Technical and Economic Considerations on Autonomous, Connected, Electric, and Shared Vehicles

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***Abstract*—Autonomous driving, connectivity features, electric powertrains, and car sharing are four important fields on which the automotive industry is currently working. The technological developments in those areas have the potential to change the industry in a way it has never changed before. Those changes will not only have a large economic effect but will also affect vehicle designs in the future. Not only will it be of importance to implement high cyber security standards in order to protect private and sensitive data but also to prepare power system and internet infrastructure in order for future cars to succeed.**

Keywords-electric car; connected; cyber security; network requirements; mobility as a service; vehicle communication; application fields; mobility

I. INTRODUCTION

The automotive industry is currently undergoing a transformation that has the potential to change the whole industry and their business models. Connectivity, autonomous driving, sharing and services, and electrification are four important trends on which OEMs and their suppliers are currently working. While companies set different priorities on those trends, connectivity and electrification is most pressing for many. According to several studies, 250 million connected cars will be on the road by 2020.

This number is likely to increase to 470 million until 2025 being one reason for the market volume of mobility and digital services to potentially increase to 140 billion euros. Moreover, one out of three cars could have integrated biometric sensors that support certain connectivity features by 2025 according to studies. With more and more connectivity features being present, car manufacturers aim to foster electric vehicles through offering new services that increase the attractivity of electric cars for customers [1, 2, 3, 4, 5].

As more electricity will be needed with an increasing number of electric vehicles, the power system infrastructure needs to be adapted accordingly. Whereas a higher demand for electricity will challenge the infrastructure, intelligent battery management and cars communicating with their charging infrastructure and other vehicles will help to find solutions for the challenges coming with the technological developments. This paper investigates current trends for future mobility concepts by considering economic and technical aspects critical for electrified new mobility solutions to be able to succeed.

II. TECHNICAL AND ECONOMIC CONSIDERATIONS

A. *Transforming Perception of the Car*

With emerging connectivity features, data will be collected to further foster the development of autonomous driving. Some studies estimate that 25% of all passenger vehicles in mature markets could drive fully autonomous by 2030, providing its drivers and passengers a multitude of possibilities how they could spend time in cars. Depending on the speed of development of autonomous driving, some connectivity features will enter the market faster or slower.

With more and more autonomous functions being present, the car will transform from mainly being a mobility solution into a 3rd living space that will allow people to use their time more efficient and productive while serving them as an intelligent assistant to facilitate their lives.

One company defined this shift as a process from "building cars to selling personal travel time well-spent", implicating that "the personality of the car might even become more important than its physical shell" [6]. According to a study, 20% of car buyers would switch to a different car brand if it had better connectivity features. While this number seems comparably low, the perception of the importance of connectivity features in the car keeps increasing [3, 7, 8, 9, 10, 11, 12, 13, 14].

B. *Frameworks*

In literature, a variety of categorizations and frameworks for connectivity features is available. Generally spoken, connectivity features will affect three areas of the car.

First, by being self-integrating and self-configuring, the interaction between the car and its occupants will change. Second, by being self-socializing and self-driving the collaboration with other vehicles and devices will transform.

Third, by being self-learning and self-healing the car will take care of itself automatically [5, 11, 15].

C. Mobility as a Service

Instead of using the car as a simple transportation solution, the digital user experience will be of high importance for OEMs and their suppliers in the future. By creating a seamless integration of technology into the human-machine interface, interactions with the car will feel more natural.

Mobility will become a highly personalized service with the help of enormous amounts of data that will be collected and used to create a unique and individualized experience for the customers. Whereas measures such as horsepower or acceleration were indicators of vehicle performance in the past, functionality, comfort, entertainment, computing power or high-tech experience will be success factors of cars in the future [15, 16, 17, 18, 19, 20, 21, 22].

D. Network Requirements

Companies forecast that cars might produce up to 4,000 gigabytes of data per day when being connected and autonomous, transforming them to computers on wheels as some experts describe them. Besides handling the enormous size of collected data, further key challenges are an intelligent way of data processing and data security as much information included in those data sets is very sensitive.

Two innovative technologies that are currently developed and that will help foster car connectivity are quantum computing and the 5G network. Quantum computing will provide even faster and more efficient processing of data while the rollout of the 5G network will ensure that internet networks will not be overloaded, suppling more capacity as well as a higher safety and reliability standard.

Whereas nowadays, those amounts of data seem relatively large considering that they will be produced on a daily basis by millions of cars, they might not be such an issue in the future due to technological progress. According to Moore's law, computing power increases every year by roughly 60%, meaning that every 18 months, computers become more than twice as powerful. However, besides an improved performance of computers, a strong and reliable internet network is needed as well.

A very similar law applies to the technological development of internet bandwidth. Following Nielsen's law, the internet bandwidth will grow by 50% every year, equivalent to doubling its speed every two years. The past has proven both laws, and science predicts the validity of both laws for the near future.

However, scientists also claim that the growth will stagnate at some point in time. Fortunately, there is a broad acceptance among scientists and companies that technology development will be fast enough, ensuring that car connectivity will not be restricted by computer power or network capabilities [23, 24, 25, 26, 27, 28, 29, 30].

E. Vehicle Communication

Cars will be in interaction with many different objects in the future, creating a complex ecosystem that accommodates a variety of different players. This technological development is called vehicle-to-everything-communication (V2X) meaning that cars will be designed to connect with nearly everything that could be of interest.

Examples of V2X-communication are vehicle-to-infrastructure-communication, meaning that cars will be connected to traffic lights or traffic signs, vehicle-to-vehicle-communication, meaning that cars will communicate with each other to prevent accidents or drive more efficiently, or vehicle-to-network-communication, meaning that cars will be connected to the cloud to receive software updates.

Moreover, even more personalized features might exist in the future such as vehicle-to-pedestrian-communication, meaning that cars will communicate with pedestrians and their devices to create a more dynamic traffic flow or to pick up a person at a certain place, as well as brain-to-vehicle-communication, meaning that cars will be able to recognize brainwaves and, for instance, could be steered by them [31, 32, 33].

F. New Application Fields

The large variety of communication channels opens up many possibilities for new connectivity features in several areas of application. Together with technologies such as augmented reality or AI, in particular machine learning, cars could be transformed into places like bureaus, gyms, entertainment centers, or doctor's offices.

Worldwide, 1.2 billion people spend approximately 50 minutes in their car on a daily basis. Assuming that a typical day contains 8 working hours, productivity could increase by 10 to 15% if this time was used more effectively. Considering that an average US citizen is stuck in traffic for 52 hours per year, car connectivity features have the potential to improve the quality of time spent in the car on the one hand and to decrease the time being stuck through better traffic management on the other hand [31, 34, 35].

One interesting application field of car connectivity features is passenger health. According to a study, investments into healthcare IoT solutions will reach up to one trillion dollars by 2025, improving the access to highly personalized and on-time healthcare services for people. This might also open up possibilities for health solutions in the car through new technological developments.

Already today, it is possible to analyze the mood of the passengers, which can be especially helpful for accident prevention as studies show that the likelihood of an accident increases by a factor of ten when showing emotions. After recognizing the situation, the car could start countermeasures to improve the mood of the driver and thus would decrease the probability of an accident.

With autonomous driving and health connectivity features, the car will have the ability to prevent accidents and to save lives by, for instance, switching into autonomous mode and driving to the next hospital when recognizing a driver's steering incapacity [36, 37, 38, 39].

III. Conclusion and Future Works

To conclude, the car is about to go through a transformational process in a variety of areas. While this transformation will provide many new possibilities regarding the usage of cars, several challenges such as cyber security or network capacity need to be worked on. This thesis aimed to provide insights on technical and economic aspects that need

to be considered when new technologies in the fields of autonomous, connected, electric, and shared vehicles are being developed in order to ensure that new technologies in cars are able to succeed.

This paper should give an overview on topics that are important to consider. However, this paper is not exhaustive. As this is a constantly developing technology field, many questions are still unanswered. One interesting further research topic could be, for instance, deeper research on cyber security challenges that are linked to technological progress in the car.

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