# Collective Perception: Impact on Fuel Consumption for Heavy Trucks

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Abstract: With on-board sensor technology, the environment can only be perceived to a limited extent. This can lead to energy-inefficient driving maneuvers due to the late perception of objects. The fuel consumption of heavy trucks is a major cost factor for transport companies, which is why energy-efficient systems are being sought. With collective perception, perceived objects are exchanged via Vehicle-to-Everything (V2X) and merged to a common environment model. Therefore, it is possible to achieve a greater awareness, which allows for improved planning for automated vehicles. In this publication, a system with collective perception and energy-efficient maneuver planning is presented. The functioning of the collective perception is presented using real vehicle data. A vehicle simulation shows the positive effect of collective perception in combination with an energy-efficient maneuver planner for determining the fuel consumption of heavy trucks.

## 1 INTRODUCTION

A number of publications deal with V2X (Lozano Domínguez & Mateo Sanguino, 2019). In addition, there are a large number of projects in the EU dealing with cooperative driving (Botte et al., 2019). The hope is that connected and automated vehicles will make traffic safer in the future (Wang et al., 2020). One problem with today's vehicles is the limited visibility their own local sensor technology provides. First, the range is very limited, e.g., a commercially available LRR4 radar sensor from Robert Bosch GmbH has a maximum range of 250 m (Robert Bosch GmbH, 2014). Second, blind spots can also be caused by vehicles owing to being in the shade, so that objects cannot or very late perceived. Messages have already been designed that use V2X communication, which allows data to be transmitted directly between vehicles. The first series-produced vehicles are already using V2X to exchange warnings, for example, (ADAC e. V., 2020; Rudschies, 2020). However, currently, not all new vehicles can communicate. In addition, automotive companies advocate that in the future autonomous vehicles must be able to drive safely even without V2X (Wood et al., 2019). Therefore, in mixed traffic, vehicles with and without V2X must be assumed in the future. In addition to hazard alarms, collective perception is another way to increase safety using V2X. Here the captured objects are distributed to other vehicles via an object list. The sent objects increase the perception range, because it is now also possible to perceive hidden objects. The simulation has already shown that collective perception increases perception and enhances safety (Günther, 2017).

So far, no experiments with real vehicles and collective perception have been conducted. Furthermore, the effect on fuel consumption is unclear. Fuel consumption is particularly important for heavy trucks in long-distance haulage, since fuel costs account for between approximately 30% and 41% of a forwarding agency's total costs. (Esch & Dahlhaus, 2016; Nowak et al., 2016). In addition, savings in fuel consumption lead to reduced $CO_2$ emissions from internal combustion engines. In view of the global warming caused by the greenhouse effect and its negative consequences for people and the environment (Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit [BMU], 2019; Bunz & Mücke, 2017; Masson-Delmotte, 2018), fuel consumption has a social relevance in addition to its economic significance.



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# 2 RELATED WORKS

## 2.1 Vehicle-to-Everything

Basically, there are two ways to realize V2X. Messages can either be transmitted via a cellular network or directly via an ad-hoc network. An overview of both technologies is given by Weber et al. (2019), Sjoberg et al. (2017), Festag (2015), Naik et al. (2019), Ganesan et al. (2020) and Molina-Masegosa and Gozalvez (2017). Cellular networking such as 5G NR mode 1 distributes messages via mobile radio while ad-hoc networks such as IEEE 802.11p usually use WLAN technology. Cellular networks have the advantage of a theoretically infinite range and messages can be prioritized, thus the channel load can be regulated well. In return, ad-hoc networks have the advantage of operating independent of the mobile network coverage. However, the research question regarding which information is desirable for the realization of driving functions is initially independent of the transmission method.

In Europe, the Cooperative Awareness Message (CAM) (European Telecommunications Standards Institute, 2014a) and Decentralized Environmental Notification Message (DENM) (European Telecommunications Standards Institute, 2014b) are currently specified. The CAM contains information about the current vehicle status, such as position or speed, and is distributed to all surrounding vehicles via broadcast. The DENM is used for broadcasting warnings, such as the presence of black ice. The DENM is only sent when an event occurs and the position is fixed. Unlike the CAM, the DENM is also forwarded from one vehicle to another vehicle, using a multi-hop algorithm to increase the range.

Similar to the standard defined in Europe, the Basic Safety Message (BSM) exists in the USA (Kenney, 2011). Here a distinction is made between Part 1 and Part 2. Part 1 is similar to the CAM and sends the current vehicle status, while Part 2 contains information similar to the DENM. In contrast to the European standard, there is no multi-hop algorithm. The messages are only distributed by broadcast to surrounding vehicles.

## 2.2 Collective Perception and Cooperative Prediction

Cooperative driving can be divided into several levels. A distinction can be made between explicit and implicit communication, as well as according to the utility. Explicit communication refers to the use of V2X and is also referred explicit cooperation. Collective perception is also called cooperative perception and is the cooperative vehicle function with the least utility. With cooperative prediction, driving planes are distributed in the form of trajectories, which eliminates the need for predicting other vehicles and can improve planning by reducing the uncertainty of a wrong prediction. The highest levels of cooperative driving are negotiating a common driving strategy and collaborative maneuver planning (Burger et al., 2017). However, of all the cooperative levels, collective perception is the only method that is explicitly designed for mixed traffic involving V2X and non-V2X road users.

In the Technical Report 103 562 of the European Telecommunications Standards Institute (2019), it has been shown that collective perception can increase awareness. In addition, it has been shown in various scenarios that collective perception increases the time-to-collision compared to a local environment model (Eiermann et al., 2020; Günther, 2017). Allig and Wanielik (2019), Delooz and Festag (2019 - 2019) and Thandavarayan et al. (2019) presented possibilities for reducing the channel load, so that information can be exchanged reliably even during high traffic density. Currently, the Collective Perception Service and thus the Collective Perception Message (CPM) are defined as a standard (European Telecommunications Standards Institute, 2020a). The CPM contains all necessary information for creating a common environment model. If objects are measured in vehicle coordinates relative to the own position, then in addition to the object list, a reference object with the absolute position is also necessary.

In addition to CPM, the Maneuver Coordination Service and the corresponding Maneuver Coordination Message (MCM) are currently being defined as a standard (European Telecommunications Standards Institute, 2020b). With this message, cooperative maneuvers can be coordinated via trajectory exchange, for example, by implementing the concept of planned and desired trajectories (Lehmann et al., 2018). However, only by sending the own plan in the form of a trajectory without of any other information, it is also possible to represent a cooperative prediction.

# 3 SYSTEM OVERVIEW

Figure 1 shows an overview of the overall system. The local and global perception module, the road model and road API, the visualization and the COM module are implementations of the IMAGinE project. The IMAGinE project aims at developing cooperative driving functions (European Center for Information and Communication Technologies (EICT) GmbH, 2017). The road model defined in IMAGinE describes the roads in frenet coordinates. Road information can be accessed through an API by all modules. Also, a library for handling collision checks is available. The visualization represents objects and roads, and is only used for visual monitoring. The COM module is the software interface to the communication unit. The desired driving action, which includes coasting advise and a calculated trajectory is published by the planning module. The controller translates the output into control signals, such as desired acceleration $a_{desire}$ or steering wheel angle $\delta_{desire}$ and passes on to the actuators. In the following, the perception modules and the planner for the energy-efficient trajectory calculation are described in more detail.

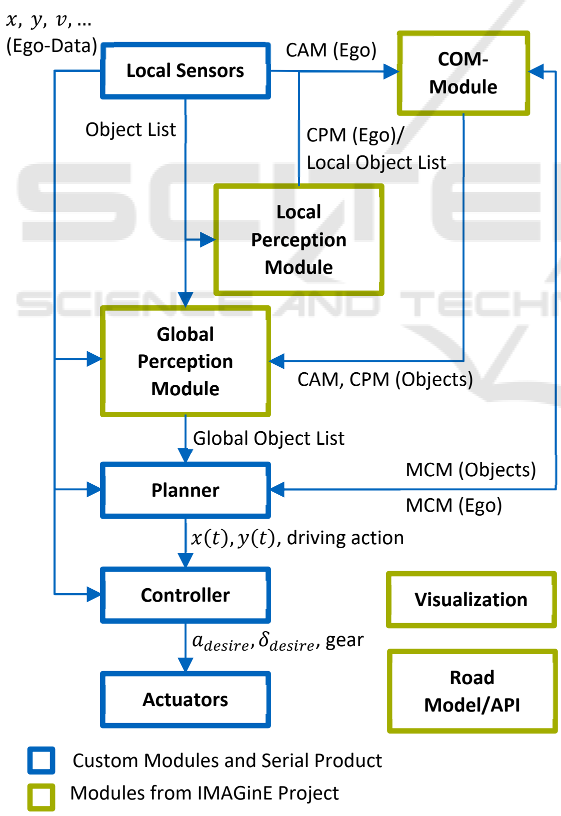


Figure 1: System overview.

## 3.1 Cooperative Perception

The vehicle detects objects with its sensor system. The list of perceived objects is passed on to the local object fusion. The local perception module assigns each object to an existing track or creates a new track. A new track is created if the object state differs too much from a tracks state. In addition, the objects are predicted, which is necessary to keep objects that are not recognized for a short time in the environment model. The local fusion object list is sent to other surrounding road users via CPM. Since the object states are expressed in relative coordinates to the sender vehicle, the ego-vehicle is also sent as a reference object, which contains the absolute position. In addition, all necessary data for the CAM is determined from the acquired ego-vehicle.


Figure 2: Cooperative trucks form IMAGinE project.

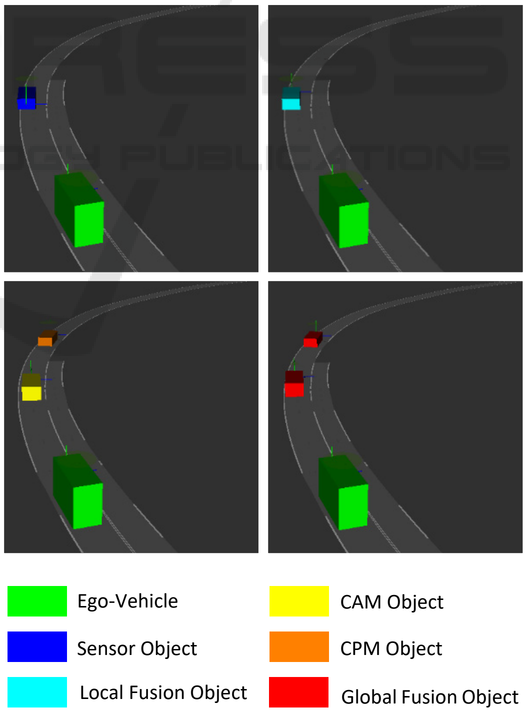


Figure 3: Two cooperative trucks following one non-cooperative vehicle. Perception from following truck on the same time and different data types are displayed.

The global perception module uses the ego-data and the objects from the ego-sensors to provide objects with absolute positions as input. In addition, the received objects via CAM and CPM are used as further input variables. The objects are assigned to existing tracks or new tracks are created and additionally predicted into the future in the same way as in the local fusion. The output is a global object list which is used by the planner.

Within the IMAGinE project, two cooperative test vehicles were set up at MAN Truck & Bus SE, which are shown in Figure 2. Figure 3 shows how collective perception works in an actual vehicle. Two cooperative trucks follow a non-cooperative vehicle, which is detected by the second truck with the local sensor system. The locally fused object is sent via V2X to the rear truck. In contrast to the local environment model, the rear truck perceives two instead of only one object with the collective perception.

## 3.2 Maneuver Planning

Figure 4 gives an overview of the planner. The planner gets the global object list from the global perception module as input. For cooperative vehicles, additional trajectories are received over V2X by the COM module as MCM, thus the behavior of these vehicles is known. Non-cooperative vehicles do not send any information via V2X, therefore, their driving behavior is predicted in the first step. It is assumed that they continue to move at constant speed.

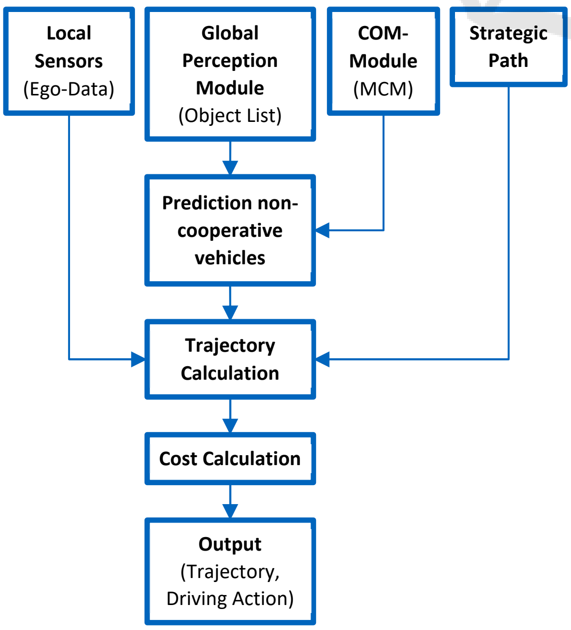


Figure 4: Maneuver Planning.

In the second step, possible trajectories for the ego-vehicle are calculated. The present investigation does not require complex trajectory calculation, but it is important that alternative trajectories are calculated, which also include energy-efficient trajectories in the form of coasting maneuvers. A previously defined path defines the strategic decision of the target and the route. Starting from the current position, the upcoming path section is linked to a velocity profile. By defining the velocity to the position and describing the initial state, a fully described movement in space over time is given, which corresponds to the definition of a trajectory (Biagiotti & Melchiorri, 2009). The velocity profiles represent either constant accelerations (Equation 1) or coasting maneuvers with open clutch (Equation 2).

$$v(t) = a * t + v_0 \tag{1}$$

$$v(t) = q_0 + q_1 * t + q_2 * t^2 + q_3 * t^3 \tag{2}$$

Here $a$ is a constant acceleration. $v$ represents velocity and $t$ time. The constants $q_0$, $q_1$, $q_2$ and $q_3$ are determined from a coasting test where $q_0$ is identical to the corresponding initial velocity $v_0$ of the test 80 km/h. The coefficients $q_1$, $q_2$ and $q_3$ are dependent on mass. Table 1 shows the driving maneuvers considered in this paper.

Table 1: Overview of velocity equations and the corresponding parameter for the considered maneuvers. Equation 1 describes linear motion, equation 2 describes non-linear motion (3rd degree polynomial).

| Maneuver | Eq. | Parameters |
|---|---|---|
| Cruising | 1 | $a = 0\frac{m}{s^2}$ |
| Acceleration | 1 | $a = 1\frac{m}{s^2}$ |
| Slight Deceleration | 1 | $a = -1\frac{m}{s^2}$ |
| Deceleration | 1 | $a = -2\frac{m}{s^2}$ |
| Strong Deceleration | 1 | $a = -3\frac{m}{s^2}$ |
| Coasting (mass 7 t) | 2 | $q_1 = -0.2355\frac{m}{s^2}$, $q_2 = 9.3027 * 10^{-4}\frac{m}{s^3}$, $q_3 = -2.0612 * 10^{-6}\frac{m}{s^4}$ |
| Coasting (mass 40 t) | 2 | $q_1 = -0.1446\frac{m}{s^2}$, $q_2 = 2.5459 * 10^{-4}\frac{m}{s^3}$, $q_3 = -3.1443 * 10^{-7}\frac{m}{s^4}$ |

During the acceleration maneuver, speed is limited by the maximum allowed speed on the track section. When maximum speed is reached, the maneuver continues with constant velocity. Likewise, during deceleration, the maneuver is limited downward by 0 m/s and the velocity is maintained afterward.

In the following, a collision check is performed. In our work, a collision is understood as a violation of the safety distance. According to the German §4 StVO (Straßenverkehrs-Ordnung (StVO), 2017) law, proper distance must always be maintained so that if the front vehicle suddenly brakes, the vehicle following will be able to either decelerate or stop safely. In addition, the law prescribes further distance requirements, e.g. that a minimum distance of 50 m must be maintained for trucks travelling at speeds above 50 km/h on German freeways, which is not relevant in the present work, since the initial distances are sufficiently large. The safety distance can be defined by the headway. The headway indicates how much time elapses until two following vehicles reach the same point on the road. The recommendations of the countries are not uniform and can be as high as 3 seconds, but for times greater than 2 seconds, a safe distance can be assumed (Mahmud et al., 2017). Headway is not calculable during standstill, which is why a minimum distance $d_{min}$ with 10 m is defined. In this paper, the collision is defined as follows:

$$d < \max\left(v * t_{collision}, d_{min}\right) \quad (3)$$

with

$$d = x_{leading} - x - l_{leading} \quad (4)$$

$x_{leading}$ and $l_{leading}$ state the position and length of the front vehicle. $x$ is the position along a lane of the relevant following vehicle and $d$ is the corresponding distance to the front vehicle. The ITS-G5 reference point for the position is used, it is indicated as the front center bumper projected on the ground (European Telecommunications Standards Institute, 2014a). $v$ is the current speed and $t_{collision}$ is the desired time interval. Derived from the headway, 2 secs are selected for $t_{collision}$.

Table 2: Maneuver costs.

| Maneuver | Maneuver Costs (Priority) |
|---|---|
| Cruising | 1 |
| Acceleration | 0 |
| Slight Deceleration | 3 |
| Deceleration | 4 |
| Strong Deceleration | 5 |
| Coasting | 2 |

Next, the collision free trajectories are charged with costs. The costs are determined based on the maneuver, which represents a prioritization of the maneuvers. Table 2 shows the allocation between maneuver and costs. The collision-free trajectory with the lowest costs is set as the output trajectory. This is passed on to the controller and sent as an MCM to other road users.

# 4 SIMULATIVE EVALUATION

## 4.1 Simulation Environment

The code for the function logic is written in C++ and integrated in the Framework Robot Operating System (ROS). Ubuntu 16.04 was used as the operating system and the corresponding ROS version ROS Kinetic. By using the ROS Framework, it is possible to use the same implementation in the simulation as in the real vehicle. The real-time vehicle simulation TruckMaker 7.1 has been extended within the IMAGinE project of IPG. On the one hand, an interface to ROS was created and on the other hand, the extension SimNet allows the detailed simulation of several ego-vehicles (An & Specka, 2019). V2X communication is simulated by exchanging ROS topics, which corresponds to communication without packet loss. A typical tractor-trailer combination used in long-distance traffic in Europe was selected to act as the truck. Based on a demo vehicle with a 353 kW engine available in TruckMaker, a 12-speed transmission according to Fries (2019) and Wolff (2016) was added, which is typically used in long-distance traffic. For the investigations, two trucks with two different sensor setups are available (Figure 5). The ranges and beam angles for the long-distance range are based on the radar sensors described by Baek et al. (2020). The radar sensor for the short range is specified according to A.D.C. GmbH (2017).

The simulation is based on a perfect sensor model in which all state variables are known for perceived objects, e.g. the length of the vehicle, which real radar sensors cannot measure.

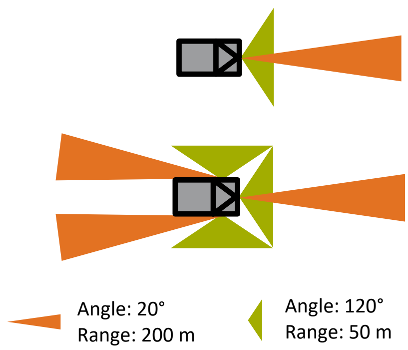


Figure 5: Sensor setups in the semi in top view. Top: only front sensor. Bottom: round view.

## 4.2 Scenarios

The optimal driving strategy can be driven without traffic. Only when other road users claim driving space for themselves do they need to adjust their driving strategy. Through cooperation, these scenarios can be solved better than without cooperation. Ulbrich et al. (2015) has classified and presented various cooperative scenarios. Most of the scenarios are associated with lane changes or intersections. In (Rudschies, 2020) the cooperative scenario, stops are also mentioned. When investigating the impact on fuel consumption, only those scenarios are relevant where it can be expected that using a global environment model will show less fuel consumption. Improvements regarding fuel consumption are mainly expected by avoiding braking followed by an acceleration to the desired velocity or by performing coasting maneuvers instead of cruising with an injecting internal consumption engine. Often these scenarios are equivalent to the improvement owing to early detection of obstacles or conflict situations. Based on this, five scenarios were derived, which are shown in Figure 6. In all scenarios, cooperative vehicles forward their detected objects via the CPM and communicate their driving behavior to other vehicles via the MCM.

In the first scenario, stopping before a traffic jam, there is a stationary vehicle on the road. Two cooperative trucks drive toward the vehicle. The first cooperative vehicle perceives the stationary vehicle based solely on its own sensors, whereas the second cooperative can use the information from both CPM and MCM.

Scenario two, stopping before a traffic jam and departing, is similar to scenario one. However, in contrast to scenario one, the first cooperative vehicle drives past the stationary vehicle and takes a different route than the last vehicle. In contrast to scenario one, where the last vehicle could also only react to the first cooperative vehicle, here the non-communicating stationary vehicle is most relevant.

In the third scenario, merging before a traffic jam, a cooperative truck wants to merge into a lane. At the end of the lane he is merging into, there is a stationary vehicle. Another cooperative truck is driving in the same lane as the stationary vehicle and can detect it earlier than the vehicle that is planning to merge.

The fourth scenario, merging with conflict, is similar to the third scenario. A cooperative truck follows a non-cooperative vehicle in a lane. A further cooperative truck wants to change to the lane of the non-cooperative vehicle. The lane change is conflictual, i.e., the merging vehicle is not allowed to change lanes. Owing to the collective environment, this conflict is able to be detected earlier.

In the last scenario, turning left with oncoming traffic, a cooperative truck wants to turn left at an intersection while the cooperative truck in front continues straight ahead. The cooperative truck is approached by an opposing non-cooperative vehicle, so that this vehicle must first be let through. The environment model allows earlier detection of the fact that an immediate turn is not possible.

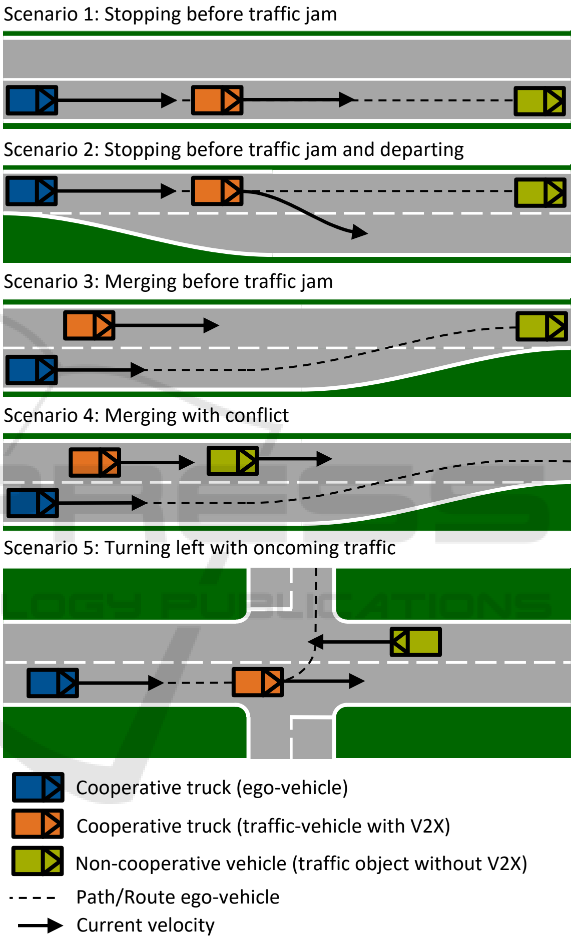


Figure 6: Schematic representation of investigated scenarios.

Table 3 shows the examined variations. The distance, the total mass and the sensor configuration are varied. The start distance between the two cooperative vehicles is based on the ranges for communication. Actual tests have shown a maximum range of 700 m when using IEEE 802.11p (Almeida et al., 2018). Mertens et al. (2020) describes 400 m as the feasible range for trucks using IEEE 802.11p in direct vision. If the range is less than 200 m, then detection using commercially available radar sensors is already possible, which is why this is chosen as the minimum distance for the variations. The total mass is varied by the use of a semi-trailer, resulting in total masses of 7 or 40 t. 40 t, which corresponds to the German §34 StVZO law regulating the maximum permissible total mass (Straßenverkehrs-Zulassungs-Ordnung (StVZO), 2017).

For the investigations, the planner is operated with the local object list from the local perception module instead of the global object list as the reference scenario for each variant. This enables a comparison between global and local environment models.

Table 3: Variations for scenarios.

| Scenario | Trailer | Vehicle Distance | Sensor Setup |
|---|---|---|---|
| 1 | No, Yes | 200 m, 400 m, 700 m | Front |
| 2 | No, Yes | 200 m, 400 m, 700 m | Front |
| 3 | No, Yes | - | Front |
| 4 | No, Yes | - | Front, Round View |
| 5 | No, Yes | 200 m, 400 m, 700 m | Front |

## 4.3 Results

In section 1, fuel costs are mentioned as the largest part of the total cost of ownership for freight forwarders. In addition, the reduction of fuel consumption is beneficial for the environment. Based on this, absolute fuel consumption is the most important evaluation parameter. Only the ego-vehicle, which benefits from the transmission of the CPM, is considered in the following. In the scenarios presented, the other cooperative vehicle only serves to transmit the sensor data. This vehicle cannot benefit from the V2X data and drives the same trajectory both in the scenarios with and without cooperation, which is why the fuel consumption is identical in each case and therefore does not need to be considered.

Figure 7 shows the velocity profiles of the first scenario with collective perception as a function of distance, and the velocity profile when using the local environment model is also shown. It is recognizable that the farther the distance or the communication range is, the earlier a coasting maneuver can be initiated and the longer the coasting maneuver is. Figure 8 shows the fuel consumption. The longer the coasting maneuver is, the greater the benefit of the environment model. Also visible, the larger the mass is, the greater the reduction in fuel consumption.

In scenario two, the velocity profiles (Figure 9) show a different behavior, although the reason for the necessary deceleration, a stationary vehicle, is the same. The front cooperative vehicle leaves the lane and therefore only the stationary vehicle is relevant for the collision check. The cooperative vehicle sends a CPM as long as the stationary vehicle is detected by its own sensors. After the lane change, the object is no longer within the range of vision of the sensors and is therefore no longer detected. Objects are further predicted over a horizon of 2 seconds after the last CPM has been received. If the distance between objects is great, a roll maneuver is initiated and continued until the object is removed from the global environment model owing to a lack of new information. The vehicle then accelerates to the desired speed again and brakes only when the vehicle is perceived by its own sensors. Consequently, fuel consumption at the distances 400 and 700 m is much higher than at 200 m where acceleration to the desired speed is not necessary (Figure 10).

In the scenario merging in front of the beginning of a traffic jam, the velocity profiles (Figure 11) show that with collective perception, a coasting maneuver is performed before the necessary braking is performed. Reducing fuel consumption also depends on the total mass (Figure 12).

The velocity profiles in scenario four, merging with conflict, show that a conflict cannot be avoided with a local environment model and only front sensors, since the speed is not adjusted here (Figure 13). With extended local environment sensors, the vehicle brakes to 5 m/s, whereas with collective perception less speed reduction is necessary. Again, Figure 14 shows a significant improvement in fuel consumption when using collective perception.

In the last scenario, turning left with oncoming traffic, the velocity profiles (Figure 15) show similar behavior with and without collective perception. In all variants, braking must be applied up to the maximum permissible curve speed. Braking cannot be avoided with collective perception. Avoiding braking to a standstill has little effect on fuel consumption. Likewise, higher communication ranges or greater distances have no effect on fuel consumption (Figure 16). Differences in fuel consumption are mainly due to the non-deterministic behavior of ROS.

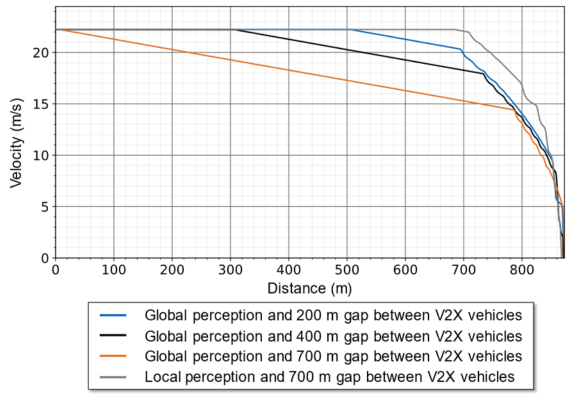


Figure 7: Velocity profiles of the first scenario, stopping behind traffic jam.

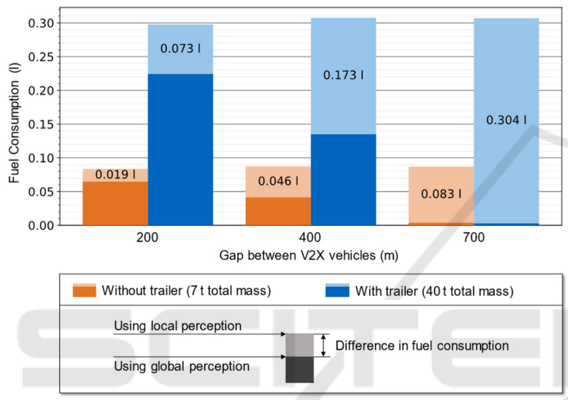


Figure 8: Fuel consumption of the first scenario, stopping behind traffic jam.

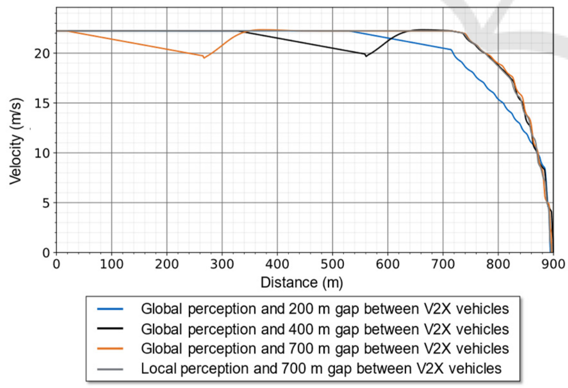


Figure 9: Velocity profiles of the second scenario, stopping before traffic jam and departing.

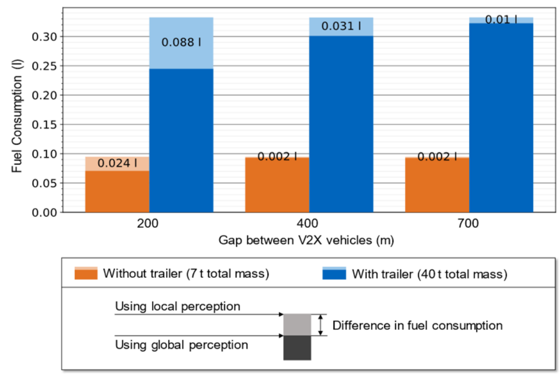


Figure 10: Fuel consumption of the second scenario, stopping before traffic jam and departing.

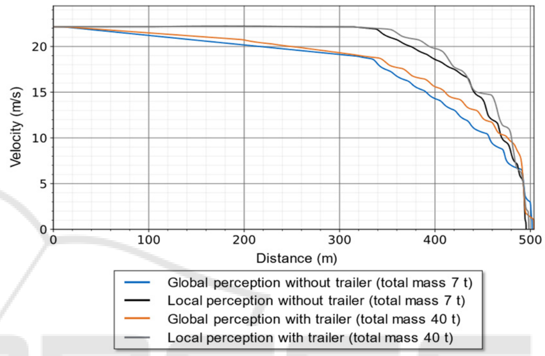


Figure 11: Velocity profiles of the third scenario, merging before traffic jam.

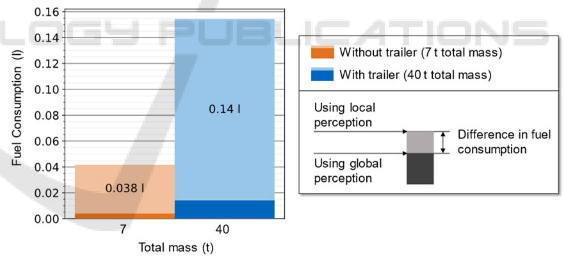


Figure 12: Fuel consumption of the third scenario, merging before traffic jam.

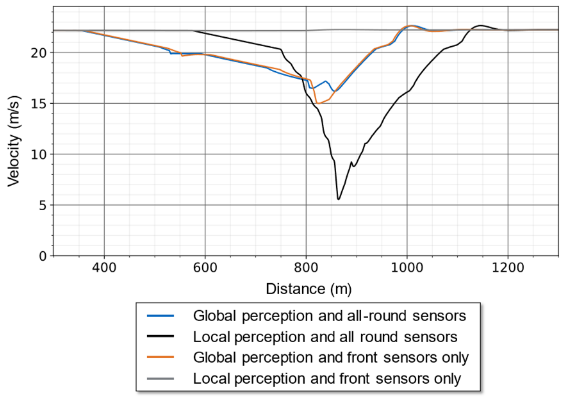


Figure 13: Velocity profiles of the fourth scenario, merging with conflict.

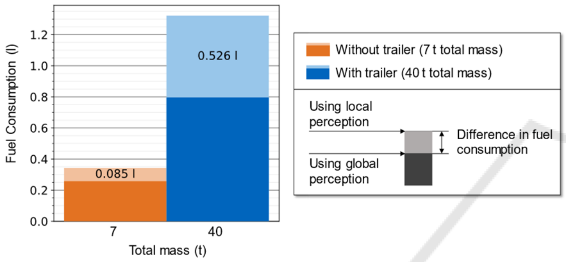


Figure 14: Fuel consumption of the fourth scenario, merging with conflict. Sensor setup round view.

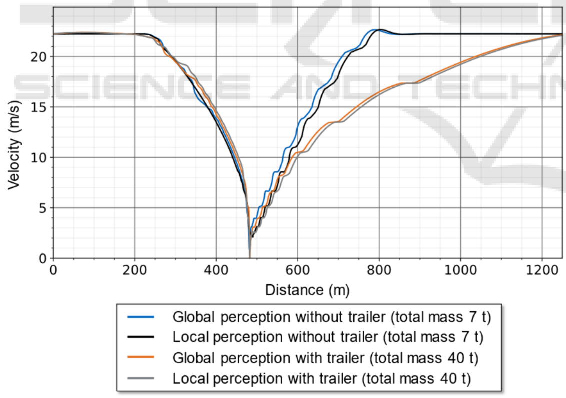


Figure 15: Velocity profiles of the fifth scenario, turning left with oncoming traffic.

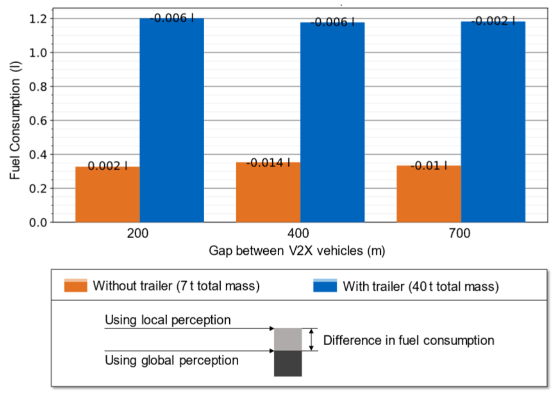


Figure 16: Fuel consumption of the fifth scenario, turning left with oncoming traffic.

# 5 DISCUSSION

The benefit of the global environment model in individual situations was shown in the previous section. However, the benefit for forwarding agents depends on the frequency of the situations. Therefore, a detailed analysis for the occurrence of situations in the daily routine of long-distance haulage is necessary. Problematic here is the complex data acquisition of sensor values, which is however necessary, so that these can be used for the global environment model and thus the analysis in the follow-up. In addition, storing large amounts of data is a challenge.

Various parameters can be set for the environment model, e.g. the lifetime of the objects if no sensor detects them anymore. If objects are discarded at an early stage, it is possible that a vehicle can stop driving in a fuel-efficient manner as in scenario 2. Predicting objects for a very long time can lead to unrealistic driving behavior. In (Schubert et al., 2008), for example, the assumption that vehicles continue to move with constant acceleration is considered a valid approach, but in practice it may be that the object can leave the road or the driving lane if the prediction is long, especially when cornering (Figure 17). More complex models may be able to predict objects better, e.g. by map matching onto the road. However, under certain circumstances a large number of objects must be predicted, which can lead to computational time problems.

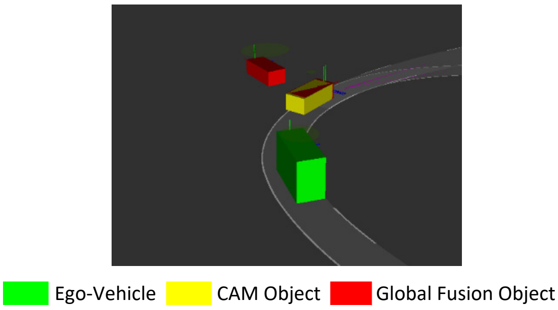


Figure 17: Long prediction with object leaving road.

The range of the communication has little meaning for the benefit of the collective perception if the distance to the received object in the CPM is significantly larger than the sensor range and at the same time the prediction time of the objects is very short. This is particularly clear in scenario 2, where a meaningful coasting process is interrupted again after the end of the prediction period.

Despite higher awareness, the collective perception cannot lead to lower fuel consumption in every scenario. For example, when turning left in the face of oncoming traffic, it is necessary to decelerate to the maximum possible curve speed, which is close to zero anyway.

## 6 CONCLUSIONS

In the presented paper, the benefits of collective perception on fuel consumption were shown. A system architecture with collective perception, cooperative prediction and a maneuver planner that allows energy-efficient driving was presented. The correct functioning of the collective perception was proven by simulations and real-world tests. In the simulative evaluation, up to 0.526 l fuel could be saved in individual situations. The analysis showed that especially heavy trucks with high mass benefit from the collective perception. In addition, it was shown that a long prediction after which objects are no longer perceived is a decisive factor for saving fuel.

In future work, the simulative results regarding fuel consumption with collective perception will be confirmed in actual tests. Two cooperative trucks and a test track are available for this purpose. According to Burger et al. (2017), negotiated and collaborative maneuver planning offer the greatest utility in cooperative driving. Therefore, in the following investigations, cooperative maneuver planning with trajectories and their effect on fuel consumption will be investigated in simulation as well as in real-world tests.

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## CONTRIBUTIONS

As first and corresponding author, Juergen Hauenstein initiated the paper, wrote the original draft, defined the approach and contributed the main parts of the conceptualization, methodology and investigation goals. Jakob Gromer integrated the perception modules, developed the planner module with interfaces and evaluated the concept as a part of his master thesis. Jakob Gromer contributed to the conceptualization, methodology and investigation. Jan Cedric Mertens contributed to driving tests related to the collective perception and supported the methodology with discussions and insights. Frank Diermeyer and Sven Kraus contributed to the concept of the research project and revised the paper for intellectual content. Frank Diermeyer and Sven Kraus gave final approval for the version to be published and agree to all aspects of the work. As a guarantor, Frank Diermeyer accepts responsibility for the overall integrity of the paper.

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