Report on the Acceptance Evaluation for the Geofencing Use Case Study in Gothenburg

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Synopsis

This document describes the acceptance evaluation for a geofencing use case study performed in Gothenburg as part of the GeoSence project. In the use case the Gothenburg's aim was to test the geofencing technology in combination with intelligent speed assistance to improve the safety of special transport services (both for its passengers and other vulnerable road users) by regulating speed of urban zones where the city see higher traffic safety related risks, as for instance at school zones. Geofencing was used to define physical areas digitally and to assign a speed regulation policy to it that could be equal or even lower than the maximum permitted speed on roads in the geofenced area. A geofencing compatible retrofitted intelligent speed assistance (ISA) system was installed in vehicles of two publicly procured companies offering special transport services in order to support their drivers to comply with the speed regulation in geofenced areas.

The study consisted of three study conditions, a baseline condition where no information about geofence zones and speed limits were provided, an informative ISA condition, which provided feedback on geofence zone location and speed limits via the installed ISA, and a mandatory ISA condition, which additionally included an automatic speed limiter. Acceptance and effectiveness of the system was analysed by assessing driving behaviour, as well as acceptance of the ISA system, attitudes towards stricter speed limits, and perceptions of geofencing technology with a survey among participants.

The driving data analysis revealed that drivers exhibited speeding behaviour within the geofenced zones. However, the effectiveness of the tested ISA systems in reducing speeding was limited. Only for the mandatory ISA condition a statistical significant reduction of speeding was observed compared to the baseline condition. No reduction in speeding compared to the baseline was evident for the informative ISA system, and no difference was found between informative and mandatory ISA system. Results of the acceptance survey were also inconclusive. On a positive note, more drivers were willing to use such an ISA system in the future if it remained in the vehicle, compared to the utilisation rate of the conventional ISA system already installed in the vehicle before the use case. Otherwise, the survey did not indicate a preference for the use of ISA in general or a preference for one of the two ISA system variants tested. However, concerns were raised regarding ease of use, trust in the system, and data privacy and security.

Several implementation-related and technical limitations were identified during the study, including issues with the installation and functionality of the ISA system, battery charging problems, and issues related to geolocation inaccuracies. These challenges significantly impacted system performance and user acceptance, highlighting also the importance of thorough testing and more user-centred approaches and broader stakeholder engagement and collaboration in the implementation process. Geofence zone selection and configuration were also identified as areas for improvement, in order to avoid inconsistencies in zone definitions and improve understanding and acceptance for the introduced traffic safety measures among the affected users.

To address these challenges and enhance the effectiveness and acceptance of geofencing solutions for road safety, the document closes with several recommendations. These include prioritizing thorough testing and quality assurance, investing in user-centred design and usability testing, implementing robust data privacy and security measures, optimizing geofence configuration and location selection, and promoting stakeholder engagement and collaboration throughout the implementation process. In conclusion, while the study provides valuable insights into the acceptance and effectiveness of geofencing-based ISA systems, it also highlights the need for improvements in system design, implementation processes, and stakeholder engagement to overcome existing barriers and ensure successful deployment in real-world settings.

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1. Introduction Case study Gothenburg

1.1. Background

The city of Gothenburg is Sweden's second largest city. It has a strategic position by the sea and harbours Scandinavia's largest port. The city is growing substantially and the competition for city space is hard. Gothenburg works actively with traffic safety. In 2022, Gothenburg was selected as one of Europe's 100 climate-neutral and smart cities. Altogether, this sets demands for new ways for traffic planning and traffic management.

Traffic safety has a large dependency on speed. The higher the speed and the heavier the vehicle, the higher the risk for incidents and the more severe the injuries. Different measures can be made to ensure relevant speed, both physically in the road infrastructure but also digitally by using new techniques. The city of Gothenburg is investigating how geofencing functionality can be included in public procurement to get better speed compliance for fleets and transport services that are used by the city. Within GeoSence, a case study has been conducted by retrofitting some of the vehicles that are used for special transport services. Drivers' behaviour and acceptance have been evaluated. When the project is finished, recommendations for usage in public procurement will be a part of the project result.

1.2. Special Transport Service (STS)

Special Transport Services (STS) 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.

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. The mission is to offer safe and secure trips, which is followed up regularly in customer surveys.

The fleet of vehicles is divided into two parts. **Traffic operators that are specialised in this kind of trips**. Three companies are contracted. 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 are 243 vehicles, of which 106 vehicles are fitted for wheelchairs and 137 are ordinary passenger cars. 73 of the passenger cars are pure electric. **Ordinary taxis**, that supplement the ordinary fleet at peaks/periods of higher demand. The taxi companies are paid per trip. Two companies are contracted for this purpose.

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

Public procurement for a new contract period of 5 years was made in late 2020.The contract sum is around 1,5 billion SEK (150 million EUR). The new contracts came into force in February 2022.

1.3. Systems for Intelligent Speed Assistance

The transport operators use intelligent speed assistance (ISA) systems that inform the driver about official speed limits. The national road data base is the source for the legal speed data. The ISA-systems register the actual speed for each vehicle. The information is also stored in fleet management systems of the transport operators. Different transport operators use different ISA and fleet management systems. If there are customer complaints, the city of Gothenburg can ask the operator about details for the trip, i.e. data registered by the ISA and fleet management system. The city of Gothenburg otherwise does not have access to any other data registered in the operators' ISA systems.

1.4. Complaints about STS

Some passengers and traffic participants have raised complains or concerns about the driving behaviour of STS vehicles, in particularly, that the drivers are speeding and/or go to fast. Because of that, the trip does not feel safe and secure. 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). It gives the city a bad reputation.

In the last year the Urban Transport Administration received the following number of complaints related to STS trips:

- 2018: 54
- 2019: 31
- 2020: 20 (fewer trips than normal were made due to Covid)
- 2021: 17 (fewer trips than normal were made due to Covid)
- 2022: 42 (more new-recruited drivers than usual)

This is a very small amount considering that a million trips are made every year, but you need to bear in mind that not all thoughts/comments regarding a trip result in a complaint. The city of Gothenburg has dialogue on a regular basis with associations that represent the passengers (for example the national association for visually impaired) and they convey their member's experiences of using the Special Transport Services.

Every complaint the city gets is reported to the operator that has carried out the trip. The operator is responsible for taking proper measures. If the same driver repeatedly gets the same kind of complaints, the operator can be asked to set up an action plan and regularly report how the situation develops.

1.5. Cause of the problem and possible solutions

At an initial stage of the project, the following reasons have been discussed that might contribute to unsafe driving behaviour:

- The driver's support to comply with the speed limits is not good enough, especially in areas with higher safety risks.
- 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 contracted company/operator uses).

The City of Gothenburg does not have mandate to handle or prosecute speed violation. Only the Swedish police is authorized to do that. Therefore, the city's objective is to investigate what kind of technical solutions and functionalities that can provide a better support for the drivers to keep the speed and avoid speeding. Furthermore, the city wants to explore the possibilities to set lower speed than regulated at certain urban areas and roads, in particularly where there have been complaints in the past and where the city sees a higher risk for traffic safety and incidents.

The traffic operators themselves also have an interest to improve the support for drivers for keeping the speed limits. This could potentially reduce damage and wear and tear on vehicles, which in turn would reduce costs and increase the safety of journeys and service operations.

1.6. Description of the Gothenburg use case study

Passengers with need for special transport services belongs to a vulnerable group. The case study investigates how public procurement can be used to ensure that speed limits are always respected and thereby strengthens the passengers' right to safe transport.

It is not in the city's interest to really force drivers to speed compliance, but previous research on ISA system acceptance has shown, that informative/advisory ISA systems that provide speed information and warnings are often less effective in reducing speeding than mandatory ISA systems that additionally can reduce the vehicle's speed automatically (for an overview see Ryan 2018). In the use case study conducted in Gothenburg, both an informative (advisory) ISA and a mandatory ISA system were tested to investigate drivers' compliance with speed regulations. The city also wanted to test compliance with "contracted" speeds in geofenced areas. This means that in urban areas where the city identifies potential risks or impairments to the comfort and safety of passenger transport and the safety of other vulnerable road users due to speeding, it aims to test stricter speed limits that are lower than the officially permitted speed limit. These higher risks are particularly assumed at destinations of STS trips, such as schools and day or activity centers, where a higher number of vulnerable road users is expected during peak times.

A technical solution to define such areas and to implement lower speed limits is to use a geofencing-based ISA system. Geofencing can be used to define geographic areas and to assign traffic related policies to it, like for instance speed limits. The ISA system is the technical interface to inform the driver about such speed regulations within geofenced areas. Since geofencing compatible ISA systems are not available in the vehicles of transport companies that offer STS, a retrofitable solution had to be found and installed as part of the preparatory tasks in the uses case. Additional to investigating the effectiveness of such a technical geofencing solution the city wanted to explore drivers' behaviour, experiences and opinions when using two variants (informative vs mandatory) of a retrofitted geofencing based ISA system.

Furthermore, the city was interested to explore if compliance with contracted speed in geofence zone would create compensatory effects for driving outside these zones, such as increased speeding to make up for possible time loss.

1.7. The city's overarching aims and questions related to the planned use case

1. Test/validate if the opportunities of geofencing to implement stricter speed regulation (i.e. lower than the official maximum permitted speed)
    - How does the technology support the city's mission to achieve safe and secure transport trips (by leading to better compliance with speed regulations)?
    - How is a geofencing-based technical and regulatory solution accepted by driver?
2. Explore the technical, practical, organisational and regulatory requirements to implement geofences for special transport services

Furthermore, the Special Transport Services department wanted to gain knowledge and experience about the following questions:

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 support for drivers is needed and effective to comply with recommended speed (i.e. lower than the maximum permitted speed limit)?
3. What working routines and processes must be established to use geofencing in daily operations both from the purchaser's (the City of Gothenburg) and the provider's (the traffic operators) point of view?

2. Aims, questions and hypothesis of the acceptance evaluation study

Aim of the acceptance analysis is to investigate drivers'/participants' experiences, opinions and behaviours while using the geofencing based ISA system during the use case. The plan and methods for this analysis are in large part motivated by the following research questions.

- Is there a need to introduce speed regulations?
- Is the implemented ISA system useful to support drivers to comply with speed regulation?
- Which of the two tested ISA variants is more effective in supporting driver to comply with the speed regulation within geofence zones?
- Does the introduced measure have side effects like increased speeding outside geofenced zones to compensate for time loss?
- What is the acceptance for a geofenced based retrofitted ISA system?
- Which of the two ISA system variant is accepted more?
- Which factors possibly influence or drive the acceptance judgements?
- How do participants perceive stricter speed limits in geofence zones and the application of geofencing?

For some of the questions, more specific hypotheses can be proposed based on previous findings in the research on ISA system. However, this research has almost exclusively been conducted in the context of traditional ISA system use, that is limiting speed to the regulated speed limit. However, in the present use case study geofencing will be applied to implement speed limits that are even lower than the regulated speed limit. It is therefore unclear whether the hypotheses formulated below are valid in this context.

Hypothesis 1: Average speed and amount of speeding is lower when using the activated ISA system compared to a baseline driving condition without specific information about geofences and speed regulations.

Explanation: Research on the effectivity of ISA to regulate speed exist for more than 20 years. The research has shown that ISA system can be helpful to reduce speeding and increase traffic safety (for a review see Ryan 2018).

Hypothesis 2: The mandatory ISA variant is more effective than the informative ISA system to reduce the amount of speeding and average speed.

Explanation: Research has also investigated the effectiveness of different versions of ISA systems. This research suggests that mandatory ISA systems are often more effective to reduce speeding (Ryan 2018).

Hypothesis 3: Using the ISA systems leads to increased amount of speeding and increased average speed after leaving a geofenced zone.

Explanation: Driving slower in geofence zones may lead to increased trip durations and perceived time loss, which drivers may try to compensate by driving faster when leaving a geofence zone.

Hypothesis 4: Acceptance for the informative ISA system is better than for the mandatory ISA.

Explanation: Research on ISA systems (Ryan 2018) has shown that in most contexts and for most potential user groups informative or advisory ISA is preferred over mandatory ISA since it restricts and influences the vehicle control to a lesser extent.

3. Method of the evaluation study

3.1. Study design

The use case was designed as field study with a group of professional drivers from two companies providing transport services on behalf of the special transport service department of City of Gothenburg. The study included three study conditions, a **baseline condition** (henceforth **BL**), which served to collect driving behaviour data under normal conditions, **an informative ISA system condition** (henceforth **inf ISA**), in which a retrofitted ISA system supported the driver by providing information on geofence zone location and assigned speed limits and **a mandatory ISA condition** (henceforth **mand ISA**), in which the ISA system had the same functionality as the informative ISA condition, but provided additional support by reducing the speed within zones automatically to the assigned speed. In strictly methodical terms the study has a one-factorial design with a repeated measurement of the three different study conditions, i.e. each participating driver took part in study each condition. The time and sequence of the study conditions were the same for all participating drivers. First we conducted the baseline phase, followed by the informative ISA phase and finished with the mandatory ISA phase.

The study aimed to investigate and test the impact of the different ISA versions on the driving behaviour, by analysing speed and speeding within geofenced zones and outside geofenced zones. Furthermore, the acceptance for the retrofitted ISA system variants and for the implemented traffic measure/policy (equal or lower than regulated speed limits in geofenced zone) was investigated.

According to a preceding power analysis, the study design will be able to detect statistically significant differences between the three study conditions only, if the effect size is large. For testing of medium effect sizes, performing the testing with a smaller sample (N<18), or for the analysis of a second factor within the design, the study will be underpowered.

The main practical restriction for the study implementation were the available budget for equipping vehicles with a retrofitted ISA system, limiting the number of vehicles to be equipped and therefore the number of potentially participating drivers.

3.2. Study sample

Two companies providing special transport services in behalf of the Urban Transport Administration of the city of Gothenburg participated in the project. The companies are commissioned to carry out the trips for the city as part of a public procurement process. In addition to the details of the agreed transport services, additional requirements such as necessary vehicle equipment and consent to participate in studies to improve traffic safety were regulated within the public procurement process.

In the planning stage for the study 20 drivers (10 from each transport company) initially agreed to participate in the study on a voluntary basis. The requirement for their participation was a strict confidentiality and anonymity of the driver's identity. For that reason, interaction and communication with drivers had to be performed anonymously. When conducting the use case this meant, we had (at least initially) no direct contact with the participating drivers. All study related information and requests from the project and research team had to be communicated via the responsible operational managers in the STS companies without exposing drivers' identities.

Before the start of the field study, all participating drivers received written information about the aim and procedure of the study as well as about the data collection, analysis, and applied privacy policy. Voluntary participation and agreement to the study conditions was confirmed with signed consent.

Due to several reasons (drivers left the company or refrained from participation, holidays, sick leave, ISA equipment installation problems, malfunction, theft of equipment) fewer than the originally planned number of drivers/vehicles participated in the study. During the study implementation in autumn 2022 finally 16 vehicles were available. Data of 15 drivers was collected in the baseline phase, 13 drivers participated in the informative ISA phase and 6 drivers participated in the mandatory ISA phase. The reason for the low number in the mandatory phase is explained in detail in the following chapter.

The following information about the sample of participating drivers were collected as part of the acceptance survey. Eight of the 15 participants completed the pre-study questionnaire, which had to be filled before the baseline phase (Aug 2022). Reported age range was between 40 and 60 years. Except one woman, all respondents were male. The annual driving experience was larger than 10.000 km per year for all but one respondent who reported less than 10.000 km. All respondents hold a driving licence for 19 years or more. Only one driver reported having being fined once for speeding during the past three years.

3.3. Study procedure

The study started with the baseline condition, was followed by the informative ISA condition and finished with the mandatory ISA condition. Each phase was planned to last two weeks (or 10 working days) in order to collect a sufficient amount of driving data and to provide a sufficient experience with the tested system variants. It was planned that each participating driver took part in all three study phases. Additionally, one-week breaks were planned between each study phase to solve unexpected technical or organisational difficulties.

The initial time plan was set for a period between 9th April 2022 – 17th June 2022 to perform the field study in a time window uninterrupted by major vacation periods and under comparatively stable weather conditions. However, due to delays in the procurement, delivery and installation of ISA equipment, only a fraction of the vehicles were ready at the scheduled start of the study, and it ultimately took until end of May to complete the installation process. Furthermore, although local union representatives had been informed beforehand about the study, concerns were raised by national representatives during the start phase of the study. They requested more detailed insight into the study procedure and the planned data collection before giving their final approval. As a result of these delays the study could not have been conducted in the remaining time (before summer holiday). It was therefore decided to suspend use case and to restart it after the summer holidays in late summer/early fall.

The updated time plan covered a range of seven weeks (15th Aug – 30th Sep 2022). The baseline phase (three weeks) and the phase for testing the informative ISA system variant (2 weeks) were performed according to the new schedule until 16th September. However, when the third study phase started, it came apparent that the most important feature of the mandatory ISA system – the automatic speed reduction function within zones – was not working as expected. The process of troubleshooting included several joint meetings and weeks of testing involving research partners, third party system suppliers and the participating drivers.

A service technician from one of the component suppliers finally confirmed that the source for the malfunction was an incomplete/incorrect installation of the equipment components. Since the remaining budget for the use case implementation did not cover cost to re-install the system in all vehicles and because of the also advanced timing (Nov 2022), it was decided to perform a correct re-installation (with working automatic speed limiter) in only six vehicles and to conduct the final project phase with this smaller group. The third phase with mandatory ISA finally lasted from 22th Nov – 7th Dec 2022.

3.4. Technical set-up retrofitted ISA system and Geofencing solution

According to the STS companies, all vehicles used in the field study were already equipped with an inbuilt ISA system, however, these systems did not provide geofencing functionality. Therefore, a retrofitted system had to be additionally installed into the vehicles for the duration of the study to provide the required ISA and geofencing functionality.

For the use case we used a modular system consisting of software services and hardware components provided by the companies SkanTech and Lindgaard-Pedersen. The set-up of the system included a tablet device (Samsung Galaxy TabActive3, 8" display size) with SkanTech's Android based navigation app, a speed limiter device, a break relay device and cables connecting the components. Furthermore, a tablet holder with a bracket and a USB charging cable to power-up the tablet's battery completed the system. SkanTech's navigation app communicates to a geofencing management system via mobile network. Therefore, a mobile sim card (and data volume contract) was needed as well. Navigation data (maps) and geofence information is stored locally on the tablet and enables function of the ISA system without a constant and stable mobile connection. Updates of the app's software, as well as for navigation- and geofencing data was provided via over-the-air updates. Available updates were downloaded when the tablet was started and a mobile connection was available. Driving data is recorded and temporarily stored locally on the tablet and uploaded to the geofencing management system when a mobile connection is available.

Placement of the tablet bracket in the vehicle was at a lower half of the central console (see Figure 1). The tablet's GNSS sensor was used to provide the location signal for the system. The main power source is the tablet's battery, but as the active tablet display consumes a lot of power, the tablet's battery drains quickly and a stable power connection (via the supplied charging cable) is recommended to provide continuous power and recharge the battery.

Figure 1: Installation of the tablet in the vehicle's central console

The tablet information screen is shown in Figure 2. It provided a navigation display (in wide screen format) and some additional status information of the system (battery level, battery loading indicator, LTE and GPS signal, speeder-box connection indicator and less relevant driver code, vehicle code and Zone code) in the status bars on top and bottom of the navigation window.

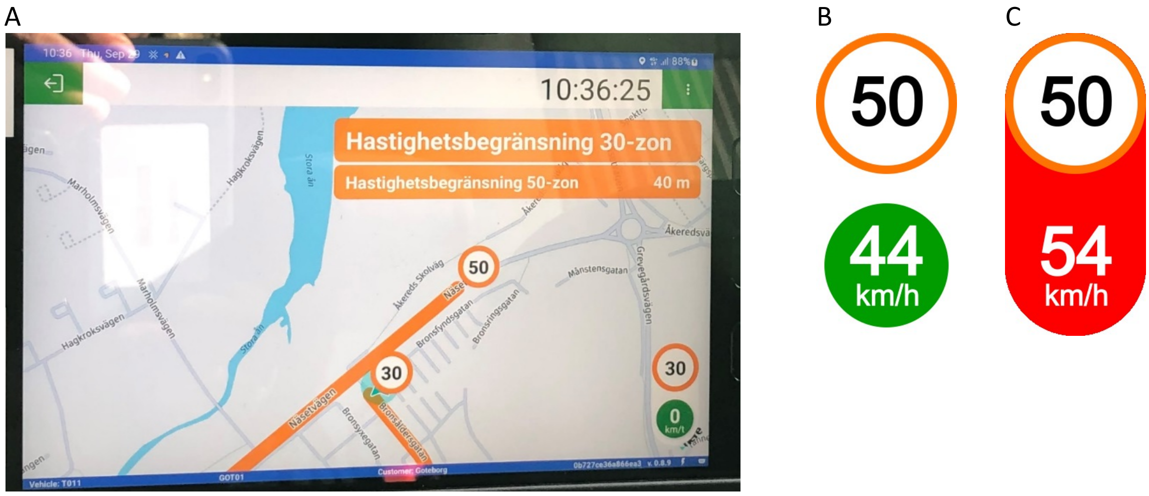

Figure 2: Display screen of the SkanTech navigation system when driving within a zone (A) and appearance of the speed indicator display when driving below (B) or above(C) zone speed limit

Functionality of ISA in the different test conditions

During the **baseline condition** the system was active but no zone information was displayed yet in the navigation window. However, a map and the vehicles current location on the map as well as the regulated speed for the current road and the actual speed was displayed. Furthermore, data logging was active including GPS, vehicle speed and the detection of within zone driving.

During the **informative ISA condition,** the geofenced zones were active. Driver received a visual warning and an audio message when approaching and entering a zone. Geofence zone location was shown by orange patches overlaid within the navigation app (see Figure 2A). Vehicle position was indicated by a transparent light blue dot and by a solid arrow indicating the estimated driving direction. Speed information for the currently visited and upcoming geofence zones was highlighted by orange text fields at the top edge of the navigation display. Additionally, the zone speed was shown with a speed sign attached to the zones location patches. The current speed limit as well as the current vehicle speed was shown also on the lower right part of the navigation window. If current speed exceeded the speed limit, the background of the (lower) vehicle speed indicator turned from green to red (see Figure 2B and C). However, there were no auditory warning when the vehicle exceeded the zone speed limit.

During the **mandatory ISA condition,** the informative ISA functionality was supplemented by an automatic speed limiting function which was activated when the vehicle speed was higher than the assigned speed limit within a zone. Technically it was achieved by adjusting the signal from the accelerator pedal by reducing petrol supply to the engine until the assigned speed was reached. Drivers were able to override the automatic speed limiter function by flooring the accelerator pedal to the bottom for more than one second. After overriding the accelerator pedal would work in a normal way until speed within a zone dropped again below the assigned zone speed limit. When overriding occurred a signal was added to data logging indicating the overriding event.

Battery and charging issues: In order to avoid the system not being activated (intentionally or unintentionally) during the study, the tablet device was initially configured in such a way that it could not be switched off (first half of the study period). The system simply restarted when the power-off button was pressed. The tablet device was thus usually disconnected from the vehicle in off-shift periods and charged with an external power supply during the night to avoid discharging the vehicle’s battery and to start with a recharged tablet in the morning. However, not all participants recharged the battery during the night, resulting in empty tablet battery at the start of the shift and the necessity to re-charge the device during first minutes of the shift to functional level. However, during the study we discovered problems related to charging the tablet battery in the vehicle while driving. This resulted in dysfunctional systems and data loss in some vehicles and for some days. The charging issue was related to a wrongly installed USB charging cable and other battery issues. In the later course of the study, it was decided to reconfigure the system, so that participants were able to turn off the tablet if necessary.

Costs for the use of the whole geofencing ISA solution during case study included the installation and de-installation of the ISA system components from the vehicles, weekly leasing rates for the equipment components and geofencing management service, as well as costs for mobile data use (sim cards and data volume). (De)Installation was performed by contract workshops of the involved transport companies. Due to extended length of the study a much higher budget for the equipment leasing was needed, almost tripling the initially planned service cost.

3.5. Geofence zone definition

Twenty-three areas or road stretches in Gothenburg area were defined as geofenced zones. Location of zones across the city area are shown in Figure 3.

Figure 3: Overview geofenced zones in Gothenburg area

Zones for geofencing were chosen based on the information about trip frequencies for destinations of the special transport service. “Destination-candidates” with high visiting frequencies were further analysed and discussed with a traffic engineer from the transport authority, focusing on current speed regulations, safety requirements and the possibilities and necessities for additionally lowered speed on the included road segments. Most of zones were set up at areas around schools or activity centres. These zones often also included main access roads through residential areas leading to the destination at a school or activity centre. For a few locations, zones were assigned around or at major urban roads and once on express roads (see Figure 4). Therefore, zones included roads with different regulated speed limits (30-70) on which different zone speed limits (equal to regulated speed, 10 km/h slower, or 20 km/h slower) were assigned.

A B C

Figure 4: Three examples of geofenced zones with different road types involved. Panel A) illustrates a zone with a road through a residential area and a urban road passing by the area, panel B) a zone at an entrances and exit from a express road, and panel C) a zone at a major urban road leading along a nearby school and pedestrian crossing for pupils.

The geofence areas were defined manually by specifying the coordinates enclosing the selected area in the geofencing management system (integral part of SkanTech's fleet management system). This was done either by drawing a line along a selected road segment or drawing polygons to outline the zone area. If lines were used to define the geofence for a road, the system internally added a margin (of approx. 15 m) automatically (this extends zone space on the road crosswise to the direction of travel and is necessary to accommodate GPS inaccuracies).

Furthermore, for each entrance of other roads into the designated geofence area an entrance trigger had to be assigned. These triggers were necessary to implement a pre-warning period in the system before the driver will eventually enter a zone. Each trigger specifies a distance when the geofence information is released and the angle and direction for detection of vehicle movements into a geofence (see Figure 5).

A B

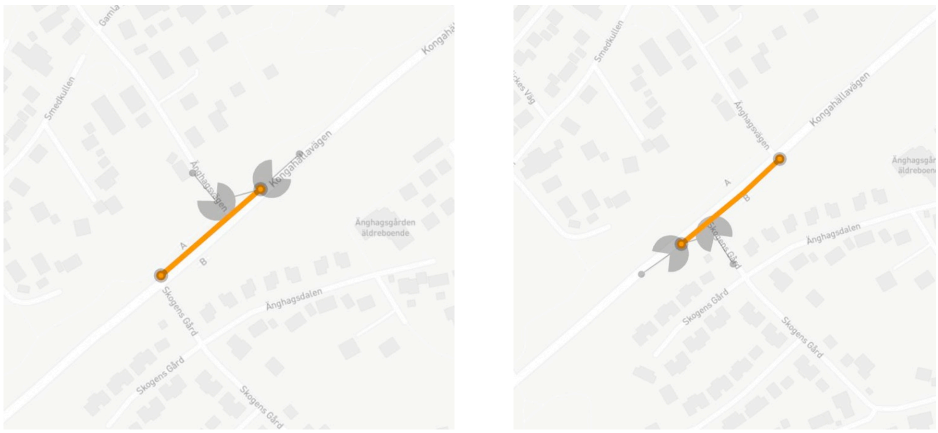

Figure 5: Assigned trigger signals in SkanTech's geofence zone designer interface for two road segments leading in opposite directions

Note, for some zone configuration such triggers may by prone to issue false detection and warn about an upcoming zone although the driver may finally turn in a different direction at a zone entering location. Furthermore, the data and experience of the use case showed, that in some cases driving on a road directly next to the geofenced road can lead to false detection of zone entries, i.e. erroneous zone enter information and speed recommendations.

Technically, each trigger is associated with a unique zone identifier (zone segment) in the recorded dataset (the example in figure 5 results in four unique zone segments in the data). Therefore, the analysis of speed in zones is based on zone segments rather than on the actual geofence zones area (which may include several zone segments). Table 1 summarizes the number of zones segments for which driving data was available in the whole study, split by regulated speed limit and assigned speed limit.

Table 1: Number of zone segments for combinations of regulated speed and assigned zone speed limitation

Maximum permitted speed on zone segment	Assigned zone speed limit relative to maximum permitted speed			
	Equal	10 km/h slower	20 km/h slower	30 km/h slower
30 km/h	10	4	-	-
40 km/h	3	-	-	-
50 km/h	21	17	37	10
70 km/h	2	-	2	-

Note: Zones with regulated speed of 50 km/h and an assigned zone speed regulation of "20 km/h slower" results in a zone speed limit of 30 km/h. This zone speed limit was the most common one in the study. Indeed, such zone segments often resemble road stretches in residential areas where officially the maximum permitted speed is 50 km/h but often a recommended speed of 30 km/h is sign posted. In this case, the ISA system would inform/enforce an already existing sign posted speed recommendation.

3.6. Concept for acceptance evaluation

Various fields of research have shaped how we understand acceptance. Despite this, no common definition exists. It is usually agreed that the construct of acceptance is associated with terms like acknowledgment, consent, affirmation, agreement, or approval. According to Klosa (2016, p. 6) it describes an affirmative or tolerant attitude of persons or groups towards normative principles, regulations, new techniques or consumer products. Since acceptance is an abstract concept, it cannot be measured directly. In most theoretical accounts, it is therefore assessed through attitudes, behavioural intentions or the actual behaviour (use) of the acceptance object, whereby the behaviour is often considered as its most direct indicator (e.g. Schade & Schlag 2005, Adell, 2009). Most theoretical concepts or models of acceptance also try to explain, which are the most influencing factors for acceptance. While behaviour can be directly assessed by observing and measuring it, intentions, attitudes and other influencing factors are often not directly observable and therefore need to be investigated by means of questionnaires or similar methods of social science.

This is also the point of departure for the current analysis. Methodically, we focus on two aspects in the assessment of acceptance. The first aspect is the analysis of behaviour itself. Acceptance in the current use case should manifest itself by adapting the driving behaviour to the speed limits within the zone. The actual driving behaviour will be analysed to assess how the measure is complied with, how effective the retrofitted ISA system is to reduce speed within the zones and whether its usage resulted in unforeseen and unexpected side effects behaviourally. The main variable of interest for this analysis is vehicle speed and speeding. This analysis is described in the following chapter. The second aspect is the evaluation of preference judgments, attitudes, opinions, perceptions related to acceptance and its influencing factors by means of a survey, accompanying the use case study's procedure. The structure and content of the survey concept and procedure is explained in the subsequent chapters.

3.6.1 Driving data analysis

In order to perform the driving data analysis, data was logged second-wise during driving. Main parameters in the log files were: vehicle ID, driver ID (anonymous), date, time, GPS (latitude, longitude), GPS accuracy index, GPS height, vehicles speed (GPS based), zone ID, zone speed limit, zone enter indicator, zone leave indicator, speed limiter override indicator, regulated speed for GPS coordinate, status messages (battery level, Speed limiter connection status). Data exports from the fleet management tool were available 24 h after the recording took place on a per vehicle and per day basis in tabular CSV file format (file size about 4-12 Mb). Original data files from all records used in the analysis were about 2 Gb. Data access was provided only to scientific partners in the GeoSence project to ensure anonymity and confidentiality of data.

All data analyses were performed using statistic software R (R Core Team 2021) and several publicly available toolboxes for R (leaflet, geodist, ggplot2, mapview and rstatix among others).

Assuming that speeding occurs in the sample under normal driving conditions (i.e. baseline condition), a reduction in the average speed or frequency of speeding when passing through the geofence zones is the most direct indicator of compliance with the speed limits and the actual use of the ISA systems. If no reduction occurs, then the ISA system is either not effective or not used. Additional behavioural measures include the frequency of overriding the mandatory system. In the analysis we were specifically interested in two variables related to speed and speeding in zones. For that we calculated the **deviation from zone speed** as the mean difference between actual speed and assigned speed limit for all data samples that were indicative of unrestricted driving in the zone. Unrestricted driving was defined as all data samples with a speed of at least 10 km/h or not slower than 20 km/h than the assigned zone speed. This data filtering heuristic was used to avoid a bias from situations where the vehicle is not driving at all or unrestricted driving is not possible due to the general traffic situation (dense traffic etc.). As the second indicator we calculated the **percentage of time speeding** (above assigned speed limit) while driving in the zone. For that the same data filtering was applied. Then the ratio between the number samples driving above the assigned speed limit in a zone and the number of all (valid) driving samples in a zone was calculated. Additionally, we were exploring dedicated time windows (five seconds before and after) when entering and leaving a zone, to analyse the effect of ISA variants on a more detailed level.

The described parameters were all calculated for each driver and each of the three use case conditions. Since for each condition data from different numbers of participants is available, we used pairwise t-test for dependent samples to compare the three test conditions (BL vs infISA, BL vs mandISA, infISA vs mandISA) to include data from as many as possible participants in each condition in the evaluation.

A further challenge in the analysis is related to the fact that the zone visiting was different both across participants (different drivers drove different routes and visited different zones) and time (same driver visited different zones on different days). In the analysis we therefore accumulated data (for each indicator) first for each zone and participant and in a second step accumulated data for each participant. Only zones with more than 7 valid data samples per visit and which were visited in both of the compared conditions were included for statistical analysis. To our understanding this approach provides the most valid comparison of the test conditions. However, this approach comes with a considerable amount of data loss. Therefore, we also reported indicators of each condition for the whole sample of drivers and all zones, for descriptive purposes and comparison.

For the outside zone driving a similar procedure for data analysis was applied but since drivers had different tours on different days and therefore left the zones on different routes, the driving conditions for outside zone analysis are even more variable than for within zone analysis. To analyse the outside zone driving, the following data filtering scheme was applied. For each zone visit (with a duration of more the 7 valid data samples) we analysed the speed in the subsequent period of driving. Data of post-zone-driving was only taken into account if driving took at least one minute before entering a new zone and driving distance between the two subsequent zone visits was more than 500 m. Following this specification, all periods of post-zone-driving with a duration of at least one-minute (but cut-off at a maximum of 3 minutes) were included in the analysis. Similar as for the analysis of within zone driving only speed samples with a minimal speed larger 10 km/h and with a speed larger than 20 km/h below the regulated speed limit were included in the calculation. If less than 20 % of all recorded data samples in a post-zone driving episode survived, all data from this episode was excluded. This heuristic filtering ensures that only data was taken into account from episodes where free driving was possible and the vehicle was not stuck in traffic jams or similar incidents. Average speed and percentage of speeding were used as parameters for analysis. Statistical analysis was performed in the same way as for the within-zone analysis.

3.7.1. Acceptance survey concept

Acceptance of the introduced traffic measure and for the tested technical system was evaluated with a quantitative online survey. The general concept for the acceptance survey was developed based on previous findings related to acceptance for driving assistance and speed assistance systems and more broadly acceptance for traffic measures to increase traffic safety and avoid speeding. Furthermore, we included relevant findings about the acceptance, impact and effects of ISA systems to derive the topics and concept for acceptance evaluation.

There were several prerequisites that influenced the development of the concept and the design for an appropriate measurement instrument for the acceptance evaluation. The first pre-condition was the small number of participants in the use case study (max N=20). The second pre-condition is the requirement to test and compare two different technical ISA solutions within the use case. The third pre-condition is that in our geofencing use case, acceptance is actually related to at least three different aspects – firstly, the use of a specific retrofitted ISA system variant, secondly, a specific traffic safety measure, i.e. the implementation of speed limits that are lower than the officially speed regulation, and thirdly, the application of geofencing as a tool (for an authority) to implement the regulation. In the survey we aimed to disentangle and evaluate the different aspect of the introduced measure.

As a proxy for acceptance of the specific retrofitted ISA system we used the preference ratings for using the retrofitted ISA system, the preferences for using one of the two tested ISA system variants as well as the intentions for its future usage. To assess the other two aspects (speed limits and geofencing), the survey included several judgements focusing on the perception and understanding of geofenced zones and geofencing as a tool for authorities as well as the perception and acceptance for the speed limits.

Theoretical accounts of acceptance often conceptualize attitudes as precursor of acceptance (see e.g. Ajzen 1985). Attitude is most often associated with some evaluative affect toward a target behaviour or some particular entity (Davis 1986). A standardized instrument for attitude measurement in the context of driving assistance systems already exist (simple acceptance scale, see van der Laan et al., 1997) and has been used also in other application contexts. The scale uses eleven bipolar adjective item pairs to measure the meaning the utilitarian and hedonic response aspects towards an attitude object. We plan to use the scale to assess attitudes towards the two ISA systems variants and for the lower speed limits. Attitudes toward the two ISA variants would allow us to compare the two ISA systems variants directly. Attitudes towards speed limits in zones will allow us to evaluate whether these judgements will change due to the experience in the use case.

Literature on the acceptance related to driving assistance functions has acknowledged a wide range of factors that influence acceptance (Vlassenroot 2011). The most important factors are often **ease of use** and usability of a system as well as its **perceived** effectivity or **usefulness** (e.g. Stiegemeier et al. 2022). Another important factor is **trust** (see Stiegemeier et al. 2022) which may relate to reliability and validity of systems behaviour, information and function but also data privacy and security, or the trustworthiness of included stakeholders providing the service. Acceptance or rejection of ISA and speed limitations is often also related to the perception of certain **risks**. These may on one hand relate to traffic situations that occur when using the system and that may affect traffic safety perceptions (Blum & Eskandarian 2006, Lai et al. 2007, for overview see Ryan 2018). Other risks may be related to job performance as time loss or safety of transport (Pawar et al. 2023). In addition to problems with the ease of use, traffic-related risks and negative expectations of job performance can have a negative impact on workload (Pawar 2023, Ryan 2018), for example by increasing time pressure or requiring more attention and cognitive load while driving.

Moreover, additional information will be assessed to get a better understanding about the sample of participating drivers including their prior opinions and attitudes about traffic safety and speeding, their prior experiences and opinions of ISA systems, their expectations concerning efficiency and effectivity for the planned traffic measure and their intentions to use the system and comply with the introduced regulation during the use case.

The above mentioned aspects were planned to be collected with a survey accompanying the different phases in use case study. The initial plan for the survey can be found in Table 2.

Table 2: Content and constructs to be measured with the online survey across the four planned measurement time points (column 1 to 4) and content of online-survey of the final survey after finishing the study (column 5)

Pre-study	**After Baseline**	**After Informative ISA**	**After Mandatory ISA**	**Updated plan for final survey Mandatory ISA**
Demographics	Inbuilt ISA use	Inbuilt ISA use	Inbuilt ISA use	Usefulness
Speeding offences	Workload	Workload	Workload	Workload
Driving style	Risky traffic situation	Risky traffic situation	Risky traffic situation	Ease of use
Problem awareness	A-priori attitude towards speed limited zones (simple acceptance scale)	Retrofitted ISA Use	Retrofitted ISA Use	Perceived Risk/Anxiety
Attitude about Speeding		Usefulness	Usefulness	Trust
Attitude about Safety		Ease of Use	Ease of Use	Perceived risky traffic situations
ISA Use prior to the study		Trust	Trust	Preference of use for ISA retro-fitted ISA
Attitudes towards ISA		Perceived Risk/Anxiety	Perceived Risk/Anxiety	Acceptance for geofenced zones, geofencing and speed limits
Expected efficiency		Attitude for informative ISA (simple acceptance scale)	Attitude for mandatory ISA (simple acceptance scale)	ISA usage during the use case
Expected effectiveness			Preference retro-fitted ISA	Malfunctions
Attitudes to lower speed limits			A-posteriori attitude towards speed limited zones (simple acceptance scale)	Study organisation
Self-efficacy retro-fitted ISA			Attitudes toward geofencing	
Use Intention				

3.6.2. Survey procedure

The plan for the acceptance survey included data collection at four time points along the use case study implementation: a pre study survey and a survey at the end of each study phase (baseline, informative ISA, mandatory ISA). For each data collection, a questionnaire was designed and implemented as online survey with the tool LimeSurvey. Table 2 (column 1 - 4) summarizes the contents and constructs that were planned to be measured at each time point of the survey. Some constructs were planned to be measured at several time points to investigate changes and differences across the course of the study (e.g. work load, perceived traffic risks, usefulness, ease of use). It was possible to fill the survey by smart phone or with regular PC/Laptop. The survey had to be filled by the participating drivers. The operational managers at the participating transport companies assured that drivers had enough time to complete the surveys during breaks during their work hours.

Required adaptations during the use case

However, as described in the chapter 3.3., the study could not be completed as originally planned due to technical problems with the equipment. Furthermore, we also experienced a low response rate at the beginning of the survey in both the pre-study and the baseline phase. Only about half of the participants filled the questionnaires, often delayed and only after repeated reminders to do so. To address both problems, it was decided to adapt the survey with the aim, to increase response rate and to focus on information related to problems with the ISA system and the reported malfunctions of the system. Some aspects that were initially targeted in the concept had to be removed from the survey, to limit number of questions and the amount of time to fill the questionnaire. Therefore, only one final survey was conducted at the end of phase 3 (mandatory ISA). The survey planned after the informative ISA phase was removed. Table 2 (column 5) summarizes the constructs collected within the survey after the mandatory ISA phase. In the final survey some questions had to be framed slightly differently, depending whether they targeted at participants from the small group of drivers that finally used the correctly working mandatory ISA system or to the group of remaining participants (the main difference was, that in the mandatory ISA group specifically asked for experience in the last two weeks of testing, while remaining drivers (faulty system set-up) were asked for their experiences during the past weeks more generally). A drawback of the updated survey procedure was, that a direct comparison between the two ISA versions was not possible any more. However, due to the technical issues (and hence the long time lag between testing both ISAs), such a comparison would be biased and not very valid anyway. Moreover, to learn about the impact and participant’s experiences related to the technical problems, additional questions were included about how the ISA system was used in the study and what kind of malfunction occurred when using the system. Also, some questions about the study’s organisation were included.

4. Results

4.1. Driving data analysis

4.1.1. Number of zone trips through zones

As described above each geofenced area resulted in several distinguishable zone segments. Firstly, because a geofenced area can (in terms of assigned speed) consist of several distinguishable zones itself and secondly, for each road entering in one of the geofence zone a distinguishable zone identifier was created by the system in the data set. Altogether, this resulted 117 distinguishable zone segments for the 23 zone areas.

Over the course of the study phase (baseline, informative ISA, and mandatory ISA) altogether 3240 trips through zones were recorded form the participating drivers. Of that 2738 contained valid driving data. Table 3 shows number of valid trips through zones for the three study phases. Furthermore, table A1 in the appendix shows distinct numbers of trips for each distinguished zone identifier in the dataset. As can be seen in this table, not every zone has been passed through in every study phase and by every driver and some zones did not provide any valid data for analysis at all.

Table 3: Number of zone segment visits in each study conditions.

	Study Phase		
	BL	inf ISA	mand ISA
Number trips through zones	1181	999	558

Table 4 depicts the percentage of samples above the zone speed limits for each study phase and zone speed limit when unrestricted driving was possible (vehicle speed is at least 10 km/h or higher than 20 km/h below the zone speed limit). Data from all drivers is accumulated. Altogether, the values for mandatory ISA condition show a lower amount of speeding when passing through a zone.

Table 4: Percentage of speeding above zone speed limits for different speed limits in the three study conditions

Zone Speed Limit		Condition		
		BL	inf ISA	mand ISA
20	N_{valid}	920	615	444
	$N_{speeding}$	198	97	31
	$\%_{speeding}$	21.5	15.8	7.0
30	N_{valid}	6453	7219	3323
	$N_{speeding}$	1487	2711	194
	$\%_{speeding}$	23.0	37.5	5.8
40	N_{valid}	9036	5505	4463
	$N_{speeding}$	1214	762	311
	$\%_{speeding}$	13.4	13.8	6.9
50	N_{valid}	6225	4173	3447
	$N_{speeding}$	2096	970	682
	$\%_{speeding}$	33.7	23.2	19.8
70	N_{valid}	3216	2628	297
	$N_{speeding}$	1044	826	52

$\%_{speeding}$	32.5	31.4	14.9

Additionally, we also checked the amount of speeding when compared to the official speed limits for within zone driving during the baseline condition. We found that speeding occurred in 11.7% of data sample. Speeding occurred more frequently in the three seconds after entering and before leaving a geofenced zone (19%) as compared to all other sample while driving in the zone (9%). Furthermore, speeding also occurred more frequently on roads with a higher speed limit >50kmh (28%) compared to roads with lower speed limits (9%). Excessive speeding (i.e. 10 km/h more than the official speed limit) occurred in 2 % of data samples.

4.1.2. Average speed (Mean deviation from zone speed limit)

As outlined above, number of participants varied in the three test conditions. Therefore, the primary statistical analysis was performed by pairwise comparisons of the conditions to include data from as many as possible participants. Figure 6 shows the mean and error bars for the conditions in the three comparisons for the parameter *mean deviation form zone speed*. The average speed is in all conditions below the zone speed limit (about -4 to -4.8 km/h). The statistical analysis revealed no significant difference in this parameter between the Baseline and the informative ISA condition (one-sided test, t = 0.1284, df = 11, p = 0.545), no difference between baseline and mandatory ISA (one-sided test, t = 1.48, df = 4, p = 0.107) and no difference between the informative and mandatory ISA condition (two-sided test, t = 0.733, df = 5, p = 0.496).

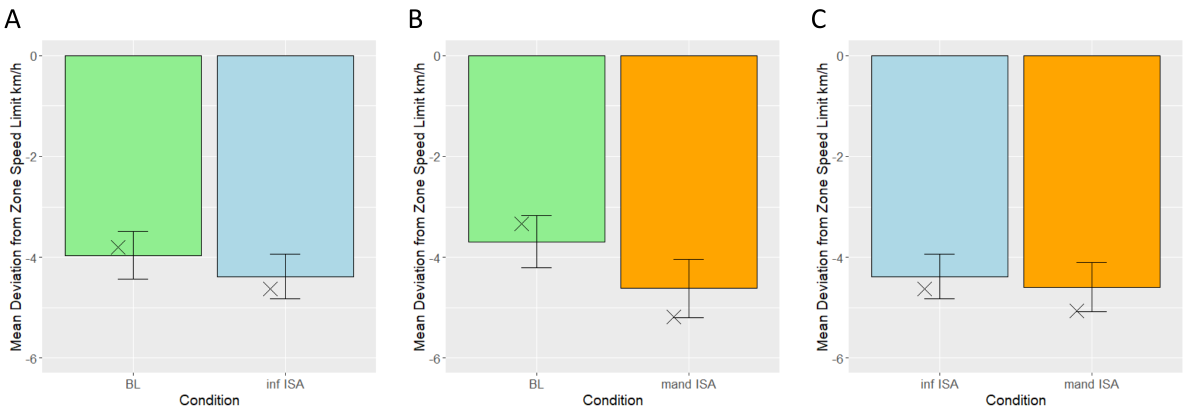

Figure 6: Bar plot of the mean deviation from zone speed limit for A) the comparison between BL and inf ISA, B) the comparison BL and mand ISA, and C) the comparison between inf ISA and mand ISA. The "X" in the figure denotes the mean, if data from all participants and zones in the condition are included. The error bars indicate the standard error of the mean.

4.1.3. Percentage of speeding

Figure 7 shows the results of the analysis for the parameter percentage time speeding. Again, mean value and error bars for each study condition in the three comparisons are depicted. The statistical analysis revealed no significant difference for this parameter between the *Baseline* and the *informative ISA* condition (one-sided test, t = 0.13, df = 11, p = 0.55), but a difference between baseline and mandatory ISA (one-sided test, t = 3.23, df = 4, p < 0.05). The test for difference between the informative and mandatory ISA condition failed to reach significance (two-sided test, t = 1.55, df = 5, p = 0.09).

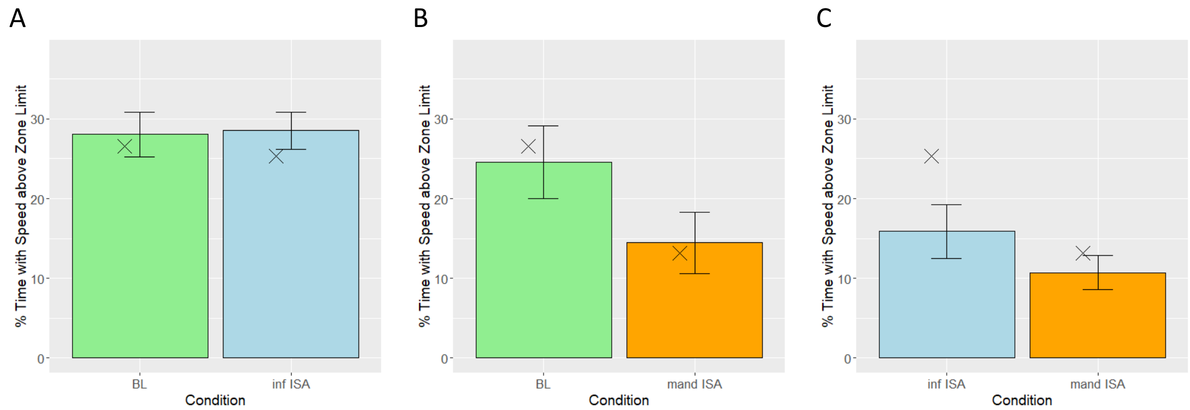

Figure 7: Bar lot of the percentage of time speeding above zone speed limit within zone for A) the comparison between BL and inf ISA, B) the comparison BL and mand ISA, and C) the comparison between inf ISA and mand ISA. The "X" in the figure shows the mean values if data from all participants and all zones in the condition is included, for comparison. The error bars indicate the standard error of the mean.

4.1.4. Descriptive analysis of speed when entering and leaving a zone

The previous analysis focused on all data while passing through the zone. More specific information on the effect of the speed reduction may be available from the analysis of the short periods when entering and leaving a zone. This post hoc exploratory analysis was motivated by single case analyses of zone driving, which revealed that speeding often was apparent when entering and leaving a geofence zone. For that purpose, we analysed the speed in a short time window (5 seconds) directly before entering and after leaving a zone, and for the first and last four second within zone driving. The analysis was performed for each zone speed limit separately. Statistical comparisons cannot be provided, since data is not available from every driver in every condition. Instead of mean values we calculated 75% quartile values (splits off the highest 25% of speed values from the lowest 75%). Figure 8A provides a descriptive illustration of the results. For all zones the average speed (Mean of 75%-quartile values) was near the zone speed limit. Differences between the study conditions were most pronounced for the 50 km/h zones especially when leaving a zone, with lowest speed for the mandatory ISA and largest speed for the baseline conditions. Also note, the same level of speed in the mandatory ISA condition before leaving the zone, which indicates that the automatic speed limitation prevented the drivers from going faster than the zone speed limit. A difference between the mandatory ISA and the other two conditions is also observable in 70 km/h zones but data here is based on a small number zone passages only, especially for the mandatory condition.

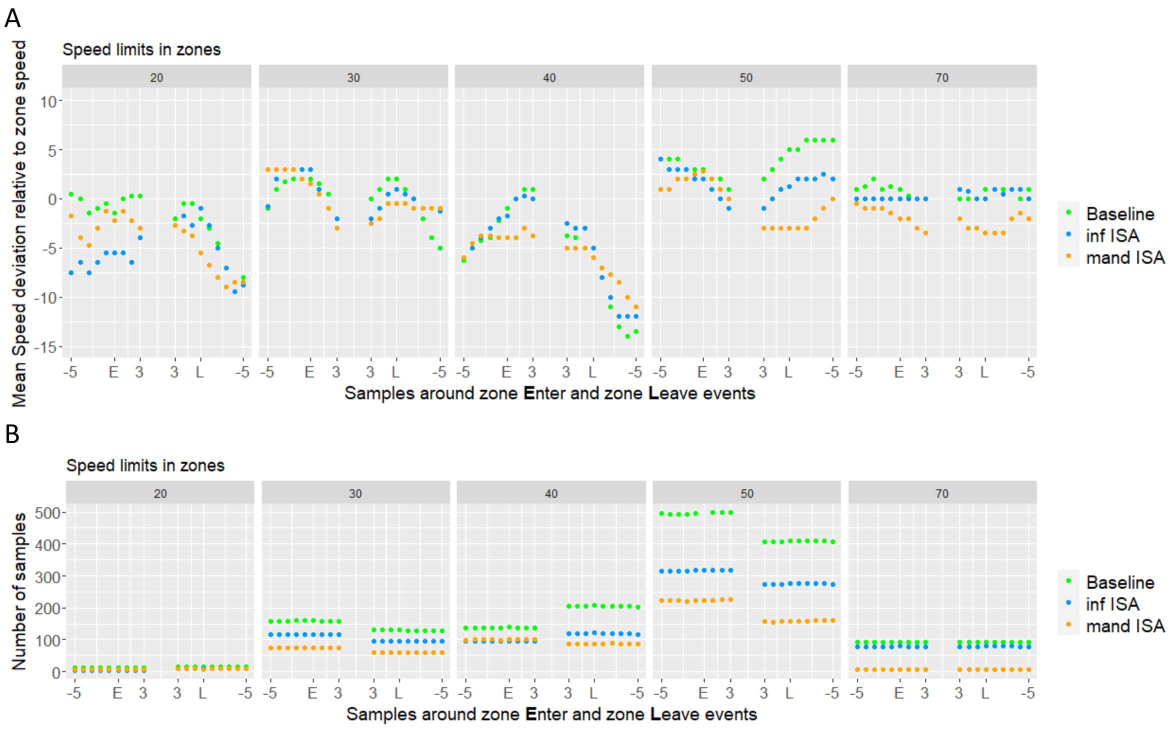

Figure 8: Speed relative to the zone speed (mean of 75%-quantile) shortly before and after entering and leaving a zone, separated for the different zone speed limits and for the three study conditions (A). The x- axis denotes consecutive data samples before entering (E) and leaving (L) a zone. Panels B shows numbers of samples that were available for this analysis.

4.1.5. Outside Zone Driving analysis

Analysis of driving data outside zones was performed in order to investigate the question, if stricter speed limits in some zones will lead to more extensive speeding outside zones in order to compensate for lost time within the zones. To do that we analysed the speed of driving episodes of 1-3 min length directly after leaving a geofence area. On these short driving episodes, drivers may have used routes including roads segments with different regulated speed limits. Therefore, we calculated the speed and speeding parameters for the different regulated speed limits separately.

Table 5 summarizes the results of that analysis. It shows the average (mean) speed on road segments with different regulated speed limits for the three study conditions. Mean speed values are fairly equal across the study conditions, apart from 30km/h road segments, where the speed was higher in the mandatory conditions. However, for that particular condition only data from one subject was available.

To statistically test for differences between the conditions we performed pairwise t-tests in a similar fashion as for within zone speed analysis (i.e. BL vs inf ISA, BL vs mand ISA and inf ISA vs mand ISA), but separately for the different regulated speed limits. None of the pairwise comparisons reached significance, that means there are no statistically significant differences in mean speed for outside zone driving between the three study conditions.

Similar results were also found for the parameter *percentage time speeding* (see

Table 5). The analysis is based on the same data as the mean speed analysis. There were no statistical differences between the study conditions for none of the different levels of regulated speed limit.

Table 5: Mean speed and Percentage of speeding for outside zone driving for road segments with different regulated speed in the three study conditions. Furthermore, the table shows standard deviation of the mean speed values, total number of data samples included in the analysis ($N_{samples}$) and number of participants the data was derived from ($N_{subject}$) for comparison.

	ISA condition		
Regulated speed limit on road segment	**BL** *Mean speed [km/h] (SD)* *Percentage Speeding* $N_{Samples}$ $N_{Subjects}$	**inf ISA** *Mean speed [km/h] (SD)* *Percentage Speeding* $N_{Samples}$ $N_{Subjects}$	**mand ISA** *Mean speed [km/h] (SD)* *Percentage Speeding* $N_{Samples}$ $N_{Subjects}$
30	23.3 (2.37) 18.7 % 203 8	26.6 (3.30) 31.9 % 210 6	36.6 (-) 87.5 % 24 1
40	38.5 (1.42) 45.6 % 313 6	34.3 (1.85) 29.5 % 428 6	33.0 (1.92) 15.3 % 332 4
50	43.2 (1.05) 19.0 % 27973 14	42.7 (0.93) 17.4 % 25620 13	43.0 (0.76) 17.4 % 6966 6
60	55.8 (2.46) 26.3 % 3889 13	55.8 (2.56) 29.6 % 2463 11	55.4 (2.18) 20.2 % 988 6
70	63.5 (1.84) 15.3 % 19245 14	62.9 (1.09) 14.1 % 17349 13	63.2 (0.99) 15.0 % 2719 6
80	73.3 (2.88) 12.4 % 3832 12	74.6 (2.02) 15.5 % 2243 10	76.1 (2.57) 13.7 % 523 5

4.2. Acceptance questionnaire analysis

As reported in chapter 3.1. there were several challenges during the execution of the use case, that required various adjustments in the procedure and the implementation of the acceptance survey compared to the original research plan. Major restrictions were a **lower than expected number of participants** taking part in the use case, **an even lower response rate in the prepared online surveys** and technical difficulties particularly in the phase testing the mandatory ISA system postponing its execution by almost two months and further restricting the number of participants taking part in this study condition.

Due to these limitations, we could collect fewer than expected responses for the acceptance evaluation. The initially planned comparison of survey responses for the informative and mandatory ISA system could not be performed. Due to a low response rate in the beginning (pre-study and baseline survey), we decided to collect the information about the two ISA system versions at the end of the study in one final survey. However, because of the long delay resulting from technical problems, the planned direct comparison of the two ISA versions was not possible anymore, since we expected a strong bias in the response (firstly, because of the experience of technical problems with the incorrect installed mandatory ISA system and secondly, due to memory effects, since the informative ISA phase had been started three months before the final evaluation). In the end, **8 participants** took part in the **pre-study survey**, 7 **participants** took part in the **baseline** survey and **8 participants** took part in the **final evaluation** (3 of them were from the small group with the corrected mandatory ISA installation in the vehicles).

Participants that filled the final evaluation survey had a two-month long experience with a system that did not work properly and for which the automatic speed reduction function either did not work at all or worked unreliably, and which could have been overridden easily by using the vehicles cruise control, which should not have been possible.

4.2.1. Results of the pre-study survey

The main aim of the pre-study survey was to understand, who the participants in the use case are and what prior experiences, attitudes and opinions they had about traffic safety, speeding and ISA systems. Furthermore, we were interested in what they thought and expected about the traffic measures that were going to be introduced during the use case and what their prior intention towards using the system and complying with the speed limits was.

Eight participants filled the pre-study survey (1 female and 7 male). All of them were from the same company. Further description of the sample is provided in section 3.2. (study sample).

Concerning their **driving style** most respondents judged their speed as being similar when comparing it to the general traffic flow, one judged it as slightly faster and one as slightly slower. Except one, all participant rated their driving style as not having safety issues. "The freedom how to drive" seems not to be a major source of their job satisfaction, since all but one participant had either disapproved with that statement or had a neutral opinion. Only one participant reported to have been fined for speeding within the past three years. When asked about *whether speeding is a problem among drivers in their company* a majority (n=4) did neither agree nor disagree, but two participants each agreed or disagreed with the statement.

There was a strong consent among the participants related to statements on **problem awareness** concerning passenger's safety and comfort. They all agreed that *passengers feel always safe and comfortable during the trip* and that *ensuring passenger's safety is the most important part of the job duty*. In turn, all disagreed that *passengers sometime complain about the driving style* or *are worried about their safety because of the driving style*.

On average, participants also expressed agreement with the seven statements that focused on compliance with speed regulation and speed limits (**attitude to speeding**). Similarly, statements about **attitudes towards traffic safety** were answered in a way, that suggests agreement with behaviour supporting traffic safety. Only two items about stricter speed regulations *(I would be happier if the speed limits were more strictly enforced* and *On my tour, there are places that are particularly critical in terms of road safety and where I would suggest to have lower speed limits than the current ones*) received a somewhat less agreement, but in average still a neutral evaluation.

All vehicles in the use case were already equipped with an in-built ISA system. Therefore, we asked for the **previous usage and experience with ISA** systems. Only two participants reported to use the in-built ISA system, one on a daily basis and another participant on a more selective basis (using it in city regions with 30/50 km/h speed limits). Only one driver had an ISA system in a private vehicle and used it to comply with speed in 30/50 km/h zones (Note, this was also the only participant who reported to have been fined for speeding).

Since only a few respondents reported prior practical use and experience with ISA systems, the complete set of statements about the **expected usefulness** for an **ISA** system was answered only by a fraction of the participants (N=5). Taken together (across all items that covered the aspects of the expected usefulness of an ISA system), we observed a rather neutral evaluation, i.e. on average the participants did not expect a particular usefulness of an ISA system for improving road safety and compliance with speed limits. Of course, some statements about usefulness were rated more positively than others. For example, there was strong agreement that an ISA system could prevent speeding tickets. And there was some agreement that ISA systems can help to improve road safety and ensure that people obey existing speed limits. However, only a few agreed that ISA reduces the need to look at the speedometer or speed signs, or allows to pay more attention to other road users, or that an ISA system can help make driving more relaxed or comfortable.

Regarding **expected effectivity** of the to be introduced traffic measure (geofencing-based retrofitted ISA system to support speed limits in zones), the participants reported on average a tendency for approval for the related statements, all at a similar level. However, one participant strongly disagreed with all statements, i.e. did not expect the measure to be effective. Due to the small sample size, this had an overall negative effect on the effectivity expectation. Overall, there were four participants who expressed a neutral or negative expectation and another four who expressed a more positive attitude.

Expected efficiency was measured with three items. Overall respondents reported a neutral rating. But the statements were rated somewhat differently. While the statement on *whether other measures would not be better suited to achieve the desired traffic safety goals* received a neutral rating, respondents expressed higher agreement to the statement *that traffic safety in geofenced zones could only be improved if most or all road users had to comply*. Otherwise, respondents slightly disagreed that *Geofences are a good method to implement temporally limited or vehicle/user selective speed limits.* On an individual level, three respondents tended to question the efficiency assumption and only one had a more positive attitude towards it.

Regarding their **attitude towards additional speed limits in zones**, participants also expressed neutral opinions. Neither negative nor positive aspects associated with additional speed limits found explicit agreement. However, on an individual level, there were two respondents who indicated a rather negative attitude towards additional speed limits, while all others expressed a neutral or slightly positive attitude.

The statements about **self-efficacy expectation** with the system (being confident to use the system with or without help) were rated rather neutral. Two respondents each expressed a slightly less or more favourable opinion regarding existing competencies and expectation of being able to use the system independently, all others held a neutral position.

Five statements were used to explore the **intention to use** the system and to comply with the speed limits. There was an overall tendency among the participants to agree to the statements indicating an intention to comply with the measure. Four of the participants expressed in average a clear agreement to the statements (>="agree" across the five items), four other participants had a more neutral opinion. The item that received the strongest agreement was *During my professional driving, I intend not to exceed the speed limits recommended by the retrofitted ISA system, even when I am in a hurry.*

4.2.2. Survey after baseline condition

This survey was supposed to be filled at the end of the three weeks driving in the baseline condition (installed and activated ISA system but geofenced zones not activated). The invitation for the survey was sent to the STS company managers at the start of the last week of the baseline phase. However, none of the participants filled the survey in the suggested time window until end of the baseline phase. Only after repeated reminders in the two subsequent weeks the survey was finally filled by seven respondents. However, due to the delayed response, all participants already had some days of experience with the informative ISA system.

We will here therefore only report the answers provided for the scale measuring attitude towards the speed limits in zones. The scale uses nine items to measure the subcomponents usefulness and satisfaction. A five-point Likert scale from -2 to +2 was used (low usefulness/satisfaction to high usefulness/satisfaction). The average rating for the five items measuring usefulness was M = 0.22 and the average rating for four items of the satisfaction scale was M = 0.25. Since these mean values are close to the *neutral* point of the scales, this suggests, that the participants had no particularly positive or negative attitudes concerning usefulness or satisfaction towards speed limits in zones.

4.2.3. Results final acceptance survey

The final acceptance evaluation was performed within the four weeks after finishing the mandatory ISA phase (07.12.2022). As before, several reminders were necessary to motivate participants to fill the survey. Finally, eight participants provided their feedback. Three of them were part of the small group whose vehicles received a reinstallation of the mandatory ISA system (henceforth mISA). The remaining respondents belonged to the group where the mandatory ISA system did not work properly (fISA).

Predictors of acceptance

Perceived usefulness (PU) of the system was measured with 12 items related to driving, safety, speeding, and job-related aspects of work. Respondents had to rate if the quality of the PU-aspects had changed within the past (two) weeks compared to a normal driving situation. Answering format was a five-point Likert scale using the anchor terms *worsened a lot = 1, worsened = 2, stayed the same = 3, improved =4, improved a lot = 5*. On average, respondents reported a slight tendency towards improvement when using the system. Four participants reported a tendency toward improvement (the individual mean with the most positive rating was 3.9 - i.e., on average, this participant judged PU-aspects as "improvement" during past two weeks of driving), the remaining four other participants reported a neutral opinion ("neither improvement nor worsening") or reported a slight tendency toward worsening (two each). The PU-aspects that showed on average the least improvement were the items *traffic interaction with other road users* and *freedom/autonomy while driving* - both received a neutral rating on average (3). For both aspects, 2 and 3 participants, respectively, reported having experienced a worsening. The aspects for which the greatest improvement was reported were *passenger safety*, *safety of driving in the zone*, and *compliance with speed limits in the zone*. The largest variations in judgments were observed for the items *traffic interaction with other road users*, *compliance with speed limits in the zone*, and *freedom/autonomy in driving*. The tendency for a slight improvement of PU aspects was evident in both subgroups of drivers (mISA, fISA).

The **workload** scale asked with five statements for the change in workload experienced when using the retrofitted ISA system compared to a situation before the introduction of the system. On average, participants reported a slightly reduced workload and this was also true for each of the five items individually. The mISA group reported on average slightly more workload (3.0) than the fISA group (2.64).

Ease of use was measured with 12 items using a five-point Likert scale answering format with the anchor terms (1 = *strongly disagree*, 2 = *don't agree, 3 = neither disagree nor agree, 4 = agree, 5 = strongly agree*). Overall, there was a tendency to disagree with ease of use for the ISA system. The fISA group reported on average higher disagreement (average all items M = 2.5) regarding *ease of* *use* compared to the mISA group (average all items *M* = 3.0). Driving with the correct installation of the ISA system was thus accompanied by an improved evaluation, but only to a limited extent and not yet generating a positive trending response towards ease of use.

The highest disagreement was reported for the statement *charging the system's battery was easy* (*M* = 1.8). This is related to the wrong USB charging cable installation, which caused problems for charging the tablet during driving. Only two participants reported a neutral or positive opinion for this statement. In contrast, in addition to *learnability*, two other statements about how the tablet worked (*installing the tablet was easy* and *I always knew if the tablet was properly inserted in the bracket*) received the most positive ratings among the usability items, indicating that participants at least assumed they knew how to properly install the system in the vehicle and were able to judge when the tablet was not properly inserted in the bracket.

Furthermore, the participants tended to disagree that the GPS accuracy of the ISA system was already working well enough. Inaccurate GPS signals will cause faulty detection and warnings for geofence zones (which happened infrequently, see below). Participants also disagreed that *overriding the automatic speed limit function* was easy. Surprisingly, the ratings were similar in the mISA and fISA group although overriding the automatic speed limit (by flooring the accelerator pedal briefly) only worked in vehicles with correct installation (mISA group), and only this group had the chance to experience it in the intended way. However, drivers from the fISA group also had the possibility to override the automatic speed limitation by activating the vehicle's cruise control function. Indeed, overriding (by flooring the accelerator pedal) was inspected only rarely in the data (less than 10 times in the mISA group). In summary, responses for this question may suggest that overriding the automatic speed limitation function have been experienced as equally inconvenient in both mISA and fISA subgroup.

Perceived risks were measured with 5 items using a five-point Likert scale answering format with the anchor terms (1 = *strongly disagree, 5 = strongly agree*). Overall, participants tended to disagree with the risks described in the statements. The fISA group tended to express concerns about risks somewhat more often compared to the mISA group (*M* = 2.7 vs. *M* = 1.8). This group difference exists across all statements. Noteworthy, compared to other scales reported above, the difference between the groups is much more pronounced.

Trust in the system was measured with 5 items using a five-point Likert scale answering format with the anchor terms (1 = *strongly disagree, 5 = strongly agree*). On average, participants tended to disagree with the trust statements, indicating a lack of confidence in the technology. Lowest trust was expressed for the *behaviour of the system* (*M* = 1.9), its *functioning* (*M* = 2.0), and the *data security of the system* (*M* = 2.0). Overall, the mISA group expressed slightly greater trust in the system than the fISA group.

Various studies related to effectiveness and acceptance of ISA system have also reported possible side effects of ISA on the (driving) behaviour of users and that of other traffic participants. The occurrence of these side effects was also addressed in the current survey. Nine statements were used to assess the frequency of **occurrence of various safety-critical behaviours in traffic**. A three-point response scale was used to estimate the occurrence of the behaviour (less often - equally often - more often) compared to the situation before the use of the ISA system. Overall, the analysis showed that the named risky situations tended to occur less frequently compared to a comparison period before. The fISA group reported a slightly lower frequency of occurrence than the mISA group, which tended to believe that situations occurred just as often. Across all nine items, it occurred 6 times in the mISA group that a safety-critical behaviour was reported as occurring more often, compared to only 3 situations in the fISA group. Tailgating and risky overtaking by other road users stand out slightly, as they were each mentioned by two of the three participants in the mISA group.

Acceptance and intention of use for ISA systems

Regarding the preference for future use, four participants did not want to use either system and two each chose the informative and the mandatory system. *If the current system were to remain in the vehicle*, this would be acceptable for three participants, little or unacceptable for three others, and two had a neutral opinion. *If the system was better integrated with existing assistance systems in the vehicle*, at least four of the participants would accept it, but three would still disapprove it. At least four participants found it very or somewhat acceptable that the system automatically regulates speed in zones. Only two participants found this somewhat or very unacceptable. Based on these statements a clear tendency for acceptance of the system could not be identified in either of the two groups, as both agreeing and disagreeing answers were found across all statements.

Approval for geofence zone location

Participants were also asked about, whether they were able to recognize objective reasons for setting up geofence zones and about their understanding of the reasons for establishing them. For both statements, the majority of the respondents disagreed, that *they could always see a good reason (e.g. a nearby school) why geofenced zones were set up at that location*, nor that *they understood why lower speed limits were set for some of the geofenced zones.*

Furthermore, regardless of group membership, participants slightly disagreed that the *geofence zones were in places where it would be helpful for improving road safety* and that *they thought there was a particular risk for accidents in the places in question*.

Acceptance for speed limits

We also asked respondents about their acceptance for different speed limits (equal, 10 km/h less, or 20 km/h less) as a function of the regulated speed limit imposed on the road (>= 60 km/h vs <= 50 km/h). In general, acceptance for speed limits was slightly higher on >= 60 km/h roads compared to roads with slower regulated speed. However, the best acceptance was obtained for speed limits equal to the regulated speed on <=50 km/h roads. In contrast, additional speed restriction on slower roads received the lowest acceptance ratings.

Speed limits in geofence zones were rated as a good method *if as many road users as possible had to comply with these rules*, although the information provided by the mISA group indicated that it might also be acceptable if only some, i.e. specific vehicles and road users, had to comply. When asked about the personal benefit of speed limits in geofence zones, participants rated this as a slight advantage on average.

Usefulness for geofencing technology

Four questions were used to assess the usefulness of geofencing technology for authorities.

A slightly agreeing opinion was expressed by both groups with regard to the statement that *geofences are a good method to implement temporally limited speed limits in areas with risks or road safety concerns*.

All other items received less agreement. Participants slightly disagree that *geofences are a suitable tool for authorities to increase traffic safety in a flexible and dynamic way* and that *geofences are a good way to implement speed limits for specific vehicles or groups of road users (taxi services, public transport, goods and delivery traffic) in areas with risks or road safety concerns.* The latter item was in particularly viewed with scepticism in the fISA group, where four participants stated that they did not agree. This negative view is also present in the fourth item, were respondents also slightly agreed that *geofences are just a means for the authorities to patronise and hassle motorists even more*.

Usage of pre-installed vehicle assistance systems and retrofitted ISA

Several questions were used to understand how preinstalled assistance function and the retrofitted ISA system were used and what problems and errors or incidents were experienced during the use case period.

Four respondents reported that the vehicle's pre-installed ISA system was used most of the time or all the time and each two reported to use it occasionally or never use it at all. This is in contrast with the information form the pre-study survey, where only two respondents reported an active use of the ISA system for professional driving. We suspect that the question was misunderstood by some participants and that their answers did not refer to the pre-installed ISA but to the retrofitted ISA.

A second item was about the use of pre-installed speed limiters (cruise control) during the study period. All respondents used the speed limiter, (6 x occasionally 2 x either often or all the time). Almost all reported to apply the speed limiter manually.

When asked how often the retrofitted ISA was switched off during the study period, five respondents reported they had turned it off at least once or several times (three respondents selected *did not turn off the ISA system*). Two reported turning off the ISA system for breaks during work hours, but three chose reasons related to ISA functionality (*ISA did not work*, or because of *negative influence on driving*). One respondent also reported being *distracted by the system's information*.

We also asked how often the respondents had forgotten to switch on the system at the start of the shift or after breaks. Four reported that this had happened but only a few times.

Five respondents reported to turn down the volume for auditory warning messages of the ISA system at least occasionally, but all three respondents from the mISA group stated not having changed the volume.

Most respondents (n=6) only occasionally looked at the ISA when auditory warnings were issued, but two did it more often (1 x often and 1x most of the time). Most (n=5) of the respondents reported to look at the ISA to check the assigned speed for the zone only occasionally (2 x often, 1 x never).

When asked how often respondents experienced the retro-fitted ISA system actively limiting the vehicle's speed within geofenced zones, only one reported that it never happened, five reported an occasional experience and two reported it to have happened often.

When asked, *how often respondents had tried to drive faster than the suggested speed limit within a zone*, two reported that they did not do so, five did it occasionally and only one reported it to happen often. Time pressure, a not working speed limiter, a too high speed when entering the zone, or requirements of the traffic situation were selected as reasons for driving faster than the zone speed limits.

Problems and malfunction of the retrofitted ISA system

We also assessed problems and malfunctions of the ISA system by asking how often the described problems had occurred during the past weeks. That the *ISA system suggested a higher speed limit than was officially allowed on the road* was reported by four respondents to happen a few times, (remaining answers: 2 x never, 2 x don't know). That *the same road section was sometimes displayed as a zone and sometimes not as a zone* was experienced by four respondents (3 x a few times, 1 x several times, 2 x never, 2 x don't know). That *the system showed a zone warning on a road that led close a zone but did not belong to it* was experienced by five respondents (3 x a few times, 2 x several times, 1 x never, 2 x don't know). That *the maximum achievable speed was often significantly lower than the specified speed limit in the zone* was experienced by three respondents a few times (remaining answers: 3 x never, 2 x don't know). Unspecified hardware/software problems or malfunctions of the system were reported by almost all respondents (4 x a few times, 1 x often, 2 x almost every day). That *the geolocation detection (GPS) of the system stopped working or was highly inaccurate* was reported by five respondents (3 x few times, 2 x almost every day, 1 x never, and 2 x don't know).

Study organisation

The last part of the survey was related to question about the organisation and procedure of the use case study. These questions were added to explore possible reasons for low participation in the survey. Five respondents felt that the information given at the beginning of the study about the aim, content and procedure of the study was not sufficient and comprehensible. Furthermore, five respondents replied that they did not feel well informed about the ongoing changes in the study schedule. Four of the respondents would have preferred a more interactive and participatory process for being engaged and informed about the use case study. Five participants reported not having had enough time to fill the survey during their working hours. One respondent reported about technical problems with filling the survey (based on the log files we assume, that this is related to a longer interruption when filling the survey, which caused the loss of the already entered answers). When asked *how strong their personal obligation and responsibility is to take part in a project to increase traffic safety in your area of work,* four respondents replied that they had a strong or very strong obligation, three had a neutral opinion and only one respondent reported a weak obligation.

5. Discussion

The aim of this study is to evaluate the acceptance and attitudes towards a geofencing based retrofitted ISA system among drivers of vehicles of an urban special transport service. To this end twenty-three areas were selected in the urban region of Gothenburg, were the city expected safety risks related to speeding for both transport customers and vulnerable road users. Geofencing was used to define the areas digitally and to assign and enforce stricter speed regulations within them. The speed limit for road sections within the geofenced areas could be either the same or lower (10, 20 or 30 km/h lower) than the official speed limit. The retrofitted ISA was installed to support STS drivers to comply with the assigned speed limits within the geofence zones.

5.1. Driving behaviour

The most direct measure of acceptance is behaviour itself. Therefore, we analysed the driving behaviour (speed and the speeding) of drivers participating in the use case study. For the within zone driving, we analysed two parameters - one parameter describing the average speed (speed difference from the assigned zone speed) and one parameter describing the percentage of time driving above the assigned zone speed limit within zones. Our hypothesis was that both ISA system variants tested can support the driver with adhering to assigned zone speed limits, but based on previous research on the effects of ISA systems, a stronger effect is expected for the mandatory ISA system. Hence, we expected a larger speed difference from zone speed and a fewer percentage of speeding in the ISA conditions compared to the baseline. Furthermore, we expected a stronger speed reduction effect in the mandatory compared to the informative ISA system. However, this effect is only likely to occur if the drivers exceed the assigned speed limits within zones in the baseline condition too. Only then, there will be potential for an ISA system to reduce speeding behaviour.

Concerning our research questions, our data analysis revealed that participating drivers were indeed driving above the speed limit within the zones. It was more prominent for the road segments with an assigned zone speed limit of 50 or 70 km/h (compared to lower speed limits). Furthermore, the data indicates that speeding happens more often when drivers were entering or leaving a zone area. The amount of driving above the assigned zone speed limit was substantial (up to 30% percent of the time) but did not affect all road segments in all zones. Noteworthy, speeding in geofence areas in the baseline phase did also occur with regard to the existing official speed limits, but to a lower extent and severe speeding >10km/h than the limit occurred only rarely (<2%). Nevertheless, our data suggests that speeding is an issue and a retrofitted ISA system might be a way to mitigate speeding by providing better support for drivers.

The analysis for the parameter *percentage of time speeding* within a geofenced zone revealed that speeding occurred in all three study conditions. However, the reported numeric values (e.g. around 28 % for the baseline condition as shown in Figure 7a) have to be interpreted with caution, since we used only data samples from moving vehicles that exceeded a certain speed threshold, to ensure, we were looking at incidences of unobstructed driving. Furthermore, the analysis revealed no statistical difference between baseline and informative ISA condition but a significant lower percentage of speeding for the mandatory system compared to the baseline. There was no statistical significant difference for this speeding indicator between the two ISA conditions.

For the other parameter *average speed difference from zone speed limit* the analysis revealed negative values for all three use case conditions. That means, the average speed was always below the zone speed limit (more than 4 km/h lower). Secondly, the average speed difference within zones was smallest in the baseline condition. Compared to the baseline condition the average speed was about 0.5 km/h lower for informative ISA version and about 0.8 km/h lower in the mandatory ISA condition. However, there was no statistical difference between the baseline condition and the two tested ISA system versions (informative and mandatory).

Taken together, the analysis of both parameters indicates that there was no detectable effect on speed and speeding when drivers were supported by the informative ISA system. In contrast, with the mandatory ISA system, we were able to reveal a significant reduction in percentage of speeding but found no reduction of the average speed compared to the baseline. That is, with regard to our initially postulated research hypothesis 1, we found only partial support. Also, there were no significant differences for both indicators between the two ISA versions. While it suggests that the mandatory system is somewhat effective for reducing speeding and that the informative ISA is probably not supportive to reduce speeding, the study's results are inconclusive whether a mandatory ISA's functions is superior over an informative ISA system. Therefore, based on the present data, research hypothesis 2 must be neglected, since we expected the mandatory system to be more efficient.

An additional analysis provided further insight into the observed effect by looking at the speed when entering and leaving zones. It revealed that the observed speeding is often related to the phases when entering and leaving the zone. The data might also suggest, that speeding was more prominent for zones with a zone speed limit of 40 km/h or higher (see Figure 8) but this could not be tested sufficiently with the presently collected data. However, an explanation for this may be, that many road segments with a zone speed limit of 30 km/h had additional physical speed reduction measures already in place together with a sign posted recommended speed limit of 30 km/h. Thus, in these geofenced areas speeding was less possible and less likely.

Analysis of driving behaviour when leaving a geofenced area showed no differences in average speed or percentage of speeding between the three study conditions. This means that the use of the geofenced ISA system did not lead to unwanted side-effects such as increased speeding to compensate for time lost within the geofence zones. However, as the effect on speeding within the geofenced zones was small at best, there may simply have been no time loss experienced and therefore no need to compensate. Consistent with this, related questions in the survey (time pressure in the workload questions and experience of time loss in the perceived risk question) did not indicate an experienced fear or risk of time loss.

5.2. Acceptance Survey

Our survey focused on three different aspects associated with acceptance in the use case. Firstly, acceptance for the ISA system variants, secondly attitudes for the implemented measure to increase traffic safety (stricter speed limits in geofence zones) and thirdly, attitudes on geofencing as a technological tool for authorities. However, the interpretations and conclusions drawn from this survey are constrained by the small number of participants (N = 8) who filled the survey.

Concerning the direct assessment of acceptance for the two ISA systems we did not find a clear preference among the participants for one of the two ISA variants (25% of the respondents would have continued to use one of the two variants). Rather contrary, 50% would not prefer to use the ISA system, and answers also did not reveal a clear preference to use such a system for professional driving in future or if the system was better integrated with already existing driving assistance functions. Interestingly, automatic speed control function, as the distinctive feature of the mandatory ISA system, was judged as acceptable by half of the respondents. The fact that 50% preferred to use one of the two retrofitted ISA system variants may also indicate an increased willingness to use ISA, compared to the reported usage rate of 25% before the use case for the already installed ISA system. It is possible that this increased willingness is related to the fact that the geofenced ISA in the current use case only provides support (information, warning or speed restriction) in specific geographical areas, whereas a more traditional ISA provides feedback all the time, which could be perceived as distracting or even annoying.

With regard to the acceptance of (stricter) speed limits, responses were also inconclusive. Although some respondents judged speed limits in geofenced zone as personal advantage, a majority did not really understand why stricter speed limits were set in zones. Speed limits in zone were rated most acceptable if they were in line with official speed limits and were rated less acceptable, and tending to be not accepted, if the assigned zone speed limit was lower than that. A majority considered the speed limits only as effective tool to improve safety in zones if most or all vehicle would have to comply with it.

Concerning the implemented geofencing zones, respondents had a rather negative opinions and attitudes. Respondents had difficulty understanding why geofences were set up in certain areas, did not understand why stricter speed limits were set, and tended not to agree that there were traffic risks in the selected geofenced areas or that geofences were useful to improve safety in the zones. Responses to the usefulness of geofencing as a tool for authorities to improve safety where again mixed. Overall, there was a slight trend toward scepticism that geofencing could be a useful tool. Only one aspect, the ability to implement speed limits temporarily, received more positive usefulness ratings than negative ones.

Overall, these judgments are likely to reflect the experiences of respondents during the use case. In particular, the more negative judgments about the understanding and purpose of the geofences may be biased by the experience with one particular geofenced area, which was actually deactivated during the use case (just before the start of the mandatory study phase) because some drivers had complained about it and perceived the speed limits as problematic for driving safety. It was also one of the most frequently visited zones by drivers. Negative experiences associated with driving in this particular geofenced zone may have biased the responses on geofencing usefulness to some extent. In addition, participants may be aware that geofencing technology is not yet available, or is only available in a small number of vehicles on the road, and therefore cannot be easily enforced by the authorities, which limits its expected usefulness under current conditions.

The lack of understanding and appreciation of geofencing might also be due to an insufficient strategy for informing participants about the use case’s aims and objectives. Information was provided to drivers through the operational managers of the transport companies and via an information letter, which included a description of the use case, its aims, content, procedure, a data privacy declaration, and a consent form. However, in the survey, most drivers rated the provided information as insufficient, and half expressed a preference for a more active information format. Therefore, a more participative approach, such as workshops, would likely have been more effective in building knowledge, understanding, commitment, and trust. Unfortunately, privacy restrictions to ensure drivers' anonymity, ongoing COVID restrictions, and a lack of resources and expertise made this impossible in the current case.

Furthermore, the feedback in the ISA system when entering a geofenced zone was rather general and focused on the speed limit. There was no information on the reason and purpose of the geofenced zone, i.e. a school zone, so there was no indication for the driver within the system as to why a geofence was there. It should be technically feasible to include such information in the system, and it would likely be good idea. Designing information for a technical interface of an ISA system to be easily accessible and not distracting is a research and development topic that should be entrusted to usability experts. The lack of an effective information strategy and the failure to provide specific information and feedback on geofences within the technical system have likely hindered a good understanding of the reasons for geofencing. This, in turn, has affected the acceptance, commitment, and compliance of participating drivers.

Additionally, the survey assessed several other influencing factors that can at least partly help to understand the responses and judgments towards acceptance. With 12 questions on perceived usefulness, we assessed how driving with the ISA system affected important driving, traffic, and job-related aspects. In average, respondents reported a slight improvement for these aspects while using the system. Also, respondent's answers indicate a slightly decreased workload. Moreover, our participants did not experience typical risks and fears that were associated with ISA system usage in earlier research projects. However, these reported improvements were marginal and not consistent within the participant group.

On the other hand, the collected responses suggested problems with the ease of use and usability of the ISA system. In particularly, participant's answers indicated problems with correcting or overriding the ISA system, with charging the battery of the ISA tablet computer and with GPS accuracy issues. All these issues have certainly contributed to negative usage experiences during the use case and very likely affected acceptance in a negative way, as has been shown in many previous acceptance studies.

Problems in trust for the ISA system were also evident and related to the perception of reliability for information, functioning and behaviour of the system. Noteworthy, for all three questions on trust only one respondent actually provided a positive rating once. This is supported also by information collected in the survey on problems and malfunctioning. The occurrence of various types of errors was reported by at least 50% of participants, with general tablet malfunctions and GPS inaccuracies appearing to be the most common ones.

Geofencing applications often involve collecting and processing of geospatial location data, which entails also a certain risk that such personal information can be disclosed. Moreover, in the present use case we also collected and processed speed information, i.e. data that may convey a driver's violation of traffic laws. Privacy concerns and data security issues are thus often seen as important aspects that can affect acceptance for geofencing based solutions. Two questions in the survey specifically focused on data privacy and data security. The results indicate that more than half of the respondents reported low levels of trust for data privacy and data security of the system. Taken together, the respondents reported evident restriction for trust and data security/privacy, which may have influenced acceptance.

5.3. Limitations

Several aspects of our use case study implementation limit the generalisability and transferability of the obtained results. During the use case there were technical problems with the ISA system, problems of selection bias and drop out in our study sample as well as with the design of geofencing zones. They will be discussed in detail in the following section.

5.3.1. Technical and technology related limitations

One problem with the technical set up of the implemented ISA system was caused by a wrong installation of the retrofitted ISA in the workshops (see chapter 3.4). This installation error had a serious impact on the function of the automatic speed limiter and the overriding function of the mandatory ISA system. Due to this the automatic speed reduction was working only in few vehicles once the mandatory ISA system was activated and even in these vehicles, the automatic speed limiter could not be overridden as planned by flooring the accelerator pedal briefly. Instead, the automatic speed limiter's function could be stopped by activating the vehicle's cruise control mode, which should not be possible. This means that the mandatory ISA function was not fully functional until it was fixed by a service technician two months later. The repair was carried out only in six vehicles. This means that all participating drivers had several weeks of experience with an ISA system that did not function as specified in the provided study information, which may have raised concerns about the reliability of the system.

A second issue was a problem with charging the ISA's tablet computer battery. This meant that the tablet could not be recharged properly during operation in the vehicle, causing the battery to discharge completely and, at least in some vehicles, sometimes disabling the ISA and causing a loss of driving data. We suspect that the issue caused a negative user experience, as it required extra effort to charge the tablet outside the vehicle. Some drivers commented that they were concerned that charging the tablet in the vehicle overnight would drain the vehicle's battery. There were also concerns that leaving the tablet in the vehicle would make it an attractive target for theft. Indeed, two tablets were reported to be stolen during the use case period. In a related question in the survey 50% of the respondents expressed concern about the potential risk of theft.

There were also problems with the ISA system and its configuration. One of these contributed to the battery problem. In order to ensure that the ISA system was activated at the start of a driving shift, it was decided to configure it with an always-on setting, meaning that the tablet could not be switched off permanently, but would immediately reboot when switched off. This exacerbated the problems with recharging the batteries. The always-on status also created a privacy issue. When the driver took the tablet out of the car (during breaks or after work), it continued to record GPS coordinates, revealing information about private whereabouts. This was not an intended function, and most likely happened without the participant's awareness, knowledge and probably consent. This only became clear to the research team after extensive data analysis, which was performed to find the cause of the problems with the mandatory system described above. To avoid this, and mitigate the battery problem, the always-on function was then turned off.

Other problems with basic function of the ISA system were related to accuracy issues of the geo-location measurement (GNSS). This inaccuracy led to some rare and inconsistent geofencing detection errors (there were some anecdotal reports from drivers, that vehicle speed was affected or incorrect speed information was displayed in locations outside geofencing zones) and more frequently some consistent and repeated detection errors within or near geofenced zones.

In the driving data we were able to uncover both false-positive and false-negative detection errors. A false-positive detection means the vehicle is detected within a zone albeit driving on a road outside. In our data, we found a few instances where the vehicle was driving on a main road adjacent to a geofence area that had a higher official speed limit than the geofenced road. A mandatory ISA system will then try to adapt the speed to the limit assigned to the road in the geofence zone. It can lead to an unexpectedly slowing of the vehicle and may be perceived as a safety issue. And there have also been cases where a vehicle on a small secondary road (with speed bumps and a recommended speed of 30 km/h) was detected as being within the geofence area of a main road running parallel to it with a higher speed limit. In this case, the higher speed of the geofence (50 km/h) was suggested for driving on the secondary road by the system, which probably also raises safety concerns.

False negative detections (i.e. a vehicle is detected outside of a geofence area but is actually inside a geofence area) were also evident in the data, particularly during the baseline phase. This was because the triggers for some geofence zones were missing or not configured correctly. This led to situations where a vehicle entering a geofence zone on a road was initially correctly detected, but not when leaving the zone on the same road. This means that, depending on the direction of travel, the ISA system would give different speed feedback. Again, this can lead to confusion and questions about the reliability of the system. Fortunately, these errors were largely eliminated after the baseline phase and had a limited impact on ISA data collection.

Taken together, we cannot rule out that the above described issues had a substantial influence on the driving behaviour and on the way how the system was evaluated in the survey. However, we think and also experienced that many of the technical problems (related to the installation of the retrofitted ISA system and the configuration of geofences) can be resolved and improved by taking more time to test the system before implementation and by engagement with relevant stakeholders to develop the processes, tools and systems further.

5.3.2. Methodological limitations

The small study sample and a presumed selection bias among participants likely influenced the results. Participation in the use case study was voluntary, so we cannot rule out that our participants already had a positive mindset and attitude towards traffic safety and responsible driving. They might have been careful drivers with a strong commitment to complying with speed regulations. The pre-study survey supports this assumption, showing that participants had a positive attitude towards traffic safety behaviours and avoiding speed violations, indicating they generally don't tend to speed. With such a selective sample, the potential for an ISA system to reduce speeding may be limited from the start. Additionally, all survey participants were from the same company that employed them directly, whereas the second company also used drivers from subcontractors.

Another limitation was the small sample size, which further decreased during the use case. A small sample size limits the likelihood of detecting differences in speeding behaviour between study conditions and affects the validity of the results. Even substantial differences in speeding behaviour may not be detectable. Additionally, an even smaller number of participants completed the survey. We cannot rule out the possibility that participants who were more sceptical about road safety and speed limits measures chose not to complete the survey, which could bias the results positively. Other factors, such as language barriers or limited time, might also have played a role. Although the companies assured us during the planning stage that participants would have sufficient time to complete the survey during their regular shifts, five out of eight respondents denied this in the survey. To increase participation in the final survey, we offered a gift voucher as compensation for their effort, but this did not substantially improve the participation rate.

Lastly, there were also issues with the geofence zone selection and definition. In at least one of the created zones, feedback from the participants suggested that the speed limit was perceived as a safety risk for driving. This zone was therefore deactivated before the final phase with the mandatory system. Furthermore, geofences were often defined around schools and its neighbouring residential areas. Structural measures to reduce speed (bollards and road narrowing) were often already in place and a recommended speed of 30 km/h was signposted on the access roads to residential areas. Together with experienced technical problems caused by GPS-inaccuracy issues as discussed above this may have influenced the evaluation of geofence zone suitability and the expectations on the usefulness of geofencing as for tool authorities in a slightly negative way.

Finally, the weather could also have had an influence, at least on the driving behaviour. The use case began at the end of August and was not completed until the beginning of December. Although there had been no significant onset of winter by then, there were still expected seasonal changes in the weather and light conditions, such as an increased likelihood of rain, which may have also affected the driving behaviour. However, as we did not observe significant changes in speed for the outside zone driving analysis, this effect is probably small.

6. Conclusions and recommendations

The case study tested two variants of a retrofitted geofencing-based ISA system and evaluated their effectiveness in supporting drivers to comply with stricter speed limits in geofenced zones. The driving data analysis found no evidence for the informative ISA system's effectiveness and only limited evidence for the mandatory ISA system's effectiveness in reducing speeding. The results of the accompanying acceptance survey were also inconclusive, showing no preference for the use of the ISA system or for one of the two ISA system variants among the drivers. Reported problems with usability and low trust in the system likely contributed to the limited acceptance of the measure.

The observed results are likely influenced by the encountered technical and technology related problems in the use case. However, our retrospective evaluation is that most of the encountered technical problems could have been avoided and improvements can be expected in several aspects as the systems get further developed in the future. The results obtained in the present study are therefore merely the consequence of a specific implementation situation (including but not limited to faulty installation of the ISA system, battery charging issues, issues with geofence configuration and geolocation inaccuracy) and should not be interpreted as ineffectiveness of ISA systems per se or of geofencing-based ISA solutions.

Effective communication and collaboration with stakeholders are crucial for successful project management. In particular, it is essential to involve end-users (drivers) more actively and intentionally in the implementation process and to adequately inform them about the study's goals and objectives. This approach helps increase their understanding of geofencing and the measures being introduced, leading to better acceptance and compliance. In our current use case, drivers were involved only at a late stage, almost too late. Nevertheless, their feedback was vital for troubleshooting technical problems and completing the project successfully. Paying attention to end-users' opinions and ideas during the implementation can also help avoid negative experiences, such as creating zones that cause more safety issues rather than resolving them.

Based on our experiences in the present use case we would like to propose the following recommendations when testing or implementing future application of geofencing in similar scenarios especially with the focus on improving compliance, participation and acceptance.

1. Prioritize Thorough Testing and Quality Assurance:

- Challenge/Barrier: Technical issues such as incorrect installation of the ISA system, battery charging problems, and geolocation inaccuracies significantly impacted system functionality and user trust.
- Rationale: Conducting comprehensive testing and quality assurance measures before deployment is essential to identify and address potential technical issues. This includes rigorous testing of hardware installation, battery charging mechanisms, and geolocation accuracy to ensure optimal system performance and reliability.

2. Invest in User-Centred Approach for Design, Implementation and Usability Testing:

- Challenge/Barrier: Participants reported difficulties with system usability, including geofence detection errors, challenges with overriding the system, charging the tablet battery, and concerns about trustworthiness.
- Rationale: Prioritizing user-centred design principles and conducting usability testing can enhance the system's ease of use and user experience. By incorporating feedback from end-users throughout the design process, authorities can identify and address usability challenges, resulting in a more intuitive and user-friendly geofencing solution.

3. Implement Robust Data Privacy and Security Measures:

- Challenge/Barrier: Low levels of trust regarding data privacy and security of the system were identified among participants, indicating concerns in this area.
- Rationale: In many cases, geofencing will involve the collection of data that contains personal information. Establishing robust data privacy and security measures is essential to protect user information and foster trust in the geofencing solution. Authorities should be aware and ensure that appropriate encryption protocols, data anonymization techniques, and transparent data handling practices are used to safeguard user privacy and mitigate security risks.

4. Optimize Geofence Configuration and Location Selection:

- Challenge/Barrier: Issues were identified with the selection and definition of geofence zones, including perceptions of safety risks associated with certain speed limits and inconsistencies in zone configurations.
- Rationale: Thoroughly evaluating geofence locations and configurations based on road safety data, traffic patterns, and user feedback can optimize the effectiveness of the geofencing solution. Authorities should prioritize zones with demonstrated safety risks, align geofence boundaries with existing speed regulations, and ensure consistency in zone definitions to minimize confusion and enhance user acceptance.

5. Promote Stakeholder Engagement and Collaboration:

- Challenge/Barrier: The study highlighted the importance of stakeholder engagement in system development and implementation processes, including feedback from end-users and collaboration with relevant stakeholders.
- Rationale: Actively engaging stakeholders, including end-users, transportation authorities, technology developers, and community organizations, fosters collaboration and ensures alignment with user needs and expectations. Authorities should establish multi-stakeholder partnerships, facilitate open communication channels, and solicit feedback throughout the implementation process to enhance system effectiveness and user acceptance.

Given the results and the situation, it's uncertain whether a better implementation would have truly led to greater acceptance and compliance. Past experiences with large-scale introductions of safety measures, like seat belts or speed limits, have proven successful, but these successes required time and significant efforts, including scientific research, public attitude changes, and legislative action to build acceptance, awareness, and appreciation. Small pilots, which last only a few weeks and have limited resources, may not achieve this easily unless the benefits of the restrictions are clear and substantial.

Based on our findings, we recommend that implementing lower speed limits through geofencing, supported by an informative ISA (Intelligent Speed Assistance), should include a data monitoring strategy with control mechanisms and sanctions for non-compliance. While mandatory ISA systems may achieve safety goals faster, they could face higher resistance and thus require more engagement, information, and education to build understanding and acceptance. Our participants, although not a completely representative sample, showed varying degrees of indifference rather than significant resistance. Considering the technical and organizational challenges we faced, this can be seen as a relatively positive outcome. Initial pushback shouldn't discourage the implementation of changes if there are potential significant benefits. Instead, we should learn from this and other examples to implement improved solutions and measures.

7. Literature

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Appendix

Table A1 (refers to information in chapter 4.1.1.)

Distinguishable ZoneId	Area Code	N mandISA	N infISA	N BL	Distinguishable ZoneId	Area Code	N mandISA	N infISA	N BL
8	1	0	0	0	27	8	17	5	0
25	1	0	0	0	31	8	0	1	0
30	1	27	40	86	75	8	0	1	0
36	1	28	37	82	76	8	9	13	24
43	1	4	0	0	96	8	6	5	13
45	1	2	1	0	34	9	1	0	0
49	1	25	30	63	73	9	18	18	24
62	1	4	1	0	81	9	13	22	29
74	1	0	1	0	82	9	18	17	24
79	1	64	41	62	86	9	12	17	24
10	2	0	3	7	90	9	1	0	0
12	2	0	1	1	9	10	13	9	10
13	2	0	2	4	17	10	0	0	1
14	2	0	4	7	51	10	18	25	35
41	2	0	3	2	116	10	20	6	0
60	2	0	1	0	117	10	0	0	1
93	2	0	2	3	18	11	0	4	5
101	2	0	4	6	20	11	0	2	1
105	2	0	2	1	38	11	0	60	26
110	2	0	0	1	63	11	0	52	18
5	3	3	9	11	39	12	0	76	34
23	3	15	16	22	47	12	0	11	8
53	3	4	1	2	67	12	0	1	1
55	3	7	7	9	97	12	0	53	14
57	3	14	16	19	3	13	5	3	2
72	3	16	4	0	56	13	2	5	3
95	3	1	0	0	80	13	0	0	0
106	3	7	7	9	4	14	1	0	1
112	3	8	13	15	42	14	0	1	2
1	4	2	8	5	59	14	4	4	6
7	4	0	1	0	6	15	2	6	1
16	4	12	10	11	68	15	0	0	1
28	4	7	5	4	103	15	5	2	2
88	4	2	3	5	11	16	25	54	107
89	4	2	4	4	24	16	30	48	66
111	4	3	7	3	104	16	2	5	0
21	5	7	6	0	15	17	4	1	1
37	5	0	0	0	84	17	1	3	1
64	5	2	11	6	102	17	2	0	1
65	5	0	0	0	46	18	1	4	7
99	5	0	0	0	58	18	3	2	5
107	5	5	11	10	85	18	0	0	1
19	6	0	0	2	70	19	0	0	1
40	6	0	0	6	100	19	0	0	1
48	6	0	1	4	113	19	0	0	1
71	6	3	5	10	83	20	1	1	2
87	6	6	5	6	98	20	0	0	0
109	6	1	2	9	115	20	1	1	2
26	7	0	4	4	2	21	0	0	1
29	7	2	9	17	78	21	0	0	0
66	7	4	6	10	22	22	7	35	34
69	7	7	1	3	77	22	2	45	58
92	7	2	2	4	94	23	15	30	43
108	7	0	4	4					

Note: Data is already pre-filtered and contains only zone visits where at least 7 valid data samples were available. The Area Code describes the zone areas. Zone with area code 11 and 12 were removed from the analysis, since the zone was deactivated in the phase when testing the mandatory ISA.