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Evaluation of Car-2-X Scenarios for Automated Driving

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Abstract: Car-to-X technology enables vehicles to directly exchange information with other vehicles or with roadside infrastructure components using standardized communication and message protocols. Such a communication technology is necessary to deploy cooperative intelligent transport systems (ITS), which make driving safer, more efficient and more convenient. Therefore, several cooperative Car-to-X use cases were defined to improve road safety and traffic efficiency, which will be introduced in different stages. In this paper, we are evaluating major use cases of the early deployment phase – such as electronic emergency brake lights, traffic jam ahead, or weather warning – with respect to their suitability to automated driving. We will see that their current specification only have minor contributions for improving automated driving scenarios. However, we will also see that by improving these use cases we may achieve a significant impact on automated driving technology. Moreover, our evaluation shows that Car-to-X needs to be considered as an essential base technology for cooperative automated driving scenarios.

Keywords: Car-to-X Communication, Automated Driving, Cooperative ITS.

1. INTRODUCTION

Car-to-X technology enables vehicles to directly exchange information with other vehicles or with roadside infrastructure components, as illustrated in Fig. 1. Therefore, vehicles communicate with each other using particular communication technology, such as the ITS G5 communication technology in Europe [Kosch et al (2012)]. The original goal of Car-to-X technology was to improve both road safety and traffic efficiency by several cooperative services. However, cooperation in this sense means that such a standardized system has to work independent of vehicle types, vehicle brands, or manufacturers of infrastructure components. However, standardization – and global harmonization –among so many stakeholders is a rather complex task. Therefore, cooperative use cases based on Car-to-X technology will be introduced in different stages: in the early deployment phase, warning systems like the electronic emergency brake lights, hazard warnings, green light optimal speed advisory or road works warning will be introduced. At a later stage, more complex and assisting cooperation functionality will follow.

Car-to-X communication is based on exchanging messages among vehicles or between vehicles and infrastructure components. Therefore, two message types are specified for Car-to-X communication [Kosch et al (2012)]:

- Cooperative Awareness Messages (CAM) are exchanged periodically among all entities in order to distribute basic vehicle and infrastructure information such as the current position, vehicle type, speed, acceleration, and other information.
- Decentralized Environment Notification Messages (DENM) are sent only in case of special events, such as a warning for other entities in the vicinity.

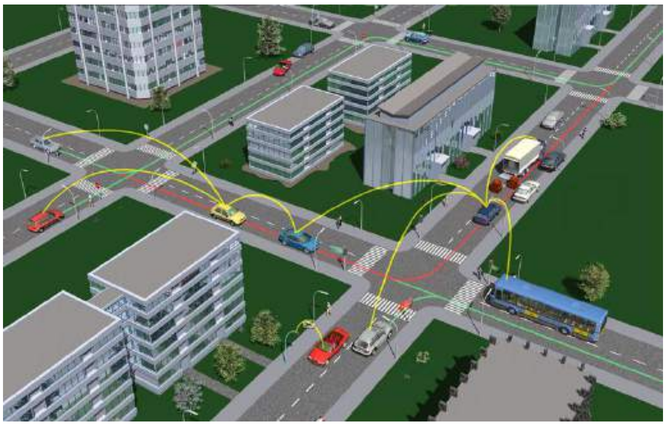

Fig. 1. Car-to-X scenario according to ETSI (and Car-to-Car Communication Consortium) [Car-to-Car (2015)].

In the past years, the rapid development in information technology, data processing and automotive-grade computation capabilities paved the road for automated driving scenarios, which requires complex algorithms, lots of sensor information, as well as environmental and context information. This way, automated driving is definitively one the most challenging future vision in automotive technology. It will be also introduced in different stages with different feature sets: today, we already have systems on the market that allow to park a car automatically ("park assistance") or to follow another car driving in front automatically ("traffic jam assistance"); but the final vision would be a car, which is able to drive completely autonomously without any driver interaction. So far, several car manufacturers and other companies showed prototypes for automated driving, such as Google, Mercedes, BMW, Audi, or Honda. These prototypes are already able to drive in an automated way in defined conditions or on specially prepared tours. The basic algorithms being used typically rely on sensors sensing their environment as well as the availability of a huge amount of information about the environment.

In this paper, we will examine the early Car-to-X use cases with respect to their contribution to automated driving. Therefore, we will first discuss in section 2 some important sensing technologies necessary for automated driving. We will also see how Car-to-X systems will be integrated in such a technology framework. Section 3 then discusses selected (but important) Car-to-X uses cases from the early deployment phase with respect to their contribution to automated driving. We therefore will focus on both the weaknesses as well as the potential of the use cases, and we will also show what would be needed in order to improve their contribution to automated driving scenarios. Finally, section 4 evaluates the results from a more global perspective and concludes this paper.

2. CAR-TO-X FOR AUTOMATED DRIVING

Before we are actually able to evaluate existing Car-to-X use cases with respect to their usefulness for automated driving, we first have to take a closer look on how Car-to-X will be integrated into the framework for automated driving.

2.1 Basic Technology for Automated Driving

In general, the most important part for automated driving is the sensing and interpretation of the environment around the vehicle. Current state-of-the-art vehicles therefore rely on several sources, which provide information about the environment of the vehicle. These sources have different sensing characteristics and capabilities, as illustrated by the following examples, which are illustrated in Fig. 2 (see also [Australian Communications Authority (2001)]):

- Sensor systems based on radar technology or lidar technology typically scan the near range and midrange of the vehicle for relevant. Such sensing technologies are nowadays used for various driver assistance systems. Examples include front radar for adaptive cruise control (ACC) or Honda's iACC (intelligent ACC), or for emergency braking. Radar technology is also used for sensing the area behind a car, which can be used for park distance control available in many cars today, or for Honda's Cross Traffic Alert, which warns the driver for crossing cars while driving backwards out of a parking lot. Finally, radar sensors on both sides of a car are typically used for blind spot detection, which is also available in many cars today.
- Camera-based systems are typically used for sensing the front area of the car. Systems could be based on infrared cameras, common mono cameras, or stereo cameras. Powerful image processing algorithms thereby scan the camera information for relevant information, such as traffic signs, persons on the road, other vehicles (or obstacles) in front of the car, or (in case of stereo cameras) they are able to scan the surface of the roads. This information is typically used by different driver assistance systems, such as traffic sign recognition, or (together with radar-based information) for realizing City Break Assistance system. Road surface scanning by stereo camera is nowadays used for the Magic Body Control system by Mercedes-Benz, which adapts the damper setup based on the detected road surface condition. Moreover, camera-systems typically are used to identify markings on the road. Such information can be used for lane keeping assistance, where the car notifies the driver (or even automatically keeps the car within the lane) when leaving the current lane without activating the turning lights.
- Using cellular communications, the car also has access to environmental information provided by third party service providers. Examples include traffic flow information (or congestions on the road) provided by suppliers like, e.g., INRIX, TomTom ore HERE, or it may even provide information within an ecosystem of other vehicles, such as the Mercedes-Benz Drive Kit Plus, which sends events marked by the driver of a Mercedes-Benz to other Mercedes-Benz cars in the vicinity of the event.

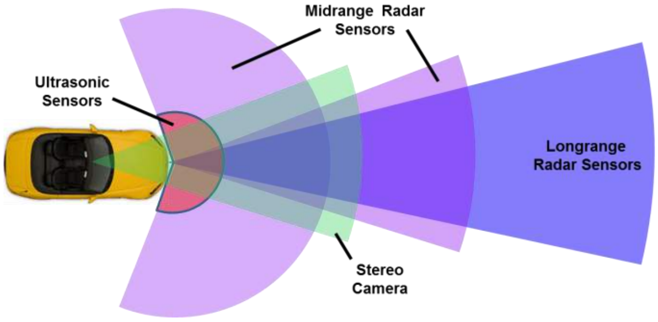

Fig. 2. Typical sensing technology used in current cars (for front detection).

From this point of view, a Car-to-X communication system is considered as an additional sensor technology, which provides further information about the environment of the car. Car-to-X technology therefore provides information from other Car-to-X-enabled vehicles in the vicinity, which typically cover short range to midrange area around the vehicle. Examples for information provided by Car-to-X communication are periodically transmitted information about positions, speeds, turn indicators, vehicle type, accelerations etc. of other Car-to-X-enabled vehicles in the vicinity, or events like hard braking vehicles, vehicles having an accident, or information from road infrastructure such as traffic lights information, traffic signs, or construction sites on the road. Warnings, however, are typically "multi-hopped", i.e. this information is forwarded by the entities to a certain degree, resulting in a larger coverage area.

This information is used to interpret the situation around the vehicle. The information is partially redundant. Hence, it needs to be fused by each vehicle with the available sensors' information. For example, information about other vehicles in front detected by both the radar system and the camera of the car must be consolidated to improve the quality of the situation interpretation in order to avoid misinterpretations. The result of this interpretation is typically reflected in the electronic horizon of the advanced driver assistance system (ADAS) deployed in the vehicle.

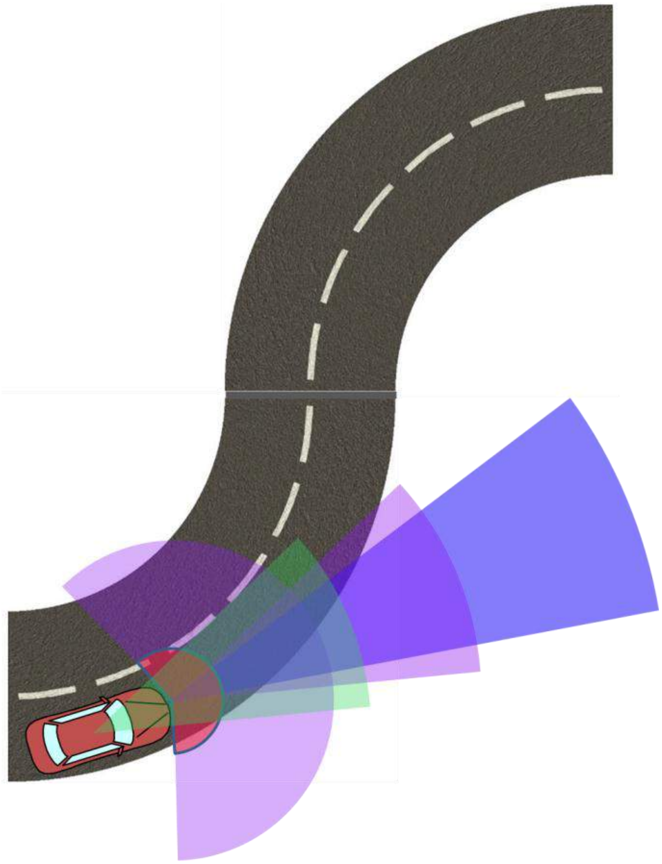

Fig. 3. Example: sensor detection on curvy roads.

Another important technology for automated driving is the availability of high-definition maps (HD maps). Such maps not only provide precise information about the streets and their properties, they also have to support detailed information about lanes, lane markings, and landmarks. Respective map-matching algorithms, which map a vehicle's current position onto the current street in the map, also must be able to map the vehicle onto the lane it is currently driving. Therefore, positioning also has to take into account other vehicle parameters (such as wheel speeds, steering angle) to improve the accuracy of the vehicle's own position. Obviously, this position must be precise enough to map the vehicle onto the lane it currently drives – probably in combination with information coming from other sensors like, e.g., the front camera system. HD maps are important for automated driving, because they are the basis for planning trajectories. Such a planning algorithm is one of the most important aspects for the convenience of automated driving: it avoids dangerous situations on curvy roads, where an automated driving car has to adapt its speed in time before a dangerous curve, which is out of sight of the car's sensors. Thus, the automated driving car does not have to brake hard before the curve. This scenario is illustrated in Fig. 3, where sensor systems only "see" a very small area of the road ahead, and thus cannot directly recognize that this will be a dangerous curve.

Another very important requirement for Car-to-X-based systems being used for automated driving is the automatic detection of obstacles. Obstacles have to be detected automatically by the car – and not triggered by the driver as this is realised, e.g., for the Drive Kit Plus by Mercedes-Benz. A system where the driver manually has to trigger events (like lost goods, pedestrians or animals on the road, or wrong-way drivers) is of no use for automated driving, and may even be dangerous: the information is highly unreliable, because drivers often do not trigger the events while driving, they may play around with the system and generate false messages, and it may be even dangerous because using the system may distract the driver especially in dangerous situations. This way, it is very important that the information for automated driving is generated automatically by a reliable algorithm in order to ensure a suitable quality of the information. It is worth mentioning that this reliability is of importance not only for the own vehicle, but also for the other vehicles in the vicinity, which will receive this information by Car-to-X communication.

3. CAR-TO-X USE CASE EVALUATION

In this section, we will closely investigate selected early Car-to-X use cases with respect to their suitability for automated driving. We therefore will briefly describe each use case and its characteristics, and we will outline the shortcomings and potentials for automated driving. In the early deployment, Car-to-X-based system will provide both Car-to-Car and Car-to-Infrastructure use cases. We will take our focus on the electronic emergency brake light, approaching emergency vehicle, weather warning, traffic jam ahead, hazard warning, and road works warning in our evaluation.

3.1 Car-to-X Technology for Automated Driving

Before we evaluate the use cases, we first discuss some common features of Car-to-X technology, which need to be considered. In general, there are three characteristics that are of relevance for automated driving:

1. *Positioning.* Car-to-X technology was originally developed without mandatory deployment of map information. This way, positioning is basically achieved by standard positioning systems such as GPS, GLONASS or the upcoming GALILEO system. This positioning can be improved by using vehicle sensor data, achieving high position accuracy. However, Car-to-X technology provides neither map matching nor a sufficient accuracy to determine which lane a vehicle is driving. This way, neither roads, the course of roads, nor lanes are supported.

2. *Imprecise Information.* The information generated by Car-to-X use cases is often not very accurate. For example weather information is typically very coarse (e.g., "storms in southern Germany"). Thus, it does not reflect the current real situation around the vehicle.
3. *Partial Deployment of Car-to-X Technology.* Even with a shipping rate of 100% of all new vehicles, it will not be possible that all vehicles driving on the road will be equipped with Car-to-X technology in the next 20 years. This way, there will still be several vehicles on the road, which will not support cooperative ITS. Also, other traffic participants like, e.g. bicyclists may not be considered by Car-to-X technology.

This way, it is important to mention that Car-to-X technology does not provide information in the accurate and reliable way required for automated driving. Consequently, an automated driving vehicle must be able to sense its environment autonomously with its own sensor systems to generate the environment model with the accuracy required for automated driving.

3.2 Electronic Emergency Brake Light (EEBL)

In this use case, a hard braking vehicle sends a respective Car-to-X message about the strong deceleration to other vehicles in its vicinity. This way, drivers of following vehicles are warned right in time about the hard brake and, thus, can adapt their speed accordingly.

In its current specification, EEBL does not have any real benefit for automated driving. This is due to the fact the trigger condition basically relies on the speed reduction due to braking, which first needs to be measured, before in can be communicated. It also requires that both vehicles – the braking vehicle and the following vehicle – are equipped with Car-to-X technology. Furthermore, since EEBL is based on positions only – which may be highly imprecise due to the location technology being used – it is often difficult to determine the relevancy of this information: the information is typically of relevance for a following vehicle only if it drives on the same lane. However, the inaccuracy of positioning does not allow for lane-based mapping of the vehicles, which may result in false warnings.

Finally, the advances in sensor and data fusion technology in the past years resulted in automated breaking vehicles based on information from radar and camera systems. This way, EEBL in its current specification does not have any additional value to automated driving. However, it could be useful for the validation of the existing sensor system used to identify braking vehicles in front. An enhanced version of EEBL also can be beneficial if it is possible to detect or even predict hard braking scenarios earlier, e.g. based on a vehicle's own radar and camera system. This way, the information about a hard braking would be available in subsequent cars earlier than these cars are able to detect the braking by their autonomous sensors. Such a solution would be also highly valuable for a cooperative adaptive cruise control (ACC), because it allows a proactive control of the ACC algorithms. Current ACC systems are controlled reactively, which may cause an inconvenient driving behaviour, if the ACC shows knock-on braking effects if several cars follow each other using the same ACC system. For such purposes the positioning of the system of the cars must be highly accurate, since a lane-matching of the position onto the HD map has to be available.

3.3 Emergency Vehicle Warning (EVW)

If an emergency vehicle approaches, EVW notifies about this potentially dangerous situation by indicating the direction in which the emergency vehicle is driving. Therefore, the emergency vehicle sends an emergency vehicle message in case it activates its light bar.

Although the relevance of an emergency vehicle warning depends on precise position information combined with street information EVW is very useful for automated driving, because it may have an effect on the automated driving strategy. Especially on motorways, drivers are urged to give way to approaching emergency vehicles; and in case of a traffic jam, drivers are urged to give way by forming a corridor for the emergency vehicle. This behaviour has to be implemented in the automated driving algorithm of the car, or the automated driving system has to give back the control about the car to driver in case of an approaching emergency vehicle. Even a warning about an emergency vehicle on a neighbouring lane (which has no relevance for the own vehicle) can be useful because the driver typically will realize the blue light bar or the siren of the emergency vehicle and, thus, may be warned about this distraction in advance.

3.4 Weather Warning (WW)

C2X-based weather warning functionality informs a vehicle about potentially dangerous weather situations, such as fog, heavy rain, snow, or black ice on the roads. The information about weather conditions may be generated either from another vehicle using the on-board sensor systems, or respective road conditions may be generated by road sensors or third party weather information providers, which are transferred to the vehicle using road-side stations. This way, weather warning could be both, a Car-to-Car use case as well as a Car-to-Infrastructure use case.

Road conditions in general are highly useful for automated driving, because it has an impact on the driving strategy for the automated driving system. For the example of slippery roads or restricted sight due to heavy rain, snow or fog, an automated driving car may have to reduce its speed, or the driver even has to take over the control of the car, because sensors and/or camera will not work as required under these conditions. However, it is important that such information must be highly reliable, and vehicles (or road sensors) must be able to detect respective situations highly accurate. Moreover, the automated driving functionality of a car must not rely on this information exclusively, because it cannot be guaranteed that this information is available for the route the car drives in an automated way, so an automated driving car must be able to detect road conditions in order to react in an appropriate way.

The contribution of weather warning to automated driving is two-fold. For pure car-to-car functionality, it is rather worthless since the trigger conditions for dangerous road situations do not meet the reliability requirements: Fog needs to be detected automatically and reliably (e.g., by a camera-based system) and not by activated fog lights, and slippery roads require sophisticated friction value estimators, which are currently not available in many cars. Moreover, to improve the quality of this information, respective crowd sourcing mechanisms may be deployed to validate and verify the road conditions in a backend system. This way, the information generated by other cars is almost worthless for automated driving. On the other side, current sensor systems for road condition surveillance (e.g., ice detectors, water level detectors) are nowadays able to provide reliable information or estimations about dangerous road conditions using Car-to-Infrastructure communications, which can be highly useful for the automated driving systems. This enables the car to return the control of the car to the driver in advance, so the driver has enough time to get back into the driving context and can take over the control of the car seamlessly and safely.

In contrast, third party weather information, such as heavy storms, snow, rain, etc. is almost useless for the automated driving. This is due to the fact that the information does not reflect the road conditions, and a mapping from weather information to precise road conditions is not possible in a reliable way.

As a result, WW in its current specification is not very useful for the automated driving system of car. However, with an improved specification of the system together with suitable sensors in mass market vehicles providing reliable information about road conditions, such a system is highly useful for improving the automated driving functionality of a car – although the car always has to be able to drive automated without relying on this information.

3.5 Road Works Warning (RWW)

Road works warnings are typically generated in case of construction sites, which could be of static (e.g., renewing the road surface) and of dynamic nature (e.g., mowing the grass besides the street). Such construction sites are highly challenging for automated driving cars in several ways:

- Entering/Leaving the construction site is very confusing for sensor detection and motion planning – even for experienced drivers it is sometimes difficult to identify the traffic routing in a construction site.
- Lanes are often narrow, vehicles from other lanes may drive onto neighbouring lanes, lane markings may have different colours or may even be rubbed away partially. Moreover, there may be "strange" signs in the construction site, e.g. indicating shifted driving on two lanes without overtaking.
- The boundaries of lanes are "marked" different, e.g. by using plastic pylons or high boundaries made of concrete or metal, which cannot be run over by the cars. This makes it difficult for the car's sensor systems to predict the lane markings in a reliable way.

Moreover, construction sites themselves are hard to detect by a vehicle's sensor system; construction sites do not have typical characteristics, they always look different in different countries and may have to follow different regulations. This way, detection is basically limited to camera systems only.

For automated driving cars, RWW is an important use case for several reasons. On the one hand, passing a construction site has a significant impact on the car's automated driving strategy. On the other hand, construction sites often use "modified" lanes, which often do not match with the available HD map material. This way, the driving strategy must not rely on HD map material (for motion planning) exclusively, but the vehicle also must be able to drive in an automated way completely by its own sensor information. If this is not possible, RWW will support automated driving by indicating the algorithms to give back the driving control back to the driver right in time, before the car reaches the construction site. To overcome this limitation, RWW needs to provide highly precise information about the construction site, its routing lane characteristics, and ideally the traffic flows on each lane. This way, an automated passing of the construction site can be realized efficient and comfortable, e.g. by choosing the quickest and safest lane.

3.6 Hazard Warning (HW)

Hazard warning use cases basically comprise two scenarios: in the breakdown vehicle scenario, a vehicle having a defect or an accident notifies following vehicles about the dangerous situation. This is triggered when the vehicle does not move and has activated its hazard lights, or if the vehicle system detected a crash. In the second scenario, a vehicle warns about dangerous situations on the road caused by obstacles (e.g., lost goods), pedestrians, or animals on the road. In contrast to the breakdown vehicle scenario, the message generation has to be triggered by the driver manually, because an automatic detection basically requires camera systems which will not be available in cheaper cars.

HW also may comprise infrastructure support. For example, if a traffic management centre realizes a hazardous situation on the road, it may generate a respective HW message in the traffic management centre, transfers this message to related roadside stations in the vicinity of the hazard, where it is sent to the passing vehicles.

Like EEBL, the HW use case does not have a significant benefit for automated driving, because it is almost impossible to determine the relevance of the hazard being received. This is due to the fact that no lane-specific (or street-specific) positioning of the own vehicle and the hazard is possible: often, obstacles or defect cars are located at the side of the road, which has no effect on the passing vehicles, whereas an accident typically occurs on the road and sometimes may result in a blocked lane. This way, many false alarms about hazards may be generated, which is of no real benefit for automated driving. However, a more accurate positioning as well as an automatic detection of the obstacles, pedestrians or animals on the road may help to validate the detected information by the autonomous sensor systems of the car, making them more reliable.

3.7 Traffic Jam Ahead (TJA)

The detection of traffic jams is very important for automated driving, because it is a typical and common situation for driving on motorways in many countries, where automated driving will play an important role. It is also a highly challenging situation, because it requires stopping the car from potentially very high speeds. As a result, TJA using Car-to-X technology is a highly useful functionality for automated driving. Although an automated driving car must be able to detect the tail of a traffic jam by its own sensor systems, the car requires a rather long distance to slow down in time. For example, in case of 120 km/h an emergency brake on wet grounds requires a minimum of 80m to stop the car. However, such emergency brakes are neither comfortable nor convenient for the driver. If the car gets a TJA warning before the sensor systems can detect the end of the traffic jam, the autonomous driving strategy can react accordingly, e.g. to preventively reduce speed in order to approach to the traffic jam very smoothly. Therefore, it is not that important to know the exact position of the last car in the traffic jam; it is basically sufficient to know that there is a traffic jam ahead.

As a result, we consider TJA as a highly useful functionality for automated driving, which is important information to smoothen the autonomous driving strategy. Nevertheless, a good prediction of the exact end of the traffic jam may improve this further on. Also, a street dependent matching of this event could be very useful in order to determine if the TJA is relevant for the automated driving car or if it is on a different (and not relevant) street.

4. EVALUATION & CONCLUSION

Our examination shows that the early Car-to-X use cases being deployed will not provide a significant contribution to automated driving technology. In particular, this is due to the fact that the partial deployment in both vehicles and infrastructure components, positioning and information accuracy do not meet the precision requirements for automated driving. As a result, a vehicle must be able to detect all these situations by its own sensor systems autonomously, from which one may deduce that Car-to-X technology is of no use for automated driving. This is certainly true for the basic automated driving algorithms implemented in the cars. However, in the mid term, Car-to-X will become an important technology to make automated driving more comfortable, more efficient and, thus, more convenient for the driver. This factor will be very important for the driver acceptance of automated driving cars, as illustrated by the following examples:

- *Smooth Braking.* Since relevant information may be available in time, a car can adjust its speed in a comfortable way without the need for hard braking. For example, in case of a traffic jam ahead warning, the automated driving car can reduce its speed very early to stop right in time at the end of the traffic jam. In case the traffic jam needs to be detected by the car's sensors very late, the car needs to break hard, which makes traveling very inconvenient (and unacceptable) for the passengers. A driver would likely not like the system if his coffee permanently spills over his cup due to hard braking.
- *Efficient Driving.* For the example of traffic jam ahead or road works warning, the automated driving strategy can be adapted to the situation to approach to the end of the traffic jam very efficiently. This may include utilization of the optimal strategy for powertrain configuration, but also, e.g. to switch of the engine very early in order to save fuel.
- *Safe Driving.* Since relevant information will be available at the time it may be relevant, safety is also increased. For example, in case the traffic or environment situation is not suitable for automated driving (e.g., highly complicated and confusing road works), the driving control must be given back to the driver right in time, which is typically hundreds of meters before the event occurs. Therefore, the driver has sufficient time to get back into the driving context in order to take over the control. Car-to-X technology will help to provide such information very early, whereas autonomous sensing of the cars may be able to detect the event at the time it occurs, potentially resulting in a "recovery mode" to stop the car in case the driver is not able to immediately take back the control about the car.

Of course, such events will not always be available by Car-to-X technology; hence, Car-to-X technology will not be able to avoid such situations like an emergency brake completely. But even if an 80% availability of such information is possible, this highly improves comfortable and efficient automated driving and, thus, helps to significantly improve the acceptance by the drivers.

However, for the future vision of cooperative automated driving, Car-to-X is an important and indispensable technology, because it enables cooperative scenarios among vehicles. For example, imagine the following typical situation: a car enters the acceleration lane of a motorway and now has to decide if it will filter in behind or in front of an automated car driving on the motorway. This typical and frequent situation cannot be solved with autonomously sensing cars: without cooperation both cars may accelerate (or slow down) at the same time, resulting in strange, uncomfortable and even dangerous automated driving behaviours of the cars. This way, a quick deployment of Car-to-X technology is an important precondition for future cooperative automated driving scenarios.

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