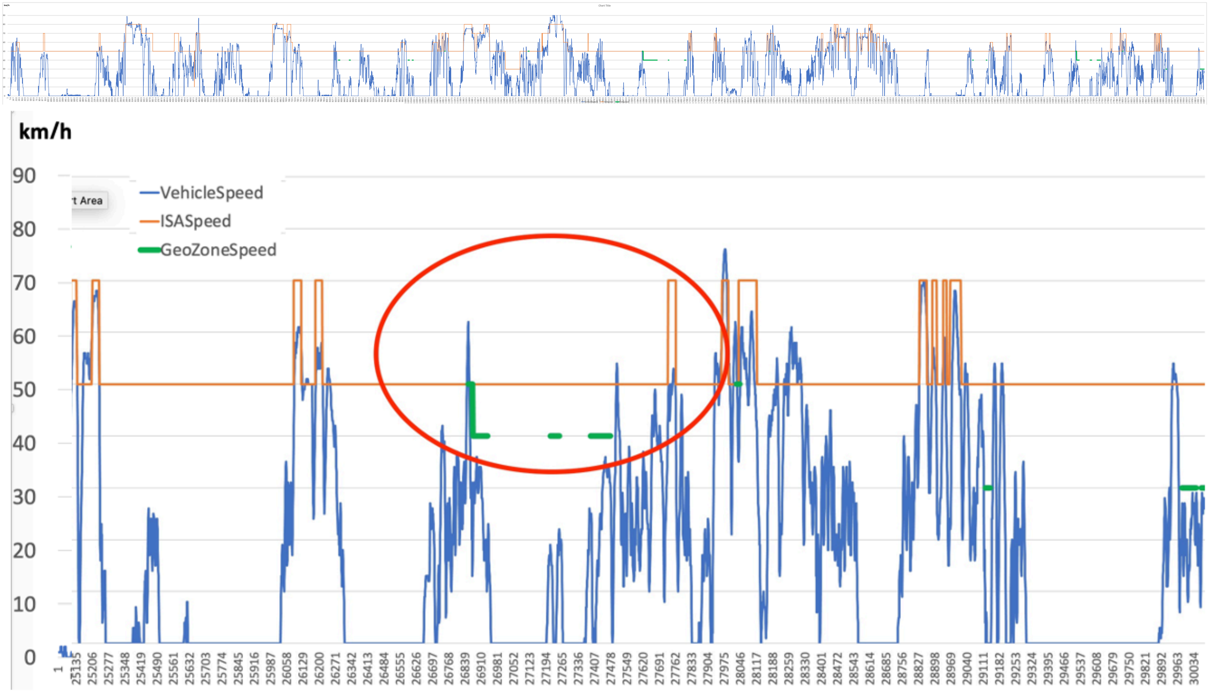
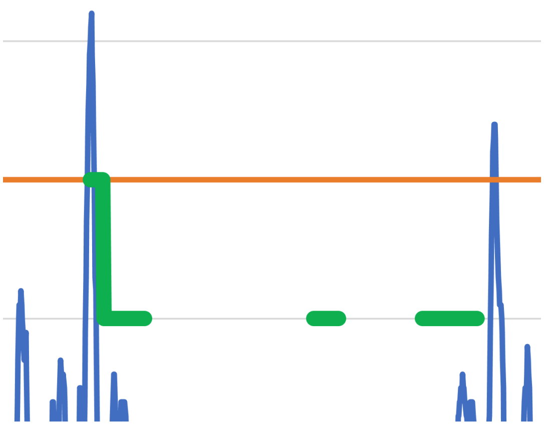


Figure 15: Speed data Stage 3, full day data record (above), extract & zoom-in (below)





Source: Skantech speed data, 2022

So, the overall effectiveness and efficiency impact objective was attained.

The design of the retrofitted devices could improve by developing integrated vehicle options, based on geofencing & speeding counteracting features, available in new vehicles.

4.4.2 Sustainability impact assessment Gothenburg trial

As concluding steps, multiple management study analyses are conducted.

The first one is the analysis of the sustainability impacts.

The objectives of a sustainability impact assessment is to produce expert estimates on how well or how acceptable the outcomes of the trial really are, when looking at the framework of overarching Urban Mobility objectives of sustainability in Europe (EC, 2021b).

Estimates are based on real trial experiences, when possible, backed with robust vehicle data, information gathered via interviews with stakeholders live on site during the trials, and later through online meetings discussing the trial results.

Main sustainability dimensions were evaluated by the partner in the Municipality service of Gothenburg, and the University of Westminster, with a scale from unacceptable to excellent (Table 3).

Table 3: Scale used for the sustainability impacts rating

Rating, verbal	Rating, numerical
top/excellent	6
very good/ very positive	5
good/positive	4
average/neutral	3
below average	2
unacceptable	1
no relevant	-

Transport technology and IT technologies were found to be average or below average for Technology Readiness Level, reliability, while the integration with other technologies was good/positive and the public R&D investment in hardware was considered average or below average.

Table 4: Sustainability Impact Assessment of Gothenburg trials

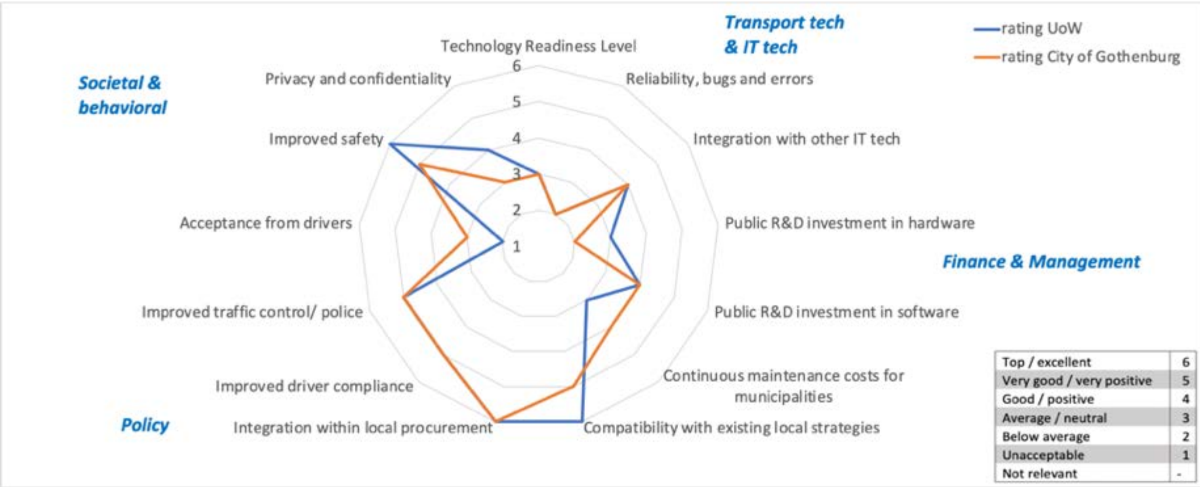
Value creation, assessment criteria	**Comments, definitions, clarifications**
Technology Readiness Level	Partly market ready with individual technologies fully market ready and other elements still to be improved.
Reliability, bugs and errors	During the trial and preparations, most of it resolved, some of it remaining. Minor bugs but communication with drivers was limited by data protection, so the bugs became too important.
Integration with other IT technology	Usability was not so smooth for the drivers. To administrate the zone, the process was complex. Need for improvements. Software and hardware compatibility issues in the communication between municipality and service provider.
Public R&D investment in hardware	Extra costs for the vehicle installation and leasing of the new systems linking ISA, geofencing and car equipment of gas pedal, tablet and compatible IT hardware fitted to the existing vehicle hardware.

Public R&D investment in software	Extra costs for the zone geofencing software / dashboard; a third-party solution would need to be integrated within all vehicles, without an extra system.
Maintenance costs for municipalities	For a scale-up, it would have been needed that all systems would be compatible with the one already in place.
Compatibility with existing local strategies	Pilot shows a Municipality is able to use those types of tools to create the desired strategical effects, using recommended speed limit and the IT upgrading digitalisation of transport vehicles. Unclear if and how we are going to implement this in future.
Integration within local procurement	Already prepared for the trials in advance, so geofencing was integrated with procurement.
Improved driver compliance	Yes, with the limitation that the data on the before situation were showing very limited speeding.
Improved traffic control/ police	Theoretically yes, in practice no possibility of individual intervention.
Acceptance from drivers	Technical issue more a problem than the technology principles itself. Acceptance of speed limits, which were not explained in detail.
Improved safety	Good compliance with lower speed limitations. Malfunction bug in the system created a safety concern by lowering the speed unexpectedly, in few instances there were zones affecting the speed limiter in place where it was not needed.
Privacy and confidentiality	We acknowledged the difficulties with confidentiality, and managed to find a solution to the challenge, which remained until the end of the trial.

Source: UTA, 2022

Valuations were given on a scale from 1 unacceptable to 6 excellent, for the selected sustainability impact criteria.

Figure 16: Sustainability impact assessment of the geofenced lower speed zones trial



Source: own design, 2024

The main Finance and Management weakness was that a continuation of the parts of the trial considered successful would have cost much funding for hardware, less for software.

4.4.3 SWOT analysis

The following analysis is directly derived from the reflexions and findings about sustainability above (Table 5).

Table 5: Analysis of Strengths, Weaknesses, Opportunities and Threats for the use case of geofencing applied in combination with an ISA system to counteract speeding

Strengths	Opportunities
1. Slightly reduced speeding inside the geofenced zones, positive effect detected 2. Small but probably limited effect on safety due to lack of evidence of safety impact of the speed reduction triggered by mandatory ISA-geofencing 3. Good compatibility with existing local strategies 4. Integration with local procurement	1. Develop geofencing integration in cars 2. Develop geofenced zones for lower speed including new regulations 3. European policy to support municipality services expanding the geofencing technology usage 4. Potentially improved traffic control
Weaknesses	**Threats**
1. Reliability, bugs and errors 2. Public R&D investment in hardware 3. Some acceptance problems from drivers 4. Privacy and confidentiality 5. Good Technology Readiness Level but low ”System Readiness Level” where the surrounding conditions of the technology is not in place (governance, policy and business model)	1. Lack of knowledge and commitment of operators 2. Bugs and errors reduce acceptance 3. Digital solutions for speeding are truly effective when complemented with physical solutions and legal enforcement regulations

Source: Own design, 2024

4.4.4 PESTLE analysis

To derive useful conclusions out of the impact assessment, further dimensions need to be analysed more in-depth. In this PESTLE analysis, inductive and deductive reflexions were conducted, focusing on the strengths and future possible steps (Table 6).

These steps were consisting of a screening of implications from previously gained knowledge on the ground, as presented above. The inductive step consists of drawing lessons from a specific case in Gothenburg, looking what from it can become generalised for a European-wide improvement of the transportation conditions. The deductive step consists of drawing conclusions out of a series of different fundamental knowledge elements.

Table 6: Multifactorial analysis of policy, economy, societal, technological, legal and environmental dimensions of geofencing use for counteracting speeding

Political	Geofencing use for counteracting speeding is fully compatible with the current European transport policy, as stated in the new EU framework for Urban Mobility document: "Better management of transport and mobility using multimodal hubs and digital solutions is needed to increase system-wide efficiency". The most important political aspect is the demonstrated improvement and effectiveness in reducing speed for the geofenced zones, when using an ISA system with added geofencing. This advantage is a big plus for a possible future mainstreaming of the solution.
Economic	Lower speed and higher safety have demonstrated economic benefits for cities and their inhabitants. There is a future potential cost reduction in compliance and enforcement costs for municipality services.
Social	Higher safety and lower accident should lead to more wellbeing. Geofenced lower speed zones should also lead to less noise and disturbances for pedestrians and residents of the low-speed zone areas.
Technological	The geofencing technology can be considered mature, but the systems surrounding it and especially the governance and business model dimensions are not advanced enough for a wider scale implementation of speed counteracting solutions involving a geofence use. The integration of geofences into vehicle navigation, speed limiter and other onboard computer software or hardware influencing speed is feasible and probably only a matter of time until widely available.
Legal	The issue of data privacy needs to be resolved before legally binding policies can be developed for ISA-based solutions to counteracting speeding, supported by geofencing techniques.
Environmental	The speed reduction, higher safety, lower noise and reduced emissions are all consequences and beneficial impacts, all aspects positive for the environment and for health of citizens. Applying lower-speed geofences in sensitive areas such as near schools or hospitals would be especially effectful.

Source: Own design, 2024

5 Munich Use Case

Before looking at the exact characteristics and functionalities of the geofencing technology itself, and at its impacts, it is necessary to describe and explain the urban transport policy application where geofences are needed and were leading to improvements in Munich. The field of application of this use case is micro-mobility. This is where the impacts are visible.

Following sections show how geofencing positively impacted micro-mobility objectives, starting with general aspects and progressively "deep diving" into more and more details.

5.1 Introduction, background on geofencing use in urban micro-mobility

Geofencing technology is becoming increasingly popular in the urban micro-mobility sector, which includes vehicles such as electric scooters (e-scooters), bicycles and e-bikes. Geofencing allows micro-mobility providers to create virtual boundaries around specific areas in cities, such as designated parking, or no-ride zones. When a user enters or leaves these boundaries, the geofencing technology can trigger specific actions, such as adjusting the vehicle's speed or disabling the vehicle's engine.

The use of geofencing to organise and regulate urban micro-mobility has been driven by several factors, including the need to address safety concerns, reduce congestion and improve the overall user experience (Hansen et al., 2021). Micro-mobility providers have been criticised for safety issues, such as riders not wearing helmets or poorly parked vehicles on pavements, which pose a safety risk to pedestrians Geofencing can help address some of these issues by ensuring that users follow safety guidelines and park their vehicles in the designated spaces. Geofencing can also help reduce congestion by directing users to less congested areas and preventing them from riding in heavily congested or dangerous sectors. In addition, geofencing can improve the overall user experience by providing real-time alerts and notifications about traffic, parking and other relevant information. Geofencing can also enable micro-mobility providers to offer personalised promotions and discounts to users based on their location and usage patterns.

More generally, the use of geofencing in urban micro-mobility has the potential to transform the way people move around cities, making it safer, more efficient and more convenient. However, it is important to ensure that the use of geofencing is transparent, ethical and respects users' privacy. The transformation phase of urban mobility with shared, automated and connected vehicles has begun, and sharing is being described as the real change in mobility, because it could potentially reduce the overall fleet. To meet the future challenges of organising shared mobility and increasing transport demand, local authorities and stakeholders are acting to adapt the transport network system, physical infrastructure, traffic regulations and planning tools, increasingly with the help of digitalisation and automation tools. To support this planning improvement, it is necessary to collect and access high quality data.

A range of IT-based solutions are being employed to assist and facilitate the implementation of existing urban transport policies in the city of Munich. This is being done within the context of a strategy that targets the more efficient use of road space and ensures road safety through the implementation of effective parking rules. The aim of this policy is to coordinate public space actions on the ground and digitally. One of these areas of action is shared micro-mobility, with an increasing number of private mobility service providers (MSPs) providing citizens with shared bikes and shared e-scooters, with a potential impact on displacing cars in the city. The main improvement target concerns the last and first-mile connections and connections where the public transport offer is not good enough, for example at night or in the suburbs. However, the magnitude of the impact of micro-mobility on car displacement is not always clear, and in some cities, it is not observed at all (Asensio et al. 2022).

5.1.1 Free-floating micro-mobility

Micro-mobility refers to lightweight, often electric-powered vehicles designed for short trips within urban areas. These vehicles include e-scooters, bicycles and e-bikes and are becoming increasingly popular to reduce congestion, promote sustainable transport and improve urban mobility. One of the key features of micro-mobility is that it is 'free-floating', meaning that users can pick up and drop off the vehicles anywhere within a designated service area without the need for fixed docking stations (Foissaud et al., 2022). The free-floating model has several **advantages** for micro-mobility providers and users. Here are some reasons why micro-mobility is benefitting from the free-floating concept:

1. Flexibility: Free-floating micro-mobility allows users to pick up and drop off vehicles anywhere within the service area without being constrained by fixed docking stations. This gives users more flexibility and freedom to travel to their desired destination.
2. Cost-effectiveness: Free-floating micro-mobility can be more cost-effective than dock-based systems as it eliminates the need for expensive docking stations and infrastructure. This can result in lower costs for both providers and users.
3. Scalability: Free-floating micro-mobility is more scalable than dock-based systems, as it can expand based on demand and usage patterns. This allows providers to optimise fleet size and usage.

Overall, the free-floating model is a key feature of micro-mobility, offering users good levels of flexibility, cost-effectiveness, scalability and accessibility.

However, there are also **challenges of the free-floating model,** such as parking and security concerns, which can be addressed using IT technologies and notably geofencing.

There are also several issues that affect the provision of free-floating vehicles, where the pick-up and drop-off points can be anywhere in a city.

The main issue is public acceptance of a rather unregulated parking situation, with many pavements and pedestrian areas fully occupied by rental e-bikes or e-scooters (Abendzeitung, 2021) (Figure 16). As shown in the GeoSence survey of European experts, this obstruction of public space occurred in many European cities and especially in Munich, at the time when the project started in 2021 (Hansen et al., 2021).

Although e-scooters are becoming increasingly popular as a means of transport in urban areas, they also present a number of problems and challenges. Here are some of the common issues with e-scooters:

1. Safety: E-scooters can pose safety risks to riders and pedestrians. Riders may not wear helmets or follow traffic rules, and pedestrians may be unaware of their surroundings and not notice e-scooters.
2. Parking: E-scooters are often parked haphazardly on pavements, creating obstacles for pedestrians and people with disabilities (Figure 16).
3. Maintenance: E-scooters require regular maintenance, including battery charging, tyre replacement and brake checks.

4. Vandalism and theft: E-scooters are subject to vandalism and theft, which can result in damage to the vehicle and loss of revenue for the operator.
5. Regulatory challenges: E-scooters often face regulatory challenges from local governments, which may impose restrictions on their use and parking.
6. Equity: E-scooters may not be accessible to all users, especially those without access to smartphones or credit cards, or to people with physical disabilities who need other modes.

Figure 17: Unregulated parking of e-scooters in Munich

Source: Abendzeitung, 2021

Overall, e-scooters present several challenges and issues that can affect their safety, convenience and accessibility. Tackling these challenges is the main motivation for developing and using more advanced IT technologies such as geofencing, which can help improve safety, parking and maintenance. To succeed in obtaining an improvement, is important that e-scooter providers work closely with local authorities, communities and users, with the aim of making e-scooters safe, sustainable and accessible to all.

To address these behavioural and transport policy issues, Munich has recently supported the development of a more regulated micro-mobility service by introducing dedicated parking spaces in the city centre, initially in the old town and then citywide, depending on the success of the Department of Mobility, while maintaining the free-floating system in areas outside the city centre (Figure 17).

5.1.2 Planning process, preparation of the geofenced parking spots

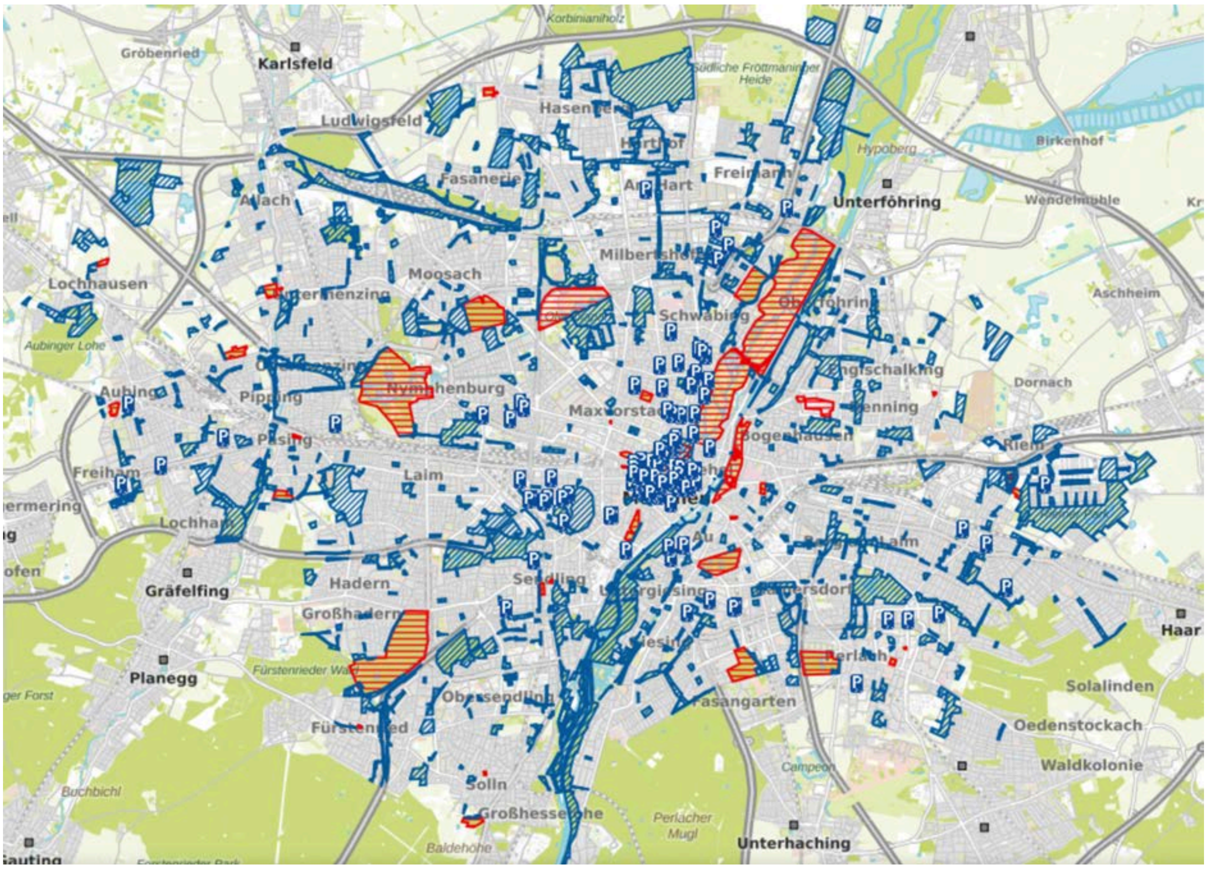
Soon after the first e-scooters appeared in Munich, the city set up a few rules to regulate this new form of mobility, including areas where e-scooters cannot be parked or ridden. These zones include green spaces such as the English Garden or pedestrianised areas, for example the Sendlinger Straße in the city centre. In 2019, the Department of Mobility sent these zones to mobility service providers as a map, by e-mail, so that they integrated these access rules into their systems.

Figure 18: Dedicated parking space for micro-mobility services in inner city of Munich (left) and free-floating e-scooter in a central Borough (right) in 2023

Source: Own pictures, June 2023

The result is a map of the entire city of Munich, developed in joint collaboration of Municipality and MSPs, targeting specifically micro-mobility vehicle use with different zones for parking, no-parking, no-go and free-floating areas (Fig. 18) (Masterportal, 2024). Since 2019, these areas have been gradually adapted and, in some cases, expanded. There are now almost 1,000 parking and no-driving zones in the city of Munich.

Figure 19: Geofences in Munich, parking spots (blue P), no-go (red) no-parking (blue zones)



Source: Masterportal 2024, © GeodatenService München

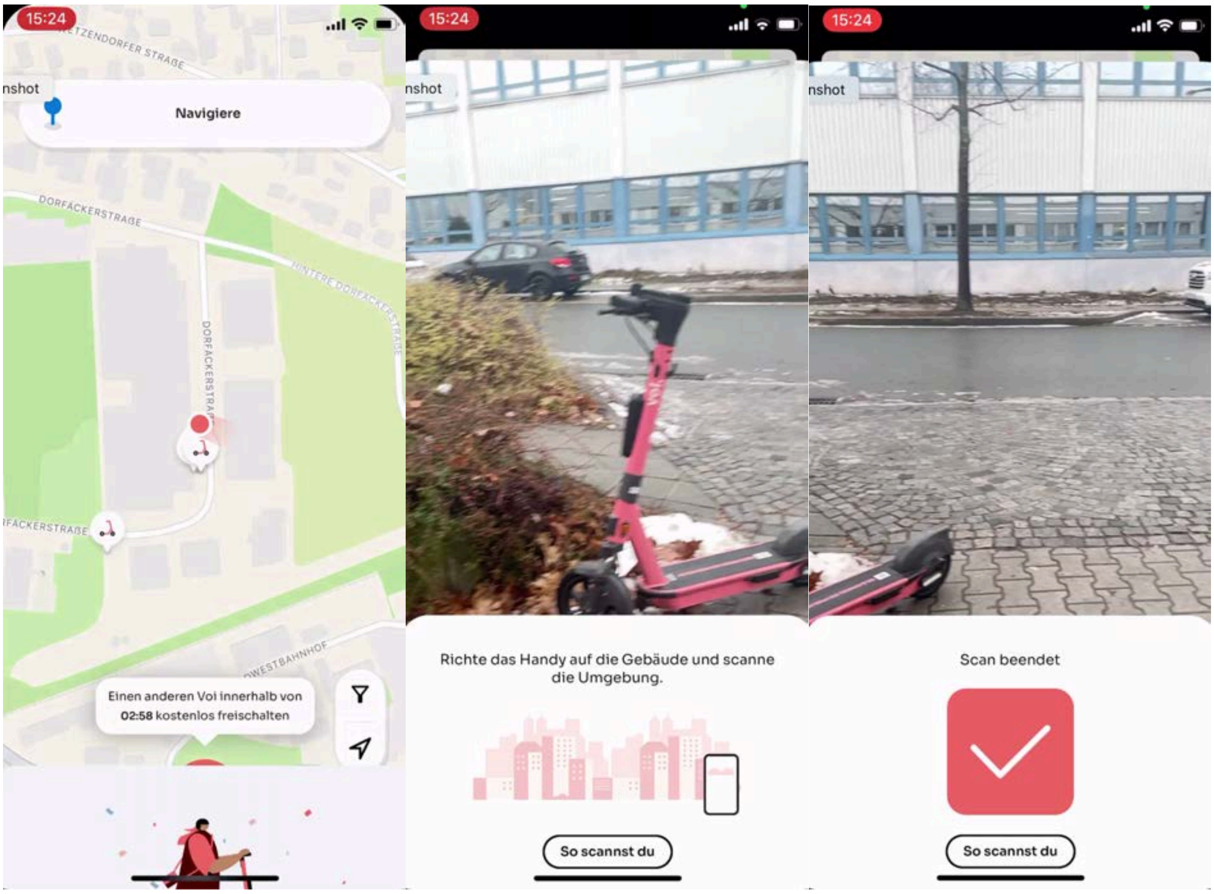
All the Munich micro-mobility geodata and geofences details can be accessed via internet by all citizens, via the free link:
https://geoportal.muenchen.de/portal/opendata/?Map/layerIds=gsm:g_stadtkarte_gesamt@WMTS,gsm:g_stadtkarte_wms,gsm_wfs:vablock_stadtbezirke_opendata,mor_wfs:opendata_ruhver_mim_abstellverbot_poly,mor_wfs:opendata_ruhver_mim_fahrverbot_poly,mor_wfs:opendata_ruhver_mim_abstellflaeche_poly&visibility=true,true,true,true,true,true&transparency=0,0,0,0,0,0&Map/center=%5b691603,5334760%5d&Map/zoomLevel=5

In this map, visualised for the whole city in Figure 18, it is possible to visualise geofences much more precisely. The same map is used in the apps of the MSPs. Using a zoom-in view function in the MSP apps, one can see at street level and clarify the exact limits of each parking spot with a level of precision up to one metre or less.

To support the compliance of e-bike and e-scooter renters, one of the solutions is to include a geofencing based restriction in the system to start or end each ride within this dedicated zone.

For example, in the case of Voi, a Sweden based mobility service provider operating in Munich, each ride can only be completed and paid for when the scooter is within the geofenced parking zone. The trip is validated by the GPS location (Fig. 19, left) and by scanning a nearby building with the phone's camera (Fig. 19, centre) to complete the scan and end the trip (Fig. 19, right).

Figure 20: Parking validation (left) and ride ending steps (middle and right) on the app of the e-scooter Mobility Service Provider Voi, Munich, June 2023



Source: Voi, June 2023

The application of a distinction between parking and no-parking zones, and the existence of an extended no-parking zone for rental vehicles, is a clear contradiction to the principle of the free-floating for the provision of micro-mobility services.

The management of geodata and geofences is therefore, as observed in many studies, a key element in urban and transport planning (Nikiforiadis et al., 2023). The application of geospatial data to local traffic regulations and planning is a new area of work for the city of Munich, and one of the objectives of the GeoSence project is to demonstrate its value.

5.1.3 Station-based micro-mobility

While free-floating micro-mobility is becoming increasingly popular in urban areas, there is still a case to be made for station-based micro-mobility. Here are some reasons why station-based micro-mobility may be preferable and leading to improvements:

1. Predictable parking: Station-based micro-mobility provides users with a predictable and reliable parking location, which can be important for users who need to park their vehicle for an extended period. This can also help reduce the problem of vehicles being left in unsafe or inconvenient locations.
2. Improved sustainability: Station-based micro-mobility can be more sustainable than free-floating systems, as it allows providers to optimise the charging and maintenance of their vehicles. This can lead to more efficient use of resources and to a reduced negative environmental impact (see details in section 5.5).

3. Improved safety: Station-based micro-mobility can improve safety by ensuring that vehicles are parked in designated areas and not left in unsafe or obstructive locations. This can reduce the risk of accidents and injuries.

Overall, station-based micro-mobility offers some advantages over free-floating systems, particularly in terms of parking, accessibility, congestion, sustainability and safety. However, some **challenges of station-based micro-mobility** can be observed, such as the need for infrastructure and the potentially limited flexibility and availability. Ultimately, the choice between station-based and free-floating micro-mobility depends on the specific needs and priorities of users and providers in each urban area.

5.1.4 Principles and functionality of geofencing technology applications in micro-mobility

Geofencing applications are currently in use or under development for different areas of activity, relevant to many types of policies and businesses in Europe (Hansen et al. 2021). In transport, it is mainly used for vehicle control, information on road access rules, parking locations, speed limits, and communication between private mobility service providers and drivers, as well as with municipal transport services (Lu et al. 2024).

Several urban transport policy objectives are relevant to or positively impacted by geofencing applications, notably the shift away from car use and the increasing share of active travel, clean vehicles, improved road safety, and more efficient shared mobility services to reduce the vehicle fleet congesting city streets and parking spaces (Bauer et al. 2022; Bozzi & Aguilera, 2021, Asensio et al., 2022). See also the excellent reviews by Liazos et al. (2022), Kapousizis et al. (2023) and Wang et al. (2023) on the multiple impacts and dimensions that need to be considered when planning geofencing for micro-mobility and e-scooters.

A 2018 Swedish study on the use of geofencing included solutions for e-scooter parking management and concluded that technological improvements, management solutions and policy measures need to be combined to further develop the systems (STA, 2018). The role of actors and their involvement in policy design is needed to enable this change (Lindkvist et al., 2023).

Geofencing technology has become increasingly popular in the field of micro-mobility, as it allows providers to create virtual boundaries around specific areas in cities and trigger specific actions when a user enters or leaves these boundaries. Here are some of the principles, functionalities and implications of geofencing technology applications in micro-mobility:

Key principles:

1. Safety: Geofencing technology can be used to promote safety by ensuring that users follow safety guidelines and park their vehicles in designated areas.
2. Efficiency: Geofencing technology can help improve the efficiency of micro-mobility systems by optimising the use of resources and reducing congestion.

Main functionalities:

- **Boundaries**: Geofencing technology allows providers to create virtual boundaries around specific areas in cities, such as designated parking zones or no-drive zones.
- **Triggers**: Geofencing technology can trigger specific actions, such as adjusting vehicle speed or disabling the vehicle's engine, when a user enters or leaves a geofenced area.

- **Notifications**: Geofencing technology can send real-time alerts and notifications to users about traffic, parking and other relevant information, for example about payment and end of the ride. These notifications can occur in communications from the MSP to the user, and back from the user to the MSP.
- **Analytics**: Geofencing technology can provide valuable data insights on user behaviour, traffic patterns or asset utilisation.

5.1.5 Main geofencing impacts expected, and tested in Munich

1. Safety: Geofencing technology could improve safety by ensuring that users follow safety guidelines and park their vehicles in designated areas.
2. Efficiency: Geofencing technology could help improve the efficiency of micro-mobility systems by optimising the use of resources and reducing congestion.
3. Accessibility: Geofencing technology can improve the accessibility of micro-mobility by providing users with real-time information about available vehicles and parking spaces.
4. Sustainability: Geofencing technology could promote sustainability by reducing the environmental impact of micro-mobility, contributing to the growth in demand for clean modes of travel while reducing car use, and optimising the use of resources.
5. User experience: Geofencing technology can improve the overall user experience by providing personalised promotions, real-time notifications and other relevant information.

Overall, geofencing technology has become a key tool in the micro-mobility sector, enabling providers to promote safety, efficiency, sustainability and personalisation. However, it is important that the use of geofencing technology is transparent, ethical and respects users' privacy.

The GeoSence use case was not starting from scratch, as geofencing techniques were already implemented in the practice and actions of micro-mobility service providers in Munich, because the localisation information was integrated into the apps and functionalities of the ride-hailing service. What was missing was smooth communication and information exchange with the municipality and drivers about the exact positions of the geofences.

Geospatial data is not always used to provide a service. Navigation and routing systems have been available to the public and to professional transport operators for a long time, at least since the mid-2000s and the beginning of GPS integration in smartphones used by transport companies. Navigation applications for vehicles and addresses are installed and rely on accurate data about the position of the phone.

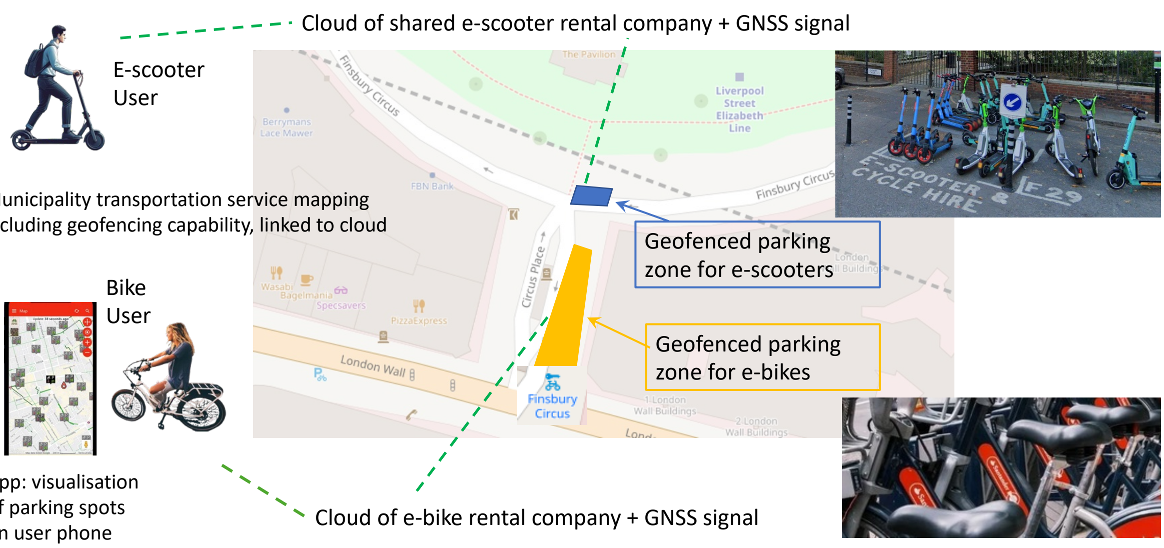
The functionalities of a geofencing application for parking management tailored to micro-mobility services can be explained step by step. A new digital and networked geofencing solution is being developed with the potential to effectively reduce parking problems. Simplified, geofencing applications are based on 5 steps (Hansen et al. 2024):

1. Displaying traffic and parking information on a map: e.g. traffic rules such as parking, no parking, speed limits (not enforced in Munich), etc.
2. Communicate (geo-)information from senders to receivers: in this case, a mobility service provider in Munich has implemented a virtual boundary for parking and non-parking areas, designed and controlled by the City of Munich.

3. Receivers can locate themselves geographically: i.e. vehicles/mobiles can locate themselves geographically, usually via a satellite system, and/or via mobile radio, Wifi signals, Bluetooth, photos of nearby buildings, etc.
4. Receivers act on the information: The driver is either informed or warned, e.g. via a mobile phone or directly from the vehicle. The vehicle can allow/disallow the driver to park in certain areas depending on what has been communicated.
5. (Geo-)information is sent back from receivers to senders: the system validates that the driver has acted correctly, in compliance with what has been communicated.

These simplified principles are visualised in Figure 20 below. All information between users, providers and municipality services are transferred and linked via a cloud.

Figure 21: Visualization of the functions used for geofencing applications in parking and micro-mobility management



Source: own design, 2024

5.2 Planning and objectives of the geofencing trials in Munich

The city of Munich has seen a strong increase in the use of micro-mobility in recent years (Sellaouti et al. 2024). The city has developed an ambitious mobility strategy and has carried out several European and collaborative research projects in the 2020s, including GeoSence, which implemented a geofencing use case with a series of measures using geofencing applications. The research projects contribute to the goals that Munich has set in the strategy, such as Vision Zero or sustainable transport by 2035.

Munich's broader transport policy and strategy is to promote more micro-mobility and shared mobility, to which this project contributes. The main objectives are to shift traffic away from private cars, to improve safety by reducing speed and collision damage, to improve environmental sustainability by increasing the share of low-emission and low-noise modes of passenger transport, and to improve the quality of life for residents and visitors.

Shared micro-mobility services are a key component in meeting the individual mobility needs of citizens. As a means of transport, especially for the first and last mile and in combination with public transport, they can help people to leave their own car at home more often. They therefore make a significant contribution to reducing emissions, increasing space efficiency and creating a more liveable city. A more practical objective of the project was to address the disruption to pedestrian footpaths and pavements caused mainly by the excessive and unregulated practice of riders starting and ending a ride at very central, most convenient locations (Figure 21). The lack of control in the early years of free-floating e-scooter development led to acceptance problems, and the proposed solution successfully addresses this challenge.

The Munich use case focuses on micro-mobility because the city faces multiple problems: public nuisance and road safety hazards from improperly parked e-scooters, political pressure and negative media coverage, and a lack of capacity in digital communication and local traffic enforcement. So, the city wanted to use geofencing to promote road safety, especially for pedestrians, increase public acceptance of micro-mobility, and transparently enforce zones and rules to integrate micro-mobility as a sustainable transport option. The city of Munich is working with the operators on a voluntary basis, as more binding regulations are not legally possible. The city has also signed data use agreements with the operators to monitor and understand the use of e-scooters in Munich.

Proof of concepts for a monitoring dashboard and an evaluation of e-scooter use have already been carried out as preparatory work for the GeoSence project. To achieve the strategic goals of organising shared mobility in Munich, a geofencing solution was procured as a monitoring and data analysis software tool to understand and monitor the use of e-scooters and to implement meaningful regulations.

Figure 22: Main practical transport disruption on pedestrian walkways and pavement

Source: Mell & Keim, 2024, Photo: Karl Keim

An additional challenge is a direct consequence of incorrectly parked e-scooters and the free-floating system: vulnerable citizens are the first to be disadvantaged in their pedestrian mobility (Figure 22).

Figure 23: Pedestrian mobility of vulnerable citizens, a challenge for e-scooter parking

Source: Wochenanzeiger 2023

5.3 Description of case studies and their overall impacts

During the GeoSence project, three “case studies” were conducted for geofencing. In the literature, case studies are interchangeably called “trials”, “tests”, “pilots”, “solutions” or “use cases” but in this report we speak about the Munich geofencing “use case”, and within this use case, we speak about three “case studies”. All case studies were defined by the city of Munich (Table 7). We considered these case studies as three “concepts” or policy “options” for micro-mobility.

Table 7: Definitions of the three GeoSence geofencing case studies in Munich

Case Study A	Static geofences for parking and no parking (old town)
Case Study B	Temporary geofences for parking and no parking (Theresienwiese)
Case Study C	Geofences for optimising parking spaces in further areas, and for other business models (scale-up, extension)

Source: own design, GeoSence, 2021-2024

In the first **Case Study A**, 43 parking spaces were installed physically and digitally inside the old town of Munich, and the entire area surrounding these parking spots in the old town was declared a no-parking zone. This aimed to improve parking behaviour in an area heavily used by pedestrians and other users. Parking spaces were identified using heat maps of parked scooters and complaint tracking, then physically marked and signposted and digitally geofenced (Figure 25). The size of a parking spot measured between about 5-20 metres length and about 1.5 metre width. Trialled from April 2022 to October 2023, the scheme improved parking and road safety. Acceptance was also high, with 40 of the 43 areas installed permanently after this trial A ended in November 2023. Based on the positive impacts and good experience gained, up to 675 parking spaces will be installed across the city, as the council has decided to extend the parking zones to the entire urban area.

The second **Case Study B** tested a temporary parking concept for the Oktoberfest to improve parking safety around the festival site, as many visitors arrive with e-scooters, and also to prevent drunk driving. Temporary parking areas were set up in 2022 and 2023 using geofencing, and zones were defined where e-scooters could not be borrowed after a certain time in the evening. The measures have worked. While there were still a lot of problems with overcrowded parking in 2022, the situation was better after the adjustment made in 2023 after analysing the data with the geofencing solution. There were also fewer drunk drivers. In the future, more car parks will be created on the edge of the restricted area around the festival site and more temporary car parks will be set up for events such as Tollwood in the Olympic Park. The concept of temporary parking zones could be applied to other events following this positive experience at the Oktoberfest.

In the third **Case Study C**, 30 physically tagged parking spaces that had been installed prior to the GeoSence project, but were not geofenced, were digitally tagged with a 100 metre no-parking radius. These spaces had previously been under-utilised. The aim was to test whether geofencing would increase the use of these spaces. To this end, geofences were defined in October 2023 and tested until March 2024. The evaluation is ongoing. Geofences were also applied to other parking spaces that had been created in the city by then as a result of the council decision mentioned in case study A (a total of 107 by February 2024, as part of the scaling process described in case study A). In addition, virtual parking spaces around the Olympic Park have been agreed with some selected providers, such as Bolt. These were set up at the end of 2023 and are still being evaluated in mid 2024.

As general observation on the impacts of Case Studies A, B and C, what can be said is that digital management can be improved through a better understanding of geofencing. First, the city starts with monitoring and understanding usage, to create appropriate policies, and secondly the city evaluates and enforce those policies, possibly while modifying it slightly, over and over again. For the enforcement phase, despite digitalisation, the city still needs a lot of resources. What has not worked so well in Munich is the automatization, expected with the test of improved communication tools to monitor the rules via standardised formats. Also limited and unfinished remains the improvement of the GPS signals of the vehicles, to make the stops even more precise.

More details on the various impacts and findings are explained below.

5.4 Research value, scenario, data management and Case Studies preparation plans

The key research questions to be investigated in the GeoSence Munich Case Studies are:

- What impact on traffic and mobility behaviour is associated with geofencing?
- How high is the effectiveness of geofencing compared to the current standard?
- What impact is to be envisioned if the measure would be scaled up on city level?
- What are the opinions of the users about geofencing (acceptance, privacy issues etc.)?
- Which data management and which traffic control strategies are necessary so that municipalities and service providers can technically and strategically control urban traffic, taking geofencing into account and applying it?

To answer the questions for each use case, emphasis was placed on designing the study and collecting the data in a way that would isolate the precise effects of the geofencing solution and separate them from other effects. Where a package of interventions was being tested that included multiple dimensions, such as technological, behavioural or regulatory elements, the aim of the data collection was to try to isolate each effect separately to identify the benefits of geofencing itself, excluding all other factors, in order to obtain meaningful data sets and avoid pitfalls in impact assessment.

Technical feasibility questions

How can geofencing be used to enforce municipality decisions or subcontracts on parking spot usage and timed events?

Effectiveness:

- Can temporary geofencing restrictions be leading to positive changes in parking, especially through limiting false parking behaviour?
- Is geofencing leading to a higher compliance with parking area rules?
- Is geofencing contributing to e-scooter usage increase?
- Are e-scooters trips for commuters replacing car trips, bike trips or walking trips?

Efficiency:

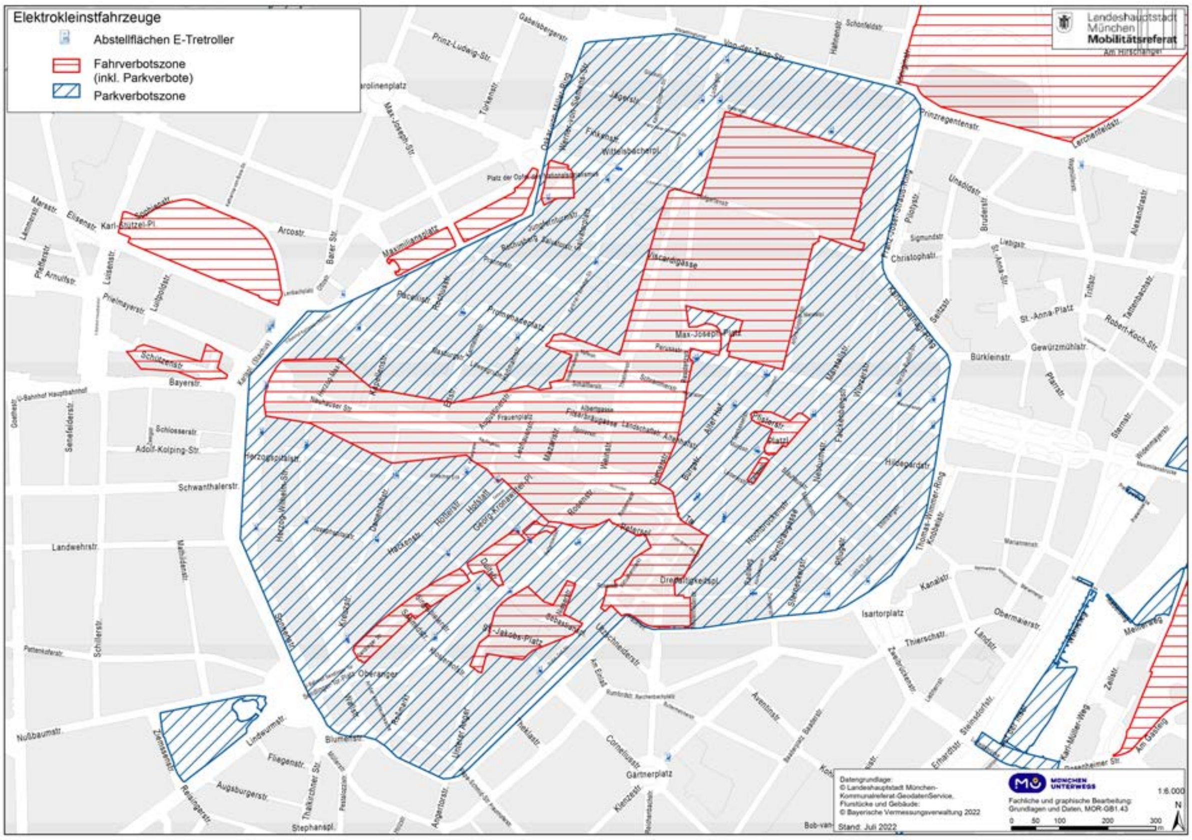
Is the use of geofencing cheaper and more efficient compared to other compliance systems for parking management of shared mobility solutions?

Case Studies: detailed description, process and results

Definition of geofenced zones, and of geofencing options for the test scenarios

In GeoSence Case Study A, 43 parking zones (Fig. 23, icons on the map) were defined, implemented and monitored in the old town of Munich. The old town of Munich was divided into (1) a no-go zone (Fig. 23, in red), where no driving or crossing was allowed; (2) a no-parking zone, where the 43 parking zones are surrounded by a large area where no parking is allowed (Fig. 23, in blue). The comparison of activity in geofenced and non-geofenced zones was made using data from company reports.

Figure 24: Parking spots, no-go (no drive, red) and no-parking zones (blue) in inner-city.



Source: City of Munich, 2022

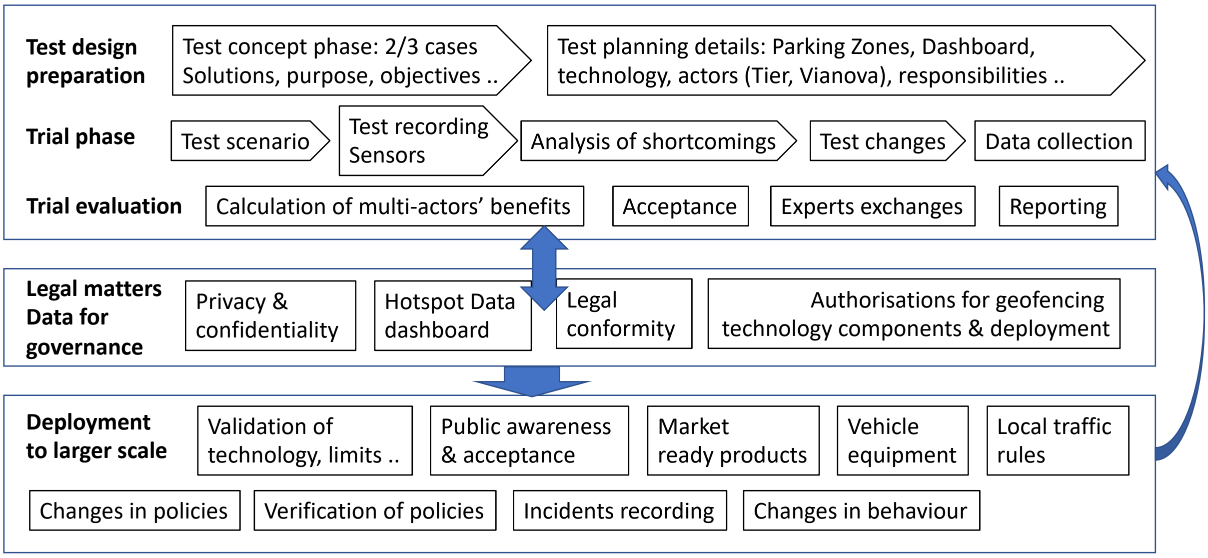
Data management

Munich carried out the strategic and practical trial steps with an appropriate data management plan for testing, implementing and deploying geofencing solutions, in line with the WP4 Data Management Framework (Figure 24). The framework was applied to the 3 scenarios.

Limitations of impact data analysis due to privacy (GDPR) rules

The city of Munich is not allowed to process information on personal data or trip data of the e-scooters. The only impact data that can be analysed is parking data. Each track of monitored parking data has been completely anonymised, and each record of a parking location cannot be linked to a specific vehicle or individual driver.

Figure 25: Data management framework of Munich Use Case



Source: GeoSence 2021.

Indicators and KPIs

The list of indicators and KPIs includes all the data mentioned above, such as area/zone location, limits and definitions, vehicle type, origin and destination, estimated journey distance, departure and arrival times, estimated average speed, etc. For the number of areas, the indicator shows an increase. Since 2019, there are e-scooters.

1. Between 2020 and 2021, 30 parking spaces were created for e-scooters, but without geofencing.
2. In 2022, 43 parking spaces with geofencing were installed in the old town. Of these, almost 40 have been decided to be made permanent as of November 2023.
3. In October 2023, geofencing was defined for the 30 spaces that were already available without geofencing from 2020 to 2021.
4. By February 2024, a total of 107 geofenced spaces were available across the city.

The main effects can be visualised with on-site observations, comparing the situation with and without the solution, before and after the implementation of the geofenced parking zones (Figure 25).

Figure 26: Unregulated (before, left) and regulated (after, right) parking of e-scooters

Source: Abendzeitung, 2023 (left), City of Munich, 2024 (right)

A public digital map with the geofences, and a source for data and real-time information was planned to be implemented to provide information and monitor the use case according to the existing policy. As of 2024, the real-time data is available, and the geodata webpage with all geofences is visible online for the public (Masterplan, 2024).

5.5 Outcomes and Impact Analysis of the Trials

5.5.1 Policy impacts and policy changes

The City of Munich's (LHM) "Mobility Strategy 2035" aims to achieve high accessibility, attractive public space quality and the expansion of an efficient multimodal transport system. This is done against the background of the City of Munich's overarching climate and transport policy objectives and is further differentiated by individual sub-strategies. The sub-strategy "Shared Mobility" (cf. document no. 20-26 / V 04857) describes the vision of a spatial, temporal and functional availability of shared mobility services in Munich, to achieve a reliable and attractive multimodal transport system.

The aim is to respond to changing mobility needs by promoting attractive alternatives to motorised individual transport, such as car and bike sharing, and newer forms of shared mobility, such as e-scooter sharing or on-demand mobility services (ODM) and linking them to public transport. In combination with public transport, cycling and walking, these services should make it possible to live without an own car and still enjoy full mobility, including that provided by the car. To realise the full potential of the public space for facilitating transportation, these modes should be fully exploited, on the one hand through more intelligent urban management, and on the other through increased promotion. The city of Munich has set itself the goal of gaining a better overview of the current land and parking capacity utilisation in the entire city area. Previously, this required expensive and time-consuming manual counts. However, these counts could only provide a snapshot of a limited area. The Department of Mobility therefore designed, developed and tested an innovative parking and space management solution for shared micro-mobility.

As part of the EU-funded GeoSence pilot project, geofencing is being tested as a new control concept for stationary traffic, providing information on applicability, feasibility and problem solving. So-called "geofences" are set up as digital no-parking and no-stopping zones and linked to providers' return and lending functions. This should lead to better coordination and control of the shared mobility parking situation in public spaces and reduce parking conflicts. The preliminary conceptual work and testing of the use of geofencing in GeoSence will continue to support and prepare the municipal IT project MDAS (see meeting submission no. 20-26 / V 04857). Against this background, the development and investigation of a pilot solution addresses the applicability, practicability and characteristics of geofencing in MDAS. The geofencing pilot will help to identify and concretise the requirements and needs of the mobility department, as well as the necessary input variables, representations and evaluations, and to implement them as far as possible as a prototype.

The existing geoportal integrates all the information, and the Mobility Service Provider's application includes the geolocation of each zone, as well as precise parking and vehicle data. The main successive **planning and intervention steps** of the trials were

1. Defined parking spaces
2. Set up parking infrastructure
3. Send geofences to suppliers with general parking ban and no-go zones

The city now has access to real-time data from parked vehicles but lacks sufficient capacity to analyse this data.

A reduction in the number of cars on the roads: As established with traffic data from the City of Munich, despite a three per cent increase in the number of inhabitants in the city between 2019 and 2023, and a five per cent increase in the number of registered motor vehicles, the volume of motor vehicle traffic in 2023 was around six per cent lower than in 2019. This is based on data from around 120 vehicle detectors in the city area. The decline was more pronounced within the city centre (14 per cent) and outside the city centre (seven per cent) than on the inner ring road (three per cent) (München Unterwegs, 2024).

5.5.2 Geofencing has a contributing effect to the growth in micro-mobility

In interviews with the Munich Mobility Service Providers Lime, Bolt, Voi and Tier, the questions asked about demand growth and profitability were unanimously answered with statements that a minimum number of rentals and vehicles need to be attained to make the business profitable, and that the recent growth contributed a lot to that commercial viability.

The key next question was, if geofencing can be considered essential to that demand growth for micro-mobility services. The unequivocal answer from all participants is that the increased number of rentals and vehicles could not have been attained without geofencing, as it was integrated into the sharing app system.

So here, it can be derived that the main geofencing impact in Munich was: geofencing has a contributing effect to the growth in micro-mobility, and this growth, including all other benefits associated with it, could not have been attained without it.

However, the exact magnitude of that effect is not quantifiable among all other factors of influence such as Covid, planning, regulation, user acceptance and cooperation etc.

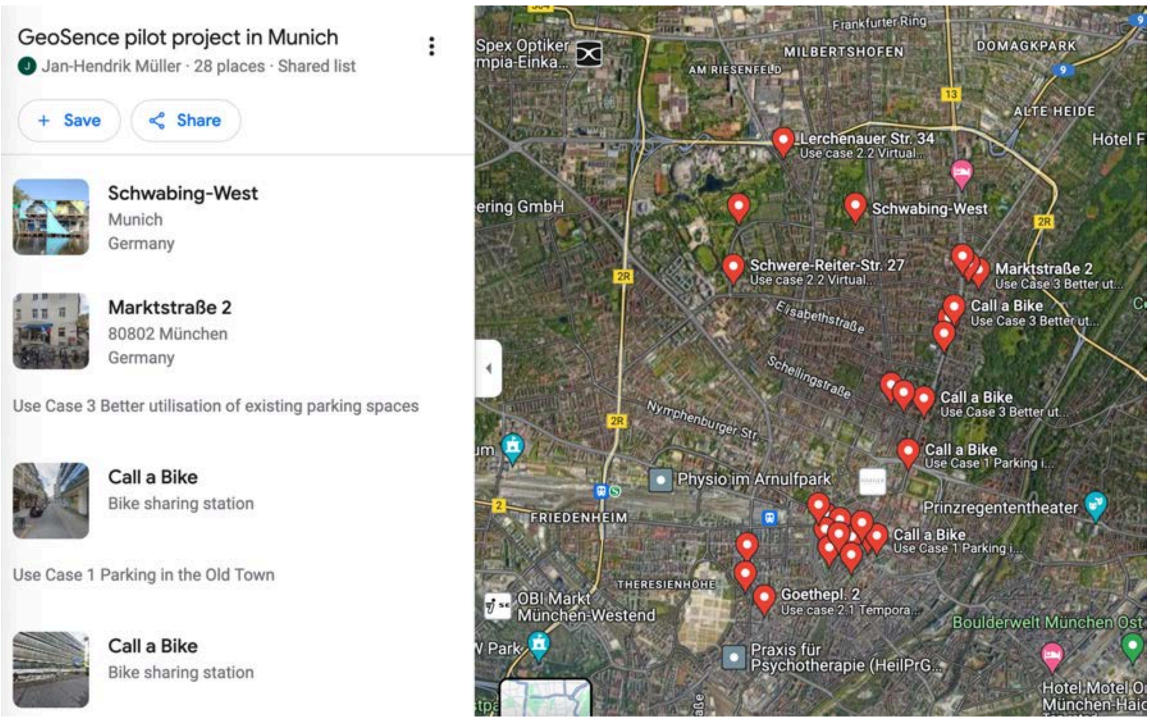
5.5.3 Virtual Fence: Special case isolation of the sole genuine effect of the geofence

Another testing element was about virtual fences, not marked on the ground. Objective is to give evidence about advantages and disadvantages of this special way of using geofencing. Advantage: low cost for setting up a parking regulation, due to no material infrastructure and no cost for installing and maintaining a parking zone other than setting it up in the system. Disadvantages are some usability limitations. The e-scooter user doesn't know exactly where the place for parking at a specific location is. How does a pedestrian or citizen know this is a legitimate space for parking an e-scooter?

To be able to find out more about the magnitude of the effect, a virtual parking zone was designed in the Olympic Park area (Figure 26, point Lerchenauerstrasse 34) to test whether the change in geofencing itself could be completely isolated from any other change in traffic, demand or behaviour, and without any change in infrastructure. The working hypothesis is that the creation of a 'virtual parking only' could help to change travel and parking behaviour. The aim is also to isolate geofencing from any other factor affecting micro-mobility.

As of summer 2024, the evaluation of the virtual parking data is ongoing.

Figure 27: Parking spots selected for monitoring and impact evaluation



Source: GeoSence 2024

From the summer of 2024, the evaluation of each additional parking zone data collection will continue.

5.5.4 Effectiveness analysis of geofencing applied to micro-mobility parking in city centre

To compare the effectiveness of the results with the previous situation, a parking heat map identified problem areas, which were confirmed by tracking public complaints.

The main change in effectiveness observed was the strong increase in supply and demand for micro-mobility and the corresponding change in transport behaviour during the trial years.

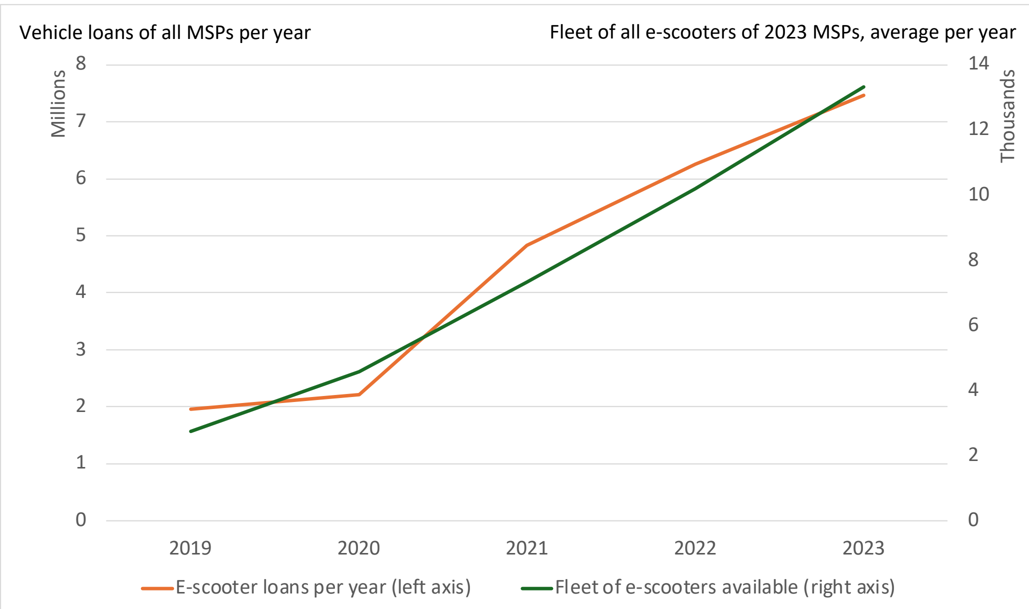
In Figure 25, the increased demand is represented by the indicator 'e-scooter vehicle rentals by all Mobility Service Providers, per year'; and the increased supply is represented by the variable 'fleet size of all e-scooters' as the average number of vehicles made available to the public by all MSPs active in 2023.

As can be seen from this data, the demand, expressed in terms of number of rides, will increase by 380 % in the five years from 2019 to 2023, and the fleet on offer will increase by 485 % in the same period. About the use of the e-scooter, the study revealed following findings

1. Temperature fluctuations and weather conditions have a strong influence on the use of electric trolleys. They are used much more in the summer months.
2. There are significant daytime differences in demand between weekdays and weekends/holidays: During the week, the number of trips increases earlier and there is a morning peak. The highest number of trips occurs in the afternoon between 16 and 18 hours.
3. The general rule for weekdays is that bookings are similar from Monday to Thursday, slightly higher on Fridays and Saturdays and lower on Sundays.
4. The average journey time has remained stable over the years at between seven and eight minutes.
5. Most trips start and end in the city centre, especially near metro and suburban railway stations. The e-scooter is used as a link to rail-based public transport for the so-called "last mile".

As a result of the study, it can be stated that the e-scooter is an important alternative to the motorised individual traffic in Munich for many residents, and that it expands the mobility options. They can be a solution for the so-called "last mile" and thus contribute to strengthening public transport.

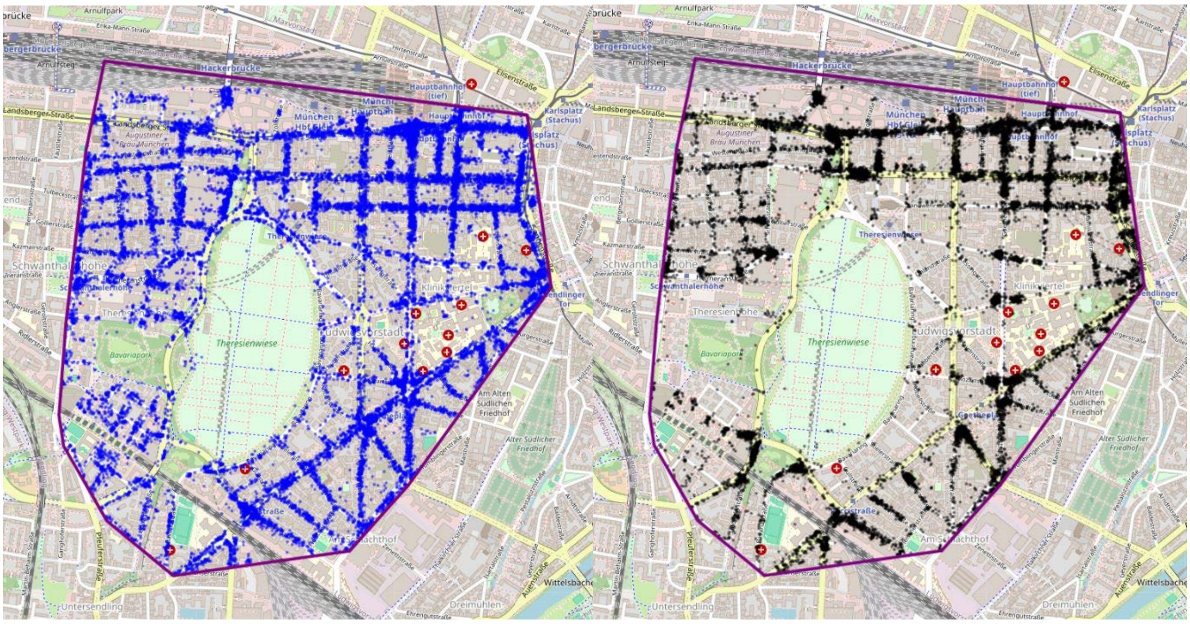
Figure 28: Increased micro-mobility e-scooter demand and offer in Munich, 2019-2023



Source: operative Mobility Service providers

A further improvement in effectiveness and strong impact was observed for parking during the Oktoberfest 2023 event (Figure 28).

Figure 29: Comparing the parking concentration in a free-floating period before (left) and regulated period during (right) the Oktoberfest 2023 event



Source: Own analysis, 2023

Main beneficial effectiveness impacts

Case Study A: Improved road safety through improved parking. Council decision to extend the scheme to 675 spaces across the city, as the trial was successful

Case Study B: Good user and public acceptance with fewer complaints

Case Study C: Creation of a geofence around all parking spaces for micromobility with a 100-metre no-parking zone

Effectiveness impacts of using a new dashboard information system for micro-mobility:

The Mobility Services of the City of Munich procured a dashboard and were able to see all parked vehicles live.

It was feasible and appropriate to set up regulations after seeing how scooters are parked.

During the test of the prototype dashboard, the city failed to send rules to providers via the dashboard system. The Services used email instead. In the future, the Mobility Services of the City of Munich will provide this data via the master portal, considering the GeoSence results.

It was proven not feasible and too difficult to automatically check if rules are installed in the provider's backend, and to automatically check live if users behave well. However, the city can control the applications and performances afterwards, with the data collected.

Figure 29 shows the situation after the implementation of the geofenced parking area. It was not possible to quantify the improvement in road safety because of improved parking.

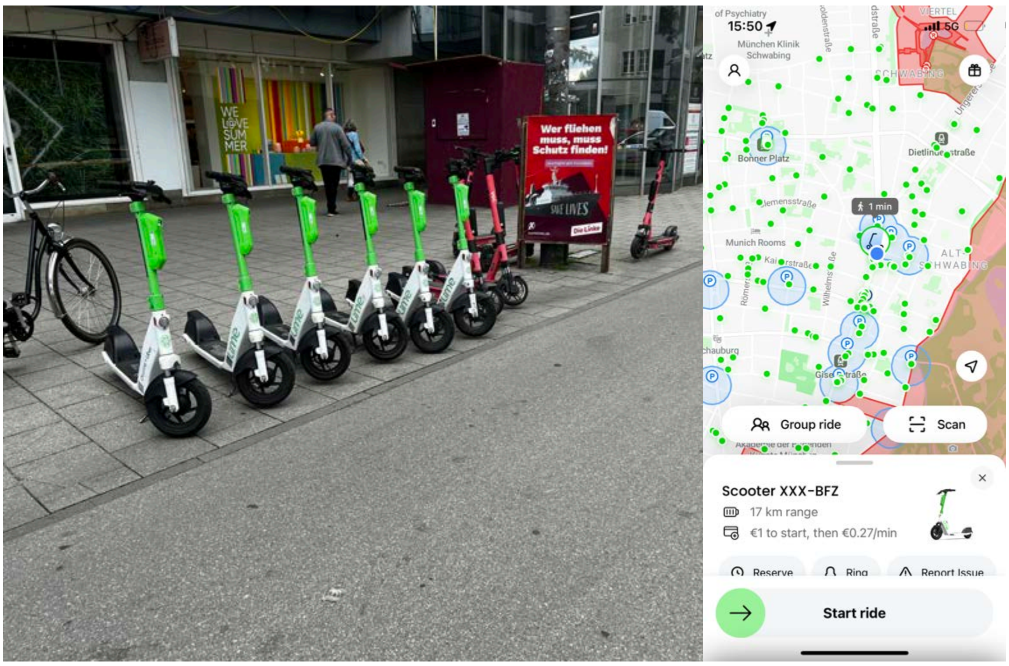
Figure 30: Design of the 43 geofenced parking spots for e-scooters, bikes and shared e-bikes

Source: City of Munich, 2023

For the city centre, there is no evidence of an increase in the number of accidents and complaints when comparing the situation before and after the new parking regulation was applied in practice. In the city centre, the number of complaints has decreased.

Another effectiveness impact results is about the accuracy and data quality, where the Munich Case Study A was showing the app information (right) matching the real situation on the street very well (Figure 30, photo on site at the same time than the screenshot).

Figure 31: Vehicle location matches in the app (right) and on the street (below) at 15:50, 23 May 2024



Source: own design, 2024

5.6 Sustainability impact assessment of Munich case studies

Following the completion of the first geofencing trial in 2024, a large number of criteria were assessed. The assessment was carried out by the City Council and the University of Westminster. The rating for each indicator was given on a scale of 1, unacceptable, to 6, excellent.

The categories of sustainability impact indicators were similar to those used in the sustainability impact assessment for the Gothenburg trials: Technical, Traffic, Management, Financial, Social and Environmental.

The three trials were evaluated separately for their impact on sustainable transport (Table 8 and Figure 31). The two situations are compared before/after (without/with) implementation of the geofencing solution.

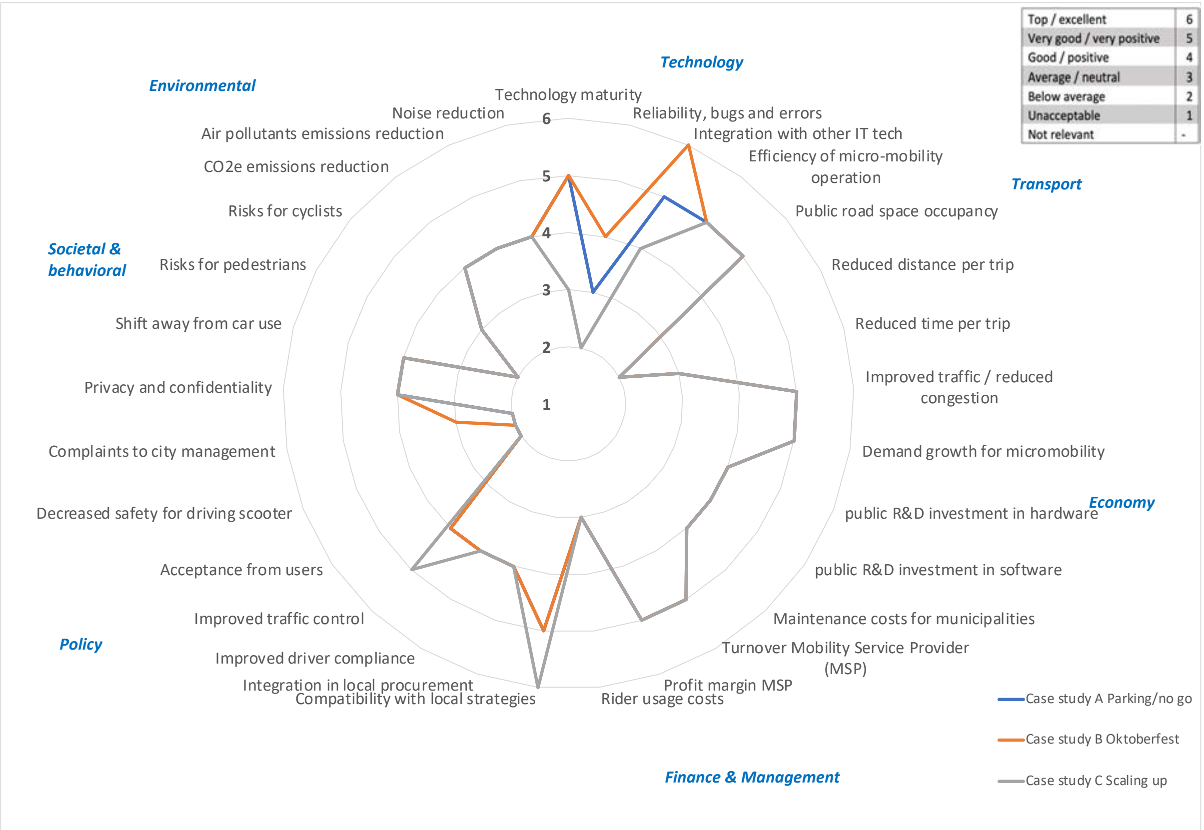
The evaluations are based on interviews with the service providers and year-long discussions with the municipal services about the effects observed for the selected criteria.

Table 8: Munich use case impact evaluation of three options: overview

Case Study	Before (without)	After (new situation with geofenced policy option)
A	No parking zone	Obligation to be within parking zone in city centre to trigger trip end validation
B	No regulation for trip end	Obligation to be within parking zone at Oktoberfest to trigger trip end validation
C	No vehicle area, beyond initial set of external boundaries	Geofences for optimising parking spaces in further areas, and for other business models (scale-up, extension)

Source: Own design, 2024

Figure 32: Sustainability impact assessment of geofencing for micro-mobility and parking



Source: Own design, 2024

The strongest positive impacts were observed in terms of increased demand for micro-mobility services, significantly improved use of public road space, compatibility with existing local policies, improved road safety, traffic management and integration with local procurement.

More problematic and with remaining challenges are the integration with other IT technologies, the safety risks for e-scooter riders, cyclists and pedestrians, and the acceptance by users and citizens. Not very critical, but a less positive impact than others, was the increased distance per trip compared to a situation with no parking obligation in designated areas.

None of the remaining problems were such a major issue that they would be considered unacceptable.

5.7 SWOT analysis of geofencing for parking and micro-mobility management

The following analysis was derived from the reflexions and findings about sustainability above.

Additionally, a Workshop on impact assessment and analysis was held in Stockholm on 13 June 2024, with all GeoSence partners, leading to additional viewpoints. These views were added to Table 9, to obtain a more complete set of explanations, and lower the risk to forget essential outcomes of the project.

Table 9: Analysis of Strengths, Weaknesses, Opportunities and Threats for the use case of geofencing applied to parking and micro-mobility management

Strengths	**Opportunities**
1. Contributes, among other factors, to strong growth in demand for active travel, micro-mobility and slight shift away from car travel. 2. Strongly improved parking inside the geofenced zones, positive effect detected. Improved driver compliance with parking rules and ride ending parking behaviour. 3. Inconclusive but probably positive effect on safety 4. Excellent compatibility with existing local strategies 5. Integration with local procurement 6. Provides a more efficient and effective way to manage parking and micro-mobility in high traffic areas. 7. Helps to reduce traffic congestion and carbon emissions by encouraging the use of sustainable modes of transportation like e-bikes and scooters. 8. Provides real-time data to city planners and transportation officials to make better decisions about parking and mobility management. 9. Can be integrated with other smart city technologies to create a more comprehensive solution for urban management.	1. Expand geofencing integration in other shared micro-mobility services, such as bikes, shared cars and shared cargo-bikes 2. Develop geofenced zones for outer boroughs including new regulations 3. European policy to support municipality services expanding the geofencing technology usage 4. Potentially improved traffic control 5. Geofencing technology can be leveraged for other use cases beyond parking and micro-mobility management, such as retail and advertising. 6. Can lead to a reduction in the number of cars on the road, resulting in less traffic and pollution. Increases safety for pedestrians and cyclists. 7. Can be used to optimize the use of public transportation by providing real-time data on traffic and mobility demand and behaviour. 8. Can increase revenue for cities through the implementation of parking fees and fines. 9. The geofencing application is implemented by a private actor with high consideration for end-users.
Weaknesses	**Threats**
1. Reliability and errors in GPS data 2. Public R&D investment in hardware 3. Requires significant investment in technology and infrastructure to implement and maintain. 4. May face resistance from traditional car owners who may not be willing to switch to more sustainable modes of transportation. 5. Limited adoption and implementation may result in a lack of data and insights for decision-making. 6. May require regulatory changes to be implemented at scale.	1. Privacy and security concerns may limit adoption of geofencing technology. 2. Cultural and behavioral barriers may hinder the adoption of sustainable modes of transportation. 3. Lack of standardization and regulation may result in inconsistent implementation and management of geofencing technology.

Source: Own design, 2024

5.8 PESTLE analysis

In order to draw useful conclusions from the impact assessment, further dimensions need to be analysed in more depth. In this PESTLE analysis, inductive and deductive considerations were made based on the interviews with practitioners and the results of the Munich geofencing trials presented above.

Table 10 presents a screening of the implications of the knowledge gained so far. The inductive step consists in drawing lessons from the specific case of Munich, to see what can be generalised for a Europe-wide improvement of transport conditions in the face of the challenges of increasing active travel and micro-mobility and improving parking management. The deductive step consists in drawing conclusions from several different elements of basic and applied knowledge. Here again, the purpose was to draw analytical and overarching conclusions that are valid for all three case studies A, B & C, in Munich.

Table 10: Multifactorial analysis of policy, economy, societal, technological, legal and environmental dimensions of geofencing use for parking and micro-mobility

Political	Geofencing use for parking and micro-mobility is fully compatible with the current European transport policy, as stated in the new EU framework for Urban Mobility document: "Better management of transport and mobility using multimodal hubs and digital solutions is needed to increase system-wide efficiency." The most important political aspect is the successful increased demand for micro-mobility services in the area of the geofenced zones. This advantage is a big improvement away from car traffic and promising for a possible future mainstreaming of the solution.
Economic	Growth of Mobility Service Providers and citizen demand enables more profitability for the operations; this has demonstrated economic co-benefits for cities and their inhabitants.
Social	More growth of active travel, away from cars, should lead to more wellbeing. Geofenced parking zones lead to less disruptions for pedestrians and residents at or near the geofenced parking areas.
Technological	The integration of geofences into vehicle navigation, and other onboard computer software or hardware influencing parking and ride hailing is feasible and probably only a matter of time until widely available for other transport modes, not only for shared vehicle or micro-mobility. To complement the public transport offer, a combination with geofenced parking management of shared micro-mobility would be useful (possibly a combined ticket offer and pricing?).
Legal	The issue of data privacy needs to be considered for the Mobility Service Providers. To use travel data, all personal information needs to be left out and the dataset anonymised.
Environmental	The shift away from car, the e-scooter induced speed reduction, higher safety, lower noise and reduced air pollutant emissions are all consequences and beneficial impacts, all aspects positive for the environment and for health of citizens. Applying no-go and no-parking geofences in sensitive areas such as pedestrian zones, around schools or close to hospitals would be especially effectful.

Source: Own design, 2024

6 Limitations

As for any study, an impact assessment has its own limitations.

Objective data and subjective analysis. As far as possible, subjective elements and opinionated statements were filtered out, with more consideration given to the tangible data collection and factual descriptions than to opinions. However, statements were included, as this is the core part of an analytical processing of the data. The main method to maintain inter-subjectivity is to include a balanced view of positive and negative aspects for multiple categories of evaluation. Another method was to include as many interviews and expert views as possible. As far as possible, the views of all the project partners are integrated.

Lack of time and resources. A project is always facing time and resource constraints, limiting the amount of evidence collected. After having collected a massive amount of data, the limits of time and resource impacted the number of checks and depth of analysis. This was forcing down the number of questions answered in the case studies. Only the questions that could be answered, even rudimentary, remained included.

Business confidentiality. Notably the cost data of various options could not be determined exactly. The best quality data were coming from the field work on site, from the interview statements of the business managers, from the follow-up emails with evidence, and from the responsible experts of the local authority.

7 Concluding remarks

Initially, the summarised key research questions related to GeoSence impacts, were:

1. What are new geofencing concepts, system and process solutions for a number of specific cases, based on findings from previous/ongoing geofencing projects and use cases?
2. What are the estimates of improvement potentials for different challenges and the results of the impact evaluation of different geofencing solutions?
3. Can a transferrable implementation strategy be developed for urban geofencing solutions including identification of challenges, description of systems, operational settings and requirements for implementation?

After nearly four years of project development and implementation, we can add another generic impact assessment question:

4. Beyond the results of individual cases, what are the generic, fundamental lessons learnt from GeoSence when looking at the beneficial impacts and analysing the effectiveness of using geofencing technologies in transport planning and applications?

As general analytical outcome of the GeoSence impact Workshop conversations, following statements are derived, starting with an answer for question 4 on lessons learnt after the whole project. This includes for example the finding that the city of Munich continues with extending the micro-mobility policy applying geofencing, so the following generic analyses are prerequisite as well as consequences of a well-designed application:

Embeddedness: A geofencing application needs to be embedded into a general transport policy aiming at reducing congestion, or improving safety, or getting road traffic more fluid, more green, more friendly to pedestrians and citizens, etc. A geofencing application is never alone efficient or effective by itself. It is always part of a policy objective, a tool that is contributing effectively, together with many other tools and working methods, to help attain the targets.

In the case of the parking zones in Munich, the solution of improving the behaviour and increasing the market share could not have been reached without geofencing, but demonstrating its unique usefulness, in the end, was embedded into a vast web of coherent actions and investments.

Testing and development towards an **improvement**: A geofencing application needs testing and development, adapted to the field and its improvement. It can hardly be neutral, contributing to maintaining the status in urban transportation conditions. The aim should be an effective situation improvement, and the contribution of the geofencing application toward it should be made clear during tests and trials in small scale.

It should be having a **high visibility**: A geofencing application should not be something a municipality or a transport service provider implements without knowing. An example of doing without knowing would be when the limits of a low emission zone or a pedestrian zone are entered into a digital map in a navigation app by a software company, or when speed limits for e-scooters are uploaded to the vehicle by the operator, and the municipality service consider this a question of digitalisation of planning document without specific other action or public information exchange. When London introduced the Congestion charge zone, it wasn't implemented into the vehicles' GPS systems, but now it is, without Transport for London having had originally a say or an influence on the maps. The driver just sees on the navigation app that the charge zone is coming, before entering the zone. Which is the exact principle of geofencing technology application. The same applies for all the German Umweltzone, Italian ZTLs etc. If the geofencing information was made available publicly without any action from the cities, this operation could be called "not knowingly applying geofencing in transport policy".

It should be a candidate for **scaling-up feasibility**: If the geofencing application is reaching its target in a small scale testing, the objective of the next step is to try reaching the industry scale implementation. How to do this extension successfully remains to be demonstrated in another possible project.

So, how could we answer our main initial GeoSence research questions?

1. *What are **new geofencing concepts**, systems and process solutions for specific cases, based on findings from previous/ongoing geofencing projects and use cases?*

   Answer 1: The main fields of new geofencing applications were presented in the publication by Hansen et al., 2021. In the years 2021-2024, the GeoSence partners were able to test new use cases for counteracting speeding, parking for micro-mobility, governance and data management.

2. *What are the estimates of **improvement** potentials for different challenges and the results of the impact evaluation of different geofencing solutions?*

   Answer 2: There is a demonstrated potential for future development of geofencing applications in parking management and shared micro-mobility in cities. Our results about potential use of geofencing for counteracting speeding, governance and data management are a bit less convincing, and will require more future development and research, before a definitive improvement can be evidenced with more certainty.

3. *Can a **transferrable implementation** strategy be developed for urban geofencing solutions including identification of challenges, description of systems, operational settings and requirements for implementation?*

   Answer 3: The transferability, defined as the possibility to extend good solutions to a wider area of application, was evidenced for the case study on parking and micro-mobility. The scaling-up process, as of mid-2024, is ongoing.

For details about implementation guidelines, please refer to our GeoSence guidance report on geofencing (D5.3) from June 2024.

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