

Autonomous Driving Aware Traffic Control – Final Report

July 2017



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AD Aware Traffic Control



Glossary

AD	Autonomous Driving
AMQP	Advanced Message Queuing Protocol
API	Application Programming Interface
CTC	Central Traffic Control
DATEX II	Standard information model for road traffic and travel information in Europe
Drive Me	Volvo Cars autonomous driving research project
GUI	Graphical User Interface
ITS	Intelligent Traffic System
LTE	Long Term Evolution
OEM	Original Equipment Manufacturer
OGC	Open Geospatial Consortium
OpenLR	Open source location referencing method
RFI	Road Friction Indication
TMA	Truck Mounted Attenuators
TMC	Traffic Monitoring Centre
V2X	Vehicle-to-Everything

Executive Summary

This report is the concluding document of a joint public private project run over a period of ten months through to the end of June 2017 financed in part by Vinnova. The partnership included Volvo Cars, Ericsson, Carmenta, Trafikverket, and the City of Gothenburg. The goal of the project was to define and propose a traffic control cloud for automated vehicles with interfaces to vehicles, road authorities and city authorities, along with the associated information flows for connected vehicles. In addition the project proposed solutions on required services including traffic control and information sharing.

The main deliverable from this project was a demonstration of the working system held at Lindholmen Science Park in June 2017. This demonstration showed the information flows from the car to the cloud, through to a Central Traffic Control platform and back again, as well as the flow of information to the Central Traffic Control from the road authority. The project utilised and built upon a lot of the already existing cloud infrastructure developed for the Drive Sweden initiative.

This report documents the technical solution implemented, from the architecture envisioned, the technologies implemented and the standards used. Additionally the findings and conclusions of this work have been recorded with where possible desired future steps or recommendations.

Finally the report contains the methodology, results, and recommendations of a large workshop held in April 2017 between the City of Gothenburg, the National Road Administration, Volvo Cars and Carmenta where future services based on the having access to the data from connected cars as well as having actual autonomous cars operating within the traffic environment were discussed.

Project participants

Volvo Cars

Volvo Car Corporation have high ambitions when it comes to sustainable mobility solutions, especially within electrification and autonomous drive. Its leading position within self-driving cars is based on the world first and largest pilot for autonomous driving with real customers on public roads, Drive Me in Gothenburg. Important building blocks to secure its journey to commercial autonomous driving offer includes the joint project with Uber, extensive recruiting in Gothenburg and Zenuity (a new joint venture company with Autoliv) which will develop software for autonomous driving. The work on autonomous driving builds upon 89 years of safety know-how.

Ericsson

Ericsson is a global leader within communication systems and services. 40% of mobile calls are made through Ericsson systems and more than 2 billion people use its networks. Now, Ericsson is leading the development towards a Networked Society, where everything that benefits from being connected - will be connected. The Transport sector will benefit extensively from getting connected, cooperative and automated. Ericsson is now developing and implementing communication services and cloud services to support this development. The next generation of mobile networks, 5G, is now being developed to fully support connected automation and new mobility services. Drive Sweden is a key project, with leading partners and use cases to ensure relevant and innovative input the development of 5G and related services.

Carmenta

Carmenta is a privately held Swedish company, founded in 1985, with offices in Sweden, Germany, France and Spain.

Carmenta has been supplying world-class software for mission-critical systems for more than 30 years – systems in which superior situational awareness is the key to success. Carmenta provide high performance software products, develop client-specific solutions and offer a wide range of services that help some of the world's most technologically advanced customers optimize their operations using real-time geospatial information. Its technology is designed to meet the highest standards focusing on high performance, high availability, openness and scalability, and ease of use. Carmenta's customers are found globally with a concentration in Europe.

Carmenta provides command and control technology for connected and autonomous vehicles which helps traffic network operators to improve traffic control and increase road safety. Background maps with integrated sensor data, weather forecasts, video streams and other information provide the type of common operational picture that will be necessary for the command and control systems of the future.

Trafikverket

Trafikverket is responsible for the overall long-term infrastructure planning of road, rail, sea and air transport. Its assignment also includes the construction, operation and maintenance of state roads and railways. They are developers of society and plan for a holistic integration of the entire transport system. In order for society to develop, the country's transportation must work. Increased accessibility

is becoming increasingly important. Its task is to develop an efficient and sustainable transport system from a perspective that encompasses all modes of transport. They work with long-term infrastructure planning in close dialogue with regions and municipalities. They are also responsible for building, operating and maintaining state roads and railways. In addition, they are responsible for ensuring that this infrastructure is used effectively and that it promotes safe and environmentally sound transportation.

City of Gothenburg

Gothenburg is a port city with a strategic location in between Oslo and Copenhagen. It has a population of around 550,000 and is Sweden's second largest city.

The city is growing strongly and is preparing to make space for 150,000 more residents by the year 2035. As the city grows, it is also evolving. New residential areas and city districts are emerging on land previously used for industrial purposes. In 2012 the city adopted the River City Vision that sets a firm direction for the future development.

One important strategy for implementing the Vision is to allow areas now under development to become living labs for development of innovative transportation and mobility solutions, always with a strong focus on sustainability. Gothenburg has a long and proud history of developing the transportation system and making it smarter and has many times piloted new advanced ITS features involving cars, buses and trucks.

System description

Basic principles

The Volvo Cars Drive Me project is the foundation for this project. In Drive Me the vehicles are aimed at Level 4 automation = secondary tasks are allowed, if the vehicle cannot manage the situation it will go to a safe stop or make a controlled handover to the driver. AD is allowed on a carefully mapped set of road segments but not under severe weather or traffic conditions. When the vehicle is in AD mode Volvo Cars takes the responsibility.

This means that Volvo Cars must be able to execute that responsibility and allow or revoke AD driving in real time.

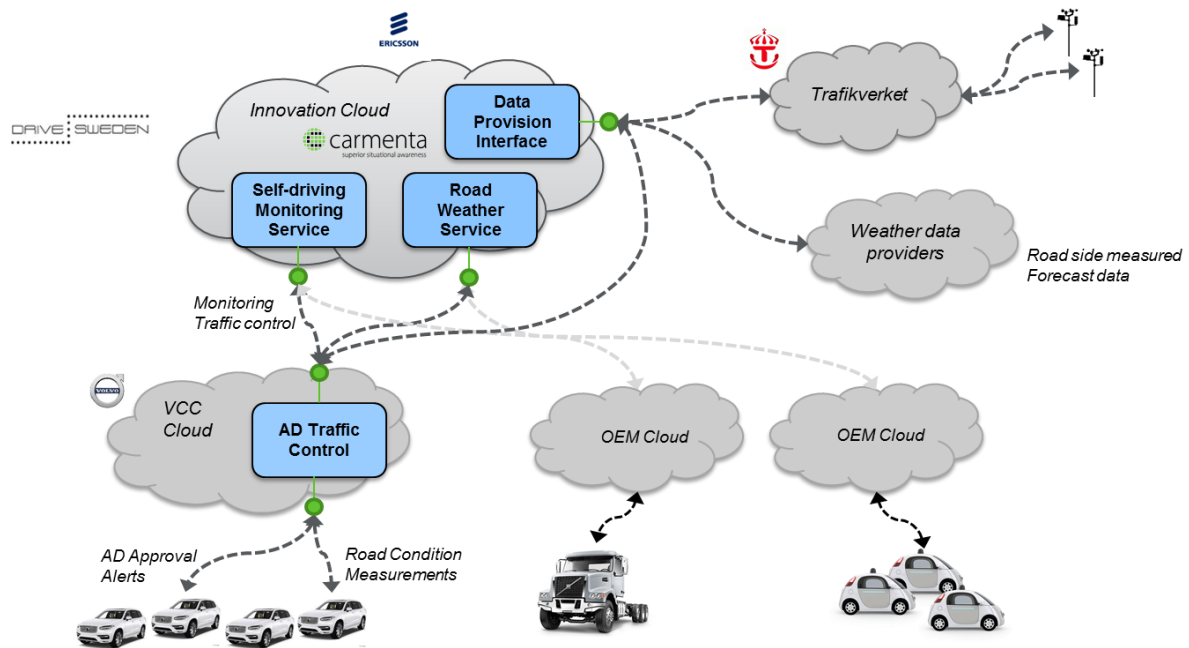
We foresee that other OEM's and fleet owners will have the same needs in the future.

We foresee that different OEM's will have different certified roads that will grow over time.

We foresee that different vehicle models will have different capabilities that will grow over time and enable AD driving under more harsh conditions.

Regulation on data protection and privacy must be fulfilled and privacy by design is preferred.

System architecture



The system is composed of a Central Traffic Control (CTC) cloud, a number of OEM-clouds and external data sources.

The OEM cloud, in our case an AD enabled instance of the Volvo Sensus Cloud, has the communication to and from the vehicles. The route, position and other data is communicated to the OEM AD traffic

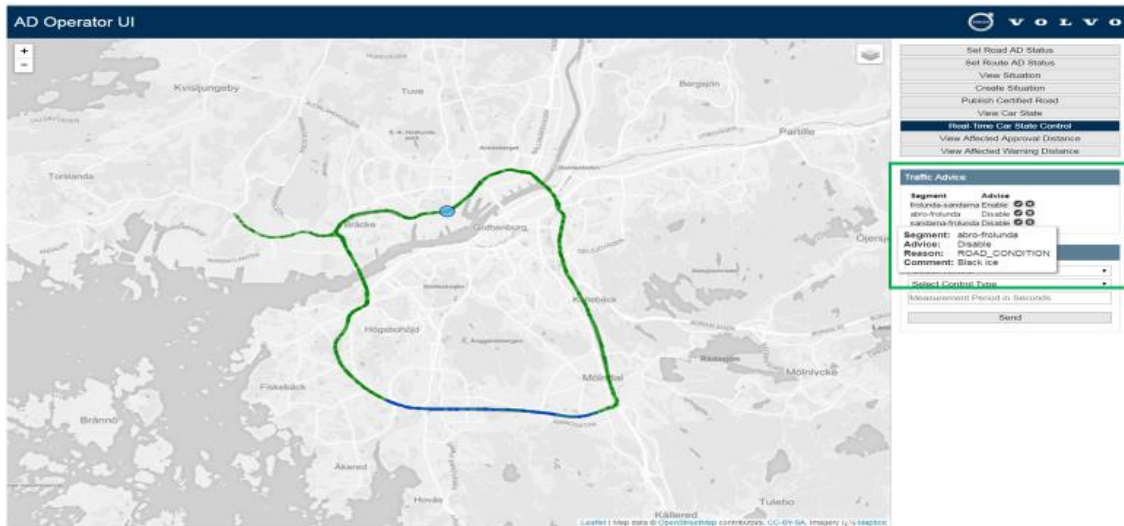
control. As the OEM is the only part that should know about the vehicles, know their AD capability, and takes the responsibility in AD mode this control function must reside in the OEM cloud.

With some inspiration from the Nordic Way project and the insight that many OEM's will have the same need for traffic and weather data we introduced the Central Traffic Control (CTC) Cloud. The CTC Cloud is assumed to be a Public or a Public Private Partnership instance that can serve any number of OEM clouds by aggregating all data of interest.

This cloud has a Publish/subscribe and Request/response mechanism. Also here is a Traffic Controller that monitors the situation (on the different certified roads) and with automation support that can trigger alerts to the OEM clouds if there is an event.

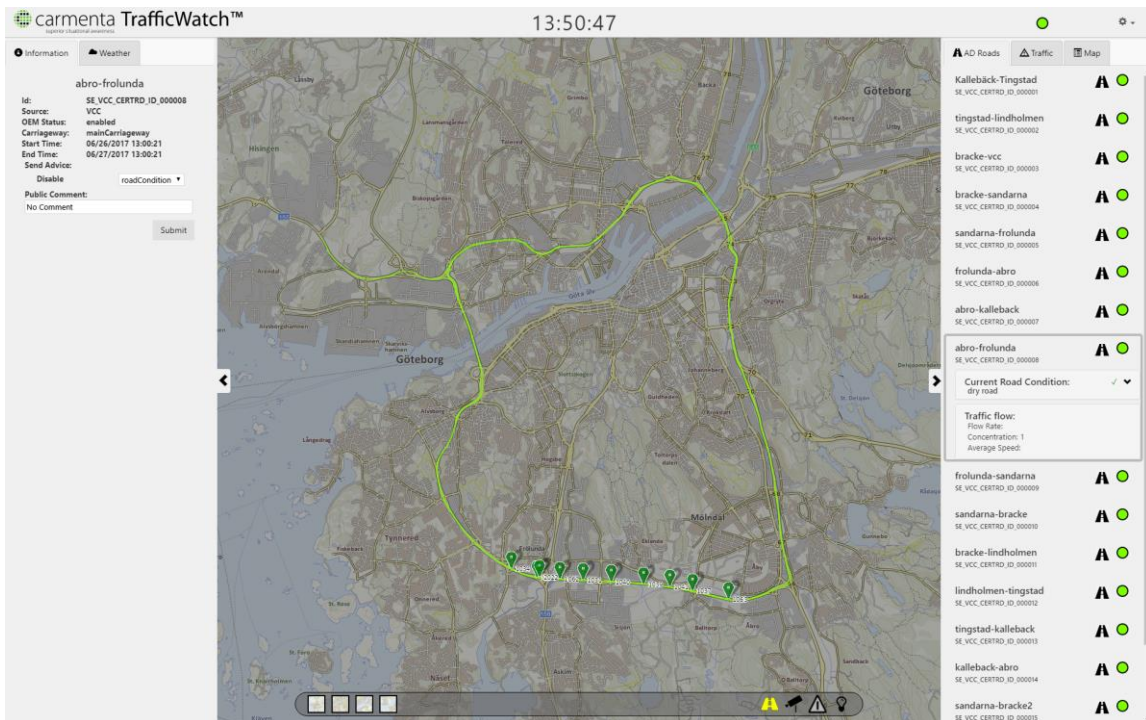
The data exchange between the CTC cloud and OEM clouds use DATEX II with some extensions for AD use cases suggested by the project.

OEM AD Traffic Control View



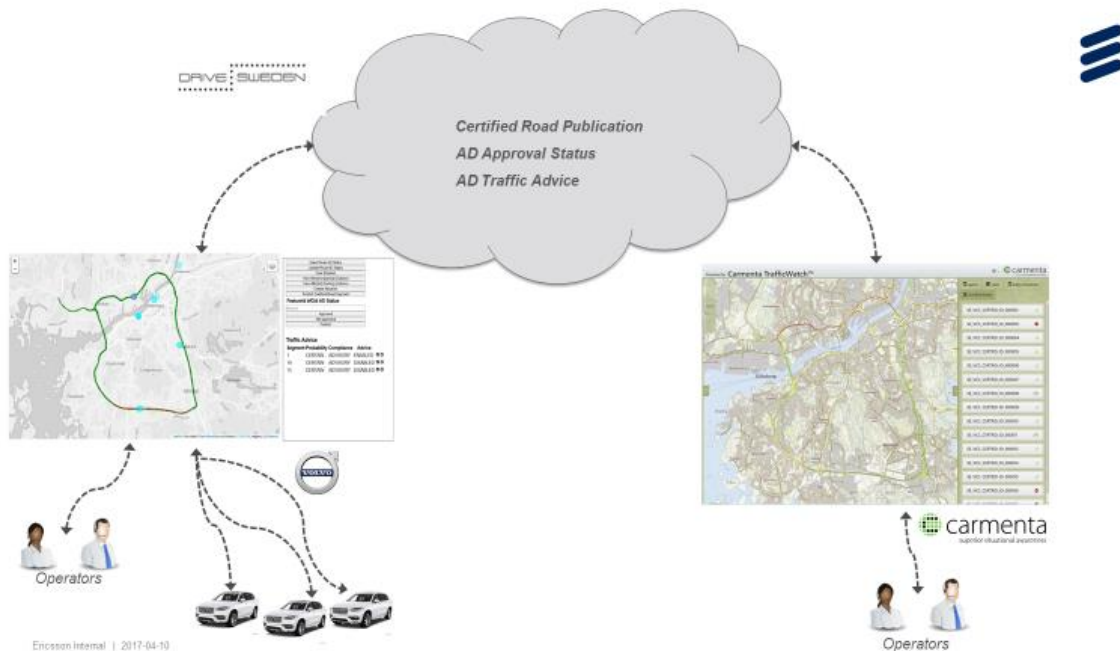
Screen dump showing the Volvo Operator GUI

Central Traffic Control view



Screen dump showing the CTC Operator GUI with the certified AD road segments transferred from OEM VCC.

System Services



The first service is **Transfer of certified road segments map data** from the OEM to the CTC. The OEM mapping of the certified road, in our case the ring motorway around Gothenburg has more than 1000 segments. This has been reduced to 17 segments to reduce complexity. Map data is transferred

(DATEX II) to the CTC that makes a map matching to the CTC map and a manual feedback is sent to the OEM to check the validity.

The next service is **Transfer of road segment approval status** from the OEM to the CTC. This allows both traffic controllers to have the same situation awareness.

CTC advice on AD driving based on situation. The CTC reads the DATEX II message stream from Trafikverket (Swedish Road Administrations Safety related traffic information service) and maps out the events. Road conditions like: Lane closures, Road blockage, Construction sites, Faulty Signs on a road segment will trigger an **advice** to the OEM AD traffic control that will then allow them to take a **decision** to allow or revoke AD driving on that segment and send this data to the vehicle. The road segment approval status is sent back to the CTC.

CTC road weather service (situation and forecast). The CTC aggregates weather data and based on thresholds will trigger an **advice** to the OEM AD traffic control that will allow them to take an action as in the case above.

Extreme weather conditions can be:

- Low visibility on a specific section of certified road
- Extreme precipitation on a specific section of certified road
- Snow on a specific section of certified road
- Low lane visibility on a specific section of certified road
- Low object visibility on a specific section of certified road
- Low friction on a specific section of certified road
- Strong winds on a specific section of certified road
- Aquaplaning risk on a specific section of certified road

OEM vehicle sensor data to CTC. Volvo Cars Sensus Cloud can today share (aggregated) road friction information and amber hazard blinker information. In the project today we get this data and road works warning from 12 TMA blocking trucks in Gothenburg from the Nordic Way Interchange Node¹. This can be developed further with more sensor data from AD vehicles to improve the situation awareness.

OEM query on data on road segments (pre trip). When the driver programs the AD route, this is sent to the OEM AD control that in turn can send a query to the CTC that will return the data to the OEM AD control that allows or revoke AD driving on the road segments. Segment approval status is sent back to the CTC.

In order to protect privacy, the OEM AD control sends the **Density (flow) of AD vehicles in AD mode** on all road segments to the CTC. This can only be simulated now but is regarded as a good function for the future public traffic management of mixed traffic.

¹ Nordic way film: <https://www.youtube.com/watch?v=gTrrl4ymvyc>

In order to protect privacy, the OEM AD control does not expose the position of an individual AD vehicle that made a safe stop. **Safe stop alert to CTC** will be based on aggregated data (like 3 safe stops within 3 km and 3 minutes).

Findings

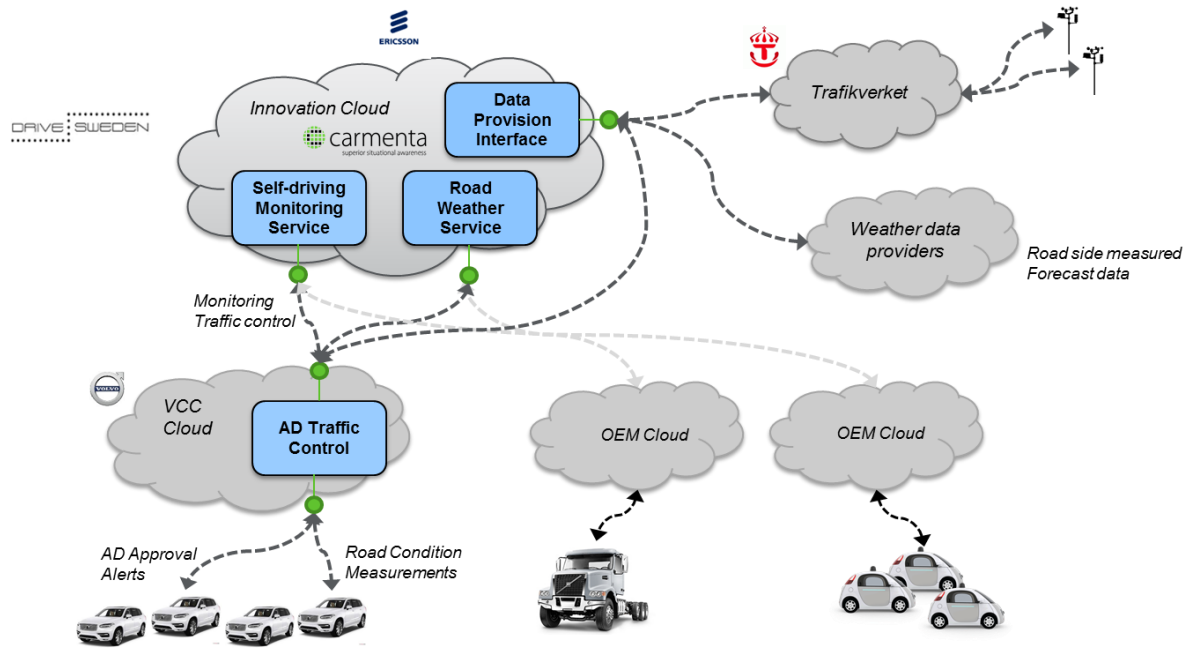
When we started out this project we had a belief in the usefulness of a platform providing governance for AD vehicles. It was perhaps a sketch to start with, but as the project has progressed the picture has become clearer. There are still areas that need more research, where we do not fully understand the implications. But it has become clear to all of us participating in the project that this type of platform for the governance of AD vehicles is an important piece of the puzzle in solving the future problems of traffic management in modern cities.

The AD Aware Traffic Control project has been a great way to prepare for the Drive Me pilot that is coming in the end of 2017. It has been an important part of Volvo Cars' preparations and thinking about AD Control, the way it would work and what kind of stakeholders will participate.

There are a number of benefits that we initially assumed and that we still believe are there after further analysis but since the platform hasn't been tested in real production use this is still very much an analysis on paper.

There are also a number of findings that were not part of the initial assumptions coming into the project but that have an impact on how we think going forwards. All of those findings and ideas have come about thanks to the cooperation and the spirit of freely sharing ideas across companies and government agencies.

Benefits and findings are listed under each work package. Since the deliverables in the project plan were mostly about building the platform itself we have summarized them in Appendix A, with a short description and explanation for each deliverable.



Autonomous Traffic Monitoring

Having full traffic situation awareness is a cornerstone to create safer, more efficient and environmental friendly traffic. Real-time traffic situation monitoring on a central level will provide connected entities guidance for a better traffic control including guidance to OEM AD clouds.

Better traffic control

Conclusion

The platform gathers, stores and distributes a lot of relevant data points from various sources, matched to road segments. Data about traffic situations and road conditions are vital for making an informed decision about whether or not to allow AD. Despite being in such an early phase, as we are right now with the Drive Me program, the data available in the platform is also valuable for commercial and public transport providers as they face similar situations.

The fact that more data about road conditions and traffic situations from different sources is shared between OEMs as well as authorities and third parties makes for better decisions. There is however a concern over the diversity of data and lack of sharing. More cooperation and standard data formats and terminology need to be developed.

Increased road safety

Conclusion

The AD Aware Central Traffic Control extends the OEM Traffic Control with data that is shared between OEMs as well as authorities and third parties allowing for better decisions on allowing AD-mode or not. The platform increases the road safety by having monitoring of the conditions that the AD-vehicles are used in. The platform only deals with anonymized data and therefore not violating the privacy of the AD-user.

The project has shown in several demos that the information flow between CTC and the Drive Me AD-vehicle works, but this relies on timely data, open trust between OEM's and government bodies, standard interfaces as well as legislation to ensure commitment.

The transition period involves all connected cars

Conclusion

In order to effectively transition AD-vehicles into full use we will need to have access to more data. There are several ways of achieving this. One is to add more OEMs, another is to connect more types of vehicles. The benefit of having more data is that the probability of an AD vehicle running into an undetected situation, where the driver (without wanting to) exits AD mode and takes control, is minimized. It will of course still happen but the probability is in relation to the number of connected non-AD vehicles in total. The data we are collecting is not only useful to AD cars but could also provide assistance to public transport as well as traffic planning in general.

Common terminology is a foundation

Conclusion

The naming of things might seem a simple task but solving the problems of future traffic management requires a common terminology that is precise, clear and comprehensible. The meaning of what a *certified road segment* is and what role it plays cannot be in doubt in a collaborative ITS setup. As more and more decisions are being automated it's crucial that a common foundation for speaking about traffic management is developed. It will not only reduce time in developing new functionality but will also shorten the time it takes to find and fix problems. Last, but not least, a common language allows for a common foundation for business rules and as such creates an easier way to gain insight and trust in implementations of other stakeholders.

Whole picture Benefits/Findings

Community/Society,

- The CTC creates a Collaborative Situational Awareness that is beneficial for all connected stakeholders, many of which both contributes and use the information in the CTC. By using a collaborative approach to ITS it is possible to collect and fuse information that contributes to a safer traffic situation.
- The need for data privacy (i.e. GDPR) makes it necessary to have several levels of traffic control. Vehicle and personal information are aggregated and filtered when communicated with CTC from OEM Traffic Control to protect the privacy of individuals.
- This project together with Nordic Way point out the way to evolve traffic management by aggregating and sharing sensor data from connected vehicles. The situation awareness will reach new levels of detail. The other important feature is that traffic management now, via the OEM cloud, can reach out to the vehicles. In this project we focus on AD vehicles, but the principles can be used for all connected vehicles.

Environmental,

- Traffic Flow Information – The project has demonstrated the exchange of traffic flow information between autonomous cars and the central traffic cloud. All connected vehicles can contribute with data that enhances the possibility of proactive traffic management that can reduce congestion and also limit the environmental impact of

traffic. When the vehicles are autonomous the effect of a proactive traffic management could potentially be even more positive.

Business,

- The CTC could act as a data broker, potentially creating a marketplace for information from autonomous and connected vehicles.
- Public-Private partnership will be the most likely business set up.

Organisational

- A high level goal of the project was to suggest a roles and responsibilities model for relevant actors – i.e. driver, OEM, national/regional traffic authorities, etc. Even though the different actors in the project agree on the benefit from having a CTC that provides collaborative situational awareness, the responsibility for operating the CTC remains to be further investigated.
- Other organisational issues still to be investigated are relations between the CTC and other commercial integration platforms, relations between the CTC and traffic management systems on regional, national and international levels, etc.
- The CTC is a central node but it must be possible to arrange a “federated network” of CTC’s that can interact and cover adjacent areas (cities or nations) or even the same area (public and private roads).

Technical

- The project has shown that on a technical level it is possible to build a cloud based central traffic control for autonomous and connected vehicles using existing and open standards (i.e. DATEX II, Open Geospatial Consortium (OGC), OpenLR, AMQP). However, in order to communicate autonomous driving advice (allowed/not allowed) within DATEX II, the standard needs to be extended. One delivery from this project is the start of a proposal that can be submitted to the DATEX II standardisation board (CEN Technical Committee 278). More details can be found in Appendix C.
- The Drive Sweden Innovation cloud proved to be a good environment to execute the project in.

1. Carmenta specific findings

- a. The integration of the Carmenta products (Carmenta Server, Carmenta TrafficWatch) in the Drive Sweden Innovation Cloud infrastructure has been very smooth and efficient, proving that the products are very well suited to be used in cloud based architectures.
- b. The traffic control operator GUI and AD Aware CTC functionality developed in the project has been demonstrated to traffic management operators at Trafik Göteborg and Trafikverket, showing that CTC fulfil expectations on a future AD Aware traffic management system.
- c. The AD Aware CTC architecture and functionality has been demonstrated and discussed with a group of traffic management systems architects at Trafikverket, showing that the system architecture with a cloud based set of micro services

conforms well with the architecture of the future traffic management system planned by Trafikverket.

- d. It is important to have a technical platform flexible enough to handle different use-cases for setting up and maintaining a central road segment database. It should be possible to use both road network data supplied through national or local municipalities (such as NVDB) as well as road data from global suppliers (such as HERE, TomTom etc).

2. Volvo Cars specific findings

- a. AD Approval decisions need to happen on many levels. Ranging from what is technically possible in the vehicle, up to the level of a government authority. This means that the Business Rules surrounding the AD Approval and the terminology, describing it need to be aligned across OEMs, third parties and authorities.
- b. Extending the RFI probe sourced concept to include transmitting data from one car to others based on location/time details means increased safety.

3. Ericsson specific findings

- a. Ericsson has adopted a DevOps approach for AD Aware Traffic Control project. One of the main focuses has been how can Ericsson leverage a fast development, integration and deployment model of interchange servers, across different regions around the world to meet its current and future partner’s needs. It has been shown that Ericsson has a cloud ready infrastructure for hosting a container based messaging system solution using standard APIs, which can significantly reduce integration time with partners and OEMs. OEMs and partners are not restricted to us a specific programming language or need to be bound to a particular operating system. It are providing openness, flexibility and a faster method to reach the market.

Collaborative Road Weather Service

Readily available, updated and quality assured information about weather conditions in the road network will improve safety and efficiency.

Weather Forecast information contributes to better traffic management

Conclusion

For CTC purposes weather forecasts provides information that can be used in addition with other data to make more informed decisions for an effective and safe traffic management.

Bad weather conditions can significantly affect the traffic situation with an increased risk for slow or stationary traffic. Suddenly appearing severe weather situations such as icy roads or impaired vision due to heavy snowfall poses an immediate threat to driver safety. The integration of weather information and forecasts in the operational picture will make the traffic operator able to more proactively take actions to avoid or mitigate disturbances or accidents caused by weather phenomena.

Weather Forecasts are not yet accurate enough for guiding AD operations

Conclusion

Currently available on-line sources providing weather forecasts are not yet accurate and precise enough to be useful for operational AD Approval guidance.

Several public and private providers offer weather information services capable of delivering detailed forecasts down to geographical points or road segments. However the spacing and distribution of currently available ground based meteorological observation stations delivering 'start data' for the forecast modelling used in these services are much too sparse. This makes them unable to predict local variations and road-specific conditions on the detailed scale necessary for AD vehicle operation.

Weather Forecasting for AD guidance needs vehicle-collected data

Conclusion

Following on from the previous finding there is a need for more detailed measurements to enhance modelling to deliver accurate enough forecasts for operational AD guidance. Real-time floating car data from connected AD vehicles delivering weather-related sensor information through the OEM TC is potentially a very useful source for enhanced forecasting.

Detailed and accurate measurements of weather-related information through car sensors on AD vehicle fleets provided in real-time could significantly enhance forecast modelling.

The CTC is a good weather information hub

Conclusion

The CTC can effectively act as a weather information 'hub' for collecting, aggregating and analysing meteorological information and making it available to connected parties in a prepared and standardized way.

It makes sense to use a central unit for providing general weather information thus relieving individual OEMs the hassle of dealing with proprietary APIs and 'un-refined' meteorological information. In the project we have successfully made weather forecast data readily available to OEMs both in the form of AD Advices (hazardous road conditions) and through a generic weather 'query' interface.

Whole picture Benefits/Findings

1. There are several potential providers of weather-related data able to supply road-related weather information.
2. Lack of standardized APIs leads to specialized interfaces to external weather information providers. The content and nature of data also varies a great deal between different providers.
3. The data provision interfaces were reasonably easy to implement due to clear specifications from the evaluated offerings. An efficient plugin framework in the Carmenta's products made it also easy tailor-make the interfaces and then integrate the weather information in the CTC data flow.
4. Among the contacted providers, Foreca could offer the most complete road conditions service with best coverage and was used as the primary data source for setting up and testing the meteorological data flow in the project.

Authority Interfaces

Whole picture Benefits/Findings.

Ericsson have reused the interface to Trafikverket DATEX node for Road safety related traffic information that was developed in Nordic Way. Messages can be filtered on both geo-spatial data as well as content.

Risk

The technical challenges to develop self-driving vehicles where the OEM or organisation behind the product take legal responsibility in case of accident requires new processes, methods and solutions. The legal framework doesn't exist today for self-driving cars. For a real commercial implementation (and business opportunities) this has to be solved to secure implementation.

There is also a risk that no one wants to develop and operate a collaborative platform due to the fact that there are unclarified issues in legal frameworks. If that scenario plays out it may seriously hinder the development and implementation of AD. OEMs are more likely to re-invent the wheel and we will fall short on the society benefits.

International liaisons

Drive Me in UK and China.

When the project started there was an intent to also pilot the Drive Me program in UK and China. Along the way it has been decided to suspend those pilots and instead focus on Gothenburg. Therefore, the work of spreading the AD Aware CTC platform via the Drive Me program has been postponed.

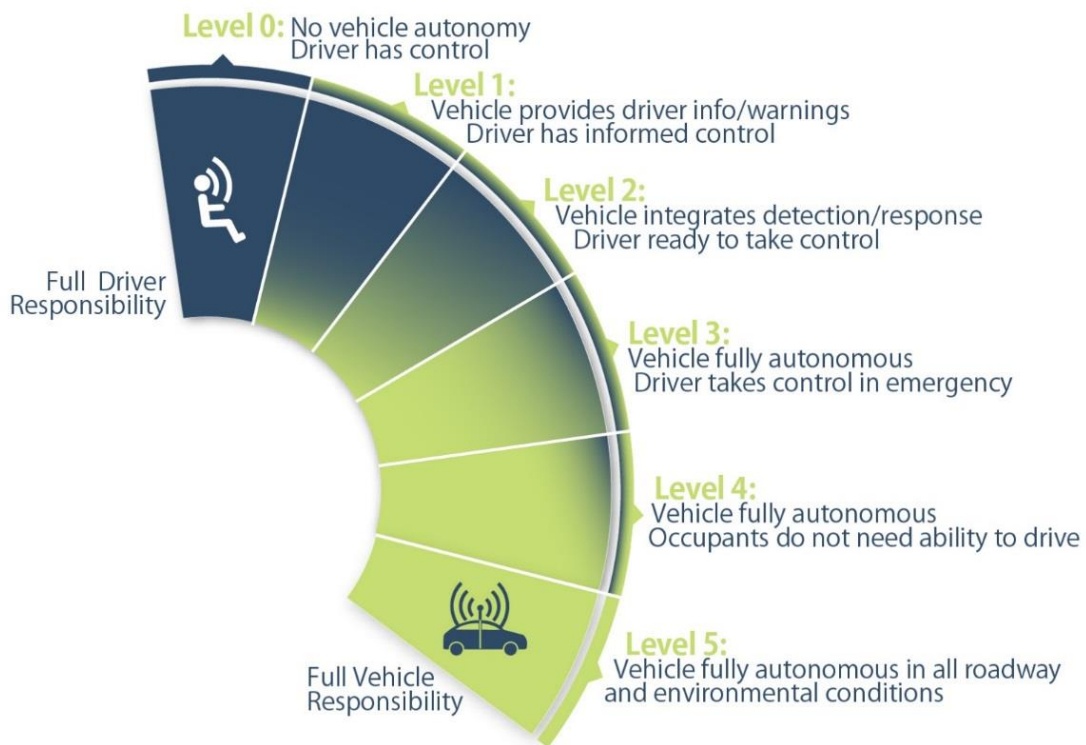
EU Cooperative Intelligent Traffic System (C-ITS) platform

The EU C-ITS-platform is an expert group dealing with connected and automated driving and our project has been presented for the working groups "Enhanced traffic management" and "Physical and digital infrastructure" for AD driving. Our architecture and the concept of OEM-certified roads for AD created a lot of discussion and interest especially among the road operators in many EU countries. Hopefully our project will get a couple of pages in the final report ready in September 2017.

Plan for commercialisation and growth

The project has used AMQP 1.0 for messaging between the clouds and used DATEX II for the data model. Extensions to DATEX II have been made to cater for AD use cases and these can be proposed as extensions to the DATEX standard. Driving the standardization of messages and formats for this type of information and data exchange across OEMs, third parties and governments is a vital part of making the platform ready for growth into other markets and for use with more OEMs. We have chosen to take the more time consuming and difficult route of doing this instead of building our own proprietary message formats. But we all believe that in order for the platform to stand a chance we need to attract more stakeholders in order to grow the platform. Which is necessary for a commercialization and future development that is market driven.

Vehicle automation is classified in 5 levels. For example, Tesla has level 2 = the driver must all the time be prepared to take over the control. Level 5 (that might be utopia) means that the vehicle can drive itself (in all situations that a skilled human could master) and the vision is to take away the steering wheel and controls. Drive Me is aiming at level 4, the vehicle can drive itself on certain roads under certain conditions, and the driver can perform other tasks. The vehicle will bring itself to a safe stop or make a controlled handover to the driver if AD is not possible anymore.



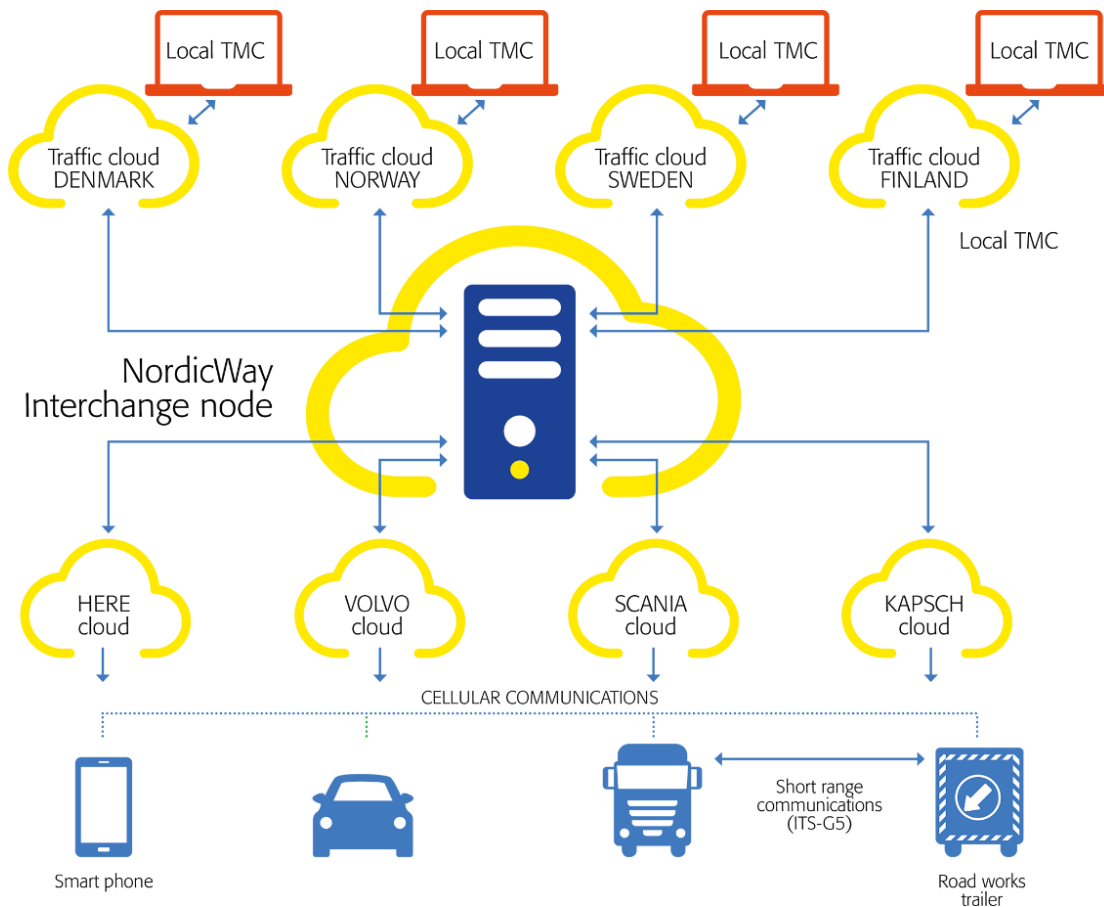
Source: https://www.sae.org/misc/pdfs/automated_driving.pdf

Volvo Cars has stated that they will take the responsibility when in autonomous mode. The logical consequence of this is that Volvo Cars then also must execute that responsibility and must be able to allow and revoke permission for AD drive.

Other OEM's and fleet owners are coming to the same conclusion according to media.

With inspiration from the Nordic Way project we established a similar system architecture to share data (publish/subscribe and request/response). To expand the Nordic Way C-ITS data sharing concept on a European level there must be a federated network of interchange nodes to avoid vendor lock in and enable flexible governance models.

AD Aware Traffic Control

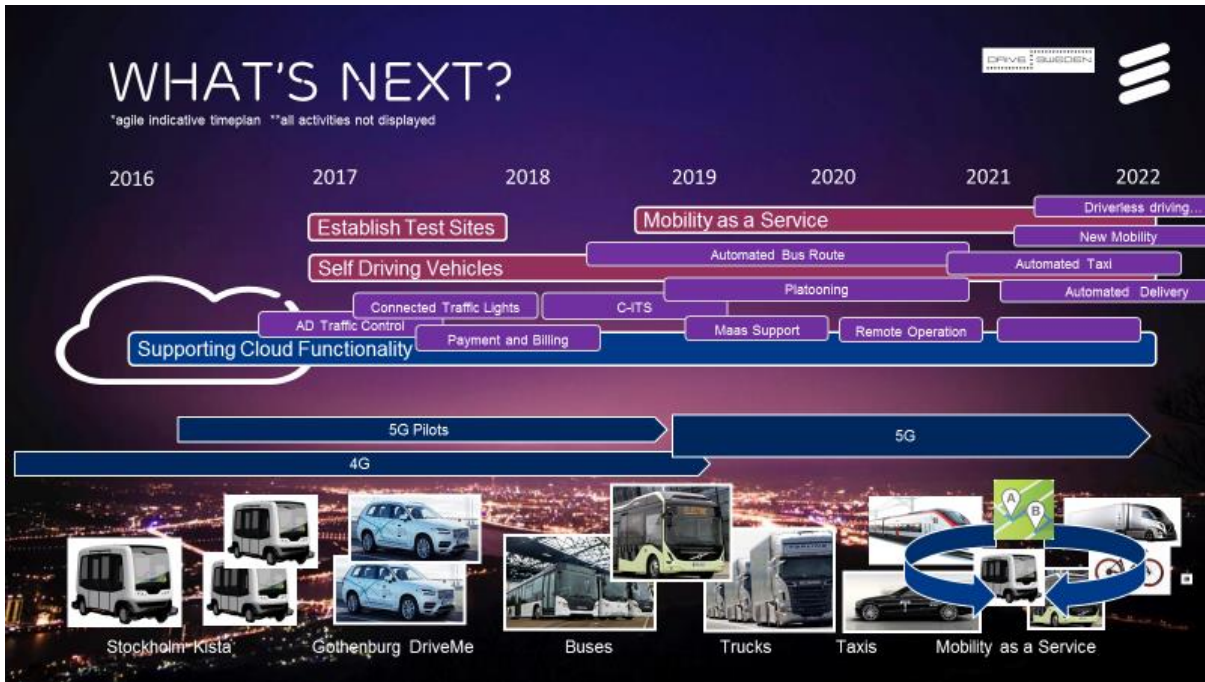


The Nordic Way project² has created a lot of interest from road operators in Europe and is more or less becoming a natural part of what in EU is called “the hybrid C-ITS” system. The cloud to cloud communication is based on DATEX II and OpenLR just as in this project.

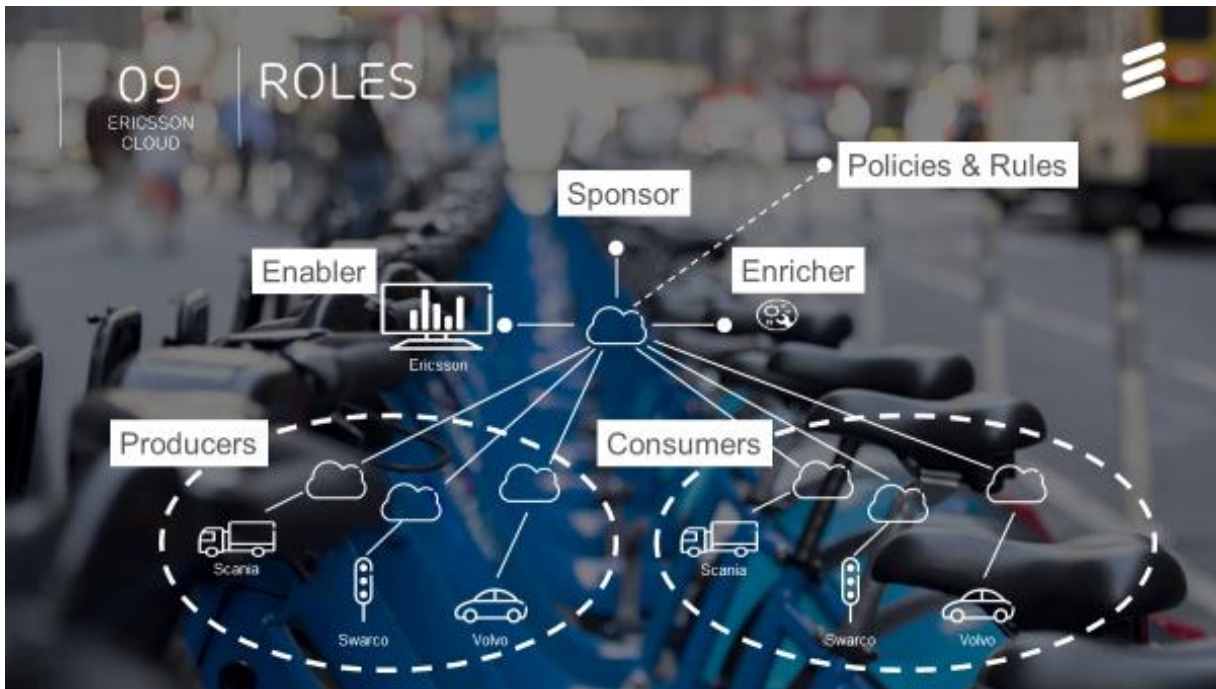
We believe that the results and architecture in the AD Aware Traffic Control project will create the same interest among road operators, OEM’s and (public transport) fleet owners aiming for level 4 and taking the responsibility. We will communicate our results of this project and the follow up Emergency Vehicle Information. It is very likely that predicted Drive Sweden projects like Mobility as a service and automated bus routes will use and evolve the platform.

Other OEM’s could come to Drive Sweden, join the platform and conduct trials. But it is also easy to set up the system on other trial sites like the German A9 or ASFiNAGs Gratz trial area. The roadmap of Drive Sweden gives us the stability to attract other players and evolve the standardization.

² Nordic way film: <https://www.youtube.com/watch?v=gTrrl4ymvyc>



With inspiration from discussions in Nordic Way and Drive Sweden we see different roles in a commercial setup.



We have elaborated that, as previously stated, it will be a federated network of central control clouds or interchange nodes. One assumption is that Public Private Partnership (PPP) can be an effective set up. Sponsor would be the Public body – Trafikverket. Enabler can be Ericsson. Enricher can be Carmenta and there are many producers of data. Consumers would be OEM clouds and Traffic management. The sponsor will need to trigger the PPP eco system with an initial investment and

gradually the internal cloud billing and settlement system will be used to track and monetize all transactions according to the policies and rules and make the system self-supporting.

Future Work

This project has aimed at developing a tool set and a technical platform for AD Aware traffic control. It has put its finger on a number of important issues and highlighted the need for cooperation across companies and regulatory organizations.

We would like to propose three categories for the next steps. To continue to add more functionality, to add more content, and a study into the use of the platform.

More functionality

Emergency Vehicle Information

The project extension to including Emergency Vehicle information has already been submitted and approved. It will provide data about Emergency vehicle's routes and allow us to respond to situations where an AD-vehicle's path intersects that of an emergency vehicle.

More content

Another OEM

By adding another OEM and their AD-vehicles we would primarily test the CTC application and the complexity of handling a many-to-one mapping of, for example, status of certified road segments.

Usage of the platform

Drive Me program

A natural extension is to utilize the platform in the Drive Me program that Volvo Cars is running. It would allow us to refine the information levels, language and other conventions used in the platform.

Automated public transport

In Drive Sweden and in many other places experiments have started with small automated buses and pod's. This is planned both in Kista and at Lindholmen as part of Drive Sweden. The public transport traffic control would need the same type of information as the OEM cloud in this project and they definitely have a certified route. In addition to this we foresee that the public transport traffic manager not only would allow or revoke autonomous driving but also would like to have the ability to take remote control of the pod and drive the passengers to a safe spot in case of trouble. This will require 5G mobile network technology and Ericsson has this type of remote control with haptic feedback working on the research level³.

³ <https://www.ericsson.com/en/mobility-report/remote-monitoring-and-control-of-vehicles>

Appendix A – Deliverables

WP 1 Autonomous Traffic Monitoring

WP1.1 Central Traffic Control

D1.1. Report with findings, lessons learned and recommendations.

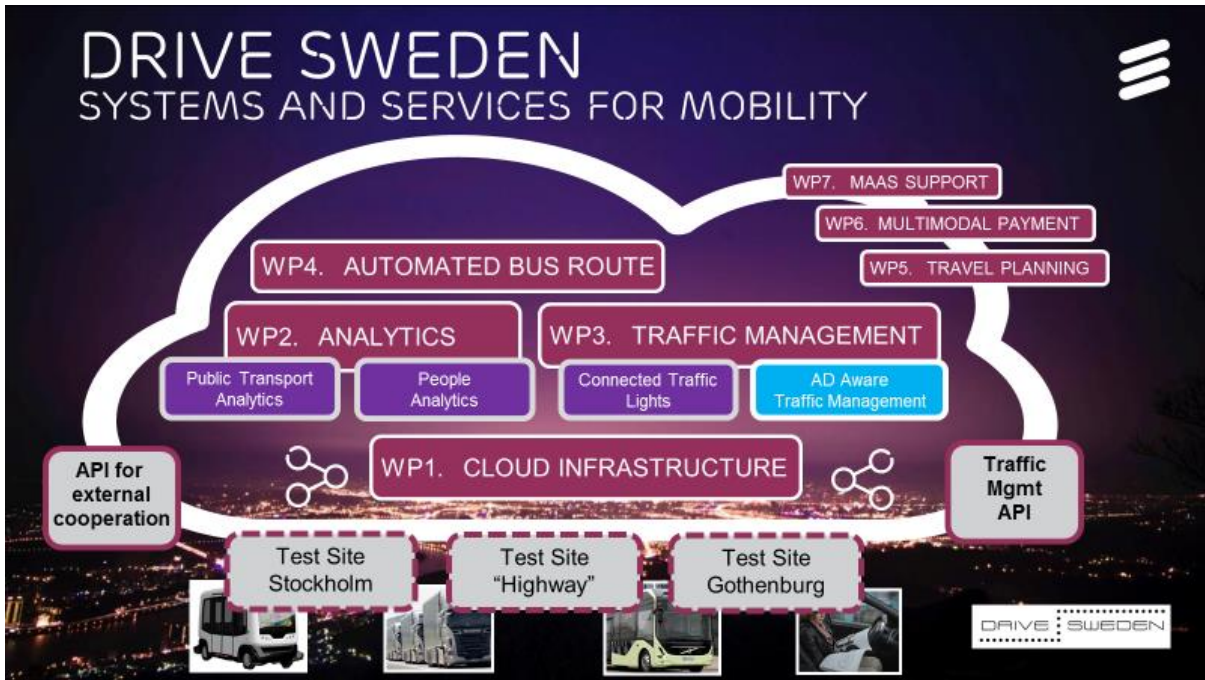
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D1.2. Description of used and proposed interfaces and the flow of information.

We have successfully developed and deployed an up-and-running solution for a Central Traffic Control function. Implemented as a set of services, the solution is smoothly integrated as a demonstrator in the Drive Sweden Innovative Cloud infrastructure. Existing frameworks and tools already part of the Drive Sweden Strategic Project “Systems and services for mobility” have been successfully re-used in this project.

The project has resulted in an efficient operator user interface for an AD vehicle monitoring service that has been used to test and evaluate various interactive operator actions to support OEMs. Valuable insight has been gained on how to operate an AD vehicle monitoring and guidance service as part of the Innovative Cloud solution.

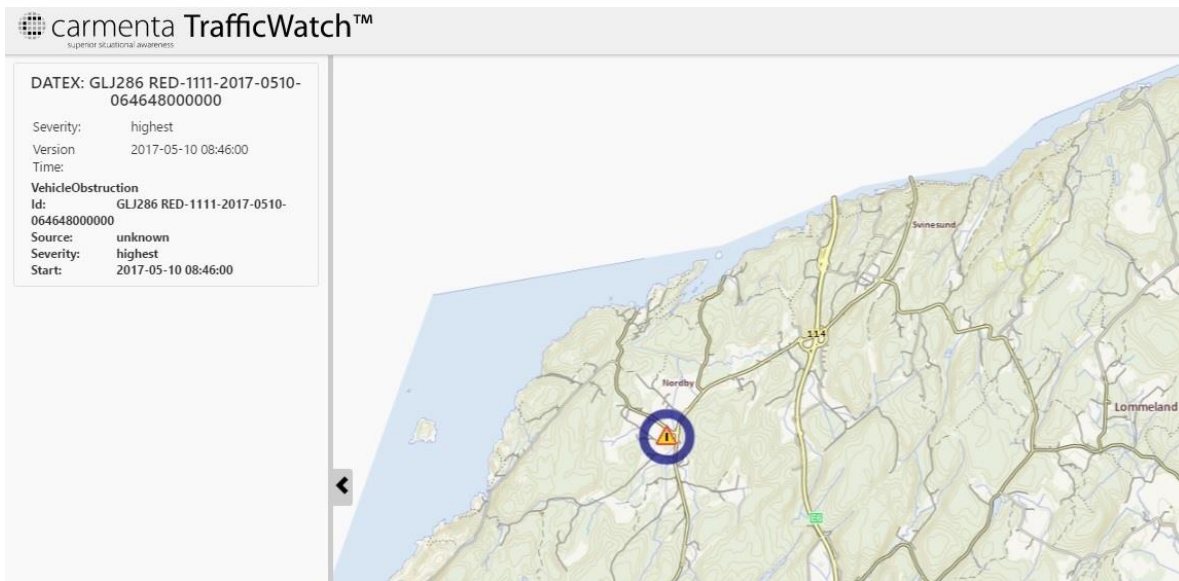
We have established the needed technological foundation for the project SW delivery as well as for further function development including communication, computation and storage capabilities. Based on SW resources made available through parallel projects such as the Drive Sweden Strategic Project “Systems and services for mobility; WP1 – Implementation of cloud infrastructure and base services” (lead Ericsson). Below is a schematic view of existing and planned systems and services in this initiative.



Schematic view of Drive Sweden's overall project structure with the AD Aware Traffic Management sub-project highlighted in blue.

Another fundamental piece that has added value to the project is the Interchange Server solution used in the "Nordic Way" project. We have re-used this (AMQP) solution as the communication back-bone for the message based cloud-to-cloud communication. A specific component/service is developed as part of the CTC system that connects to the Interchange Service, hosted by Ericsson, for further connection to the OEM clouds.

Practical tests have been performed with the Nordic Way service itself and a connection has been established. The figure below shows an example of a 'Vehicle Obstruction' situation registered in that service and transferred to the CTC and displayed for the traffic operator.



Screen dump showing the result of a DATEX 'Vehicle Obstruction' message received from the Nordic Way Interchange Server during tests performed in the Svinesund area near the Norwegian border.

The main capability supported by the AD Aware CTC and implemented in the project is to build and maintain an aggregated traffic situation picture for the traffic operator to interactively dispatch AD messages (example AD driving 'recommendations') to connected OEMs. The traffic situation picture established in the project and used for testing is mainly composed of the following parts:

- **Detailed background map**

In the project we have used Carmenta Sverigekartan⁴ as the operational background map. This is a digital map of Sweden optimised for use in command & control systems. The map's layout and colour scheme have been carefully chosen and it has sufficient detail to give the operator a good understanding of the road network and its surroundings also in very 'zoomed-in' views. The map is integrated in the CTC as an external map service and no map data is stored in the CTC itself. One big advantage with using Carmenta Sverigekartan in the CTC is that the road network comes directly from Trafikverkets NVDB (see below). Alternative online map services useful as background maps can be sourced from a large number of suppliers such as HERE, TomTom or OpenStreetMap.

- **Geometry and characteristics of the physical road network**

The road network data used in the CTC is "Nationell VägDataBas" (NVDB) the National Road Database of Sweden. A data processing chain has been established that takes data from Trafikverket's 'Lastkajen'⁵ downloading site and process it for storage in a central road segment database. All AD segments from connected OEMs are map matched (OpenLR) to segments in the central database. Test has also been done using alternative road network data from HERE and OpenStreetMap.

⁴ http://www.carmenta.com/files/4813/9083/1932/Carmenta_Sverigekarta.pdf

⁵ http://www.trafikverket.se/tjanster/Oppna_data/hamta-var-oppna-data/lastkajen---sveriges-vag--och-jarnvagsdata/

- **Real time traffic information**

This data is read from Trafikverket's open dynamic API⁶ using the DATEX II standard.

- **OEM AD vehicle activity and operations**

Real-time data about AD Certified Roads and their status transferred from connected OEMs. In the project we have integrated AD data from Volvo Car Cloud.

- **Weather data**

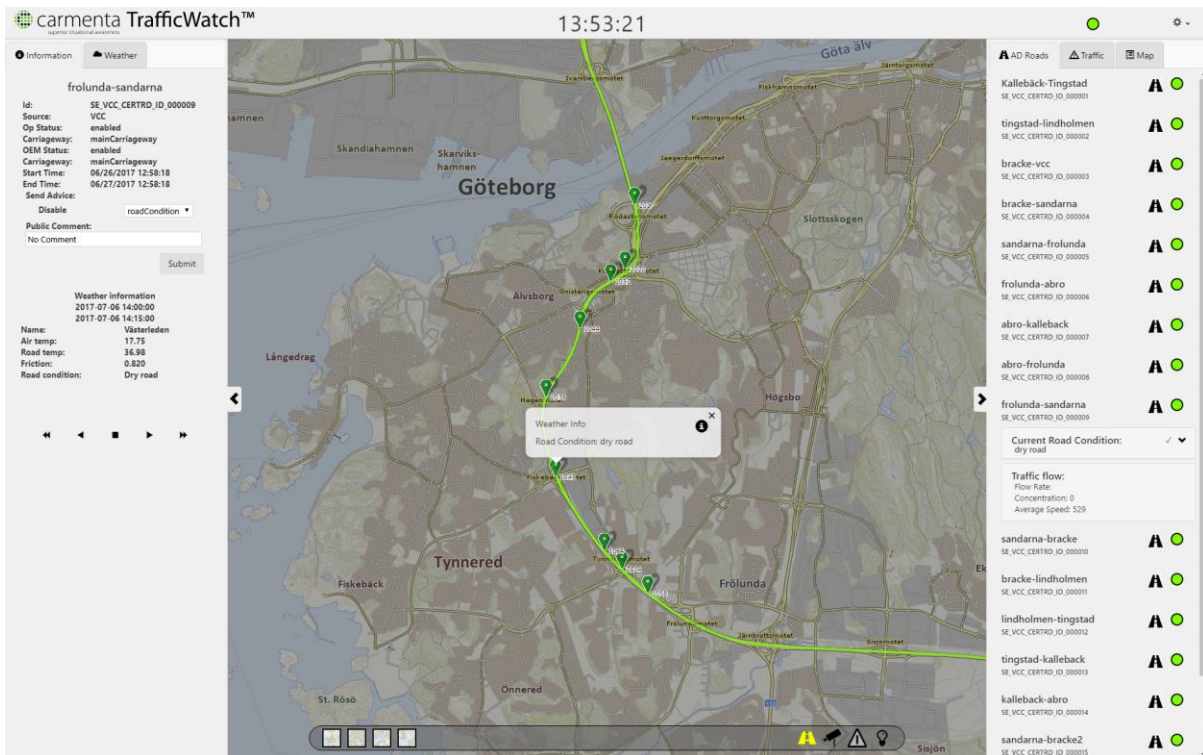
Measured and forecasted weather information including road condition data sourced from four external weather providers have been used and evaluated in the project. These are:

- Trafikverket (information part of the DATEX II API)
- SMHI
- Foreca
- The RSI demonstrator project

More specific information about the integration tests of weather data in the CTC is found in the Appendix A describing the deliverables from WP2.2.

A custom operator graphical user interface (GUI) has been developed and tested as part of the project. The GUI is map-centric and has been designed based on general principles for command & control operator GUIs but its functions are dressed down and entirely focused to support the monitoring and guidance of connected OEM's AD operations. So far the GUI has been used solely for testing within the project but it has been demonstrated and discussed in meetings with traffic control operators at Trafik Göteborg and Trafikverket, assuring that it fulfil the expectations to be part of any future traffic management system.

⁶ http://www.trafikverket.se/tjanster/Oppna_data/hamta-var-oppna-data/datex-trafikinformation-vag-i-realtid/



Screen shot showing the CTC operator GUI with a damped down background map. Map and situation control panels to the right and a general information panel on the left. A status panel on top shows current 'situation' time and if all external connections is running ok (shows the green light). A 'Quick Action Bar' at the bottom makes it easy for the operator to toggle on/off information layers and quickly 'jump' to special interest areas.

The operator GUI shows the overall AD-related traffic situation on top of a detailed and colour-tuned background map. The map can be 'dimmed' darker to allow overlaying objects to be more clearly seen. A map control panel allows the operator to select what is shown in the map window and quickly toggle on/off the presentation of different kinds of information. One control panel is dedicated to show a sorted list of all traffic-related incidents (i.e. DATEX II 'situations') and another panel shows a list of currently monitored OEM AD roads (i.e. OEM VCC 'certified roads'). The operator can easily follow the real-time traffic situation while the lists are continuously updated with data through connected services. The focus can quickly be set on a particular incident or an AD segment by picking a list item. The map centres automatically on the selected object and an information panel opens showing all relevant textual metadata.

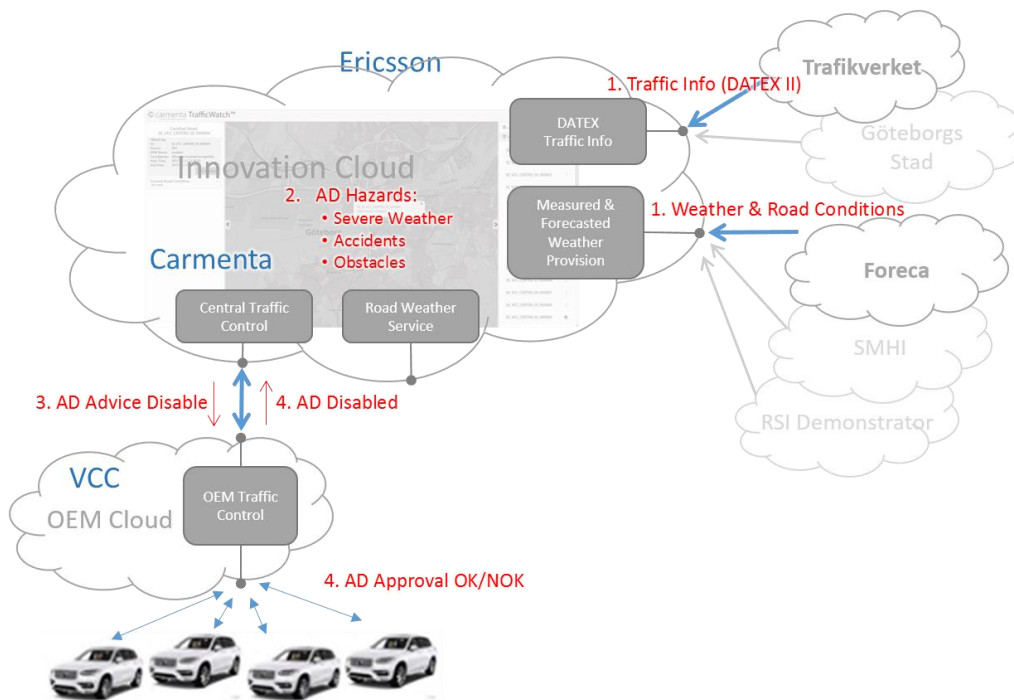
The traffic operator is notified by an automatic warning service when a potentially hazardous situation has occurred on any monitored AD road segment. Current implementation detects when accidents or major obstacles occurs anywhere on the AD road network. This is based on real-time data from Trafikverket's traffic information web service (DATEX II) and analysed on-the-fly by a map matching service in the CTC cloud backend. Also weather data provided from sourcing partners is analysed and warnings triggered whenever a hazardous road condition is detected on the AD road network. All warnings appear in the GUI as a clearly visible notification message on top of the map demanding operator action. Simply by clicking on the message link, the map focuses on the affected AD segment and all connected metadata is displayed for quick action.



Screen dump showing the warning message that notifies the operator that a hazardous road condition has been detected on a monitored AD road segment.

Traffic operator tasks used for building and maintaining the central AD Aware CTC function can be summarized as follows:

- Establish a common AD situation picture.**
 Connected OEMs publishes all new AD certified road segments with unique ID and version that will be used for AD driving. CTC automatically acknowledges the publication for each road segment and use location referencing functions (OpenLR) to translate it to the CTC internal road database for subsequent use. All changes related to the monitored AD roads will then be related to its unique IDs and stored as situation records in the central database.
- Guiding OEM vehicle operation through AD Traffic Advices**
 CTC publishes dynamic AD Traffic Advice as defined by each OEM. In the current version of CTC the AD Traffic Advice is published interactively by the traffic operator, who decides when and what to publish. The automatic warning service is a useful tool that notifies the operator when hazardous events occur on the AD road network. The operator can choose to act and then use dedicated functions in the GUI to prepare and publish an AD Traffic Advice with a ‘disable’ recommendation for the affected road segment also stating the cause etc. It is then up to the OEM Traffic Control if any action is taken based on the advice. If decided to revoke the AD permission on the segment in question, a message is posted back to the CTC which automatically updates the AD status. Below is an overview of the data flow used to collect traffic information and weather data for detecting AD hazards and transferring AD Traffic Advices.



Data and message flow for AD Hazard warnings.

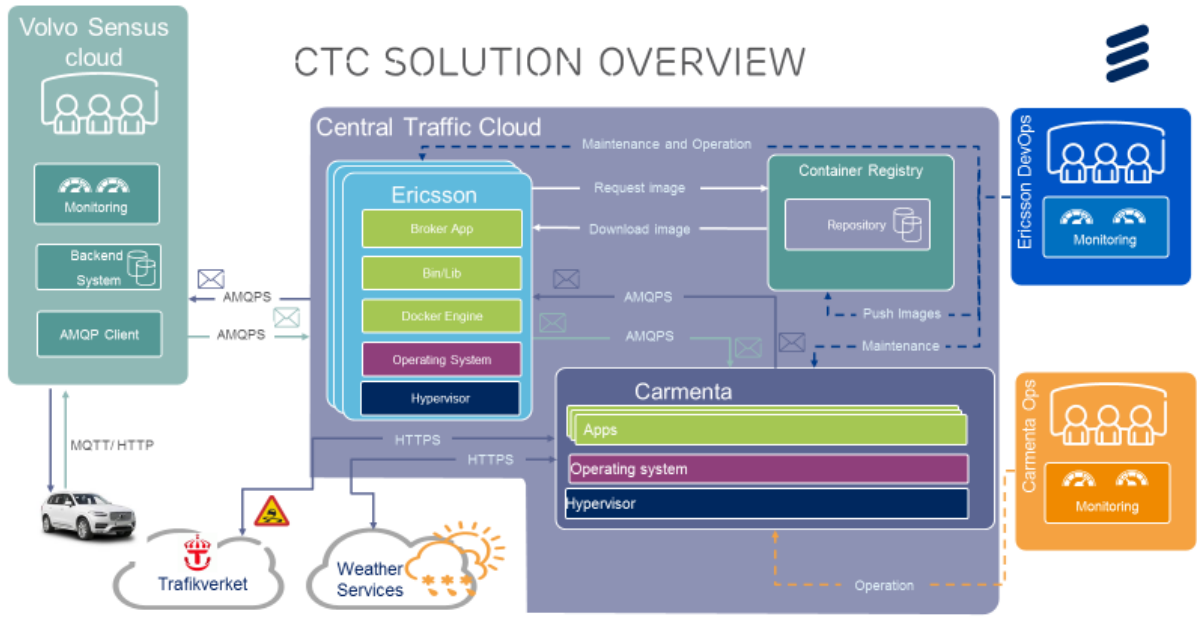
- **Using AD Traffic Information for an improved traffic situation awareness.**

Large amounts of valuable information is collected by AD vehicle fleets operated by OEM's. In anonymized form this could provide a significant contribution to the traffic situation awareness in a central traffic control. We have implemented and performed preliminary testing of functions to get periodically updated traffic information related to monitored AD road segments. Specific AD Traffic Info messages are published from the OEM containing information regarding AD vehicles such as; Average Vehicle speed (km/h), Vehicle Flow Rate (vehicles per hour) and Vehicle Concentration (vehicles per km).

We have used DATEX II as the basis for the data model used in the central traffic control as well as when modelling the message content in the data exchange solution used in the project. Additional information to support AD vehicle operations have been added to relevant parts of the DATEX II model resulting in a working solution where AD related traffic information is transferred between OEM VCC and the central traffic control. More details about DATEX II and the proposed extensions used in the projects are found in Appendix C.

System Description:

The AD Aware CTC solution is smoothly integrated in the Drive Sweden Innovation Cloud infrastructure. The figure below shows a schematic view of the Central Traffic Cloud part of the Innovation Cloud (hosted by Ericsson) and depicts where the AD Aware SW components supplied by Carmenta and the Volvo Sensus cloud operated by VCC are integrated in the cloud.



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Diagram showing the overall CTC solution.

The Central Traffic Cloud backend installation consist of several components:

Broker App:

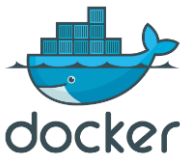
The messaging system provided by Ericsson, which provides standard APIs for partners and OEMs to exchange messages over AMQPS (SSL/TLS)⁷

Container Registry:

Ericsson container registry, is a private repository which Ericsson uses to store new container images. Docker engine and container registry are some of the tools Ericsson uses for continuous integration and deployment in the cloud. Ericsson has managed to significantly reduce integration time by applying CI/CD⁸ workflow model, Ericsson is now capable of deploying multiple copies of the same instance within seconds, scale out the instance around the world to different regions such as Asia, North America within minutes

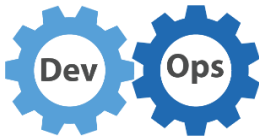
⁷ AMQP = Advanced Message queuing protocol, SSL = Secure Socket Layer, TLS = Transport Layer Security

⁸ CI = continous integration, CD = Continous delivery



Ericsson DevOps:

The Ericsson DevOps (=continuous development and operations) manage the monitoring of the system, builds new containers and pushes the images to container registry to make the images ready for deployment. Ericsson DevOps also monitors Carmenta’s virtual infrastructure, ensuring their system is up and running at all times.

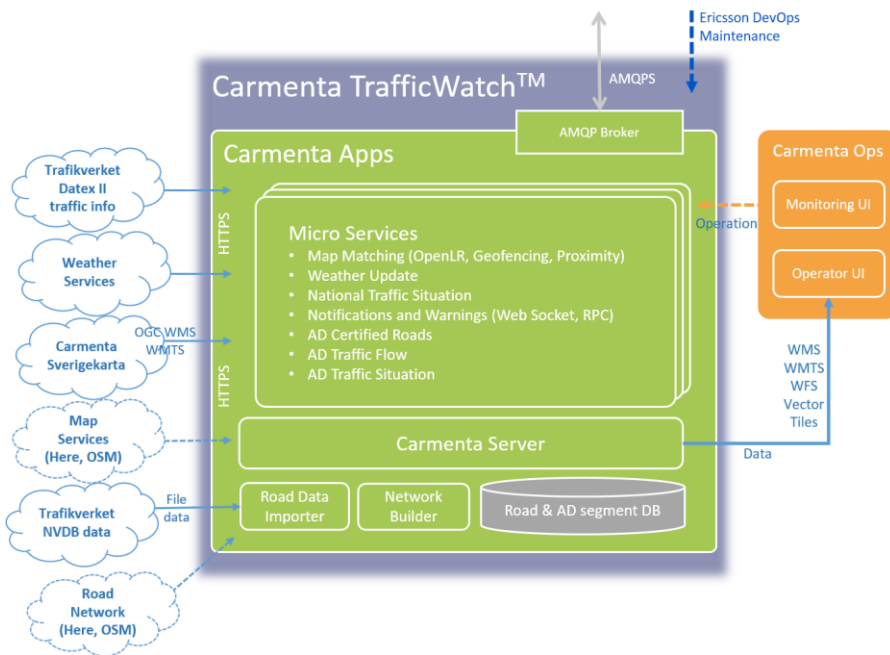


Carmenta:

Carmenta’s AD Aware CTC application is connecting to the messaging system operated by Ericsson and all communication between Ericsson and Carmenta is over AMQPS.

The figure below shows a more detailed view of the cloud components Carmenta have implemented and customized in the project. The solution is based on Carmenta TrafficWatch™, an adaptable and scalable SW platform for effective decision-making in traffic control centers⁹. Implemented and deployed as a set of services using the latest container technology it is easy to integrate in any cloud platform. Interfaces to external data providers are handled by functions in the Carmenta TrafficWatch platform and can be aggregated for use within the Innovation Cloud. An AMQP Broker component opens the secure cloud-to-cloud message communication to the Volvo Sensus Cloud through Ericsson’s Interchange Services.

⁹ <http://www.carmenta.com/en/products/carmenta-trafficwatch/>



Detail showing the Carmenta part of the Central Traffic Cloud Solution where the AD Aware functions are implemented.

Volvo Sensus cloud:

Volvo Sensus cloud connects to the messaging system over AMQPS, in order to exchange information between CTC and Volvo Sensus cloud, the information provided by CTC may be propagated via the AD traffic control to the cars over HTTP/MQTT¹⁰

The solution implemented in the project has worked very well as a first Proof of Concept for a CTC function and it has been very useful for initial prototyping and testing of the communication of messages and data between different parties. The project has resulted in a working AD Aware traffic control SW platform that will be very useful for further development of the Drive Sweden Innovation Cloud. Suggested future work includes the following:

- More OEMs needs to be added to the platform and integrated in the tests. Current CTC demonstrator platform has VCC as the only connected OEM.
- Tests with larger data volumes has to be performed. Only relatively small data volumes (number of AD segments, road network) has been handled in the current project
- Test in a larger geographical region has to be performed. Only a very small (Göteborg - Drive Me) operation area has been in focus for the project.
- More automated and/or semi-automated functions to dispatch AD advices needs to be added. Focus in the current project has been on interactive GUI operator tools for manual message dispatch.

¹⁰ MQTT=Message Queue Telemetry Transport

D1.3. A first version of a live demonstrator with an interactive operator interface showing a dynamic map with the aggregated traffic situation picture, implemented as part of the “Innovative Cloud”.

Carmenta has showcased a first version of the functionality as part of the 4 internal demos, held at Volvo Cars on the 21st of January, 28th of March, 24th of April and 8th of May 2017.

D1.4. An updated version of the demonstrator with more functions such as displaying the measured and forecasted weather picture from WP2.2 and WP 2.5, implemented as part of the “Innovative Cloud”.

Part of the public demo at Lindholmen Science Park on the 27th of June 2017.

D1.5. A summarizing chapter in the final report.

Part of this document. See chapter Autonomous Traffic Monitoring

WP1.2 OEM Traffic Control

D1.6. Demonstration

Part of the public demo at Lindholmen Science Park on the 27th of June 2017.

D1.7. Experience report

So far the Drive Me program has not started so all of our experience from using the platform comes from our own testing. The desired feeling of the Operator GUI was that of a flight control tower. From a project research point of view the following is of interest to monitor:

- The cars real time position (displayed as a dot on the map)
- The cars real time AD-mode status (dot on the map is a different colour)
- A summarized view of the AD-route and individual road segments
- Any traffic situations that have occurred

This information, together with the AD-advice, allows us to take informed decisions about whether or not to allow AD-mode for either an individual car, a road segment or the entire route.

There is a relatively small amount of data in the platform at the moment and getting an overview is therefore a simple task. We're currently looking into how to manage getting an overview with a larger number of AD-vehicles as well as from a larger geographical area with more road segments.

D1.8. A summarizing chapter in the final report.

Part of this document. See chapter Autonomous Traffic Monitoring

WP1.3 OEM AD Approval

D1.9. A demonstration of the system in Q2 2017 showing the system functions and interacting with a limited number of running (Drive Me test) cars on public roads in Gothenburg.

Part of the public demo at Lindholmen Science Park on the 27th of June 2017.

D1.10 Part of final report incl. experiences, threat, opportunities and recommendations.

Since the Drive Me program has not started all of our experiences is from our own tests. The AD-approvals that we have granted or revoked have very much been based on the information in the platform. Specifically information about traffic situations. It will be very interesting to see the effects of the platform and the information provided during the piloting of AD-vehicles in the Drive Me program, when “the rubber hits the road” as the saying goes.

We don't necessarily see any threats at the moment apart from that the information stops or that the platform is taken down. The Volvo Cars Operator GUI has been built with the CTC in mind and is to some extent dependent on information from it in order to function. At least, to function as well as we'd like.

We haven't been able to test the accuracy of the road conditions based on weather information. We have a concern about whether or not that service will be able to deal with sudden changes during periods of unpredictable weather. The effect of a very local and very heavy shower of rain is something that we'd like to spare our Drive Me participants experiencing. Not necessarily because we believe that the car can't handle it but simply because it might not be a pleasant experience. There will be a period of adjusting these types of boundary conditions but regardless we will require a very accurate forecast in order to utilize the information in a good way.

Additional sources for weather information can be added in the future. One example is local measurement of rain by monitoring the signals in radio links connecting mobile telephony masts. SMHI collects this information from 3's network in Gothenburg¹¹ in collaboration with Ericsson

There are plenty of opportunities for the information in the platform to be used in all connected cars, not only AD-vehicles. This is part of an ongoing discussion internally at Volvo Cars where we can see large benefits for traffic management if more cars share their sensor data. This is however not entirely straight forward since we have the GDPR legislation to take into account. We're currently investigating if and how we can share data from the Volvo Cars cloud.

Our recommendation is to continue to build on top of the platform, to add both more functionality and more content. We at Volvo Cars will continue to build on our part and will test it in the Drive Me program and we would very much like to continue the cooperation with the other project members.

¹¹ <https://www.smhi.se/om-webbplatsen/om-smhi-se-lab/microweather-livedata/>

WP 2 Collaborative Road Weather Service

WP2.1 Road Weather Service

D2.1. Report with findings, lessons learned and recommendations.

This document.

D2.2. Description of used and proposed interfaces and the flow of information.

We have successfully built a flexible and an open message-based infrastructure, based on AMQP 1.0 for the AD Aware CTC platform. The infrastructure provides OEM's and partners an API framework to easily integrate and build robust, cross platform, messaging applications to exchange business messages between the different parties.

Ericsson can be seen as the container of the communication medium, between the different parties, as a result Ericsson has concentrated on providing a reliable broker solution based on QPID C++ in CTC.

Security has been one of the main focus throughout the project, Ericsson has implemented AMQPS (SSL/TLS encryption) in the broker, meaning all business messages traversing the internet between OEMs and CTC are highly encrypted with SSL/TLS. Mutual authentication is also another level of security perimeter which we have implemented in CTC, in order to use the APIs available, mutual authentication is required. Each party will be supplied a username, strong password and a certificate for authentication, this is to prevent attacker from successfully impersonating OEMs. Despite these security perimeters in place, we have also adopted ACLs (Access Control List) this is a level of security within the broker system to protect the OEMs messages from being read by unauthorized parties.

The AD Aware CTC platform has adopted the client-server model, for example one OEM transmits a message on a specific queue which they have permission to publish on, to CTC. CTC will read and internally process the message, in response to the OEMs request, CTC will transmit a reply message on a separate queue which the OEM have only read permission.

Ericsson have defined 9 APIs (queue) for AD Aware CTC, were Weather and VolvoWeather is specifically used for weather services:

- Roads
- VolvoRoads
- Situations
- Situation-Alert
- Prio-Alerts
- Data
- DataReturn
- Weather
- VolvoWeather

The Weather queue, allows Volvo to query CTC for certain weather data for a particular road section, while VolvoWeather is primarily used for CTC to respond with the required data queried by Volvo.

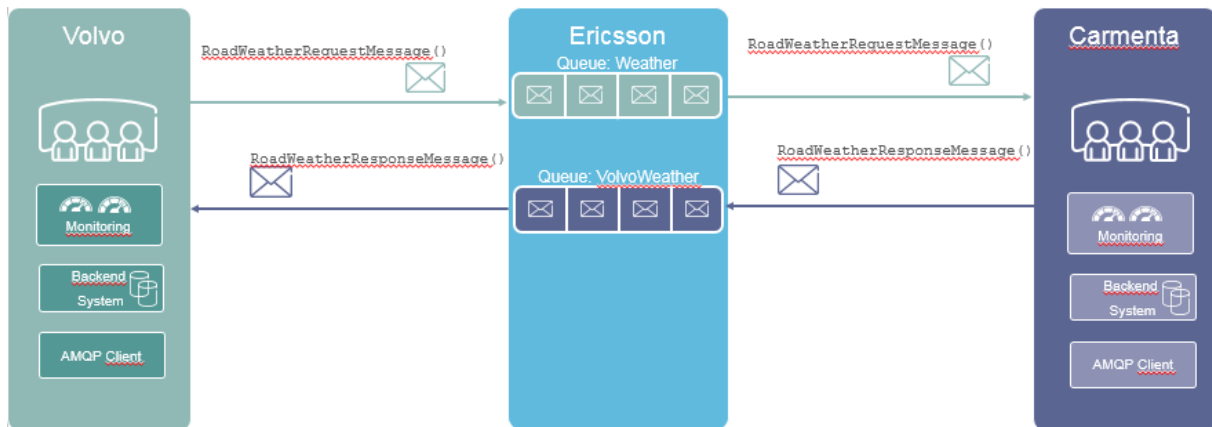


Illustration the broker setup for weather service.

D2.3. A first version of a live demonstrator implemented as part of the “Innovative Cloud”.

Showcased as part of the 4 internal demos, held at Volvo Cars on the 21st of January, 28th of March, 24th of April and 8th of May 2017.

D2.4. An updated version of the demonstrator with more functions implemented as part of the “Innovative Cloud”.

Part of the public demo at Lindholmen Science Park on the 27th of June 2017.

D2.5. A summarizing chapter in the final report.

Part of this report. See chapter Collaborative Road Weather Service

WP2.2 Measured weather data provision

D2.6. Report with findings, lessons learned and recommendations.

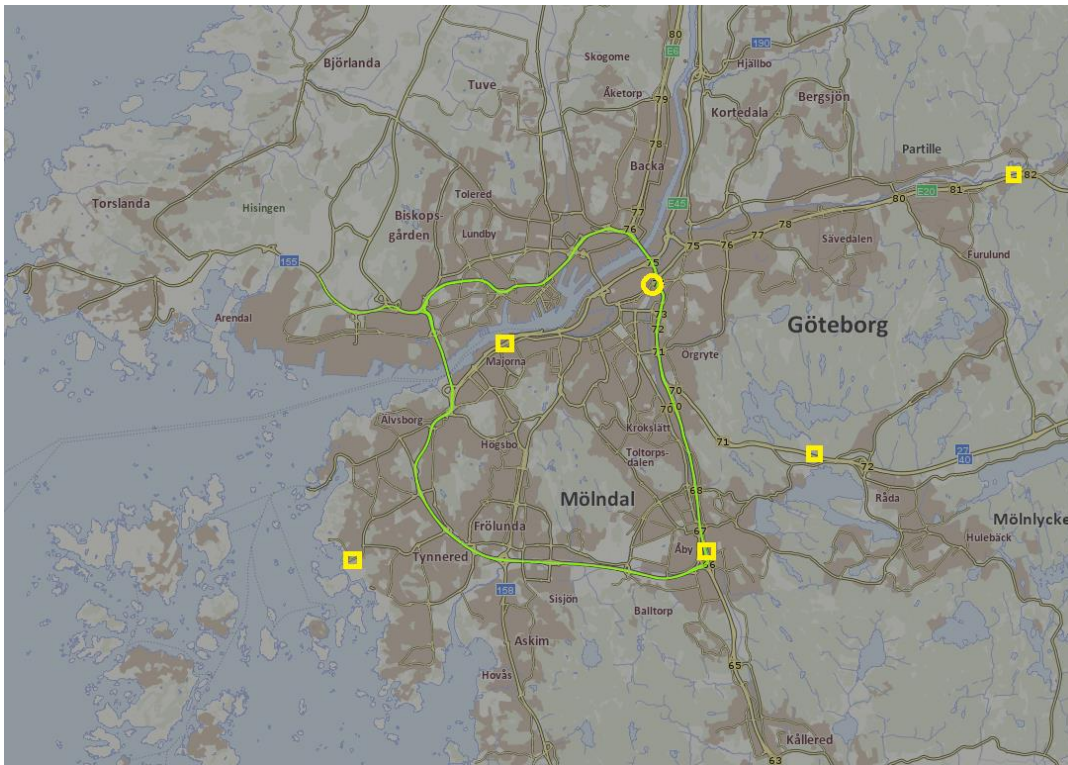
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D2.7. Description of used and proposed interfaces, query API's and the flow of information.

In this section we give a short background and describe how weather data has been integrated and used in the CTC. We have chosen to describe the result from both work package 2.2, the “Measured weather data provision”, and work package 2.5, “Forecasted weather data provision” in this section as used interfaces, query API's and flow of information are basically the same for both observed and forecasted weather.

It is important to state that this project has focused entirely on establishing the technical framework for connecting to external weather data providers and integrating the meteorological information in the running data flow as well as in the traffic operators situation picture. The validation of the actual data quality and usefulness for AD vehicle operation is subject to extended trials.

In Sweden measured weather data is collected by two national ground-based systems of observation stations. One is VViS (VägVäderInformationsSystem) run by Trafikverket and dedicated to measure weather conditions on major roads. The VViS stations are placed where extreme weather is likely to occur and isn't representative for the road network in general. The other observation system is run by SMHI and collects general weather information. The total number of stations is relatively few and also unevenly distributed over the country. The figure below shows the distribution of weather observation stations in the Gothenburg area.



Map over the Gothenburg (Drive Me) area showing the location of VVIS weather observation stations (squares) and SMHI's observation station (circle).

Between the stations no data is available so interpolation through different meteorological models has to be used to estimate weather values for any given point in an area. The uncertainty of the estimation grows with the distance from the stations and local variations are often missed. Furthermore relatively few stations are located in urban environments, as seen in the figure above, making it even harder to predict the local weather where the traffic intensity is highest.

Detailed knowledge about the current weather situation is also important to make good weather forecasts. Observations from the weather stations are then combined with data collected from satellites, radars, weather balloons, airplanes and ships and loaded as start values for the forecast modelling. Long-term forecasting depends on running sophisticated numerical weather prediction (NWP) models to predict how the weather situation is going to evolve over larger regions and in a longer time perspective. NWP models are not suitable to forecast weather on a very short term period of up to 2 – 4 hours most relevant for AD operations. Nowcasting is a term often used to describe weather forecasting in this short time frame, i.e. more or less an extrapolation in time of measured weather parameters.

Weather agencies and companies compete in applying their own methods to refine the predictions to make more detailed forecasts based on their expertise taking into account things like topographic variations, differences in vegetation, sun exposure and shading etc.

Weather-related effects on AD vehicle operation are obviously connected to the very local road environment and safety issues involve how slippery the road is due to rain, snow and ice. Other safety

issues include how visibility is influenced by fog or heavy rain and snowfall. Strong and gusty winds can also affect the safe operation of AD vehicles, especially for larger vehicles. All these weather-related effects are both measured and can be forecasted but the problem is to make them detailed enough in time and space to be useful for a traffic control center when guiding the AD operation or issue warnings to avoid dangerous road paths caused by severe weather.

It is a common understanding, when discussing the issue with the weather data providers that more detailed, de-facto and up-to-date data, preferably sourced from vehicle-mounted sensors is key to make a production-ready weather forecasting service for AD vehicle operation.

We have established an up-and-running technical solution for integrating real-time weather data including weather forecasts in the AD Aware CTC. Several external weather data providers have been screened and evaluated with the aim to find a viable solution for sufficiently detailed and qualitatively relevant weather data supporting AD vehicle operations. A common weather data interface using the message-based infrastructure described above (WP2.1 Road Weather Service) for AD Aware traffic control is delivered as part of the AD Aware CTC platform. Internally this is developed as a micro service, loosely coupled and agnostic to the sourced data.

A technical proof-of-concept implementation of a weather situation picture has been developed based on weather data aggregated from the selected providers, primarily from Foreca who has offered a trial service specifically designed to publish road condition data.

The weather data is potentially an important contribution to the Traffic Operators overall situation perception. Automatic functions have also been added to map the provided weather data to parts of the road network down to individual road segments. The built-in warning service extends this function to detect and trigger notifications when thresholds for “severe weather” are exceeded. This information can then be passed on to OEMs to allow or revoke AD driving in real time for their vehicles.

External query API’s in general provides weather predictions and forecast values for a number of parameters connected to geographical points. In the AD Aware CTC these points are automatically map matched to the nearest AD certified road segment and then its values are made representative for that part of the road network. Obviously the amount and distribution of forecast points in relation to the road network have a large effect to which level of detail the roads can be monitored.

Potentially useful on-line sources for building the AD aware weather picture were identified, approached and evaluated in the first phases of the project. The inventory included meteorological data from a number of institutes and companies but the selection for subsequent testing was narrowed down to on-line services made available from the **Swedish Hydrological and Meteorological Institute (SMHI)** and **Foreca**. Furthermore some initial integration tests were also done on road surface condition data provided as part of the **Road Status Information (RSI)** demonstrator project.

Below these providers and their contributions to the project is briefly described.

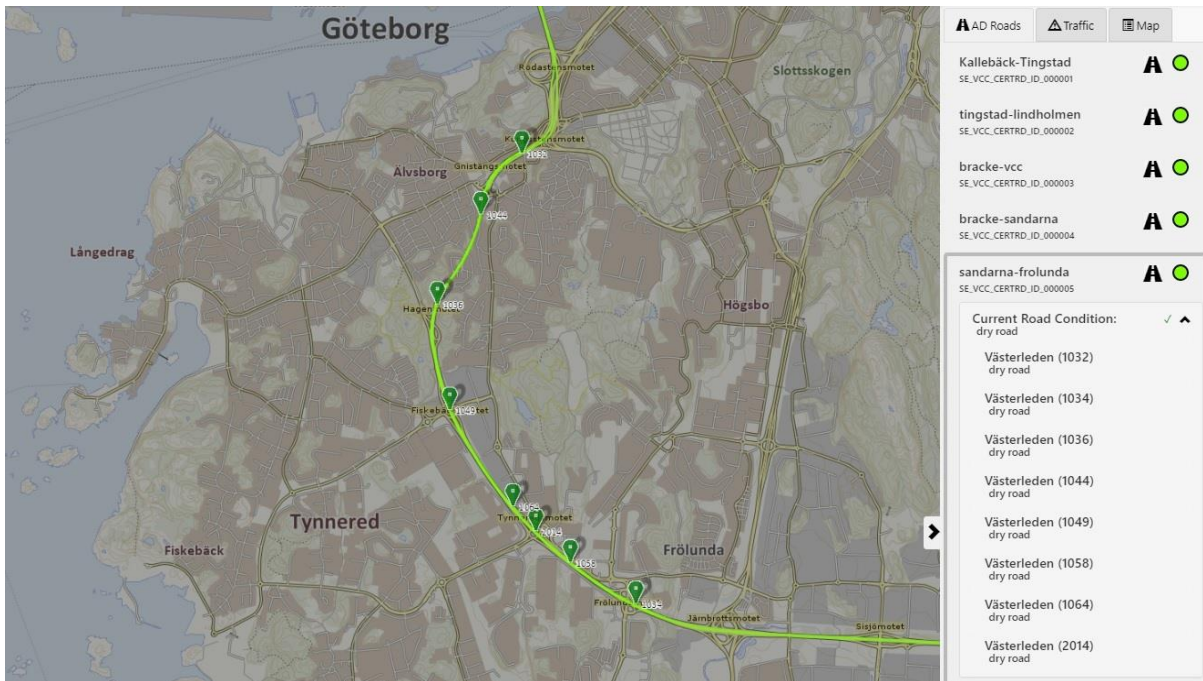
Trafikverket’s open dynamic traffic information service provides weather measurement data collected in real time through VVIS and this data has also been integrated in the measured weather provision solution and tested in the project.

Foreca¹² is a provider of digital weather data with a product and service portfolio utilizing the latest technology and the most accurate weather forecast models available. The company can specifically provide road weather data as full-scale digital weather services everywhere in the world. The services can also be custom designed to be used in navigation and automotive applications. Through the combination of atmospheric weather forecasts with radar and 2nd generation satellite data enabled Nowcasting techniques ensures high data accuracy for demanding users. The Foreca road weather services are also prepared to supports incoming 3rd party vehicle sensor data where and when available.

An on-demand weather forecast service was established in the CTC using Foreca's NaviFeed API that delivers quality weather forecasts to every coordinate point or route in the world. The interface can provide hyper-local forecasts and is suitable for integrating weather conditions into a wide range of applications. The forecasts can be asked by coordinate or by location name and in the interface used for trials we used the coordinate API. All commonly used weather parameters are available and road parameters can be added according to Foreca.

A custom road weather data provision interface was tailored by Foreca and was used and integrated in the AD Aware CTC demonstrator. Together with experts from Foreca we defined a set of forecast points to be used to specifically monitor the AD segments part of the Drive Me tests. To cover the area, 77 evenly distributed points along the path were selected and used in the weather hazard warning service. Each forecast point is specified as either "road" or "bridge" and Carmenta's map matching service couples the forecasts into the AD certified road network by choosing the nearest forecast point for each road segment, taking into the account if the segment part is a bridge or a regular road.

¹² <http://corporate.foreca.com/se/>



Screen dump from the CTC operator GUI showing the forecasting points for a selected AD certified road segment. Symbol color reflects the forecasted road condition for selected time period.

The following forecast values are provided in the service. It is updated every 15 minutes with 15 minutes forecast intervals for the next 2 hours and 1 hour time-steps for 36 hours.

- AIRTEMP: air temperature at 2m height over the surface (Degrees Celsius)
- DEWPOINT: dew point temperature (can also be used to compute relative humidity, if needed)
- ROADTEMP: road surface temperature
- ROADWATER: thickness of water film on road, in mm
- ROADSNOW: thickness of snow cover on road, in cm
- RAINFALL: forecast intensity of liquid rain, in mm/h (instant, not accumulated)
- SNOWFALL: forecast intensity of solid precipitation, expressed as liquid water equivalent (LWE) mm/h (close to cm/h of snow)
- FRICTION: friction coefficient, often values above 0.7 indicate good friction (dry road =~ 0.8) and values below 0.6 indicate bad friction
- RCCODE: road condition code representing a classification of road conditions in some 50+ categories.

Among the tested weather data providers, Foreca could offer the most complete road conditions service with best coverage and was therefore chosen as the primary data source for testing meteorological data flow as well as the hazardous road warning service.

SMHI, the Swedish Meteorological and Hydrological Institute¹³, is an expert agency under the Swedish Ministry of the Environment and Energy. The agency's mission is to; "Through expertise in

¹³ <https://www.smhi.se/omsmhi>

meteorology, hydrology, oceanography and climatology, SMHI contribute towards greater public welfare, increased safety and a sustainable society”.

SMHI makes forecasts, produces decision guidance for the community and follows up climate and environmental development. SMHI’s operations run around the clock every day of the year. Warnings in the event of extreme weather events are an important task.

SMHI provides a wide range of forecasting and professional services that can be tailored to the needs of different users. For test and demonstration purposes SMHI allowed the AD Aware Traffic Control project to connect to a custom web service publishing road condition forecasts. This service publish updated forecasts for the 3 weather measurements stations part of the VVIS network closest to the Drive Me test road. SMHI states that too much uncertainty makes it very difficult to make forecasts for any other points in the area and that a contribution of real-time road condition measurements from vehicles such as AD cars would be very useful for improving the ability to provide detailed forecasts.

We have added an up-and-running service using downloaded road condition data for the 3 forecast points where the map matching service choose the closest of these points for each road segment. We have also done some initial testing of road surface data from the RSI demonstrator project and it is integrated in the data flow as a potential source of real-time information about road conditions. More testing is needed to verify the usefulness the SMHI data for AD vehicle operation.

The RSI demonstrator project¹⁴ is an initiative aimed at making winter road maintenance more effective. Representatives for the project describes RSI as follows; *“RSI stands for Road Status Information and is a new type of service where a number of different sources of information work together to make current road maintenance more efficient. In order to assess future road surface conditions and relevant measures Trafikverket and its subcontractors now use weather services with forecast, satellite and radar pictures together with RWIS (Road Weather Information System)”* (<http://www.roadstatus.info/about-rsi/>).

The RSI project has resulted in a demonstrator where a number of sources of information has been integrated and used, including ‘Floating Car Data’, i.e. digital car information which has been ‘depersonalized’ and gives data such as friction, temperature and more. The data are assessed in a climate model and processed in a climate interpreter, which takes into account all accessible information, both in a real-time and in a prognosis mode.

We have done some initial testing of road surface data from the RSI demonstrator project and it is integrated in the data flow as a potential source of real-time information about road conditions. More testing must be done to make any conclusions on the usefulness of the RSI data in a central traffic control situation.

D2.8. Demonstrator of a Weather Data Provision Service answering queries about road weather conditions and implemented as part of the “Innovative Cloud”.

Part of the public demo at Lindholmen Science Park on the 27th of June 2017.

¹⁴ <http://www.roadstatus.info/about-rsi/>

D2.9. A Weather Data Visualization Service providing an aggregated weather situation picture for integration with the Central Traffic Control user interface in WP1.1.

See D2.7 Description of used and proposed interfaces, query API's and the flow of information in WP2.2 Measured weather data provision.

D2.10. A summarizing chapter in the final report.

Part of this report. See chapter Collaborative Road Weather Service

WP2.3 OEM weather based approval

The implementation of this work package has been delayed due to ongoing internal discussions about whether to use an existing weather service that is available for Volvo Cars. Also, since the CTC's AD-advice contains weather information the effects that were sought can be realized anyway.

We are evaluating how to proceed but this discussion is also linked to the deliverables in WP 2.4 OEM Measurement Collection (see below) since they are, at least to some extent, different sides of the same issue.

D2.11. Demonstrate in AD test vehicle on real road.

N/A see above.

D2.12. Experience report.

N/A see above.

D2.13. A summarizing chapter in the final report.

N/A see above.



WP2.4 OEM measurement collection

The implementation of this work package has been delayed due to ongoing internal discussions about how the GDPR legislation affects our possibility to share data with others.

D2.14. Plan and execute a demonstration of the system in Q2 2017 showing system function and interacting with a limited number of running (Drive Me test-) cars on public roads in Gothenburg.

N/A see above.

D2.15. Create a public report at the end of the project documenting experiences, threat, opportunities and recommendations.

N/A see above.



WP2.5 Forecast weather data provision

D2.16. Report with findings, lessons learned and recommendations.

This document.

D2.17. Description of used and proposed interfaces, query API's and the flow of information.

See D2.7 *Description of used and proposed interfaces, query API's and the flow of information* in WP2.2 *Measured weather data provision*.

D2.18. Demonstrator of a Forecast Weather Data Provision Service answering queries about forecasted weather conditions and implemented as part of the "Innovative Cloud".

Part of the public demo at Lindholmen Science Park on the 27th of June 2017.

D2.19. A Forecast Weather Data Visualization Service providing an aggregated weather forecast picture for integration with the Central Traffic Control user interface in WP1.1.

See D2.7 *Description of used and proposed interfaces, query API's and the flow of information* in WP2.2 *Measured weather data provision*.

D2.20. A summarizing chapter in the final report.

Part of this report. See chapter Collaborative Road Weather Service

WP 3 Pre-study for Authority Interfaces

The global trend of digitalization opens new opportunities for road authorities to improve their services and reduce the negative external effects of traffic. In order to prepare for the development and to gain some first insights in future potential roles of road authorities and cities, a workshop was organised to initiate discussions. The setup and the results from the workshop are presented in Appendix B - PM: Pre-study for Authority Interfaces. Key findings and recommendations indicate that need for developing business models related to the exchange of data between different actors is crucial to support the development of new services.

Road authorities can benefit from the exchange of data both as service providers and as managers and operators of infrastructure and from a city perspective the technological development will enable more efficient street designs.

WP3.1 Road Authority Interface

D3.1. Report with findings and recommendation.

See Appendix B - PM: Pre-study for Authority Interfaces.

D3.2. Description of proposed interface and flow of information including list of in- and out signals (information content).

Current situation

As most of the stakeholders in this eco-system, the road authorities will be both producers of data and consumers of data. In the short term the DATEX-interface will be the major real-time channel both for publishing data from the road authorities and for receiving data coming from external actors as Volvo Cars. Although it is important to have in mind that already today Trafikverket and other actors also publish data via their own API's. Trafikverket also receives data from external actors using their API's.

Static data like road attributes and traffic regulations, is currently available via a public interface called "Lastkajen". Updates of static data are also available via an interface based on a European cooperation called TN-ITS.

Data published from Trafikverket

DATEX (push and pull):

- Travel times (Stockholm, Göteborg, Malmö)
- Accident
- EmergencyInfo
- Ferries
- RestAreas
- TrafficMessages,
- RoadWorks
- RoadCondition
- RoadConditionStatus
- FrostDamage

- TruckParking
- RestAreaStatus
- Weather

Also TrafficFlowCameras and RoadConditionCameras are available via DATEX.

Extensions with current speed per minute and current number of vehicles per minute will be available in September. Also extensions with the information available on Variable Message Signs (e.g. temporary speed limits per lane, closed lane, etc.) will be available. Traffic Management Plans via DATEX has been tested in other countries and is of great interest to provide in the future. Road attributes and traffic regulations from Lastkajen and the TN-ITS interface.

Data that could be of interest to receive from Volvo Cars in the Drive Me pilot trial:

- Safe stops – when and where
- Number of vehicles per road segment driving in AD-mode / not driving in AD-mode
- Road-segments currently allowed for AD
- Accident- and incident reports
- Queue-reports

General data elements of interest include:

- Position (along the road and lateral)
- Speed
- Heading
- Acceleration
- Emissions
- Distance/Time gap to vehicle in front and behind
- ABS/ESC status
- Road surface status
- Wiper on/off
- Headlight on/off
- Ambient temperature
- Visibility
- Hazard alert on
- Destination
- Route choice
- Broken vehicle warning
- Traffic jam warning

Possible future scenario for data exchange and traffic management

Potentially all data sourced by Trafikverket, which is not classified, could be published and available for external actors, static data, real time data and statistical data. Trafikverket will also promote the exchange of open data in Sweden. The EU-commission urges the member states to establish National

Access Points for data, an access point can potentially be further developed towards a more advanced data exchange platform for open data.

Future traffic management will need a strong cooperation between public and private actors. Several initiatives like TM2.0, C-ITS platform and Socrates2 are working in this direction. What can be called as a Common Operational Picture is needed to inform vehicles and travellers in a harmonized and coordinated way. Also policies and agreements on how to manage traffic should be transparent and available for all actors. The Central Traffic Control established in this project enables a common operational picture and is a promising way to implement the needed cooperation between public and private actors. However, how to operate and finance a Central Traffic Control remains to be investigated.

D3.3. Chapter in final report.

Part of this report. See chapter Authority Interfaces



WP3.2 City Interface

D3.4. Description of proposed interface and flow of information including list of in- and out signals (information content).

See D3.2

D3.5. Chapter in final report, incl. findings and recommendation.

Part of this report. See chapter Authority Interfaces



Appendix B - PM: Pre-study for Authority Interfaces

This PM is a deliverable within work package 3, Road Authority Interface, a part of the strategic innovation project “AD Aware Traffic Control”, funded by the Swedish innovation agency Vinnova. The aim with the activities in this work package is to increase knowledge on the potential benefits, the needs and the requirements for information flow between a traffic cloud and a road authority. This will result in first insights of what potential roles cities and other road authorities can and should take in relation to external actors when it comes to information flows and control in a future with connected and increasingly automated vehicles.

Background

Modern vehicles are increasingly becoming connected to OEM-cloud solutions and the onboard sensors and the sensor fusion becomes more and more advanced. At the same time, there is a global trend of digitalization that eventually will enable new mobility services to emerge. Through the exchange of information between different actors, there will be a multitude of progress for society, industry and individuals to benefit from.

For the development of new services, there will be a need for existing and new mobility actors to find new ways of co-operation. This will allow for the take up of new business models.

To start discussing what the future will hold, key actors including representatives from City of Gothenburg, National Road Administration, Volvo Cars and Carmenta, were invited to a workshop on the 20th of April 2017. The focus of the workshop was to identify benefits resulting from increasingly connected and automated vehicles and what services that will be needed to achieve them. In total, there were about 15 participants at the workshop.

Scope

The development of self-driving technologies is currently running at a fast pace. It is highly likely that in five years there will be vehicles on the market with limited level 4 functionality (level of automation per SAE standards). At the same time many experts believe that it will take a long time before fully automated vehicles, that will be able to operate almost everywhere under almost any weather conditions, will be introduced (level 5).

Running in parallel with the development of autonomous vehicles is the development of LTE and 5G mobile communication technology also with short range AD-hoc modes as well as ITS G5 5.9 GHz V2X short range communication. Already today many vehicles sold are connected to an OEM cloud solution. This means that there are already many vehicles in the market that can be used to exchange information between OEM's and road authorities.

Taking this into account the workshop focused on identifying solutions based on an increased number of connected vehicles as well as the development of autonomous vehicles (level 4 and up).

Method

Services and benefits were identified using a conceptual framework as shown in figure 1.



Conceptual framework used for discussion

The discussions followed a top-down structure starting with identifying benefits before going on with services. Identifying information content was left out due to restrictions in time and format of the workshop. Finally, the identified services were ranked based on attractiveness and actualization, thus resulting in a list of desirable future project ideas.

The workshop was split in three parts; identifying benefits, identifying services and ranking of services.

For the first part, a combination of brainstorming and clustering techniques resulted in a set of benefits, including societal, individual and other benefits. In total, there were 73 ideas generated that were clustered in to 12 segments.

For the second part, the participants chose five segments to continue work with. Different supporting services were discussed in a "fish-bowl format". This format means that the group was split in two halves. One half started with an open group discussion focusing on one segment and the other half sat silent and listened. Then the groups changed roles, and the discussion took up where the first group left it. Finally, the whole group joined the discussion. In total 39 services were identified.

For the third part, each participant was given three votes to vote for the attractiveness of the identified services and another three votes to vote for the actualization of the services. There was no limit in how many votes a participant could use on one service. Even though there were 39 services to choose from there were some services that were more attractive and easily actuated than others.

Benefits from increasingly connected and automated vehicles

The first part of the workshop, brainstorming benefits, generated 73 ideas which were clustered in to 12 segments as shown below.

Segment	No of ideas
Improved Traffic performance	13
Enhanced data collections	10
Improved Traffic safety	7
Prioritized accessibility	7
Increased accessibility	7
Enhanced traffic information	6
Reduced local emissions	6
Enhanced traffic optimization	5
Improved mobility services	4
Energy efficiency	3
New traffic planning prerequisites	3
Increased individual needs	2

Identified benefits from the workshop

As the table shows most ideas generated were clustered into the segments of traffic performance and data collection. Ideas within traffic performance were often coupled to intelligent connected traffic signals in combination with connected cars. Also, some ideas about optimized traffic flows through optimal routing were discussed. When it comes to data collection the discussions were about big data opportunities, using cars as probes and new types of real time information that could be possible, for instance air quality.

Using geofencing as a tool was a use case discussed that would fit into several segments. The ability to control speed and powertrain would probably benefit several different segments, e.g. traffic safety, local emission and traffic performance.

From a road authority perspective, using vehicles as probe to enhance maintenance and operations are of great interest. Discussions ranged from the use of static data, to update geometry, to the use of dynamic data to manage traffic.

Services to support identified benefits

Five segments out of twelve were chosen by the participants to continue working with. For each of the chosen segments supporting services were derived using the “fish-bowl” method.

In total, 39 services were derived as shown below.

Segment	No of services
Enhanced Traffic Information	9
Improved Traffic Performance	9
Energy efficiency	9
Improved Traffic Safety	8
Increased accessibility	4

Services supporting the ideated benefits.

As was the case with ideating benefits, several services are applicable in many segments.

Many services discussed were coupled to Traffic control and dynamic road usage. One conclusion was that the use of dynamic information is the key to produce more advanced services that will provide new benefits.

There was also an interesting discussion about how data should be enabled and distributed. Suggested services include digital market place for data and the use of raw-data. There is clearly a need for developing business models that facilitate the interchange of data between involved actors.

A more dynamic use of streets is of great interest to cities due to space scarcity. This is not only limited to traffic efficiency through dynamic routing but also allowing for mixed use of city streets depending on demand. Today cities offer different kinds of services except for just providing the infrastructure. Parking is one such example where connected vehicles open up new opportunities.

Ranking of attractiveness and actualization of services

The final part of the workshop was to identify which services were seen as attractive to develop and which are easy to actuate, a.k.a. “low-hanging fruits”. The top ten results from the voting procedure, ranked by ease of actualization, are shown below.

Service	Ease of Actualization	Attractiveness
Steady speed by AD	6	1
Traffic signal control	4	0
Digital marketplace for data	3	0
Electronic signage	3	0
Gamification of driving behaviour	2	3
Convoys	2	1
Topography	2	0
Real time information	1	3
Virtual speed bumps	1	2
Accident information	1	1

Top ten services ranked by ease of actualization.

Many people believe that the increasing share of autonomous vehicles will make it easy to pace the traffic flow in the future. Pacing of the traffic flow is expected to bring several benefits, including increase traffic safety, less local emissions, better throughput etc.

Developing traffic signal controls is also considered as a “low-hanging fruit”. This can be achieved with an increasing number of connected vehicles and is also seen as a must-do to promote the development of autonomous vehicles.

Obviously, a digital marketplace for data is almost a prerequisite for developing new services and it is also considered as easy to actuate.

When the result is ranked by attractiveness the result is a bit different as shown below.

Service	Attractiveness	Ease of Actualization
Gamification of driving behaviour	3	2
Real time information	3	1
Virtual speed bumps	2	1
Route/congestion information	2	0
More dynamic traffic control	2	0
Traffic management controlling traffic	2	0
Level of service	2	0
AD vehicles enables dynamic PT	2	0
Steady speed by AD	1	6
Convoys	1	2

Top ten services ranked by attractiveness.

Gamification of driving behaviour was voted most popular and it is also thought as rather easy to implement. Various types of real time information applications is also popular.

Findings and recommendations

The exchange of data between different actors is key to almost all development of new services. This is not just a technical question but relates very much to business models, roles and responsibilities. This is not an easy task but it is essential that actors take initiatives to push the development forward since there are so many potential benefits to gain. If data is related to personal information there is obviously also need to find efficient solutions that respects the privacy of individuals.

Road authorities can benefit from both services provided to the public and the way the infrastructure is managed and operated. There are numerous services ranging from static/slow data, like geodata, to highly dynamic data that are of value. For instance, geofencing technologies can be used to limit the negative external effects of traffic, e.g. noise, emissions and accidents.

For city planning, the technological development makes it possible to come up with more space efficient designs. The use of a more dynamic data exchange will allow for more mixed use of city streets, both in time and space. In the future, it will also be possible to implement dynamic regulations of traffic. This means that a typical city street can be used for different purposes during the day or depending on the circumstances.

Appendix C – DATEX II schemas

This appendix shows some of the resulting UML schemas for the messages modelled from DATEX II and used in the project.

DATEX II (TS 16157 1-3)¹⁵ is the acknowledged European technical specification for modelling and exchanging ITS-related information between different parties and it provides a standardized way of communicating and exchanging traffic information. It has a huge but well-structured data model, currently mapped to XML schema as the exchange message syntax.

DATEX II has built-in flexibility and a well-defined set of rules for users to extend the model to suit local application needs. It is also possible to select only those elements for schema creation that are actually used in specific services.

DATEX II is developed and maintained under the umbrella of the EasyWay¹⁶ project and is supported by the European Commission.

In the schemas below standard DATEX II objects are pictured as gray boxes and AD extensions is shown as white and light green boxes.

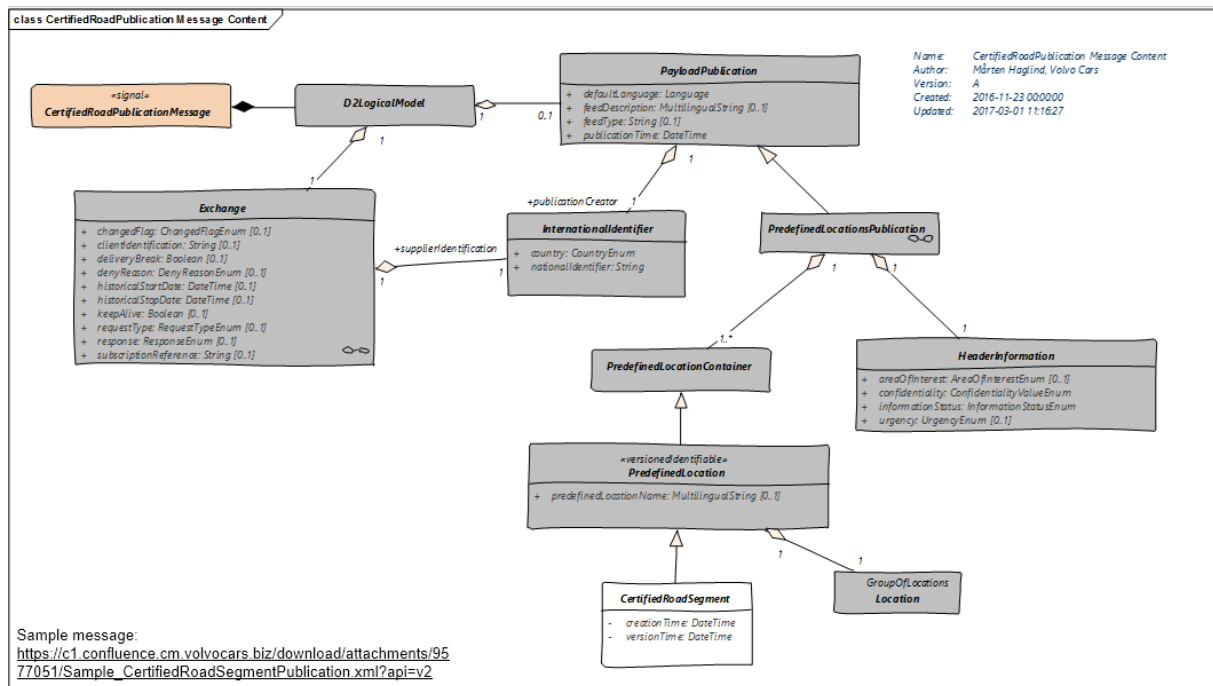


Diagram showing the data model for the CertifiedRoadPublication message.

¹⁵ http://www.datex2.eu/sites/www.datex2.eu/files/Datex_Brochure_2011.pdf

¹⁶ <https://www.its-platform.eu/highlights/easyway-programme-2007-2020-and-its-projects>

AD Aware Traffic Control

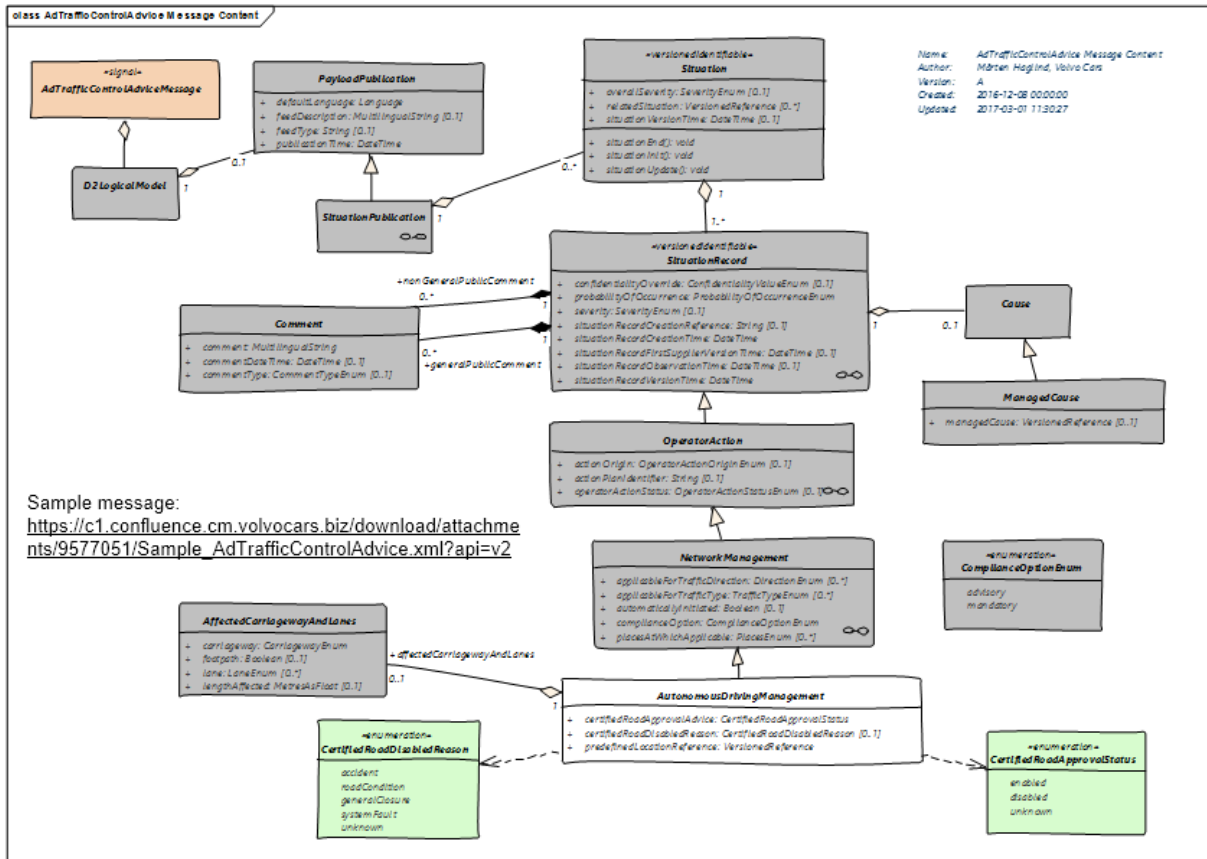


Diagram showing the data model for the AdTrafficControlAdvice message.

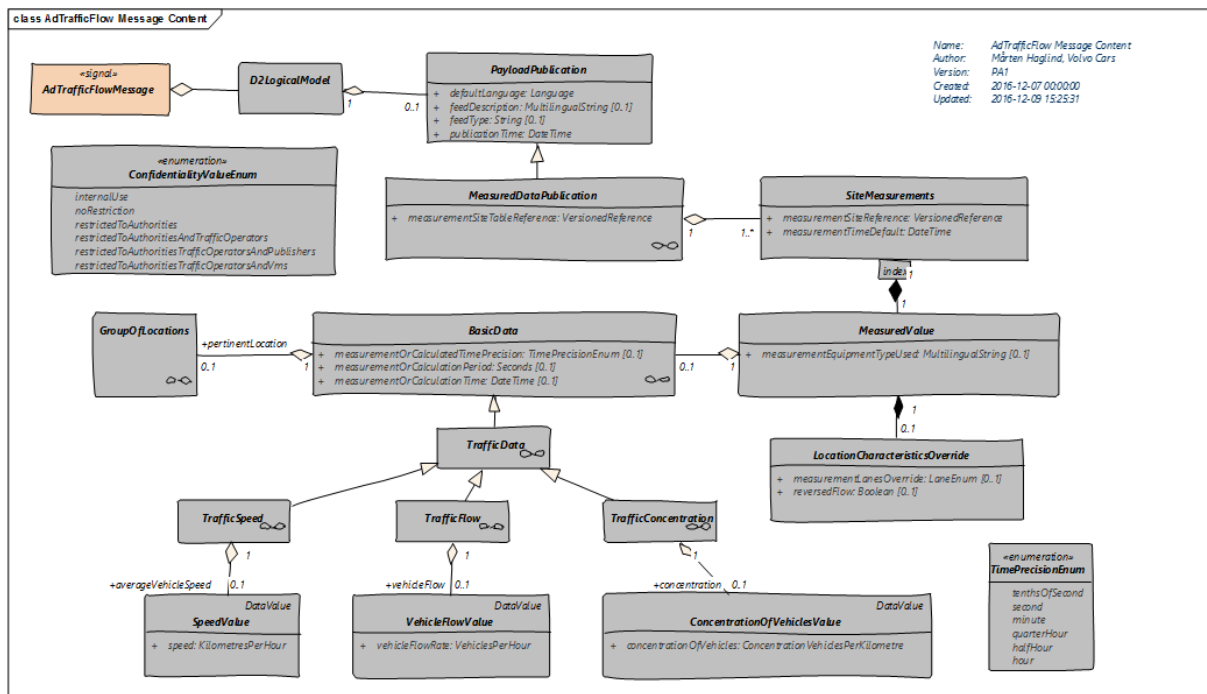


Diagram showing the data model for the AdTrafficFlow message.

AD Aware Traffic Control

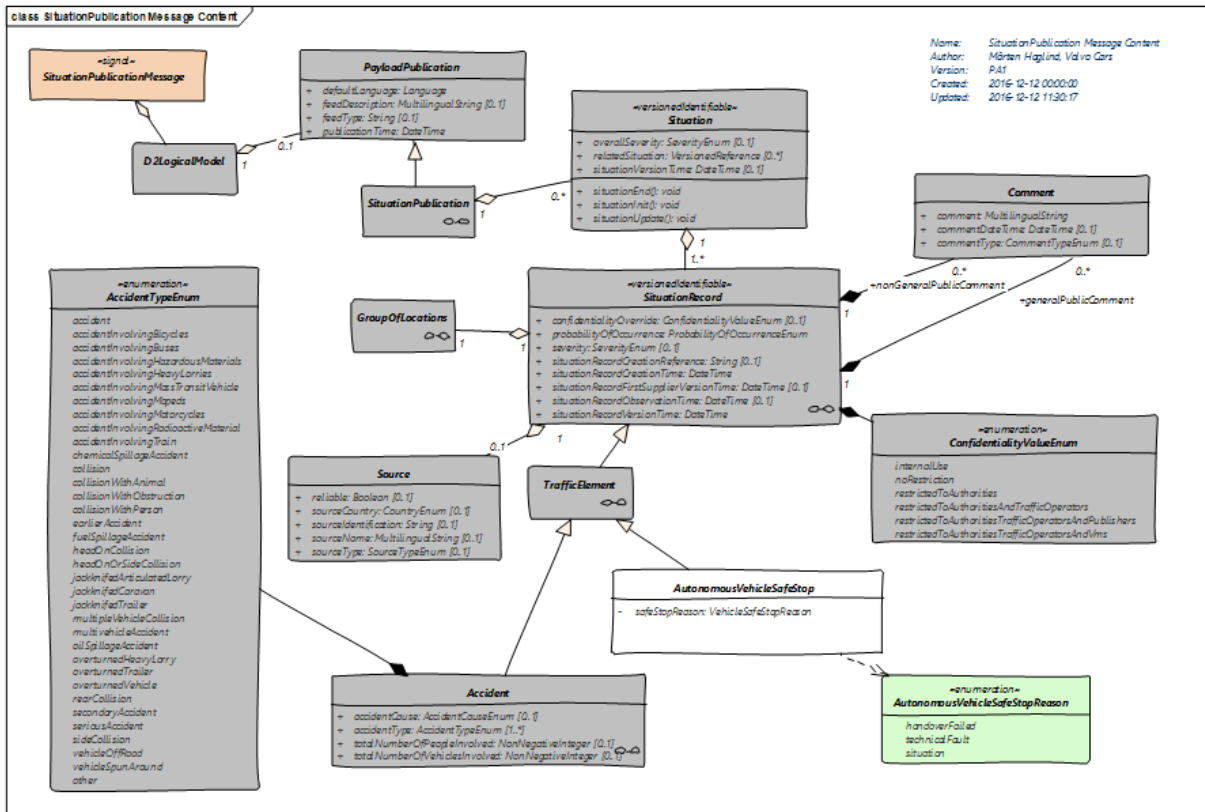


Diagram showing the data model for the SituationPublication message used to exchange AD safe stop information.

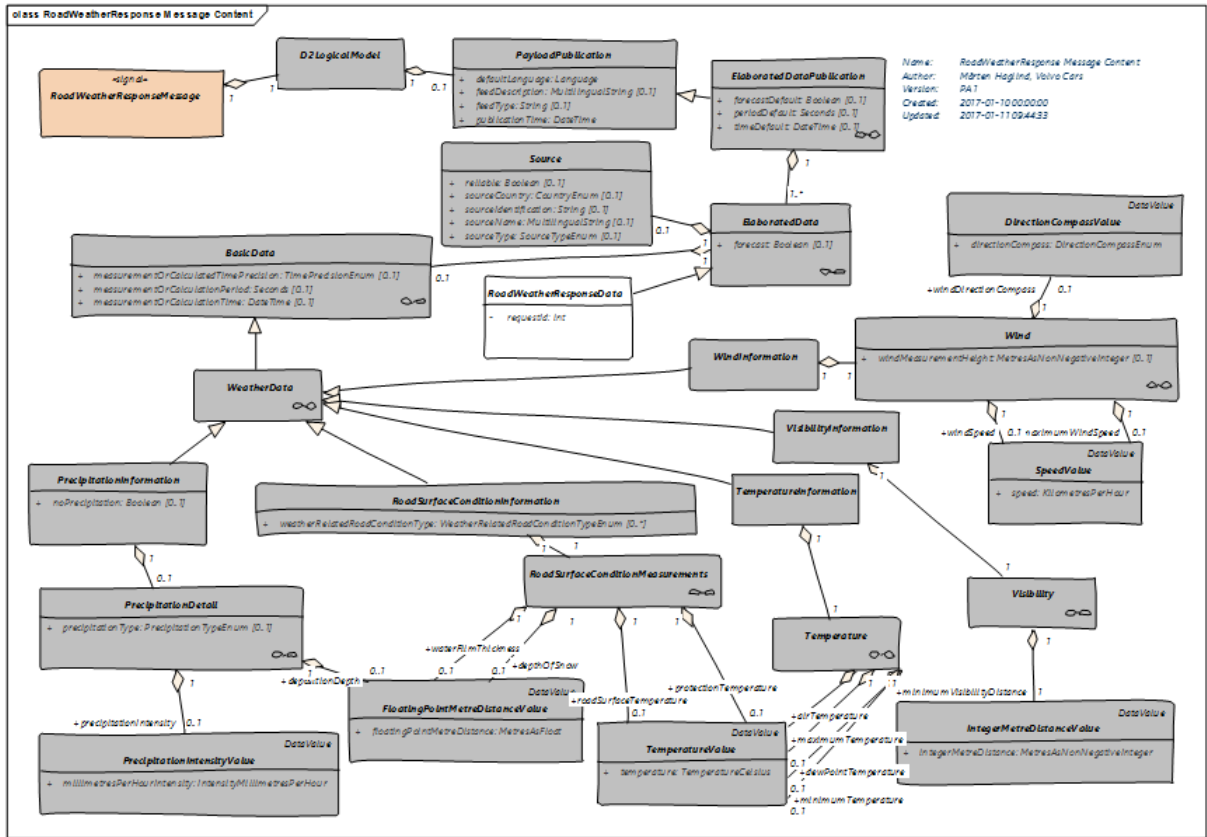


Diagram showing the data model for the RoadWeatherResponse message used to exchange road weather information.