iQPilot

Public report

Project within	**Road Safety and Autonomous Vehicles**
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Content

1. Summary

The iQPilot project represents an important step towards the realization of a safe, energy efficient and fully autonomous transportation system of people and goods, completely integrated into everyday urban life.

This project followed immediately on from an earlier FFI funded project iQMatic that laid the foundations for autonomous transportation in mining and off-road areas, with the same industrial partners.

The intention within iQPilot has been to extend the knowledge from off-road areas to gain knowledge of how to drive autonomously safely and efficiently in urban areas with heavy vehicles.

This project supported the build-up of required competence and expertise in Sweden, both in industry and in academia, and led to advances within the areas of sensor technology, sensor fusion and perception, localisation, mapping, artificial intelligence, controls and motion planning.

The project utilised 2 full sized city buses from Scania as heavy vehicle test platforms for validation and verification of technology developed within the project, as well as a logging vehicle from Veoneer.

The key aim at the start of the project aimed to enable test and demonstration of the following scenarios;

1. Autonomous driving of individual vehicles, capable of safely navigating complex road situations involving other road users such as cars, pedestrians and bicycles;
2. Individual buses safely and autonomously navigating in and out of bus stops;
3. Coordinated driving of two vehicles, in urban environments (platooning).

By the end of the project, a strong technical basis has been developed to allow parts of the first 2 scenarios under test track conditions, or under limited ODD's (Operation Design Domains), but additional development and research must continue after this project to allow under real life conditions.

The 3rd scenario related to platooning was not completed during the course of the project and has become increasingly obsolete.

Scenarios that were looked at during the course of the project that were not originally intended were;

4. Remote Driving of a vehicle from a control centre environment over 5G
5. Autonomous driving of buses in open areas and depot environments

The project had some presence in the Connected Mobility Area (CMA) / Test Site Stockholm area.

The key industrial and academic partners in this project have been;

- Scania CV AB (lead applicant)
- Veoneer AB
- KTH (Robotics, Perception and Learning)
- Saab AB (withdrawn before end of project and replaced by Scania)
- Ericsson (Not directly funded by project)

The project iQPilot ran in parallel to a another FFI project iQMobility that intended to look at aspects related to operating of city buses in a complete transport system, effectively delivering vehicles to that project.

The projects iQPilot and iQMobility were brought to a technical end on June 30th 2020 in a 2 part webinar, where the use cases and technology that were worked on were showcased. This webinar was together with all project partners and comprised 2 parts;

- Part 1; overall project summary and showcases
- Part 2; technical results dissemination (in 3 streams for iQPilot and associated projects + 1 for iQMobility)

2. Sammanfattning på svenska

Projektet IQPilot representerar ett viktigt steg mot realisering av ett säkert, energieffektivt och fullt autonomt transportsystem för människor och varor integrerat i stadens vardagsliv.

Med samma parter som ett annat FFI-finansierat projekt kallat iQMatic kopplade detta projekt an där man la grunden för ett autonomt transportsystem inom gruvor och områden utan vägnät.

Målet inom iQPilot har varit att utöka kunskapen från körning i gruvor och öppna fält till hur man kör autonomt säkert och effektivt i stadsmiljö med tunga fordon.

Detta projekt har stöttat industrin och den akademiska världen med att bygga upp kunskap och ta framsteg inom områdena; sensor teknik, sensor fusion och perception, lokalisering, kartering, artificiell intelligens, kontroll och rörelseplanering.

Två fullstora bussar från Scania har använts i projektet för validering och verifiering av den teknik som utvecklats, även ett loggfordon från Veoneer har nyttjats.

Ambitionen från start har varit att möjliggöra prov och demonstration av följande scenarion:

1. Autonom körning med ett fordon som säkert kan navigera på en väg med svåra situationer som innefattar andra fordon, gångtrafikanter och cyklister.
2. Autonom körning med ett fordon som säkert kan navigera in och ut ur busshållplatser.

3. Autonom körning med två fordon som samarbetar i stadsmiljö, sk kolonnkörning(platooning).

En stark teknisk bas har utvecklas i projektet för att möjliggöra delar av de första två scenariona på provbana eller med begränsad ODD(Operation Design Domain). Fortsatt forskning och utveckling måste fortsätta efter projektet för att möjliggöra körning under mer verkliga former.

Det tredje scenariot slutfördes inte och dess värde minskade under projektets gång.

Scenarion som inkluderades i projektet men som inte vad med från start;

1. Fjärrstyrning av fordon från ett kontrollcenter via 5G.
2. Autonom körning av bussar på öppna ytor och depåer.

Projektet nyttjade bland annat testplatsen Connected mobility area (CMA) i Stockholm.

Nyckelparter för detta projekt har varit:

- Scania CV AB (Huvudsökande)
- Veoneer AB
- KTH (Robotics, Perception and Learning)
- Saab AB (Hoppade av och ersattes av Scania)
- Ericsson (Ej direkt finansierat av projektet)

Projektet iQpilot drevs parallellt med det FFI-finansierade projektet iQMobility som utforskade aspekter kring hantering av stadsbussar som ett komplett system, samma fordon kunde användas i båda projekten.

Projekten iQpilot och iQMobility avslutades tekniskt den 30 juni 2020 i ett tvådelat webbinarium där scenarion och tekniken demonstrerades. Alla parter deltog i webbinariet som var indelat i två delar;

- Del 1; Projektsummering och demonstration.
- Del 2; Detaljerade tekniska resultat(i tre strömmar för iQPilot och närbesläktade projekt och en för iQMobility)

3. Background

In the present global environment, there is a huge emphasis on the autonomous driving industry. Since the start of iQPilot, there is a trend towards mainstream OEM’s and Tier 1 suppliers working towards “robo-taxi” style autonomous vehicles for transportation of people and “pod-buses” that are smaller than typical style buses (sometimes much smaller, with 8 to 12 passengers). For example, VW has unveiled “Cedric” and started running trials with retro-fitted autonomous Golfs in Hamburg,

There is also a trend towards that many OEM’s have started to pair up with, invest in and purchase non-traditional suppliers of autonomous drive software applications that have grown out of start-ups. For example, VW and Ford both made large investments into Argo AI. Similarly GM purchased Cruise with the goal of developing robo-taxis.

Similarly, many Tier 1 suppliers have also made large investments and purchase of companies focussed on robo-taxis or pod-buses, or to increase their capability to deliver autonomous solutions such as ZF's acquisitions of 2Getthere (pod-buses) and TRW to broaden their component portfolio towards autonomous drive solutions. Or as another example, Aptiv purchased nuTonomy as a sringboard into robo-taxes.

One outlier remains Tesla, in the sense that they continue their drive towards full-autonomy as a standalone OEM, remaining confident in their own ability to deliver a fully autonomous vehicle and robo-taxi solution in house. Even in 2020, Elon Musk proclaimed that by end of 2020 they would release full autonomy into their fleet. This ambitious goal should be treated with some level of caution, but nevertheless the company has made great strides in autonomous driving and data collection from the field.

In the heavy vehicle industry, several OEM's have unveiled prototype autonomous vehicles for a variety of different scenarios. Sweden has been particularly strong in this area, with Scania, Volvo and newcomer to the scene Einride having their own demonstrator or pilot vehicles showcased in a variety of forms based on their in-house efforts. Daimler also has demonstrated various autonomous vehicles and also started testing together with its partner Torc Robotics in the US.

Given the challenges of bringing autonomous vehicles to the road, there is also a general trend that some companies such as Waymo that had previously been focussed towards autonomous development for robo-taxis are starting to realise that the heavy vehicle industry could be easier to focus on in the short term.

Broadly speaking there is an industry wide consolidation of efforts to accelerate and deliver autonomous transport solutions across the automotive and transportation industries.

But it remains an extreme and complex challenge to realise autonomous vehicles out on the roads. Deployments in general remain small scale and localised to specific areas or confined to specific routes. In this sense, it remains easiest to focus on industrial solutions for goods and people, rather than large scale mass-produced passenger vehicles. It will take still many years before there is possibility for generic and safe fully autonomous and driverless vehicles for the general public.

4. Purpose, research questions and method

The iQPilot project was broken down into 13 work packages to drive the work and reach its end goals[1], as per Figure 1.

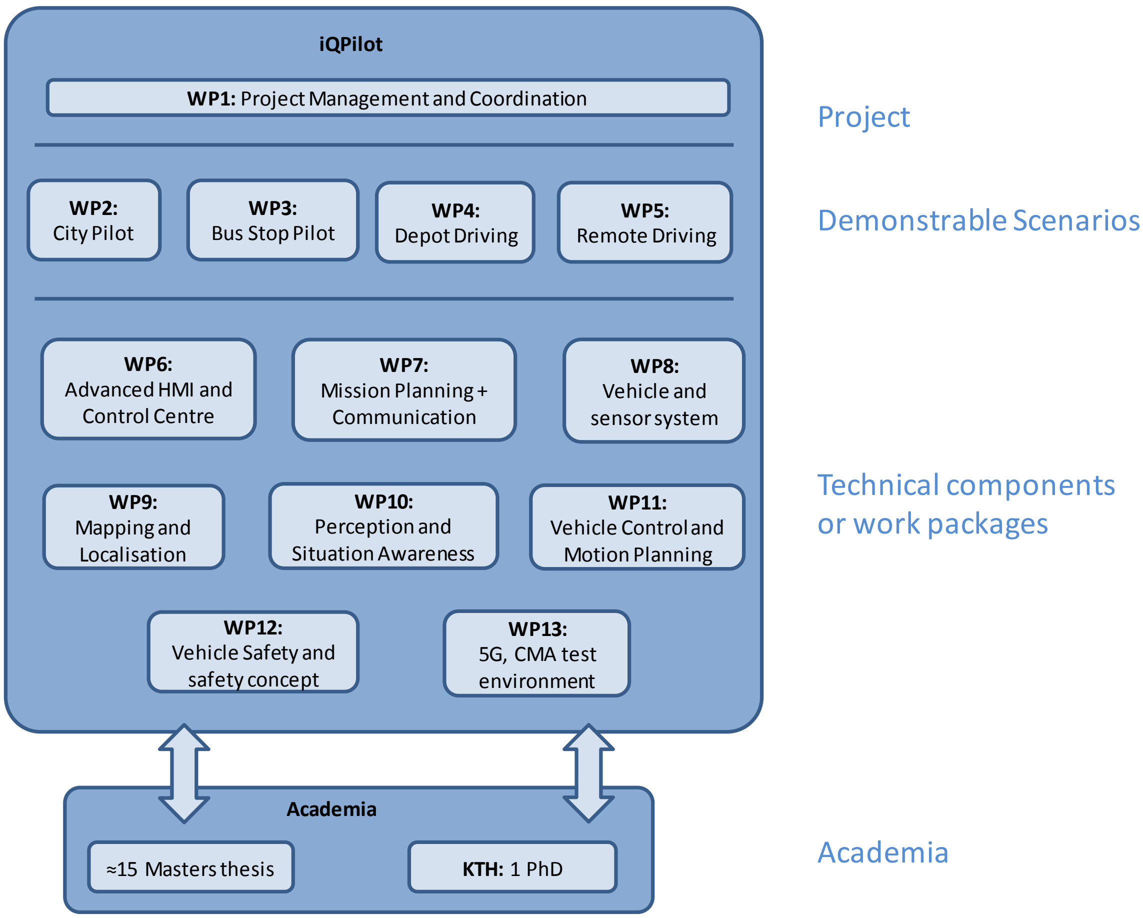

Figure 1 - iQPilot Work Packages

From these work packages, we can explain;

Purpose of the project; to demonstrate the feasibility of autonomous vehicles in public transportation and to understand the fundamental technical needs to achieve this. This is subdivided into 4 showcase areas;

[1] The project started with 10 work packages. Some work packages were subdivided compared to the start (e.g., to create a vehicle system work package), some new based on new understanding, some removed due to reduced relevancy.

1. **City Pilot (WP2)**; to safely drive autonomously in scenarios relevant for autonomous driving in urban areas, taking into account the static and dynamic environment of the vehicle
2. **Bus Stop Pilot (WP3)**; be able to drive autonomously into bus stops in urban scenarios to allow a city bus to drive a complete drive cycle with passengers as its primary function.
3. **Depot Driving (WP4)**; to be able to handle the driving in depot areas where vehicles would be stored when not operating to service passengers.
4. **Remote Driving (WP5)**; to be able to drive an autonomous vehicle remotely if there is a need for human interaction to assist the vehicle in continuing with its mission

4.1. Research questions;

- The key question in this project is what do we require technically to allow us to demonstrate our showcase areas? This primarily is answered through the technical components of the project and the research questions with each of these areas;
  - **Advanced HMI and Control Centre (WP6)**. An autonomous vehicle, where the ultimate aim is for *driverless* vehicles cannot exist as an isolated system. It is part of a larger transport system, where control and supervision of the system takes place in a control centre context with human operator at the transport system level. This leads to questions around;
    - How does the operator understand on a *strategic* level to understand the context of what the vehicle should do and where it is going?
    - How does the operator understand on a *tactical* level to understand the current situation of the vehicle at the immediate period of time?
    - How does an operator interact with an autonomous vehicle?
    - To what extent does an operator *need* to interact with an autonomous vehicle?

    Within the iQPilot project, the control centre is looked at a relatively vehicle centric level and complemented by the iQMobility project that focusses at the higher level transport system and operational level.
  - **Mission planning and communication (WP7)**. How an autonomous vehicle understands its purpose and executes its mission in conjunction with the higher level control centre functionality. This leads to questions around;
    - What is the strategic mission plan for a fleet of vehicles and the individual vehicles in the fleet?
    - How should an autonomous vehicle's mission be communicated between control centre and individual vehicles?
    - How should the vehicle mission be constructed?
    - How and when should the vehicle refine the mission plan on a strategic and tactical level?
    - How should the vehicle respond to disturbances in the plan?

- **Vehicle and sensor system (WP8)**. A vehicle intended for urban operation must be equipped to make it autonomous from an actuation point of view and equipped with sensors from a perception point of view. This leads to questions such as;
  - What sensors are required for autonomous operation in urban areas and why?
  - Where should the sensors be fitted in the vehicle for optimum function and safety?
  - What range and accuracy of the sensors is required? Possible?
  - What support is required on an autonomous vehicle chassis and body to allow the vehicle to drive autonomously?
  - Are there special requirements to make an autonomous bus?

  As this project builds up on an earlier project iQMatic (autonomous mining), many basics were established through that project and knowledge carried over into iQPilot for continuation and to take to the next level.
- **Mapping and localisation (WP9)**. An autonomous vehicle must understand its own location to be able to drive and have some representation of the road to be able to drive autonomously. Under most circumstances an autonomous vehicle on real roads will be able to use GPS based technology. In other circumstances, such as in some depot areas, or terminals the vehicle may need to drive inside buildings, or even underground. This leads to research questions;
  - What technology is required to allow a vehicle to drive autonomously and safely in areas where GPS is available?
  - What technology is required to allow a vehicle drive autonomously and safely in buildings or underground where GPS is *not* available
  - How accurately is it possible to locate the vehicle?
  - What sort of mapping technology is optimal for autonomous driving in urban areas?
  - What sort of information is required for autonomous driving in urban areas?
  - To what extent is mapping of the local environment required?
- **Perception and Situational Awareness (WP10)**. An autonomous vehicle must understand its static and dynamic environment to be able to drive autonomously. This leads to research questions;
  - How should an autonomous vehicle understand the *static* environment around the vehicle based on the sensors and information available to the vehicle?
  - How should an autonomous vehicle understand the *dynamic* environment around the vehicle based on the sensors and information available to the vehicle?
  - Based on the static and dynamic environment, how should the vehicle interpret the immediate situation?
  - How can the vehicle understand how the situation will unfold in the future? (e.g., in 5 or 10 seconds time)
- **Vehicle Control and Motion Planning (WP11).** An autonomous vehicle must drive within its immediate environment to achieve its mission, based on its location, destination and surroundings (both sensed and mapped). This leads to questions;

    - How should the general longitudinal and lateral motion of the vehicle be planned for both comfort and safety?
    - How should the longitudinal and lateral motion of the vehicle be planned in relation to the layout of the road?
    - Based on the planned motion of the vehicle, how should the longitudinal and lateral motion of the vehicle be executed from a controls perspective?
    - How accurately is it possible to control the vehicle laterally and longitudinally? What is sufficient?
- **Vehicle safety and safety concept (W12)**. Autonomous vehicles are and will be safety critical systems. On the other hand autonomous vehicles are not yet a mature technology. This led to the question of;
    - How can an autonomous vehicle be engineered or operated for safety of the vehicle and other agents in the environment, but still allow development to progress at a high pace?
- **5G and CMA (Connected Mobility Arena - Kista) (WP13)**. One of the newest areas of communication during the iQPilot time frame has been 5G, with high bandwidth and low latency. This led to the general question of;
    - What benefits can 5G bring to the autonomous vehicle area?
    - What considerations must one make to usage of 5G in a safety critical context?

  5G installations from proof of concept, through to true 5G installations at later points of time were installed in the CMA in Kista, hence the intention to work in this area. This will be covered in more detail in the results section.

Several other areas were utilized by the project group, but not directly within the project context or as defined work packages, but which can be understood to contribute to the success of the project. These were not tackled as areas with research questions and emerged during the course of the project, but are worthy of mention in the results section;

- **Data logging**. Multiple areas of the project required extensive logging to either understand the needs or behavior of the system, as well as make some first steps into AI.
- **Simulation**. Due to the practicality of testing of real systems, much physical effort has been replaced by developing simulations of relevant environments.

4.2. Research Method;

- iQPilot has been driven as an applied research project, with the aim of reaching a TRL 6 level (System prototype in a relevant environment) for the overall use cases. Due to safety constraints for such prototype systems, the environment for driving autonomously has been a test track environment. Several methodologies have been employed for achieving the primary purposes and can be viewed as also achieving several different technical readiness levels.

- Technical research and application to achieve our TRL 6 demonstration of the main autonomous city drive and bus stop pilot showcases through the following process;
    - Survey and observation of a key on-road route in Södertälje to identify key features to work on to deliver the showcases
    - Collation of the surveys into a scenario catalogue
    - Prioritization and publication of the surveyed scenarios to the development groups to understand what would be the content of the demonstrable features and functionality for the project
    - Identification of areas on the Scania test track equivalent to areas from the on-road survey to allow the scenarios to be systematically developed, tested and brought together into a continuous demonstration sequence
- Test of sub-systems in intended environments with manually driven vehicles to benchmark the final system performance (TRL 5 or 6), such as;
    - Test and evaluation of perception systems from Scania and Veoneer on the key test-route in Södertälje to have a common frame reference for all participants of the project in a real urban environment
    - Test and evaluation of perception, situational awareness and localization systems on key-test routes including selected routes in Södertälje, Kista (CMA), Barkarby and on the E4 motorway between all these areas
- Applied research on individual sub-systems in all working packages (TRL 1 to 6)
    - Formulation of required capabilities and functionality based on analysis of projected usages of autonomous vehicles in the target environment
    - Identification of possible technology based on research and understanding state-of-the-art solutions in the academic and industrial research domains
    - Evaluation and selection of technology based on research and experimentation of the identified possible solutions
    - Development of prototype solution to confirm technology selection
- Application of already developed working solutions in the autonomous platform to demonstrate suitability for new scenarios. For example;
    - Generation of maps and open area planner in depot areas to show possibility to drive such showcases by using technology developed for different projects in a different / not originally intended environment

5. Objective

At the start of the iQPilot project, the following key research areas were detailed in relation to the strategisk färdplan:

- Programme area A (analys, kunskap och möjliggörande teknik): development of new HMI for control centres, for the management of autonomous transport systems;
- Programme area B (grundläggande säkerhetsegenskaper hos fordon): development of new algorithms for adaptive, optimized vehicle manoeuvring; new functions for scene interpretation and collision avoidance;
- Programme area E (intelligenta och krockundvikande system och fordon): new techniques for advanced, autonomous manoeuvring; development of sensors and sensor fusion techniques for improved safety;
- Programme area G (automatiserade fordon i transportsystemet): development of functions for partial and full vehicle automation within urban environments.

From the outcome of the project, we had achieved results in all of the intended programme areas. These will be detailed in the end results and summary.

In more general terms, an additional objective was to maintain the competitiveness of Swedish automotive manufacturers, in the context of the high development costs associated with operations in Sweden. This was identified by means of innovation and constant research through the cooperation of industrial and academic partners, and developing strategic competences in Sweden.

6. Results and deliverables

Our key results for our main showcases can be described as follows;

6.1. City Pilot (WP2);

- This was the main showcase for iQPilot that includes running an autonomous vehicle through a continuous series of on-road scenarios according to Figure 2
- This was run together with iQMobility as a full drive cycle, running out from a depot to a bus route, then through a series of 5 timetabled bus stops of different types
- Video footage for this showcase was shown as a continuous (but sped up) sequence in the final iQPilot webinar and released also as a separate self-contained video

- Footage for several other extended iQPilot scenarios that did not fit into the main road layout and human resource possibilities were also show-cased in a different part of the test track
- During these demonstrations, it is possible to see in the video that the driver does not need to use the steering wheel for controlling the vehicle. The vehicle maintains also full longitudinal control, though this is not visible in the camera angle.
- This demonstration was pre-recorded without visitors to Scania due to the corona-virus pandemic, instead of with visitors as originally intended
- This demonstration ran first time during our recordings and almost without issue. The only unintended events in the recorded version of the video were;
    - A planned, but harsher than desired stop on entrance to the roundabout
    - That the driver touched some controls at the side for various reasons
- This demonstration was run with all integrated sensors and perception on board the vehicle, assisted with V2V (vehicle to vehicle) information between vehicles in the demonstration using Ericsson's Proof Of Concept 5G antenna
- This demonstration utilized a suitable Minimum Viable Product to show the possibility of an autonomous bus to run to a complete drive cycle, including interacting with other vehicles in the environment
- It must be noted that there are still many scenarios that were not covered in the demonstration, that would have to be solved for a real world deployment, but this formed a solid basis for future work
- The demonstration used the 1st iQPilot vehicle with a "2D" sensor configuration more suitable for flatter ground
    - In this hilly test track environment, the onboard perception needed to be filtered in a way to filter out ground detections, which compromises object tracking
    - The 2nd iQPilot vehicle with "3D" sensor configuration would have been a better choice, but the software was not ready in time to substitute for the demonstration

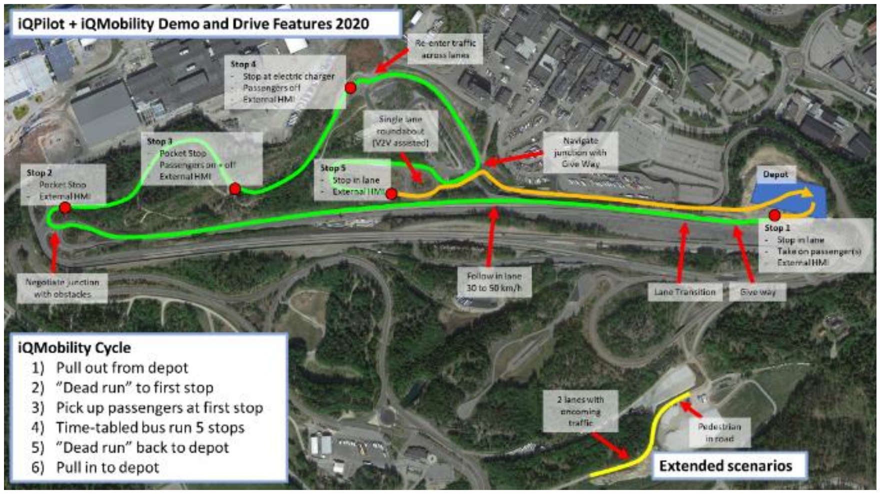

Figure 2 - iQPilot and iQMobility Drive Cycle

- Footage of key scenarios executed during the main showcase drive can be seen in Figure 3 and Figure 4 (but recommended to watch the video version for clarity)

Figure 3 – Footage from key scenarios executed during the main showcase drive

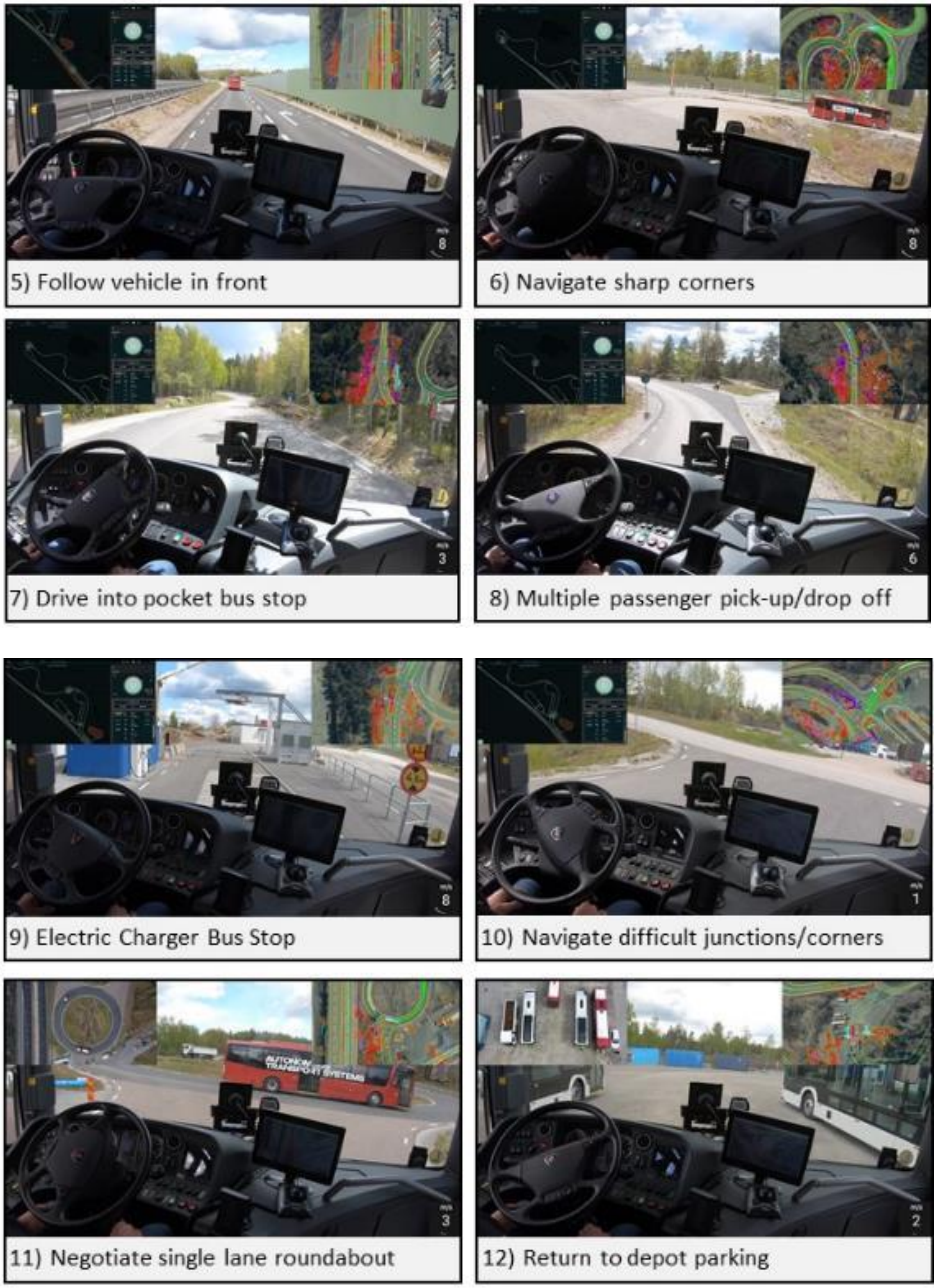

Figure 4 - Additional scenarios executed in the main drive showcase

6.2. Bus Stop Pilot (WP3);

- Within the drive cycle in Figure 2, autonomous driving into pocket bus stops, electric charger stops and simple stops in the road were showcased according to the layout of the road
- This included allowing passengers on and off the bus stop at 3 of the stops with a simple level of autonomous door operation
- Footage from some of the bus stops can be seen in Figure 3

6.3. Depot Driving (WP4);

- This was not one of the main featured demonstrations, but footage was collated from the drive scenarios indicated in Figure 5 and separately collected footage to show
  - Driving between different stations in the depot
  - Driving within structured and unstructured areas of the depot
- This was put together to highlight that a large proportion of depot functionality can be achieved through the level of functionality developed during the course of the project by laying out suitable road or open areas into depot areas
- We highlighted our demonstration vehicle parking between 2 other buses in our depot area.
- We highlighted the work that had been done with Landmark Based Localisation to allow driving inside buildings for depot areas, or underground and presented results from road areas.
  - Due to time constraints, we were not able to film extensively this within the depot area, but this was explained in more detail in one of our results webinars.

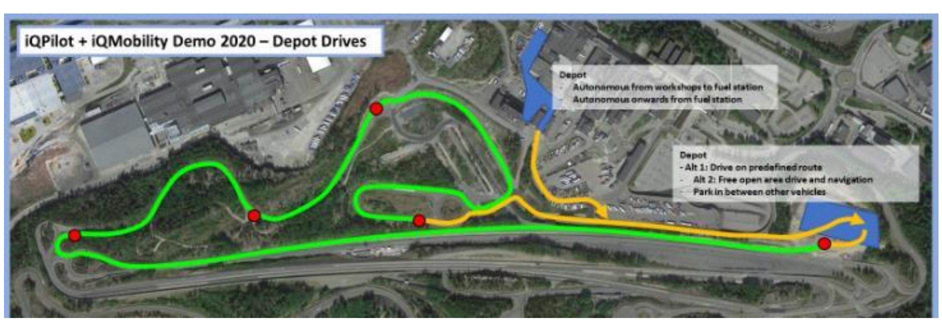

Figure 5 - Depot Drive Demonstrations

Figure 6 – Sample footage of the iQPilot demo vehicle #1 driving autonomously to a fuel station at Scania Technical Centre in the depot area

6.4. Remote Driving (WP5);

- This was one of the main drive use cases developed between Scania and Ericsson to show Remote Drive functionality in the first years of the iQPilot project
- Remote Drive was implemented on;
  - 1 remotely driven iQPilot bus, where the first trials were made in an open area according to the following YouTube link
    https://www.youtube.com/watch?v=lPyzGTD5FtM
  - 1 remotely driven truck loaned from iQMatic (due to vehicle availability) where first trials on a road based area were made according to Figure 7
- The solution included;
  - Driving station control interface at a remote station with a steering wheel, accelerator and brake for the remote operator
  - Forwards looking view for the remote drive operator, with the camera positioned to allow rear view of the mirrors
    - Note; the preferred solution would be streaming of additional cameras for the rearwards facing view
  - Strategic view of location of the vehicle globally with respect to the world and the vehicle
  - Virtual instrument cluster showing speed, gear, and other features based on an instrument cluster from another real prototype
- The key positive result is that it was possible to demonstrate that an autonomous vehicle could be driven from a remote drive situation
- Key observations with this solution going forwards were that
  - Latency was good in general with the overall video feed and round trip for data between antenna and core network for this scenario

- Latency of the control loop as implemented was too slow, but effort was not put in to resolve this
- 5G provides good possibility for prioritized network traffic on the radio level, but needs to be matched by prioritization also in the general network level to ensure data packets are not dropped

Figure 7 – Remote Drive Demonstration. The demonstration comprised a control station, forwards view in the vehicle, strategic map information, external view of the vehicle and mirroring of on-board HMI

6.5. Advanced HMI and Control Centre (WP6);

- A cloud / web based control environment ICE (Intelligent Control Environment) was developed over the course of the project. On the basic level this was developed as a common interface between buses and truck.
- This interface was developed to provide the remote operator in the control centre with;
  - Real time strategic information regarding location and speed of every vehicle in a fleet, based on real time position reporting from the vehicle
  - Real time information regarding the vehicle's current mission and behaviour
  - Tools to allow interaction with the vehicle remotely, such as ways to tell the vehicle to move to a certain location (Click and Drive), open doors, honk the horn, etc.
- The target level of this interface aims to have the vehicles in constant operation with the remote operator monitoring the vehicle and interacting only if necessary
  - The desired concept is that the vehicle is sufficiently self-sufficient not to need to provide on-board or external video feeds

- It is noted however that many control centre operations do provide this as a tool for the operator; most demonstrations with this system have to some extent used on-board video for context
- This “basic” control interface has been the basis of extending a fleet of vehicles to operate as a complete bus transport system as implemented in the iQMobility project (see the project report for that project for further details)
- The general allocation of fleet vehicles and management is intended to be autonomous without interaction by operator, other than for issue resolution
- It is envisaged that this interface would also be the integration point for remote driving of an autonomous vehicle as part of a single unified application

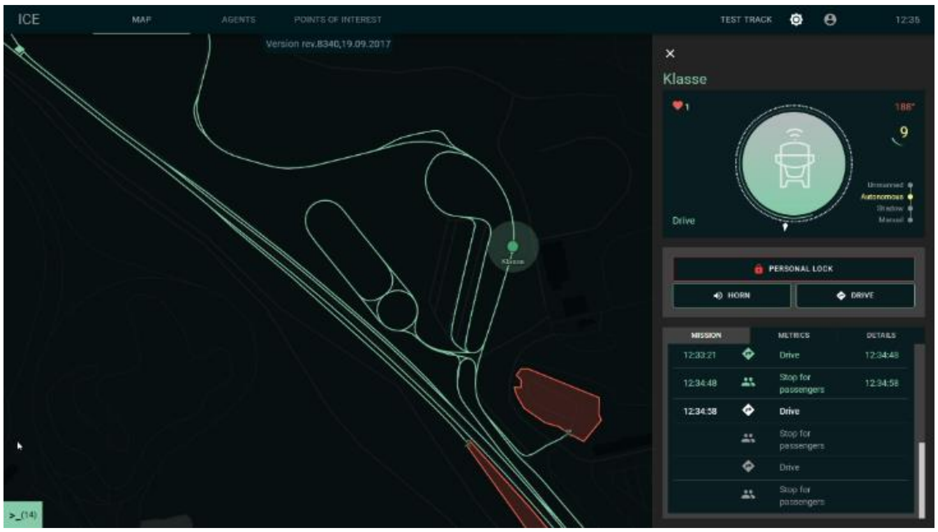

Figure 8 – ICE (Intelligent Control Environment). Scania’s offboard vehicle control interface

- An HMI system onboard the system “PlanGui” is also used to complement the offboard control system, as per Figure 9
    - This system is primarily for understanding of what the vehicle is doing in any given time for development purposes
    - Although not how one would expect a fully driverless vehicle to operate in a real deployment, this is key for a research and development perspective to understand the operation of a vehicle

Figure 9 – PlanGui. The onboard HMI system

6.6.Mission planning and communication (WP7);

- Commands to the vehicle have been carried from the ICE / strategic planning cloud server to vehicle via internet and 4G or 5G connection at different parts of the project
  - As the commands are very high level, at the mission level, even 4G is sufficient
  - The command and communication has used protocol buffers for point-to-point communication
- It has been possible to form a common mission and command interface that is able to support multiple applications with a common interface, including buses (iQPilot), mining and long haulage / platooning applications, which provides a lot of flexibility
- For the implemented autonomous bus, it was chosen to send a multi-part mission for the vehicle to follow to allow the vehicle to continue its mission if for example it loses connectively
  - An example mission can be seen in the bottom right hand corner of Figure 8 as a series of drive and stop for passenger commands
  - Another alternative choice for the off-board control system could be to feed a bus on a command-by-command basis, but in the event of loss of communication a vehicle would be stuck
  - Yet another alternative would be to “return to depot” in the event of loss of communication
  - There are different issues for all these policies, e.g.;
    - In the multi-part mission, an off-board control centre would not know the location of a vehicle if communication is lost
    - In a command-by-command basis, a vehicle would be stuck until recovered

    - In a return to depot strategy, people on-board the vehicle would have to be let off first to avoid irritation
- Hence in a real implementation, there must be a deliberate policy that balances out the possibility to continue missions, vs the risk of losing track of vehicles in the event of an issue
- In the case of a multi-part mission, the mission comprises a series of commands;
    - Go to a certain geographical location
    - Perform a certain operation at that location (e.g., let on passengers, fuel up, etc)
    - Arrive or depart at a certain time
- The multi-part mission is then translated to a series of on-board commands, e.g.
    - Moving to a geographical location results in the vehicle generating a route according to the vehicle's on-board map and certain on-board policies (e.g., use bus lanes) and executing that command
    - Performing an operation to let on passengers results in the vehicle operating the doors to allow passengers on board and generally handling the bus stop scenario
    - Departing at a certain time invokes a timer to move to the next command
- As an example, the complete mission for our main showcase drive on the Scania test track required at 11 part mission as shown in Figure 10.

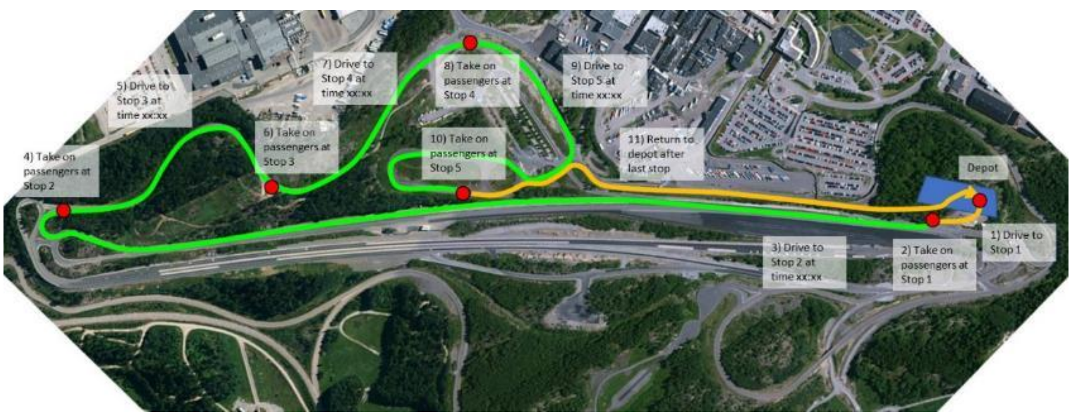

Figure 10 – Multi-part mission for the main iQPilot and iQMobility drive showcase

- It is found that there is a need under some circumstances to modify or fully replace plans whilst in operation due to change in circumstances or disturbances
    - Example reasons could be to skip a stop (e.g., no passengers to get on or off), stop at a different position due to a blockage, etc
    - This could be either a choice of the on-board control system, the off-board system, or off-board operator
    - It is a matter of policy where such deviations can be chosen and must be balance the need for understandability, safety, passenger satisfaction etc

- This is the same in a manually driven bus, however to do this effectively autonomously remains an open challenge

6.7. Vehicle and sensor system (WP8);

- The iQPilot project developed 2 prototype vehicles with 2 different sensor configurations due to the technology available at the time
  - Vehicle 1; “Klasse”
    - Suburban bus, with high floor (due to the autonomous steering actuators available at the time)
    - Primarily “2D” sensor configuration, with 8x lidar and 7x radar (6x short, 1x combined medium + long range) with limited vertical field of views
    - Limited number of “3D” lidar (total 2) looking either at the road, or directly outwards for localization
    - 1x Veoneer stereo camera (as an industrial partner in the project)
    - 1x “Scania” mono Forwards Looking Camera (the production solution)
    - 8x Surround camera
    - Designed to have 360 degree sensor coverage, with minimal blind spots, but limited vertical field of view as in Figure 11

Figure 11 - Sensor Modality Coverage for vehicle 1 “Klasse”

  - Vehicle 2; “Klara”
    - City bus with low entry floor (closer to the project target vehicle)
    - Primarily “3D” sensor configuration with 8x 3D lidar and lidar focused sensing, with 45 deg vertical field of view / sensor.
    - 7x radar (6x short, 1x combined medium + long range)
    - 1x “Scania” mono Forwards Looking Camera (the production solution)
    - 10x Surround camera (including more downwards facing cameras to cover close to the vehicle)
    - Designed to have 360 degree sensor coverage, with no blind spots with the 3D lidar and camera
    - Nearly “Full” vertical field of view with 3D lidar and cameras, as in Figure 12

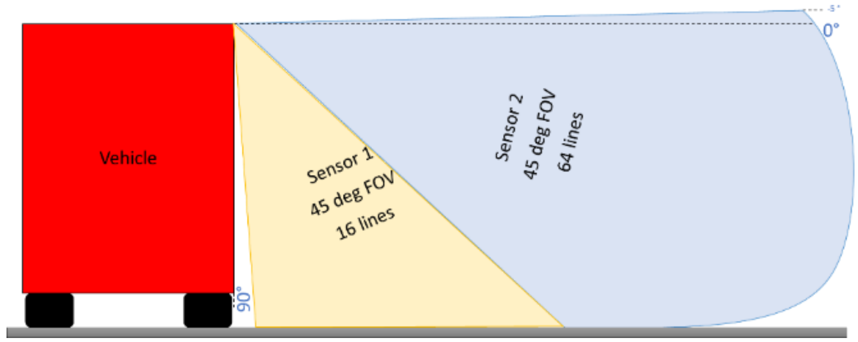

Figure 12 – Vertical field of view of 3D lidar on vehicle 2 "Klara". The design with 2x "3D" lidar with 45 degrees vertical field of view provides total 90 degrees field of view. Close to the vehicle lidar with fewer vertical beams were used compared to further away from the vehicle

- Both vehicles required installation of an autonomously actuated steering system
- The iQPilot project developed 2 prototype vehicles with 2 different sensor configurations due to that the technology changed and matured continuously through the project
- Otherwise, it was possible to automate the vehicle using production parts and modified software
- Automation was implemented through a dedicated computer and sensor network based on Ethernet, connected via a single gateway to the basic CAN based vehicle chassis as per Figure 13

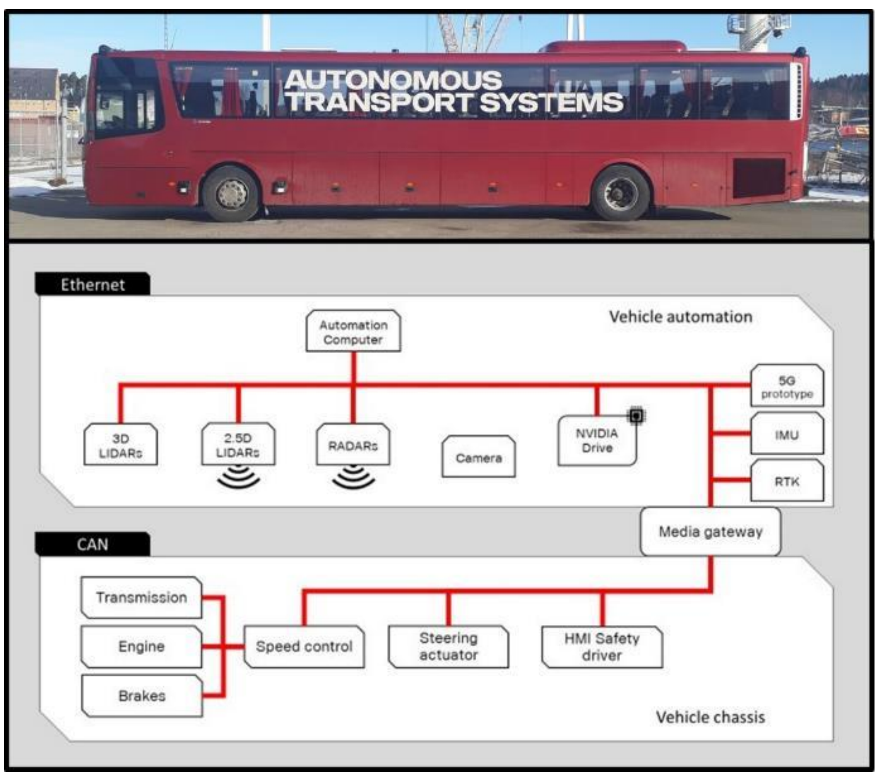

Figure 13 – the vehicle automation computer and sensors operate on Ethernet. They are connected to the basic CAN based vehicle chassis through a single gateway

6.8. Mapping and localisation (WP9);

6.8.1. Mapping

- The iQPilot project introduced the area of “HD Maps” (High Definition) maps into the autonomous drive software to provide the vehicle with a representation of the road
    - The HD Maps were generated by high accuracy lidar and camera based surveying of areas of interest to drive, together with referencing of fixed points in the environment

Figure 14 – Lidar (Trimble MX8) and camera data collection vehicle (left), surveying of reference points (top right) and point cloud representation of the environment (bottom right)

-
    - The collected data was collated to compile a road representation forming;
        - HD Maps compiled from geo-referenced point clouds
        - Hierarchically organised road structure with logical relations and traffic rules
        - Junctions modelled with give way and stop rules and traffic light locations
        - Landmarks such as poles, walls, road lines accurate to 10cm

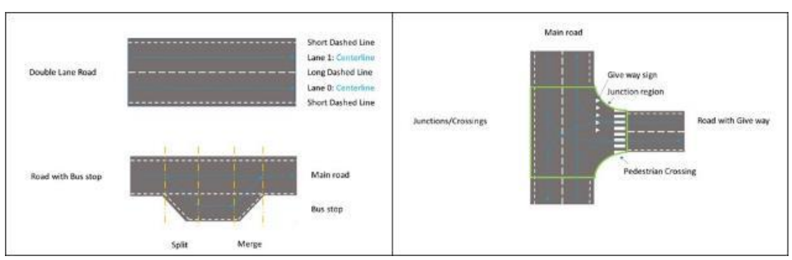

Figure 15 – Example Road and Junction structures

-
    - The maps formed the basis of multiple features in the overall software
        - High level and lane-aware routing of the vehicle
        - Prediction of road user behaviour
        - Traffic rule awareness

- Road and junction layout and structure
- Boundaries of the road
- Landmark based localisation

- The project generated maps of Scania Test Track and Södertälje for usage in various experiments, as per Figure 16

Figure 16 – HD map coverage for Scania Test Track (Bottom Right) and Södertälje

- It should be noted that there are challenges for usage of HD maps in autonomous vehicle applications;
  - Surveying and map creation takes a lot of time
  - Keeping maps up to date is challenging. After the initial survey and map creation, several areas needed to be updated or added due to changes in the road itself, or new road construction.
  - Scaling of the solution. The current scale is suitable for development or relatively small scale pilot projects, not for a mass production scale.
- The main advantage of pre-recorded maps such as this is that there is far less dependence on real-time sensors, allowing the overall development to progress forwards far more quickly

6.8.3. Localisation

- The iQPilot vehicles facilitated experiments into 2 complementary forms of primary localization;
    - RTK GPS, IMU and odometry based localization. In this form of localization, the final solution by end of the project included;
        - GPS[2] (Global Positioning System) as the primary form of localization. Even in open areas, GPS is not sufficiently accurate alone, with errors up to several metres. In urban areas, the error can increase up to 10's of metres due to reflections from buildings. Hence the overall solution is extended to a wider variety of inputs.
        - RTK (Real-Time Kinematic) positioning. In this case, the raw GPS for our "mobile" vehicles are supplemented with real-time correction factors from fixed based stations in Sweden's RTK network (Swepos)
        - IMU (Inertial Measurement Unit). It was found that high grade IMU's were required for accurate positioning of the vehicle.
        - The GPS, RTK and IMU system in use was combined in a single unit combining all information together featuring a tightly coupled integration of the inputs. At the start of the project "reference" grade systems were used, not intended for autonomous vehicle use. By the end of the project, new systems were available developed with autonomous vehicle use in mind.
        - This basic unit was complemented by real time odometry from radar and lidar and fused together to provide the overall position and velocity of the vehicle down to approximately 2cm in open areas, but degrading to 20cm accuracy in non-open areas such as urban canyons, or under bridges, as per Figure 17.

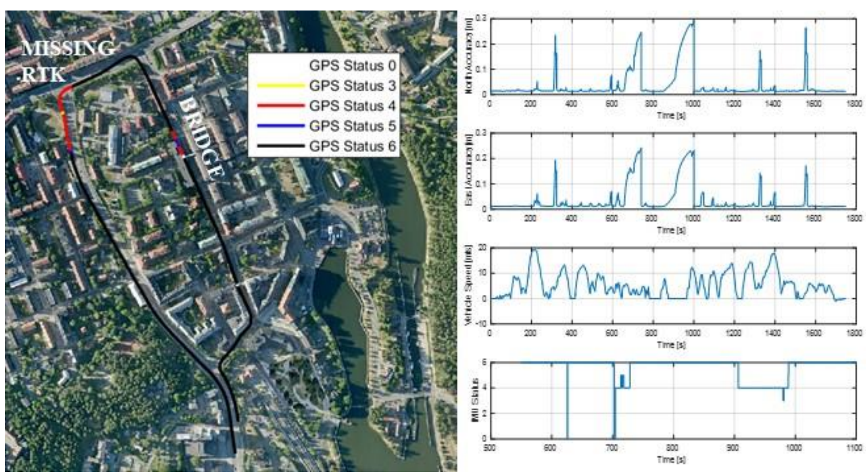

Figure 17 – RTK GPS Status in central Södertälje and corresponding accuracy

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[2] iQPilot actually used both GPS and GLONASS satellites

- Landmark Based Localisation. In this form, location of the vehicle is derived from a combination of the a-priori landmark maps and sensors that identify and track the features. Overall;
  - The landmarks are collated into the overall HD Map in use in the system, as per Figure 18

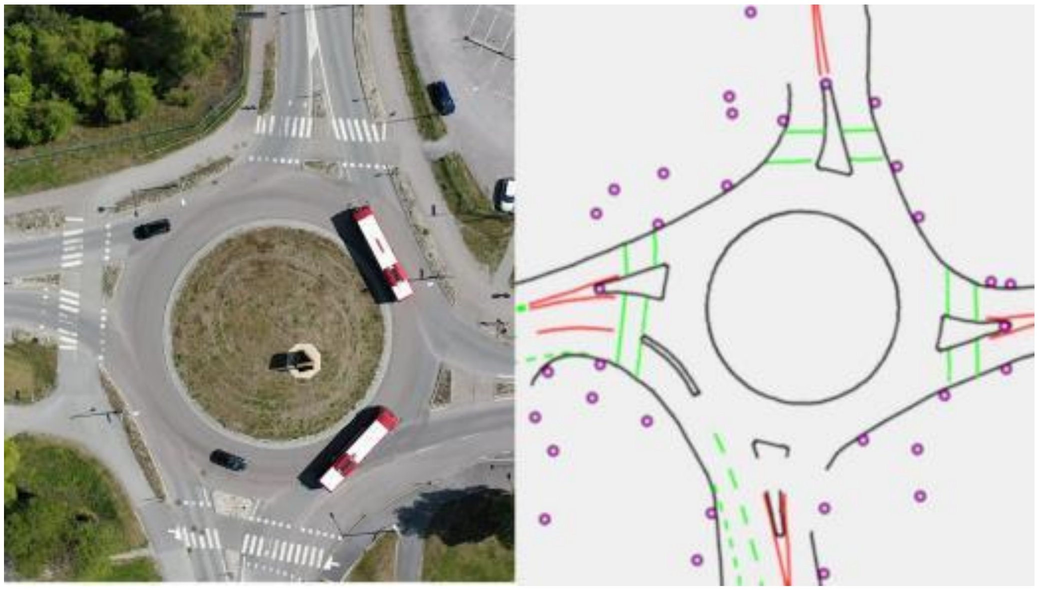


Figure 18 – real road (right) and landmark layer (right). This includes poles, kerbs and road lines

- Landmarks are identified in the sensor system, tracked and cross-referenced to the HD Map, as per Figure 19

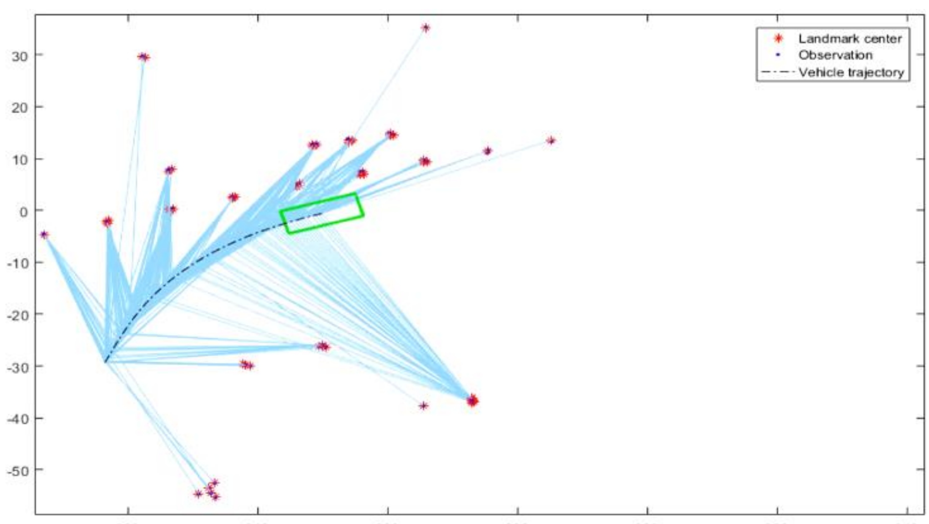


Figure 19 – position and trajectory of the vehicle is tracked by cross-referencing observed landmarks (poles in this case) in the sensor data with the corresponding landmarks in the HD Map

- With a single lidar sensor detecting poles it is possible to continuously track the position of the vehicle as per Figure 20.
    - This lidar was a single 16 beam lidar on vehicle #1
    - iQPilot vehicle #2 is equipped with 4x 64 layer lidar and 4x 16 beam lidar and is expected to provide a step change in the level of accuracy, but was still work in progress at the end of the iQPilot project itself.

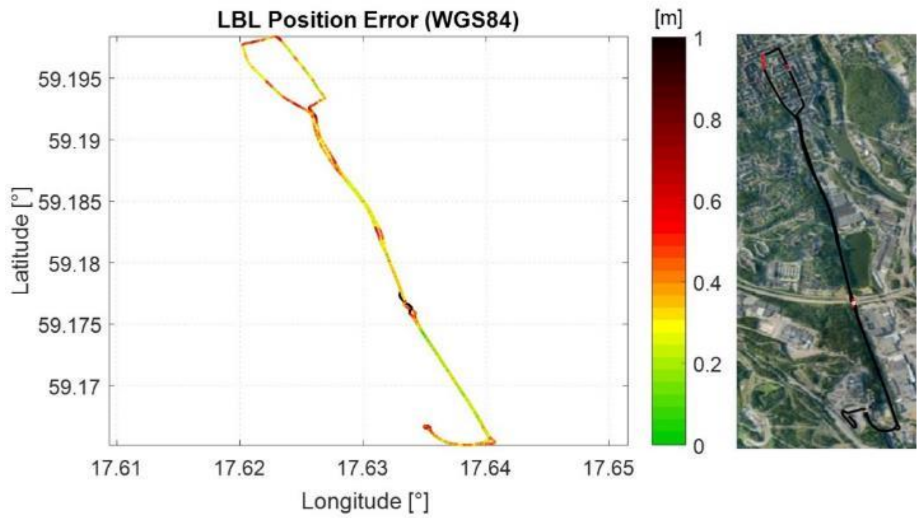


Figure 20 – Landmark based position calculated with a single lidar identifying poles (left) and reference route from Scania into Södertälje (right)

- Additional work was also performed using the Veoneer stereo camera to track landmarks identified in the vision system
    - Veoneer also focussed on identification and tracking of vertical structures, as per Figure 21
    - Position of objects in the vicinity in this case is through usage of stereo vision
    - This would be able to provide identification of additional landmarks into the Landmark Based Localisation in future development

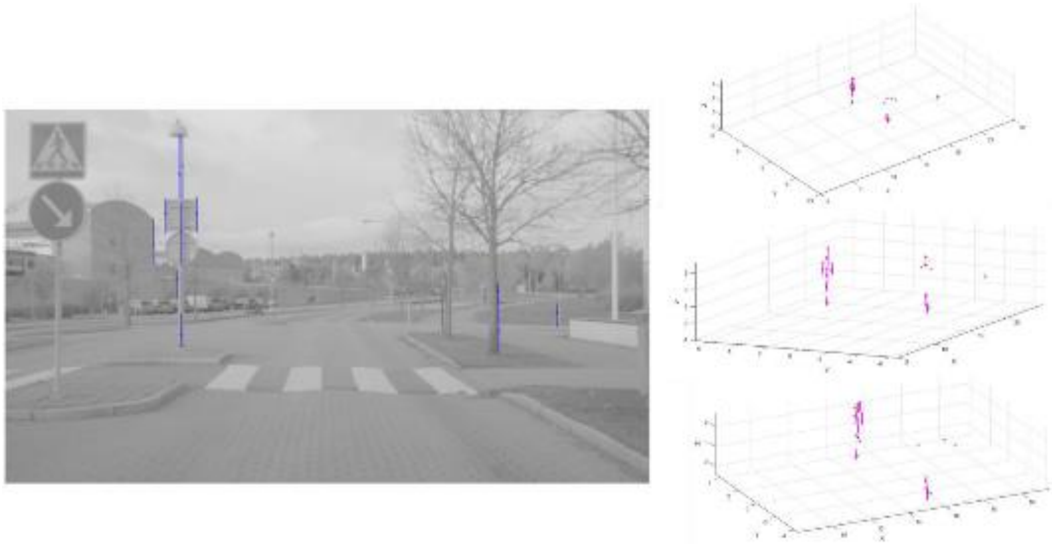


Figure 21 – Identification of vertical structures in the stereo camera

- Veoneer also studied the capability of visual odometry to the onboard vehicle GPS / RTK / IMU reference and were able to verify that stereo camera odometry is able to estimate state of the vehicle, as in Figure 22. In principle, it would be possible to fuse the vehicle motion odometry from stereo camera into the other on-board sensors as a future activity.

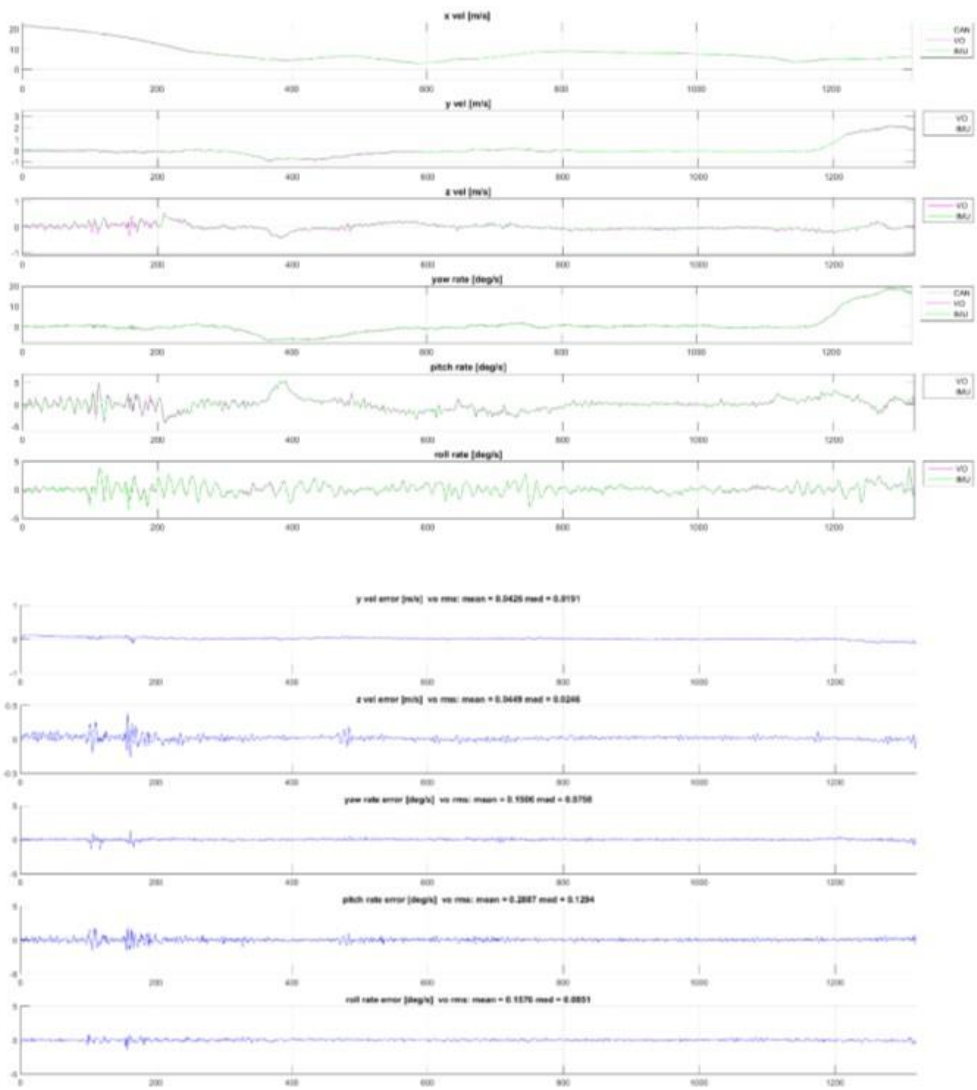


Figure 22 – Vehicle motion estimated from visual odometry in the Veoneer stereo camera vs the onboard IMU system

6.9.Perception and Situational Awareness (WP10)

6.9.1. Perception

- The primary perception framework fuses together information from radar, lidar and cameras to understand both the static and dynamic environment around the vehicle
    - All 3 sensor modalities are used due to that each has strengths and weaknesses, but also for redundancy
        - Lidar provides the best distance information
        - Radar provides the best velocity information
        - Camera provides the best classification information
    - Fusing together of all 3 modalities required methodologies for accurate calibration of the sensors for the fusion to perform adequately, typically with calibration using either static or dynamic targets in the environment with known positions

- In terms of understanding the dynamic environment, the research within the area reached a solution where;
    - It was possible to classify both vehicles and pedestrians. It was necessary to have separate models due to that vehicles are non-holonomic and pedestrians can have both non-holonomic and holonomic behaviours.
    - A common object representation is made for the characteristics of dynamic objects that is parameterised according to the sensor based measurements associated with that object

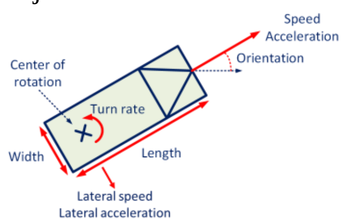


Figure 23 – Parameterised object state and dimensions

    - Creation of dynamic objects based primarily on radar (moving objects) or camera (classified objects)

    - Fusion of the key sensor modalities to a single object based on clustered point clouds for the radar and lidar and high level objects from the camera

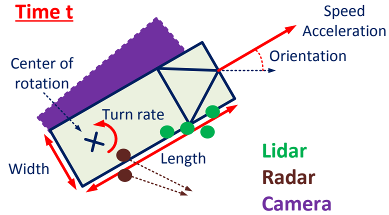


Figure 24 – Objects are composed of fused point clouds from radar and lidar and high level camera objects

- Kalman filter based object tracking and prediction

- Through these methodologies, it was possible to track objects in real-world environments, as per Figure 25, Figure 26 and Figure 27

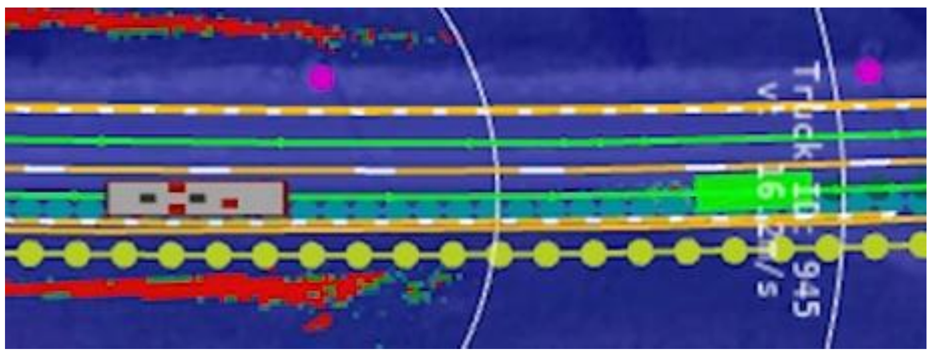


Figure 25 – An object (right) being tracked on Nyköpingsvägen in Södertälje, in front of the iQPilot vehicle (left)

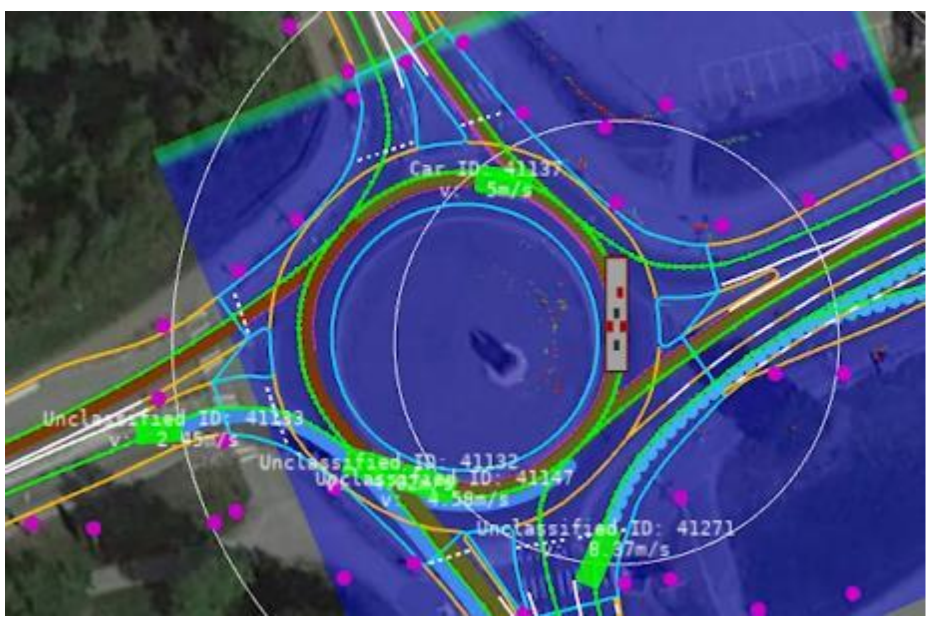


Figure 26 – Multiple objects (green boxes) being tracked on a single lane roundabout outside Scania Technical Centre in Södertälje

Figure 27 – Multiple high level pedestrian objects around an iQPilot vehicle and the real world situation

- In terms of understanding the static environment, the research within the area reached a solution where;
  - It was possible to detect the static environment around the vehicle, including both structured objects (e.g. walls, barriers, poles) and unstructured objects (e.g., trees, bushes, stones) in real time

  - The static environment was captured in 2D grid maps orientated in world coordinates as per Figure 28.

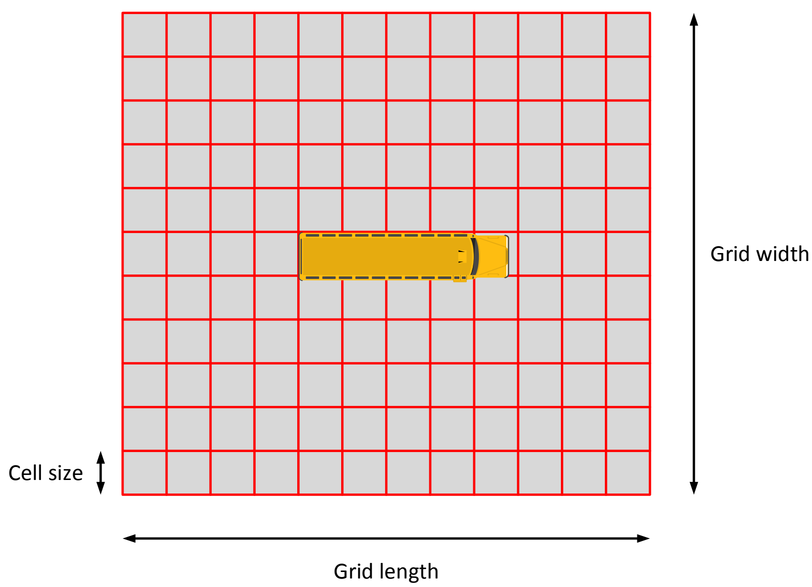


Figure 28 – Example grid map superimposed over a vehicle

- It was found to be beneficial to use more than 1 grid map to capture the environment,
    - Low resolution grid map (e.g., 1m cell size) to collect data over as wide a range as possible
    - High resolution grid map (e.g., 10cm cell size) to have fine detail at close range to the vehicle
    - This allows high enough detail close to the vehicle for fine manoeuvring and long range without such high computational performance or memory limitations as using a single high range, high resolution map

- The solution in use is primarily lidar based, with input of the point clouds of type illustrated with Figure 29
    - It has been found to be possible to use the same algorithm with both 2D and 3D lidar

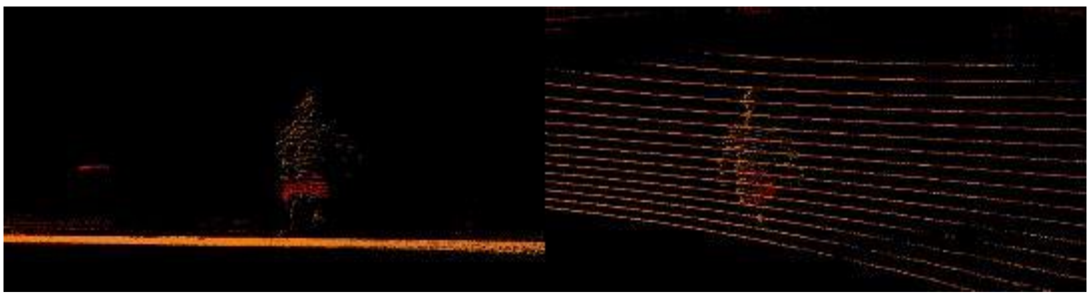


Figure 29 - Object (person) detected in a 3-D lidar

- With a 2D lidar solution, it was found to be necessary to filter out objects where the lines are spread out over a wide lateral distance, as per Figure 30
    - This limits the types of roads that can be driven with full functionality with this type of sensor solution to roads that are relatively flat
    - This has included our main test route on-road in Södertälje, which is sufficiently flat not to be affected by this issue
    - Continuous driving on Scania’s hilly test track was only possible with this type of filtering

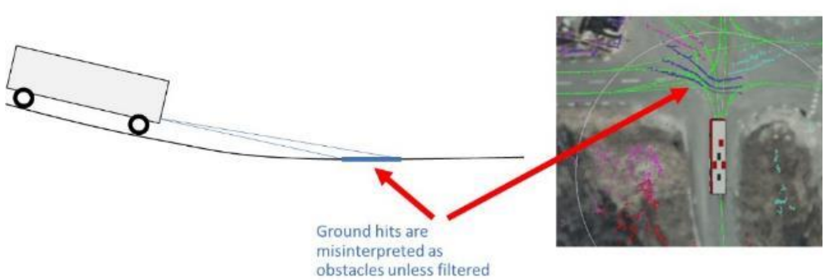


Figure 30 – With 2D lidar, the lidar can be pointed towards the ground on hilly areas

- With a 3D lidar solution, it was found to be necessary to separate the ground plane detected by the lidar, as per Figure 31
    - The ground plane is instead useable as a measurement of the ground surface as a separate area of functionality

- After removal of the ground plane, it was possible to use the same static obstacle detection algorithm as with the 2D lidar, due to the generic nature of lidar point clouds. An example of this from iQPilot vehicle #2 is seen in Figure 32

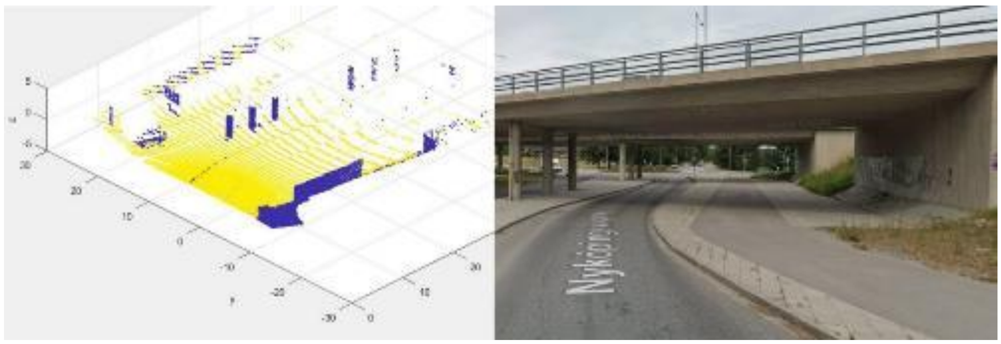


Figure 31 – Ground plane detection in 3D lidar data (yellow) and vertical objects in blue. The 3D data in the left hand diagram can be clearly associated to the reality of objects in the right hand image at the same location.

Figure 32 – Example of static obstacle detection from 3D lidars after removal of the ground plane in central Södertälje, Black areas surrounded by red are areas detected as static obstacles by the vehicle.

- Veoneer were also able to demonstrate an equivalent level of system output for object detection and static object detection from a single system, the stereo camera used in the project, as highlighted in Figure 33. This included;
    - Depth detection from the stereo images using image disparity, where comparison with ground truth in is more comparable in quality to a lidar than a simple mono-camera
    - Detection and classification of dynamic objects using CNN (Convolutional Neural Networks) and equivalent parameterisation as with the Scania object tracker
    - Detection of static objects and representation in the environment in a grid map form
    - Detected and classified points as a 3D point cloud for fusion into perception algorithms in similar way as a lidar
    - Road surface roughness estimation and small object detection based on slope and flatness in the image disparity

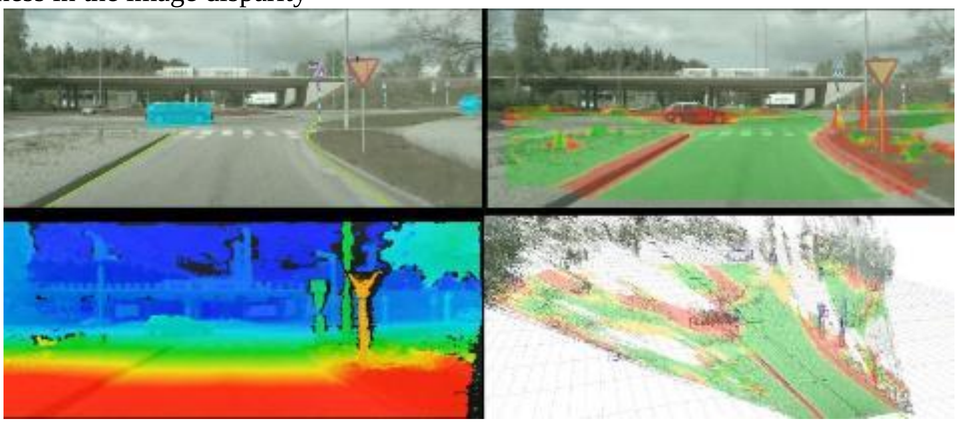


Figure 33 – Output of Veoneer Stereo Camera. Object detection and tracking (top left), distance detection (bottom left), static obstacle detection (top right), position in 3D space as classified 3D point cloud (bottom right)

- Scania made also experiments with surround cameras fitted to the iQPilot project vehicles and developed software that primarily focused towards object detection and classification for integration into the object tracking, as per Figure 34.
    - A multi-camera framework was developed, with possibility to run a configurable set of DNN (Deep Neural Networks) for functions such as object tracking, freespace, lane detection and image segmentation
        - Image segmentation has been found to be particularly useful, due to that it separates ground from other objects and provides an easily fusible, classified point cloud similar to lidar
    - Depending on function and availability of other sensors on the vehicle, distance and heading angle were either
        - Estimated from position in the camera view. Particularly in this case, for association to high level radar and lidar objects, heading angle has been found to be more useful than absolute position

- Measured using back-propagation of lidar data into the image frame. Using this method, absolute positions are more accurate, but as it is preferable to use 3D lidar, this could only be used in the forwards direction on iQPilot vehicle #1

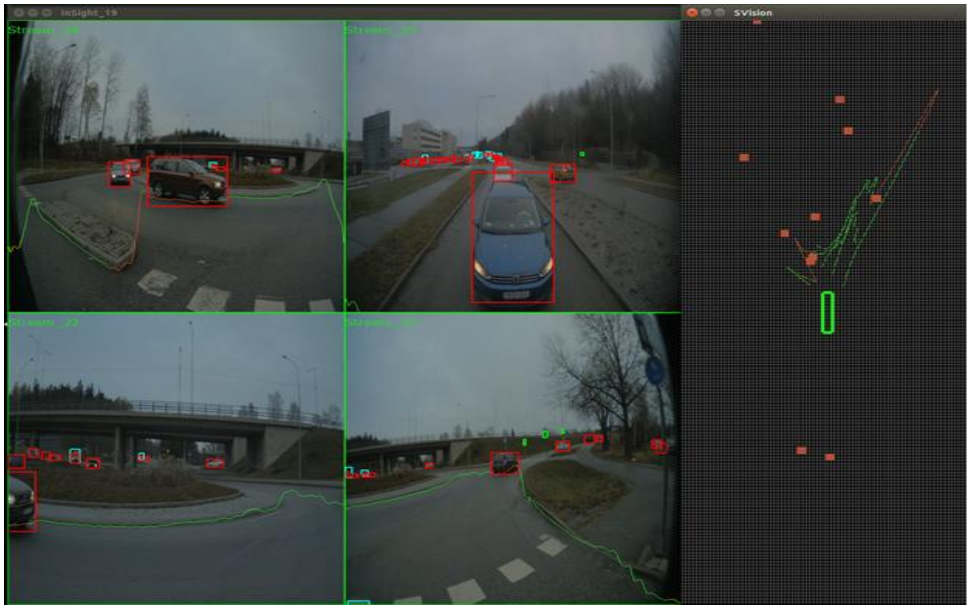


Figure 34 – Surround mono-vision cameras (4 out of 8 cameras shown) with bounding boxes for detected objects and freespace + approximate position in space

- Additional research was performed in the image domain of sub-features on identified cars or traffic lights. For detecting vehicle light status;
  - An example can be seen in Figure 35 from efforts to identify the location and status of lights on a vehicle as a sub-ROI (Region Of Interest) on the ROI identified as a car

Figure 35 – Example of processing a ROI that has been classified as a car to detect and track the lights as a sub-ROI

  - The overall process for identifying the status of lights on a vehicle is shown on Figure 36

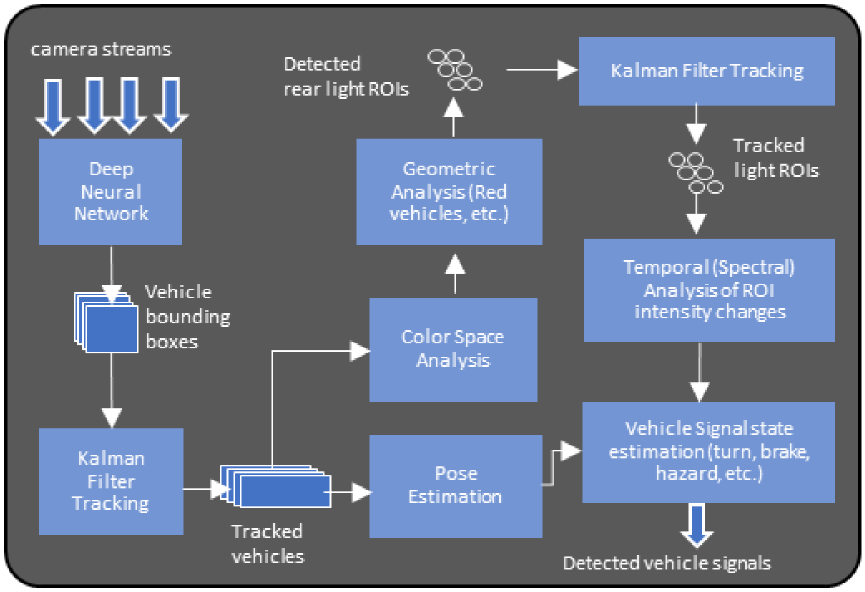


Figure 36 – Overall process for identification of vehicle light status

- The initial work has generated sufficient understanding to develop the process at a protype level. A significant challenge remains in scaling this up to all vehicles in the environment in a computationally feasible way.

- Due to the volume and complexity of this area, work continues with this surround vision area beyond the scope of iQPilot into an associated project iQDeep and future projects. An example of output or image segmentation from part of the iQPilot / iQDeep cooperation is shown in Figure 37.

Figure 37 – Sample image segmentation and uncertainty on one of the iQPilot vehicles during a drive in Södertälje. This focus area continues with the iQDeep project

6.9.2. Situational Awareness

- Situational awareness can be described in 2 main areas;
    - Scene awareness of static objects and features.
        - This area in general makes use of HD map and sensor based input such as the 2D obstacle grid map to understand the area in terms of where it is possible to drive, what obstacles and features there are in the environment (such as traffic lights or pedestrian crossings) and where other agents in the environment are
        - The static scene is used to understand both how the ego vehicle may drive, but also to make predictions for dynamic objects as will be illustrated later

    - Status and prediction of dynamic objects in the environment
        - Work has focused on 3 main aspects of prediction of dynamic objects, as per Figure 38. Within these areas, 3 areas have been worked on;
            - **Physics based models** predict the future motion of another vehicle based on the dynamic properties of the agent in question. Similarly to modelling of dynamic objects in the sensor frame, different models are used for predicting the future motion of the agents based on the identified type of agent. E.g., due to that motion of a large vehicle may be different to a small vehicle and that vehicle motion is non-holonomic but pedestrian motion may not be
            - **Maneouvre based models**, based on the possible (/ most likely) paths a vehicle may take based on the immediate layout of the road
            - **Interaction-aware models**, based on how a vehicle may behave based on its interactions with other road users or features.

Figure 38 – the 3 main areas of prediction of dynamic objects

        - An example that already shows 2 of the modelled methods is as in Figure 39, where 2 agents detected in the environment (1 bus and 1 truck) also have;
            - Associated predicted future paths based on the upcoming layout of the road (in this case 2 possible future paths are predicted for each vehicle on the roundabout)

- Predicted future paths that are based on the speed and dynamics of the detected vehicles

Figure 39 – Example of predicted motion of other agents in the environment based on road layout

- More advanced methodologies for motion prediction have been developed, including use of Baynesian networks (with possibilities going straight, left, right, or U-turn) to identify the probably of manoeuvres of other agents in the environment and thus the risk associated with manoeuvring of the ego vehicle

- Trajectory prediction in traffic scenarios with high levels of interaction and uncertainty were also worked in by iQPilot's PhD student as follows;
    - Encodeing of the traffic scenario into a generic birds-eye-view representation and poses the problem as an image sequence prediction task using deep learning.
    - Predictions generated by a Conditional Variational Auto-Encoder (see Figure 40) conditioned on the scene history and road topology. All traffic agents are predicted simultaneously, with interactions implicitly learned through the representation and 3D convolutions.

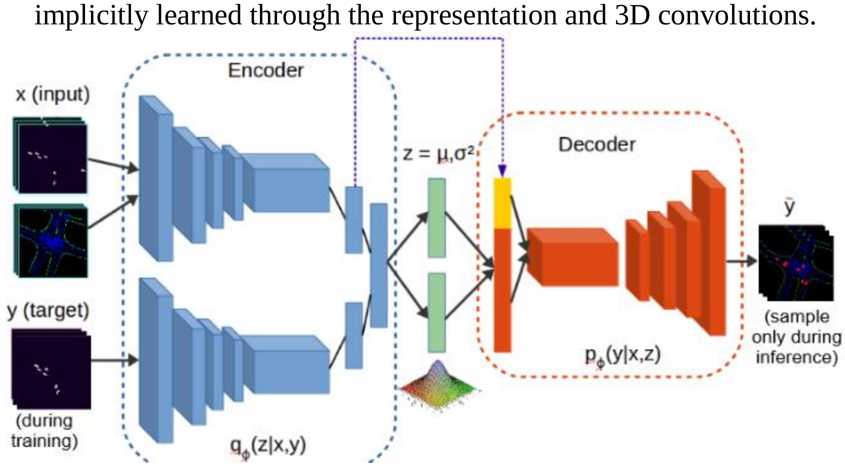


Figure 40 – General Conditional Variational Auto-Encoder neural network investigated

- Decoded samples can generalize to different scenes, and lead to different likely future trajectories which can be used to approximate a distribution for future positions (Figure 41).

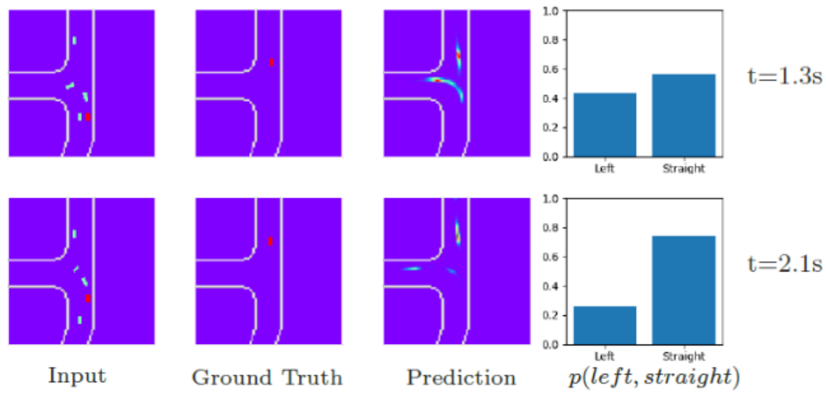


Figure 41 – Example predictions of future behaviour of 1 vehicle (red) using a Conditional Variational Auto-Encoder Neural Network to predict future direction and probability of future direction

- The "black box" effect of Deep Learning is removed by incorporating a developed interpretability framework for video classification models. This module produces explanations for the predictions showing what was most important in the input regarding traffic agent positions, road topology, and specific sub-sequences in the input frames as shown in Figure 42).

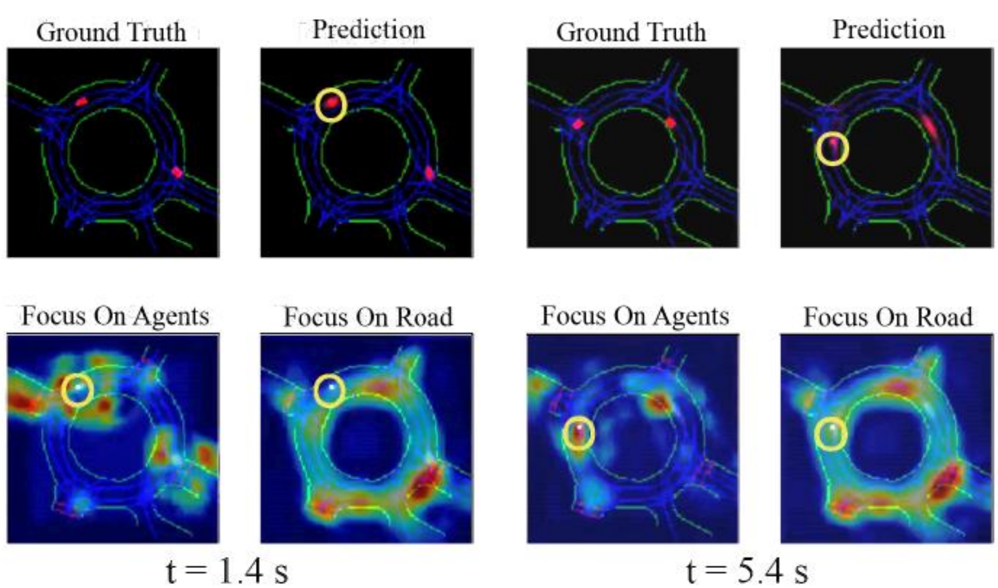


Figure 42 - Examples of explanations for predictions in a roundabout. The prediction focuses on the surroundings of the agent of interest, as well as the entry/exit points it is approaching.

- As a proof of concept, the resulting system was integrated into the 2nd iQPilot project vehicle as a prediction module. This allowed for testing and simulation in the environment for data collection purposes, with an example shown in Figure 43).

Figure 43 - An example of the prediction system being interfaced with the Scania system. In this case the predicted gap between the agents is too narrow, and the planner produces a yielding manoeuvre.

- Both perception and situational awareness are areas where huge volumes of work have been conducted and reached a solid framework. But it will remain as a future area of work for foreseeable years to come due to the overall complexity

6.10. Vehicle Control and Motion Planning (WP11)

6.10.1. Motion Planning

- During the course of the iQPilot project, 2 main planning areas were addressed, the first being driving on structured roads.
    - The main backbone of this is
        - The high level routing as derived from the mission plan (see Section 6.6)
        - HD maps (see Section 6.8) to understand the structure, inter-connections and boundaries of the road
        - Usage of the static and dynamic objects in the environment and the perceived situational awareness (section 0)
    - The general architecture for motion planning is generally according to Figure 44

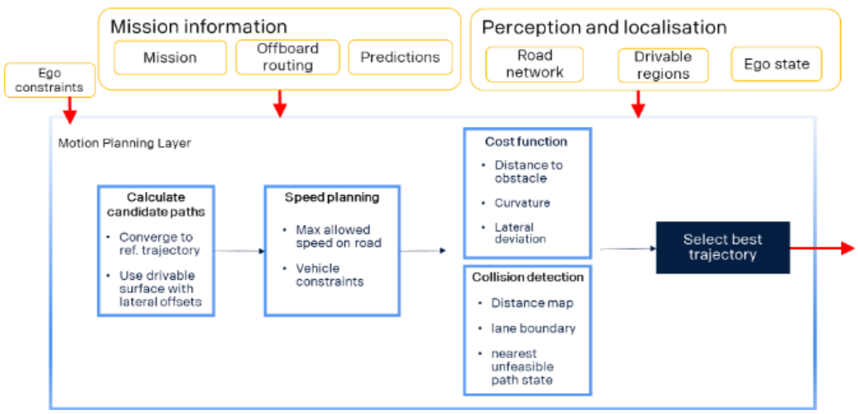


Figure 44 – general structure of motion planning

- The overall plan is derived through the following process;
    - Generate multiple candidate paths for the vehicle to follow along the road and the edges of the road. These paths are between various "look-ahead" points ahead of the vehicle on the centre line and multiple parallel paths, sampled with Bezier curves.

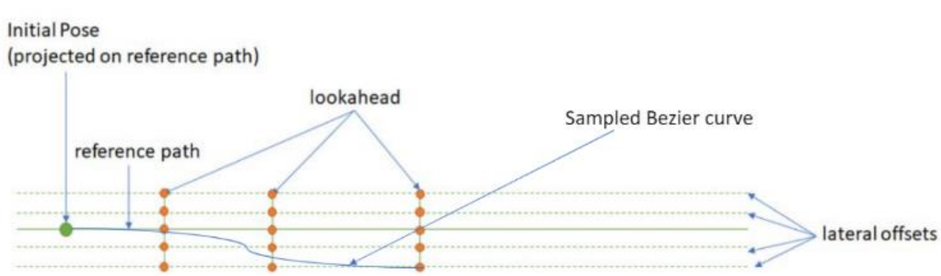


Figure 45 – Trajectory generation through look-ahead points in front of the vehicle using Bezier curves

        - Generate a speed profile for each path according to the constraints of the vehicle, layout / curvature of the road, speed limits, other vehicles in the environment.

        - Rate each possible trajectory according to distance from other objects along the path, curvature, lateral deviation, jerkiness, etc.

        - Evaluate and rate the trajectory against risk of collisions with static or dynamic objects (with the vehicle body) and the edges of the road (with the wheels)

        - Discard all trajectories that would result in collisions and select the best trajectory based on all ratings

    - When it is known that a lane change is required for the road planner to reach its next destination
        - The same basic methodology is used, except that the look-ahead points traverse into the adjacent lane that the vehicle intends to drive into

        - The evaluation of trajectories includes also transitioning to the adjacent lanes at multiple points across the length of adjacent lanes ahead of the vehicle and traffic in the adjacent lanes

- The project also made use of driving in open areas, to show the potential for driving of buses in open areas such as in depots
    - This embodiment used a lattice planner with pre-defined primitives, modified to allow optimised shortcuts through the local area to plan through an open area and around obstacles in the vicinity

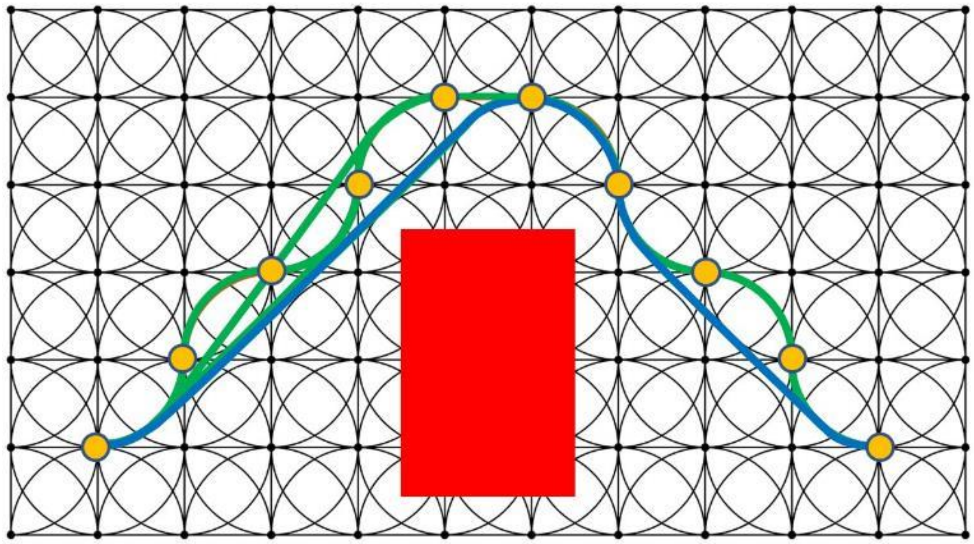


Figure 46 – Lattice planner with traversable nodes (black dots), pre-defined primitives (black lines), selected nodes for path (yellow), initial and optimised paths (green) and final optimised path (blue). The red area represents obstacles in the area.

- Usage of this type of lattice planner allowed usage of the iQPilot test vehicles to navigate open areas in our depot test area

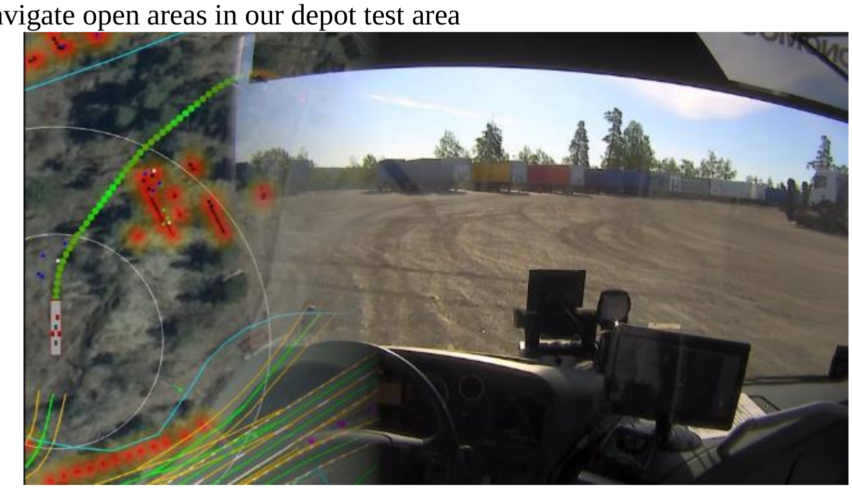


Figure 47 – Open area planner planning through an open area with obstacles on the left hand side. Real situation in forwards view camera on the right.

- iQPilot also utilised results from a (WASP) PhD project in the area of planning for buses that investigated planning methodologies for planning motion of buses on road
  - The project worked to segment the vehicle into areas based on wheelbase of the vehicle and overhanging areas as per Figure 48 (left)
  - The environment is also segmented to divide the environment into areas that are fully driveable, areas the bodywork overhangs can sweep over and obstacles in the environment

Figure 48 – Regions of vehicle characterised to segments according to wheelbase and areas with overhands. The environment is also segmented into driveable areas according to the road layout (green), sweepable area (yellow) and obstacles (red).

- The resulting planner maximised distance from obstacles with the overall vehicle body, constrained the wheelbase to be within the driveable area and minimised the amount of the bodywork outside the driveable area as in Figure 49

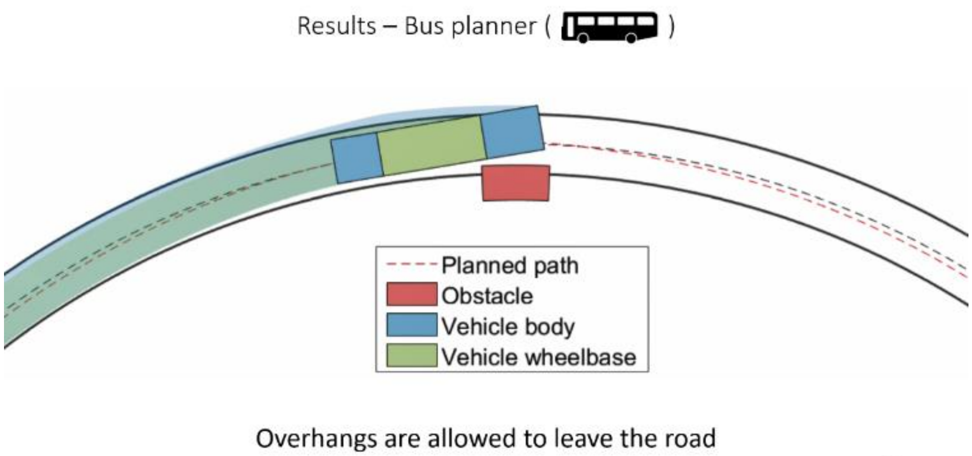


Figure 49 – Example of output of a planner that aims to avoid collision with obstacles with the overall vehicle body, keeps the wheels within the boundaries of the road, but allows overhangs of the vehicle to go outside the boundary of the road

6.10.2. Vehicle Controls

- The plan generated through the methodologies described is subsequently executed by longitudinal and lateral controllers with structure in Figure 50

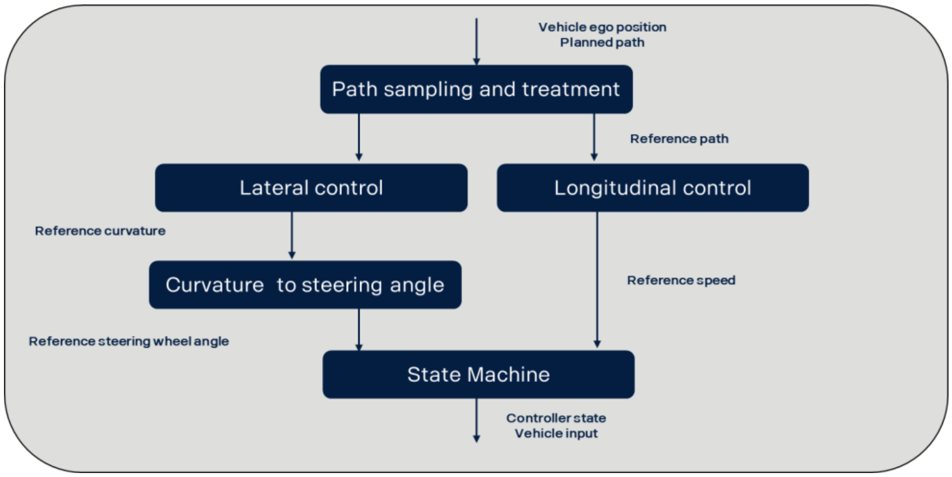


Figure 50 – Lateral and Longitudinal controller

  - Laterally, the controller functions as a path follower, generating a steering angle that a chassis level steering controller is able to follow
    - Due to the challenges of following a 2-dimensional path with a vehicle, an MPC (Model Predictive Control) approach is used, which comprises
      - An internal kinematic model of the process of the underlying vehicle and steering dynamics
      - A cost function along the upcoming path for the vehicle
      - Optimisation to minimize the cost using the control input
    - The MPC cost function includes;
      - Accuracy of tracking the trajectory (distance to path and vehicle heading)
      - Smoothness of driving (comfort)
    - The MPC dynamics includes;
      - Bicycle kinematic model with centre of rear axle as the reference point (the fundamental model)
      - Limitations and restrictions in the steering control (as it was found that the system oscillated during driving without understanding of the limitations)

- The overall effect of the controller is to execute a control command to move the vehicle to the planned path, taking into account the dynamics of the vehicle (see Figure 51)

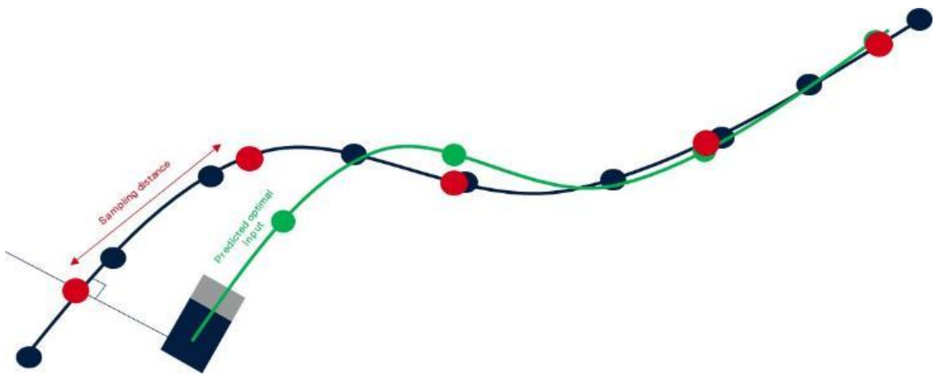


Figure 51 – The vehicle control is executed to try to command the movement of the vehicle to the planned path

- The lateral control generates a reference curvature for the vehicle to follow to achieve the path that is subsequently converted to a steering angle request as the control command to be executed
    - The curvature is the raw curvature that the vehicle should traverse
    - The steering angle command also takes care of some of the underlying dynamics of the vehicle when achieving the desired, such as effect of understeer in the vehicle tyres as in Figure 52

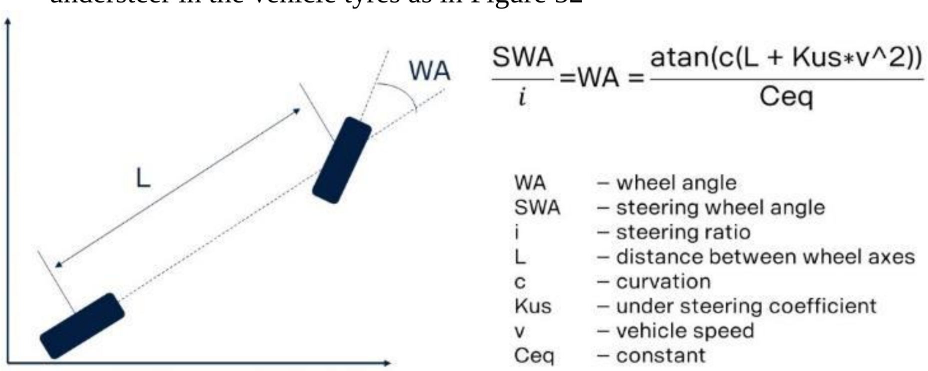


Figure 52 – Curvature to steering angle calculation including dimensions of the vehicle and understeer coefficient

- The lateral control generates a reference curvature for the vehicle to follow to achieve the path that is subsequently converted to a steering angle request as the control command to be executed

- The longitudinal control in Figure 50 is only to extract the desired speed from the planned trajectory alongside the current position of the vehicle

- The key outputs generated through this process are the steering angle request and vehicle speed request. Both requests are actuated at the chassis level, beyond the autonomous system and outside scope of this project.

6.11. Vehicle safety and safety concept (W12)

- One of the challenges with operating a system in continuous development has been how to ensure safety for operating the vehicle whilst allowing development to continue at a fast pace
  - During early phases of the main project development, this was handled by simply setting a low maximum speed of the vehicle at an “always safe and controllable” level of 15km/h
  - As this is highly limiting towards being able to further develop the system, it was necessary to put further safety measures in place to allow the project to proceed

- The general approach was;
  - To partition the level of safety such that the vehicle chassis has a high level of integrity, with all systems approved even for road use + safety controls (for cutting off forwards propulsion and automation) fitted to the vehicle system
  - Ensure that it was always possible for a safety driver to have full control of the lateral and longitudinal control of the vehicle if they need to override the autonomous system (with steering, brakes, accelerator)
  - Ensure that the driver had a guaranteed time window to intervene if required
  - Ensure that the driver had training to understand how the vehicle is expected to behave at the current design level

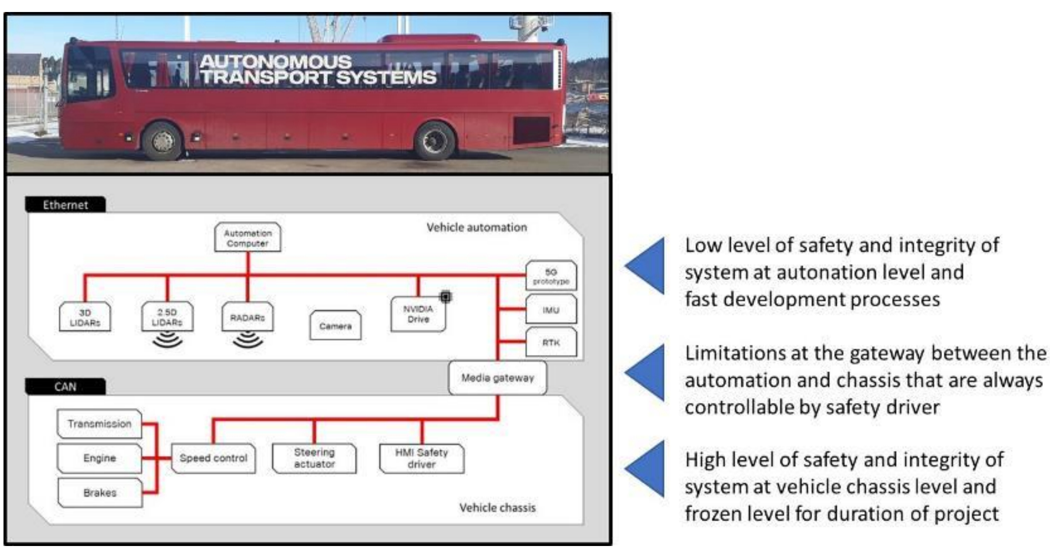
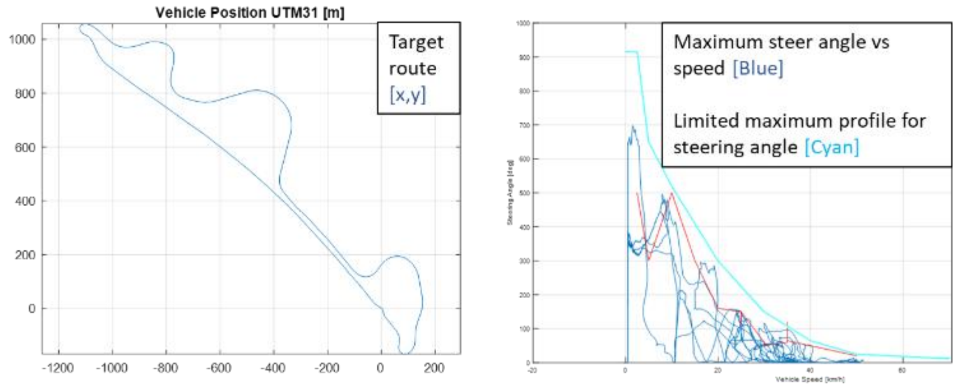


Figure 53 – The system is partitioned into levels where safety of the autonomous system is always guaranteed by a high level of safety at the chassis level and limitations of speed and steering control that guarantee safety and ability of a safety driver to intervene if necessary

- A key method of allowing the vehicle to be driven at higher speed can be described as follows;
  - The target demonstration route was driven by an expert driver in a calm and comfortable manner to define the maximum operating envelope for steering angle and speed



  - The limitations were implemented in the gateway between the automation and chassis systems to ensure the steering commands can never exceed this calm and comfortable nominal profile no matter what happens in the automation system

  - The allowable speeds were derived according to hazards in the environment and available width of the road as illustrated in Figure 54

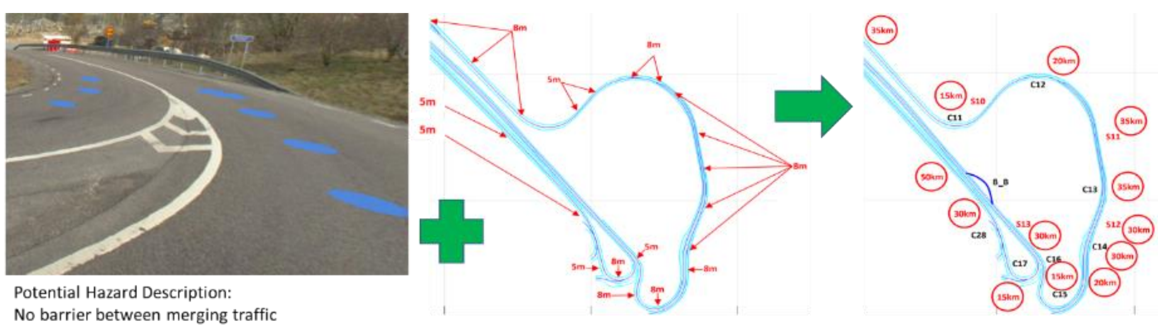


Figure 54 – Cross checking of potential environmental hazards and available width of the road to derive maximum allowable speed in different areas of the route of interest

  - The behaviour of the vehicle was simulated and adapted under the following conditions (see also Figure 55);
    - Check all straight line segments and curved segments in conjunction with the chosen speeds and steering limitations
    - Simulate a maximum possible +ive and -ive steering angle error of the automation system to verify that there would be no collision or hazard within a period of time allowed for a safety driver to react

    - Further restrict the speed or steering angle limitations in case of risk of hazard within the reaction time

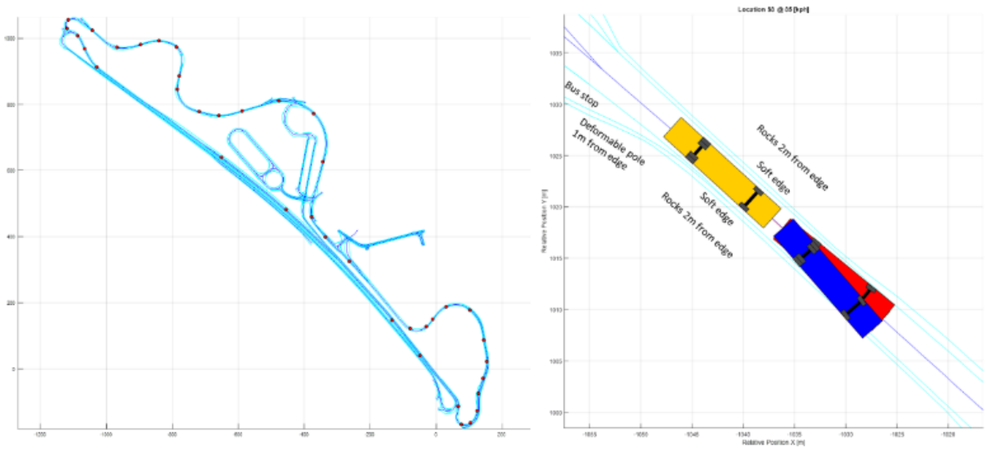


Figure 55 – Every straight and curved section of the target test route (red points) was analysed in simulation to understand the effect of maximum +ive and -ive deviation of the vehicle in the event of a system failure, based on the layout of the road and hazards in the vicinity

- Through this general methodology and iterative process to derive operational limits for the vehicle, it was possible to have a system where it was possible to drive at typical road speeds with an operational envelope to ensure safety

- Other resulting actions;
    - It was found to be necessary for both the vehicle planner and controller to take into account the limitations imposed on the vehicle so that plans would only be generated that the controller could execute and so the controller would not try to control beyond the possible limitations of the vehicle.
    - As high accuracy vehicle position and map are within the lower safety integrity part of the system, it is still necessary for a safety driver to monitor that the position is correct and the speed of the vehicle is within the defined limits.
        - The driver had a monitor showing identified position to ensure this
        - Each safety driver was provided with a map for maximum speeds at different locations in a correctly functioning system
    - After implementation of these actions, the software that ensured all limitations was not altered for the remainder of the project.

- This is an acceptable set of measures and methodology for testing on the scale of iQPilot.

- As a system such as this matures from prototype to higher levels of safety and integrity, it is expected to be possible for the system to perform its own safety monitoring and for the automation system itself ultimately to be the primary safety, rather than the operating envelope of the system.

6.12. 5G PoC test network and CMA (Connected Mobility Arena - Kista) (WP13)

6.12.1. 5G PoC Test System

- The aim of the collaboration with Ericsson in the 5G “Proof of Concept” (PoC) area was to identify and showcase possibilities in the autonomous area that would benefit from this new, upcoming technology
    - The initial introduction of 5G into the iQPilot project started with installation of a 5G “Proof Of Concept” antenna system and a 4G LTE base-station usingf “Evolved Packet Core" at the test track in Södertälje, connected to Ericsson’s Core Network in Kista (see Figure 56 and Figure 57)

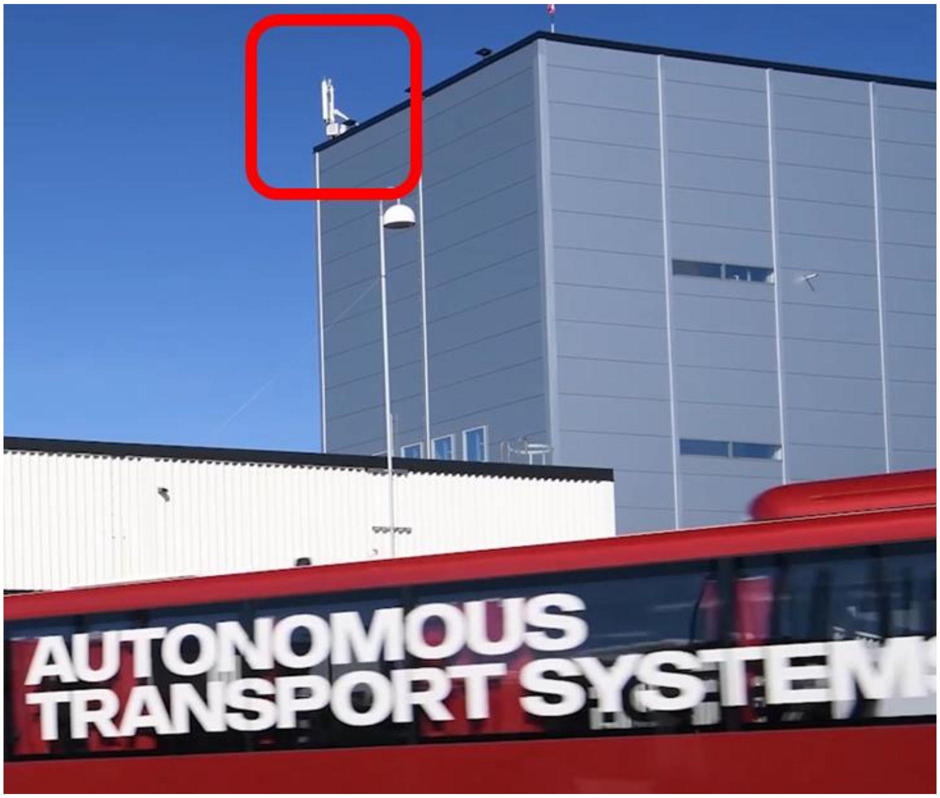


Figure 56 – Proof Of Concept 5G antenna pictured on top of the Scania wind tunnel above iQPilot vehicle #1 (zoomed in from Figure 6

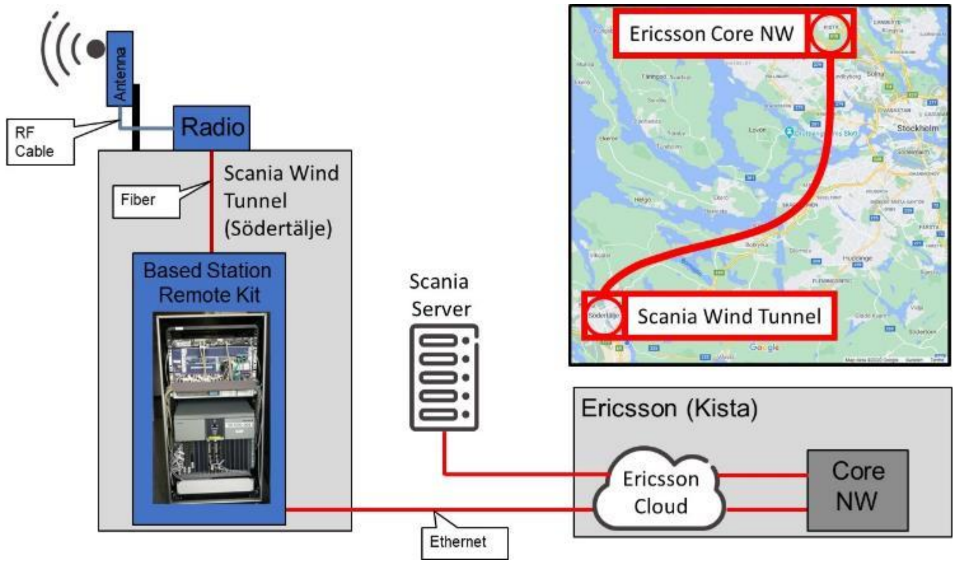


Figure 57 – General system structure of the overall antenna / base station installation and connections to the Ericsson Core Network, conceptually and geographical locations

- The POC antenna was positioned on top of the Scania wind tunnel to provide as wide coverage as possible across the Scania test track from as high a position as possible due to the hilly nature of the test track area, as Figure 58.
- The performance of network in terms of latency can also be seen in Figure 58. With respect to performance;
  - Under normal operating conditions, it was found to have a latency of between 30 to 50ms for data traffic from vehicle in Södertälje to core network and Kista and back
  - Some locations of time periods where the performance became significantly worse were also noted. Based on the characteristics it is believed that
    - Some of the observed degradation is related to the topography of the environment. E.g., when there are hills between the vehicle and antenna, or when the vehicle goes under bridges
    - Some of the observed degradation was likely due to lost data between Södertälje and Kista. This was identified by measuring packet loss between the 2 locations and debugging where the packet loss occurred in the overall network

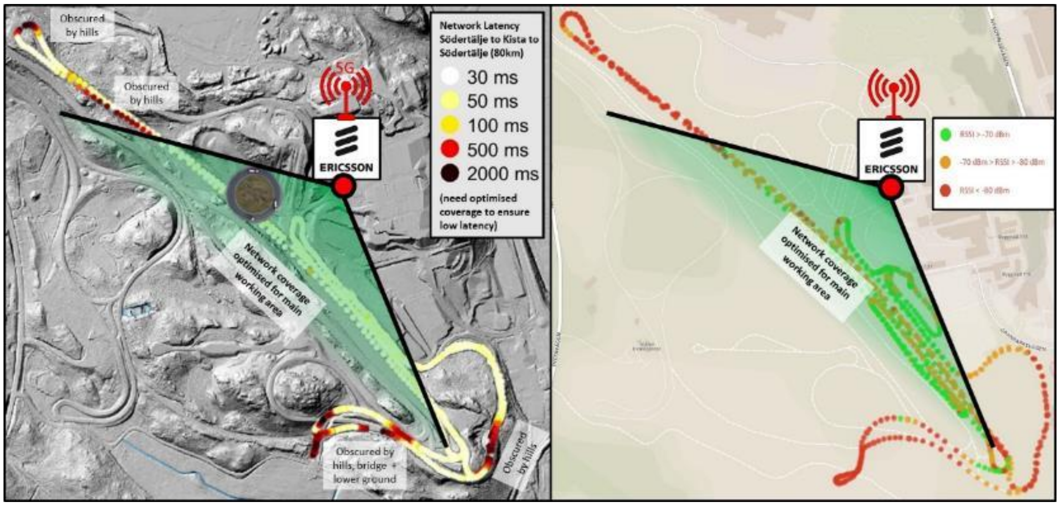


Figure 58 – The network coverage was optimised for working on the most open areas of the Scania test track. Assessment of the network latency was performed and generally provided overall latency of 30 to 50ms for round trip of data between Södertälje and Kista, as measured on board vehicle. Areas of high latency were also found, which may be due to either the topographical features, or disturbances in the general traffic of data outside of the radio network.

- The installation was later modified to route data only on site for continued testing to not be dependent on uncontrolled network areas.
    - Before this change, the areas / time periods where degraded performance was obvious when working with video streaming from the vehicle due to degraded image quality
    - Following this there was no further obvious degradation of performance for the remainder of the project, though the performance vs vehicle position was not remeasured

- As general conclusions related to performance;
    - For a real world deployment it is necessary to ensure sufficient network coverage of all areas geographically where it is required to operate an autonomous vehicle. Due to cost constraints this was not feasible within the iQPilot project
    - It is necessary to ensure priority of critical data not only in the access network but on all sections forming the end-to-end connection between mobile device and application server (in this case Södertälje to Kista and back over which the project had control of parts of the connection) to ensure there are no disturbances. This was not feasible to ensure this with the prototype nature of iQPilot

- One of the key areas worked on with the 5G POC network was streaming of full HD video, using a tv-quality camera and a single frame encoder to stream high quality, low latency images to a receiving monitor off-board the vehicle, as in the architecture in Figure 59
  - This was one of the main enablers for the Remote Driving demonstration in Section 6.4.
  - Using a single frame encoder (latency of 1 frame) on the on-board hardware side allowed very low latency video transmission
  - A software decoder was implemented at the remote drive station
    - The hardware decoder that was initially trialled was not robust to data packets that were lost in the network
    - It was found to be possible to use a different encoder/decoder solution provided that the decoder was designed to request any missed packets
  - Overall this provided a solution that was of sufficiently high quality to allow a remote driver to drive one of the iQPilot vehicles around a structured road area

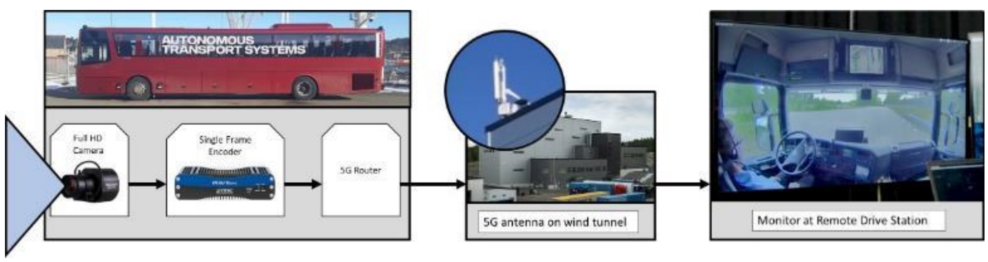


Figure 59 – Camera streaming solution implemented over 5G

- Another key outcome to the joint cooperation was with concepts for allowing prioritisation of network slices to allow bandwidth for safety critical applications such as remote driving to have prioritised bandwidth without competing with lower-priority traffic as in Figure 60.
  - This included methodologies and interfaces to allow prioritisation of the network when demanded, instead of prioritised all the time

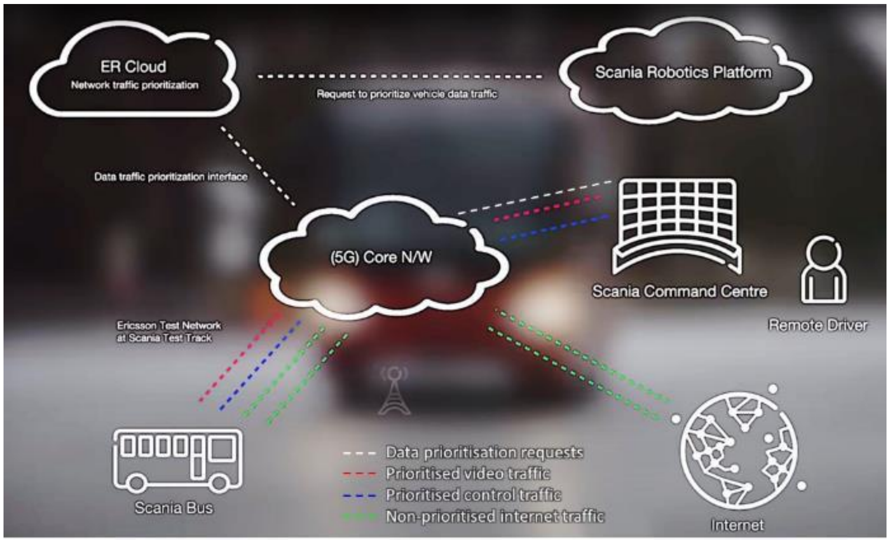


Figure 60 – General network slice prioritisation structure

- The iQPilot also equipped both iQPilot buses and an additional truck to be able to run experiments into Vehicle to Vehicle communications over the network (Vehicle to Network to Vehicle, or V2N2V), as shown in Figure 61
  - Each vehicle determined its own high accuracy position using methodologies described in Section 6.8
  - The position information was continuously transferred between the vehicles to be supplement the onboard sensors and perception

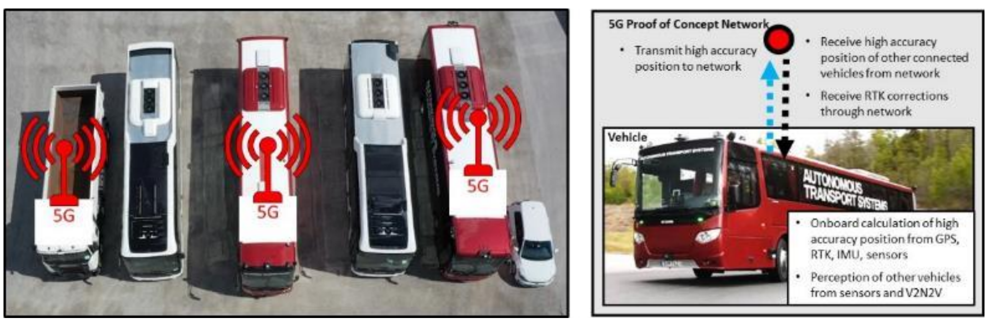


Figure 61 – 3 vehicles were connected to the 5G POC network for the final iQPilot demo. These vehicles continuously provided other vehicles connected in the network with high accuracy position information

  - The iQPilot vehicles were able to integrate the V2N2V information into the overall perception system of the autonomous vehicle, allowing tracking of other vehicles in the environment even when hidden from direct view, as in Figure 62.

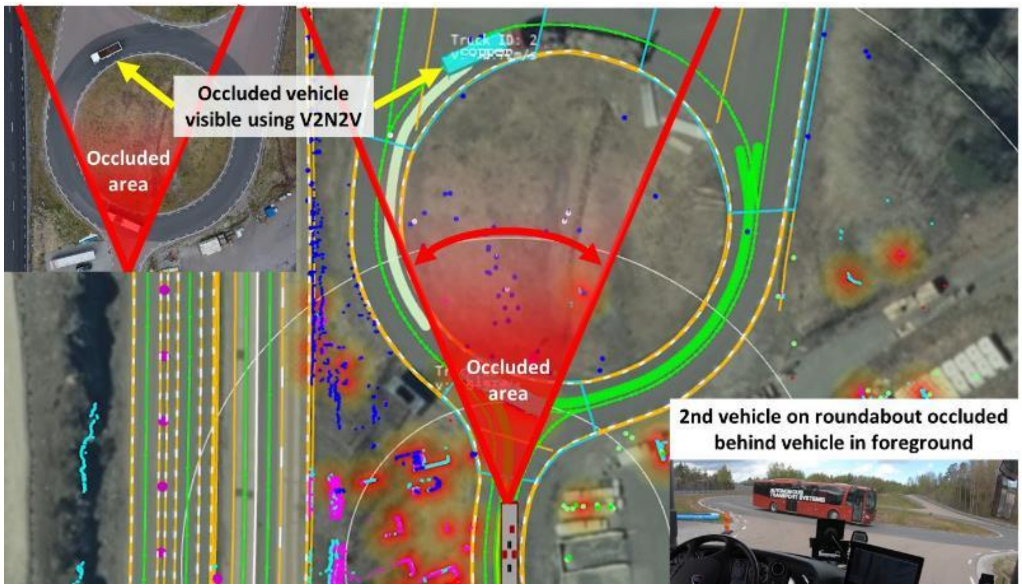


Figure 62 – Using V2N2V transmission of vehicle positions, the autonomous vehicle is able to see occluded vehicles that otherwise would be hidden. This is seen here from the autonomous vehicle perspective (bottom right), aerial view from a drone (top left) and the strategic view in the on-board HMI (central main picture)

- One key observation with usage of V2N2V in this was is that it allowed for continuous planning of motion of the vehicle, even in situations where otherwise the vehicle would be unable to have line of sight and beyond also the information that a human in the same situation would have
- However, this is a difficult to scale solution until such time as the majority or all vehicles in the environment have this type of connected solution
- A more likely solution in small scale / pilot deployments of autonomous vehicles is to have junctions equipped with sensing and perception of other vehicles / pedestrians in the local environment, and for the systems at the junction to provide the detections to the autonomous vehicle.
- Assuming a common interface for describing location of detected vehicles / pedestrians, an autonomous vehicle is able to act on that information relatively independently of if the source is its own onboard sensors, from another vehicle, or other sensors in the environment, provided that the *quality* of the detection is equivalent
- The key quality required for high accuracy and precision of the location and size of other vehicles (based on the sensors and sensor technology) and low latency of that information being received by the motion control systems (another key benefit of low latency in a real 5G system)

6.12.2. CMA (Connected Mobility Arena)

- It was intended at the start of the project to run trials of the autonomous vehicle in the CMA (Connected Mobility Arena) in Kista, where Ericsson also had implemented their 5G POC network for their own trials
    - Due to that iQPilot did not run autonomously on public road, this part of the project did not reach its full goal

- There were other non-autonomous drive activities that were run during the iQPilot project in Kista and neighbouring Barkarby as follows;
    - Mapping of the Kista area as a reference area and for drive simulation of the area as per Figure 63

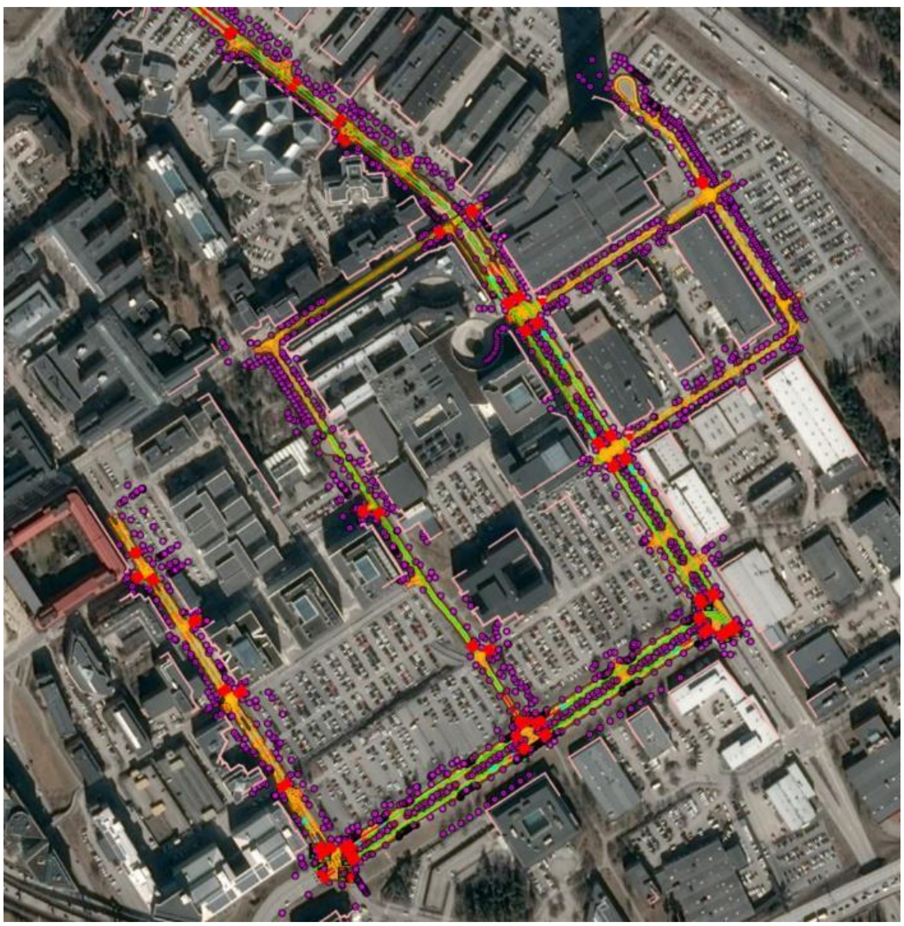


Figure 63 – Reference HD map in the Kista Connected Mobility Arena

    - Driving of the Kista area as a reference area to develop the common scenario catalogue, as shown in Figure 64

Figure 64 - Scenario Catalogue Generation

- Assessment of the capability to drive with RTK GPS in urban canyons, under bridges and underground, as in Figure 65 and Figure 66

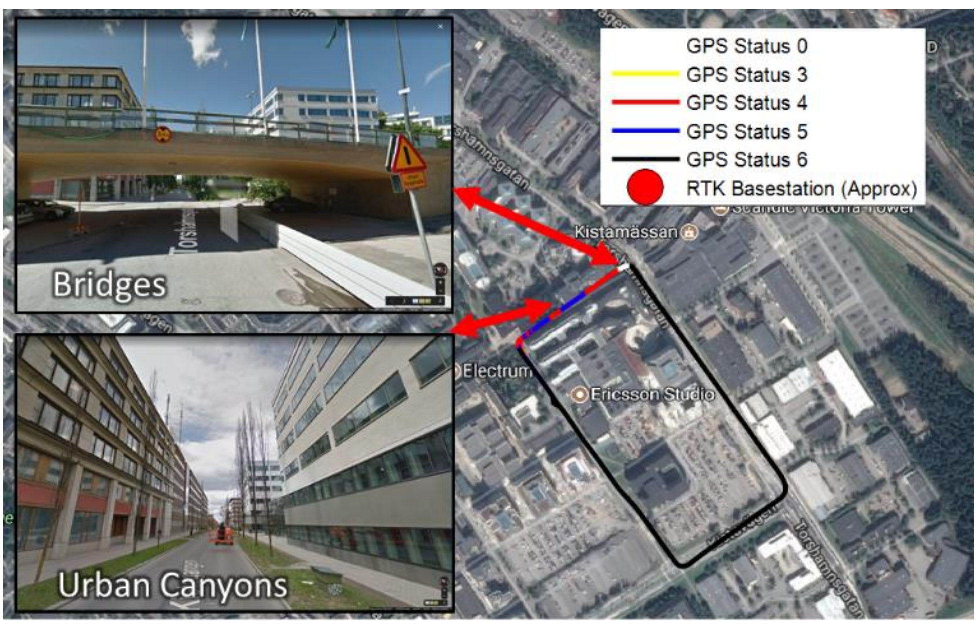


Figure 65 – Reference area in Kista for RTK based localisation with bridges and tight urban canyons

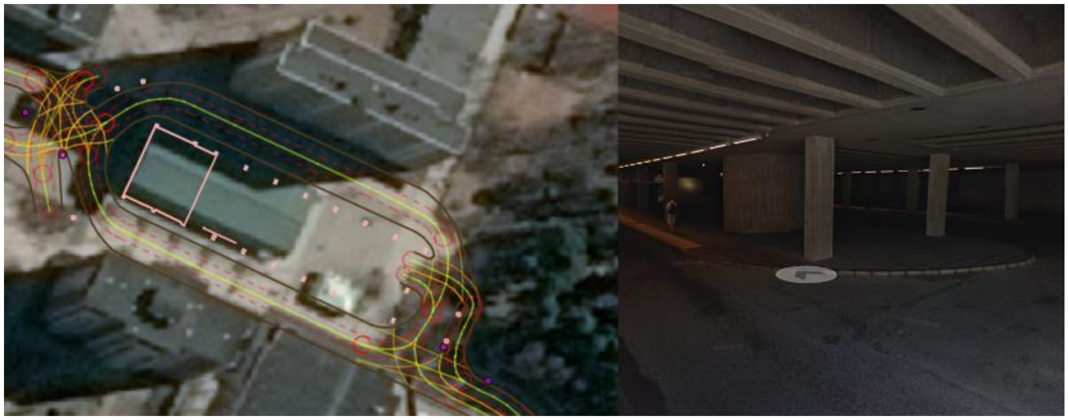


Figure 66 - Reference area in Akalla / Barkarby for underground localisation and driving

- Vehicle, sensor and film display at the Test Site Stockholm event(s) for Drive Sweden together with ITRL, Ericsson, etc, as seen in Figure 67

Figure 67 - iQPilot vehicle #1 outside Ericsson Studio in Kista during a Test Site Stockholm / Drive Sweden event

- Although the overall goals for autonomous operation in Kista were not achieved, study of the area nonetheless provided valuable insight for the iQPilot project.

6.13. PhD and Masters Theses

- iQPilot had one PhD student (Joonatan Mänttäri) at KTH in the division of Robotics, Perception and Learning
  - Joonatan has been working alongside the Situational Awareness group at Scania actively during the last couple of years as work in iQPilot accelerated towards the end
  - The work will continue after the iQPilot project end until completion and in general the Situational Awareness group will continue to actively research going forwards with other internal and external projects
  - It is predicted that the PhD project will finish after approximately 4 years in late 2020 / early 2021

- Within the research department for autonomous driving at Scania, there are 16 MSc students that we can attribute to the project iQPilot as part of the research process

MSc	Student	Title
1	Abhiram Rahatgaonkar	Velocity planning approach for autonomous vehicles (in junctions)
2	Rawan Hasan	Convex Optimization-based Design of a Speed Planner for Autonomous Heavy Duty Vehicles
3	Simon Frölander	Convex Optimization-based Design of a Speed Planner for Autonomous Heavy Duty Vehicles
4	Bjartur Hjaltason	Predicting vehicle trajectories with inverse reinforcement learning
5	Yiru Lyu	Behaviour Prediction of Surrounding Vehicles in a Road Network for Autonomous Driving
6	Anton ter Vehn	Longitudinal Control Design for Autonomous HDVs
7	Joanna Ekehult	Risk analysis of software execution in an autonomous driving system
8	Albina Shilo	Detection and tracking of unknown objects on the road based on sparse LiDAR data for heavy duty vehicles
9	Marc Sigonius	Speed and yaw rate estimation in autonomous vehicles using Doppler radar measurements
10	William Miles	Bezier curve based lattice planner and lateral controller for highway scenario
11	Addi Djikic	Segmentation and Depth Estimation of Urban Road

MSc	Student	Title
12	Jiangpeng Tao	3D LiDar based Driveable Road Region Detection for Autonomous Vehicles
13	Vishnu Pradheep Raveendran	Route planning for autonomous vehicle in a dynamic environment
14	Martí Girona	Numerical Optimization-based Motion Planning for Heavy-Duty Vehicles
15	Truls Nyberg	Design and Implementation of a Strategy for Path Tracking on Autonomous Heavy-Duty Vehicles
16	Oscar Törnroth	Design and Implementation of a Strategy for Path Tracking on Autonomous Heavy-Duty Vehicles

Table 1 - MSc Students whose projects supported the iQPilot project

6.14. Summary of Results and Deliveries

With reference to the FFI programme objectives listed in Section 5, by the end of the iQPilot project the results contribute to all of the declared objectives.

There was only 1 part mentioned in the listed objective where there was not the originally intended results of "partial" vehicle automation. This was in relation to plans to look at self-contained functionality for stopping in buses stops (which was achieved), but also at the possibility of implementing partly autonomous "urban platooning", which was not worked on by the end of the project. The background of this was that;

a) Industry is moving so quickly to focus on full autonomy with a small window for opportunity for an area where there is small gain relative to effort to achieve
b) Platooning functionality at Scania is more at a point of working towards more industrialised / pilot solutions, where the possibility for this functionality will in the end emerge without direct need for focus in the context of this project

Of our own goals of taking autonomous vehicles onto real public roads autonomous, this goal was not fulfilled in the course of the project. This is largely due to the prototype nature of the vehicles and functionality, where the vehicles were adapted to run as autonomous vehicles from manually driven prototypes, rather than designed for that purpose in the first place.

As a result, the first vehicles to go onto real roads autonomously into urban areas will be vehicles that have been designed for that purpose in the first place.

However, in the goal of developing and demonstrating a suitable Minimum Viable Product for the purpose, this is a goal that we did achieve during the project.

In terms of maintaining competitiveness of Swedish automotive manufacturers through demonstrable innovation and research;

- We were able at the end to showcase the outcome of industrial research at Scania, Veoneer and Ericsson in our end webinar
- We were able to showcase one of the most comprehensive autonomous bus demonstrations to date of any OEM, particularly in Europe. The challenge to European OEM's at present is to remain competitive against similar competition globally (for example in China and Singapore)
- We were able to highlight cooperation between industry and academia, in particular through inclusion of all the ITRL directors from Scania, Ericsson and KTH in our end webinar, as well as several Vinnova and WASP PhD students
- Part of the visibility of the urban autonomy area from this project has led to;
    - Other high profile autonomous bus projects at Scania (particularly towards the world cup in Qatar in 2022) and considerable funding towards this
    - Rapid expansion of the area of strategic competence in Sweden to support the autonomous vehicle development in general
    - Interest in Scania's competence in this area in key global areas such as Singapore
- We were able to showcase other key research projects in Scania, academia and Vinnova/FFI in our final webinar (see section 7.3) by including;
    - Results from iQDeep from the same funding call as iQPilot, together with results from the project and overview of cooperations with Linköping and KTH Universities
    - Results from other project(s) with background in Controls and Situational Awareness that have run in conjunction with iQPilot and contributed to the overall knowledge
    - Results from a variety of industrial and academic PhD students in Vinnova and WASP programmes
- We reached a far ranging audience through our final webinar in different global location despite the Covid-19 pandemic in a way that otherwise would not have been possible and communicated our results in an interesting and effective way

7. Dissemination and publications

7.1. Dissemination

How are the project results planned to be used and disseminated?	Mark with X	Comment
Increase knowledge in the field	X	
Be passed on to other advanced technological development projects	X	Scania has multiple new research areas, with new projects and PhD students working in areas of perception, situational awareness and decision making. There is less focus now on “full stack” projects
Be passed on to product development projects	X	Other areas within the project work packages have been passed to product development projects
Introduced on the market	(x)	Partially in terms of an upcoming pilot project together with VW towards running autonomous bus transportation at the football World Cup in 2022 in Qatar[3], but not yet full market introduction
Used in investigations / regulatory / licensing / political decisions	(x)	Led indirectly to investigation and discussion of regulations in Sweden and Singapore, but in context of follow on projects

This remains broadly speaking a platform into which various research activities contribute at Scania, partners and academia will contribute, but towards a higher TRL level than iQPilot (approx. TRL 7).

7.2. Publications

Several publications were made by the research groups involved to support the iQPilot project, with many test performed on the 2 iQPilot vehicles (buses) themselves and trucks from the last project iQMatic in the group fleet, due to that the functional development is parameterised to the size of the vehicles.

The research group comprises of engineers from industry, as well as industrial and academic PhD students both directly from iQPilot, but also working together with the research group. The last 2 papers are from WASP funded students who used either the iQPilot buses or studied Scania articulated buses in general as part of their studies and wished this to be reflected in the references.

[3] See https://www.volkswagenag.com/en/news/2019/12/project-qatar-mobility.html

Item	Authors	Title	Where published
1	J Mänttäri, J Folkesson, E Ward	Learning to predict lane changes in highway scenarios using dynamic filters on a generic traffic representation	IV2018
2	J Mänttäri, J Folkesson	Incorporating Uncertainty in Predicting Vehicle Maneuvers at Intersections With Complex Interactions J	IV2009
3	J Mänttäri, S Broomé, J Folkesson, H Kjellström	Interpreting video features: a comparison of 3D convolutional networks and convolutional LSTM networks	ACCV2020 (upcoming at time of report)
4	J Mänttäri, J Folkesson	Interpretable Trajectory Prediction for Traffic Scenes With High Levels of Interactions	T – ITS 2020 (submitted at time of report)
5	I Mitsioni, J Mänttäri	Interpretability of Contact-Rich Manipulation Tasks via Visualization	CoRL2020 (submitted at time of report)
6	Nazre Batool, Per Sahlholm	Real-time Recognition of Turn and Brake Signals for Autonomous Urban Buses	2018 ECCV workshop
7	Rui Oliveira, Pedro F. Lima, Jonas Mårtensson, Bo Wahlberg	Path Planning for Autonomous Bus Driving in Highly Constrained Environments	2019 IEEE Intelligent Transportation Systems Conference (ITSC)
8	R Oliveira, O Ljungqvist, PF Lima, B Wahlberg	Optimization-Based On-Road Path Planning for Articulated Vehicles	IFAC World Congress 2020
9	Rafia Inam, Athanasios Karapantelakis, Leonid Mokrushin, Elena Fersman	5G Network Programmability for Mission-Critical Applications	Ericsson Technology Review (ETR'18), Kista, Sweden, Jan 2018
10	Rafia Inam, Nicolas Schrammar, Keven Wang, Athanasios Karapantelakis, Leonid Mokrushin, Aneta Vulgarakis Feljan, Elena Fersman	Feasibility Assessment to Realise Vehicle Teleoperation using Cellular Networks	IEEE 19th International Conference on Intelligent Transportation Systems (ITCS'16), Rio de Janeiro, Brazil, November 2016
11	Rafia Inam, Athanasios Karapantelakis, Keven Wang, Nicolas Schrammar, Leonid Mokrushin, Aneta Vulgarakis, Elena Fersman, Viktor Berggren	Remote operation of vehicles with 5G	Ericsson Mobility Report (EMR'17), Kista, Sweden, June 2017

Table 2 – Publications either directly from project participants, or that supported work towards functionality and understanding for the iQPilot vehicles

7.3. Dissemination Through Final Results Webinar

To mark the end of the iQPilot project, a final webinar was run, with a good selection of results were presented in the 2-part final webinar in the following links.

Part 1;

- Main Project Presentation (joint iQPilot and iQMobility)
  - This was run as a webinar due to that we could not run a live demonstration with passengers and visitors due to the Corona Covid-19 pandemic
  - Instead, we pre-recorded our main showcases and presented them during the different sections of the webinar
- 8 sections, including;
  - iQPilot and iQMobility 2016 to 2020
  - Autonomous integrated public transport system
  - Autonomous bus in the system
  - Remote management of autonomous fleet
  - 5G, connectivity for driverless vehicles and beyond

        - Perception and the streets of Södertälje
        - Automated depot management
        - The future of public transportation
    - Multiple presenters from Scania, partners and academia, including;
        - Project managers from iQPilot and iQMobility
        - Product Owners from showcased areas at Scania
        - Industrial representatives from partners Veoneer, Ericsson and INIT (iQMobility)
        - Academic representatives from KTH and Örebro Universities
        - KTH ITRL Director and co-directors from Scania and Ericsson
    - This can be re-watched at the following link;
      https://www.youtube.com/watch?v=f-56Ekt1xtI

Part 2;

- The final results were presented in 4 streams (3x iQPilot and 1x iQMobility), with presentations for each work package area in the projects

- The webinars can be re-watched in the following links;

    - **Stream 1**; iQPilot (Technology, motion and command)
      https://www.youtube.com/watch?v=L8t_1_ee0G4

    - **Stream 2**; iQPilot (iQPilot Perception and Situational Awareness)
      https://www.youtube.com/watch?v=cyknLNHj3Aw

    - **Stream 3**; iQPilot (Academic and Industrial PhD presentations)
      https://www.youtube.com/watch?v=RT_0FVn1oDg

    - **Stream 4**; iQMobility (Transport System Control Centre, operations and other technology)
      https://www.youtube.com/watch?v=HeL2dSbg8t4

- This segment also included special guests from the iQDeep project in Stream 3 and PhD students (Vinnova and WASP funded) who work with areas connected to the iQPilot project

8. Conclusions and future research

Overall the iQPilot project has resulted in a solid Minimum Viable Product that;

- Fulfils the majority of goals according to the FFI programme objectives

- Effectively showcased the main functional objectives of the project, namely
  - Functionally demonstrating technology that will allow driving autonomous buses in urban areas as we progress to pilot phases
  - Functionally demonstration of autonomously driving into bus stops as part of the main urban driving demonstration

- Effectively showcased other areas that were not part of the original project description, namely
  - Remote Driving together with our industrial partner Ericsson as part of 5G trials
  - Autonomous drive functionality as the basis of depot driving to complement the strategic goals of the partner iQMobility project

- Successfully developed a core of technology required for urban areas and were able to demonstrate this as;
  - Full system for the main project showcase(es) at TRL 6
  - Partial / sub-systems from the industrial partners Scania and Veoneer in our Södertälje joint demonstration drive at TRL 5/6
  - Presentations for the technical areas that made this possible

- Successfully cooperated with academic participants
  - We will have 1 PhD student graduate at KTH as a direct result of the project
  - 16 MSc students graduated with theses that supported the project
  - Provided vehicles referenced by WASP students in their publications

- Provided visibility for and maintained the competitiveness of Swedish automotive industry, particularly through the final webinar

- Paved the way for an high-profile pilot project at the Qatar 2022 Football World Cup with autonomous buses as a next step

- Has come to a successful conclusion despite the backdrop of the Corona Covid-19 pandemic

In conclusion, this project is regarded as a success and has received strong feedback from participants in the final event and the audience

Multiple work packages within the scope of the project can be considered to move more towards productionisation and pilot phases. There are on-going areas of research still within the work package areas of perception, situational awareness, motion planning and decision making. Overall the research in these areas are overall that the original several times larger than the original iQPilot group.

The overall area for autonomous driving in urban areas is still an area where there will be more research for years to come to before it is complete beyond the current level of iQPilot. There are many on-going research activities at Scania that continue to work with research in an “agile” process to progressively increase the level of functionality and develop knowledge in the area.

9. Participating parties and contact persons

Company / Institution	Person	Role
Scania CV AB	George Dibben George.Dibben@scania.com	Project Manager / Coordinator
Veoneer	Jonas Hammarström	Director Pre-Development, Computer Vision
Ericsson	Viktor Berggren	Manager Ericsson Research, Service Layer Technologies
KTH	John Folkesson	Associate Professor, Robotics, Perception and Learning

In general, for further information, please contact George Dibben as first step