Cooperative Longitudinal Control for Commercial Vehicles

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***Abstract*— Increasing traffic is likely to make cooperation more and more necessary in the future. Further fuel efficiency is very important for commercial vehicles, because of the high proportion of total vehicle ownership costs that are made up of fuel costs. Vehicle-to-Everything (V2X) communication enables new opportunities for automated driving, e.g. collaborative driving, instead of selfish driving. This paper combines cooperative and fuel-efficient driving and proposes an approach for cooperative longitudinal control for commercial vehicles.**

A strategy trajectory ensures a long look-ahead distance, which allows fuel-efficient driving, e.g. allows the vehicle to recognize the optimal start point of a roll maneuver early without high computational power. This long look-ahead preview leads to a fuel-efficient longitudinal control for commercial vehicles. Furthermore, planned and desired trajectories allow cooperation with other road users. Finally, vehicle simulation with a virtual test driving software evaluates the implemented algorithm.

Keywords—cooperative automated driving, Look-Ahead Control, V2X communication, commercial vehicles, heavy trucks

I. INTRODUCTION

In Germany, traffic is increasing every year. The German Federal Motor Transport Authority reported 50.9 million vehicles in 2010 und 57.3 million vehicles in 2019 [1]. This leads to a shortage of traffic space on the roads, as can be seen from the congestion lengths on German highways, which have increased from 400,000 km in 2010 to 1,528,000 km in 2018 [2]. The lack of space makes cooperation indispensable. Today, it is only possible to change lane on a highway if other drivers help. If other road users do not open a gap, changing lanes without violating the safety distance is not possible. Advanced driving assistance systems (ADAS) usually do not consider the desires of other traffic objects. For example, full range adaptive cruise control in line with ISO 22179:2009 [3] can only handle following a traffic object or driving at a desired speed, but not a merging situation, such as driving on highways with a lane change. Thus, ADAS are not cooperative like human drivers, who might allow a gap in traffic for other road users in this situation. Fully automated vehicles would not violate traffic rules. Hence, in the future, cooperation must be a part of high-level automated vehicles.

One important issue for consumers of commercial vehicles like heavy trucks are the fuel costs. The biggest cost element for forwarding agencies are fuel costs. These make up 40.8 % of the total cost of ownership [4]. Without a fuel-efficient system, fully automated trucks are of less interest to customers. In addition, new systems cannot neglect other issues, such as brake wear, due to maintenance costs and the downtime.

However, although systems do already exist that drive energy efficiently, e.g. ACC InnoDrive from Porsche [5], but no system is currently in place that is fully cooperative and energy efficient.

In section II, a short overview of related works is presented. Section III contains the proposed approach for cooperative longitudinal control for commercial vehicles, and section IV shows the results of the evaluation. The results discussed in section V and, finally, section VI give a summary and outlook of this work.

II. RELATED WORK

A. *Longitudinal Control for Commercial Vehicles*

Cruise Control (CC) is the simplest possibility for longitudinal control, but does not consider the topology of the road, for instance. Usually, commercial vehicles are heavy and, therefore, have high kinetic energy when traveling on roads at high velocity. This means braking converts a lot of energy into heat. Avoiding braking can help to save fuel. Using information about road gradients, commercial vehicles can use their high weight to their advantage. Before reaching descent, they can reduce their velocity with a roll maneuver. During the descent, vehicles can accelerate with the gradient force and reach their desired velocity without consuming fuel. A system that uses information about the upcoming topologies is called Look-Ahead Control (LAC). Hellström [6] designed and investigated a LAC for heavy-duty trucks. The algorithm uses the dynamic programming approach. A disadvantage is the high computing power required by the algorithm. Another method by Huber [7] calculates a trajectory for coasting at the current speed for every time step, to generate a velocity profile. Once the velocity reaches the desired speed after the velocity is reduced through driving resistance, then this is the optimal start point for a roll maneuver. The algorithms described cannot make predictions, for future rolling operations. Nevertheless, LACs that use road information are widely used in modern heavy-duty trucks, e.g. EfficientCurise from MAN Truck & Bus SE [8], Predictive Powertrain Control form Daimler AG [9], HI-CRUISE from IVECO MAGIRUS AG [10], I-See from Volvo Trucks [11],

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Optivision from Renault Truck [12], Predictive Cruise Control from DAF Truck N.V. [13] or Opticruise from Scania CV AB [14]. The project results from Virtual Driving Coach [15] shows that roll maneuvers are not useful only on roads with downhill sections, but the system also recognizes roll phases for velocity restrictions like speed limits, curves with a high curvature and roundabouts.

B. *Definition and Levels of Cooperative Driving*

Düring and Pascheka [16] describe cooperative behavior as a knowing and willing behavior aimed to increase utility in several situations. Cooperative driving means vehicles drive with cooperative behavior. Burger et al. [17] categorize cooperative driving as either implicit or explicit communication. Cooperative driving behavior with no communication channels, e.g. changing lane so that another road user can use the lane, works with implicit communication. Explicit communication means using a communication channel that exchanges data between vehicles. The simplest shape of explicit cooperative communication is sharing information, e.g. intention or sensor data. The information can help do make better plans for their own driving strategy. Higher levels of cooperative driving can negotiate cooperative maneuvers, or use collaborative cooperative maneuver planning, which is only possible with explicit communication. Additionally, cooperative maneuver planning is separated between decentralized and centralized maneuver planning [18]. Centralized maneuver planning has a higher instance of coordination of all cooperative vehicles. Decentralized maneuver planning has no master or higher instance; all vehicles have computers with cooperative planner.

C. *Communication*

Usually, communication for vehicle applications uses ad hoc networks. In Europe, the European Telecommunications Standards Institute (ETSI) defines a communication standard that includes some basic messages. The communication standard is based on WiFi and works with 5.9 GHz. [19] The Cooperative Awareness Message (CAM) [20] is the most important message and is intended to share basic information such as the position or velocity of the ego-vehicle. Vehicles send the CAM periodically, depending on the actual vehicle state or situation, at a frequency between 1 and 10 Hz. In addition to the CAM, ETSI has defined the Decentralized Environment Notification Message (DENM) [21]. Events such as ice on the road trigger the DENM and include a fixed position of the event. The message should warn other road users of hazards. The multihop algorithms for this message type extend the range, vehicles forward the message to other road users. [22]

Dedicated Short-Range Communications (DSRC) or IEEE 802.11p is similar to the European standard and is used in the United States. Fifteen message types are defined in SAE J2735. The Basic Safety Message (BSM) is similar to the CAM and may optionally include event data such as hard braking. [23]

Nowadays, the standard messages in ETSI do not define messages for collaborative cooperation or collective perception. These kind of messages are often called Maneuver Coordination Message (MCM) [24, 25] or Collective Perception Message (CPM) [26–28]. Every user must define these messages themselves until a standard is available.

D. *Cooperative Automated Driving System*

Themann et al. [29] demonstrate an advanced ACC, which considers Vehicle-to-Infrastructure (V2I) information. Communication between traffic lights and vehicles makes it possible to plan energy efficient trajectories. It is also possible to consider other traffic objects with Vehicle-to-Vehicle (V2V) communication in the control strategies [30]. Although the system only uses implicit communication, fuel consumption may be reduced by an average of 6 % in a traffic light situation [30].

In the past, many cooperative driving systems that use explicit communication have dealt with platooning. Tsugawa et al. [31] and Bergenhem et al. [32] show the function and important platooning projects. Platooning means driving a short distance in a string formation. Trucks, in particular, use the reduced drag coefficient in platooning to save fuel. The fuel saving depends on the distance between the vehicles. It is not only the truck in the following position that has a reduced drag coefficient, the leading truck also saves fuel, albeit less than the truck in the following position. Usually short distances lead to higher fuel reduction, but very small distances between trucks can lead to less fuel reduction for the truck in the following position because of engine cooling and the additional power that is required by the fan [33]. A field test by DB Schenker with a system from MAN Truck & Bus SE shows fuel reduction between 3 and 4 % [34].

Platooning is a collaborative driving system, but it works only in situations in which vehicles follow other vehicles. There are different ways of implementing cooperative driving vehicles, which work in more situations. Sawade, Schulze and Radusch [35] suggest a Collaborative Maneuver Protocol (CPM). Vehicles have different roles in a situation, e.g. overtaking vehicle and vehicle to overtake. A distributed state machine ensures that every vehicle in this situation has the same understanding of the situation. A maneuver will only take place if all vehicles have the same state. The advantage is the high confidence level, because all vehicles have the same knowledge and the same plan. The main disadvantage is that all possible situations need a distributed state machine.

Lehmann, Gunther and Wolf [24] introduce a continuous approach by sharing planned and desired trajectories. The planned trajectory is the actual driving plan, which takes into account traffic rules. This means right of way rules will be also considered. Normally, planned trajectories are conflict-free. Desired trajectories cross planned trajectories. Other vehicles can recognize the desire and change their planned trajectory. If the planned and desired trajectories are free of conflict, the vehicle with desired trajectory changes the trajectory to a planned trajectory. The advantage of this approach is that it works in all situations with clear traffic rules, but there are also some disadvantages. The problem has an order of $O(m)$. The parameter m describes the received trajectories, which must be compared to all the trajectories generated by the approach itself. This means the concept needs a lot of computational power when traffic is heavy, which could lead a maximum number of other considered road users. Cooperation is only possible if trajectories are crossing. It is not possible to coordinate a platoon, for instance for two vehicles to drive with the same velocity profile and a distance of 500 m on a highway. The trajectories of the two vehicles never cross, but the vehicles are suited to driving in a platoon. Furthermore, computer power limits the trajectory length, because a lot of trajectories need to be calculated with different options. Hence, long look-ahead maneuvers are not possible.

III. COOPERATIVE LONGITUDINAL CONTROL

The approach with planned and desired trajectories offers the greatest benefit, because of the continuous nature of maneuver planning. Additionally, this is a decentralized approach and has the advantage of independence from any higher planning level, which increases the robustness. The disadvantage of limited trajectory length makes the important LAC, which include long roll maneuvers, for instance, for commercial vehicles impossible. To compensate for the disadvantage, an additional level for long-term maneuvers is required. Many projects for autonomous driving use a route as the highest planning level [36], but routes have no information about the time. For cooperation, the information about space and time must be on hand in order to decide whether cooperation is necessary or to start a roll maneuver at the right point, for example. For this reason, an additional strategy trajectory is needed to supplement the planned and desired trajectories, and ensures a long look-ahead distance. Because of the disadvantages of dynamic programming or the algorithms by Huber, a new method for calculating a strategy trajectory is suggested with following properties:

- Driving with maximum speed, without breaking speed limits or exceeding the maximum desired speed of the driver
- Roll maneuver before speed limits, e.g. traffic signs
- Roll maneuver before downhills, which accelerate the vehicle

The assumption that the vehicle will follow a desired route in the right lane allows the lateral dynamic to be neglected, and reduces the problem by one dimension. Fig. 1 gives an overview of the approach, which is described in more detail below.

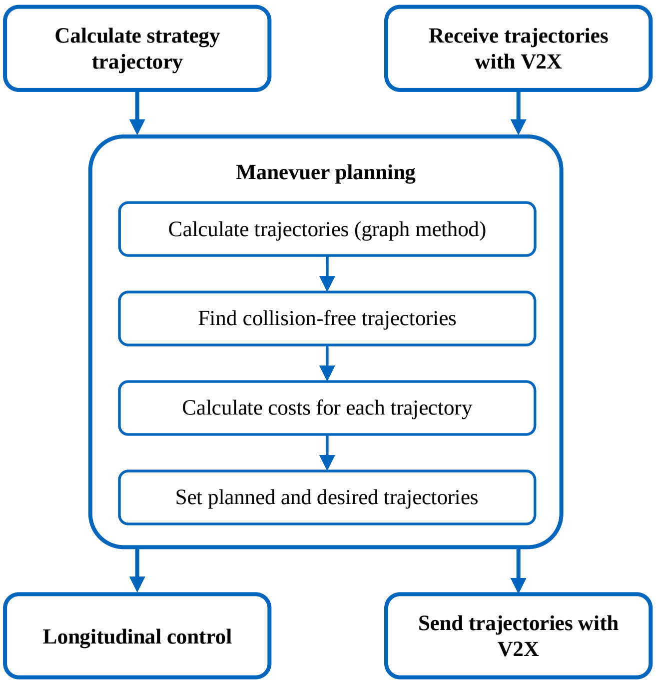

Fig. 1. Overview of cooperative longitudinal control algorithm

A. *Vehicle Model*

A vehicle model for the longitudinal dynamic is necessary for calculating the strategy trajectory. The model is based on driving resistance. Detailed information about driving resistance contains the following literature [37–39].

Equation (1) describes the motion:

$$\sum F = F_\mathrm{R} + F_\mathrm{D} + F_\mathrm{G} + F_\mathrm{E} = ma = m\ddot{x} \tag{1}$$

F_R is the rolling force or resistance, F_D is the drag force or resistance and F_G is the gradient force. These three forces are also known as driving resistance. F_E is the engine force. Equation (2) defines the rolling force:

$$F_\mathrm{R} = c_\mathrm{R} mg \cos\alpha \tag{2}$$

c_R is the rolling coefficient, m is the mass of the vehicle, g is the gravitation coefficient and α is the road gradient. Equation (3) defines the drag resistance:

$$F_\mathrm{D} = \frac{1}{2} c_\mathrm{D} A \rho v^2 \tag{3}$$

c_D is the drag coefficient, A is the front area, ρ is the air density and v is the velocity of the vehicle. Finally, (4) defines the gradient force:

$$F_\mathrm{G} = mg \sin\alpha \tag{4}$$

The equations neglect the gearbox and the acceleration resistance in the powertrain.

B. *Calculation Strategy Trajectory*

The algorithm calculates local trajectories for every section with a constant speed limit. In addition, local deceleration and acceleration trajectories are calculated for changing speed limits and stop points. The local trajectories solve (1). The method connects the local trajectories to a global trajectory. A threshold for the look-ahead horizon limits the length of the strategy trajectory. Only sections above the horizon will be considered.

In sections with a constant speed limit, the vehicle moves at the maximum speed allowed or, if the desired speed of the driver or vehicle is lower than the allowed speed, at the desired speed. Speed limits are road signs, dynamic speed limits, e.g. on highways, events like traffic jams or road construction, road types that limit the speed for vehicle types, curves with high curvature that limit the speed, roundabouts or stop points, such as stop signs. The local trajectory for a constant speed limit starts with the maximum speed and holds the speed. If the engine force is too low, e.g. on uphill sections, the velocity of the vehicle decreases and after the uphill, the vehicle accelerates until the maximum speed is reached. The trajectory is as long as the section with a constant speed limit.

After every speed limit or stop point, the vehicle accelerates with maximum engine force until the maximum allowed speed or the desired speed of the driver or the vehicle is reached. Before the speed limit, commercial vehicles use their high kinetic energy to let the vehicle roll towards the speed limitation. If the gradient force during a period of descent on a road is too high, a roll trajectory cannot be calculated. In this case, a trajectory with constant deceleration replaces the roll trajectory. At stop points, too, the algorithm calculates brake trajectories with constant deceleration. The roll or brake trajectories are calculated backwards from the target speed until the speed reaches the maximum speed of a section or the desired speed.

Before the start of an uphill section, a roll trajectory decelerates the vehicle and accelerates it during the subsequent descent. In this case, a difference in velocity substrate from the maximum allowed speed or the desired speed is set as the target speed at the point the uphill starts. Two roll trajectories are calculated: one forward and one backward from the uphill point. If the roll trajectory is longer as a threshold, the trajectory will be neglected because of the traffic flow.

Fig. 2 gives an example of a road definition. The road has one downhill and one uphill section. In addition, speed limits for trucks are included. Fig. 3 shows the example of the strategy trajectory for the road definition in Fig. 2. There are several possible ways of defining a trajectory. Basically, a trajectory describes the relation between space and time [40]. Usually a trajectory is defined as $x(t)$. Equation (5) derives $x(t)$ after t. The result is the velocity. It is also possible to derive $x(t)$ after x, and the result is the velocity, depending on the way. The integration of the velocity gives $x(t)$ again, but the start state must be known (7).

$$v(t) = v_t = v = \dot{x} = \frac{\partial}{\partial t}x(t) \tag{5}$$

$$v(x) = v_x = \frac{\partial}{\partial x}x(t) \tag{6}$$

$$x(t) = \int v_t dt + v_{t0} = \int v_x dx + v_{x0} \tag{7}$$

It is easier to interpret $v(x)$, therefore the following figures present $v(x)$ for the trajectories. Fig. 4 shows the local trajectories and the resulting strategy trajectory. Furthermore, the figure also displays the speed limits for the strategy trajectory.

C. Maneuver Planning

The first step is to calculate the strategy trajectory, and the second step is to calculate variants of trajectories. There are several ways to generate trajectories [41]; the sole requirement is that a choice must be given between different trajectories. Fig. 5 shows possible trajectories with the start point at 7,400 m and the velocity 70 km/h. When x is 7,500 m, the speed limit changes from 80 to 60 km/h. The trajectories are generated using a graph method, by which a driving action is selected at each node. The five driving actions are accelerate, hold speed, roll vehicle, smooth decelerate and hard decelerate. Conditions such as that trajectories must not violate speed limits or a maximum number of driving actions additionally limit the number of trajectories.

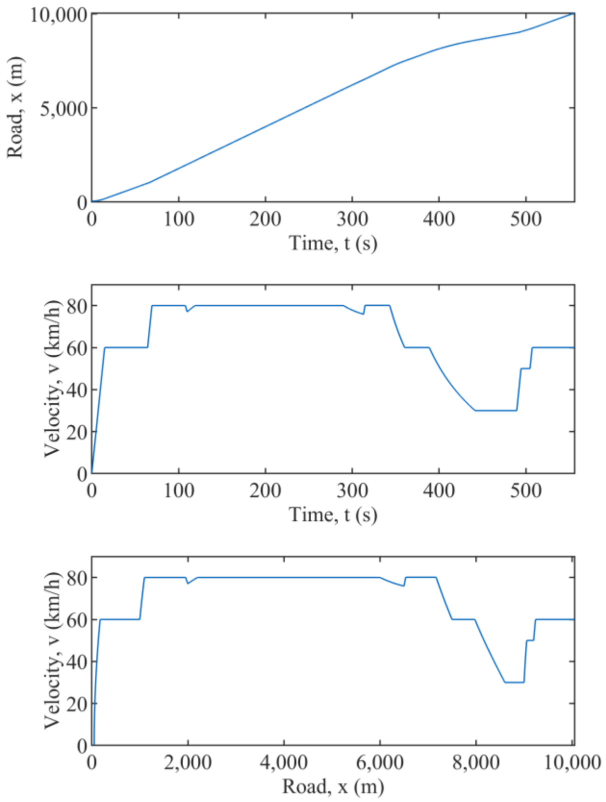

Fig. 3. Example of a strategy trajectroy with three different describtions $x(t)$, $v(t)$ and $v(x)$

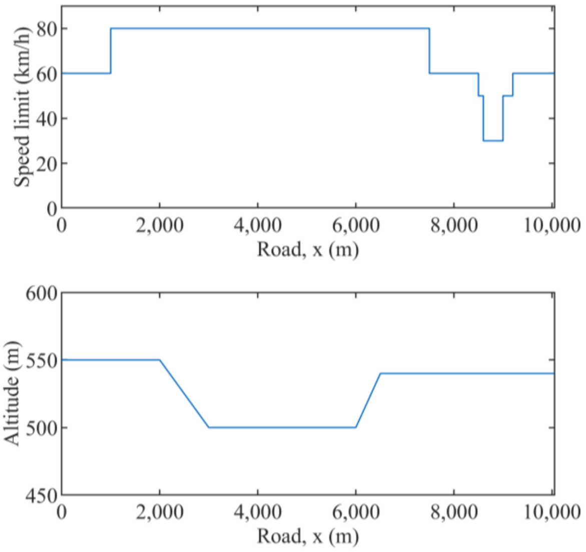

Fig. 2. Example for a road definition with speed limits, descending and ascending slope

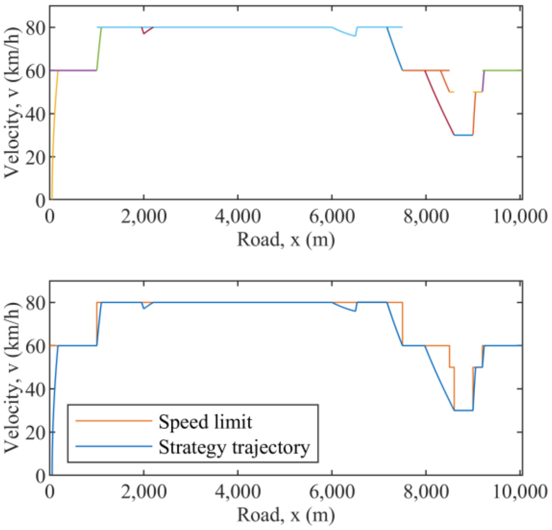

Fig. 4. Example of 15 local trajectories for a strategy trajectory and the resulting strategy trajecotroy with speed limits

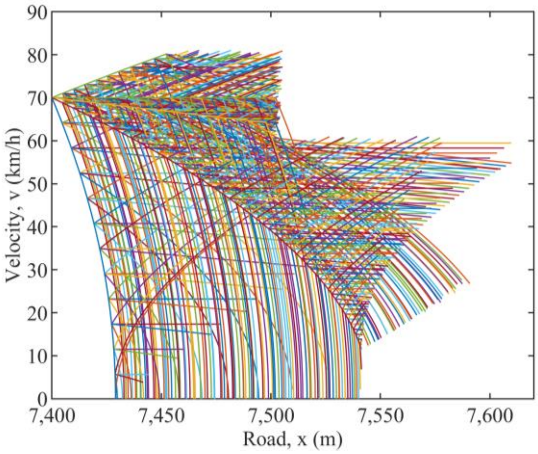

Fig. 5. Example of calculated possible trajectories for the next planned and desired trajectories with changing speed limit from 80 to 60 km/h at 7,500 m

The next step is to perform a collision check with the trajectories received from other road users. The collision check also checks the safety distance for German roads, e.g. 50 m for heavy trucks on German highways, if they drive faster than 50 km/h [42]. The algorithm searches collision-free trajectories between the planned trajectories of other road users and the calculated trajectories. In addition, the algorithm searches collision-free trajectories between the desired trajectories of other road users and the calculated trajectories.

A cost function evaluates each trajectory. Equation (8) describes the cost function. Equations (9)-(11) are restrictions. The costs are the sum of defined single costs for desired properties. The restrictions are not necessary, but they allow a simple assessment of the relationships between the individual factors.

$$Cost_{Trajectory} = \sum w_i Cost_i \tag{8}$$

$$\sum w_i = 1 \tag{9}$$

$$w_i \in [0,1] \tag{10}$$

$$Cost_i \in [0,1] \tag{11}$$

In this paper three factors are considered: the similarity to the strategy trajectory, the driving cost and the length of the trajectory. The similarity to the strategy trajectory enables a long look-ahead distance. For example, a roll maneuver could have a length of several kilometers, but the trajectories are only hundreds of meters long. When the trajectory is similar to the strategy trajectory, the algorithm can recognize the optimal start for a roll maneuver. Furthermore, the similarity to the strategy trajectory ensures that the vehicle is traveling at an appropriate velocity. The similarity is calculated by sampling the trajectory and calculating the distance at each time stamp. Finally, the costs are added up and normalized to 0 and 1. The driving costs are the sum of each driving action. Table I shows the cost factors for each driving action. The cost factors take into account energy, and wear on the brakes. In commercial vehicles, brakes with low deceleration are applied by braking with the retarder. This auxiliary brake has no wear. The last cost factor prefers trajectories calculated over a long period. This factor provides better cooperation through long trajectories.

TABLE I. COST FACTORS FOR DRIVING ACTIONS

Accelerate	**Hold speed**	**Roll**	**Smooth deceleration**	**Hard deceleration**
0.2	0.1	0	0.3	1

Trajectories that enable cooperation are given a bonus. This means a factor is subtracted from the trajectory costs if the trajectory is collision-free to a desired trajectory. The trajectory that has the lowest cost and is collision-free to other planned trajectories will be set as the planned trajectory. If no collision-free trajectories are enabled, the algorithm calculates an emergency trajectory, e.g. emergency brake, which will be set as the planned trajectory. If the trajectory with the best cost is lower than the costs of the chosen planned trajectory with an additional threshold factor, the trajectory is set as the desired trajectory. Finally, the trajectories transmit to the communication and control unit.

D. *Longitudinal Control*

The controller uses the planned trajectory with the additional information about the planned driving actions. The controller outputs are the gas and brake pedal, the retarder stage and the gear. The inputs are the current position, the current time and the planned trajectory. In this paper, the controller neglects the retarder stage and the automatic gearbox sets the gear. If the driving action is a roll maneuver, the outputs gas and brake pedal are zero. For all other situations, a PI controller works. The input for the PI controller is the position error. Positive output values control the gas pedal and negative values control the brake pedal. All output values have saturation conditions.

IV. EVALUATION

A simulation evaluates the concept. The maneuver concept is implemented in the commercial software MATLAB R2018b [43]. The MATLAB-Coder converts the code in C++ and this code is integrated in the Robot Operating System (ROS) Kinetic Kame [44]. The controller is directly implemented in C++ and embedded in ROS. The simulation runs on Ubuntu 16.04.6 LTS (Xenial Xerus) [45]. The vehicle communication is approximated with a specified ROS topic. The ROS topic describes a MCM, which includes the trajectories. Finally, the commercial software TruckMaker with the extensions for a ROS Interface (CMRosIF) and the co-simulation for ego-vehicles (SimNet) simulates the vehicles and the environment [46].

Section I described the lack of space due to increasing traffic and the importance of fuel saving for commercial vehicles. Section II describes roll maneuvers as important factors in fuel-efficient driving, but on the other hand, could not neglect driving time and, thus, the cost to the driver. For these reasons, a traffic jam scenario on a German highway, which includes an accelerating and decelerating phase with roll maneuver, evaluates the concept. Fig. 6 shows the selected scenario with the presented cooperative approach and two trucks with tractor and trailer. The highway is a flat road with a speed limit of 60 km/h over 2,000 m. The speed limit could be a dynamic speed limit or a speed limit before road construction. The leading truck has a total mass of 40,000 kg and the following truck has a total mass of 20,000 kg. Both trucks start at zero velocity and accelerate during the first phase. After that, the trucks maintain the maximum allowed speed of 80 km/h for trucks on German highways [42]. A roll

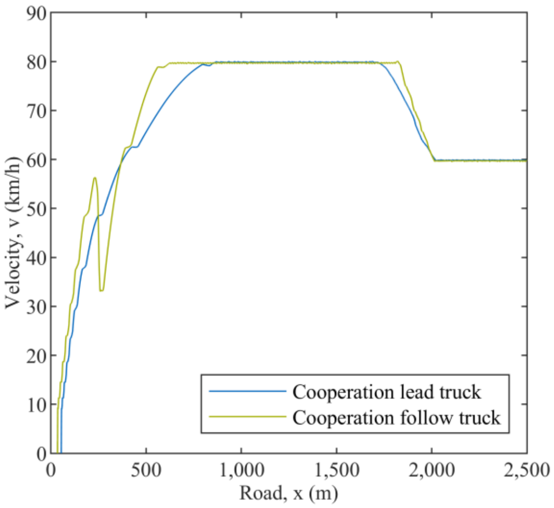

Fig. 6. Velocity profile of two following cooperative trucks on a German highway with a speed limit of 60 km/h at 2,000 m

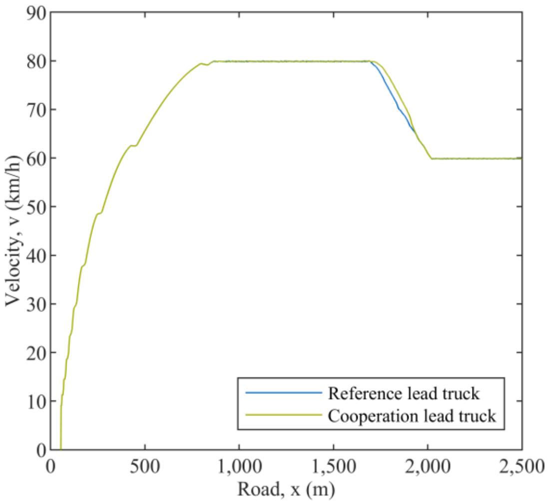

Fig. 7. Velocity profile of the leading truck on a German highway with a speed limit of 60 km/h at 2,000 m

maneuver against a brake maneuver before the speed limit saves fuel. Finally, the trucks maintain the speed. In the acceleration phase, the following truck brakes rapidly for a short period. Above 50 km/h on German highways, a safety distance of 50 m is prescribed for trucks with a mass above 3.5 t [42]. The following truck wants the leading truck to accelerate more quickly, but the leading truck accelerates with maximum power. The following truck brakes to establish the safety distance. Additionally, the gear shifting moments lead to an open clutch and thus an interrupted acceleration. This leads to the step shape of the profile. Finally, a lower roll distance with a lower total mass is presented on the roll phase.

Fig. 7 compares the leading truck in the same scenario with and without cooperative behavior. The cooperative leading truck accepts the desired trajectory of the following truck and rejects its uncooperative strategy. The truck disturbs its roll phase for a short moment, which leads to a later roll phase with short braking moments. The roll maneuver takes approximately 320 m and 17 s, with closed clutch. The duration of the phase is longer than the planned and desired trajectories and is only possible with the strategy trajectory.

V. DISCUSSION

Section IV shows the correct working of the concept with planned, desired and strategy trajectories in one scenario. The scenario consists of only two vehicles, which are able to communicate and show cooperative behavior on a flat road. The topography has a significant influence, especially for roll maneuvers. Alam [47], for instance, describes that roll maneuvers on uphill gradients can lead to inefficient driving when several trucks are in string formation. The vehicles in the scenario are not validated for fuel consumption. Thus, it is not possible to make comprehensive statements about traffic flow or fuel efficiency. Further investigations with validated vehicles, more vehicles and more scenarios are necessary for future research.

The implementation consists of many parameters, e.g. cost factors. In this paper, only one working parameter set is investigated. Optimization of the parameter could lead to better traffic flow or greater fuel efficiency. In addition, improvements in the control system for the longitudinal control, e.g. using the ACC-system controller or using an optimal gear shifting control, can have the same effect. The gear shifting control, in particular, has a big impact on the longitudinal control in commercial vehicles, because of the open clutch and thus the interruption in the engine force. Regaieg [48] shows that an optimal gear shifting strategy is advantageous in following a trajectory more effectively.

The approach needs crossing trajectories for cooperation. Suitable vehicles for a platoon have similar trajectories. Driving two vehicles at the same constant speed, for a constant distance within the communication range on a highway, the trajectories never cross, but the vehicles are suitable to build a platoon. In this situation, an additional system with situation analysis for platooning is necessary.

The concept uses only the strategy trajectory for a long look-ahead distance. The strategy trajectory can also be used for a billing concept for cooperation. It is easy to recognize potential conflict with other road users. Give up the own plan for other traffic users and take additional cost can settle with a billing concept. The difference between the original strategy and the driving trajectory is key in the cost calculation. Furthermore, the strategy trajectory can be used for building platoons with vehicles that have the same dynamic. The similarity of strategy trajectories could be used as an indicator of suitable platooning vehicles.

Llatser et al. [49] introduce a cooperation concept with three trajectory types. The vehicles can send alternative trajectories, which are offers for other vehicles. In addition, every trajectory has its cost, which is also sent to other road users. Compared to the concept with planned and desired trajectories, this concept should lead to faster cooperation decisions. More data leads to larger messages and higher data rates. This reduces the communication range and the packet delivery rate [50]. The simulation in this paper negotiates real communication influences. Further investigation must show the influence of communication and the practical negotiation time for cooperation.

The computational time depends on the number of trajectories. More cooperative vehicles share more trajectories. Thus, the collision check, in particular, takes more time. In situations involving many vehicles, e.g. traffic jams, computing time can explode and communication can collapse due to the large amount of data. There are several ways to reduce the computational power and the data traffic, for instance, data rate can be adjusted to suit the traffic situation or the length of trajectories can be reduced.

VI. CONCLUSION AND OUTLOOK

This work proposed an approach for cooperative longitudinal control for commercial vehicles. The method extends the concept of planned and desired trajectories with a strategy trajectory. The strategy trajectory takes care of the long look-ahead distance that commercial vehicles need for fuel-efficient driving. The paper describes a method for generating a strategy trajectory with local trajectories and how this can be used for cooperative look-ahead control. One simulation scenario with a speed limit evaluates the approach.

In future works, the concept will be used as proof, with more and validated vehicles, in order to make a statement about fuel efficiency. Furthermore, the concept should be extended with lateral control, to ensure that merging situations, for example, are also considered in the algorithm. Clearly, if a cooperative driving system is introduced, not every vehicle will immediately be able to communicate and drive cooperatively. Future research must show work with non-cooperative vehicles. To consider these road users, a driving prediction is necessary. Finally, tests with real vehicles can demonstrate the practicability of the concept in the real world.

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