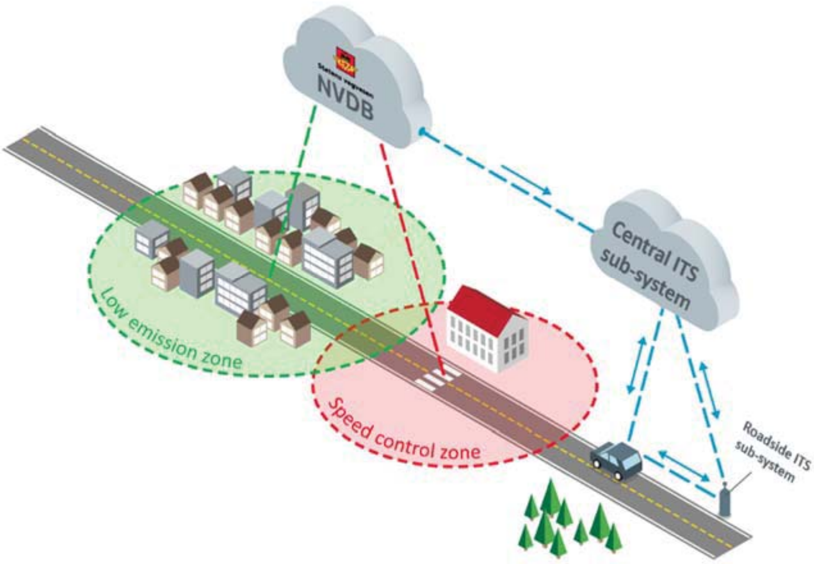
2020:00100- Unrestricted

Report

Geofencing for smart urban mobility

Summarizing the main findings of work package 2: Pilot Design and work package 3: Piloting

Authors
Petter Arnesen
Hanne Seter
Trond Foss
Erlend Dahl
Per Johan Lillestøl
Gunnar Jenssen



SINTEF Community
Digitalization in Transport

2020-02-14

SINTEF Community
SINTEF Community

Address:
Postboks 4760 Torgarden
NO-7465 Trondheim
NORWAY
Switchboard: +47 40005100

info@sintef.no

Enterprise /VAT No:
NO 919 303 808 MVA

Report

Geofencing for smart urban mobility

Summarizing the main findings of work package 2: Pilot Design and work package 3: Piloting

KEYWORDS:
Geofencing
Low emission zones
Speed zones
Pilot design
ITS
HMI

VERSION
1.0

DATE
2020-02-14

AUTHORS
Petter Arnesen
Hanne Seter
Trond Foss
Erlend Dahl
Per Johan Lillestøl
Gunnar Jenssen

CLIENT
Norwegian Public Roads Administration

CLIENT'S REF.
283431

PROJECT NO.
102015754

NUMBER OF PAGES/APPENDICES:
56

ABSTRACT
Norwegian cities are heavily affected by car traffic, which brings major challenges related to efficiency, safety and the environment. In GeoSUM cooperative ITS and geofencing will be used to develop new tools to meet these challenges. Using geofencing, digital zones is defined on a map and specific rules inside these zones can be transmitted to the vehicles. This technology is a prerequisite for the future transport system, for instance to make self-driving vehicles a reality. This report sums up the finding from work package 2: Pilot Design and work package 3: Piloting of the GeoSUM project and are a collection of the (slightly revised) project notes written within these two work packages. In short, it contains an overview of the functionality of the GeoSUM pilot-cases, technical and HMI designs for the pilots, overview of the data to be collected and details of how the two pilots where conducted in practice. Please note that some of the notes included in this project might change during the rest of the project period, and that updates may occur.

PREPARED BY
Petter Arnesen

SIGNATURE
Petter Arnesen

CHECKED BY
Terje Reitaas

SIGNATURE
Terje Reitaas

APPROVED BY
Roar Norvik

SIGNATURE
Roar Norvik

REPORT NO.	**ISBN**	**CLASSIFICATION**	**CLASSIFICATION THIS PAGE**
2020:00100	978-82-14-06307-3	Unrestricted	Unrestricted

SINTEF

Document history

VERSION	DATE	VERSION DESCRIPTION
1.0	2020-02-14	Final

SINTEF

Table of contents

1 Overview of the GeoSUM functionality

Trond Foss

1.1 Introduction

This chapter describes the first version of the GeoSUM use cases functionality by means of a generic UML sequence diagram that could be used for the four use cases that are piloted in the GeoSUM project. The roles used in the diagram are further explained in [1]. The roles are shortly described in the table below for those not having access to [1].

Role name	Main responsibilities
Controlled Zone (CZ) manager	• To identify a CZ and to achieve control of it • To disseminate information on existence of its CZs and the related conditions such that potential road users are informed in due time about restrictions to access the CZ In many cases the CZ Manager and the ITS service provider will be the same legal entity, e.g. a road network operator.
ITS service manager	• To define and manage the ITS service as a response to the ITS service user requirements related to safety, efficiency, comfort, availability and sustainability • Handle the contractual (explicit or implicit) and informational interface to the ITS service user also including any handling of claims and payments for the ITS service.
ITS service operator	• To operate the ITS service and deliver it to the ITS service user In many cases the ITS service manager and the ITS service operator are the same legal entity, e.g. a road network manager and operator. In these cases, the legal entity is called an ITS service provider.
ITS service user	• To define the ITS service requirements, enter into an agreement with an ITS service manager, benefit from the service and if required, pay for the ITS service. The ITS service user may also be an object, e.g. a vehicle, as an ITS service may be provided to a vehicle without any interaction with the driver or any passenger. However, the vehicle owner will often be involved both for the definition of the service and the payment for the service. E.g., a person purchasing a vehicle with the ITS service *Collision avoidance* will both define the service and pay for it.

1.2 The four uses cases in GeoSUM

1.2.1 Air-quality traffic management

1.2.1.1 Use case 1: Approaching a CZ boundary and Operation in a CZ is subject to a fee

The use case includes a vehicle approaching a CZ where there is an access regulation regarding the vehicle emission and where the vehicle is subject to a fee in those cases where the vehicle power is based on fossil fuels. The vehicle (the driver) gets a message when it approaches the CZ informing about the CZ and the fee to be paid for vehicles powered by fossil fuels. The vehicle (vehicle owner) is charged for the operation of the vehicle in the CZ when leaving the CZ, ref. Figure 1.

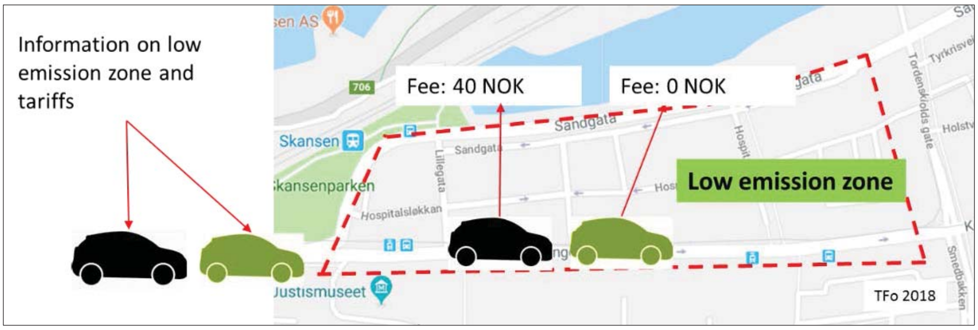


Figure 1: Use case 1

1.2.1.2 Use case 2: Approaching a CZ boundary and Vehicle power is changed to electricity

The use case includes a hybrid vehicle approaching a CZ where there is an access regulation regarding the vehicle emission and where the hybrid vehicle power is changed to electricity by the ITS application[1]. The vehicle (the driver) gets a message when it approaches the CZ informing about the CZ. When entering the CZ, the ITS application supporting the use case changes the vehicle energy from a mix of fossil fuel and electricity to pure electricity.

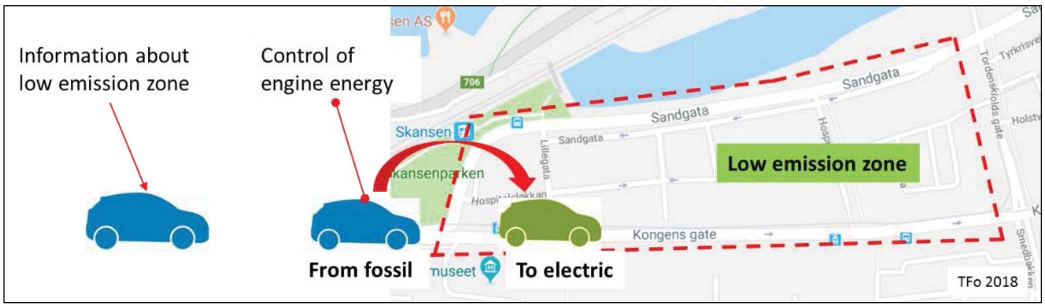


Figure 2: Use case 2

[1] An ITS application is defined as the software allocated to the different ITS equipment, e.g. a Vehicle ITS station or a vehicle ECU and a Central ITS station or an OEM cloud, supporting a specific ITS service.

1.2.2 Speed control in zones with vulnerable users

1.2.2.1 Use case 3: Approaching a CZ boundary and Automatic speed control

The use case includes a vehicle approaching a CZ where there is an access regulation regarding the vehicle speed due to vulnerable users, in this case school children in the streets close to a school. The vehicle (the driver) gets a message when it approaches the CZ informing about the CZ and the speed limit. When entering the CZ, the vehicle maximum speed is automatically reduced to 30 km/h. Ideally, this should be done by reducing the power supply down to a level where the vehicle speed is not exceeding 30 km/h. In the GeoSUM pilot this is not a feasible solution and the automatic speed reduction is replaced by an active speed limit reminder function that makes the driver aware of speeding. Details of this function can be found in Section 6.2.3.2

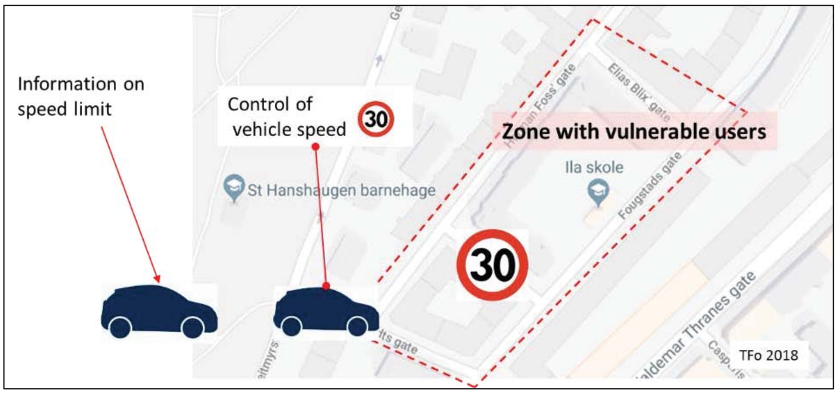


Figure 3: Use case 3

1.2.2.2 Use case 4: Approaching a CZ boundary and Automatic speed warning

The use case includes a vehicle approaching a CZ where there is an access regulation regarding the vehicle speed due to vulnerable users, in this case school children in the streets close to a school. The vehicle (the driver) gets a message when it approaches the CZ informing about the CZ and the speed limit. When entering the CZ, the driver will receive an audio-visual warning whenever the vehicle speed exceeds 30 km/h.

Figure 4: Use case 4

1.3 GeoSUM functionality described by a generic UML sequence diagram

The high-level functionality of the four GeoSUM use cases is described by the sequence diagram in Figure 5 and in the table following the diagram where the messages in the diagram are further explained.

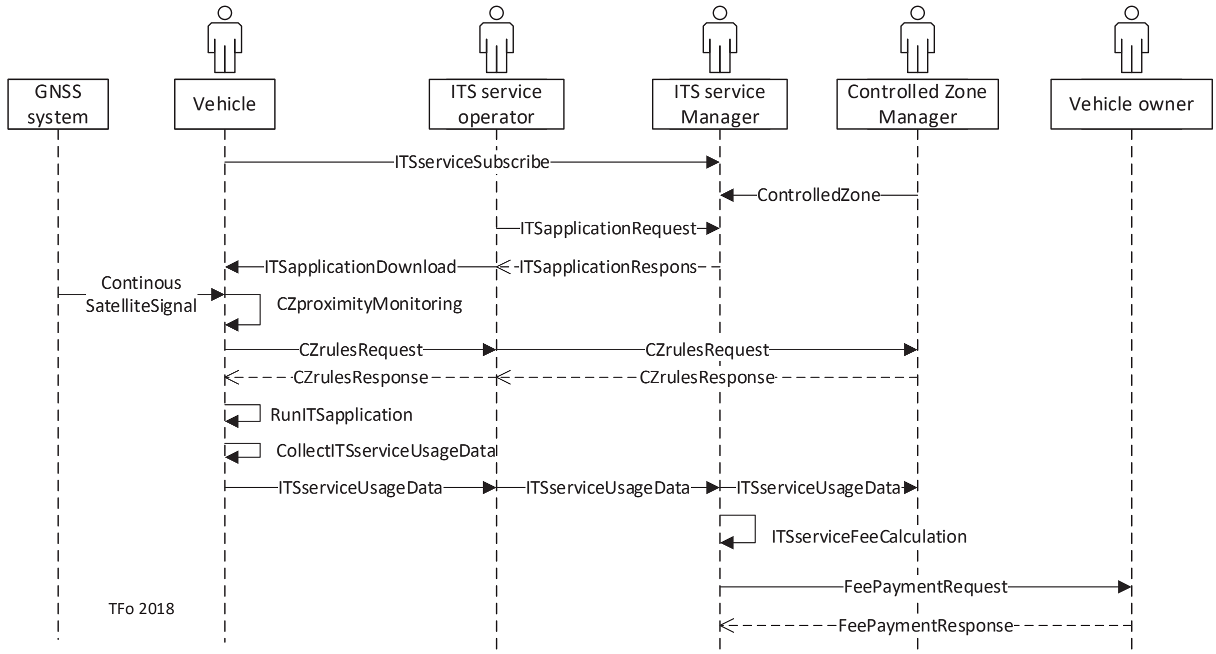


Figure 5: High level sequence diagram for the 4 use cases in GeoSUM

Table 1: Messages and descriptions

Message	Description
ITSserviceSubscribe	The message is a general request for ITS services subscription identifying the ITS service user, in this case the vehicle and its ITS equipment, e.g. a trusted Vehicle ITS station.
ControlledZone	This is the CZ definition as defined in [2]. The message consists of three components: • czId: the globally unique identifier of a CZ • czArea: The area of the CZ within which the access conditions apply • czAccessConditions: the set of applicable access conditions The ControlledZone message is further described in Clause 0.
ITSapplicationRequest	This message contains a request from the ITS service operator to the ITS service manager on the definition of the ITS services to be implemented and operated by the ITS service operator. The following ITS applications are used in the GeoSUM pilots: • Air-quality traffic management – vehicle subject to fee • Air-quality traffic management – automatic change of vehicle energy • Automatic Vehicle Speed Control • Automatic warning on speed limit exceeding

Message	Description
ITSapplicationResponse	The message includes the specification of the ITS application(s) requested
ITSapplicationDownload	The message includes the ITS application(s) that is (are) downloaded to the vehicle ITS equipment, e.g. a Vehicle ITS station.
ContinousSatelliteSignal	The message includes the satellite signal continuously received by the GNSS sensor in the vehicle ITS equipment.
CZproximityMonitoring	The message is an internal command to monitor the proximity of the vehicle to any CZ that is integrated in any of the ITS applications downloaded to the vehicle. The internal command triggers the *CZrulesRequest* in those cases where the proximity is less than a defined distance, e.g. 200 meters and/or at the latest exit before entering the CZ.
CZrulesRequest	The message includes a request to the CZ manager for the latest and/or valid version of the *ControlledZone* message. The message may also be sent to the ITS service operator and not to the CZ manager if the ITS service operator is always updated with the latest version of the *ControlledZone*.
CZrulesResponse	The message includes the latest and/or valid version of the *ControlledZone*
RunITSapplication	The message is an internal command to run the ITS application that is relevant for the CZ that is within the defined proximity limits, e.g. the ITS application supporting the ITS service *Air-quality traffic management – vehicle subject to fee.*
CollectITSserviceUsageData	The message is an internal command to collect UTS service usage data to be used for different purposes, e.g. charging the user for service or statistics for the ITS service manager.
ITSserviceUsageData	The collected ITS service usage data are forwarded to the ITS service operator, ITS service manager and CZ manager.
ITSserviceFeeCalculation	The message is an internal command to calculate a fee for the ITS service provided to the ITS service user. The message is optional as many ITS services are free of charge.
FeePaymentRequest	The message is a request to the vehicle owner to pay the fee in those cases where the ITS service is subject to a fee and the fee has been calculated by the ITS service manager.
FeePaymentResponse	The message is a response to the ITS service manager that the fee has been or will be paid.

One of the ITS service operators, i.e. Volvo, will allocate parts of the ITS service application to the ITS service operator central system (Volvos cloud). This has an impact on the sequence diagram in Figure 5. An alternative to the diagram in Figure 5 is shown in Figure 6 and the additional messages needed are shown in Table 2: Additional messages for use case 2, the alternative sequence diagram

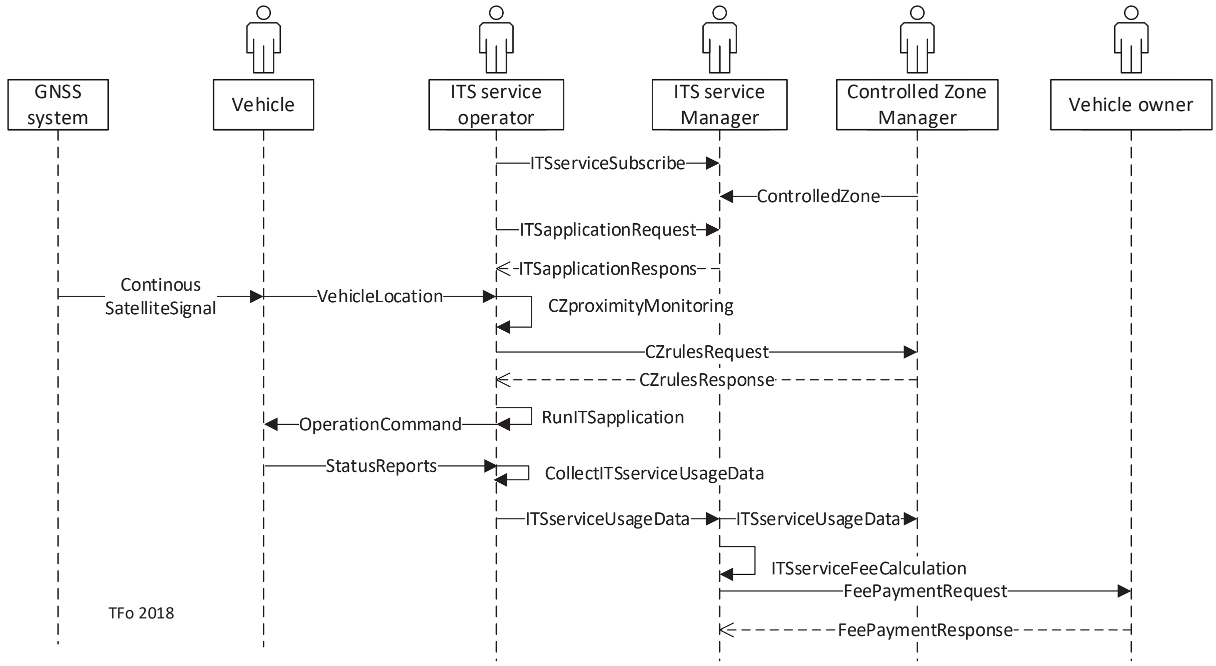


Figure 6: Sequence diagram for use case 2 in GeoSUM. No reports (ITSserviceUsageData) are sent for use case 3.

Table 2: Additional messages for use case 2, the alternative sequence diagram

Message	Description
VehicleLocation	The vehicle transmits its location enabling a monitoring of whether the vehicle is approaching a controlled zone.
OperationCommand	The message includes the command to change the operational mode of the vehicle. In this case it implies changing from a mix of fossil fuel and electricity to pure electricity or vice versa. (Activation/deactivation of the speed limit reminder function in use case 3).
StatusReports	The vehicle sends combustion engine usage data to the Volvo cloud (ITS service operator) enabling ITSserviceUsageData.

1.4 The ControlledZone message

1.4.1 The data

The `ControlledZone` message is defined in [2] as a sequence of three components:

- `czID` which is a globally unique identifier of the controlled zone (CZ) defined by the CZ manager
- `czArea` which is a specification of the geographical area inside the CZ. The area is defined by a data type called `LDMarea` (Local Dynamic Map area) imported from another standard [3]. So far,

the LDMarea only defines a polygon that easily could be used for a zone in a city. However, if the zone also included a tunnel or two roads crossing each in two different levels where one of the roads was not included in the zone, this could cause some problems.
- czAccessConditions which is a set of applicable access conditions in the CZ

The czAccessconditions (the last component of the ControlledZone) is defined in [2] as a sequence of two components:

- lastUpdate which is date of last update of a CZ access condition of the type Time48IAT imported from [4]
- accessConditions which is a sequence of CzAccessCondition

The CzAccessCondition is a sequence of the components:

- czAccessConditionRef which is a globally unique identifier of the CZ access condition defined in czAccessConditionFormat (see next component)
- czAccessConditionFormat which includes details of the access condition identified by the globally unique identifier defined in the czAccessConditionRef (see previous component)
- czAccessConditionValidity is the definition of the time validity of the CZ access condition, e.g. start and end of the access condition. The time validity is defined by TimeInformation imported from [3].
- czApplicableCzExemptions which is information on whether and which CZ exemptions that are applicable for the access condition defined in the czAccessConditionFormat.

The czAccessConditionRef is in [2] so far defined by a value (0….3) where the Table 3 shows the references defined in the standard.

Table 3: Identifiers for the access condition

Reference number (CzAccessConditionRef)	Description/ASN.1 type
0	An unknown CZ access condition / CzACunknown
1	No access restrictions apply / CZACallowed
2	Access is prohibited generally without a given reason / CzACprohibited
3	Access is allowed for CZ users, e.g. vehicles with given properties / CzACrequestedUserProperties

The czAccessConditionFormat is not further described in [2].

The czAccessConditionValidity describes the time validity of the CZ. It is defined as a sequence of the ASN.1 types TimeInformation imported from [3]. For now, only two types of time are defined in [3]. The first one is a single time value, e.g. a full day given by the date or a full month of a year. The second one is a pair of time values indicating a start and stop time.

The czApplicableExemptions is defined in [2] as a sequence of CzExemptRef where the Table 4 shows the references defined in the standard.

Table 4: Identifiers for the CZ exemptions

Reference number (CzExemptRef)	Description/ASN.1 type
0	This indicates that no CZ exemptions are granted, or that exemptions are unknown / czexemptUnknownOrNone
1	This indicates that all CZ exemptions are applicable for a given access condition / czexemptAll
2	The CZ user may only leave the CZ. This requires a proof that a journey started inside the CZ / czexemptLeaveZoneOnly
3	Operation of a CZ user, e.g. a vehicle, in a CZ is subject to a fee. If this CZ access condition is presented together with other CZ access conditions, then the fee shall be applicable only in case these other CZ access conditions result in a prohibition / czexemptFee
4	Operation of a CZ user, e.g. a vehicle, in a CZ is allowed for a limited time span. If this CZaccess condition is presented together with other CZ access conditions, then the maximum time span shall be applicable only in case theses other conditions result in a prohibition. This CZ access condition requires a proof of "start of journey". / czexemptMaxTime

1.4.2 Overview of the ControlledZone message

An overview of the ControlledZone message sent from the CZ Manager (Norwegian Public Roads Administration) to the CZ operators (Volvo and Q-Free) is given below:

- `ControlledZone`
  - `czID` (the unique ID of the controlled zone)
  - `czArea` (the geographic definition of the controlled zone, e.g. the corners in a polygon))
  - `czAccessConditions` (the set of applicable access conditions)
    - `lastUpdate` (date of last update of a CZ access condition)
    - `accessConditions` (a sequence of CzAccessCondition)
      - `CzAccessCondition`
        - `czAccessConditionRef` (unique identifier of the CZ access condition)
        - `czAccessConditionFormat` (details of the access condition)
        - `czAccessConditionValidity` (time validity of the access condition, e.g. start and stop time)
          - `TimeInformation`
          - `TimeInformation`
        - `czApplicableCZExemptions` (the applicable exemptions for the CZ access condition)
          - `CzExemptRef` (e.g. (3) operation in CZ allowed when a fee is paid)
          - `CzExemptRef`
        - `czAccessConditionRef`
        - `czAccessConditionFormat`
        - `czAccessConditionValidity`
        - `czApplicableCZExemptions`

- `CzAccessCondition`
- `CzAccessCondition`
- `lastUpdate`
- `accessConditions`
- `lastUpdate`
- `accessConditions`

1.5 References

[1] Roles and value network in GeoSUM

[2] CEN/TS 17380:2019 Intelligent Transport Systems – Urban ITS – 'Controlled Zone' management for UVARs using C-ITS.

[3] ISO 18750:2018 Intelligent transport systems -- Co-operative ITS -- Local dynamic map

[4] EN ISO 17419:2018 Intelligent transport systems - Cooperative systems - Globally unique identification

2 Technical design – GeoSUM

Petter Arnesen

2.1 Introduction

Geofencing has great potential of contributing towards a more digital and automated transport sector. Within the GeoSUM project interviews with the project partners, NPRA, Volvo and Q-Free was conducted to investigate the range of possibilities in relation to this technology, as well as its limitations, with respect to technical aspects. In particular, we conducted semi-structured interviews to acquire in-depth knowledge of information flows, technical possibilities and barriers. Questions were also asked about how such a system might be implemented as ITS services. In addition, they were asked about the different types of data and available standards for the data links 1-4 in Figure 7 showing the high-level architecture and data flows for the application of the GeoSUM project.

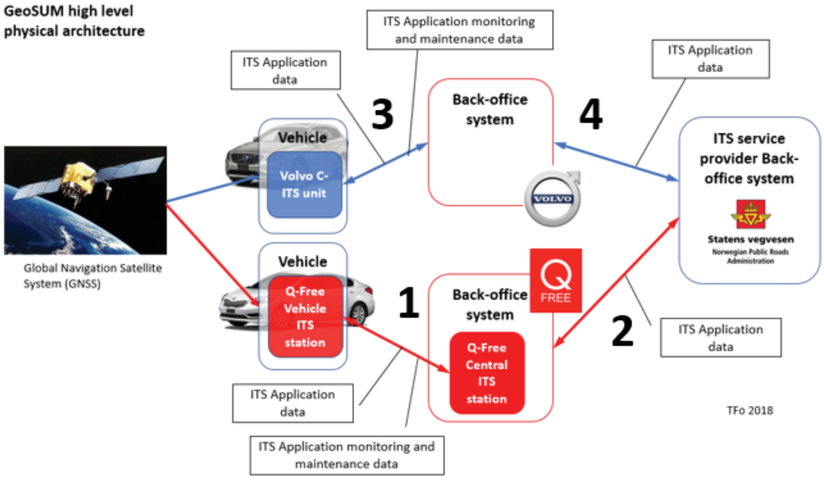


Figure 7: Objects, ITS stations and major information flows

In the following we sum up the responses given to the main discussion themes of the interviews, information flows and technical possibilities and barriers. Privacy issues are not covered by these interviews, the reader is referred to Foss et al. (2019).

2.2 Information flow

Two of the interviewees started by commenting that there is an ongoing battle of who should own the information and transfer of information between vehicles and vehicles and infrastructure. Delegated act (EU, 2019) is a much-debated document. One of the interviewees highlight that services relying on C-ITS are challenging to establish if communication needs to be based on solutions that are not free of charge to use. Therefore, the telecom solution, cellular V2X (vehicle-2-everything), is not necessary the best solution. The sharing of information is said to be problematic, especially with respect to safety critical data. In this case actors, such as OEMs (original equipment managers), is often prepared and willing to share, but one might be interested in ensuring that no one profits on these data and that one gets something in return. Data is a valuable resource and important questions such as who should own data and/or the digital link transferring data are critical questions.

Two of the interviewees went on talking talk about CAM (Cooperative Awareness Message) and, in particular, information that contains GNSS-position data that is shared with nearby vehicles. Both interviewees point to that these are useful information but limited in practice to the simple use-cases that do not need very precis information about vehicle GNSS-positions. The CAM message was not developed for supporting the more advanced use-cases that are discussed today, such as automated and connected driving, so for these use cases both interviewees state that additional information is necessary to obtain the required accuracy, such as sensor data from the vehicle itself, e.g. lidar, video etc. There is ongoing work in SDOs (Standard developing organizations) to create sensors for collective perception.

With respect to the two use cases in this project, the interviewees were asked which information that is important to get from other and from who? One of the private partners says that the geofence obviously must be provided by others, along with its rules. But apart from that, no clear responsibilities between actors exists. Who should follow up on the rules for instance? If a hybrid vehicle does not drive on electricity in a low emission zone who have the responsibility and what will be the consequences? For instance, through sanctions, tolling or road charging. To really get going with this, the transport sector needs a proper way to ensure that the rules are followed, and that there exists a system to deal with situations where they are not followed.

2.2.1 Information flows in low emission zones

Going back to Figure 7, to/from the NPRA to/from the private partners (link 2 and 4), the NPRA needs to receive information of the type and quantity of emissions, and distance and time driven within a zone. In return, the NPRA should provide geofences with attributes such as rules and cost. Both the data flows to and from NPRA should be on standardized formats and could be provided for instance using DATEX2. For the links 1 and 3, the back office needs to provide zone-initiated data recordings and in return the vehicle needs to report combustion/electric usage. For the GeoSUM architecture this can be proprietary solutions as the system owner would be the same on both side of these links.

2.2.2 Information flows in speed control zones

Firstly, for link 2 and 4 going from NPRA to the private partners, the information of the zones should be provided using a standardized format. With respect to information flow back to NPRA there are (at least) two different possible scenarios, both outlined by the interviewees. One scenario being that no information is shared back to the NPRA, and the other being that the private partners report back aggregated statistics for speed limit violations and compliance within the zone. These two different scenarios do have consequences for the data being exchanged at link 1 and 3 though, where the vehicle to back-office information flow is not needed if this information is not to be forwarded to link 2 or 4. In either scenario, information regarding the zones (geography, location, speed limits etc.) must be communicated from the back-office to vehicle. As for the low emission case, in the GeoSUM-project this information could be proprietary.

All interviewees comment on privacy as an issue for information flows in these cases. For this project, detailed GNSS data can be collected and analysed, however in a full implementation there are many additional questions that needs to be worked out in this regard. Also, the integrity of the information needs to be ensured.

Another important issue raised by one of the interviewees is how to ensure that the data that is distributed is interpreted the right way? This is a big question and might lead to reluctance to share data because you want to make sure that your data are understood the right way. On the same note, you want data from different actors to be comparable to each other.

2.3 Technical possibilities and barriers

For the NPRA the zones must be stored, maintained and communicated from a defined data base. In this project NVDB (National Road Data Bank) would be used as the best option easily available today. For services that needs to update a zone quickly, NVDB is problematic. NVDB is not designed today to respond to pushed changes with low latency, rendering geofences dynamically generated around car accidents to not be a possible ITS-service using NVDB, for instance. Changes to geofences based on time rules, for instance, is possible, or a set of predefined zones that a traffic manager might choose from is also possible. However, the interviewee states that it is reasonable, and possible necessary, that geofence zones are located at and maintained by a national authority. For instance, through DATEX-service in the future for lower latencies.

For HMI (Human Machine Interface) there are two possible solutions within the project. Through retrofit equipment or integrated in the vehicle. The retrofit equipment could be presented in an app on a tablet, even on a standalone device, or if there is a web-browser available one could run the app online. Integrating geofence into available navi-solutions already in the vehicles, is challenging for this project as there is not only one simple standard solution of these products. One could imagine several forms on the HMI, especially for the retrofit equipment, where the presence of information through a screen is necessary or not. For these use-cases the drivers already have information about which fuel they run on, and what speed they are driving in. But they might need some warnings about approaching zones, but there are several ways of interacting with the drivers, e.g. dedicated device like tablet, sound through car stereo via Bluetooth or via web-browser in vehicle. It is stressed that third party actors cannot make reconfigurations of the engine functionality of vehicles, at least not in a standardized way, making retrofit equipment feasible only for information in these two use-cases.

Other technical barriers highlighted by the interviewees was:

- GNSS accuracy. Important to distinguish between 1) low accuracy and knowing your accuracy is low and 2) having low accuracy and not knowing that it is low. Even accurate GNSS equipment needs a good starting point. If you start in a parking building, narrow street etc., the second case of low accuracy is a very hard problem to overcome and an inaccurate start position can be transferred into the GNSS-trajectory for a significant amount of time.
- Standardization. There is a need for increased effort here regarding these technologies, for instance with respect to geofencing and reporting back to authorities. Even small differences in data representation between countries or areas must be taken into consideration when implementing either a retrofit or an integrated system. We have to trust that the standards are used, interpreted in the same way, so that a vehicle or equipment would work the same way all over. This is a great barrier today.
- Amounts of data. Neither of the interviewees view this is a large problem for the GeoSUM use-cases and closely related application.
- Communication coverage. There are some roads in Norway and in Europe that do not have coverage. One alternative is that NPRA installs multiple ITS stations with ITS-G5 communication to covers every road in Norway. The other option is to let the telecom providers enhance the networks and require all vehicles to support cellular communication. The question is also whether the telecom providers would take this cost. None of the two options are for free, and one of the interviewees states that "I do not believe it is possible to get 100 MB bandwidth for every little road segment in Europe".
- Non-technical issues are also mentioned, although not topic for the interviews: Laws and regulations, sanctions, behavioural changes, and value networks. In these topics there are now several heavy-weight actors with different views, needs and agendas now gathering to discuss and agree upon common platforms and solutions.

2.4 Summary

For the GeoSUM project and possible implementation of the future use-cases, there are indeed technical challenges that need to be addressed. The technical solutions seem possible to develop for the objectives of these pilots, an several alternatives exists in terms of for instance data flows and HMI. However, there are some complex questions that need to be answered before a full implementation including standardization, integrity, who owns data, what data should be shared and how they should be shared, and what could/should be collected.

2.5 References

Foss, T., Seter, H., & Arnesen, P. (2019). Geofencing for smart urban mobility. Summarizing the main findings of Work Package 1.

European Commission (2019) "Commission Delegated Regulation Supplementing Directive 2010/40/EU of the European Parliament and of the Council with regard to the deployment and operational use of cooperative intelligent transport systems".

3 Technical verification and evaluation – data specification

Petter Arnesen, Trond Foss and Erlend Dahl

3.1 Introduction

In this chapter we describe the technical verifications and evaluations that will be conducted through the GeoSUM-pilots. The motivation of this verification and evaluation is two-fold. Firstly, we would like to investigate the accuracy of the different piloted GPS-systems with respect to geofence zones and verify its feasibility and limitations as an ITS subsystem. Secondly, we would like to evaluate the impact of the two piloted services. This evaluation will be conducted together with the evaluation of the user and system acceptability studies. The two involved industry-partners, Volvo and Q-Free, will each provide vehicles to use in the two pilots, each of the partner having different solutions for the implementation of the GeoSUM use cases, see Figure 8 and chapter 1 for a more detailed description. The text in Section 3.1 - Section 3.4 corresponds to the original note developed within work package 2: Pilot Design, while Section 3.5 was added in this report to show the final result of data types to be collected.

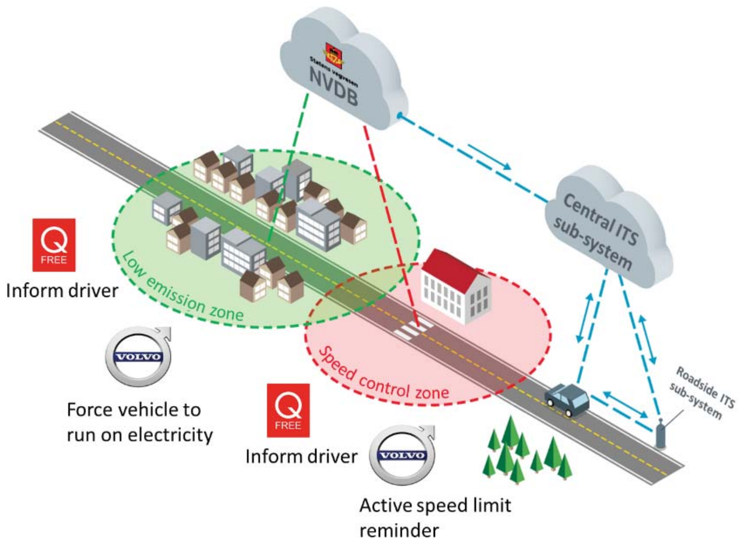


Figure 8: The GeoSUM pilots and the proposed technical solution for each partner.

Since Q-Free do not have the option to change any of the configurations of a hybrid-vehicle as Volvo will do, they will test an informative solution, that is, to motivate (or instruct) the driver to change the fuel type to electricity within a low emission zone, and to keep the posted speed limit within a school zone. Volvo on the other hand will automatically change from a mix of fossil fuel and electricity to pure electricity when the Volvo test vehicle enters a low emission zone and activate the speed limit reminder function when entering a school zone. Q-Free will provide a fleet of 40-50 vehicles for the pilots while Volvo will implement this technology in single test vehicles to be used in a test route with 40-50 participants.

There are four important points that to some degree applies to all the test proposed here:

1. The vehicles should report all data in messages including the same events, the same data attributes and with the same resolution (suggestion for resolution found in chapter 3.4) also when driving outside a zone. That is, when the vehicle or the installed OBUs (On Board Units) do not provide any interaction with the vehicle driver. This data material will be used to construct the base-line statistics and to investigate the behaviour of both the driver and the vehicle ITS equipment before entering the zone, when entering the zone, when driving inside the zone, when exiting the zone and when driving outside the zone.

2. The vehicle with the installed logging-equipment (both Volvo and Q-Free) should be driven a significant amount of time logging data without giving any response to the drives. This represents a situation with driving as usual, i.e. baseline. Typically, from 10 % to 50 % of the observations should be included in this baseline set.
3. The zone should in each pilot be defined by taking into account the following: Firstly, the zones shall represent reality as far as possible e.g. actual school zone or areas where low-emission zones are/or could be realistic. Secondly, in the interest of gathering more data when vehicles are entering and exiting geofences, the zones shall be smaller and numerous, compared to large and few. However, we should keep in mind that too many zones would probably annoy both to Q-Free and Volvo drivers.
4. Anonymization and/or approval of gathering GPS data should be accounted for. We suggest preparing a contract, declaring that the drivers are aware that data is gathered, and a declaration of this sent to NSD[2]. In addition, we can consider removing a random number of GPS points at the start end of each trip to make start of trips and destinations point more difficult to identify.

3.2 Technical event verification

In this section we outline how the pilots could be technically verified using technical data. This section outline how data about events regarding interaction between vehicle and geofences could be registered, both in a pilot and in an implementation scenario. In the next section we then describe the attributes of a continuously sampled data set, necessary to answer the requirements of the analyses that should be done within the GeoSUM-project and will partially also cover the events described in this section. The verification will include collecting data enabling the verification of that a minimum set of events are handled and completed in compliance with the set of minimum events requirements listed below.

3.2.1 Event type 1: Vehicle approaching an identified controlled zone

The vehicle ITS equipment[3] (see chapter 1) shall register that the vehicle is approaching a zone and that its expected trajectory indicates that the vehicle will cross the controlled zone border.

The message generated, logged and sent to the Central ITS equipment whenever one or more of the events listed below occur, shall include the following data:

- Vehicle Id, in this case the vehicle licence plate number as control roadside equipment with automatic number plate recognition (ANPR) may be installed at the zone border to collect data on license plate numbers. For privacy reasons, only licence plate number connected to test vehicles will be collected. The vehicle licence plate number shall consist of two letters and five digits (Norwegian licence plate) or three letters and three digits or three letters and two digits and one letter (Swedish licence plate).
- Message Id (a sequential number between 1 and 999999999, starting with 1 and increasing with 1 each time any event message is generated.
- Controlled zone Id (defined by the Controlled zone manager)
- Driver Id
- Vehicle GPS coordinates when the message was generated
- Event type 1 - Vehicle approaching a controlled zone
- Timestamp of the message

[2] Norsk senter for forskningsdata

[3] In the Volvo implementation the Volvo cloud (central ITS equipment) will generate the message.

3.2.2 Driver is informed that the vehicle is approaching an identified controlled zone

The vehicle ITS equipment shall inform the driver about the expected entrance in the controlled zone and any important rules valid for the zone, e.g. reduced speed limit or low emission zone with regulations on fuel type and fees for vehicle not fulfilling the fuel regulation.

The message generated, logged and sent to the Central ITS equipment whenever one or more of the events listed below occur, shall include the following data:

- Vehicle Id as described in 3.2.1.
- Message Id (a sequential number between 1 and 999999999, starting with 1 and increasing with 1 each time any event message is generated.
- Controlled zone Id (defined by the Controlled zone manager)
- Driver Id
- Vehicle GPS coordinates when the message was generated
- Event type 2 - Vehicle ITS equipment informs the driver about the controlled zone and regulations
- Timestamp of the message

3.2.3 Vehicle propulsion is changed from a mix of fossil fuel and electric power to pure electricity or opposite

The vehicle ITS equipment shall change the vehicle propulsion from a mix of fossil fuel and electricity to pure electricity (or vice versa) when entering or exiting a controlled zone with low emission requirements. The change shall be done automatically (Volvo) or manually by the driver (Q-Free).

The message generated, logged and sent to the Central ITS equipment whenever one or more of the events listed below occur, shall include the following data:

- Vehicle Id as described 3.2.1.
- Message Id (a sequential number between 1 and 999999999, starting with 1 and increasing with 1 each time any event message is generated.
- Controlled zone Id (defined by the Controlled zone manager)
- Driver Id
- Vehicle GPS coordinates when the message was generated
- Event type
  - 3 - Vehicle has entered a zone and propulsion is changed automatically
  - 4 - Vehicle has entered a zone and propulsion is changed manually. This also includes cases where the driver forces the use of fossil fuel, e.g. in case of low battery status.
  - 5 – Vehicle has left a zone and propulsion is changed automatically
  - 6 – Vehicle has left a zone and propulsion is changed manually
- Distance driven with fossil fuel inside the controlled zone if event type is 5 or 6
- Distance driven with electricity inside the controlled zone if event type is 5 or 6
- GPS tracks of vehicle trajectory inside zone if event type is 5 or 6.
- Timestamp of the message

3.2.4 Vehicle speed is reduced to be below the speed limit

When entering a controlled zone, the vehicle ITS equipment shall support the driver in driving in a speed below the speed limit. The support shall be information to the driver and/or the activation of the speed limit reminder function.

The message generated, logged and sent to the Central ITS equipment whenever one or more of the events listed below occur, shall include the following data. There shall be one message for each event in case two or more events occur at the same time.

- Vehicle Id as described in 3.2.1
- Message Id (a sequential number between 1 and 999999999, starting with 1 and increasing with 1 each time any event message is generated.
- Controlled zone Id (defined by the Controlled zone manager)
- Driver Id
- Vehicle GPS coordinates when the message was generated
- Vehicle speed when the message was generated
- Event type
    - 7 - Vehicle has entered a controlled zone and the driver is informed about the speed limit
    - 8 – Vehicle has entered a controlled zone and the active speed limit reminder function is activated
    - 9 - Vehicle has a speed more than 3 km/h in the controlled zone and the driver is informed about the speeding
    - 10 – Vehicle has left a controlled zone and the driver is informed that the vehicle is outside the zone with the reduced speed limit
    - 11– Vehicle has left a controlled zone and the active speed limit reminder function is deactivated
- Timestamp of the message

3.3 Technical impact evaluation

In this section we outline how technical data can be used to evaluate impacts of implementing the piloted systems. In Section 3.4 we present a table that is the union set of all parameters identified in this section:

- For the school zones we will investigate the impact of speed reduction. At first glance, this is a classical informative or supporting ISA case Nordtømme et al. (2016), however the zones will apply only to a few dedicated areas (schools), so the results reported in Nordtømme et al. (2016) is not necessarily directly transferrable. Therefore, we aim to investigate the speed reduction, and speed behaviour, as a result of the implemented systems. In addition to the parameter sets identified in Section 3.2, parameters that would be necessary to collect in order to evaluate speed behaviour are:

    - **Speed**: Both as reported to the driver and the actual speed, to measure if the amount of speeding within school zones are reduced.
    - **Acceleration/brake pedal pressure**: To measure if number and size of hard breaking and increase in speed is reduced, i.e. smoother driving.
    - **Longitudinal acceleration** (option to above point): To measure if the number or size of accelerations (and deaccelerations) is reduced, i.e. more smooth driving.
    - **Configuration changes due to active speed limit reminder function** (Volvo only): To measure and correct/control the statistical analysis for the amount of ISA the driver is experiencing at a given time. Can be used to look at effects of the above on different levels of support from this functionality.

  Baseline data would be very important in the school zone pilot in order to have a data set to measure effects against.

- In terms of the low emission zone pilot we would like to investigate whether the drivers in fact switch their fuel type to electricity during driving. This applies mostly to Q-Free vehicles where the driver needs to make this transition themselves. These drivers can be motivated by getting a ticket to a lottery for each time they follow the instructions to switch (In a real-world implementation such motivation might come from added fee if not turning to electricity). For Volvo, the hybrid-vehicles will automatically be switched to electricity, however in case the driver has an option to switch back within the zone (as a result of for instance low battery level or lost engine power) this should also be evaluated.

- Using the baseline data collected through a "silent-mode", i.e. a period in the beginning of the pilot where no feed-backs are given to the drivers, we would like to compare the areas of running on electricity in a before after study. The objective of this task is to investigate whether the system succeeds in "moving" the usage of environmentally friendly fuel to dedicated areas. Important parameters to include are:

    - **Odometer value:** To measure the distance driven by the vehicles. Used both in the analysis to look at distance driven in environmental zones and as a control of the GPS-measured distance driven.
    - **Fuel type currently in use:** Essential to analyse the spatial distribution of fuel type usage, calculate, validate and controlling the reported fuel type usage within each zone**.**
    - **Used and/or remaining fuel level (both electric and fossil fuel).** To look at total fuel usage. Comparison of fuel usage after installing geofence system and base-line situation. Also, geographical distribution of fuel types should be investigated (compared also to baseline). Closely related to point above. Changes in the parameters of these two latter bullet points should mirror each other and can be used for controlling. Would also give information of re-generation of electricity and low battery which could explain behaviour towards changing to electricity or not.
    - **Estimated range with electric power:** Give more information of the behavioural choices of the drivers. Could for instance be used to identify cut-off values where drivers are comfortable with driving on electrical fuel within zones.
    - **Outside temperature:** Of special interest in cold climate. Influence on electric range. Could also be found from historical weather data bases.

In general, the technical impact evaluation should also include:

- The above data collection is an interesting case also in terms of investigating delays of the system. As indicated by Q-Free the geofence will be downloaded into the onboard equipment, which intuitively will result in low delay. On the other hand, Volvo has indicated using the Volvo cloud for storing the geofence, where the vehicles reported GPS-position will be checked for position relative to the geofence. This evaluation requires high resolution of the GPS-position, about 1 second.
- We would also like to install Q-Free retrofit equipment into the vehicles provided by Volvo, enabling the possibility to evaluate differences between the two systems more directly.
- We also consider adding different GPS equipment to the vehicles or using a "road-side beacon" to register passing vehicles from the pilot. This can provide a reference data set which with respect to the defined geofences can provide useful information on false-positives/negatives, i.e. events where vehicles are registered to enter a zone but in reality, do not, or events where vehicles enter a zone but are not registered as entering.
- A comparison of in-vehicle/device map-matching routine in addition to GPS registration without map-matching. Both GPS-positions are interesting in terms of evaluations accuracy on detecting geofence zones correctly.

3.4 Data fields

We have identified the verification and evaluation parameters in Table 5 based on the technical verification and technical impact evaluation descriptions above. To be able to make the evaluations precise enough for verification/evaluations we consider ≤1 second resolution to be good enough, preferable with an extra record generated each time vehicle/OBU (On Board Unit) reacts to a geofence. In terms of speed zones, for instance, less than or equal to 1 s granularity is important to be able to capture behaviour, as too aggregated data will smooth out parameters such as speeding above the speed limit, acceleration and breaking.

The periodic records and the extra records generated on geofence events, should have identical contents, and should contain the following data:

Table 5: Union of identified parameters to use in the GeoSUM technical verification and evaluations

Data fields	Why	Interval
Timestamp (including date and time with at least one second resolution. Preferable GPS timestamp.)		1 s
Geofence ID (if inside)	To easily extract which geofence the vehicle is operating in.	1 s (N/A if not in geofence) or upon event with timestamp
Vehicle ID (VIN or similar) – unique through whole pilot	To control for individual difference between drivers in the pilots	1 s or upon event where engine of vehicle is turned on. Possible added to name of the output file.
Driver ID	To control for different drivers in the statistical analysis.	1 s or upon event where engine of vehicle is turned on. Possible added to name of the output file.
Event type	Identify how and when the ITS-system is reacting to the presence of geofence.	1 s or upon event
GPS-position raw	To identify the position of the vehicle. Relative to the geofence, the event of entering/exiting geofence, measure trip length (inside and outside zones), validation. Accuracy with plain GNSS system.	1 s
GPS-position map matched	To identify the position of the vehicle. Relative to the geofence, the event of entering/exiting geofence, measure trip length (inside and outside zones), validation. Accuracy with **more** than plain GNSS system	1 s
Odometer value	Distance driven, vehicle mileage	1 s
Both actual speed and speed shown on speedometer	In order to look at different driver behaviour. Especially for school zone pilots but also	1 s

	interesting as secondary effect from low emission zone.	
Acceleration/Brake pedal pressure	To measure if number and size of hard breaking and increase in speed is reduced, i.e. smoother driving.	1 s
Configuration changes active speed limit reminder	To see the current status of the changes made when this function is activated.	1 s
Longitudinal acceleration	To measure if number or size of accelerations (and deaccelerations) is reduced, i.e. more smooth driving.	1 s
Fuel type currently in use	To map energy-usage geographically and to validate fuel change within zones.	1 s or upon event with timestamp
Used and/or remaining fuel level (both electric and fossil fuel).	To look at total fuel usage. Comparison of fuel usage after installing geofence system and base-line situation. Also, geographical distribution of fuel types should be investigated (compared also to base-line).	1 s (preferred) or upon event when fuel type is changed, or fuel is added.
Estimated range with electric power	To investigate the distance travelled within zone on electric power compared to estimated usage. Driver behaviour with regard to low estimated range compared to opposite. Identify when drivers are comfortable with driving on electrical fuel within zones.	1 s
Outside temperature	Of special interest in cold climate. Influence on electric range	1 s

3.5 Final data description

This section was added to the report to show the finalized datasets that where collected in the two pilots.

3.5.1 Data description Volvo

Through AMQP (Advanced Message Queuing Protocol) Volvo provide the data below from their cloud. The first part is additional data for the evaluation and the second part is data needed for ITSserviceUsageData.

Parameter	Description
Vehicle Identification Number (VIN)	Unique identifier
reportStartTimestamp	Time at report start
reportEndTimestamp	Time at report end
positionData with	Long and lat

timestamp	Time at the position
engine	ICE or BEV at the position
speed	Speed at the position
geofenceid	Geofence id if the vehicle is in a geofenced area
Zone Energy Usage Report	**Description**
Vehicle Identification Number (VIN)	Unique identifier
geofenceId	Controlled zone identification number
timestampEntering	Time when entering zone
timestampExiting	Time when exiting zone
timeDurationGeofence	Time spent within zone
proportionTimeICEGeo	Proportion of ICE time inside a Geofenced Zone
totalDistanceGeofence	Distance travelled within zone
proportionDistanceICEGeo	Proportion of ICE distance inside a Geofenced Zone

The report starts and ends with specific choice, i.e. start/ends every hour etc. The position data is sampled e.g. every second and a zoneEnergyUsageReport is generated every time the vehicle leaves a zone.

In addition, the test vehicle from Volvo is equipped with a computer containing INCA software, providing detailed data at high sampling-rate (e.g. 100 Hz) of numerous parameters such as triggers of geofences, pedal (de-)configuration, position, connection to cloud and so on. In total over 200 parameters are available within this data set and is stored to a PostgreSQL data base.

3.5.2 Data description Q-Free

Referring to data specification provided by Q-Free[4] and updates provided since this documentation, the following parameters are sampled every second from their OBU:

Parameter	Origin/ Sampling rate	Description
Time	System time/milliseconds	Linux time
filedate		Date file was created
IMEI number		Smartphone identifier
Userid		User on smartphone identifier
Vehicle identification number (VIN)	Obd-II/two times per second (configurable)	Unique identifier
AccuracyGPS	Smartphone ~1 sek	Estimated accuracy of GPS from smartphone
Blackmode		Boolean for black screen on smartphone or not
Odometer/distance	Obd-II/two times per second (configurable)	The total number of kilometers driven/Distance since last engine start. (Odometer parameter is to be implemented)
Revolutions per minute (RPM)	Obd-II/two times per second	Indicates if the combustion engine is running

[4] "GeoSUM system description". 03-05-2019, rev 2.0, Note, Q-Free

Speed	Obd-II/two times per second	Indicates if the vehicle is moving/actual speed
Timestamp	GNSS/configurable 1-10 times/second	Microseconds resolution
Longitude	GNSS/configurable 1-10 times/second	
Latitude	GNSS/configurable 1-10 times/second	
Heading	GNSS/configurable 1-10 times/second	
Travel distance	GNSS/configurable 1-10 times/second	Reference distance travelled
Travel time	GNSS/configurable 1-10 times/second	Reference time travelled
inZone	GNSS/configurable 1-10 times/second	Boolean, indicates if the vehicle is located within a controlled zone
currentZoneType		Controlled zone type with highest priority currently located within.
Following parameters apply for low emission zones (LEZ)		
zoneId	Controlled zone attribute/On system start	Controlled zone identification number
zoneName	Controlled zone attribute/On system start	Controlled zone name
zoneType	Controlled zone attribute/On system start	Controlled zone type, indicates what type of rules apply
Electric	Two times per second	Boolean indicates if the vehicle is moving on electric energy or fossil fuel. Determined based on RPM and vehicle speed.
EnterFeeEl	Controlled zone attribute/On system start	Fee to be paid to enter current controlled zone if moving on electric energy
EnterFeeFossil	Controlled zone attribute/On system start	Fee to be paid to enter current controlled zone if combustion engine is running
KmFeeEl	Controlled zone attribute/On system start	Fee to be paid per kilometer driven in current controlled zone if moving on electric energy
KmFeeFossil	Controlled zone attribute/On system start	Fee to be paid per kilometer in current controlled zone if combustion engine is running
timeSpent	GNSS/configurable 1-10 times/second	Time spent in current controlled zone, milliseconds resolution
kmDriven	GNSS/configurable 1-10 times/second	Kilometers driven in current zone
Price		The total price accumulated for current trip

Following parameters apply for speed control zones (SCZ)		
zoneId	Controlled zone attribute/On system start	Controlled zone identification number
zoneName	Controlled zone attribute/On system start	Controlled zone name
zoneType	Controlled zone attribute/On system start	Controlled zone type, indicates what type of rules apply
Speeding	Two times per second	Boolean, indicates if the vehicle is exceeding the speed limit that applies in the zone
speedLimit	Controlled zone attribute/On system start	The speed limit that applies in the current controlled zone
timeSpent	GNSS/configurable 1-10 times/second	Time spent in current controlled zone, milliseconds resolution
kmDriven	GNSS/configurable 1-10 times/second	Kilometers driven in current zone

3.6 References

Nordtømme, M. E., Moen, T., Dahl, E., Hjelkrem, O. A., & Arnesen, P. (2016). Evaluering av automatisk fartstilpasning (ISA) i Statens vegvesen. In SINTEF (Ed.), SINTEF rapport A27040: SINTEF.

4 HMI for the GeoSUM pilots

Hanne Seter, Petter Arnesen and Gunnar Jenssen

4.1 Introduction

In the GeoSUM project Q-Free, Volvo and the Norwegian Public Roads Administration (NPRA) is responsible for executing two pilots. The two ITS services to be piloted are Air-quality traffic management and Speed Control in zones with vulnerable users. The first service is provided in low emission zones and the second service is provided in zones located around schools:

1. In the **low emission zones** several types of information should be collected, such as the distance/time driven in a zone and what source of energy that was used by the vehicle. This information could be used for purposes such as road fee calculation, or access condition that might depend on source of energy, time of day e.g. An example that will be piloted in GeoSUM is forcing hybrid vehicles to run on electricity within a low emission zone.
2. For the **speed control zone** pilot, the driver of the vehicle will be warned that he is driving in proximity of a school. This could be done, either by informing the driver or mechanically support the driver in terms of keeping the speed limit. Among other options in the last case, this could be a limitation of fuel to the engine, or by using the active speed limit reminder functionality, the last of which will be included in the GeoSUM-pilot.

When the vehicles and back-office systems are enabling the provision of ITS services to the ITS service user (driver), this means that the vehicle and the human can be seen as a joint cognitive system, where both systems are required to collaborate to deliver safe and comfortable driving. The main communication means between the vehicle and the human in the collaboration is the human machine interface (HMI) (Carsten & Tate, 2018). In a broad sense HMI includes all the vehicle controls, but in this chapter, we focus on the feedback given to the driver from the vehicle in terms of ITS services related to low emission zones and speed control zones around schools. The role of the HMI is to make humans understand what is expected of them in each situation.

In general, there are three different strategies for alerting the driver:

i) Visual alerts
ii) Auditory alerts
iii) Haptic alerts

These have different pros and cons; Visual alerts do not disturb passengers in the car, but inattentive drivers risk ignoring the alert. Auditive alerts, such as sounds or voice, is difficult to ignore, but could also be perceived as annoying and disturb the passengers. Haptic alerts, such as vibrations, are likely to receive attention from the driver, but not from the passengers.

This chapter documents the discussions and process within the GeoSUM project to develop appropriate HMIs for the two pilots, as presented in the original note from this work package. The final HMIs developed by Volvo and Q-Free is presented in Chapter 6 of this report.

4.2 Natives for equipment

We will now briefly describe the different alternatives for equipment that are possible. Three alternatives for the visual alert on different versions of equipment has been discussed:

Alternative 1: Tablet/smartphone connected to Q-Free ITS station

This alternative uses the existing Q-Free ITS-station, see Figure 9, along with a tablet/smartphone for visual/auditable interface. The positive and negative aspects of Alternative 1 are the same for both low emission zones and for speed zones: The positive aspects are that the solution can be based on a robust, solid technology that have been extensively tested. The information from the ITS-station is complete and one then achieves better timing. Roadside unit communication is easy. The negative aspects are that the solution could be expensive for the user depending on how the ITS-station is financed, and that user acceptance in terms of design and installation is a challenge.

Figure 9: ITS-station

Alternative 2: Tablet/smartphone connected to OBD II
Alternative 1 and 2 is close to the same option because the only difference is that Alternative 1 uses the Q-Free ITS station, while Alternative 2 uses only the OBD II contact instead. The tablet would then function as a control system for the driver and would function as the communication unit to the roadside. If the solution involves a standard tablet/smartphone with an app, communication to roadside would be more complex in term of assuring the on-board unite (tablet/smartphone) are turn on. Also, given that the solution includes a visual unit, the solution would not be cheap.

Alternative 3: Simple unit in windscreen connected to OBD II
Alternative 3 would look similar as the AutoPass unit, see Figure 10. The positive aspect of this solution is that it is easy and probably less expensive for user. The negative aspect could be that this means that Q-Free must develop the unit for the window, which could take time and resources outside the scope of this project. Also, this alternative is not possible with speed control – you would then only receive a report in the afterwards, similar as the tolling solution today. However, in a further implementation of this solution, an alternative here could be voluntary use of a tablet/smartphone for instance by Bluetooth to provide information to the driver.

Figure 10: The AutoPass unit

4.3 Some principles for HMI, and how they apply to the pilots

The National Highway Traffic Safety Administration specifies that the primary requirement of the in-vehicle HMI is to deliver timely needed or desired information while minimizing driver distraction. Some principles of how to achieve this is presented in the following.

4.3.1 Appropriate understanding of the capabilities and status

It is a basic requirement for the human operator to comprehend what functions are being provided by the vehicle or the retrofit equipment, and in counterpart what is expected of the human in terms of supervision and attention (Carsten & Martens, 2018). For the speed control pilot and the low emission zone pilot this means that the driver understands when the zone is active and not. Questions that should be answered are: What should the tablet show when the zone is active/not active? For instance, should the screen just go black when there is no speed control zone available?

Speed control

In terms of the speed control pilot, it is important to answer whether the tablet only is informative, or if it is supportive as well? In addition to being informative or supportive, the speed control pilot could be controlling – that would mean that the car is forced to drive below the limit, and that the driver's request for speeds beyond the speed limit is ignored (possible to do with the integrated equipment, however not with the retrofit equipment). This is however, not part of the GeoSUM project and will not be further discussed here. In the speed control pilot, we can benefit from lessons learnt in studies of ISA which includes different technical systems that aims at helping drivers to keep the correct speed. Table 6 below summarizes the informative and supportive solutions for the speed control pilot.

Table 6: Overview of different variants of the speed control pilot according to function (Jenssen, 2010)

Type of speed management	How intervening	Level of support	Type of feedback	Feedback
On-board speed information	Advisory, display the speed limit	Informing	Visual	The speed limit is displayed, and the driver is reminded of changes in the speed limit
On-board overspeed warning	Advisory intervention, display the speed limit and remind the driver of changes in limit and when limit is violated	Warning	Visual – could be auditory	The system alerts the driver that he or she is over-speeding and allow the driver to make a choice on what action should be taken

For the GeoSUM pilot on speed control it is most likely that the level of support will be informative. When approaching a speed control zone, the driver is alerted visually. In addition, an auditory feedback could be given to warn the driver. This could be an optional functionality for the drivers. We will discuss these options in more details below.

Low emission zones

For hybrid vehicles in low emission zones it is important for the driver to understand the status of the motor to be able to adjust his or her behaviour. In this case motor status means whether it is running on fossil fuel or electricity. If you want the driving behaviour to change from using fossil fuel to using electricity, the driver needs monitoring the fuel economy. Some users have been documented in studies to be very aware and interested in monitoring the fuel economy and changing their behaviour based on this information, but most do not (Kurani, Axsen, Caperello, Davies, & Stillwater, 2009). In any case, the status on fossil fuel vs. electricity should be given instantly to facilitate use and avoid confusion.

4.3.2 Appropriate level of trust

Trust in the equipment is important for system use and acceptability. If users do not trust the equipment, they will not buy it or alternatively turn the equipment off. Trust is not a unidimensional or binary concept, either being present or absent. Trust evolves over time, based on experience with these systems. This observation means that the drivers will have a different experience as they learn to use the equipment. Furthermore, trust is hard to regain once it is lost, indicating that it is important to map experiences both with first-time users and users that are more experienced with the equipment (Carsten & Martens, 2018).

For the pilots in this project this observation means that we must map the experiences of both first-time users and users that are more experienced with the system. Only in this way we will be able to understand the acceptability of the users. Options in functionality can contribute to increase acceptability, for instance if the driver can choose whether he or she would like to have an auditory warning or not. Some users are shown to appreciate auditory warnings, while others just find it annoying. Customization could be important for increasing acceptability. This would apply for both the speed control pilot and the low emission pilot.

4.3.3 Appropriate level of attention

The HMI should ensure that the level of attention that a driver is paying to the display inside the vehicle is suitable (Carsten & Martens, 2018). A well-designed HMI should provide drivers with proactive decision-making supports and thus reduce the potential of traffic collisions; while inappropriate integration of various alerts may mislead, distract, or even disturb drivers. This is particularly significant during high workload situations (Mohamed, 2017).

In terms of the speed control pilot this is a critical point: around schools the focus should be on the road, not on a display inside the vehicle. If the screen makes drivers lose focus on the road, this could end up with reducing safety. The display should support the driver making good decisions concerning speed, but it should not remove focus from the road and its environment. It could therefore be an important point to keep the information on the display minimalistic. Elaborate information on for instance fuel economy could move focus from the road.

4.3.4 Minimise surprises

The information should be provided early enough so that the human can take proper action (Carsten & Martens, 2018). The user needs the information should not come as a surprise for the driver. Otherwise, the ITS service in the zone could be a safety issue. For instance, drivers can start to deviate from their planned route when they realize that they must pay in low emission zones, alternatively drivers could start to brake heavily when they suddenly realize that they are in a speed zone. However, it could be problematic to alert the driver before he/she arrives into the zone. It is not possible to know for sure whether the driver will enter the zone or not. The driver could stop just outside the zone, and never enter the zone. It could then be perceived as being very confusing to receive alerts about that you are now about the enter a low emission zone or a school zone when you don't. We therefore suggest that the zone rules should be that drivers should be informed 3 seconds after they arrive into the zone, and that the rules start to apply after 3 seconds. This applies for both pilots.

4.3.5 Provide comfort to the user, i.e. reduce uncertainty, stress and annoyance

There is a fine balance to be drawn between information overload and consequent stress and information that is too sparse with consequent uncertainty (Carsten & Martens, 2018). The vehicle cannot inform the driver about every activity that it is performing or provide detailed information. A balance needs to be found between at one extreme that is a very sparse HMI display that provides minimal understanding, and the other extreme, information overload from multiple constantly changing status displays (Carsten & Martens, 2018).

The development of the HMI of the low emission zone pilot should focus on simplicity in representation and interpretation to increase the understanding of the driver concerning whether the car uses fuel or electricity. The same applies to the speed control pilot, where a simple representation is to be preferred to reduce uncertainty (Kurani et al., 2009).

Another relevant issue is whether the HMI should only honour "good" behaviour, and not dishonour "bad" behaviour. Dishonouring bad behaviour could imply that drivers rather turn off the system than receiving negative feedback. Providing the user with an optional warning functionality could be a way to address this.

An important aspect is that information from the geofence must be relevant for the individual users. If the users receive information about geofences that are not relevant for their travel they could be annoyed, e.g. a driver of a light vehicle does not need information about a zone with no access for heavy goods vehicles. This could also make the driver turn the equipment off.

The importance of avoiding over-complex menu systems was demonstrated in a study looking at perceptions of PHEVs. In this study it is stated that many participants had problems placing the information from the interfaces into a useful context. A key interface is whether the car is using the fossil fuel or the electricity. For instance, the fuel-averaged economy in the PHEVs seemed to raise, rather than answer, questions in this study (Kurani et al., 2009).

4.3.6 Be usable

One should avoid over-complex menu systems and multifunction switches. There is a big virtue in simplicity and in commonality of controls between different vehicle makes and models. Standardized symbols should be used as far as possible. The system should be easy to learn and remember, which also means that it should be easy to switch between different vehicle makes and models, as well as easy to switch between an integrated system and a retrofit system. This implies a high level of commonality in display format (Carsten & Martens, 2018).

Concerning standardization, there are several standards that are relevant for the HMI of the pilots, for instance ISO/DIS 15005, ISO 15008 and ISO/CEN 17427-140. Normark and Gärling (2011) give an extensive literature review on visual displays in vehicles. For instance, an overview of the positioning of devices as a function of their positions are given, see Figure 11 We suggest that the devices in the GeoSUM project should be placed in the limit for the secondary displays.

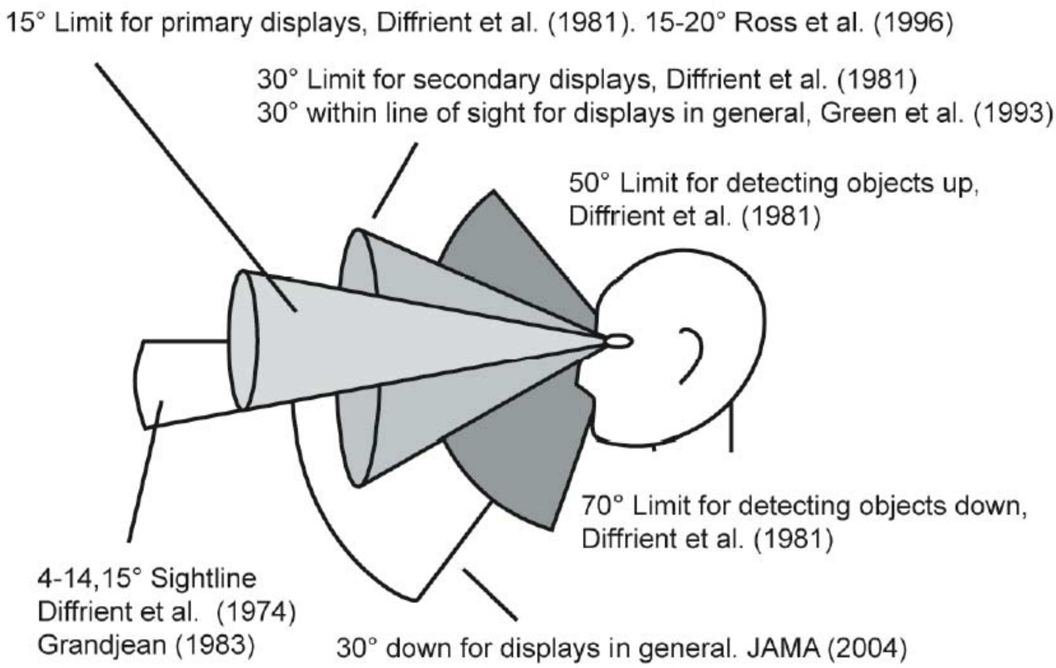


Figure 11: Positioning of in-vehicle devices.

Low emission zones
For the low emission zones, it could be relevant to use already implemented HMIs developed for hybrid vehicles as an inspiration for the retrofit equipment in GeoSUM. EVs and PEVs do not have well-established interfaces like conventional vehicles have, and different car manufacturers choose to display different information.

Traditionally the instruments in the dashboard have consisted of two primary dials – speedometer and tachometer, often supplemented with minor dials such as fuel level and engine temperature, and configurative message display area. The configurative displays enable displaying several different layers of real-time information (Wellings, Binnersley, Robertson, & Khan, 2011). Figure 12, Figure 13 and Figure 14 shows the HMI for a Toyota, Mitsubishi and Volvo, respectively. The configurative LCD displays can be seen in the HMIs below.

Toyota has a *power in/out gauge* in the dashboard – this shows energy being used or energy recovered through regenerative braking. Here there are three categories: CHG, ECO and POWER. The same HMI is also used by Mitsubishi, where the categories are named Charged, Eco and Power. This is important information for knowing whether the vehicle is using electricity or fossil fuel.

In addition, there is often a *battery state of charge indicator* and/or *a range indicator*. In the Mitsubishi HMI there is a battery state of charge in the digital screen between the speedometer and the in/out gauge in the dashboard. This is important information for knowing whether the battery has enough power to drive through the zone.

Figure 12: Toyota, 2015[5]

Figure 13: Brindley Garages Group, 2019[6]

Some car manufacturers include a *ready indication* to indicate when the vehicle is in a state that it can be driven. The picture of the Volvo display below illustrated this, and the same indicator is found in Mitsubishi's HMI.

---

[5] https://blog.toyota.co.uk/2015-toyota-auris-review/2015-toyota-auris-hybrid-instruments-566px
[6] https://www.brindley.co.uk/electric-hybrid/what-does-phev-mean.aspx

Figure 14: Volvo, 2019[7]

Speed zones
With respect to speed zones it is natural to search through the literature and lessons learned from different ISA systems (Nordtømme, Moen, Dahl, Hjelkrem, & Arnesen, 2016), see Figure 15 for the piloted system in the referenced work. In addition, standardized road-signs, both for speed and school areas already exists, so a reasonable layout and functionality of HMI should be possible to establish. For instance, a sign for schools might be relevant to add to indicate why the speed limit changed, for instance using the sign in Figure 16. In a continuation, one can then easily add other signs where the speed has been reduced, such as in zones with road works

Figure 15: Example of monitor for retrofit ISA.

[7] https://www.mcgrathvolvocars.com/new/Volvo/2019-Volvo-XC60+Hybrid-75df96eb0a0e0adf224e678d3a4ea42a.htm

Figure 16: Sign to be used in the HMI for school zones.

4.4 Recommendations for HMI

Based on standards, the specific nature of these two pilots and the recommendations made in Normark and Gärling (Normark & Gärling, 2011) we have focused on the following properties for the HMI:

- The level of support should be informing, no warning
- Show changed information both in and out of the zone
- Use familiar and as far as possible, standardised symbols
- All given information should be read and understood in less than 2 seconds.
- Limit the usage of text. The taxi-drivers should be given a small training session so very little explanatory text should be necessary.
- Given that passengers that are customers of the drivers is present, the HMI should be discrete.
- Less than 60 % of the screen should be used at any time. Blank spaces provide structure.
- Maximum of four colours for each pilot.
- The display should be placed within the secondary limit, see Figure 3.
- Any auditory alert should be voluntary, i.e. possible to turn off.
- The driver should get at least 3 seconds notice when entering and zone to make speed or fuel-adjustments.
- As the background colour of the screen, white is proposed. However alternative colour could be used, but the resulting contrast with respect to the signs must be given focus.
- Whenever the vehicle is not in a zone the screen should be black, i.e. empty.

The concrete proposal for the two pilots is given in the following.

4.4.1 Speed zone, school

When entering a school zone, the display is suggested to be visualized like in Figure 17.

Figure 17: School zone HMI, entering.

Given the assumed distance from the eyes of the driver the letters should have a height of min 6 mm. The sign used should be at least 1.5 times the size of the letters. For instance, for a screen that is 70 mm high we suggest these measures in Figure 18.

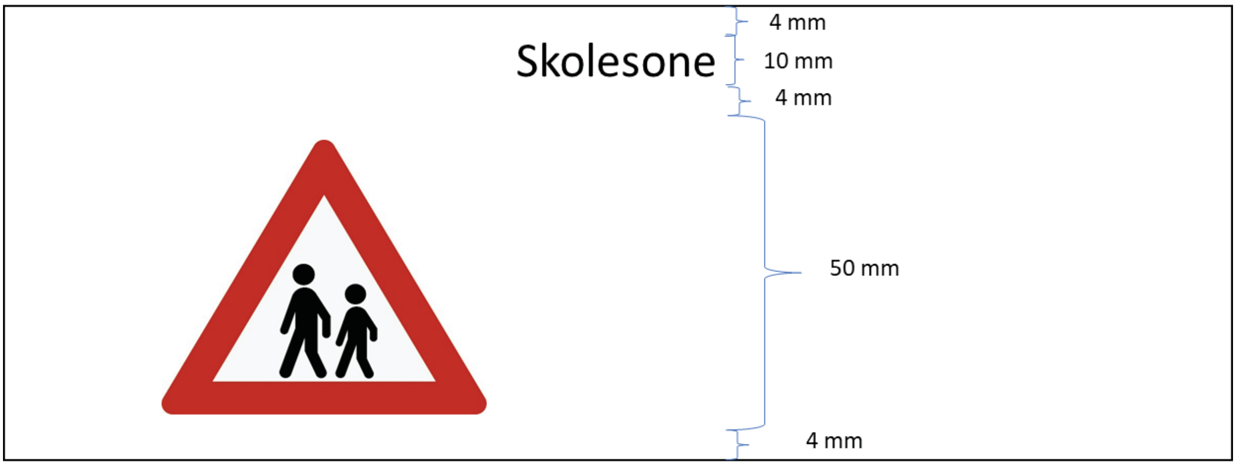


Figure 18: School zone HMI, measures.

When entering such a zone there should be a discrete audible "pling". However, to assure user acceptance this signal should be possible to mute. The signal should be only given one time, i.e. when entering a new zone.

After driving 3 second in the school zone the screen should change to one of two possibilities. If the vehicle is driving under the speed limit of 30 km/h, we suggest that the screen look like in Figure 19.

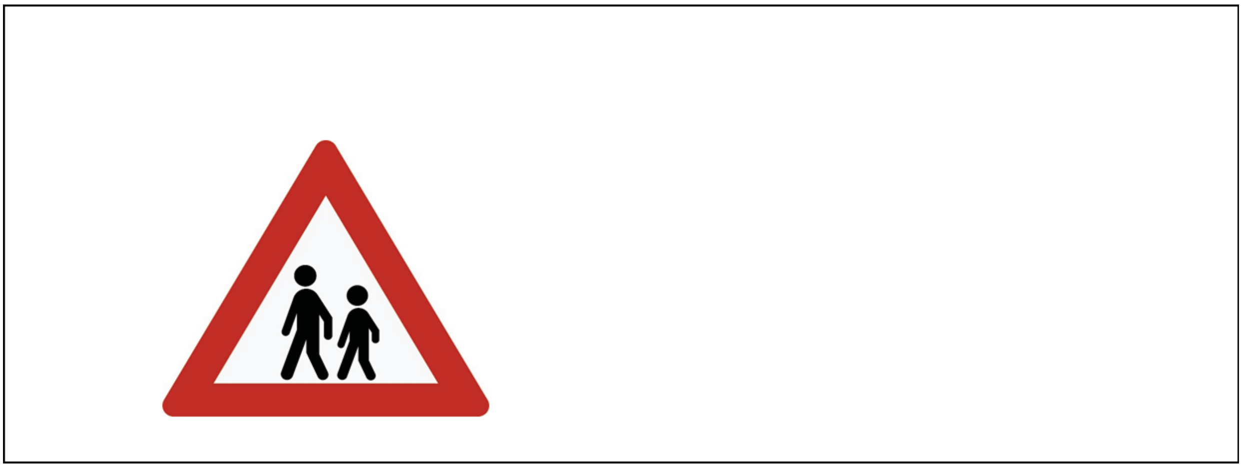


Figure 19: School zone HMI, under speed limit.

I.e. a clean screen without explanatory text. The second option, if the vehicle speed is more than 3 km/h over the speed limit of 30 km/h for more than 3 seconds, we propose that the screen should change to Figure 20.

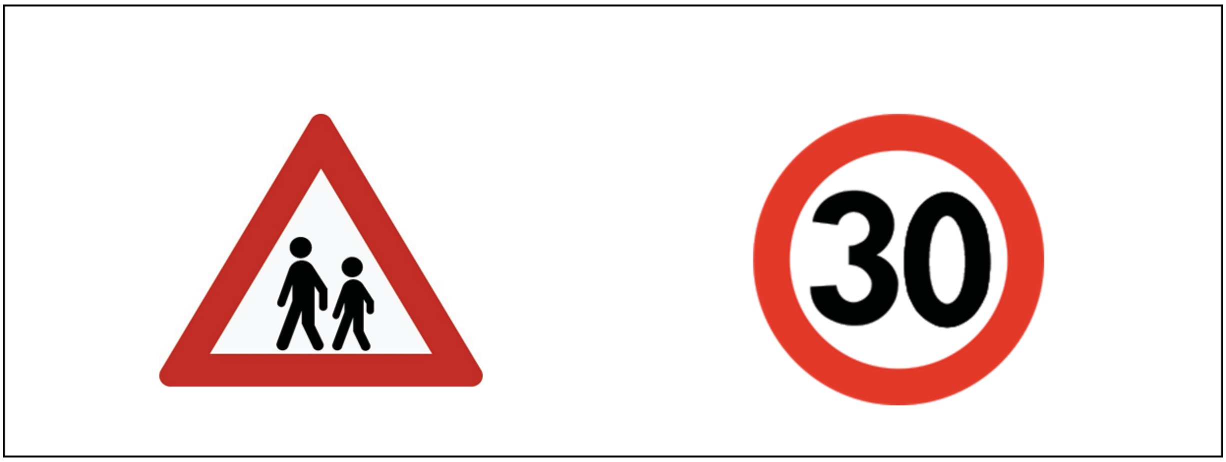


Figure 20: School zone HMI, over speed limit.

That is, the driver is simply reminded of the speed limit by making it visible on the screen. This solution is a discreet way to warn the driver, audio warning would be much more invasive. We do not recommend any audible or blinking of the signs in this case. If/when the driver adjusts his/her speed to less than 3 km/h under the speed limit the screen should turn back to the previous figure. We suggest that this change happens only after three seconds has passed after the speed went below the speed limit. Allowing 3 seconds buffer on the screen avoids rapid blinking when driving close to the speed limit. We also recommend the 3 km/h buffer on the speed limit because of uncertainty in the speed measurements to avoid bad user acceptance.

4.4.2 Low emission zone

It is important to note that we in the case of the low emission zones assume that the driven vehicle includes the functionality where the driver can choose which energy source to use. I.e., that the driver can choose between running on electric power, given that the battery is charged, and running the vehicle on fossil fuel. As discussed above, it could be perceived as being confusing to receive alerts about that you are now about the enter a low emission zone when you actually are not. We therefore suggest that the zone rules should be that drivers should be informed 3 seconds after they arrive into the zone, and that the rules start to apply after 3 seconds. Therefore, when entering such a zone we suggest the screen in Figure 21 to be shown for 3 seconds.

Figure 21: Low emission zone HMI, entering.

We suggest using the same size in letters and sign as in the speed zone pilot. These 3 second warnings of a low emission zone when entering gives the driver time to change their energy source. After 3 seconds the screen is suggested to change to one of two alternatives. Alternative one is when fossil fuel is used, see Figure 22.

Figure 22: Low emission zone HMI, fossil fuel usage.

Alternative two is used when electric power is chosen, see Figure 23.

Figure 23: Low emission zone HMI, electric power usage.

In this latter case the battery sign could be used to indicate the level of electrical power remaining in the battery, i.e. the battery status.

4.4.2.1 Alternative HMI low emission zone

As distance-based charging within low emission zone is a concept within the GeoSUM project, an alternative is to present the user with the accumulated cast when driving within a zone. From the note Tveit (2019) the following adjustment to the HMI is suggested for this use-case, see Figure 24.

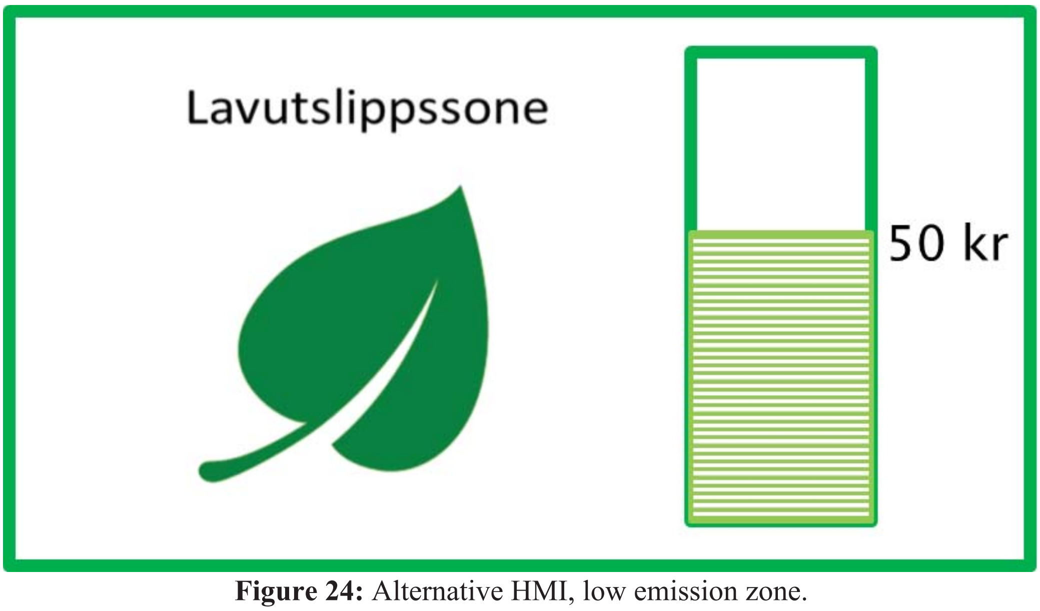


Figure 24: Alternative HMI, low emission zone.

Here the idea is that the user is presenter with a bar that fills up as one drive through the zone along with the actual accumulated distance-price of the trip within a low emission zone.

4.5 Literature

Carsten, O., & Martens, M. H. (2018). How can humans understand their automated cars? HMI principles, problems and solutions. *Cognition, Technology & Work*, 1-18.

Carsten, O., & Tate, F. (2018). *INTELLIGENT SPEED ADAPTATION: THE BEST COLLISION AVOIDANCE SYSTEM?*

Jenssen, G. (2010). *Behavioural adaptation to advanced driver assistance systems. Steps to explore safety implications* (Vol. 2010:124). Trondheim.

Kurani, K. S., Axsen, J., Caperello, N., Davies, J., & Stillwater, T. (2009). Learning from Consumers: Plug-In Hybrid Electric Vehicle (PHEV) Demonstration and Consumer Education, Outreach, and Market Research Program.

Mohamed, A. (2017). Human Machine Interface for Connected Vehicle: Requirements, Development and Assessment. Wyoming: Dept. of Civil and Architectural Engineering, University of Wyoming.

Tveit, Ø. (2019) GeoSUM piloter for brukerbetaling i lavutslippssoner. Note - NPRA.

Walker, F., Boelhouwer, A., Alkim, T., Verwey, W. B., & Martens, M. H. (2018). Changes in Trust after Driving Level 2 Automated Cars. *Journal of Advanced Transportation, 2018*.

Wellings, T., Binnersley, J., Robertson, D., & Khan, T. (2011). Human Machine Interfaces in Low Carbon Vehicles-Market Trends and User Issues. *Low Carbon Vehicle Technology R&D stream*.

5 Proposal for a reward program for the retrofit low emission zone pilot

Trond Foss

5.1 Introduction

This chapter describes a proposal for a reward program for participants in the GeoSUM project. The aim of the reward program is to incentivise drivers and car owners to participate in the pilot project.

The proposal is based on one of the most well-known case studies (Spitsmijden [1]) involving a reward system used in a pilot on possible changes in driver behaviour, performed in the Netherlands in 2006 on a section of the A12 highway between Zoetermeer and The Hague during the morning rush hour. The study entailed three phases: a two-week pre-registration period, a ten-week implementation period and a one-week post-registration period. The 341 study participants could choose between two types of reward systems, either cash reward or a point-based system leading to a gift at the end of the study (the smartphone used in the study, equipped with an app providing relevant traffic information on the road studied). Rewards were granted to participants choosing to either refrain from driving during the rush hour (07:30 - 09:30), opting for an alternative mode of transportation (e.g. biking, car-sharing or public transport) or working from home. The ten-week implementation phase was divided into three periods with different reward amounts. The cash rewards amounted to 3€ during the first three weeks and 7€ during the subsequent four weeks; during the remaining three weeks, drivers were rewarded 3€ for refraining from driving between 08:00 and 09:00 and 7€ for avoiding driving during the morning rush hour altogether. The maximum number of rewards granted to each participant depended on their rush hour driving frequency during the pre-registration period; drivers who had been driving during rush hour five times a week prior to the implementation phase were eligible for the maximum compensation. However, a driver who had only been driving three times a week had to drive two days without reward before being eligible for compensation on the third day (and potentially also fourth and fifth day).

5.2 Different reward principles

Principle 1: Participants are rewarded for a certain behaviour

In the cash-based reward system, drivers are granted money each time they opt for an alternative to driving during rush hour (such as avoiding the rush hour period or choosing an alternative mode of transportation). Each participant is assigned a personal reward account set to 0 NOK at the beginning of the study and onto which money is deposited for each positive change in driving habits. This principle entails the drawback that it may incentivise drivers to undertake more trips in order to increase their rewards. Hence, a threshold for the maximum number of rewards granted to each participant must be set, for instance within a day or a week. In the Spitsmijden case study, the maximum number of weekly rewards was set to five, and a prerequisite for reaching that maximum was that participants had been driving during rush hour five times a week also during the pre-registration period when no rewards were granted.

Principle 2: Participants avoid paying a fee for a certain behaviour

The reward system can also be designed so that a certain sum of money is deposited onto the participants' reward account at the beginning of the study. This sum then decreases each time a participant refrains from opting for a choice deemed desirable, and the amount of the decrease depends on how the various alternatives are valued. For instance, if the aim of the study is to incentivise participants to use public transport, the reward system can be adjusted so that no money is deducted for participants that can provide proof of public transportation travel, while e.g. car-sharing leads to a small fee and driving alone to a larger fee.

While both principle 1 and 2 entail rewarding positive travel behaviour, the perceived effects are different for the participants. In the first principle, the reward account *increases* when participants choose the travel modes that are preferred. In the second principle, choosing a travel mode considered positive simply leads to the account balance *not decreasing*.

Principle 3: Participants are required to change behaviour a certain number of times before being rewarded
A third principle entails that participants are required to change their travel behaviour a certain number of times before being rewarded a certain prize, for instance a lump sum of money, a gift card or a physical gift (such as a mobile phone in the Spitsmijden case study).

Reward account
In the first two principles, the balance on the reward account is monetary (see Figure 25, left axis). In the third principle, the balance will account for the number of times the participant has chosen an alternative deemed worthy of reward (Figure 25, right axis), or, alternatively, as the number of points that the participant has gained in the case where alternatives are valued differently. It is crucial that the reward account balance and transactions overview be readily available to the participants. In the Spitsmijden case study, participants were given a weekly summary of their activity, though a more user-friendly approach would be to set up a personal website ('My page') where participants can follow the progression of their account in real-time, both with respect to the account balance and the recorded transactions.

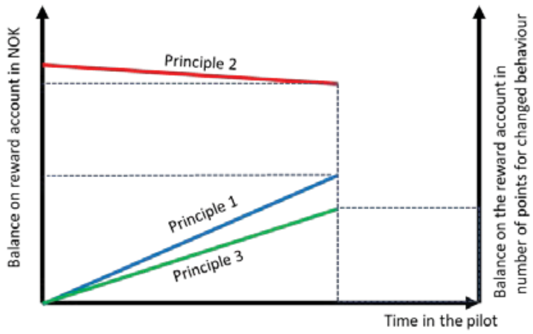


Figure 25: Illustration of the three reward principles

5.3 Proposal for a reward system

The application tested in GeoSUM entails that hybrid car drivers are charged a fee when they refrain from switching to electric mode upon entering predefined low-emission zones. The underlying principle is that drivers ought to be held accountable for the pollution associated with their driving by paying a fee that depends on how much emissions they are causing. Hence, low-emission or zero-emission cars lead to smaller or no fees, and hybrid car drivers are therefore incentivised to switch to electric mode upon entering a low-emission zone.

From the participants' point of view, the first reward principle may seem the most logical, i.e. rewarding good behaviour financially. This was also the principle applied in the Spitsmijden case study. One of the main goals of the Spitsmijden case study was to analyse how effective such a reward system would be in changing travel behaviour compared to a traditional mechanism such as introducing rush hour driving fees, i.e. comparing the effects of punishing drivers for using the road during rush hour as opposed to rewarding drivers for *not* using the road.

The second principle seems to be the most appropriate principle for the application being piloted in GeoSUM. A certain monetary amount is initially deposited onto the participants' reward account at the beginning of the study, and positive driving behaviour (that is, switching to electric mode in low-emission zones) entails that the account balance remains unchanged, while failure to do so leads to money being deducted from the account.

The first reward principle may incentivise participants to make active choices that lead to a reward; this incentive is not present in the second principle, where participants only risk losing part of their reward as a result of choosing a particular transport mode, route, etc. In the GeoSUM pilot project, a prerequisite for being faced with a choice that may affect the reward is that participants enter and exit some of the predefined low-emission zones. As such, the GeoSUM participation contract includes that the reward will only be paid if the participants fulfil certain driving requirements during the study period (e.g. that they enter / exit a low-emission zone a certain number of times each week).

The GeoSUM reward system relies on the following principles:

- The reward system is based on the second reward principle described earlier, including that participants are granted an initial monetary reward which decreases each time participants fail to switch to electric mode upon entering a low-emission zone.
- The initial reward sum is set to 1000 NOK (due to tax rules). The number of participants per car is limited to two.
- The account balance decreases by 3 NOK for each started kilometre driven on fossil fuel in a low-emission zone. In the low-emission zone in the city centre, the corresponding balance decrease is 5 NOK per started kilometre. In order to allow the participants time to perform the switch to electric mode as well as to account for lack of accuracy in the positioning system, the distance measurement starts 200 m after the car has been started and the trip begun.
- It is assumed that the entire geographical area where the tests are undertaken has been divided into zones so that all participants can encounter low-emission zones (and thereby be faced with the choice of switching driving mode) without having to change daily driving routines.
- All participants that successfully complete the pilot project following the established guidelines will be eligible to participate in a lottery in which five 2000 NOK gift cards will be awarded.

The pilot project leader agrees to:

- Delete all personal data as soon as their project purpose have been fulfilled or they have been anonymised
- Not use the data for any other purpose than the described project aim and research topic. This entails that the project leader will not, for instance, report any potential irregularities with respect to existing laws were such irregularities to be discovered along the course of the project.
- Not share the collected data with other partners in the project nor with third parties external to the project
- Keep the participants updated (at least once a week) on their reward account balance as well as on their recorded transactions
- Keep the participants updated on the pilot development and inform participants of potential changes in the project well ahead of time
- Contact participants that do not appear to be fulfilling their contractual duties judging from the registered behaviour in low-emission zones. The project leader reserves the right to cut the reward short in cases where participants repeatedly refuse to comply with the project leader's instructions.
- Pay out the rewards to the participants with no delay as soon as the pilot project has been performed

Participants agree to:

- Always prioritise their own and other's safety. This may for instance include refraining from switching to electric mode upon entering a low-emission zone if the traffic situation is such that switching driving mode might compromise the participant's ability to focus on road safety.
- Use the hybrid car for at least 10 trips during a pre-study period of two weeks (cumulative use in the case when one car is associated with two drivers). A "trip" entails a return trip; for instance, a trip from home to work will not be accounted for until the return trip has been undertaken as well. Moreover, the travel patterns during the pre-study period should preferably be representative for the participants' typical travel habits, e.g. driving to work, commercial centres or leisure activities. The pre-study period does not give basis for reward.
- Use the hybrid car at least six times a week (cumulative use in the case when one car is associated with two drivers). The minimum length of a trip is defined as 4 km. This means, for instance, that a return trip from the participant's home to a shopping centre located 1,7 km away will not be counted. A week begins on the weekday corresponding to the first day of the pre-study period. Furthermore, the travel patterns during the study period should preferably be similar to the participants' regular travel habits, e.g. driving to work, commercial centres or leisure activities.
- Inform the pilot project leader with no delay should they notice any irregularities associated with the project. Participants are also urged to keep a personal log of the trips undertaken in low-emission zones.
- Take part in interviews before, during and after the pilot project

5.4 Motivation for the 3 NOK per km fee

The 2014 travel survey performed in Trondheim concluded that 17 % of the trips undertaken were shorter than 1 km and 45 % of trips were in the range 1 - 2,9 km. This means that 62 % of trips were shorter than 3 km. Assuming that the average length of a trip is 4 km, using the car six times a week entails driving 4 km * 2 (return trip) * 6 (times a week), i.e. 48 km a week. If a 3 NOK per km fee is adopted, the maximum loss per week would hence be 3 * 48 = 144 NOK, if these 48 km were to be driven on fossil fuel inside a low-emission zone. As such, the maximum loss during the 6-week implementation period would be 864 NOK. In comparison, instating a fee of 0,5 NOK per km would only lead to a total loss of 144 NOK during the entire study period, which is arguably not a sufficient incentive.

5.5 References

[1] Donovan, S. (2010). Introducing Spitsmijden–experiments with peak avoidance incentives in the Netherlands.

6 Final design of the GeoSUM pilots

Per Johan Lillestøl

6.1 GeoSUM pilot with retrofit equipment

6.1.1 Technical setup

After a period of development and testing in several iterations the final solution was to use Alternative 2; Tablet/smartphone connected to OBD II dongle via Bluetooth. We used a Samsung Galaxy A10 smartphone running on Android v9.0 (Pie) operating system. The smartphone has a 6,2” HD screen with a resolution of 720 x 1520 pixels. The phone was installed in the cars using a car air vent clip holder. The phone was powered from a 12V USB Charge adapter, see Figure 26. An application to serve as an interface towards the test subjects was implemented and install on the smartphone by Q-Free, see Section 6.1.4 for screen shots.

Figure 26: Retrofit equipment

6.1.2 Recruitment and subjects

In order to recruit subjects to the eight-week pilot period the project team published information about the project and geofence technology in different media. We also recruited people through internal information channels in SINTEF, the Norwegian Public Roads Administration and Q-Free. Table 7 show an overview of the fleet of hybrid vehicles. Each car owner was invited to register two drivers for the trail.

Table 7: The test fleet for the retrofit pilot.

	Total	Mercedes	Mitsubishi	Volvo	VW
Oslo	18	0	6	11	1
Trondheim	28	2	14	9	3
TOTAL	**46**	**2**	**20**	**20**	**4**

The total number of subjects in pilot was approximately 80.

After signing up for the project the subjects received an "Information package" with extensive information about the project aim and data collection during the pilot. All drivers involved had to sign an agreement and a self-declaration before installation. The project team provided support services during the pilot period. The team were answering telephone calls and emails. The project also developed and maintained an online Q&A web site.

The subjects got a web-based questionnaire before the installation and pilot period, and a web-based questionnaire after the eight-week pilot period.

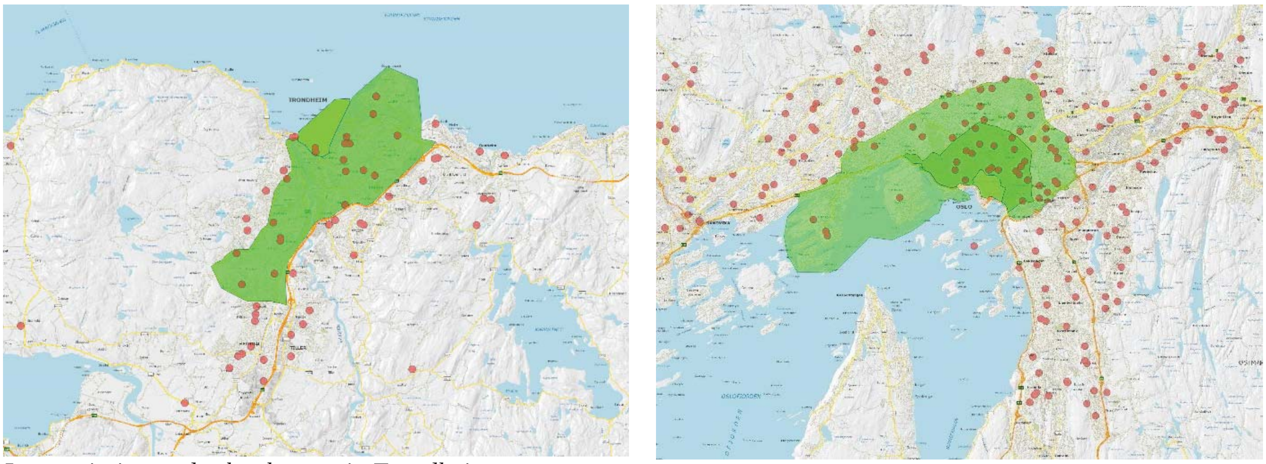
6.1.3 Definition of zones

Prior to test the project team defined low emission zones as well as school zones for the pilot. All schools in Trondheim and Oslo where identified by address and location[8]. The school zone was defined as a radius of 150 m around the school. Most roads in school surroundings have a speed limit of 30 km/h or 40 km/h. Where there is no interaction with school area roads with speed limit 60 km/h or more were excluded (see Figure 27).

After defining all zones as geographical objects, they were transferred to the Norwegian National Roads Databank (NVDB). The application in the vehicles got the geofences there.

Low emission zones were defined in 2 levels in Trondheim, and 3 levels in Oslo, see Figure 27. Central downtown area was defined as most expensive area for driving on fossil fuels. Pricing scheme for low emission zones are given in Table 8 below.

Figure 27: High speed level road excluded from school zone.



Low emission and school zones in Trondheim *Low emission and school zones in Oslo*

Figure 28: Geofences defined for retrofit equipment pilot.

The retrofit equipment currently supports non-disjoint zones, i.e. two separated areas must be made into two zone. However, holes in zones are supported. In addition, due to GPS inaccuracy, smaller fragments are not to be recommended.

Table 8: Pricing scheme for the retrofit equipment pilot.

Area	Inner (central) zone	Middle zone	Outer zone
Trondheim	6 NOK/km	NA	3 NOK/km
Oslo	6 NOK/km	4 NOK/km	2 NOK/km

[8] www.geonorge.no

6.1.4 The retrofit equipment pilot phase

The pilot period last for 8 weeks after installation of equipment in the car. The two first weeks was a black mode with no information in the display but collecting information from all trips. This data can be used as reference for analysis and evaluation. After the two first weeks the display showed map-based information about school and low emission zones.

The initial reward sum was set to 1000 NOK (due to tax rules). The number of participants per car was limited to two. Each participant (driver) received a weekly email with status and account information about the trips, see Figure 29.

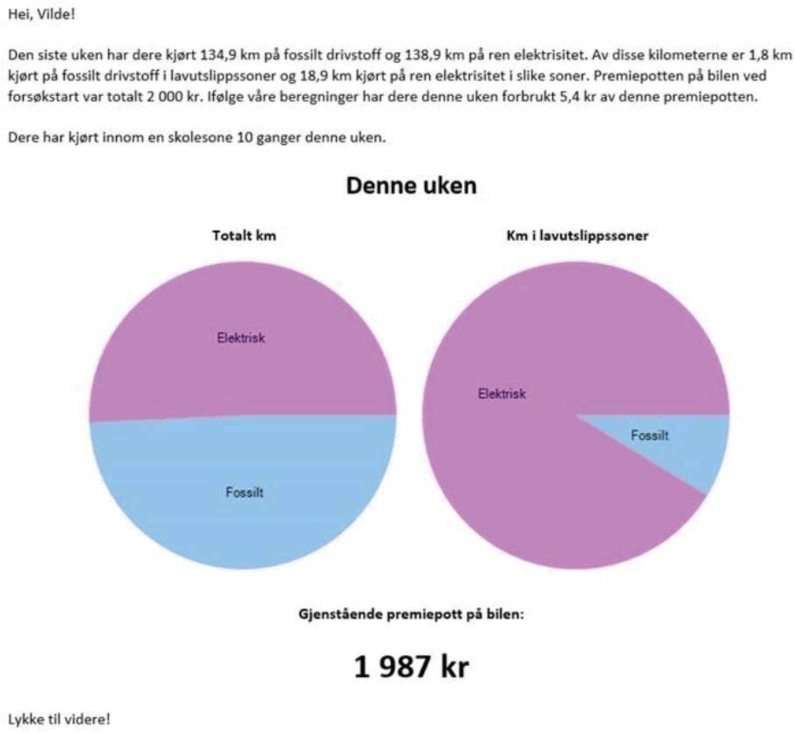


Figure 29: Example of weekly report sent to test subjects (in Norwegian). Information contains number of kilometres driven on fossil fuel or electric power outside and inside zones and number of school zones visited previous week, in addition to pricing and account information.

The following screen shots in Figure 30 show different information modes in the application:

1. Start-up screen (chose driver)
2. Black mode (no information on screen, data logging only)
3. Map overview showing school zones (red) and low emission zone (green)
4. Driving in a low emission zone (prize and car status is shown)
5. Driving in a school zone, warning sign is shown
6. Trip report (after each trip)

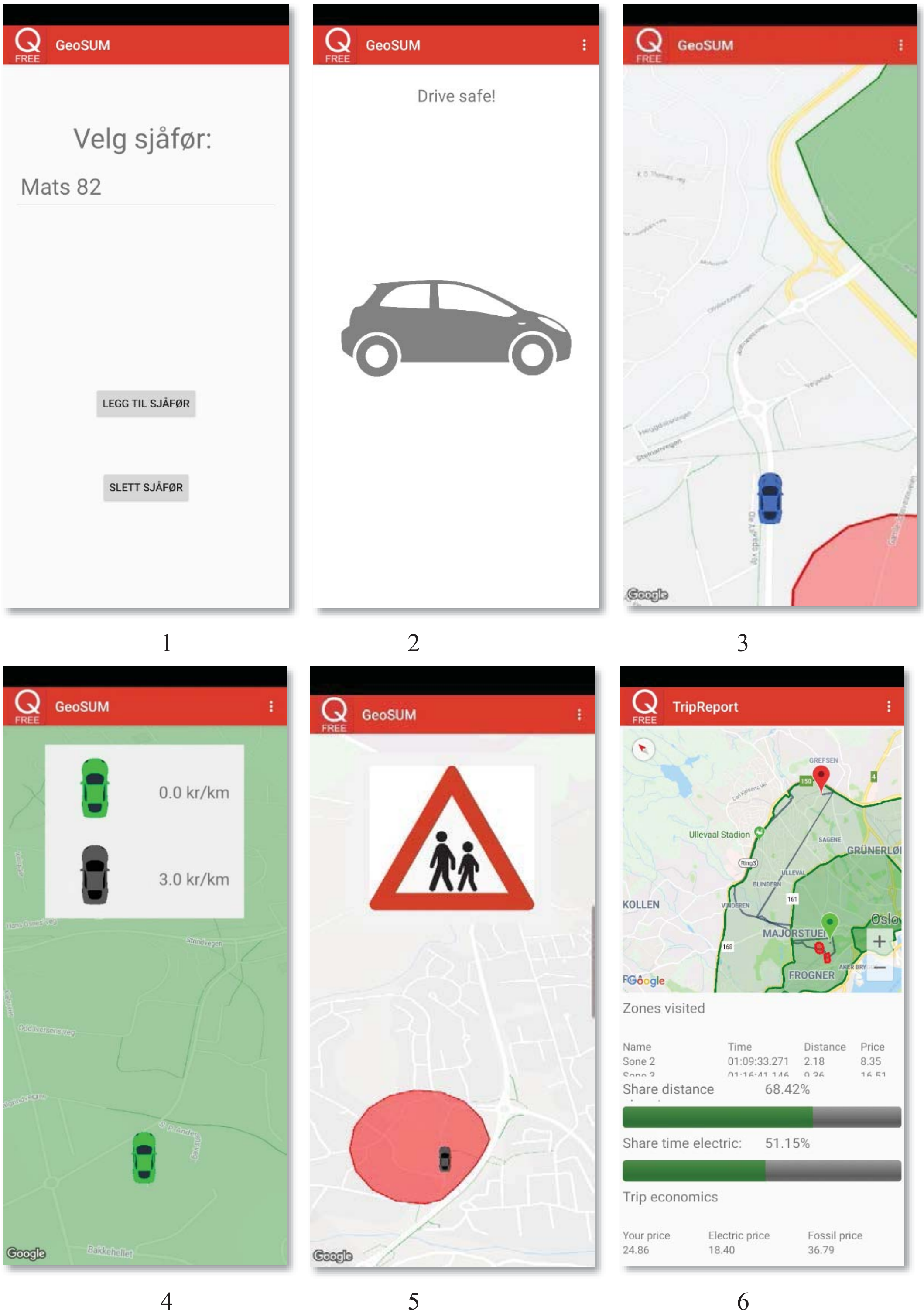


Figure 30: Retrofit equipment HMI screen shots.

6.2 GeoSUM pilot with integrated equipment

The GeoSUM pilot with integrated equipment was performed with one single vehicle provided by Volvo and took place in Trondheim only.

6.2.1 Recruitment and subjects

In order to recruit subjects to this test the project invited some of the participants from the retrofit equipment pilot in addition to recruit employees at the Norwegian Public Roads Administration. We also used social media to recruit some subjects. This resulted in a variety of age, gender and experience. The total number of subjects in test was approximately 50.

6.2.2 Technical setup (car)

The project was provided a special equipped test car from Volvo Cars Gothenburg. The car was a Volvo V90 T8 petrol hybrid, see Figure 31.

Figure 31: Test vehicle for the integrated equipment pilot.

The car is equipped with a prototype DIM (display) to provide information to the driver. This prototype DIM has been developed for Nordic Way 2, a European C-ITS pilot project where dynamic environmental zones is a part of the content in task 8. The HMI for the speed limit reminder function and school zones has been developed for GeoSUM. The car has also test software, a measurement computer to log a large variety of variables from the driving sessions and a GPS.

Test software is required in Volvos cloud as well to enable environmental zones, school zones and the active speed limit reminder function. The speed limit reminder function uses cloud data and the vehicles original sensors to read speed limit signs. There is also test software in Volvos cloud enabling the zone energy usage reports.

6.2.3 The integrated equipment pilot

This pilot was conducted as a test divided in three parts:

- Low emission zones - automatic switch from hybrid to pure electric (geofence)
- Active speed limit reminder – reduces the speed as a reminder if the driver is speeding when the speed limit is decreased.
- Active speed limit reminder in school zones (geofence)

All subjects used the same car to fulfil all three parts. The test lasted in total approximately one hour. All test drives were instructed and supervised by a test leader. The test leader gave information and instructions before each part of the test. The subject answered a small questionnaire on a tablet before and after each test.

The test took place in a semi-rural area located east in Trondheim near Dragvoll University campus, see Figure 32.

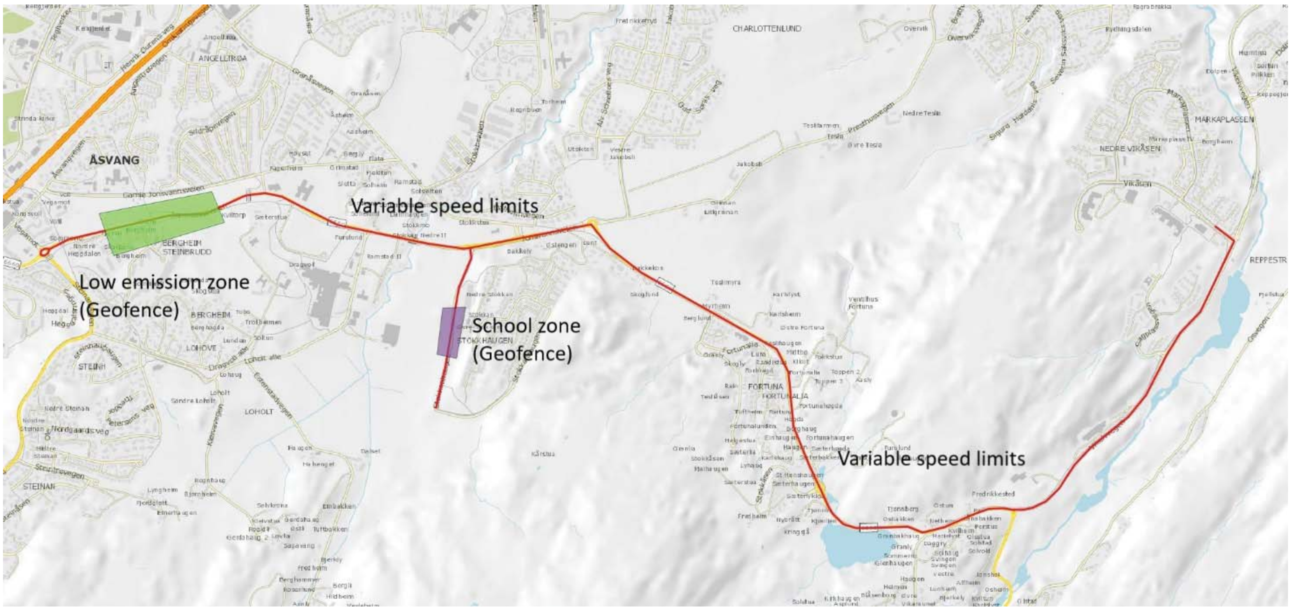


Figure 32: Test roads used for integrated equipment pilot.

6.2.3.1 Low emission zone test

Driving through the low emission zone in both directions was the first part of the test, see Figure 33.

Figure 33: Low emission zone for integrated equipment pilot.

The instrument panel (display) informed the driver about upcoming zone and automatically changed drive mode to pure electricity when entering the zone, see Figure 34.

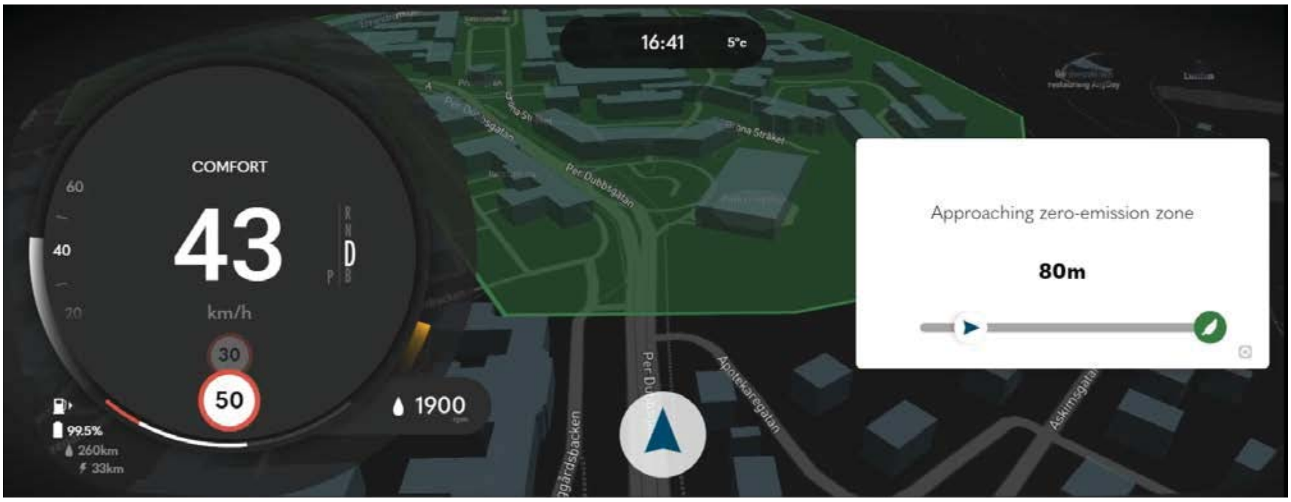


Figure 34: Integrated equipment HMI, approaching low emission zone.

When a vehicle is in a low emission zone, the flash showing that the vehicle runs on electricity are given a green colour, see Figure 35. A green frame is also added around the clock and temperature along with a small leaf sign.

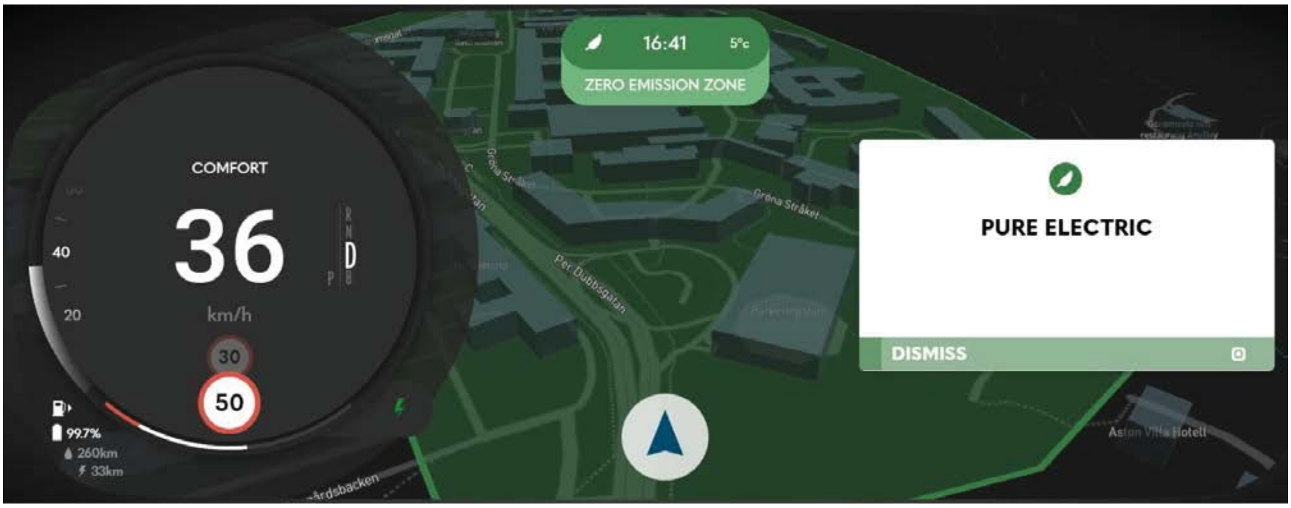


Figure 35: Integrated equipment HMI, inside low emission zone.

6.2.3.2 Active speed limit reminder

All subjects drove the 5 km long test for active speed limit reminder in both directions, see Figure 36. The section has in total seven speed limit reductions where the car assisted the driver to slow down to the lower speed limit.

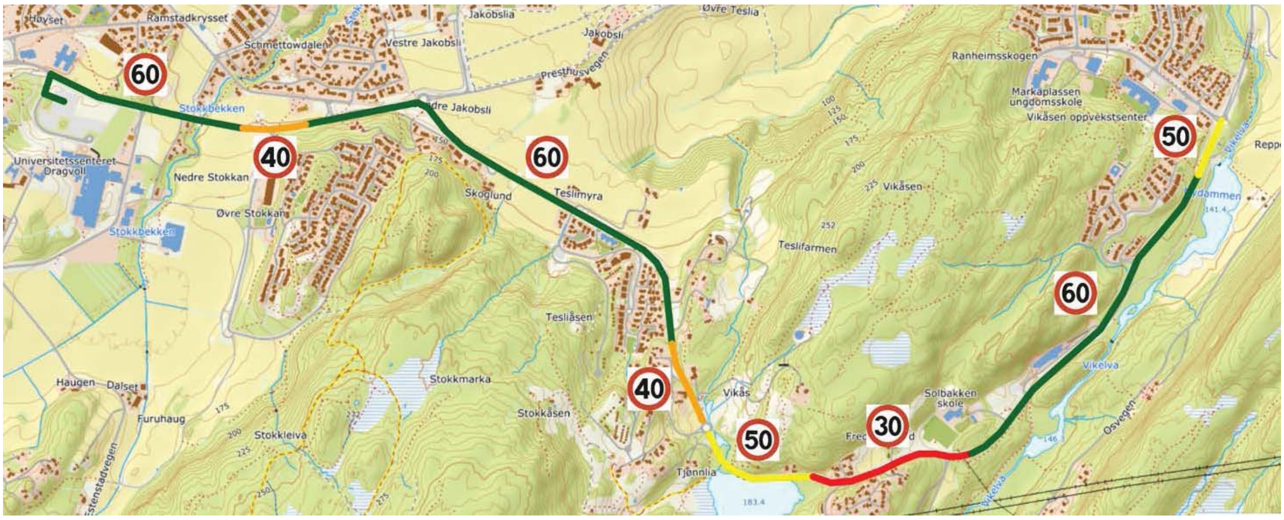


Figure 36: Active speed limit reminder test route.

The instrument panel gives the driver a pre-warning about the upcoming lower speed limit and shows a symbol with a pedal when it’s time to release the accelerator pedal, see Figure 37. The car actively assists the driver to slow down by using the electric engine to brake if needed. The driver can override this by depressing the accelerator pedal further down.

Figure 37: Integrated equipment HMI, active speed limit reminder.

6.2.3.3 Active speed limit reminder in predefined School zones (Geofence)

For this experiment we made a fictive school zone on a road section with low traffic. The speed limit is 50 km/h but the geofence (school zone) instructed the car to assist the driver to slow down to 30 km/h. This test was driven in both directions, see Figure 38.

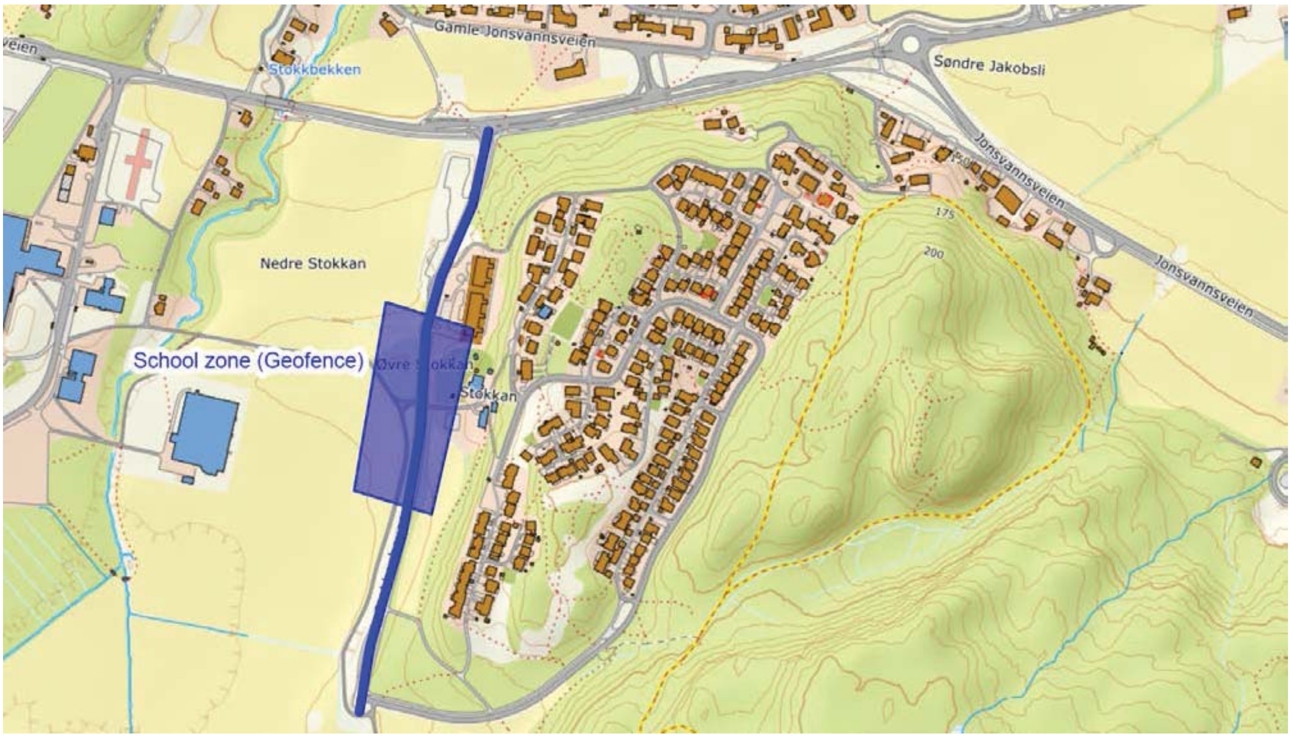


Figure 38: School zone for integrated equipment test.

The instrument panel (display) gave the driver a pre warning for the upcoming school zone, and the display showed the speed limit of 30 km/h when driving through the area, see Figure 39. When entering the zone, the active speed reminder was activated if needed.

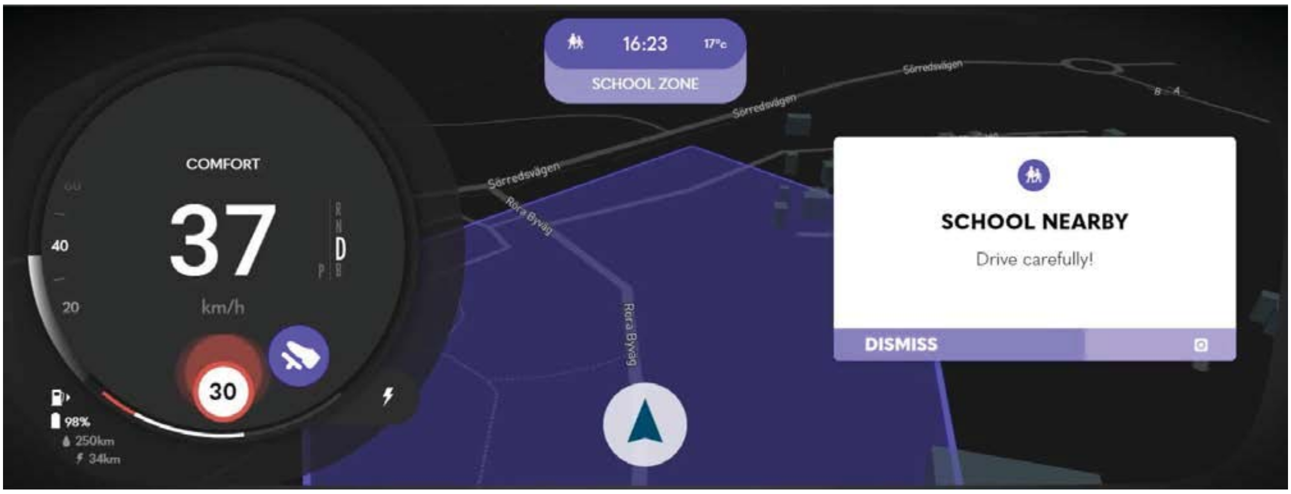


Figure 39: Integrated equipment HMI, inside school zone.

Technology for a better society

www.sintef.no