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Vehicle-to-Vehicle Negotiation via Manoeuvre Coordination Messages for Cooperative Cut-In Scenarios

Author, co-author (Do NOT enter this information. It will be pulled from participant tab in MyTechZone)
Affiliation (Do NOT enter this information. It will be pulled from participant tab in MyTechZone)

Abstract

The automotive industry is rapidly extending the capabilities of automated systems by incorporating connectivity and cooperation features that enable real-time information exchange between vehicles and road infrastructure. Within the Connected, Cooperative, and Automated Mobility (CCAM) framework, Vehicle-to-Vehicle (V2V) communication is expected to play a key role in improving road safety, traffic efficiency, and driving comfort. This work addresses a practical implementation of the standardized Manoeuvre Coordination Messages (MCMs), as defined in the ongoing ETSI standard (ETSI TS 103 561). The proposed approach is demonstrated through a cooperative cut-in use case in which two vehicles negotiate a lane change manoeuvre. In the considered scenario, the ego vehicle, driven by a Highway Pilot (HWP) system, receives the intention to cut-in from a neighbouring cooperative vehicle through an MCM. In response, the ego vehicle adapts its behaviour by decelerating to generate a safe longitudinal gap, which allows the cooperative vehicle to merge the ego's lane. The negotiation process relies on the bidirectional exchange of MCMs to coordinate the timing and trajectories, ensuring both vehicles complete the manoeuvre safely. Additionally, the Cooperative Awareness Messages (CAMs) allow the vehicles to share real-time information such as position, speed and heading. This connected-enhanced approach extends the capabilities of local perception systems, enabling an improved performance and reaction time to surround traffic participants. The described use case is implemented and validated in a prototype vehicle equipped with V2V communication capabilities and a Highway Pilot (HWP) SAE level 3 driving automation system. Proving ground tests demonstrate that the system can successfully negotiate cut-in manoeuvres in real time, enhancing both safety and traffic flow. The results confirm the feasibility of deploying standardized V2V coordination mechanisms within operational automated driving functions and lay the groundwork for broader integration into future CCAM applications.

Introduction

Connected, Cooperative, and Automated Mobility (CCAM) applications are rapidly increasing, driven by the need to create a more user-centred and inclusive mobility system that enhances road safety, reduces congestion, and minimizes environmental footprint. [1].

The development and validation of the HWP prototype has been carried out within the Sunrise project [2], which aims to accelerate a safe deployment of Cooperative, connected and automated mobility (CCAM) systems.

In parallel, Vehicle-to-Everything (V2X) communications are becoming essential for improving the performance of automated driving functions [3, 4]. In this work, a Highway Pilot (HWP) system has been extended with connectivity capabilities, enabling smooth and safe longitudinal control. This communication framework allows the ego vehicle to actively respond to changes in traffic dynamics based on real-time information provided by a connected vehicle. Additionally, a cooperative cut-in manoeuvre is implemented, highlighting the role of connectivity in enabling safe and efficient interaction between vehicles.

Cooperative Intelligent Transportation Systems (C-ITS) and emerging V2X standards are being introduced to enable continuous information exchange between vehicles, extending situational awareness beyond the capabilities of onboard perception systems [5]. Thus, vehicles can anticipate surrounding traffic behaviours earlier, leading to safer and more efficient manoeuvres. This approach proves to be valuable in complex and safety-critical scenarios, such as intersections, roundabouts, driving at high speeds or operating in adverse weather conditions, where quickly and coordinated decisions are crucial to avoid collisions. In this way, cooperation between connected vehicles in such contexts can significantly improve road safety, enhance driving comfort, and increase the efficiency of manoeuvre execution [6].

To achieve these capabilities, collaborative efforts among industry stakeholders and standardization groups are fundamental. In this context, the European Telecommunications Standards Institute (ETSI) has been defining technical specifications for Intelligent Transportation Systems (ITS) messages, such as Cooperative Awareness Messages (CAMs) and Manoeuvre Coordination Messages (MCMs), which are used in this work. While CAMs provide real-time information about vehicle speed, position, and heading, among others, for continuous environment monitoring, MCMs focus on path planning and manoeuvre negotiation between cooperative vehicles. Specifically, this study presents a practical application of the draft ETSI TS 103 561 standard, currently under development. The requirements for MCMs are established, integrating these messages into the communication flow. This standard is the foundation for the approach presented in this paper, which implements MCM-based negotiation for a cooperative cut-in manoeuvre, demonstrating its potential to enhance traffic flow and road safety within the CCAM framework.

Manoeuvre Coordination Messages

The Manoeuvre Coordination Message (MCM) framework, as described in draft standard ETSI TS 103 561, establishes the foundation for cooperative manoeuvre negotiation between connected and automated vehicles. MCMs are transmitted through the Manoeuvre Coordination Service (MCS), a functional element of the ETSI Cooperative ITS architecture, designed to coordinate complex driving actions that involve multiple Intelligent Transport System Stations (ITS-S) [6].

The MCS addresses intrinsic limitations of on-board perception and local planning, such as restricted sensor range, occlusions, complex road geometries, or adverse weather, by enabling direct vehicle-to-vehicle (V2V) communication and, when required, coordination with authorized external entities [8]. This capability supports two main cooperation types:

Agreement Seeking: A negotiation process where an ITS-S sends either an initial request or an initial offer to other relevant ITS-Ss. Each participant retains full authority to accept or reject the proposal.

Prescriptive: Manoeuvre instructions issued by an authorized ITS-S, which must generally be followed unless there is a justified cause to deviate (e.g., safety concerns).

This conceptual framework builds on earlier ETSI message types intended to improve situational awareness, such as Cooperative Awareness Messages (CAM), Decentralized Environmental Notification Messages (DENM), and Vulnerable Road User Awareness Messages (VAM). While those messages primarily share the current state of each ITS-S, MCMs extend this by enabling synchronized, multi-step manoeuvres aimed at improving traffic flow and safety, as highlighted in ETSI TR 103 578 [9] and SAE J3186 [10]. Typical applications range from short-term actions (e.g., lane changes, merging) to longer-term coordinated activities (e.g., vehicle platooning, infrastructure maintenance operations).

Communication takes place over standard ad-hoc local area network profiles (ITS-G5 or C-V2X). All ITS-S within communication range can receive the broadcast MCM, which is then authenticated and checked for relevance, consistency, and plausibility before being passed to the manoeuvre coordination logic. Position and time references are defined according to PoTi [11] when using the World Geodetic System 1984 (WGS84). For passenger cars or vans legally operable with a basic driving licence, the ITS-S position reference corresponds to the ground position at the midpoint of the front bumper.

General Structure of a MCM

An MCM consists of three main components, as represented in Figure 1:

ITS PDU Header: Includes protocol version, message type, and the unique identifier of the originating ITS-S.

Basic Container: Provides manoeuvre-independent data such as timestamp, ITS-S type and role, latest known position, and confidence level.

MCM Container: Holds manoeuvre-specific details, including coordination state (agreement-seeking or prescriptive), involved vehicle IDs, roles, optional trajectories, target resource reservations, ordered sub-manoeuvres, and advisories affecting driving state.

Messages are encoded using ASN.1 PER (Packet Encoding Rules) and may be broadcast, multicast, or unicast depending on the intended recipients. Before being processed by the manoeuvre coordination logic, each MCM is authenticated and verified for relevance, consistency, and plausibility.

This structured approach ensures that all ITS-S involved in a manoeuvre share a consistent understanding of its objectives, participants, timing, and execution details.

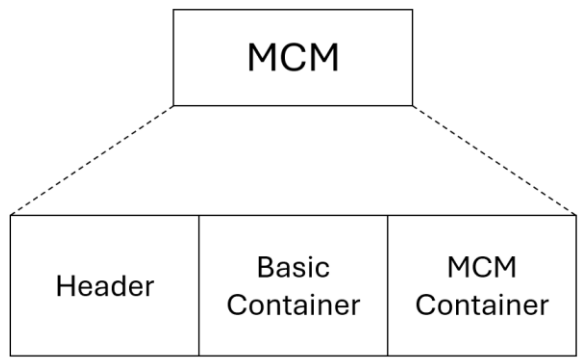

Figure 1 Representation of the high-level structure of an MCM

Event Types in MCM

The ETSI specification defines several message types that can be used depending on the manoeuvre phase and cooperation type, including:

- **Intent (Type 0)**: Announces an intended manoeuvre without initiating coordination.
- **Request (Type 1)**: Formally proposes a manoeuvre to affected participants.
- **Response (Type 2)**: Accepts or rejects a Request.
- **Reservation (Type 3)**: Confirms timing and resource allocation for execution.
- **Termination (Type 4)**: Closes a manoeuvre session (normal or cancelled).
- **Cancellation Request (Type 5)**: Requests to abort a manoeuvre before or during execution.
- **Emergency Reservation (Type 6)**: Allocates priority and space for an emergency manoeuvre.
- **Execution Status (Type 7)**: Updates progress during an ongoing manoeuvre.
- **Offer (Type 8)**: Proposes a manoeuvre as an open invitation to interested participants.

Practical implementation of MCM

To demonstrate the practical application of MCMs and the Manoeuvre Coordination Service, this work implements a cooperative cut-in scenario, a representative short-term collective action on congested highways. This transition from the generic framework to a specific use case makes it possible to evaluate how the defined message types and coordination logic perform under realistic traffic conditions, while focusing only on the subset of functions required for the manoeuvre.

In the scope of this work, only the subset necessary for the cooperative cut-in scenario was implemented, which are: Intent, Request, Response, Execution, Termination and Cancellation messages. These allow negotiation between the two vehicles involved in the manoeuvre without introducing unnecessary protocol complexity.

The following section details the selected scenario, the participating vehicles, the message exchange sequence, and the decision logic that governs manoeuvre negotiation and execution. By narrowing the scope to this targeted example, it becomes possible to validate the protocol's effectiveness in a controlled setting before considering broader applications.

Cooperative Cut-In Use Case

On busy highways, lane changes that lead to a cut-in are a common sight. When traffic is dense or changing quickly, these manoeuvres can easily create conflicts if the surrounding vehicles do not anticipate them. Vehicle-to-vehicle (V2V) communication enables a more coordinated approach, reducing risk and helping traffic to flow more smoothly.

The scenario implemented in this work considers a congested lane where the ego vehicle is travelling, and a cooperative vehicle in the next lane wishes to merge into it. To make space, the ego vehicle reduces its speed until there is a suitable gap. This scenario is a variation of the short-term collective action use cases described in the draft standard ETSI TS 103 561, so the exact scenario is not directly defined there but follows the steps defined in the standard.

The sequence is carried out in four phases, following the general structure of the manoeuvre coordination process shown in Figure 2:

Firstly, the **Awareness State** begins when the cooperative vehicle sends an MCM Intent and signals its intention to change into the ego's lane using the turn indicator.

The ego vehicle determines that the desired trajectory collides with its current path and therefore the **Manoeuvre Negotiation State** begins. The ego vehicle sends an MCM Request to the cooperative vehicle with alternative trajectories for both vehicles that avoid this collision. Based on that alternative proposal, the cooperative vehicle evaluates the trajectories and sends an MCM Response accepting or rejecting it.

If both vehicles agree on their reference trajectories, the **Manoeuvre Execution State** begins. During this state, both vehicles follow the reference trajectory. In this scenario, the reference trajectories consist of the ego vehicle slowing down to create the gap, while the cooperative vehicle waits until there is enough space and then changes lane. Additionally, if either vehicle deviates from its trajectory beyond a defined threshold, the collective manoeuvre is cancelled.

Finally, a **Manoeuvre Termination State** is defined where both vehicles finish their corresponding trajectory and terminate the exchange of MCMs related to the collective manoeuvre.

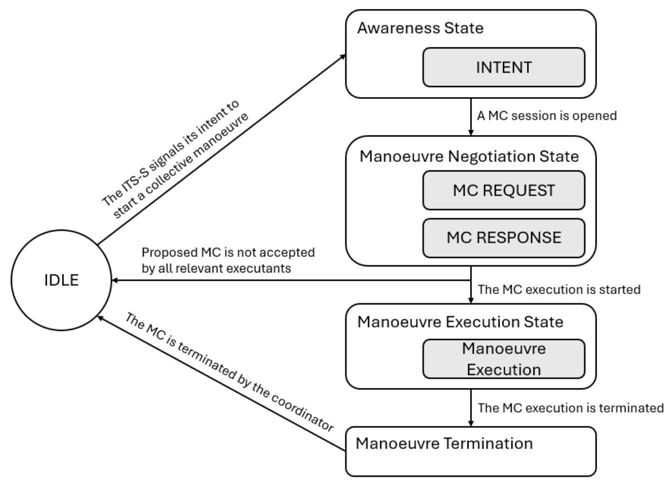

Figure 2 Block diagram representing the states for the consecutive phases of the collective manoeuvre

Scenario Description

As represented in Figure 3, the ego vehicle is travelling at a speed of *v_EGO* on a two-lane straight road with the HWP engaged. It is initially following a vehicle at a distance *d_noCoop*. The non-cooperative vehicle is travelling at a speed of *v_noCoop*.

In the adjacent lane, a cooperative vehicle is driving at a speed of *v_Coop* and at a longitudinal distance *d_Coop* relative to the ego vehicle. The cooperative vehicle broadcasts its intention to perform a lane change, which would conflict with the ego vehicle's planned trajectory.

Upon detecting this conflict, the ego vehicle initiates a negotiation to ensure the manoeuvre can be completed safely. Both vehicles agree on a set of reference trajectories, in which the ego vehicle decelerates to create a gap behind the vehicle ahead, and once there is sufficient space, the cooperative vehicle performs the lane change.

This use case is an adapted cut-in scenario inspired by the current standards, where the main difference is the use of V2X communication. This additional information exchange enhances safety, to the point where a potentially risky manoeuvre becomes a controlled, non-hazardous situation [12].

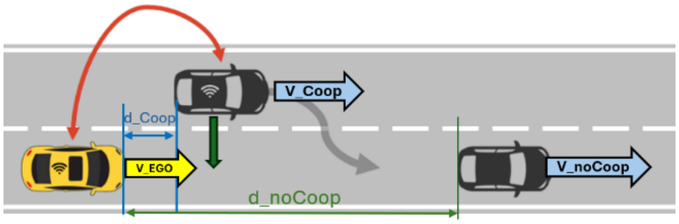

Figure 3 Representation of the cut-in scenario and the initial parameters

Communication workflow

In this scenario, the ego vehicle and the cooperative vehicle exchange information through V2V communication in order to negotiate and coordinate the cut-in manoeuvre. This process ensures that the manoeuvre can be carried out safely. The overall message flow is illustrated in Figure 4, which shows the sequence of message exchange between the two vehicles.

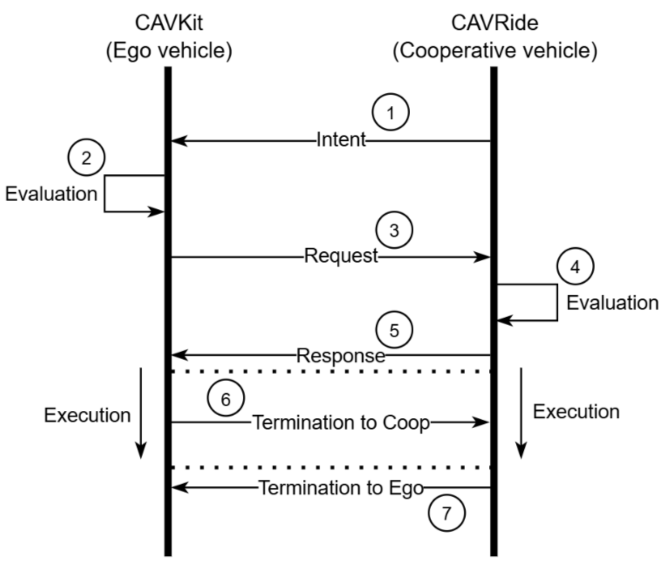

Figure 4 Sequence diagram representing the exchange of MCM messages between both vehicles

The sequence starts when the cooperative vehicle activates its turn indicator to signal the intention to perform the cut-in. Simultaneously, its V2V system broadcasts an MCM Intent to the ego vehicle, announcing the planned manoeuvre. Upon receiving this message, the ego vehicle assesses whether the proposed manoeuvre conflicts with its path and whether a safe alternative manoeuvre is feasible under the current conditions.

If the ego vehicle's internal evaluation is positive, it sends back an MCM Request proposing reference trajectories for both vehicles that would allow the lane change to occur safely. The cooperative vehicle then analyses these proposed trajectories. If the result of this evaluation is positive, it replies with an MCM Response confirming agreement; otherwise, it sends a negative response, ending the negotiation process.

When both vehicles confirm a valid set of trajectories, the Execution phase begins. In this stage, each vehicle follows its assigned reference trajectory while the ego vehicle continuously monitors the position and speed of the cooperative vehicle using the CAM messages it broadcasts. In the current implementation, no periodic MCM Execution updates are exchanged to maintain synchronisation, but if a deviation is detected, an MCM Cancellation is sent.

When the ego vehicle has finished creating the gap to the vehicle ahead, it sends an MCM Termination message to the cooperative vehicle indicating that it can proceed with the lane change. Once the manoeuvre is completed and both vehicles are driving in the same lane, the cooperative vehicle sends an MCM Termination message to the ego vehicle to formally conclude the communication exchange for the coordination process.

System Integration

Vehicles Setup

For the execution of this use case, two prototype vehicles were employed, along with a third support vehicle acting as a non-cooperative participant. The support vehicle's role was to reproduce realistic traffic conditions and enable validation of the functionality in the described scenario. The two key vehicles, the ego and the cooperative, are shown in Figure 5.

Figure 5 Image of the relevant vehicles used for the use case execution

The ego vehicle is a prototype platform known as CAVKit, developed to test new functionalities and proof-of-concept systems, such as the C-HWP functionality used in this study. The detailed architecture of the components integrated into the vehicle is shown in Figure 6. It is fitted with a sensor suite comprising cameras, radar and LiDAR, as well as processing units including a rapid-prototyping ECU and high-performance onboard computers (running a ROS-based architecture). The platform has full autonomous control capability, enabling deployment of advanced automated driving functions under controlled conditions. Dedicated V2X communication modules are also integrated, allowing direct exchange of data with other connected vehicles. The main communications device is the Cohda Wireless MK6 On-Board Unit (OBU), which supports C-V2X for sending and receiving CAM and MCM messages.

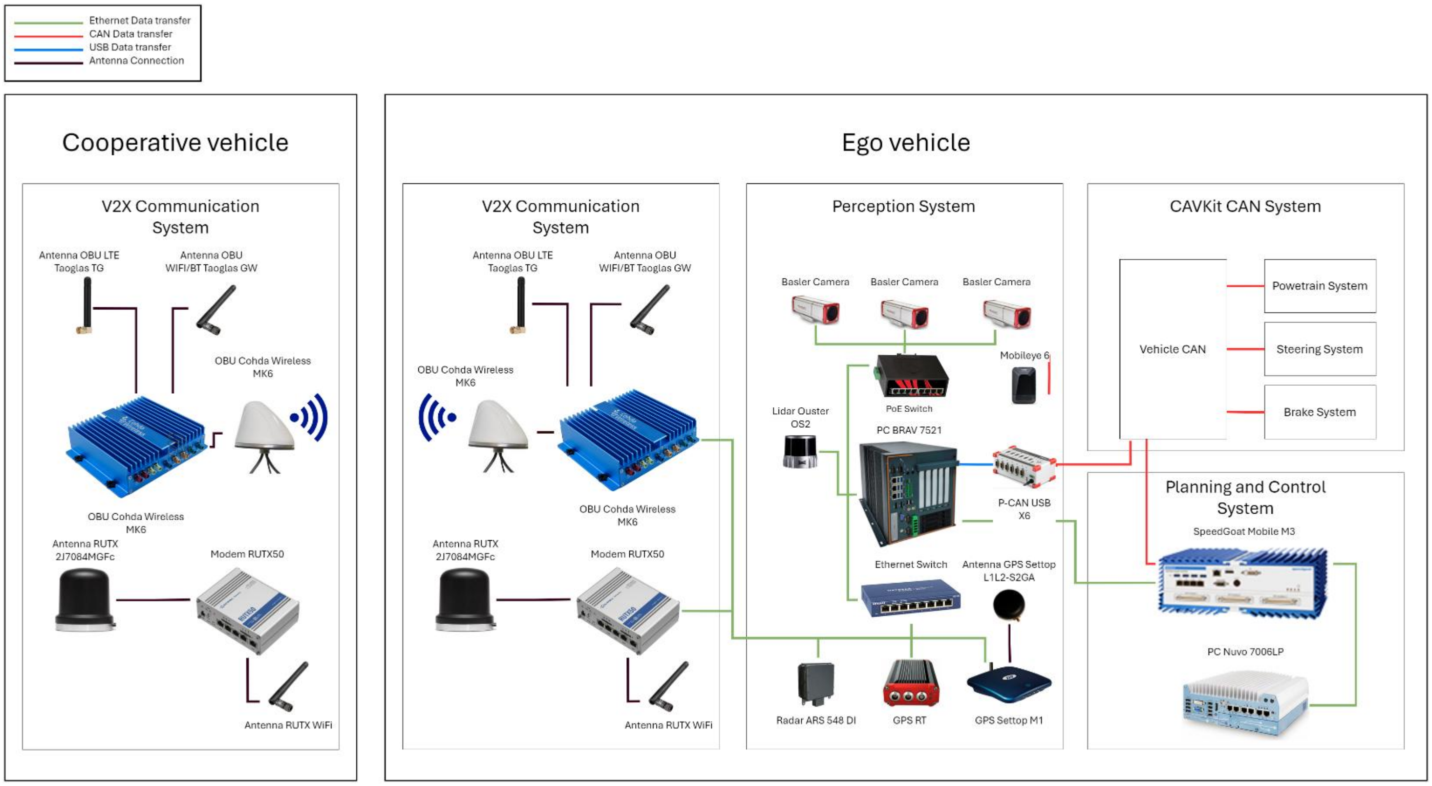

Figure 6 Devices and their communication interfaces integrated in the CAVKit prototype vehicle (right) and the CAVRide prototype vehicle (left)

The cooperative vehicle, named CAVRide, is the other prototype platform actively involved in the test scenarios. It is equipped with the same connectivity and localisation systems as the ego vehicle, ensuring full compatibility for message exchange and coordination. However, unlike the ego vehicle, the CAVRide vehicle does not feature automated motion control and is therefore driven manually in the presented use case. Information about the cooperative manoeuvre is presented to the driver via a dedicated Human–Machine Interface (HMI) displayed on a screen connected to the vehicle's connectivity system. This HMI was specifically developed for this study to display manoeuvre proposals, trajectory information and agreement status during the negotiation process.

Connected HWP functionality

To perform the tests aimed at validating the potential benefits of coordinated manoeuvres in the described use case, a Highway Pilot (HWP) system was used as the baseline. This baseline consists of Adaptive Cruise Control (ACC), which regulates the vehicle's speed to maintain a safe distance from the vehicle ahead, and Lane Centring Function (LCF), which ensures the vehicle follows the trajectory of the centre of the lane.

On top of this conventional functionality, an additional connectivity-based layer was integrated to enable the system to manage and adapt to newly negotiated shared trajectories, as described in the previous section. These trajectories are the result of Manoeuvre Coordination Message (MCM) exchanges with a cooperative vehicle.

In the specific scenario presented, the system is capable of estimating the time required to create a gap in front of the ego vehicle in a smooth manner, i.e. limiting deceleration to avoid any risk with rear vehicles, so as to facilitate the lane-change manoeuvre of a vehicle in the adjacent lane. Once the cooperative vehicle's intention is confirmed via MCM negotiation, the ego vehicle modifies its reference trajectory accordingly, temporarily prioritising the merging process over the strict following of the preceding vehicle.

It is important to highlight that this is a prototype functionality developed to assess the potential advantages of such solutions and to contribute to the technological advancement of CCAM systems. It is fully operational for the scenario described, and its behaviour has been validated under the test conditions presented in this study. However, its performance in other traffic situations or under different environmental conditions has not been evaluated, and certain limitations may exist that do not affect the scope of the current work.

Experimental Validation

Test Setup

For the execution of the tests, the two prototype vehicles previously described, CAVKit and CAVRide, have been used, together with a standard production car (a Cupra Born) acting as a non-cooperative vehicle. The tests have been carried out in a closed proving ground track under controlled conditions. The speeds of the tests have been selected within the typical highway speed range, resulting in 80 km/h, 100 km/ and 120 km/h. Additionally, slight variations in the initial longitudinal position of the cooperative vehicle were introduced in order to evaluate the robustness of the solution and ensure that the results are representative of situations that could realistically occur in real traffic.

In all test runs, the manoeuvre starts with the HWP activated and the ego vehicle in a stable following state behind the non-cooperative vehicle. The cooperative vehicle is located in the left lane, either aligned with or behind the ego vehicle, depending on the test run. All three vehicles start at the same speed (with a tolerance of ±5km/h) in a steady situation.

Data & Metrics

Both the ego and cooperative vehicles were instrumented with OxTS RT systems, which, through the RT-Range functionality, provide highly accurate relative position and velocity measurements for reporting and analysis purposes. The non-cooperative vehicle was not equipped with this instrumentation; therefore, its data in the reports are derived from the ego vehicle's onboard sensor fusion. As a result, these signals are less precise and are lost when the vehicle leaves the ego vehicle's field of view.

For each test, the sequence of MCM events is presented in a time plot (Figures 7, 10 and 13), followed by a table containing time, distance, and speed values at four specific moments of interest in the scenario:

Manoeuvre start: when the cooperative vehicle's driver activates the turn indicator and the MCM message flow begins, signalling the lane-change intent.

Ego vehicle starts braking: when the ego vehicle begins to decelerate to create space to let the cooperative vehicle merge into its lane.

Cooperative vehicle starts lateral movement: when the cooperative vehicle begins to move laterally towards the ego vehicle's lane to perform the lane change.

Cooperative vehicle in ego path: when the cooperative vehicle's trajectory crosses into the ego vehicle's path, meaning a collision could occur if space had not been created.

These four reference instants are both listed in the value table and also visually represented in the plots included in the report. Each instant is marked with a vertical dashed line, allowing direct correlation between the event and the dynamic evolution of the variables.

Figures 8, 11 and 14 illustrate the time evolution of the longitudinal speed of each vehicle involved in the test run, enabling the assessment of acceleration and deceleration phases relative to the manoeuvre timeline. On the other hand, Figures 9, 12 and 15 present the available longitudinal clearance (measured from the front bumper of the following vehicle to the rear bumper of the leading vehicle) between the ego vehicle and the non-cooperative vehicle, as well as between the ego vehicle and the cooperative vehicle. This representation allows for a clear visualisation of how the created gap evolves and confirms that a safe distance is achieved before the cooperative vehicle merges into the ego vehicle's lane.

Graphical Results

Below, the results from 3 tests at different speeds (80 km/h, 100 km/h and 120 km/h) executed on proving grounds are presented.

Test run 1: 80 km/h

The first case presented is the test performed at 80 km/h. Figure 7 shows the timeline of the message exchanges during the test. At t = 5.00 s, communication is initiated with the reception, by the ego vehicle, of the MCM Intent message from the cooperative vehicle. Immediately afterwards (t = 5.01 s), the ego vehicle proposes the new set of shared trajectories, sending the MCM Request.

It should be noted that this interval is very short because it corresponds solely to the ego vehicle's internal processing time, without considering any communication delays. All timestamps are represented from the ego vehicle's perspective; therefore, the instant associated with the MCM Intent is the moment it is received by the ego vehicle and the instant associated with the MCM Request is the moment it is sent.

The cooperative vehicle evaluates the proposed trajectories and sends the MCM Response at t = 5.30 s, thereby initiating the execution of the coordinated manoeuvre. At t = 11.30 s, once the ego vehicle has completed the gap creation process, it sends an MCM Termination message to the cooperative vehicle, signalling that it may proceed with its lane change. At t = 22.34 s, after completing the lane change, the cooperative vehicle sends the final MCM Termination to the ego vehicle and therefore closes the cooperation.

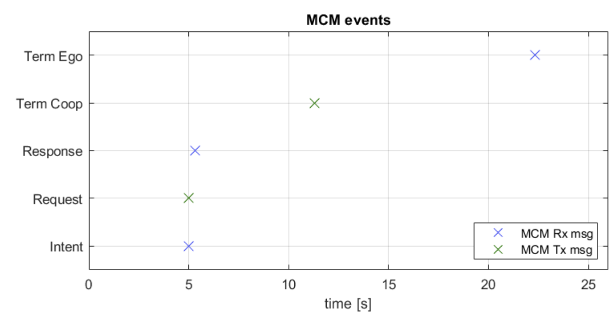

Figure 7 Events related to the transmission and reception of MCM messages in the ego vehicle in the test execution at 80 km/h

In this case, as shown in Table 1, the cooperative vehicle starts aligned with the ego vehicle, with an initial longitudinal distance of 0.6 m. All three vehicles begin at a speed close to 80 km/h (the speedometer reading is 80 km/h, but the real speed is slightly lower due to the intrinsic measurement error present in all vehicles).

The ego vehicle successfully generates the required gap in around 8.5 s, requiring a speed reduction of slightly less than 5 km/h and reaching a maximum deceleration of −0.78 m/s². When the cooperative vehicle initiates the lane change manoeuvre, the clearance already exceeds 10 m, increasing to 20 m by the time the cooperative vehicle enters the ego vehicle's path, meaning it is safe to perform this manoeuvre.

Table 1. Main KPIs from the results obtained in the test execution at 80 km/h

	Manoeuvre start	Ego vehicle starts braking	Coop vehicle starts lateral movement	Coop vehicle in ego path
Time (s)	5	5.303	13.9	20.09
Long distance ego-coop (m)	0.614	0.687	11	17.22
Lat distance ego-coop (m)	-4.209	-4.188	-3.5	-0.9
Non-coop vehicle speed (km/h)	73.07	73.24	77.17	76.74
Coop vehicle speed (km/h)	76.61	76.57	77.15	77.18
Ego vehicle speed (km/h)	74.53	74.43	71.93	72.72

This same behaviour can be observed in Figure 8, which shows the time evolution of the speeds of each vehicle involved in the scenario. While both the cooperative and the non-cooperative vehicles maintain a steady speed of around 75 km/h throughout the test, the ego vehicle reduces its speed and holds it steady at approximately 70 km/h.

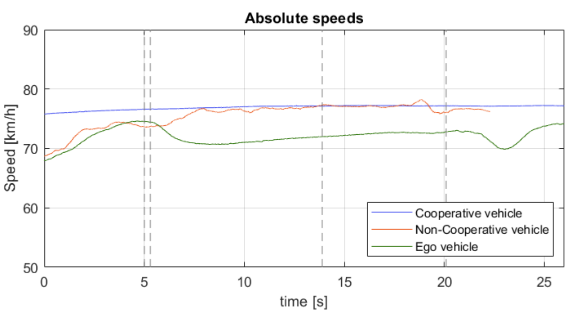

Figure 8 Time series plot of the vehicle speeds in the test executed at 80 km/h

Regarding the longitudinal clearance between the ego vehicle and the other two vehicles, Figure 9 shows that the distances remain initially stable in both cases, increasing once the negotiation process and the manoeuvre begins. The initial distance between the ego and the non-cooperative vehicle is approximately 38 m, whereas after the ego vehicle reduces its speed to allow the cooperative vehicle to merge, the distance increases to about 60 m by the time the cooperative vehicle enters the ego vehicle's travel lane.

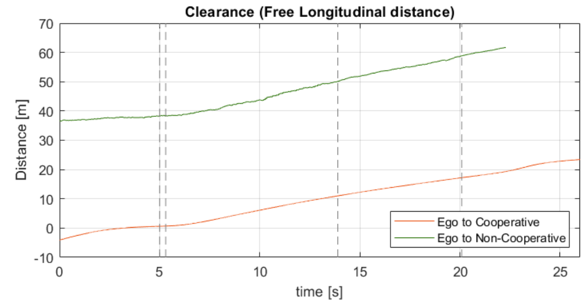

Figure 9 Time series plot of the clearance between the ego vehicle and the other two in the test executed at 80 km/h

Test run 2: 100 km/h

The second case corresponds to the test conducted at 100 km/h. Figure 10 shows the timeline of the MCM exchanges during the run. At t = 5.00 s, communication is initiated when the ego vehicle receives the MCM Intent message from the cooperative vehicle. Immediately afterwards (t = 5.01 s), the ego vehicle sends the MCM Request with the proposed cooperative trajectories.

The cooperative vehicle evaluates the proposal and responds with an MCM Response at t = 5.30 s, thereby initiating the execution of the coordinated manoeuvre. At t = 13.30 s, the ego vehicle sends an MCM Termination message to the cooperative vehicle, indicating that it may proceed with its lane change. At t = 22.00 s, after completing the lane change, the cooperative vehicle sends the final MCM Termination to the ego vehicle, thus concluding the manoeuvre.

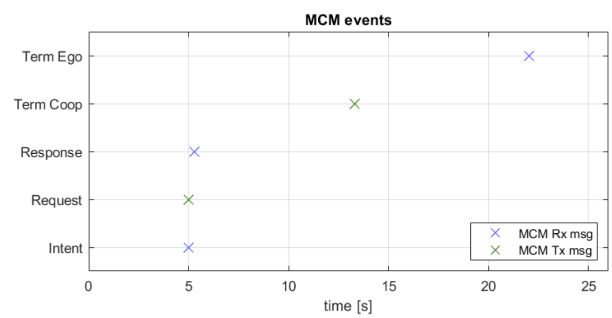

Figure 10 Events related to the transmission and reception of MCM messages in the ego vehicle in the test execution at 80 km/h

As shown in Table 2, the cooperative vehicle starts noticeably behind the ego vehicle, with an initial longitudinal distance of −8.4 m. All three vehicles begin at a speed close to 100 km/h (speedometer reading), although the actual speed is slightly lower due to the inherent measurement offset. The ego vehicle successfully generates the required gap in approximately 10.6 s, requiring a speed reduction of slightly less than 5 km/h and reaching a peak deceleration of −0.91 m/s². When the cooperative vehicle initiates its lane change, the clearance to the ego vehicle is almost 10 m, increasing to 16 m by the time it enters the ego vehicle's path, ensuring that the manoeuvre can be completed without risk and that all participants can handle it smoothly.

Table 2. Main KPIs from the results obtained in the test executed at 100 km/h

	Manoeuvre start	Ego vehicle starts braking	Coop vehicle starts lateral movement	Coop vehicle in ego path
Time (s)	5	5.303	15.92	19.94
Long distance ego-coop (m)	-8.442	-8.301	9.965	16.02
Lat distance ego-coop (m)	-4.932	-4.995	-3.499	-0.897
Non-coop vehicle speed (km/h)	92.64	92.4	94.8	97.14
Coop vehicle speed (km/h)	95.58	95.65	96.41	96.55
Ego vehicle speed (km/h)	92.43	92.52	89.47	89.47

This behaviour is also visible in Figure 11, which shows the time evolution of the longitudinal speeds of all vehicles involved in the scenario. While the cooperative and non-cooperative vehicles maintain a steady speed of approximately 95 km/h along the test, the ego vehicle reduces its speed and stabilises at around 90 km/h.

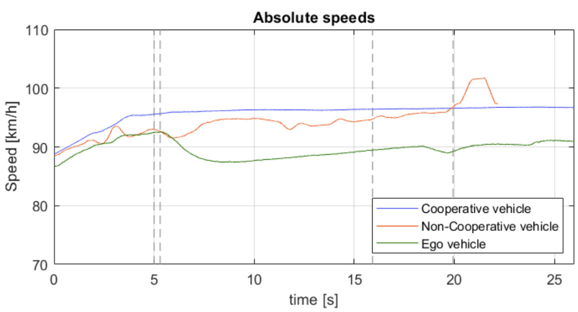

Figure 11 Time series plot of the vehicle speeds in the test executed at 100 km/h

Regarding the available longitudinal clearance, Figure 12 shows that the distances are initially stable for both pairs of vehicles, increasing once the negotiation process and the manoeuvre to create space begin. The initial clearance between the ego and non-cooperative vehicles is about 40 m, increasing to over 60 m by the time the cooperative vehicle merges into the ego vehicle's driving lane.

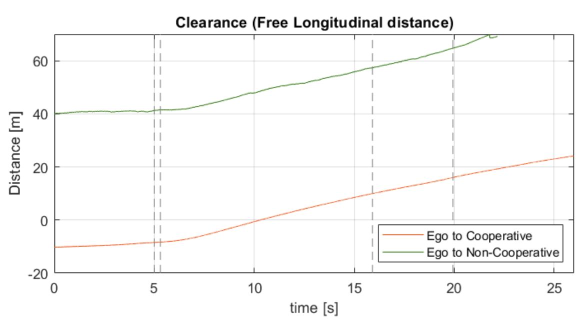

Figure 12 Time series plot of the clearance between the ego vehicle and the other two in the test executed at 100 km/h

Test run 3: 120km/h

The third and final case corresponds to the test conducted at 120 km/h. Figure 13 shows the timeline of the MCM exchanges during the run. At t = 5.00 s, communication is initiated when the ego vehicle receives the MCM Intent message from the cooperative vehicle. Immediately afterwards (t = 5.01 s), the ego vehicle sends the MCM Request with the proposed cooperative trajectories.

The cooperative vehicle evaluates the proposal and responds with an MCM Response at t = 5.30 s, thereby initiating the execution of the coordinated manoeuvre. At t = 12.30 s, the ego vehicle sends the MCM Termination message to the cooperative vehicle, and at t = 20.30 s, after completing the lane change, the cooperative vehicle sends the final MCM Termination to the ego vehicle to conclude the coordination process.

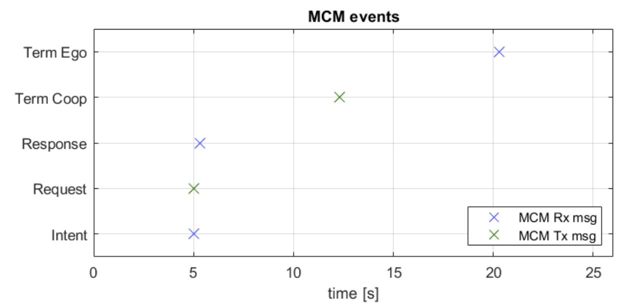

Figure 13 Events related to the transmission and reception of MCM messages in the ego vehicle in the test execution at 80 km/h

As shown in Table 3, the cooperative vehicle starts with an overlap relative to the ego vehicle, with an initial longitudinal distance of −2.9 m. All three vehicles begin at a speed close to 120 km/h (speedometer reading), although the actual speed is slightly lower due to the inherent measurement offset. The ego vehicle successfully generates the required gap in approximately 6.6 s, requiring a speed reduction of around 8 km/h and reaching a peak deceleration of −1.16 m/s². This is the case with the largest speed reduction and most pronounced deceleration among the three scenarios; however, these values are still considered low and result in a smooth and comfortable manoeuvre. When the cooperative vehicle initiates its lane change, the clearance to the ego vehicle is 8.5 m, increasing to more than 20 m by the time it enters the ego vehicle's path, ensuring that the manoeuvre can be completed without risk.

Table 3. Main KPIs from the results obtained in the test executed at 120 km/h

	Manoeuvre start	Ego vehicle starts braking	Coop vehicle starts lateral movement	Coop vehicle in ego path
Time (s)	5	5.303	11.88	18.86
Long distance ego-coop (m)	-2.924	-2.87	8.482	21.17
Lat distance ego-coop (m)	-3.827	-3.86	-3.499	-0.896
Non-coop vehicle speed (km/h)	113.8	113.8	114.6	114.1
Coop vehicle speed (km/h)	114.9	115	113.9	115.5
Ego vehicle speed (km/h)	112.5	112.6	104.8	106.9

This behaviour is also visible in Figure 14, which shows the time evolution of the longitudinal speeds of all vehicles involved in the scenario. While the cooperative and non-cooperative vehicles maintain a steady speed of approximately 115 km/h throughout the test, the ego vehicle reduces its speed and stabilises at around 105 km/h.

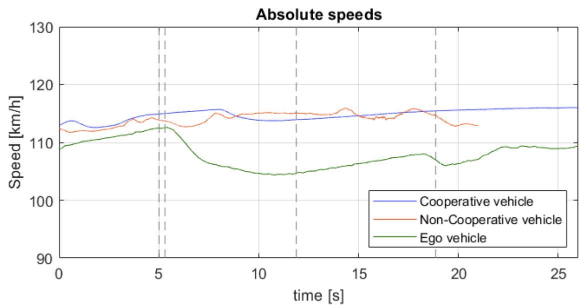

Figure 14 Time series plot of the vehicle speeds in the test executed at 120 km/h

Regarding the longitudinal clearance, Figure 15 shows that the distances are initially stable for both pairs of vehicles, increasing once the negotiation process and the manoeuvre to create space begin. The initial clearance between the ego and non-cooperative vehicles is about 50 m, increasing to over 80 m by the time the cooperative vehicle merges into the ego vehicle's travel lane.

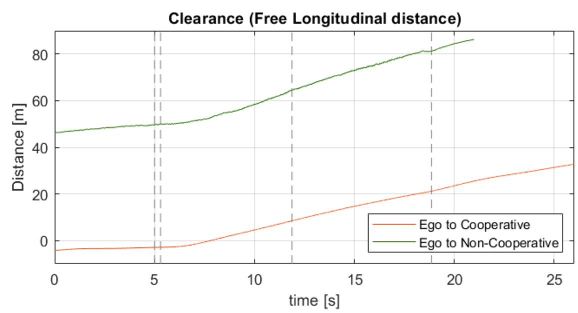

Figure 15 Time series plot of the clearance between the ego vehicle and the other two in the test executed at 120 km/h

Discussion

Based on the detailed results presented in the previous section, this analysis summarises the key observations from the three test runs executed.

The results obtained in the three tested scenarios (80 km/h, 100 km/h and 120 km/h) consistently demonstrate that the proposed cooperative manoeuvre is executed safely and smoothly, without sudden accelerations or decelerations that could cause a risk to surrounding traffic, particularly to vehicles travelling behind the ego vehicle. In all cases, the manoeuvre is performed in a controlled manner, ensuring that sufficient free space is generated before the cooperative vehicle merges, while maintaining comfortable dynamic behaviour for all participants.

The functionality performs as expected: the ego vehicle generates the required space efficiently, without significant delays in the traffic flow. The communication process between the vehicles is rapid and reliable; in all three cases, the time elapsed from the reception of the cooperative vehicle's intention message (MCM Intent) to the start of the ego vehicle's action to create space is only around 300 ms. This confirms that both communication and processing delays are minimal, enabling an almost immediate cooperative response.

The manoeuvre execution is consistent and robust, even when the cooperative vehicle starts from different initial longitudinal positions. Despite these variations, the system adapts correctly, creating the necessary space within reasonable durations and without compromising safety. This robustness, combined with fast and effective communications, highlights the suitability of the system for real-life scenarios on highways.

Overall, the results highlight the potential of cooperative manoeuvring technologies to improve both traffic flow and safety in heavy highway traffic. The demonstrated ability to negotiate and execute lane changes quickly, smoothly and predictably strengthens the value of further research and development in this area, with the aim of achieving large-scale implementation in future connected and automated driving environments.

Conclusions

The experimental work carried out demonstrates the feasibility and advantages of cooperative manoeuvres in highway scenarios. The presented proof-of-concept consistently showed its ability to create safe and predictable cooperative manoeuvres. In every case, the manoeuvre was completed smoothly, with controlled vehicle dynamics and no risks to other road users in the surroundings.

The results confirm that this functionality operates as intended: the ego vehicle efficiently generates the required space with minimal impact on overall traffic flow. Communication between vehicles proved to be both rapid and reliable; in all scenarios, the system reacted in about 300 ms from the reception of the cooperative vehicle's intention message to the start of the ego vehicle's manoeuvre, showing that both transmission and processing delays are minimal. This quick and dependable response is a key factor for ensuring safety and efficiency in dense traffic.

One of the most relevant aspects of this study is its ability to maintain robust and consistent behaviour despite variations in the initial longitudinal position of the cooperative vehicle. This adaptability, together with the reliable communication and control process, highlights the potential of cooperative manoeuvres in real-world driving situations.

The importance of the work lies in the validation of a fully functional prototype that combines real-time V2V communication, cooperative decision-making and vehicle control under realistic proving ground conditions. Given the successful results, new advances can be expected in this field, including extending the approach to multi-vehicle cooperation, integration with infrastructure-based coordination, and testing in more complex and varied traffic environments.

However, it should be noted that this is a prototype implementation validated under the specific test conditions described, and its performance has not been evaluated in other situations or environments.

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Definitions/Abbreviations

ACC	Adaptive Cruise Control
CCAM	Connected, Cooperative, and Automated Mobility
C-HWP	Cooperative Highway Pilot
C-ITS	Cooperative Intelligent Transportation Systems
DENM	Decentralized Environmental Notification Messages
ECU	Electronic Control Unit
ETSI	European Telecommunications Standards Institute
HMI	Human–Machine Interface
HWP	Highway Pilot
ITS	Intelligent Transportation Systems
ITS-S	Intelligent Transportation System Station
LCF	Lane Centring Function
MCM	Manoeuvre Coordination Message
MCS	Manoeuvre Coordination Service
OBU	On-Board Unit
PER	Packed Encoding Rules
SAE	Society of Automotive Engineers
VAM	Vulnerable Road User Awareness Messages
V2V	Vehicle-to-Vehicle
V2X	Vehicle-to-Everything
WGS84	World Geodetic System 1984