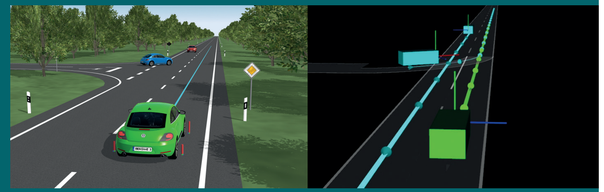


Exemplary driving functions were developed in the IMAGinE project that not only focus on a single vehicle, but also involve multiple vehicles interacting via V2X communication for joint solution finding.

Complex cooperative systems can only be adequately tested using simulations.

The complexity of cooperative integrated systems increases with the number of road users and potential cooperation partners.
Therefore, the simulations were an integral part of reproducible and safe testing of even critical situations from the earliest concept and development phases through to integration into actual vehicles.

Cooperative systems can be efficiently developed with a flexible and modular simulation architecture.

The project partners developed a flexible and modular simulation architecture that enabled research into cooperative maneuvers for multiple road users. The resulting simulations were used for developing the cooperative maneuver coordination as well as for partner-specific software components.

Testing catalogues across functions enabled a systematic variation of boundary conditions and a goal-oriented analysis of different parameterizations in a cross-system and cross-vehicle context. Furthermore, actual recorded real data was fed into the simulations and manipulated in a targeted manner for verifying technical components. This made it possible to achieve the most realistic possible behavior of the road users in specific situations.

The integration of real V2X communication hardware and the use of vehicle-related testing methods, such as vehicle-in-the-loop, paved the way for drivers to be able to experience the cooperative functions in actual vehicles. The functions were ultimately integrated into ten real test vehicles and tested in more than twenty joint workshops on various test courses. Through this extensive testing, the partners were able to successfully demonstrate the end-to-end functionality of the cooperative maneuver coordination in various scenarios and partner constellations.

CORE RESULTS
SIMULATION ENVIRONMENT

PROJECT GOALS

The goal of the IMAGinE joint project (Intelligent Maneuver Automation – cooperative hazard avoidance in realtime) was to develop new assistance systems for cooperative driving. Cooperative driving is about road traffic behaviors whereby road users jointly plan and execute driving maneuvers. Using automatic information exchange between vehicles and infrastructure, a vehicle's driving behavior is coordinated with other vehicles and adapted to the overall situation. This optimizes traffic flows and also defuses or helps avoid critical situations – making driving safer and more efficient.

To achieve this goal, the IMAGinE partners have made a crucial contribution to research in the field of connected and cooperative assistance systems in the form of five core innovations: Cooperative Maneuver Coordination, Cooperative Environmental Model, Communication Mechanisms, Human-Machine Interaction, and Simulation Environment.

COOPERATIVE FUNCTIONS

The validity of the developed concepts was demonstrated using selected cooperative functions and use cases. These were researched both in simulations as well as in actual cars and trucks in highway and rural road scenarios.

Extensive research provided the proof: the IMAGinE concepts for cooperative maneuver coordination are viable.

IMAGinE BY THE NUMBERS

€38.2 million
PROJECT VOLUME

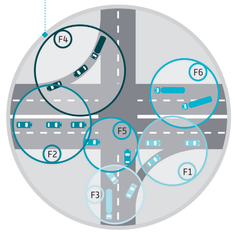
€17.9 million
FUNDING

6
COOPERATIVE FUNCTIONS

2,000
PERSON MONTHS OF WORKLOAD

12
PROJECT PARTNERS

69-MONTH DURATION
SEPTEMBER 1, 2016 TO MAY 31, 2022



- F1 Cooperative merging on highways
- F2 Cooperative longitudinal control on highways
- F3 Cooperative overtaking on rural roads
- F4 Cooperative strategic traffic distribution
- F5 Cooperative turning at junctions
- F6 Cooperative overtaking by heavy-goods vehicles on highways

CONSORTIUM

The joint IMAGinE project brought together leading companies in the automotive industry, innovative small and medium-sized companies in the field of simulation, a research institute, and a road operator to work on innovative assistance systems for the cooperative driving of the future.
IMAGinE was funded by the German Federal Ministry for Economic Affairs and Climate Action (BMWK).

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Solutions for Cooperative Driving

IMAGinE

FIRST TALK, THEN ACT.

www.imagine-online.de

The joint project IMAGinE – Intelligent Maneuver Automation – cooperative hazard avoidance in realtime – has made a crucial contribution to research in the field of connected and cooperative assistance systems and paved the way for the cooperative driving of the future.

CORE RESULTS
COOPERATIVE MANEUVER COORDINATION

Realizing cooperation between road users required investigation of the theoretical concepts for interactions between vehicles using specific functions and use cases, both in simulations and in real cars and trucks on rural roads and highways.

IMAGinE has delivered proof for the viability of cooperative maneuver coordination.

Cooperative maneuver coordination helps vehicles clearly recognize the intention of other vehicles.

The various aspects of cooperative maneuver coordination were investigated in several specific implementations of basic concepts and its potential was shown.

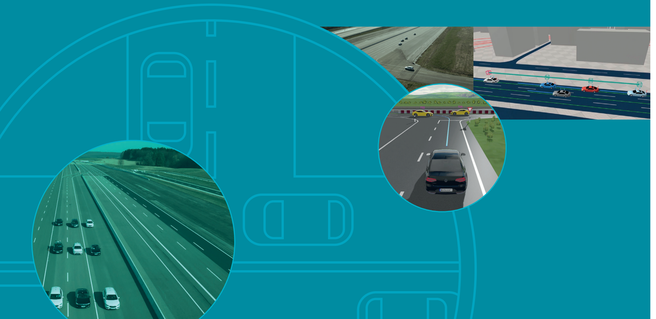
For instance, in one use case, strategic traffic information from traffic management can support optimal traffic flows.

The basic concepts of maneuver coordination cover both the limited temporal and spatial cooperation areas as well as cooperation over greater distances and thus complement one another.

Maneuver coordination is an ongoing process in which the maneuver or the intention must always be updated, however without losing sight of the character of the cooperation.

Many different aspects of this can be implemented. Factors that must be considered include the channel loads for communication, the required computing effort for maneuver planning and the general possibility of the vehicles finding a joint solution for the maneuver depending on the specific scenario.

Cooperative maneuver coordination can be implemented with currently available technologies, for instance with V2X communications. This allows many traffic situations to be handled much more safely and easily.



A vehicle's own sensor systems detect the immediate environment. However, the system reaches its natural limits when the surrounding situation becomes more complex or its perception is impaired. IMAGinE expanded the sensory view of the individual vehicle by exchanging information amongst many cooperation partners via V2X technology and by combining it into an individually expanded model of the environment.

This created a more comprehensive view of the overall situation. The idea behind it is "seeing with the eyes of others."

With collective perception, the perception of each individual is supplemented by the knowledge of others, thereby expanding the individual vehicle's model of the vehicle environment.

The cooperative environment model forms the information basis for cooperative maneuver coordination and even in this first implementation delivers a significant gain in information by enhancing the perception of the surrounding traffic. Objects hidden to onboard sensor systems can thus be detected earlier.

Collective perception is a sensible complement to expanded perception. In order to work in real time, the entire system must be set up for it, starting with the accurate localization of objects through to the precise prediction of the objects' trajectories.

CORE RESULTS
COOPERATIVE ENVIRONMENT MODEL

CORE RESULTS
COMMUNICATION MECHANISMS

The information required for cooperative driving is exchanged between road users by sending V2X messages.

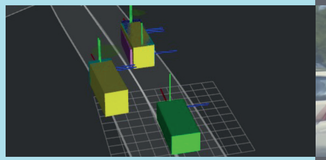
IMAGinE developed new special message formats for maneuver planning and coordination.

IMAGinE defined new special message formats and investigated proof and feasibility of standardization.

To realize the cooperative functions the IMAGinE project researched, several new message formats were defined: the "Maneuver Coordination Message" (MCM) serves to coordinate cooperative maneuvers by exchanging and negotiating trajectories between neighboring vehicles. The "IMAGinE Driving Strategy Message" (IDSM) is used to exchange additional information between road users that are required for some functions to enable strategic maneuver coordination. In the project, this message format was used mainly for the function of cooperative overtaking by heavy-goods vehicles on highways. The "IMAGinE Traffic Distribution Message" (ITDM) was developed to integrate collective strategies from traffic management into local cooperative coordination between individual vehicles.

In addition, the existing message formats Cooperative Awareness Message (CAM) and Collective Perception Message (CPM) were expanded to fulfil the requirement for collective perception in IMAGinE. The concepts developed for collective perception and cooperative maneuver coordination can be implemented with the CPM message format currently being standardized and with the MCM as defined in the IMAGinE project.

During the market launch phase, all maneuver-coordinating messages can be sent together with the standard V2X messages on one channel. The channel load studies conducted by IMAGinE showed that message transmission and reception with CAM, CPM, MCM and IDSM are feasible up to an equipment rate of 20 percent without having to regulate the channel load. For higher equipment rates, the recommendation is that the MCM be relegated to its own channel.



CORE RESULTS
HUMAN-MACHINE INTERACTION

One central challenge for the future is developing understandable and intuitive assistance concepts that motivate drivers to drive cooperatively.

The cooperative HMI involves drivers in the cooperative maneuver coordination and is therefore a prerequisite for the driver's understanding, acceptance, and trust.

IMAGinE laid the foundations for a user-centered design of the display and operating concepts. The functions developed in the IMAGinE project intuitively enable road users to behave in a cooperative manner and in partnership out on the road. This creates the opportunity to further increase driving safety.

IMAGinE investigated various aspects of cooperative driving behavior using several subject studies in a driving simulator and presented potential solutions for intuitive HMI concepts for cooperative driving.

Subject studies in various testing environments, including for instance car and truck driving simulators, were used to develop design solutions that support drivers during cooperative interactions. Different use cases considered the various cooperative functions developed in the IMAGinE project. The studies looked at idealized environmental conditions as well as at system limitations and functional failures. Along with automated driving, manual driving was also examined as a use-case scenario.

Overall, 24 empirical studies were prepared and conducted with more than 600 test subjects participating. The total trial time was more than 1,000 hours.

The studies focused on the subjects' interaction with the various cooperative assistance functions, the resulting driving behaviors, including safety aspects, as well as the drivers' assessment of understandability and acceptance of the systems.

The study results show that the subjects accepted assistance to support cooperative driving and experienced it as easy and safe when using suitable display and operating concepts. The studies resulted in a set of findings and guidelines for user-friendly design concepts for HMI for cooperative driving assistance systems.