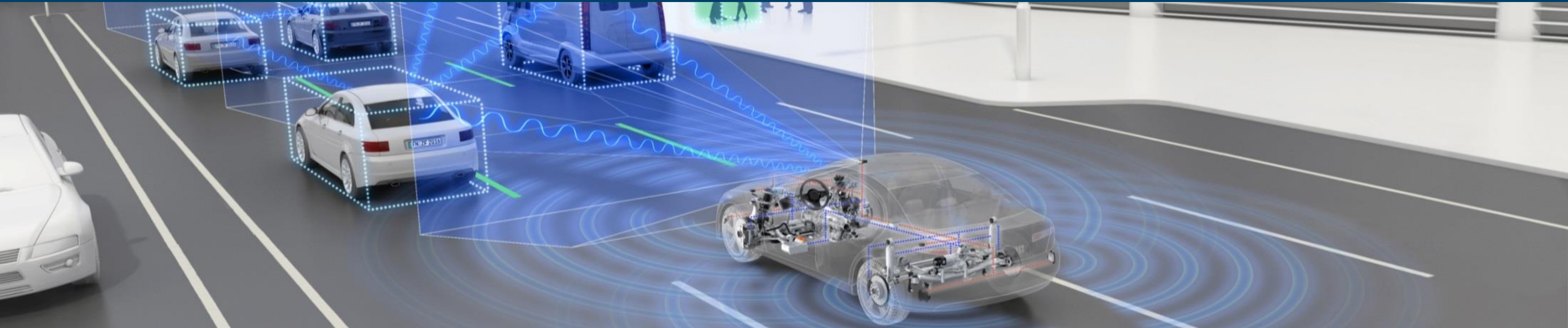
# Model-based Development of Low-speed Vehicle Motion Control Algorithms for Automated Driving Functions

Dr. Marco Wegener, Hemanth Chakravarthy



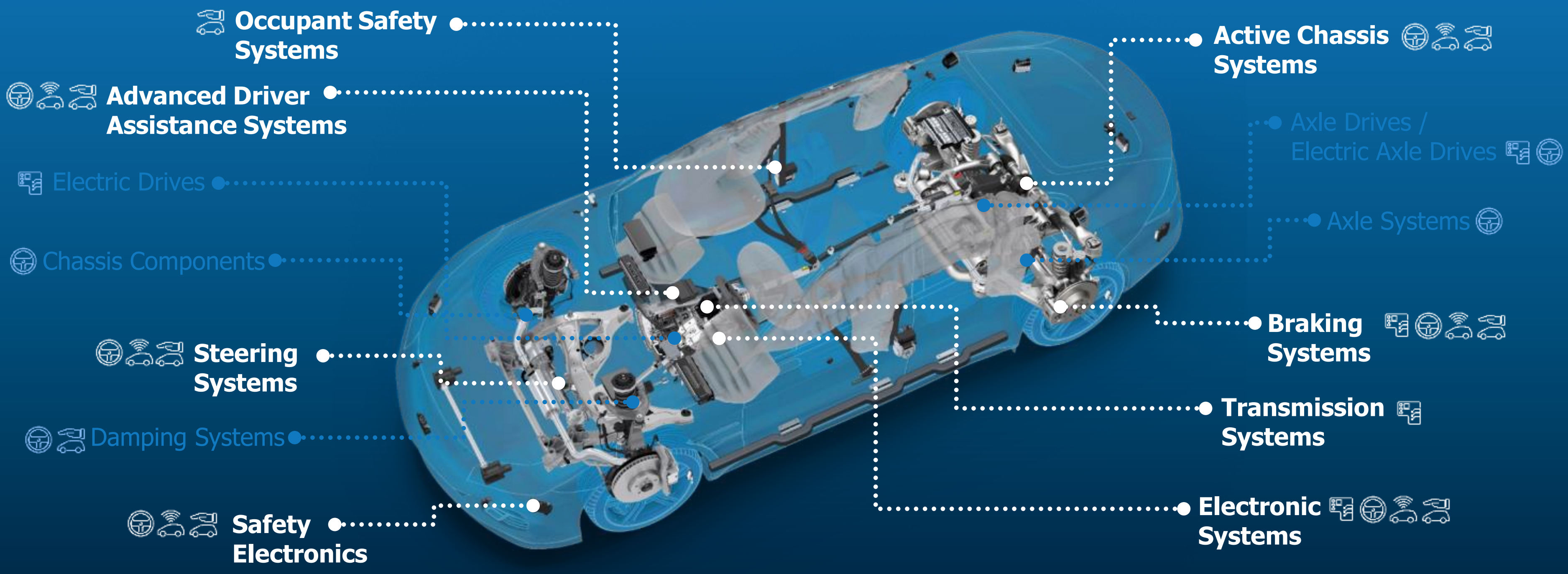
# Agenda

1. ZF Introduction
2. Overview Automated Driving Systems
3. Model-based Development of Vehicle Motion Control Algorithms
4. Development Results
5. Conclusion & Outlook

# 01
# ZF Introduction

# ZF Technology Domains

# ZF Product Portfolio for Automated Driving




Electrified Powertrain : Vehicle Motion Control: Automated Driving: Integrated Safety:

# 02
# Overview Automated Driving Systems

# Evolution of Automated Driving Systems

# Scalable System Architecture
# Example: Parking Functions

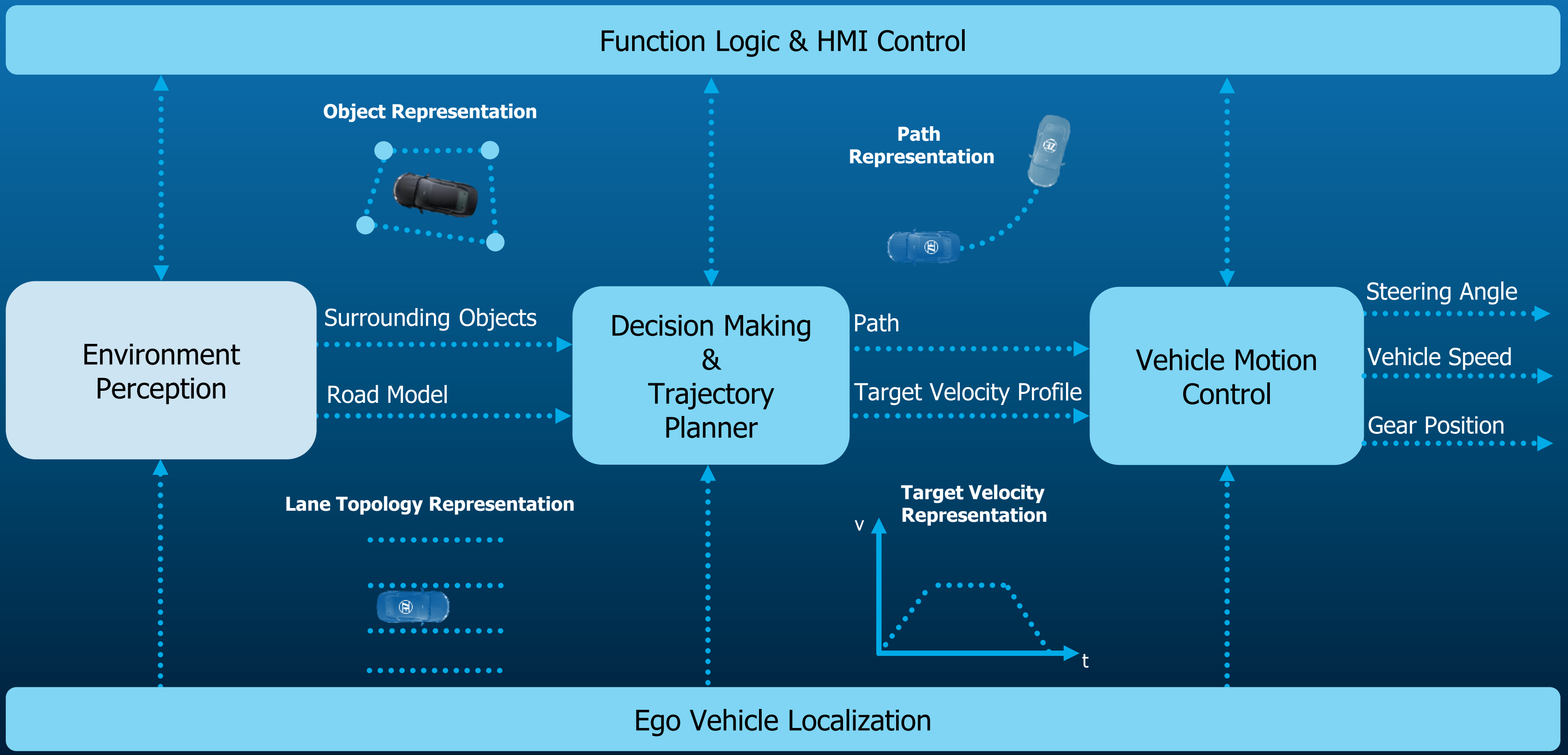
- Basic Park Aid
  - Front & Rear Ultrasonic Sensors
  - Rear Camera
- Semi and Fully Automated Park Assist (Object-based)
  - Front & Rear Ultrasonic Sensors
  - Rear Camera
  - Corner Radars
- Fully Automated Park Assist (Object & Marking-based) Remote & Valet Parking
  - Front & Rear Ultrasonic Sensors
  - Corner Radars
  - Surround Cameras

# 03

# Model-based Development of Vehicle Motion Control Algorithms

# Target Functional Architecture

Model-Based development
Non-Model-based (Manual Coding)



# Development Goals

- **Trajectory Planning**
  - Flexible to any potential perception layer interface
  - Capable of all kind of low-speed maneuvers (traffic jam, urban driving, parking)

- **Vehicle Motion Control**
  - Combined lateral and longitudinal control
  - Able to handle actuator constraints and time delays
  - High precision

- **Tooling**
  - Time-efficient implementation & testing with small agile development teams
  - Setup of a simulation framework
  - Establish toolchain to derive Key Performance Indicator driven function performance reports to track progress

# Challenges of Algorithm Design

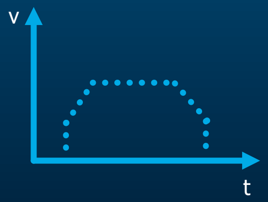
## Trajectory Planning

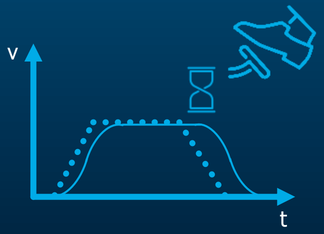
- Indefinite number of potential planning algorithms
- Many concepts fail to consider:
  - Passenger car dynamic constraints
  - Multi-stroke path planning
  - Reproducibility requirement

- Re-use of well-established planning algorithm desired
- Need to pick an appropriate concept right from the beginning to meet mass-production requirements

## Vehicle Motion Control

- High precision within cm range required
- Odometry of mass production vehicles is inaccurate close to standstill
- Actuators delay algorithm requests by low-pass filter or dead time behavior (e.g. braking down to standstill)



# Benefits of Model-based Development for Automated Parking

**Trajectory Planning:**

- **Tools:** Automated Driving & Navigation Toolboxes provide a comprehensive set of different path planning algorithms including associated functionalities of:
  - Path Interpolation
  - Optimization
  - Visualization
  - Path Metrics
- **Support:** MathWorks engineering team support to figure out the pros & cons of each planning concept and to choose a concept that fits best to the intended application
- **Collaboration:** Engineering teams from ZF and Mathworks have mutually benefitted from monthly workshops to understand each other's need and therefore to improve their products

# Benefits of Model-based Development for Automated Parking

**Vehicle Motion Control:**

- Ready-to-use toolboxes as the Control System & Model Predictive Toolboxes provide advanced control algorithms capable of
  - Predicting control errors by taking into account planned trajectory and future vehicle motion
  - Consideration of actuators limitations & time delays
  - Comfort & safety requirements can be fulfilled already by design resulting in less tuning effort
- Simple integration into rapid-prototyping ECUs by using Simulink Coder and calibration tools for early vehicle tuning sessions

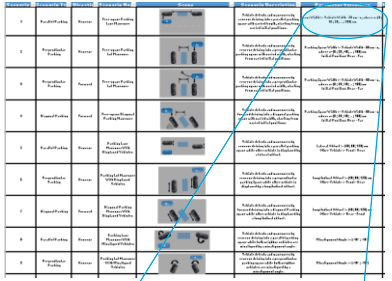
**Tooling:**

- Simulink enables function simulation at an early development stage and low-effort integration in simulation tools
- Built-in functions allow quick development of function-specific data analysis and performance validation frameworks

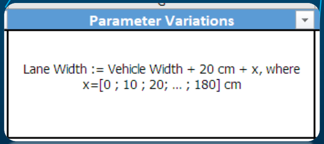
# 04
# Development Results

# Established Scenario-driven Development & Evaluation Process

## Use-case Specification

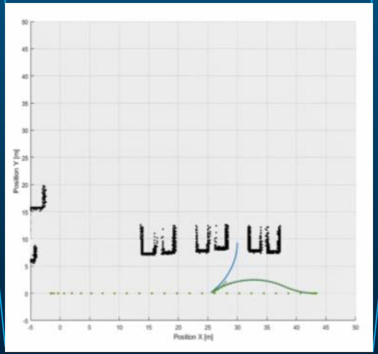


Scenario Catalogue



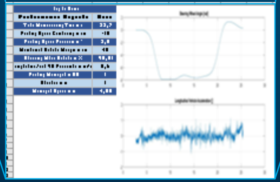

## Design & Implementation


Closed-loop Simulation Framework

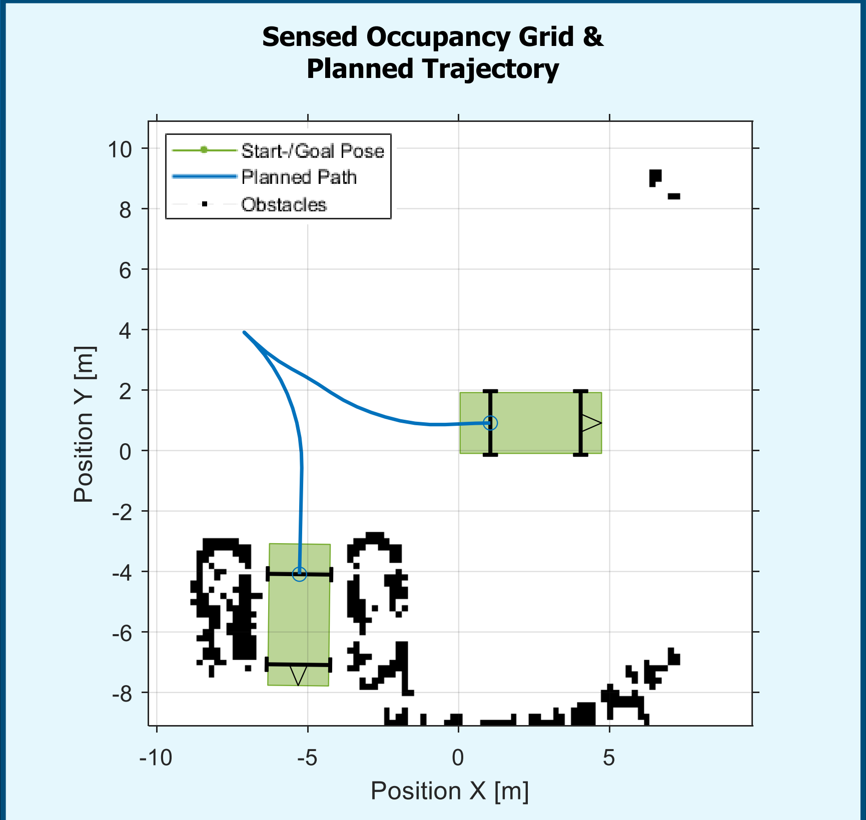


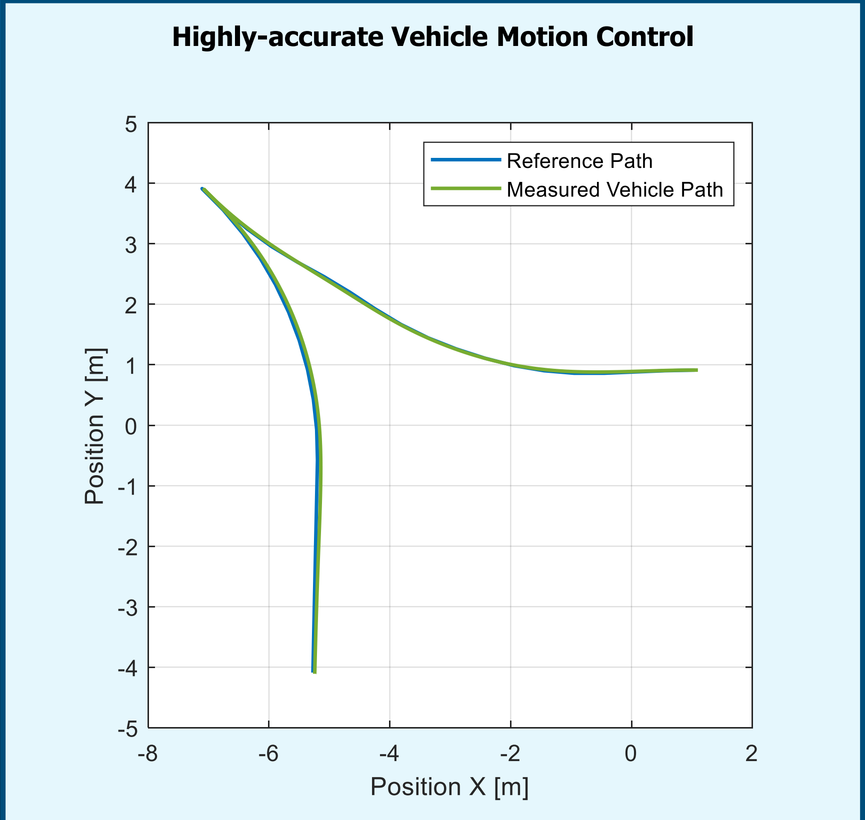

## Vehicle-level Validation

KPI-based Performance Evaluation



# Example Maneuver: Two-stroke Urban Maneuvering



# Realized Workflow for Continuous Performance Evaluation

**Data Logging**

**Data Management**
1. Upload Process
2. File Format Conversion

## MATLAB-based Performance Evaluation Tool

**Initialization**
1. Playlist Configuration
2. Run Evaluation Tool

**Automated Trimming**
1. Function-wise Use Cases and Scenario Identification
2. Log File Trimming

**Performance Evaluation**
1. Scenario-wise KPI Generation
2. Function-wise KPI Generation

**Report Generation**
1. Scenario Reports
2. Function-based Trend Report

**Result**
1. Mgt Dashboards
2. Detailed Performance Reports

**Validation Team**

**Database**

**Server**

# 05
# Conclusion & Outlook

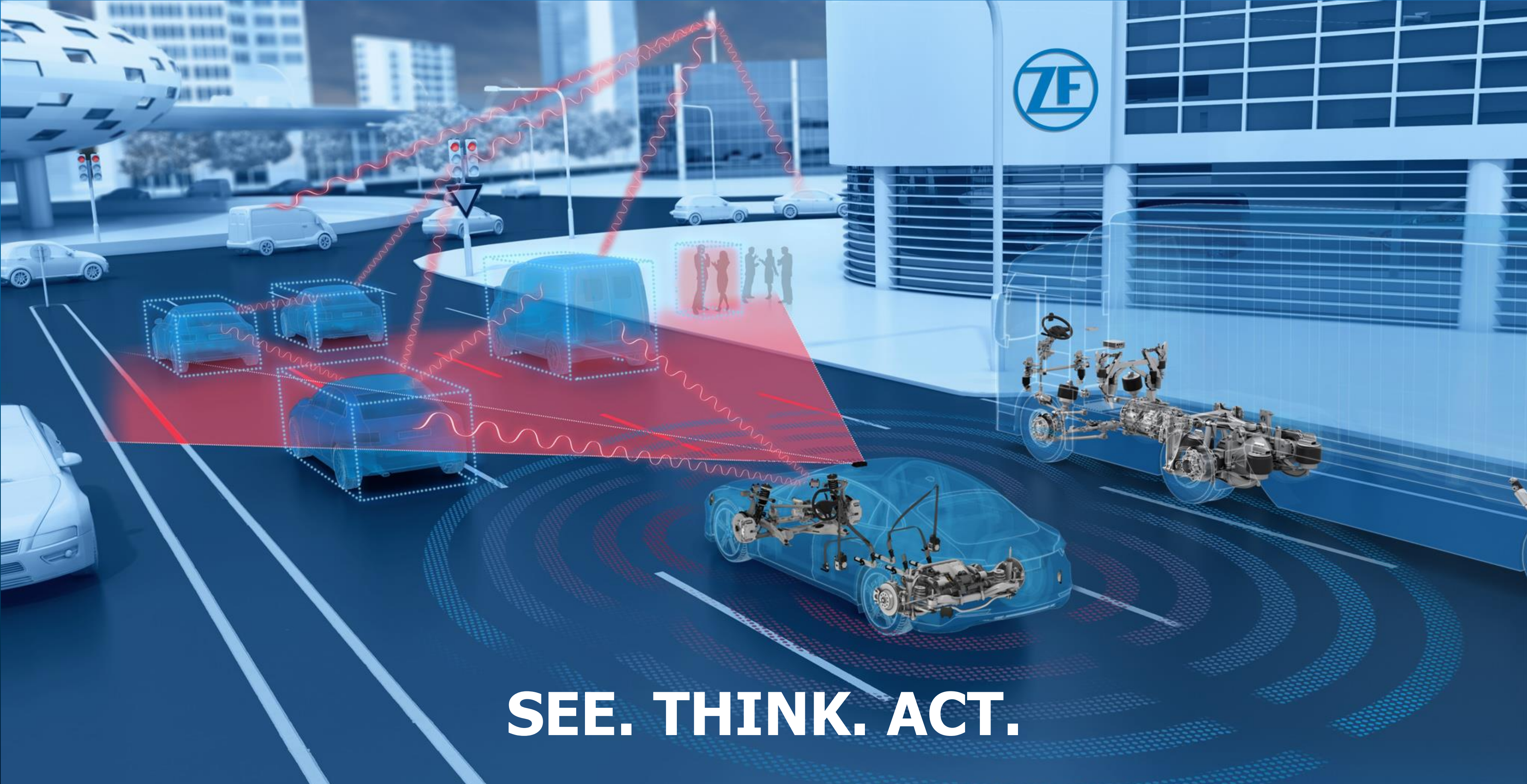
# Conclusion

**Summary:**

- ZF's ADAS function development is constantly evolving with new functions, each starting with a rapid-prototyping approach in the early project phases and then smoothly transitioning them into mass-production ready solutions
- Model-based software development is seen as an important building block for time and cost-efficient development processes
- Ready-to-use toolboxes by Mathworks enabled the development team to accelerate the development of Automated Driving functions

**Outlook:**

- Automated Driving functions will be further developed to cover extended use-cases and increased autonomy
- ZF will continue to benefit from rapid-prototyping capabilities enabled by additional toolboxes for localization, navigation and V2X communication


SEE. THINK. ACT.