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Decentralized Cooperative Intersection Management Based on Connected Autonomous Vehicles for Urban Unsignalized Intersections

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- Model-based design of vehicle mechatronic systems
- Development of the virtual test bench for modelling and simulation of the cyber-physical production systems with integrated Industry 4.0 solutions
- Networking of smart home, smart traffic, and smart grid to stabilize the energy grid and increase energy efficiency
- Development of cooperative driving functions to realize autonomous driving for AGVs in intralogistics and for vehicles in public road traffic

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Agenda

- Introduction and motivation
- State of the art
- Methodology
- Development of the decentralized cooperative intersection management
- Function validation via MiL-Simulations
- Conclusion

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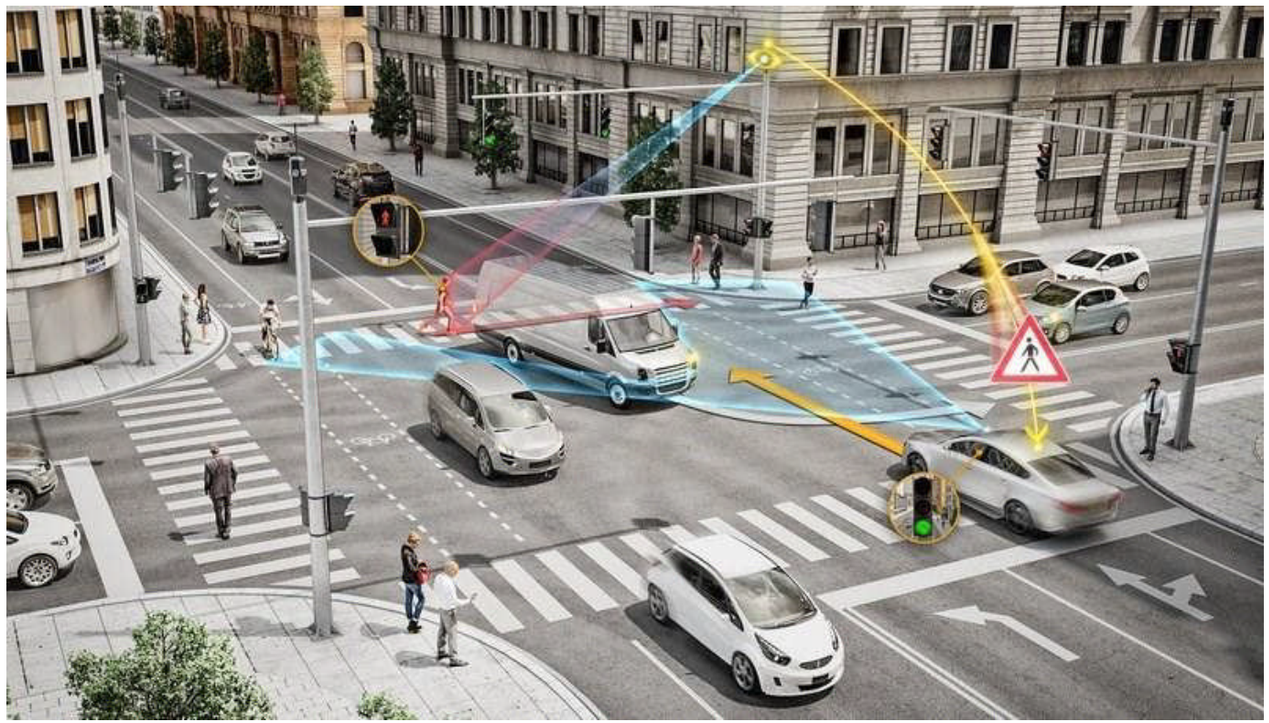
State of the art



Source: https://www.next-mobility.de/wie-intelligente-kreuzungen-smart-cities-sicherer-machen-a-672908/

- Community Database of the European Union "CARE": 20% of traffic fatalities are attributable to road traffic at intersections
- In USA: 40% of accidents and 21.5% of traffic fatalities occur at intersections
- In Germany: about two-thirds of all cyclist accidents with personal injury recorded by the police in urban areas occurred at intersections

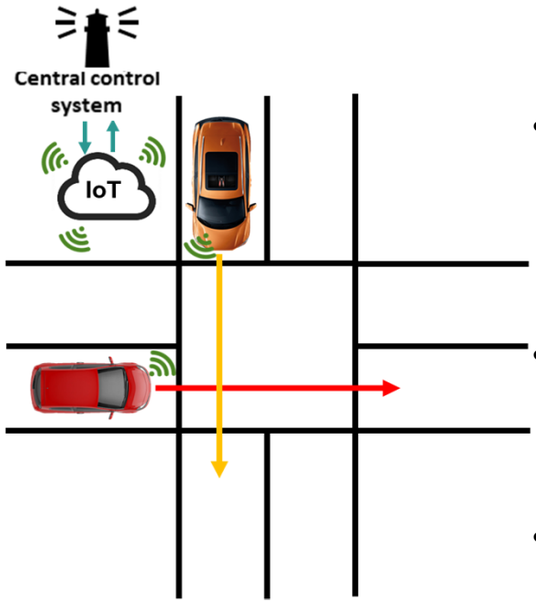
intersection management

- optimize traffic throughput
- ensure proactive safety

Introduction and motivation

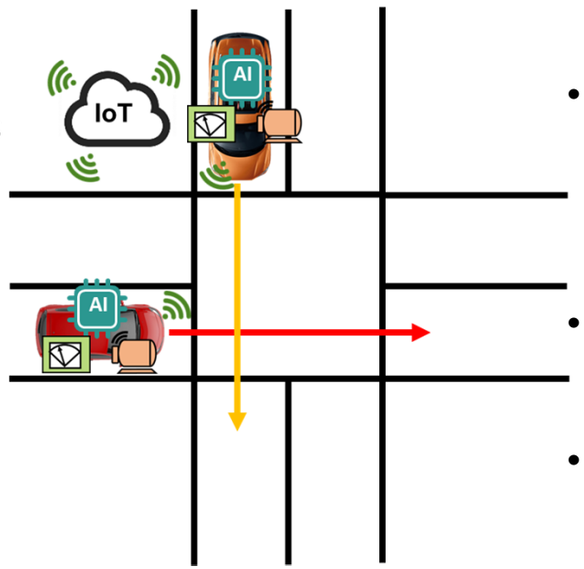
Cooperative intersection management

- based on networked autonomous vehicles
- creating and executing a (global) optimal sequence for road users



- Central control system for dispatching the passing vehicles and determining their speed and sequence
- commands from higher hierarchical level to automated vehicles through V2I
- Global optimization of traffic flow

Central cooperative intersection management



- Decentralized negotiation between vehicles to coordinate speed and sequence through V2V
- No commands from higher hierarchical level
- Suboptimal solution

Decentralized cooperative intersection management

Introduction and motivation

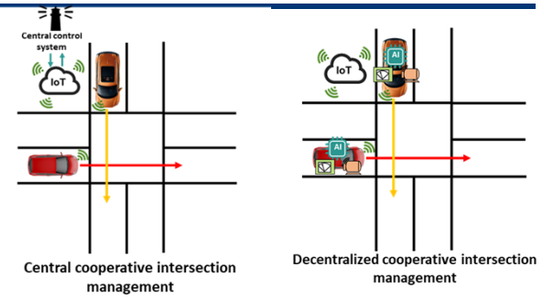
Cooperative intersection management

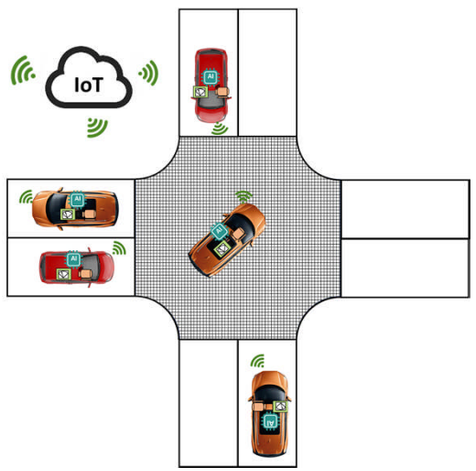
- based on networked autonomous vehicles
- creating and executing a (global) optimal sequence for road users

Deficits of the current research:

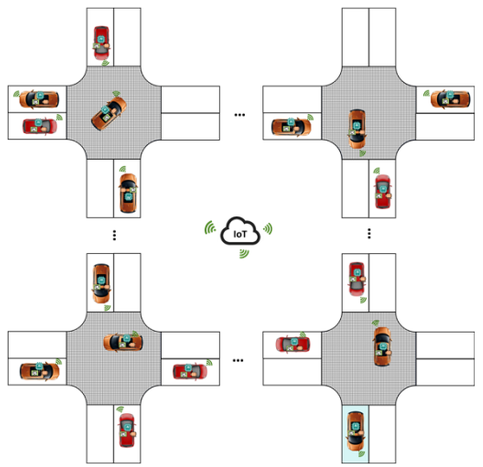
- Focus on the isolated single intersection

- vehicle's behaviors at the single intersection are interdependent
- the causality loops in the trajectory planning of the vehicles
- resulting in no reasonable solution
- developed under certain constraints and for specific application scenarios





area-wide cooperative intersection management



network-wide cooperative intersection management

Methodology

Mechatronic structuring

Cross-linked **F**unction **G**roup (CFG)

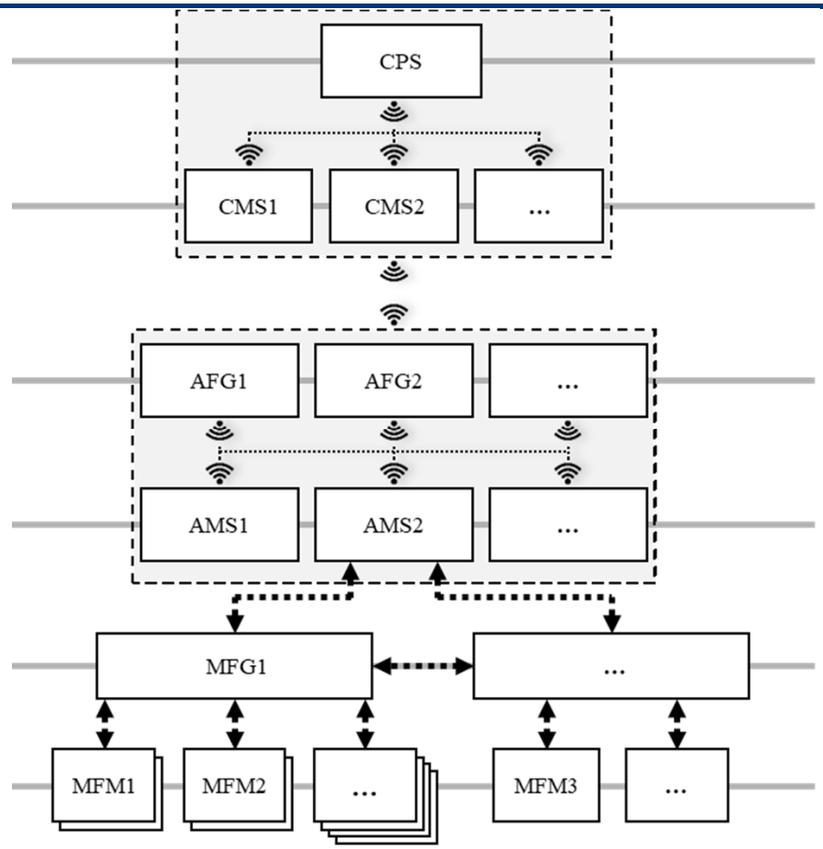
Autonomous **F**unction **G**roup (AFG)

Cross-linked **M**echatronic **S**ystem (CMS)

Autonomous **M**echatronic **S**ystem (AMS)

Mechatronic **F**unction **G**roup (MFG)

Mechatronic **F**unction **M**odule (MFM)



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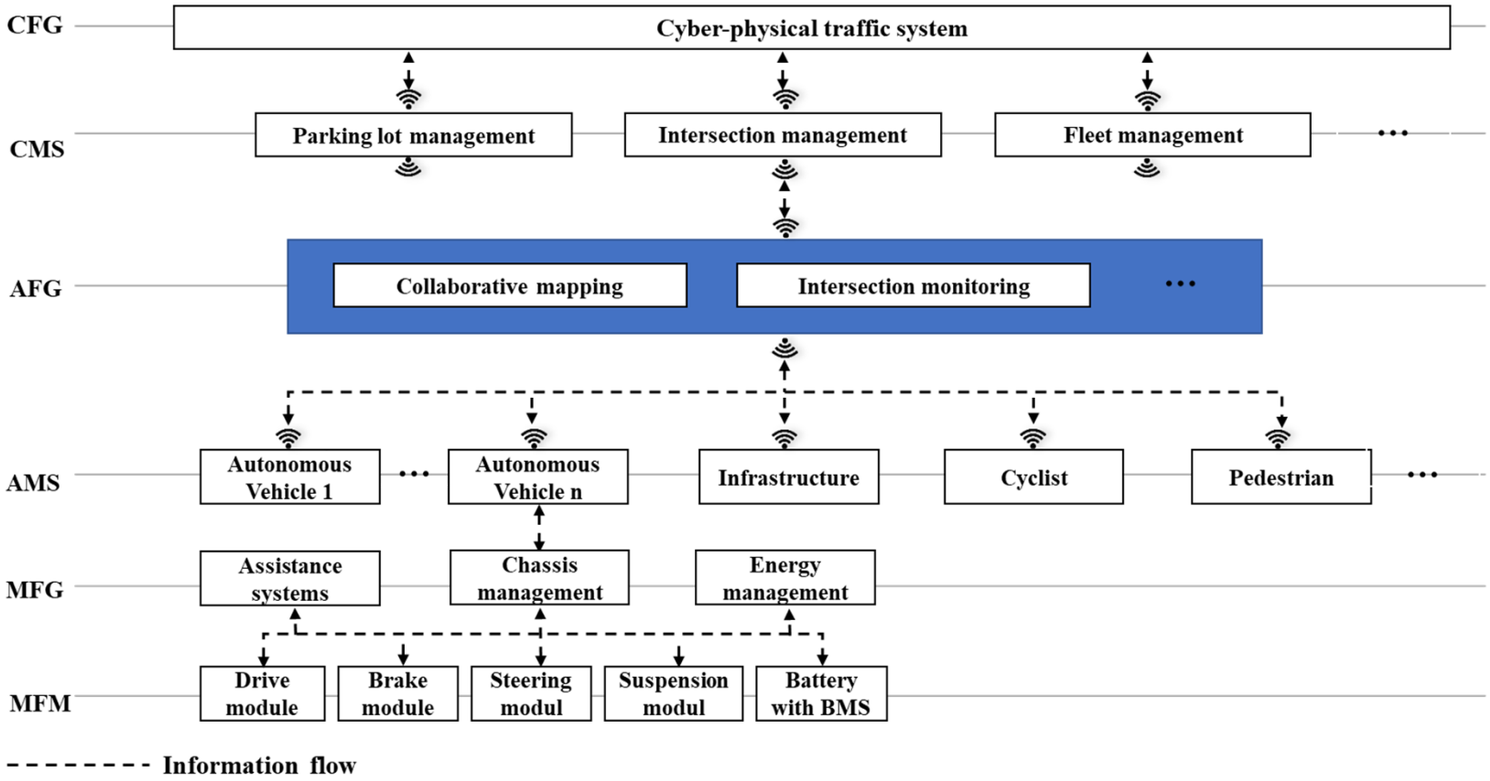
Development of the decentralized cooperative intersection management



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Function validation via MiL-Simulations

Simulation scenario

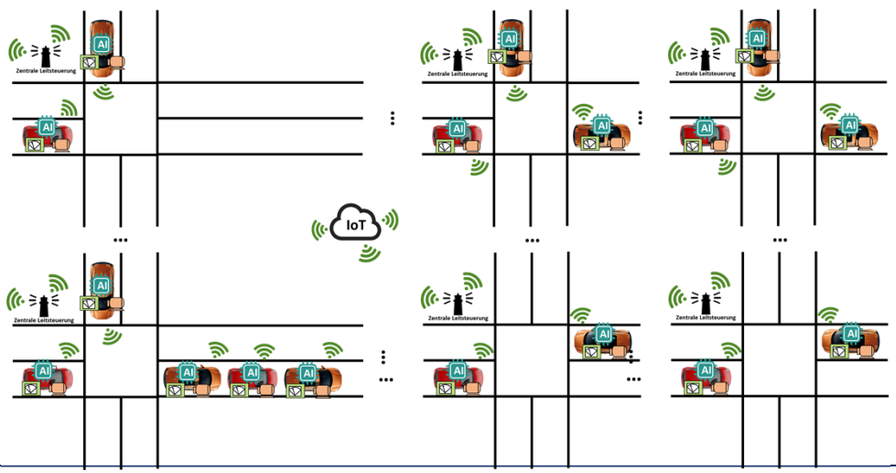
Test case 1: Single intersection with regular traffic volume in all entry directions

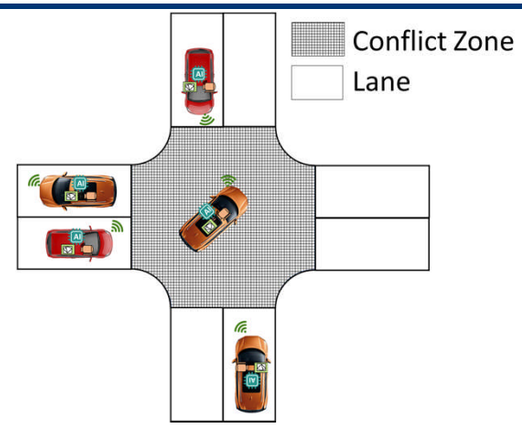
- Low traffic intensity: $<$ 1000 vehicles/h
- Medium traffic intensity: 1000 vehicles/h -2600 vehicles/h
- High traffic intensity: $>$ 2600 vehicles/h

Test case 2: Single intersection with irregular traffic volume in entry directions

Traffic intensity in east-west direction = **a*** Traffic intensity in north-south direction

Test case 3: Road network with four intersections



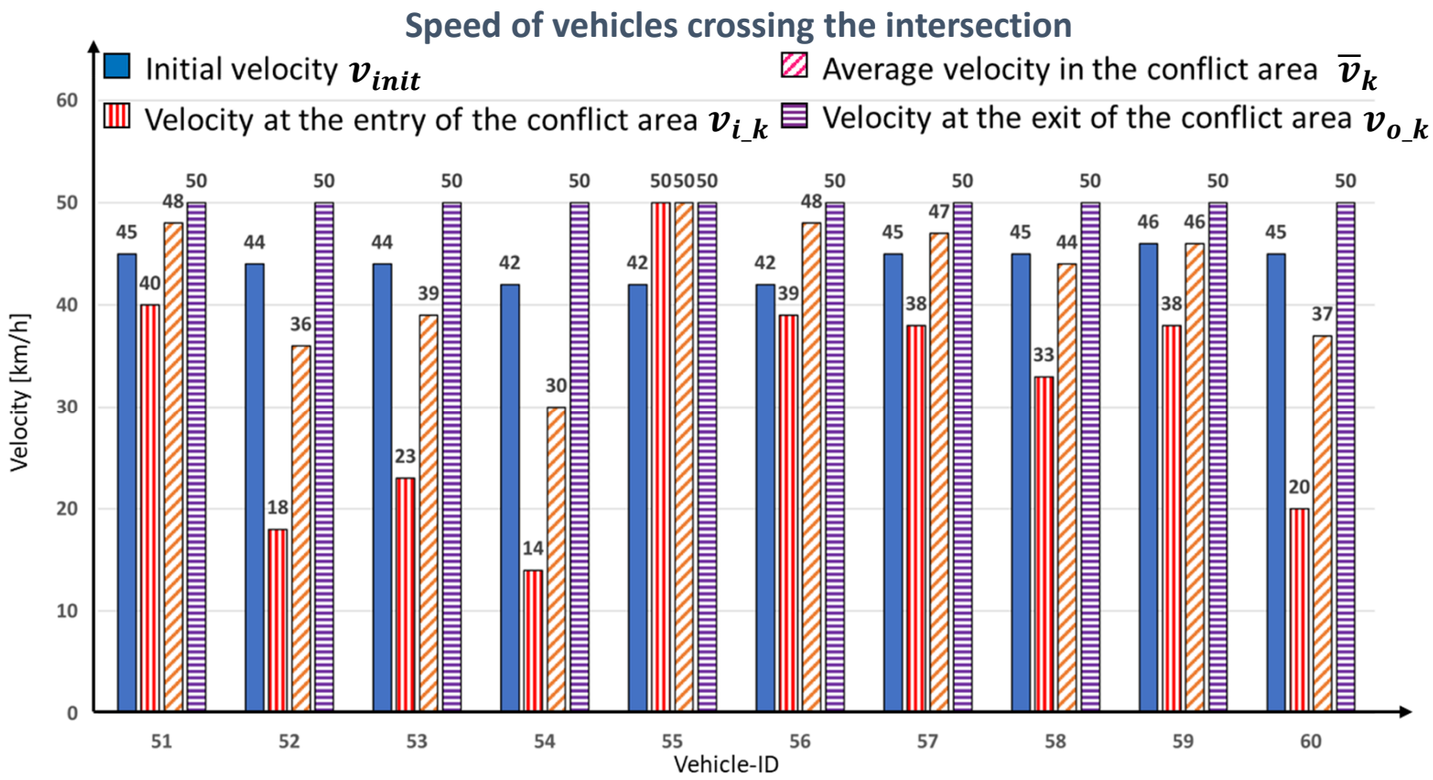


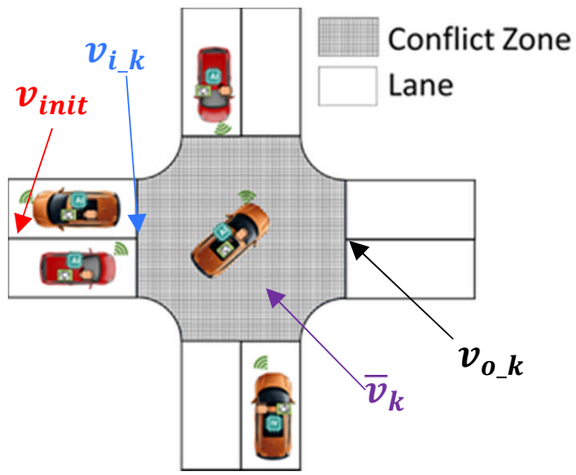
Intersection	
Width of the lane [m]	4
Width of the conflict zone [m]	24
Vehicle model	
Vehicle length [m]	4
Width of the vehicle [m]	1,9
Max. Acceleration [m/s^2]	4,5
Max. Brake [m/s^2]	10
Max. Velocity [km/h]	50

Function validation via MiL-Simulations

Analysis of the simulation results

Test case 1: Single intersection with regular traffic volume in all entry directions





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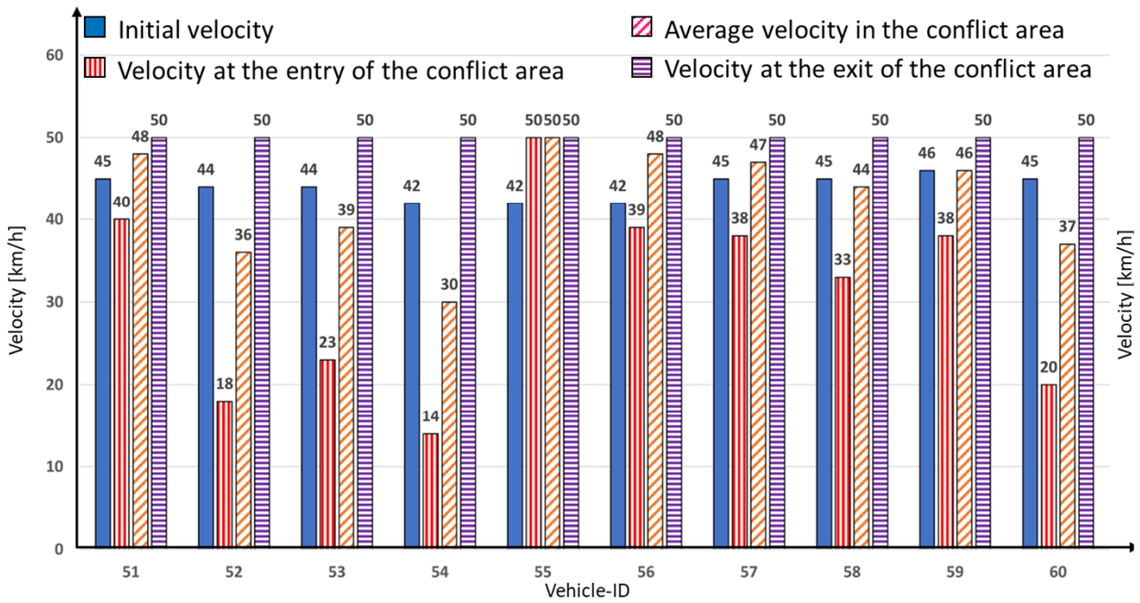
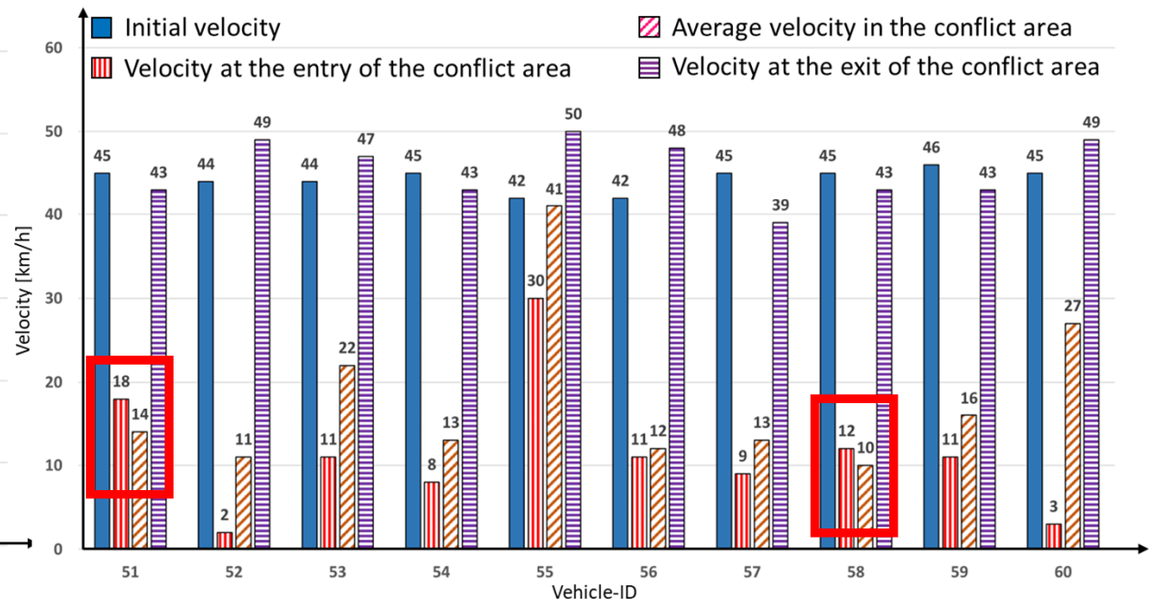


Speed of vehicles crossing the intersection with traffic volume of 3600 vehicles/h.



Speed of vehicles crossing the intersection with traffic volume of 7200 vehicles/h.

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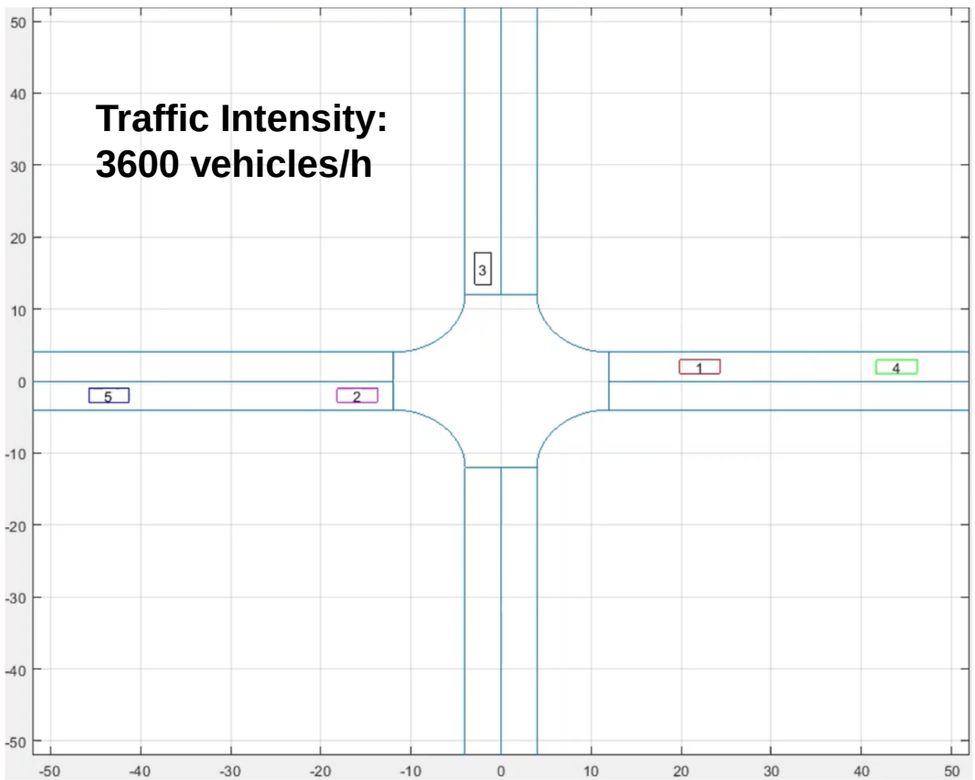

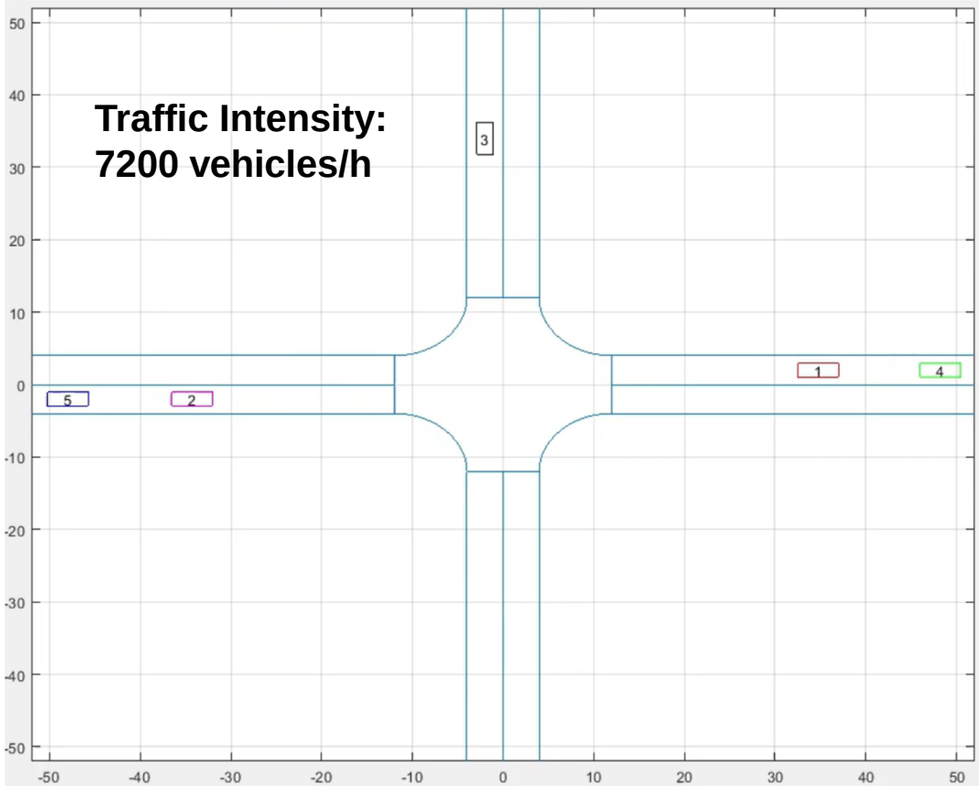

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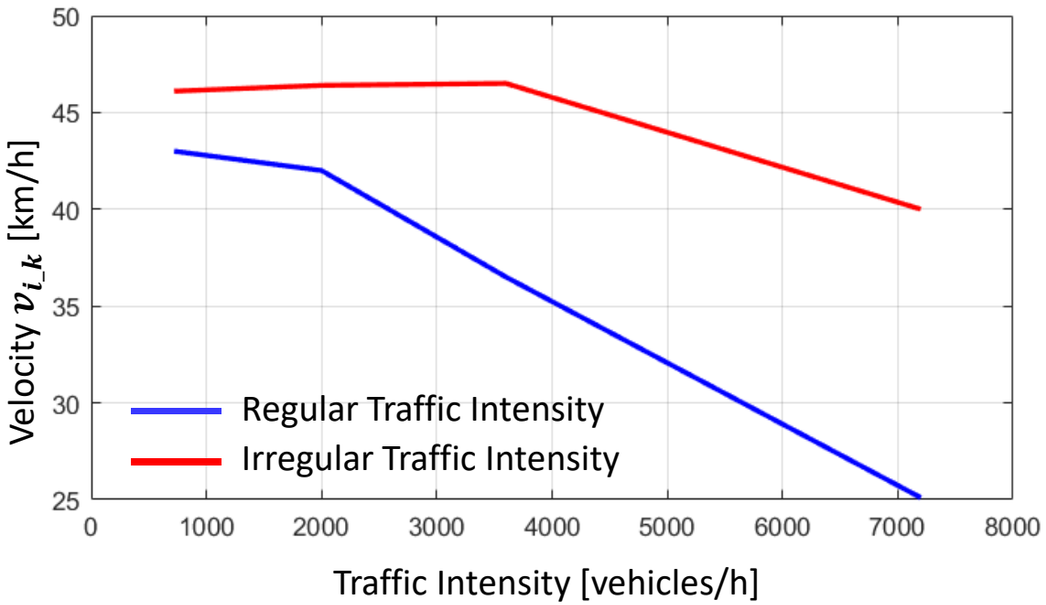
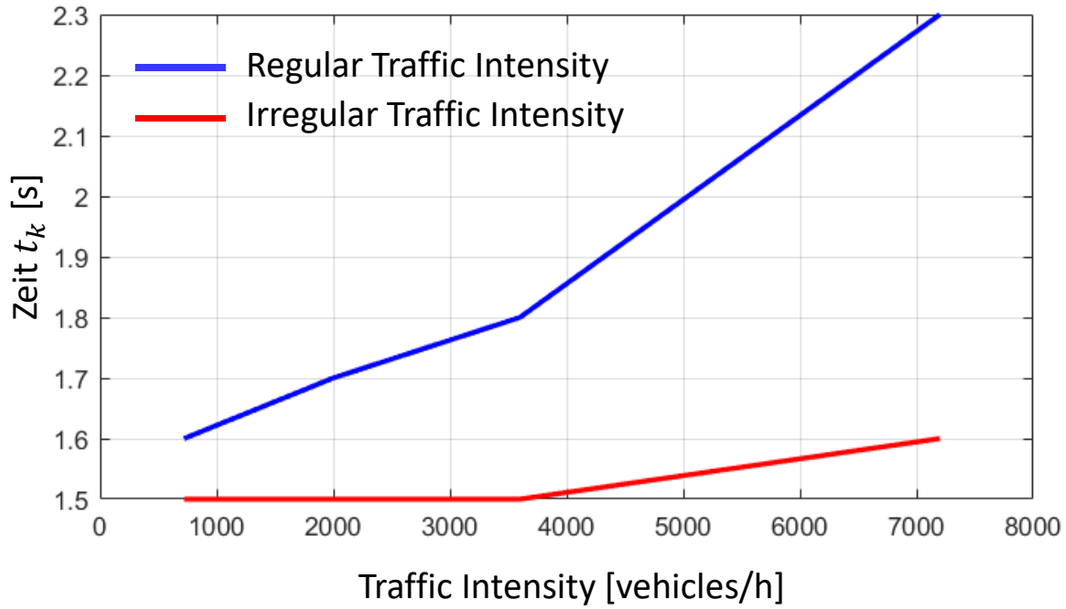
Function validation via MiL-Simulations

Analysis of the simulation results

Test case 2: Single intersection with irregular traffic volume in entry directions

Traffic intensity in east-west direction = **2*** Traffic intensity in north-south direction





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Function validation via MiL-Simulations

Analysis of the simulation results

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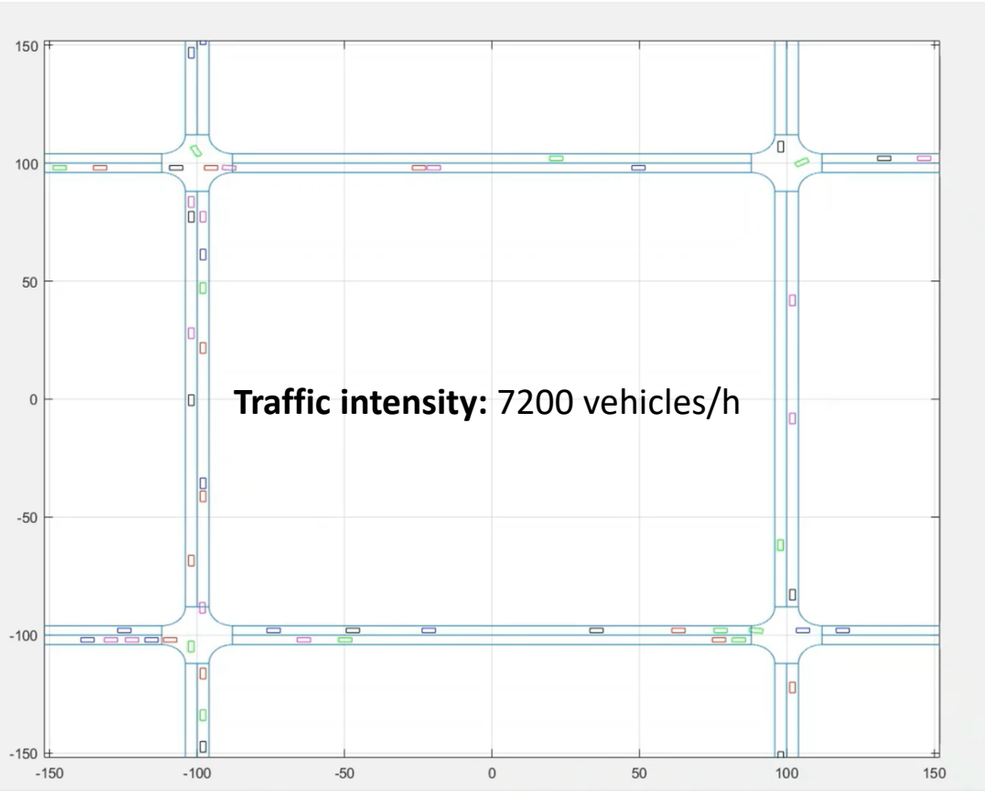

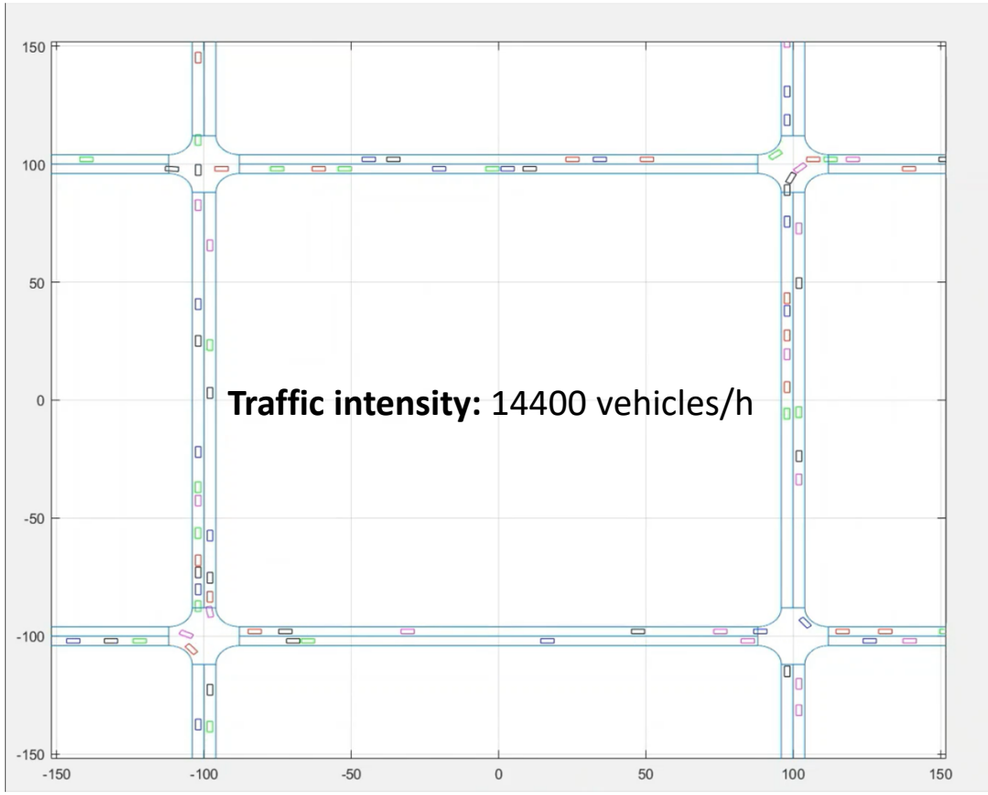

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Conclusion

- Development of the decentralized cooperative intersection management system
- Creation of the system and functional structure of the CPS based on the requirements
- Validation of the functionality through Simulation in virtual test bench with different traffic intensity
- Application in intersections with different topological characteristics
- Evaluation of the performance of centralized and decentralized intersection management

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