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Requirements for battery electric and automated passenger transport with focus on environment detection from vehicle and infrastructure perspectives

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Summary

This paper provides an analysis of the trend in autonomous driving traffic and the development of infrastructural support, whereas the requirements on the infrastructural support will be analyzed. Then selected traffic scenes will be implemented in an autonomous driving simulator tool in order to figure out the required parameters to assist the autonomous vehicle from the infrastructure.

Keywords: mobility concepts, city traffic, BEV (battery electric vehicle), autonomous vehicle, control system

1 Introduction: The Growth of Autonomous Driving in Mixed Traffic

Besides simple park and ride [1] and carsharing [2] concepts, autonomous driving is one of the most discussed mobility solutions at present. In this concept, a vehicle will provide automated individual mobility, which means, on the one hand, that from an economic point of view, driving time is no longer an effort but usable time, and on the other hand, that mobility transforms into an on-demand service. One of the resulting advantages of such a Mobility-as-a-Service transformation [3], and the other advantage for a large city is the reduction of parking lot requirement [4]. This means an immense disruption on the street, the inner city and suburbs: parking garages are no longer needed, the hard shoulder can be used as an additional lane and thus represents one of the few solutions that can effectively reduce the heavy traffic in congested cities which however requires the vehicle to be automated. The current assessment is that autonomous driving in a highly dynamic environment such as mixed urban traffic can only be implemented with the help of infrastructure [6]. The problem of infrastructure-supported driving is liability, for which nobody wants to take responsibility voluntarily [7] . For example, if a city provides a digital blind spot detection system, it cannot take responsibility in case of misinformation. One possibility is to find a stakeholder that provides both the vehicle and the infrastructure, for example, a bus line operator. In the context of a living laboratory in the German city of Waiblingen in Baden-Württemberg, the feasibility of autonomous driving for public transport will be investigated. In the urban area, an autonomous bus line in mixed traffic will be established and observed. The technical work packages include infrastructure, autonomous capability, environmental perception and the open data storage. In terms of infrastructure, the requirements in the context of autonomous driving will be clarified on the one hand and the digital infrastructure of tomorrow will be specified on the other.

1.1 Enhanced Infrastructural Support

Currently, the automotive industry is majorly working on pushing autonomous driving [8]. The infrastructure as a supporting party moving towards to a subordinate role. The first step of current efforts is to respond to the needs of the vehicle manufacturers and to see themselves as suppliers. Changes in the infrastructure automatically adapt to the requirements of the automotive industry. The current task of the infrastructure in urban areas is the representation of traffic rules and the provision of driving information [9]. Furthermore, the traffic infrastructure is designed for the human driver. The automotive industry therefore tries to adapt the vehicles to human perception, but the principal aim is to reproduce driving behavior that is as close as possible to the human's perception. With the digitalization of driving new possibilities arising to include the environment to expand the perception of the environment and thus to increase safety [2]. The vehicle's field of view can be extended by any number of perspectives through smart infrastructure and Vehicle-to-X communication, and thus possibly even exceeds that of human perception. Blind spot monitoring, dissolution of occlusion, extended field of view by other road users (cooperative perception), warning and control, static information of temporarily adapted traffic guidance, dynamic velocity limits, the list of possible use cases is long. The German Federal Highway Research Institute (BASt) has published a series of requirements for the infrastructure in the context of autonomous driving [6]. Meanwhile, the German project Co-Per (Cooperative Perception) [9] has found that both driver assistance function and traffic safety can be significantly increased by integrating the infrastructure. In the end, the problems can be attributed to the lack of standardization, for which it is often recommended that infrastructure providers meet with vehicle manufacturers to work on a feasible concept [6, 8–10].

A proposal for such a framework, which can cover all applications in a highly flexible way, is to be developed within the scope of this first publication. A so-called Urban Traffic Support Platform is to be used to create a standard that forms the bridge between infrastructure and vehicle manufacturers. This is to be achieved in a series of four publications, which will conclude with a doctoral thesis. Besides the previous publications [11, 12], this first one describes the qualitative requirements for such a system.

2 Requirements for Infrastructural Support

To describe the technological evolution of autonomous driving, the illustration in Figure 1 can be used.

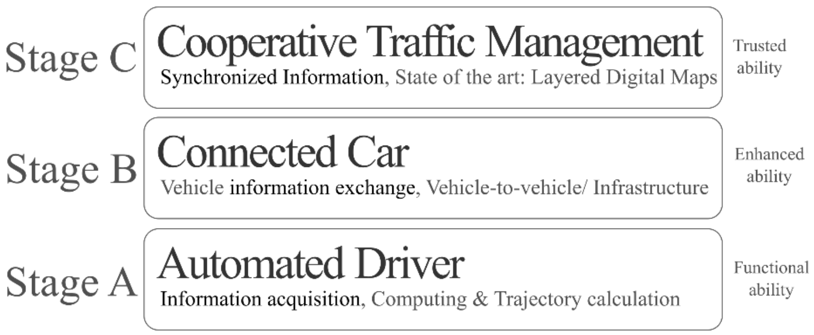

Figure 1: Evolution of Autonomous Driving

From the outside view, autonomous driving starts with the automatization of the vehicle. To achieve this the vehicle must be technologically able to detect the environment, process it and then calculate and execute a driving trajectory. This first stage deals exclusively with the vehicle itself. In the second stage, further information from other participants is added. Several vehicles and infrastructural components are considered rather than just the vehicle itself. The added value is the passive support through increased information content (digital maps, perception information, entertainment). The third level forms as a central instance the bridge to synchronize and verify the exchanged information and to optimize and minimize the communication effort gradually. If a vehicle claims to recognize a non-moving object on the road and distributes this information, it may take some time until this information is confirmed or revised by other vehicles (depending on the fusion strategy) and the correct information will be distributed. If a platform would exist (in a technically suitable shape), where road users can discuss and deposit their environmental perception, then concepts like Informal Verification, Functional Safety Mechanisms or High-Level Support Analysis could be implemented. Such a platform can provide the basis for a value-added cooperative perception. In order to allow the synchronization to take place, it is possible to divide this level again into different sub-areas, as shown in Figure 2. The following chapters describe the individual parts in terms of their technical requirements and the associated possibilities.

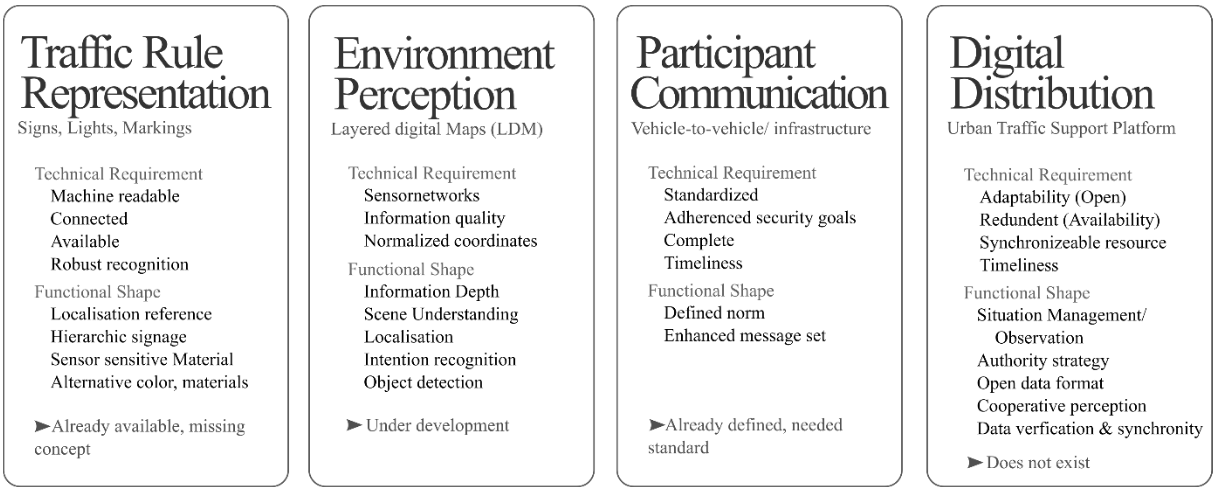

Figure 2: Different parts of Cooperative Traffic Management

2.1 Essential Traffic Equipment

One of the most popular forms of infrastructural support is the traffic signs which show the traffic rules and traffic information. The so-called Essential Traffic Equipment deals with all objects of the traffic infrastructure which are neither connected nor intelligent. With the help of road markings and the traffic lanes, the current traffic routing and mandatory measurements like velocity limits are shown. If the traffic lane is in a bad condition, the lane hold assistant will lose its functionality and the driver must take over the vehicle control. The traffic sign is currently dimensioned to fit the detection area of human eyes and provides information which is required by the human driver. The automotive industry tries to modify the machine recognition to read traffic signs which are designed for humans. For the mixed traffic of autonomous and non-autonomous vehicles, this solution is still acceptable, however, it could make sense if the already existing mechanism is reconsidered which means on the one hand the traffic signs should be optimized for the machines and on the other hand human-readable traffic signs are installed redundantly besides the machine-readable traffic signs throughout the transition period.

In a previous foundation project of the German Federal Highway Research Institute, the requirements of such adjustment could be described explicitly [6]. The recommendations are machine-readable traffic signs which are already applied on the German A9 Highway for localization measurements or in combination with QR Codes [13]. Furthermore, researches on Automotive Sensor optimized markings [14] have been done. All the measurements have the goal to increase the robustness of the vehicle-sided perception and the reliability of vehicle orientation. With the introduction of hierarchical traffic signs, the special driving situation for example a construction site can be recognized. If the signs are not occluded the sign mounted in the highest position may give the correct indication for the temporary traffic situation. With the current dependencies on a maintained infrastructure the automation level four or five in urban area according to SAE J3016 are difficult to imagine. The aim is to shape the framework condition of the infrastructure as robust as possible since all algorithms are based on it. An improvement of recognizability of traffic signs / marking / light signals of 5% may result in a 50% easier perception at the algorithm side.

The classic infrastructure has the possibility to introduce a next-generation land marking with autonomous driving. The portfolio should on the one hand be expanded and on the other hand fit into the requirements and strengths of the machines (Automotive OEMs) and a bilateral concept should be developed. Alternatively, the infrastructural dependency of the vehicle orientation must be minimized to guarantee a stable autonomous driving in a highly dynamic environment like in the downtown area.

2.2 Cooperative Perception

With the perception module, the vehicle tries to recognize its environment. After this step, a decision will be done, and an action will be executed. With the help of continuous updates, a control loop can be built up and a planned goal with the help of a dynamic route can be achieved. This causality chain starts with the object which must be recognized (Traffic participants, signs, buildings), continue with the algorithm (image processing and machine learning) and ends with the evaluation of the data. In the previous chapter (2.1) the importance of the adapted objects at the beginning of this chain has been described. In this part the requirements for the perception and the possibilities and problems of each part will be represented in this chapter. The basic tasks of the perception are depicted in Figure 3 and their special characteristics should be described with a tree diagram. It is remarkable in the Figure 3 that the infrastructure is the only part that can fulfill all functions of the perception.

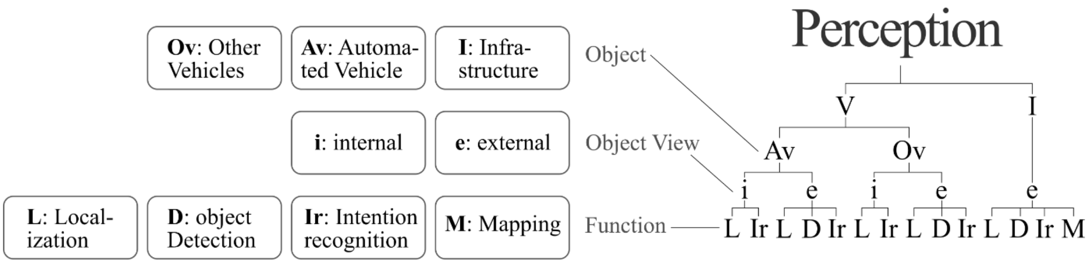

Figure 3: Qualitative taxonomy of traffic perception.

The description shows that the perception differs from the performing objects, the object views or on its own and the perception function. For example, an autonomous driving vehicle can detect another object in the traffic, such as a pedestrian, determine his/her purpose, and localize it. However, the environment detection in the sense of mapping cannot be absolved with the vehicle because it can only localize and map itself (SLAM). The information captured by the vehicle is related to itself and cannot be transferred to other coordinate systems (like those of other traffic participants). The reasons are the different implementations and methods of different OEMs and the resulting inaccuracy in positioning (e.g. [15]). A concrete characteristic of the SLAM problem is for example the lifelong orientation of landmarks which are influenced by dynamic elements like lighting, weather or season of the year and therefore are non-continuous [16]. In summary, such a moving object tries to orientate to changing features in order to localize itself in the map created by itself. Since the vehicle can either localize or map, therefore it is assumed that the vehicle is limited in localization, as the infrastructure must be calibrated and uses a built-in map to locate itself. From the view of an external observer like the infrastructure, it is possible to validate the functions in Figure 3: Qualitative taxonomy of traffic perception. and to synchronize them. With the help of a suitable medium which is standardized, highly precise and validatable the mapping for all traffic participants can be done. A possibility for a synchronization format is the so-called Layered Digital Maps (LDM). Several recommendations for LDM already exist [17, 18]. Hereby it is important that a highly precise map which can be filled with dynamic objects from the side of the traffic participants has to be provided and be verified by the external side that can locate itself in the map precisely. On this basis an infrastructural supported and central fusion of the captured information can be carried out. The fundamental prerequisite is, on the one hand, the technical communication of the traffic participants, and on the other hand, an appropriate form of the standardized map.

2.3 Machine-Machine Interface (Vehicle-to-X Communication)

One of the basic requirements for all coordination processes is the possibility of communication. There are currently two conceivable options for this: direct communication via the automotive standard IEEE 802.11p (ITS-G5) [19] and the integration of comprehensive coverage via the LTE/ 5G mobile radio standard [20]. Both technological standards have a good development status and can be implemented. The basic problems with the integration are the not yet standardized communication stack of the respective technologies. There have been some efforts [21], but there also has been no cooperation with the industry, so they are currently developing their own messages [9] to map a cooperative perception [22]. In addition to the standardization of these messages, compliance with and transmission of the five security goals [23] is essential and unavoidable in communications technology. In a parallel publication of the INEM, which is currently being developed, robustness studies of the respective technologies will be researched and subsequently published.

2.4 Urban Traffic Support Platform (UTSP)

The possibilities and influences must first be understood so that the infrastructure can provide an added value to autonomous transport to improve its robustness. The aim is to support autonomous traffic by means of a platform and on the one hand to increase safety, on the other hand to enable a cooperative perception (functional robustness). Figure 4 shows the influences, possibilities and dependencies of such a platform.

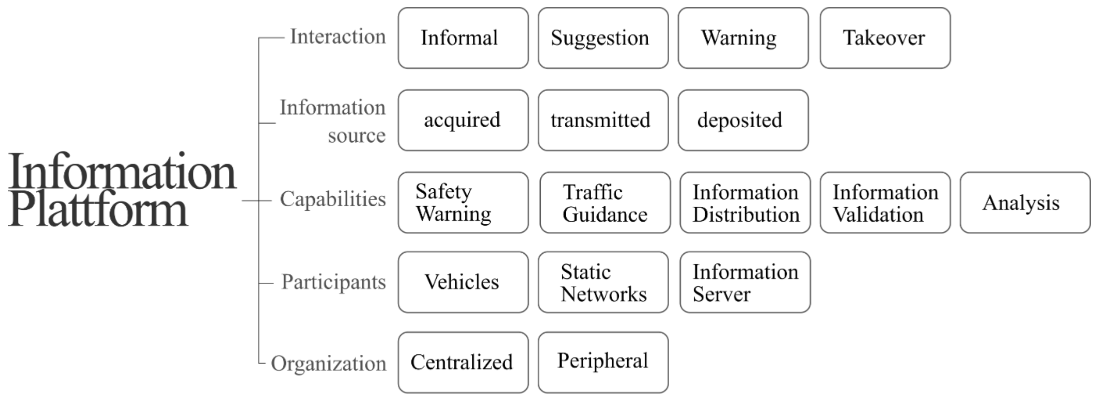

Figure 4: Influences of a possible traffic information exchange platform

In order to such a platform to provide an added value, some undefined technologies are needed first: a *communication possibility* between the participants and an *exchange format* that all participants can work with. One conceivable solution would be cloud storage in which vehicles first store their perception results. An algorithm merges this data using a defined fusion strategy and can thus verify or validate the data. To enable the platform to make independent decisions in case of doubt, it is also connected to a sensor network on the infrastructure side (at critical or highly dynamic situations, e.g. an intersection) to check the correctness of the received data. Once the map has been completed, participants can download the map and complete their own mapping using correction factors.

In this paper, this will be illustrated by crash prevention. By means of an abstract thought experiment in 2.4.1, the specific requirements are to be derived and subsequently verified by simulation (Chapter 3).

2.4.1 Velocity Controlled Traffic Management

The idea is to use a mathematical model to predict collisions between two automated or at connected road users and to prevent them based on influence possibilities found. According to the displacement-time law, the distance to be driven depends on time and velocity. Since no influence can be exerted on time, only velocity remains. The starting point is an automatic control guided autonomous vehicle. Assuming two vehicles (one automated, the other non-automated) are driving towards each other and would collide at their momentary velocity, the Urban Traffic Support Platform (UTSP) would be the only independent entity able to give recommendations regarding a maximized velocity at which the vehicles do not collide (by varying the velocity within the allowed parameters). This is where the strength of the infrastructure comes into play, being the only participant that can see all perceptions and make decisions based on them. The result to be transmitted is a velocity recommendation (qualitative; without any consideration of other influencing factors such as friction, braking force).

As shown in Figure 5, suppose that there is a Vehicle.ID_X drives at a constant velocity of v_x, while a Vehicle.ID_Y is coming from the right side at a constant velocity of v_y. To ensure there is no colliding between them, there are two extreme situations to be considered. One is the Vehicle.ID_Y reaches the intersection of the routes before the Vehicle.ID_X. In this situation, as long as it is ensured the left front corner of the Vehicle.ID_X in moving direction does not collide the left rear corner of the Vehicle.ID_Y in moving direction, a collision between them can be avoided. Another is that when the Vehicle.ID_X reaches the intersection first. In this situation, as long as the right front corner of the Vehicle.ID_Y in moving direction does not collide the right rear corner of the Vehicle.ID_X in moving direction, the collision can also be avoided.

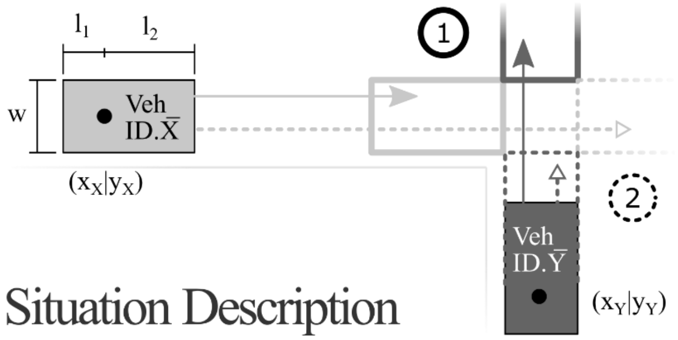

Figure 5: Description of extreme situations

Combining these two situations, in order to avoid a collision with Vehicle.ID_Y, from the current moment on, Vehicle.ID_X should drive at the following velocity limits until it passes the intersection(with the assumption that the size of the Vehicle.ID_X and the Vehicle.ID_Y is the same):

$$v_{X\_slow} < \frac{x_Y - x_X - \frac{w}{2} - l_2}{y_Y - y_X + \frac{w}{2} + l_1} * v_Y \quad (1)$$

$$v_{X\_fast} > \frac{x_Y - x_X + \frac{w}{2} + l_1}{y_Y - y_X - \frac{w}{2} - l_2} * v_Y \quad (2)$$

A virtual representation of the recommendations in combination with the traffic situation can be seen in Figure 6. The current velocity and the areas where an accident would occur are displayed.

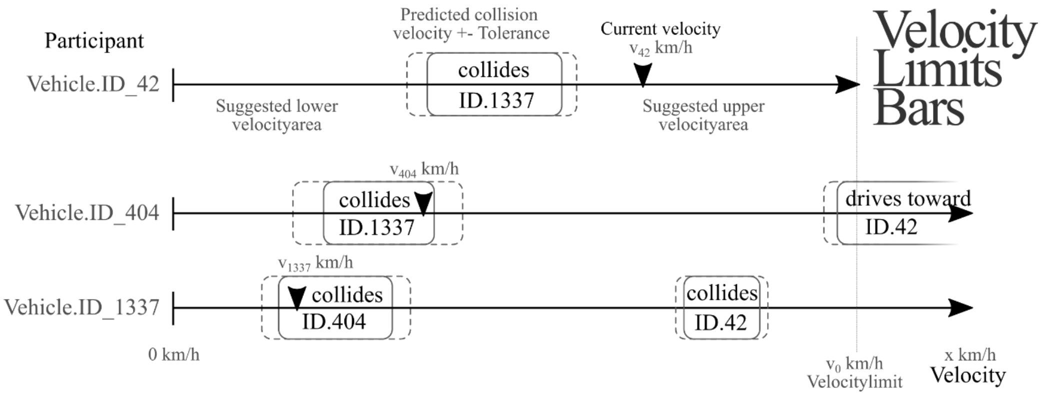

Figure 6: Automatic Control Velocity Limits Bars

The following algorithm to thwart the collision based on the recommendation can be described (qualitatively) as follows:

1. **Measure** velocity v_x, position P_x (estimate the trajectory, define the car classification [weight] and measurements l_x, …) for every Vehicle.ID_X
2. Based on the current situation **calculate: will a crash occur?** If yes: continue with 3. else with 1.
3. Calculate the **velocity limits** to avoid the collision, with the assumption that the crashing car does not change its behavior (non-automated vehicle).
4. **Adjust the velocity** with respect to the velocity limit. Suggest reverse velocity limits.
5. **Repeat**. Go to 1.

In order to a recommendation to be found, various information must be known, either from the object itself and transmitted via WLAN or the mobile phone network or collected by a sensor network. In order to effectively support the traffic, the object dimensions, the class (according to known standards), the position, the momentary velocity, the acceleration, the trajectory (or at least the intentional detection), the environmental data as well as the possible influencing actions must be known. The possibilities for action are limited to the velocity, the trajectory and the controllable actors. The behavior and the prediction can be analyzed with the help of a neural network or the geometric predetermination. The basis for this is a mathematical model in a simulation. The concept shows a preventive safety measure at maximum velocity. Comparison: due to its own detection of its environment, a vehicle must brake completely to avoid colliding with the other road user. The advantage here is calculated based on the omniscience of the infrastructure.

This thinking refers to the transversal continuation of the trajectory, but it is also possible to adapt the route and create an advantage due to the uncritical planning. A high-level layer of the digital maps, which places a grid on the LDM can, for example, declare individual cells as "occupied" and "free" and on this basis display objects with very little and highly dynamic effort. If the geometrically predicted accident location is displayed as "occupied", the trajectory is adapted, and position-based preventive bypassing is performed. In the following, this thesis will be presented, discussed and verified by simulation.

3 Simulative Investigation of Traffic Situations (LGSVL)

The aim of the paper is to find out the potential of how the infrastructural sensor application can be applied to support the autonomous driving vehicle. The approach to reach this aim is to apply a simulation software in front of the LGSVL simulator. In this section, we will firstly present the proposed simulation framework and the selected scenario, secondly present the designated simulation scenarios and thirdly the results of the simulation.

3.1 Introduction of Simulation Environment

The LGSVL Simulator, which is applied by our team to simulation differs from three major agent types which can be simulated. The first object group is the so-called EGO Vehicles, which means the vehicles that are equipped with sensors and can be applied as autonomous driving vehicles. The second category is the NPC Vehicle, which are the vehicles that act as traffic participants without autonomous driving capability. The third group is the pedestrians. Besides the agent types, there are also the so-called controllable objects. These are the objects which can be added into a simulation runtime and whose behaviors can be controlled, such as traffic cones (according to their position) and traffic lights (according to their light signal).

The objects in LGSVL also differ from their adjustable parameters. All agents can be controlled in their states, which include their position, rotation, velocity and angular velocity which can be adjusted at any later time. NPC vehicles and pedestrians can be configured in their movement through assigning them waypoints which should be followed by the agents. In addition, the EGO vehicles can be adjusted in their throttle position (0.0 to 1.0), brake position (0.0 to 1.0) and steering wheel position (-1.0 to 1.0). In this way, we can control the movement profile of EGO vehicles, NPC vehicles and pedestrians.

The simulator can send callback in different situations: For example, when the EGO vehicle or NPC vehicle reaches certain waypoints which were previously assigned, or when objects collide with each other, such as when the EGO vehicle collides with the NPC vehicle.

3.2 Simulation with different velocity settings

In the simulation implemented in our paper, we have focused on the simulation of the EGO vehicle and the NPC vehicle which will meet up at a cross. To implement the desired vehicle driving profile the LGSVL Python interface has been utilized in order to make the vehicle drive the designated simulation scheme which will be described in this chapter.

The goal of the simulation is to find out the velocity area in which the EGO vehicle will collide with the NPC vehicle. If there is a collision between the EGO vehicle and NPC vehicle, the simulator will send a callback.

In the simulation, we have configured different velocity parameters for the EGO Vehicle and NPC Vehicle. The velocity of the ego vehicle verifies from 20 m/s to 50 m/s, while the NPC Vehicle will be set constantly at 20 m/s. We firstly simulated the NPC vehicle coming from the left side then from the right side. The velocity of the EGO vehicle starts from 20 m/s and will be increased with 1 m/s for each simulation and stops at 50 m/s. The EGO Vehicle will roll at the cross and will break in front of the cross with a brake pedals position of 0.1, while the EGO vehicle will then accelerate with a throttle pedal position of 0.1.

The simulation environment, driving directions of the EGO vehicle and NPC vehicle are shown in Figure 7. The red dot symbolizes the waypoint after which the EGO vehicle will break, the blue dot the waypoint after which the EGO vehicle will accelerate. Only one EGO vehicle and NPC vehicle appear in one simulation.

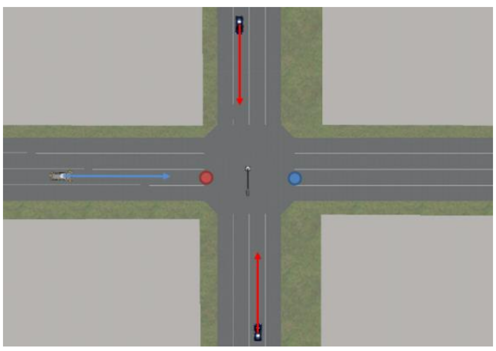

Figure 7: Directions of EGO Vehicle (blue arrows) and NPC Vehicle (red arrows). Red dot: Point to brake. Blue dot: Point to accelerate.

The results of the simulation will be depicted in Chapter 3.3.

3.3 Evaluation of simulation results

In this chapter, the results from the LGSVL Simulator will be shown. With the help of the LGSVL Simulator and the callback function which we implemented in our API-controlled simulation script, we were able to acknowledge the simulation velocity at which the EGO vehicle would crash with the NPC vehicle.

Figure 8 shows the plot of the ego vehicle distance, velocity and the timestamp. Within the velocity range from 28 m/s to 31 m/s the EGO vehicle will crash with the NPC vehicle.

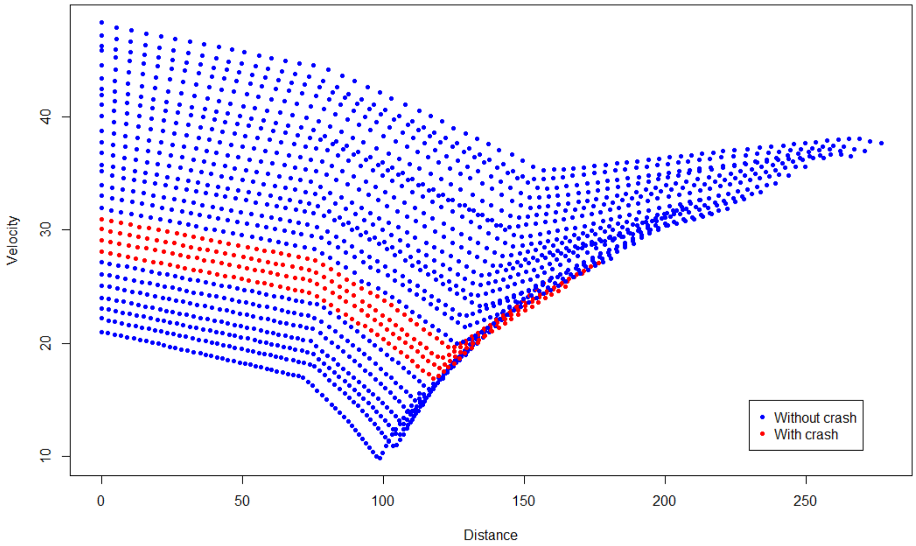

Figure 8: Driving profile of the EGO vehicle during a scenario with an NPC vehicle coming from the left.

The same procedure has been done with the scenario in which the EGO vehicle appears from the right side. The driving profile is similar; however, the crashing velocity shifts to a range within 32 m/s and 36 m/s, which is depicted in Figure 9.

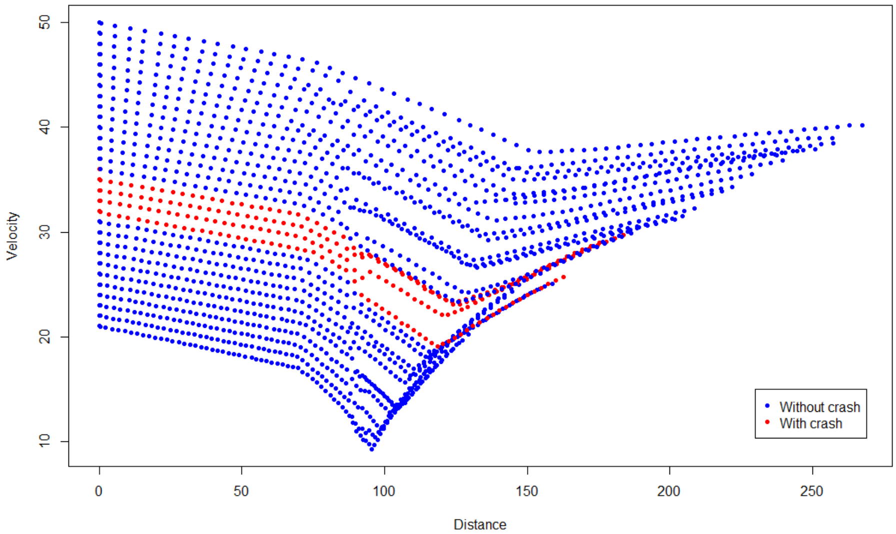

Figure 9: Driving profile of the EGO vehicle during a scenario with an NPC vehicle coming from the right.

3.4 Conclusion from the simulation result

With the simulation of different vehicle velocities and collision detection, it was able to find out the required parameters for the infrastructure to detect collision. As the condition of collision occurrence verifies from both the vehicle velocity and appearance position, the infrastructure should be able to recognize the following parameters:

- Position of EGO vehicle and NPC vehicle depending on the timestamp
- Velocity of EGO vehicle and NPC vehicle depending on the timestamp

And resulting from these two parameters

- the trajectory of the EGO vehicle and other traffic participants
- at least the intention of the EGO vehicle and other traffic participants

should also be estimated by the Infrastructural Traffic Management in order to avoid traffic accidents.

4 Summary and Outlook

The evaluation of the requirements to vehicle sensor support and its results has led to the following requirements should therefore be specified for the infrastructural traffic management:

To begin with, the infrastructural traffic management should be able to analyze the situation environment according to following aspects: Physical values which include velocity, position, acceleration, trajectory, vehicle measurements, HD map and controllable objects (traffic cone, construction site sign, traffic light, intelligent traffic display, etc.), predictive behavior and geometrical consequence (mathematical and simulated).

Furthermore, the guidance of the traffic by suggesting changing the controllable objects' status and the velocity of the AD vehicles and their trajectory is necessary.

Moreover, besides the guidance of the vehicle the infrastructure traffic management should also interact with the traffic participants. This includes the following levels: Warn (Sending warning message to participants), Inform (Send information of objects in the service area to participants), Suggest (Giving behavior suggestions to traffic participants) and control of the vehicles with AD capability.

Finally, the technologies required by the Infrastructural Traffic Management should also be mentioned. Besides intelligent road markings, HD maps and dedicated landmarks also sensor networks which contain not only LiDAR sensors but also cameras and RADARs are required to detect traffic participants precisely.

To meet the requirements mentioned above the importance of standardization and synchronization of the data from all traffic participants and infrastructure is necessary and this task can be resolved by the infrastructure centrally. Consequently, state-of-the-art Car2X Communication is required for a flawless data transfer between the different traffic participants, e.g. to transmit the recorded traffic participant position and trajectory information to the AD vehicle. Additionally, the introduction of a high-precision localization module is required so that the traffic participants and the surroundings can be localized with a high resolution. Finally, the simulation of traffic scene according to the trajectory of traffic participants can also assist the Infrastructural Traffic Management in decision making assisting the AD vehicle.

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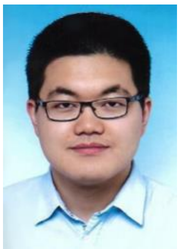

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