



**5G-PPP Automotive Working Group**

# **A study on 5G V2X Deployment**

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## Executive Summary

Although the key technology enablers for 5G Vehicle-to-anything (V2X) communication are meanwhile well-understood in the cellular community and standardization of 3GPP Rel. 16 V2X is about to start, there is still lack on insights into the required rollout investments, business models and expected profit for future Intelligent Transportation Services (ITS). It is foreseen that these advanced services, including HD maps, platooning, highway chauffeur, teleoperated driving, highly and ultimately fully autonomous driving, will be enabled through next-generation 5G vehicular networks, starting with 3GPP Rel. 16 New Radio (NR).

This white paper is a first outcome of the 5G-PPP Automotive working group and has the objective to trigger discussions and provide first insights into the deployment costs for 5G V2X and revenue analysis for financially and socially beneficial commercialization. The modelling framework for cost and revenue analysis is generic and is exemplarily applied for highways. It is further pointed out that advanced driving solutions will be most likely first applied on highways, as these scenarios are easier to handle, users' mobility behaviour is more predictable and the technical solutions less complex.

As a first approach to this problem, this work aims at drawing the 5G ITS landscape, including main stakeholders and relationships. Moreover, an investment and business model is proposed, describing the cash flow.

On the technical side, the way to achieve the ultimate goal is to deploy the so-called 5G digitalized highways, which is a prerequisite for a large number of 5G-based Connected and Automated Driving (CAD) solutions. The exemplary highway environment considered through this work includes 5G sites, digital infrastructure, fibre connections, stationary sensors, radars, lidars, video cameras etc. In order to provide some practical reference values, it is assumed that services are fully provided over the network infrastructure, meaning that the V2V interface is not taken in account. It is further assumed that this investment is used to a certain extent to provide enhanced Mobile Broadband (eMBB) services in parallel to CAD services. The overall costs are standard-wise formed by CAPEX and OPEX including maintenance and service overhead and excluding On-Board Unit (OBU) costs, while estimates for Bill-Of-Material (BOM) and auxiliary services for CAD services as HD map services are considered. For more realistic revenue estimation, a growth rate over time for 5G CAD service penetration has been taken into account. We aim at showing under which conditions a good return on investments for the 5G-digitalized highway can be expected, depending on exact costs, charged fees and percentage of investment usage for ITS services. Overall, a positive business case can be observed, enabling a positive profit over a horizon of ten years.

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## List of Acronyms and Abbreviations

3GPP	3 <sup>rd</sup> Generation Partnership Project
5G-PPP	5G Infrastructure Public Private Partnership
ACC	Adaptive Cruise Control
ARPC	Average Return Per Car
BOM	Bill Of Materials
CAD	Connected and Automated Driving
CAM	Cooperative Awareness Messaging
CLM	Cooperative Lane Merging
DCC	Decentralized Congestion Control
DSRC	Dedicated Short Range Communications
DL	Downlink
EC	European Commission
EPC	Engineering, Procurement and Construction
EU	European Union
eMBB	enhanced Mobile Broadband
eNB	evolved Node B
ETSI	European Telecommunications Standards Institute
FCC	Federal Communications Commission
FCW	Forward Collision Warning
GPS	Global Positioning System
ITS	Intelligent Transport System
LTE	Long Term Evolution
MNO	Mobile Network Operator
MSP	Mobile Service Provider
NR	New Radio
OBU	On-Board Unit
OEM	Original Equipment Manufacturer
PC5	Proximity Communication 5
PLMN	Public Land Mobile Network
QoS	Quality of Service
RSU	Road Side Unit
SDO	Standards Developing Organisations
SL	Sidelink
TCO	Total Cost of Ownership
UL	Uplink
V2I	Vehicle-to-Infrastructure
V2P	Vehicle-to-Pedestrian
V2V	Vehicle-to-Vehicle
V2X	Vehicle-to-Everything
VAI	Vehicle as Infrastructure
VRU	Vulnerable Road User

# 1 Introduction

The objective of this white paper is to provide first insights and trigger discussions about the deployment costs for 5G V2X and profit analysis for its financially and socially beneficial commercialization. The conducted modelling approach is generic for both cost and revenue analysis. Advanced driving solutions are foreseen to most likely be applied on highways first (or at least in an earlier stage), as these scenarios are simpler due to more predictable mobility behaviour and with easier to handle algorithmic complexity. Therefore, we chose to conduct this study in a highway setting. One benefit of the V2X communications technology is to enable safe transportation, which is foreseen to be available in some countries within a few years. An early 5G Automotive Vision insight was provided already in 2015 by 5G-PPP<sup>1</sup>.

In this context, automated driving is seen as a technological highlight that will shape the future mobility concept and improve quality of modern life. In technological terms, the advance towards fully automated driving is understood as an evolutionary process and is mainly driven by the corresponding stakeholders in the automotive industry. From the communication technology point of view, it is meanwhile widely accepted that future ITS services, ultimately leading to autonomous driving, will require a high level of connectivity of vehicles through an advanced communication technology as 5G V2X. The multitude of ITS services with heterogeneous requirements calls for a flexible radio air interface with the coexistence of multiple radio access technologies and automotive software virtualization.

For what concerns future radio access, after several years of research driven by academia and industry, and the delivery of mature technology enablers for 5G, 3GPP is now drafting the standard for 5G V2X, starting with Rel. 16. Efforts and discussions on 5G between stakeholders have created high expectations at the market and have put large pressure for the delivery of 5G to the industry. In order to accelerate the deployment of 5G, a first version of the standard will be released, with a focus on eMBB services, operating at frequencies below 6 GHz and probably co-existing with legacy LTE systems. It is expected that this first release of 5G will enable a significant set of advanced ITS services and provide the basis for the second wave of even more challenging services.

The roadmap to 5G V2X, which is currently assumed to begin with 3GPP Rel. 16, also includes standards and V2X technologies which are (almost) available, as e.g. LTE V2X and IEEE 802.11p. Their main role is seen in providing enhanced data rates and basic ITS services and are therefore considered as part of the future landscape of vehicular telecommunication.

Similar as for any new technology, the establishment and success of 5G V2X will strongly depend on the required investment costs and expected revenue, especially during its first years of deployment. As the level of required investment has not been yet clarified, there is reluctance by the Mobile Network Operators (MNOs) and other possible road infrastructure investors against 5G deployment. To cope with the large investment costs and to support the natural need for multi-operator vehicular communication, MNOs also consider solutions of sharing network infrastructure and other resources – especially in the first deployment phase.

At the same time, the automotive industry is seeking for ways to reduce the costs for On-Board Units (OBUs) supporting 5G V2X to avoid increase of the vehicles' prices on the market. Considering the life cycle of cars, legacy cars will need to be supported by non-5G infrastructure along highways (e.g. stationary highway video cams for old cars to generate HD maps). In the current study is assumed that cars are equipped with an OBU providing both communication functionalities as well as running software applications. The processor of the

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<sup>1</sup> <https://5g-ppp.eu/wp-content/uploads/2014/02/5G-PPP-White-Paper-on-Automotive-Vertical-Sectors.pdf>

OBU, which is powered by the vehicle's battery, is sufficiently strong to execute all functions of the 5G modem, as well as the CAD-related applications run by the vehicle.

The OBUs allow vehicles to have a role as part of the communication infrastructure, since they can take over functionalities of the network such as relaying of data or coverage extension. This is made possible thanks to their continuously growing hardware capabilities enabling to consider vehicles as part of the communication infrastructure. Additionally, from the automotive software point of view, concurrent execution of multiple applications along with Connected and Automated Driving (CAD) functions is today made possible by virtualization and powerful OBUs. To this end, vehicles can execute third party applications and in particular 5G V2X functions, referred in this document as Vehicle-as-Infrastructure (VAI) applications. As a consequence, VAI applications are going to play an important role for the V2X business models and are becoming a strong requirement in the automotive market to satisfy a user experience derived by the one of mobile devices.

The scope of this work includes following:

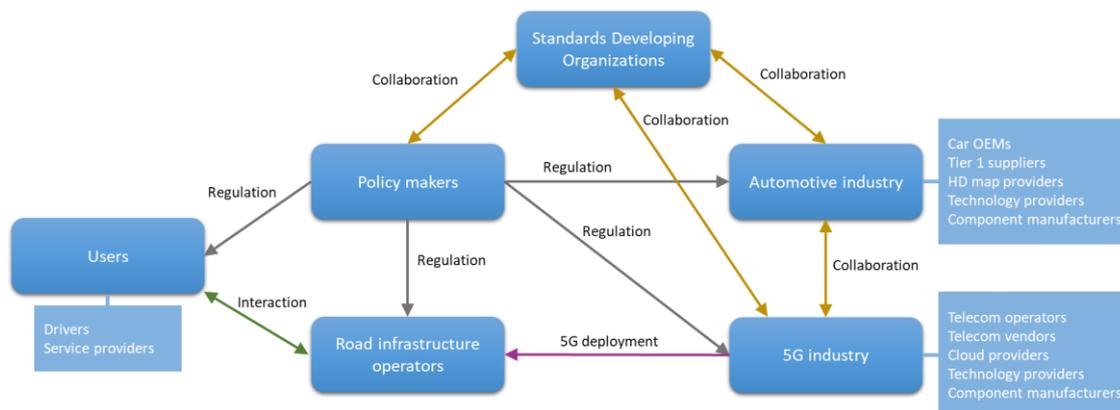
- Discussion on possible investment and business models for advanced ITS services and VAI applications.
- Modeling and estimation of investment costs and expected revenues, as well as prediction of accumulative profit from 5G highway digitization for a horizon of ten years.
- Identification of the most influential factors and analysis of their impact.
- Conclusions on the required 5G V2X investments, the estimated payback period and the potential for profit through ITS services.
- Definition of the Average Return Per Car (ARPC), which is required to cover the investment and service costs and to expect a reasonable return of investment time.

The remaining part of this paper is organized as follows. Section 2 introduces the business model and stakeholders. In Section 3, the investment costs and profits are estimated, providing critical information about the payback period. Finally, conclusions are summarized in Section 4.

## 2 Stakeholders and Business Models

### 2.1 Stakeholders and relationships

We have identified some main stakeholder categories involved in 5G V2X: 5G industry, automotive industry, Standards Developing Organisations (SDOs), road infrastructure operators, policy makers, and users. The relationship between them are depicted in Figure 1.



**Figure 1: Main stakeholders and relationships.**

The end users could be either the drivers, or the passenger or the service providers. This is due to the decoupling of the traditional “owner-driver” vs newer models of “service provider-passenger” paradigm that autonomous vehicles shall support and even encourage. All interact with the corresponding road infrastructure operator. Each European country has its own regulation about road infrastructures. Some of them are operated by public entities, while others are operated by private companies. In some cases, these private companies are partially owned by the local government.

The road infrastructure operator shall offer 5G connectivity on their roads. They could act as tenant from the perspective of Mobile Service Provider (MSP). In that case, the road infrastructure acts as a business supplier for the drivers.

Another model is also possible, where the road infra-structure is seen as a part of the 5G infrastructure and the business relationship is set-up between the drivers and the automotive industry. In that case, the automotive industry acts as a tenant from MSP perspective.

In fact, the 5G industry has identified the following roles:

- The tenant is usually a business entity that rents and leverages a 5G connectivity provided by the MSP. It can be a road infrastructure, automotive industry or other organisation that requires a connectivity and computing service for their business operations. This is done via network slicing technology.
- The MSP provides various services to end users. Furthermore, the MSP sells dedicated mobile network instances (e.g. “network slices”), each realizing a specified service (e.g. V2X), to tenants. The MSP leases all needed physical and virtual resources from one or multiple 5G infrastructure providers (5GInPs) to deploy the end-to-end mobile network.
- The 5GInP own and manage parts of or all infrastructure of the network. It can be further distinguished between RAN infrastructure provider and cloud infrastructure provider. The latter owns and manages local and central datacentres providing the virtual resources such as computing, storage and networking. The former owns the physical infrastructure such as the antenna sites and the HW equipment for the antenna which could be managed by the road infrastructure.

- Passenger targeted business models. For instance, models that sell connectivity (at various “grades”) or higher services based on connectivity from the MSP to the passenger, with the involvement of VAI or without it. Examples: higher grade infotainment (e.g. four streams of 4K full size TV or AR services), mobile office, remote assisted driving or teleoperations in various levels, location-based data-intensive services, or others.

It is also clear to us that additional business models may rise since it is expected that the whole traditional ecosystem will be disrupted and changed, as well as new use cases and societal impact could appear.

The 5G industry must collaborate with the Automotive industry to design a 5G V2X technology that meets their needs in terms of required components to be supported by the MSP and consumed by the tenant. In the automotive industry, the component manufacturers supply components to the Tier 1s, so that they can integrate them and build a higher-level component. Tier 1 companies are direct suppliers to OEMs, which are the ones making the final product for the consumer marketplace. This traditional chain has been extended with the advent of advanced driver assistance systems and autonomous driving. Now high definition map providers are also necessary, together with technology providers consisting of start-ups, SMEs, research institutes and the academia.

The 5G industry and the automotive industry would need to work hand in hand with standardisation organisations. In addition, policy makers would regulate across the whole stakeholder chain. The three profit-oriented stakeholders, thus the 5G industry, automotive industry and road infrastructure operators, will ask for their share in the 5G V2X business.

## 2.2 Investment and business models

Advanced ITS use cases will require very high performance for both connectivity and applications. As for the latter, in-vehicle applications today focus mainly on infotainment (e.g., audio/video streaming), however they are expected to cover, through virtualization and artificial intelligence, other use cases requiring isolated software execution environments and a secure interaction between applications and vehicle’s smart devices, sensors and actuators. This translates into new business model opportunities for municipalities, companies, insurances, as well as road and connectivity infrastructure owners.

The main drivers to generate revenues from automotive applications are advertising, one-time payment and subscription, which is similar to what happens in the mobile market. Standard business models are well-known and are based on the assumption that the user pays for a service provided by the application developer. However, the computing power made available by car electronics today can be also used in a different way, that is, the vehicle owner can in fact be rewarded (e.g., with money or fees discount) for providing computing resources and data. Similarly, a vehicle can be rewarded for forwarding data to nearby vehicles, i.e. serving as a mobile relay. In this way, connectivity and reliability can be enhanced, whereas such data and resources can be used by the driver for personal applications (e.g., infotainment) as well as they can be made available for VAI applications to serve the V2X and connectivity infrastructure in exchange for a reward. Such scenario can be enabled manually by the vehicle owner, installing specific applications, or in an automated way, with V2X enablers provisioning functions to be executed in vehicles. This approach can boost the adoption of smart-connected vehicles and reduce operational costs of V2X enablers.

We have identified three VAI application business models:

1. Vehicle owner provides resources/data to the infrastructure

- CAD infrastructure monitoring can be done by standard vehicles on the road: e.g., high definition maps creation and update, environment monitoring (traffic, road, whether, road surroundings like bridges, mountains, etc.).
  - Support to the connectivity: e.g., mobile relay/hotspot service for vehicles out of network coverage (or that lack of a specific connectivity), etc.
2. Vehicle owner provides resources/data to other vehicles
- CAD services: the front vehicle in a platooning configuration needs more fuel and faces higher risks of accidents (insurance), V2V interactions,
  - other support: e.g., traffic information, content caching (maps, etc.).
3. Vehicle owner gets rewards/discount fees from advertisement
- Through mobile location-based advertising, V2X enablers can lower access fees to the CAD technology, therefore boosting its adoption starting from the beginning.

## 3 Costs and Profit Calculations

### 3.1 Techno-economic model and key factors

To handle the complex problem of cost and revenue estimation, some basic assumptions and parameter choices are taken. First, a business period of ten years is considered, e.g. from 2020 to 2030. Since 3GPP Rel.16 is expected to be completed by the year 2019, the standard and enabling technology will be available by 2020. Total Cost of Ownership (TCO) includes CAPEX and OPEX, with OPEX being equal to 10% of CAPEX per year. The main cost contributions include:

- Site infrastructure: gNBs, containers, antenna mass (CAPEX).
- Digital road infrastructure: cameras, radars, sensors, cables, fibre (CAPEX).
- OPEX costs.
- HD map service fees as part of required data traffic costs.

The required costs for 5G OBUs for vehicles shall be covered by the vehicle owner and are therefore not considered in the current cost analysis. However, these costs may influence the expected user penetration rate and need to be reasonable and in general as low as possible. Moreover, spectrum costs and Engineering, Procurement and Construction (EPC) are not considered either, as not necessarily specific for CAD services.

Regarding data traffic costs, HD maps updating (include object information and raw data) will be necessary for some use cases and is estimated to require 1 Mbyte/min per vehicle on average in UL and DL. Although not applicable to all CAD services, HD maps will be required for the main ITS services related to autonomous driving. For instance, a one-hour trip of 100 km highway at a speed of 100 km/h will result into 120 Mbytes data volume per vehicle, which is foreseen to be provided by the 5G network. This service includes connection fees and map creation, a rough cost estimate would be 0.5 Euro per 100 km. The traffic density numbers are based on measurements provided by the German Federal Highway Research Institute<sup>2</sup>. It is worth noting that a certain discount, e.g. in the order of 10%, could be optionally provided to vehicles implementing VAI applications. These could support the road real-time monitoring and updating of HD maps.

### 3.2 Investment profit for connected and automated driving

In this study, an estimation of the deployment costs, income and revenue is provided for a horizon of ten years. The deployment costs presented in Table 1 are considered as our baseline scenario. Note that these deployment costs only are coarse estimates.

To estimate the potential income, a 100 km highway segment is considered, with a traffic density of 100,000 vehicles/100 km per day, a CAD service fee of 1 Euro/hour per vehicle, which shall also cover the connection and estimated HD map fees of 0.5 Euro/hour per vehicle. As a realistic market behavior, a 10% yearly penetration of new CAD users is assumed. Considering all above, it is then straightforward to calculate the investment costs, income (revenue) and profit for the period of ten years. It is noteworthy that in the fifth year after the

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<sup>2</sup> [http://www.bast.de/DE/Verkehrstechnik/Fachthemen/v2-verkehrszahlung/Aktuell/zaehl\\_aktuell\\_node.html](http://www.bast.de/DE/Verkehrstechnik/Fachthemen/v2-verkehrszahlung/Aktuell/zaehl_aktuell_node.html)

initial investment a (accumulated) profit can be expected, whereas after ten years, a total profit of almost 70 MEuro can be expected.

**Table 1: Estimation of deployment costs for the baseline scenario.**

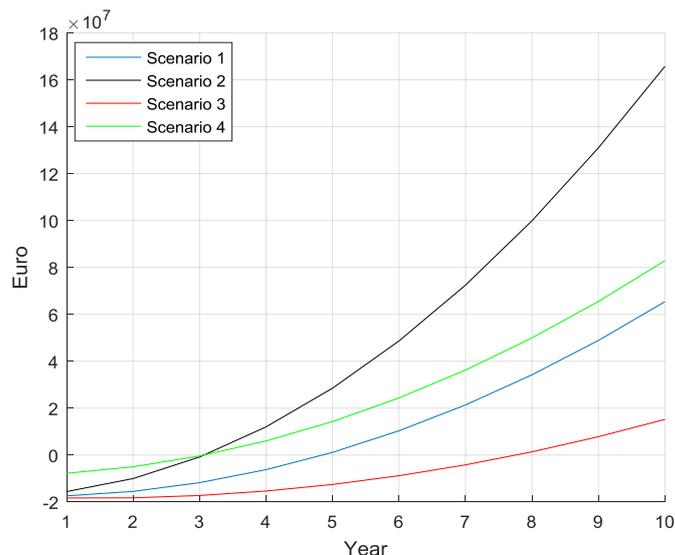
Parameter	Value
5G site (CAPEX)	40 kEuro
Digital infrastructure (CAPEX)	35 kEuro / km
Fibre (CAPEX)	100 kEuro / km
OPEX	17.5 kEuro / km / year
Inter-site-distance (ISD)	1 km

To gain more insight into the influence of individual parameters on the overall profit, four different scenarios are considered. Besides the first (baseline) scenario, three more scenarios with different values of CAD service fee, traffic density and CAPEX/OPEX costs are considered, with the full list of parameters shown in Table 2. For each scenario, the change with respect to the baseline scenario is highlighted in red. Specifically, the second scenario considers a higher traffic density, while in the third scenario a 50% lower connectivity and HD map fee is assumed, allowing the operator to also reduce the CAD service fee to 0.5 Euro / 100 km. Finally, the fourth scenario corresponds to the case where the investment is assumed to be used e.g. by ITS and other services, as eMBB, to the same extent. This also reduces the OPEX costs to the half.

**Table 2: Deployment costs and parameter values for different scenarios.**

Parameter \ Scenarios	1 (Baseline)	2	3	4
CAPEX – 100 km (kEuro)	17,500	17,500	17,500	<b>8,750</b> <b>(-50%)</b>
OPEX – 100 km (kEuro for 10 years)	17,500	17,500	17,500	<b>8,750</b> <b>(-50%)</b>
CAD service fee (Euro per 100 km)	1	1	<b>0.5</b>	1
Income (% of the CAD service fee)	50%	50%	50%	50%
Traffic density (vehicles/100 km/day)	100,000	<b>200,000</b>	100,000	100,000

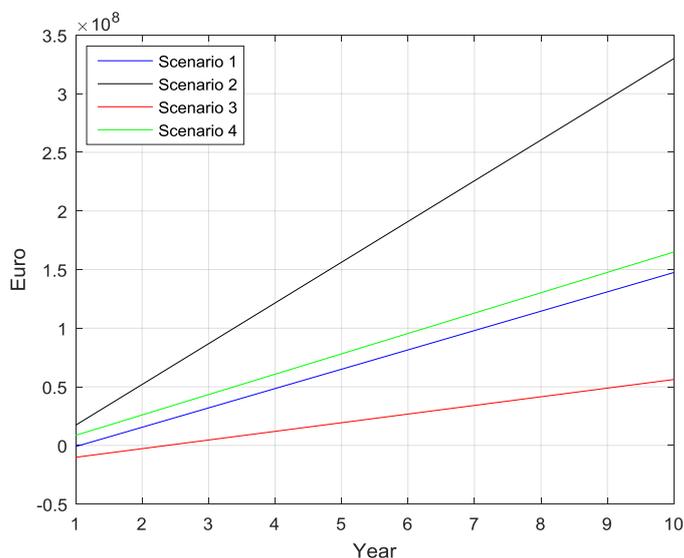
Evaluation results for the accumulated profit are depicted in Figure 2 for a fixed user penetration rate of 10% per year. As observed, a payback period between three to eight years is expected, depending on the traffic density, service fees and deployment costs. As a general rule, the profit growth rate depends on the total income, which is formed by the product of CAD service fee (excluding HD maps fees) per vehicle and the number of vehicles. At the same time, a smaller initial investment, i.e. lower CAPEX/OPEX costs results into a shift of the curves to the left which could be interpreted as shorter payback periods.



**Figure 2: Accumulated profit for different scenarios and 10% penetration rate yearly.**

For further reference and as an upper bound, calculation results for a 100% penetration of vehicles using CAD services from the first year are provided. For the baseline scenario, already from the second year the accumulated profit is positive, whereas after 10 years a profit of 154 M Euro will have been generated, which is more than double than for the case of 10% yearly penetration.

Figure 3 shows the accumulated profit for a 100% user penetration rate from the first year. Due to the full penetration, constant income and costs for every year lead to a linear growth of the accumulated profit. The influence of traffic density, service fees and deployment costs are the same as for the case of 10% yearly penetration. However, in relative terms, the accumulated profit after ten years is between two and ten times higher than for the case of 10% penetration.



**Figure 3: Accumulated profit for different scenarios and 100% penetration rate from the first year.**

## 4 Conclusions

The first part of this study provided an overview of the stakeholders and business models for providing advanced ITS services such as CAD services on highways. New business models, considering a more active role of the vehicle implementing a subset of infrastructure features were considered. To this direction, resource sharing and providing of connectivity and services to other nearby vehicles were introduced and described.

In terms of the investment costs, the role of different parameters and scenarios for providing 5G CAD services over the network infrastructure and their impact on the profit was analysed. One of the main findings is that key parameters influencing the profit of CAD services are the OPEX/CAPEX costs, which also depend on the percentage of usage of the infrastructure for ITS services. Other key parameters are the fees for CAD services and the number of users, defining the growth rate of the profit. Therefore, a positive business case shall be – at least in the early phase of 5G deployment – expected for roads with a high density of vehicles. Of course, as the number of users that can be served is limited by the road capacity, the success of investment will also depend on the affordable charging level for CAD services. Hence, a positive business case enabling profit has been observed.

Although the above findings are more qualitative, rather than quantitative, the overall message is that a positive business case can be expected, even if CAD services shall be fully provided over the network infrastructure and the user penetration rate grows slowly over time. Obviously, including the PC5 interface for selected use cases (e.g. platooning, see-through) would allow offloading data traffic and release some of the network resources.

A more detailed modelling and analysis of the investment, which will be required to derive more concrete and quantitative conclusions, shall be considered by the authors for further study.

## 5 List of Contributors

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