Robotics in Practise – The Truck as a Mobile Robot




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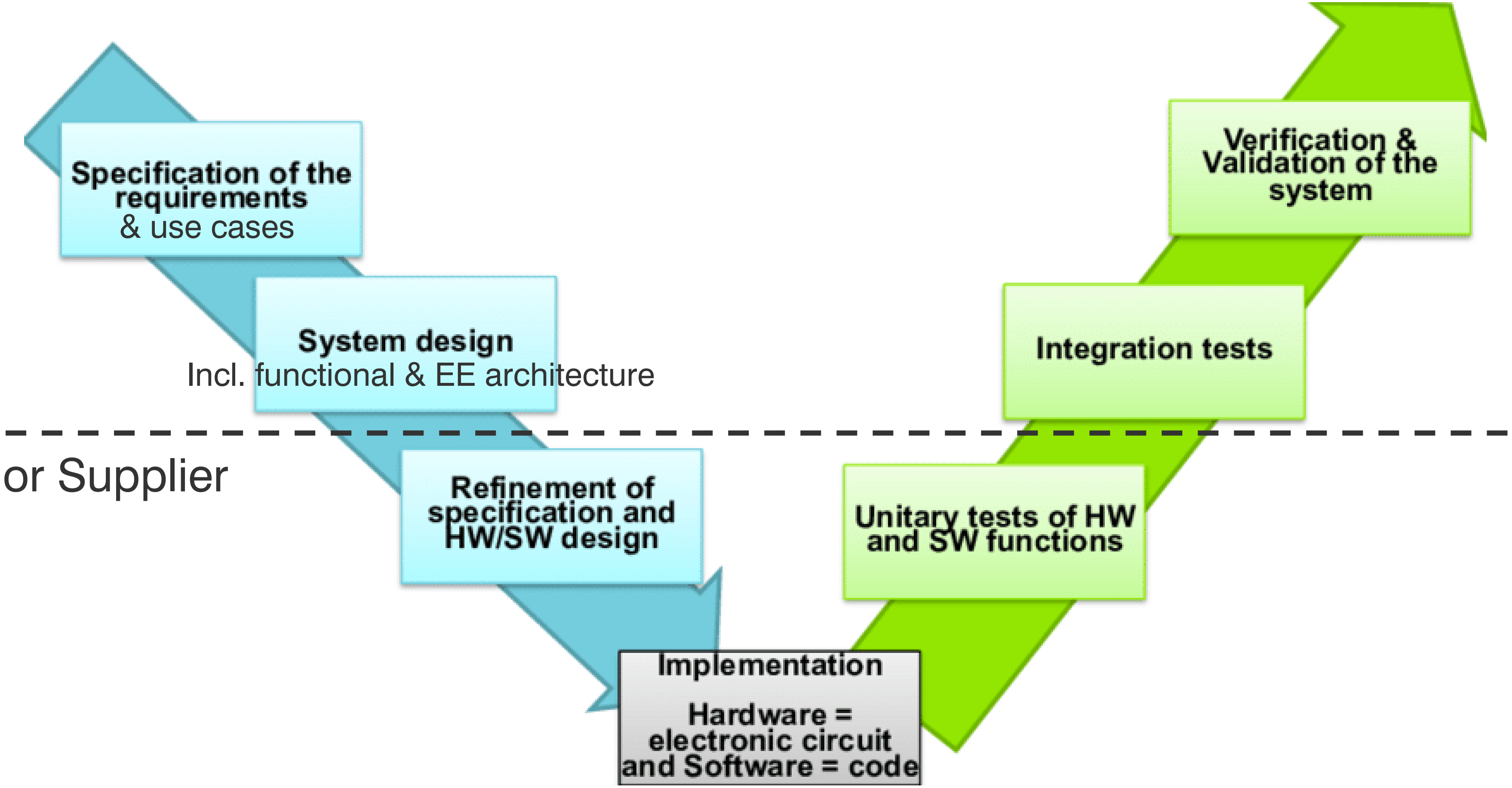
MRC learning objectives

No.	Learning objectives	Lecture “The Truck as a Mobile Robot”
1	Describe the ***problems*** of ***mobile robot navigation***	Use cases and requirements
2	Describe with your own words and develop a ***global path planning algorithm***, such as A*	High-level path planning (Hybrid A*)
3	Describe with your own words and develop a ***local path planner*** for obstacle avoidance.	Low-level path planning (CL-RRT)
4	Describe with your own words and develop a ***localization algorithm***, such as a particle filter.	Vehicle localization (feature detection, particle filter, point cloud matching (NDT))
5	Design an ***architecture*** that ***integrates different algorithms*** to enable a mobile robot to fulfill a given use-case	Control Function Architecture
6	***Validate*** your system architecture on a ***physical robot***.	Rapid Control Prototyping, Hardware-in-the-Loop, Vehicle Testing
7	Use ***tools*** common in robotics industry	DAF tools (Simulink, dSPACE, Python, ROS…)

Development process



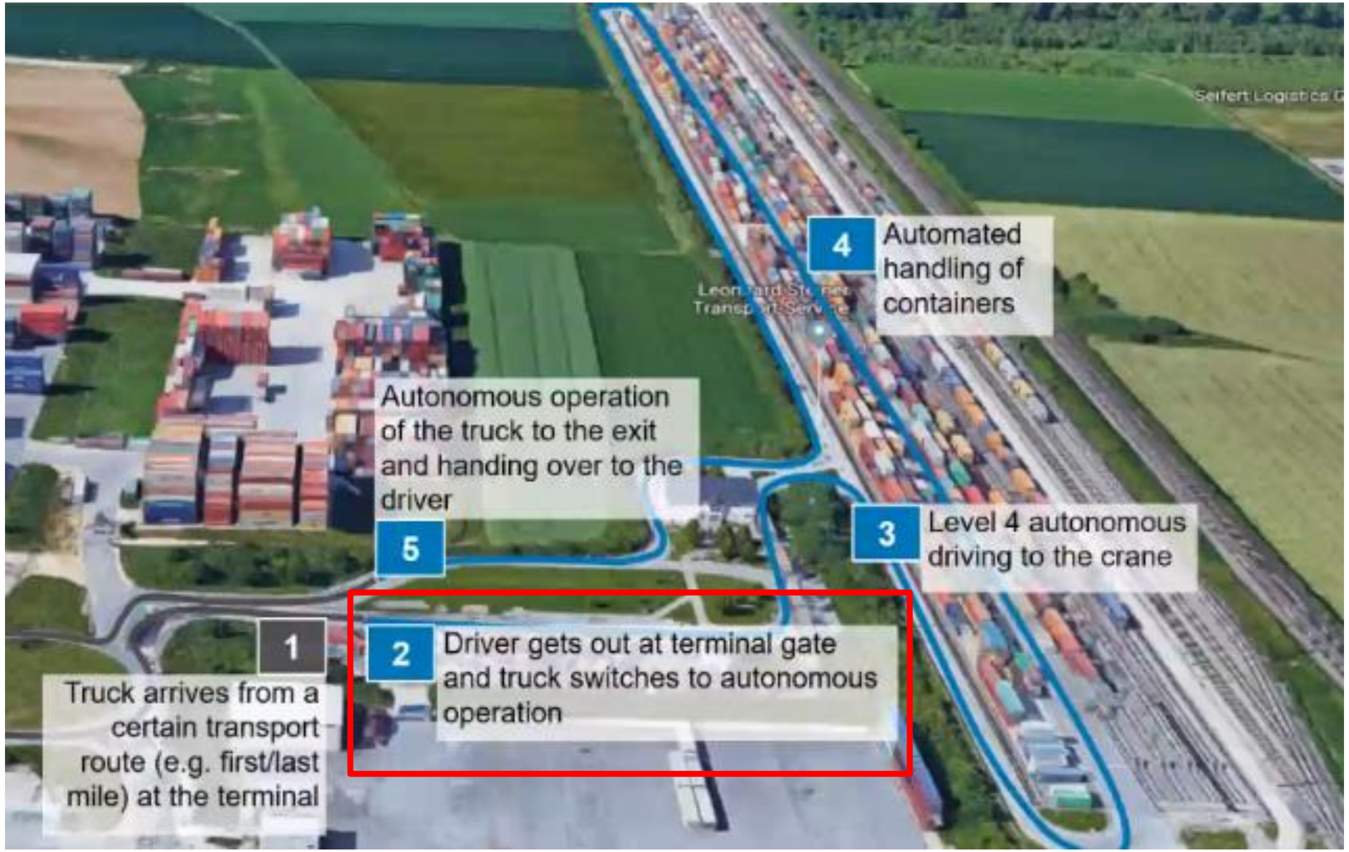
DAF

DAF or Supplier

[ISO 26262 V-cycle Development Process. | Download Scientific Diagram (researchgate.net)]

Use case example

ID	UC01 (i.e. see step 2 in picture)
Name	Drop off
Description	Driver stops vehicle at drop off area and activates Yard Automation (YA) function
Initial condition	Driver arrives at the terminal (step 1)
Trigger	Driver activates YA e.g. via switch.
Sequence	1. Driver stops vehicle at drop off area and activates park brake. 2. Driver activates YA e.g. via switch. 3. YA searches for Control Tower wireless network. 4. YA requests driver to accept connection with network. 5. When connected: YA takes over vehicle control.
Final condition	YA is enabled, vehicle and Control Tower are connected. Vehicle at standstill and from now on YA performs driving task (i.e. step 3).



[Tran2020, ANITA project]

Requirements example

Functional requirements

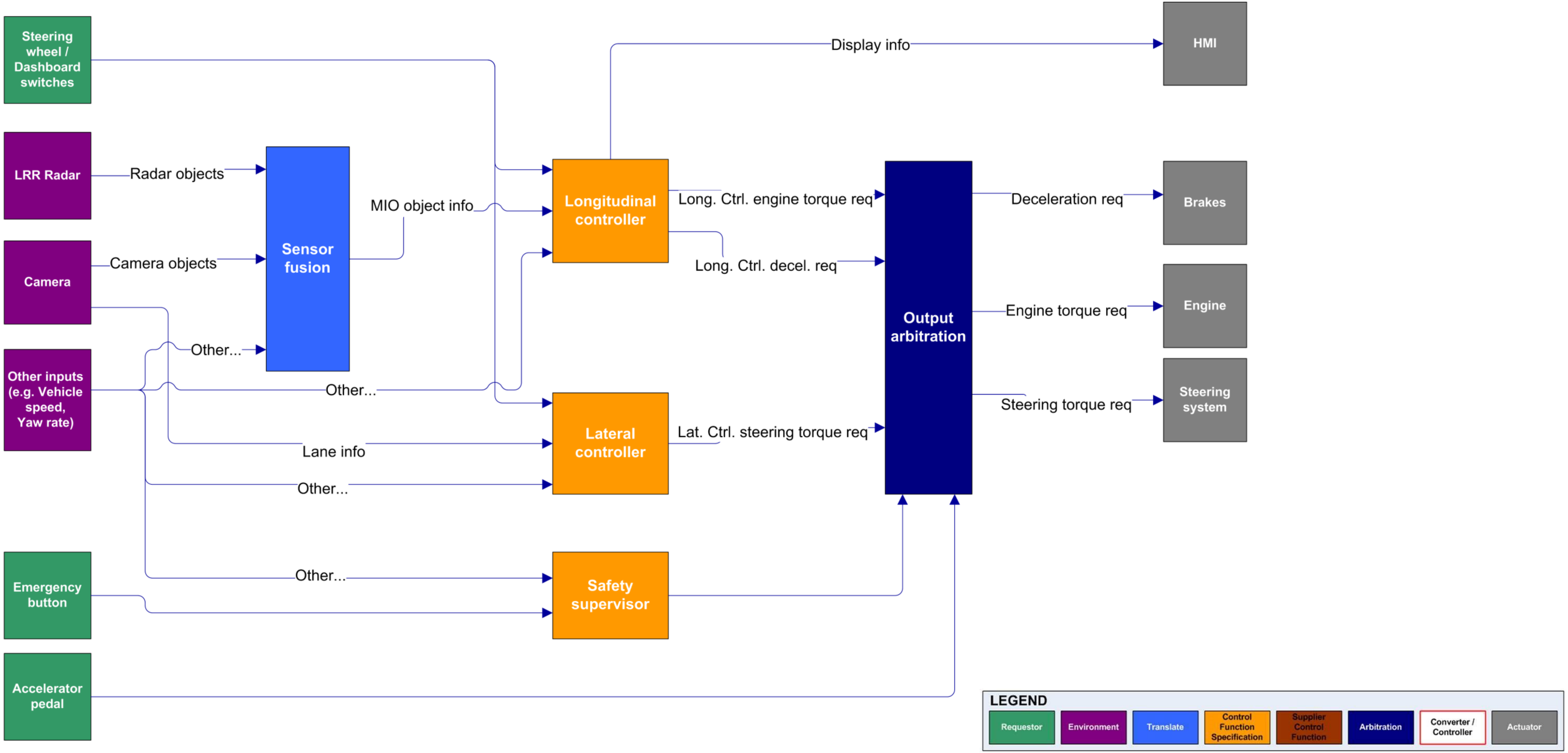
REQ01-001	Description:	Driver shall be able to activate YA e.g. via a switch if the following conditions are fulfilled: ▪ Vehicle is standing still ▪ Park brake is applied
	Name:	**Driver activation**
	Source:	DAF, UC01
	Rationale:	Driver shall be able to decide when YA can take over the driving task. The vehicle shall be in a safe state to transfer the control from driver to YA.

REQ01-002	Description:	YA shall continuously inform the driver about its enabled state.
	Name:	**Inform while enabled**
	Source:	DAF, UC01
	Rationale:	Keep driver informed about its role and about the L4 function status.

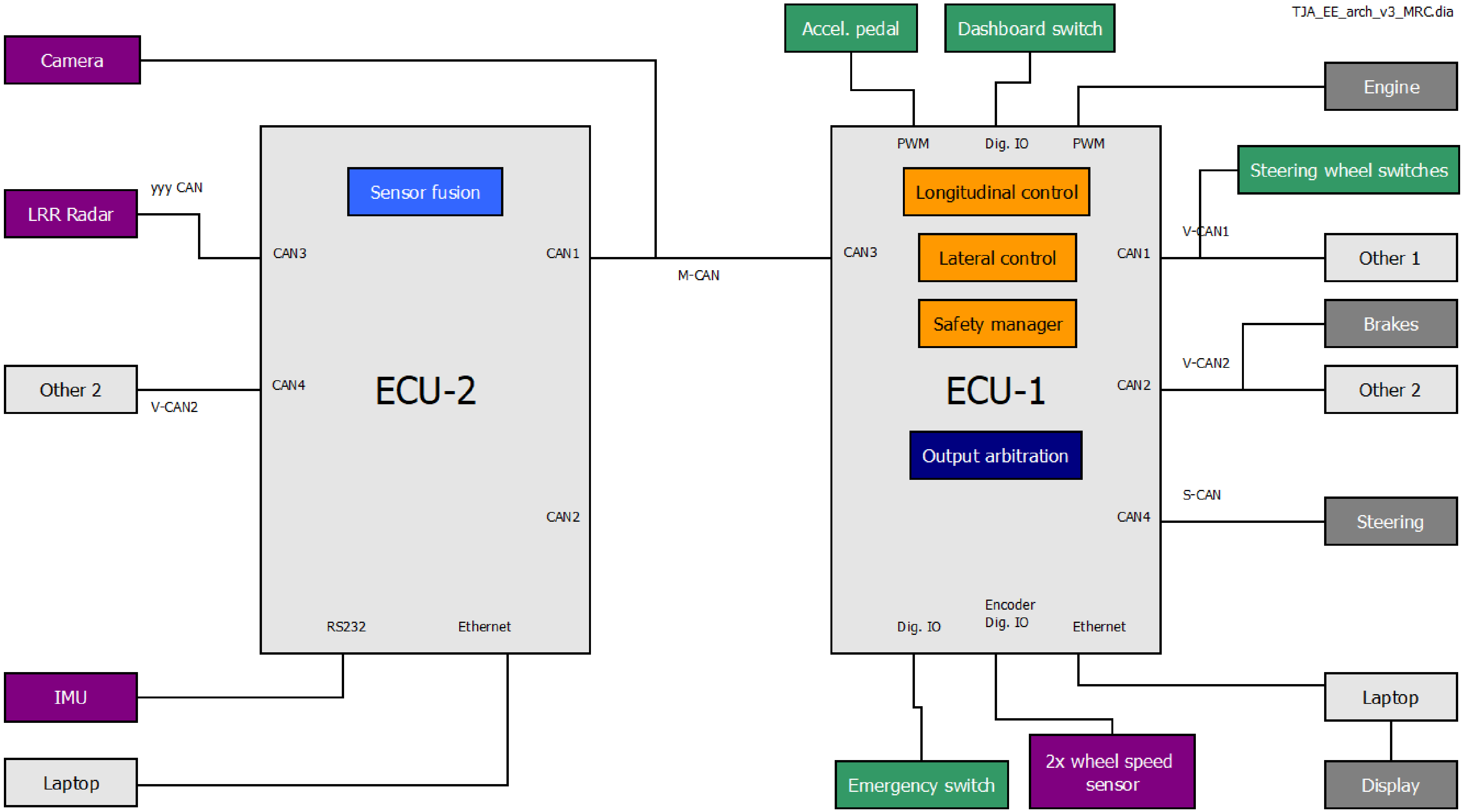
Non-Functional requirements (e.g. performance)

REQ00-001	Description:	YA shall be available in the vehicle speed range from -5 km/h up to 30 km/h.
	Name:	**Vehicle speed range**
	Source:	DAF
	Rationale:	YA shall include forward and backward driving. Maximum speed limited for safety reasons.

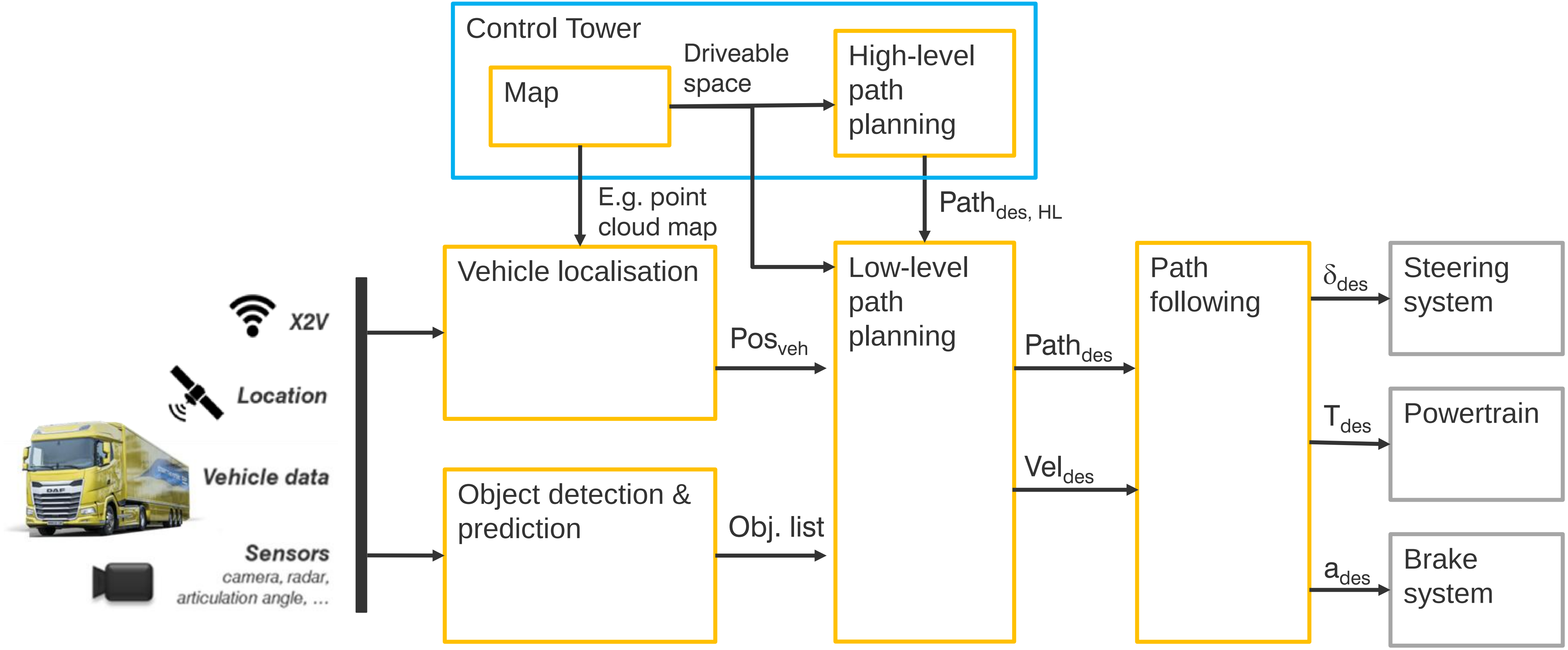
Functional architecture (example Traffic Jam Assist)



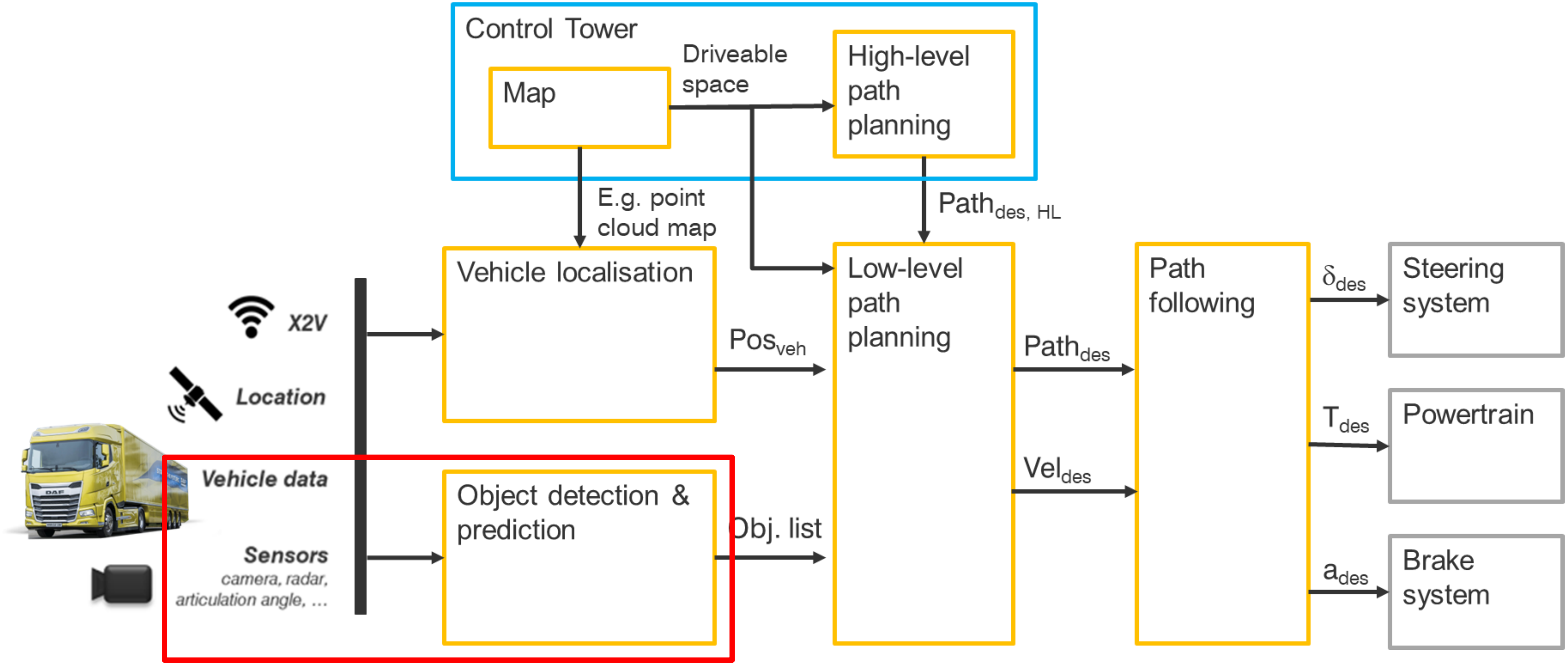
EE architecture (example Traffic Jam Assist)



Building blocks for automated driving



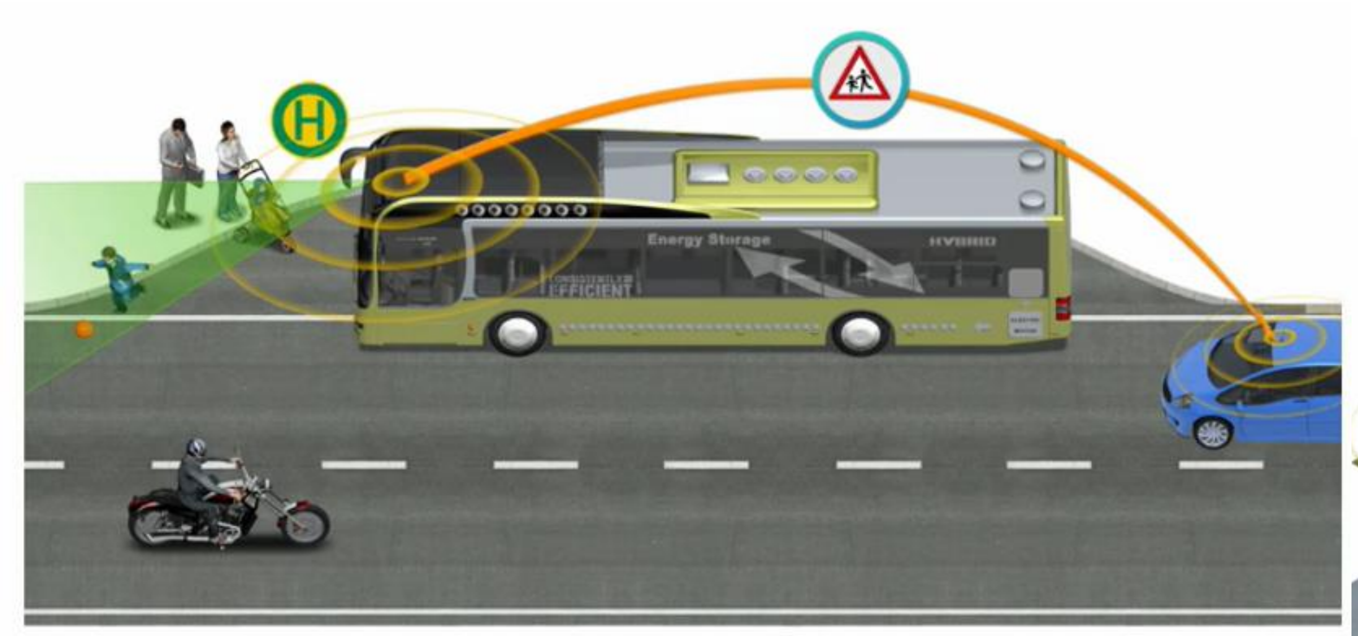
Building blocks for automated driving

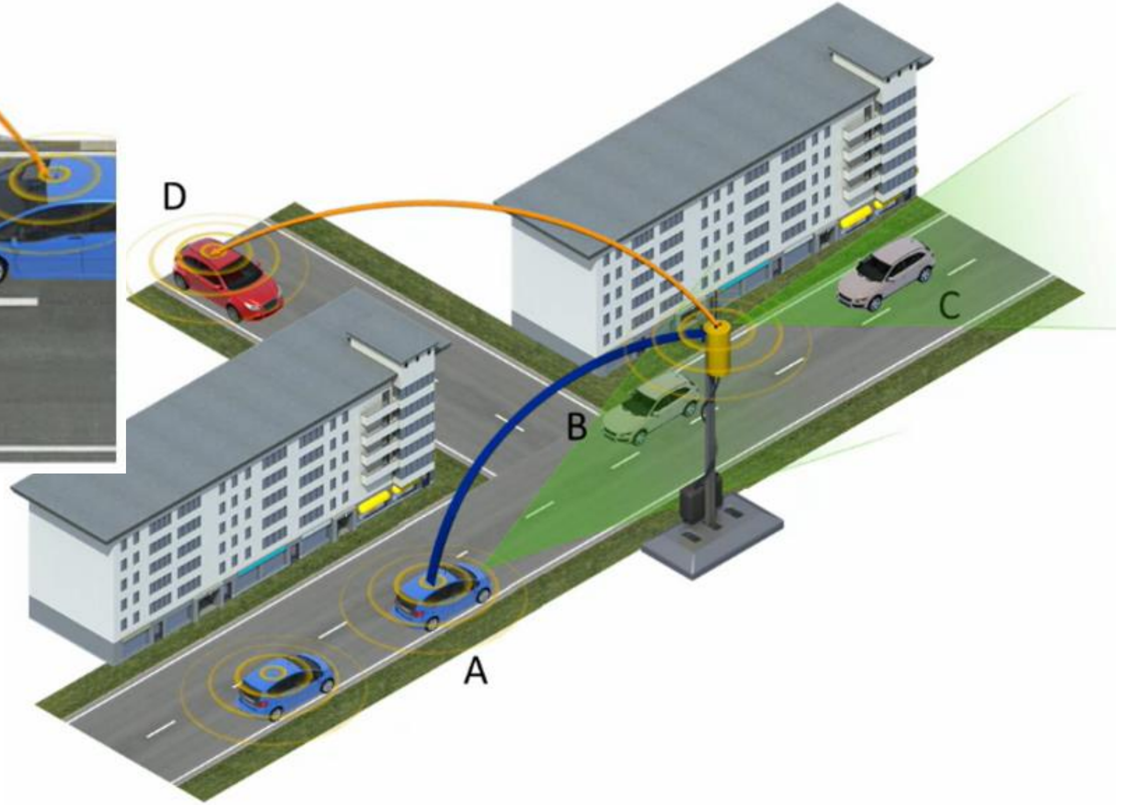


Object detection (using on-board sensors)

Type	Example	Pros	Cons
Camera	 [ZF]	- Good feature detection (e.g. lanes, VRU's) - Accurate in lateral direction	- Bad robustness for weather conditions
Radar	 [Continental]	- Good robustness for weather conditions - Accurate long. distance and speed measurement	- Limited feature detection - Limited lateral distance and speed measurement
Lidar		- Very accurate long. and lat. distance measurement - Suitable for accurate localization	- High costs - Not so robust as radar and ultrasonic
Ultrasonic	 [Bosch]	- Low costs - Good robustness for weather conditions	- No feature detection - Limited accuracy and range

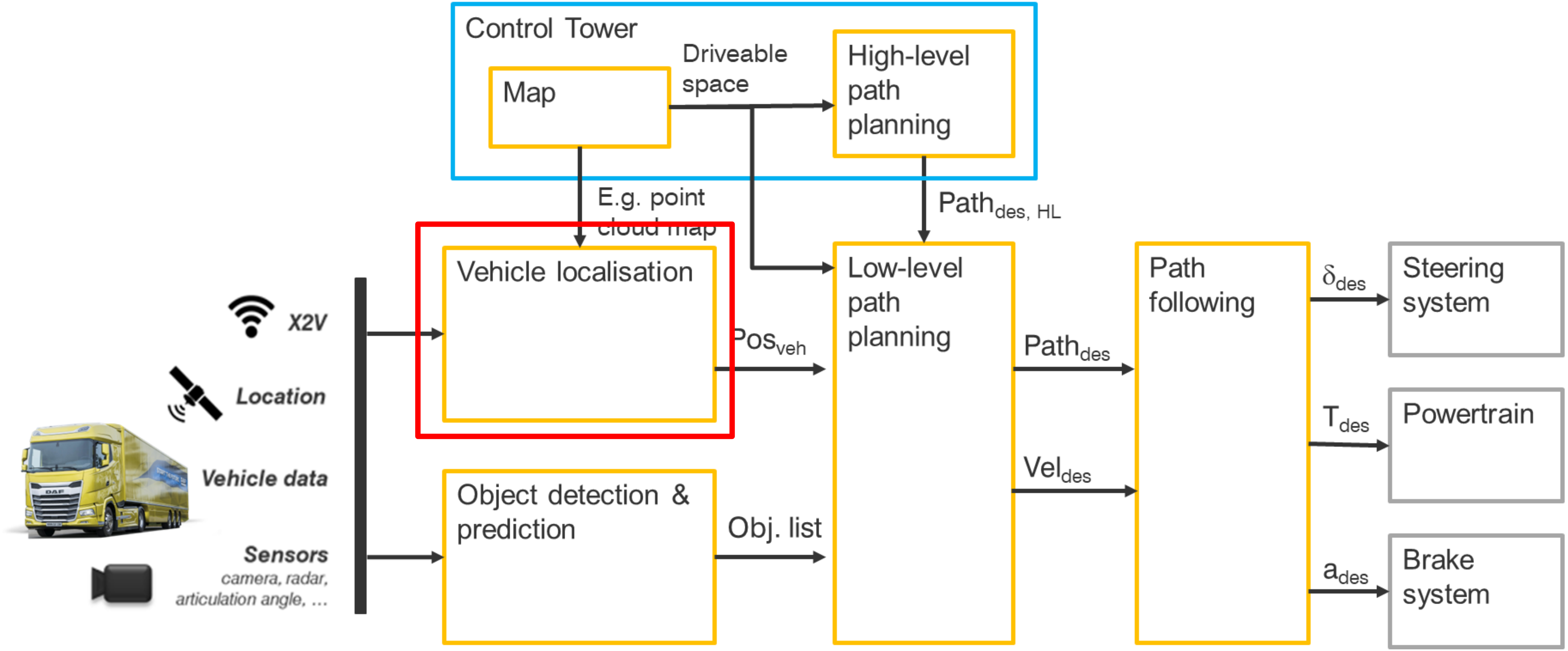
Object detection (using V2X information)



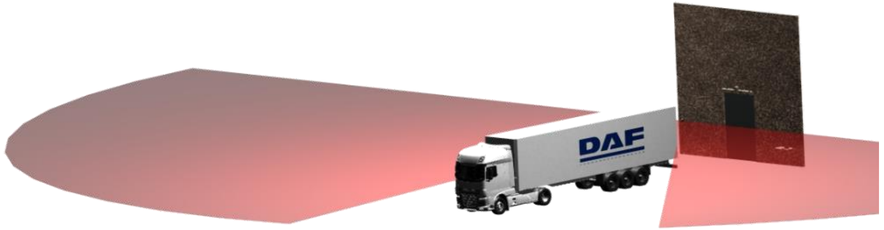


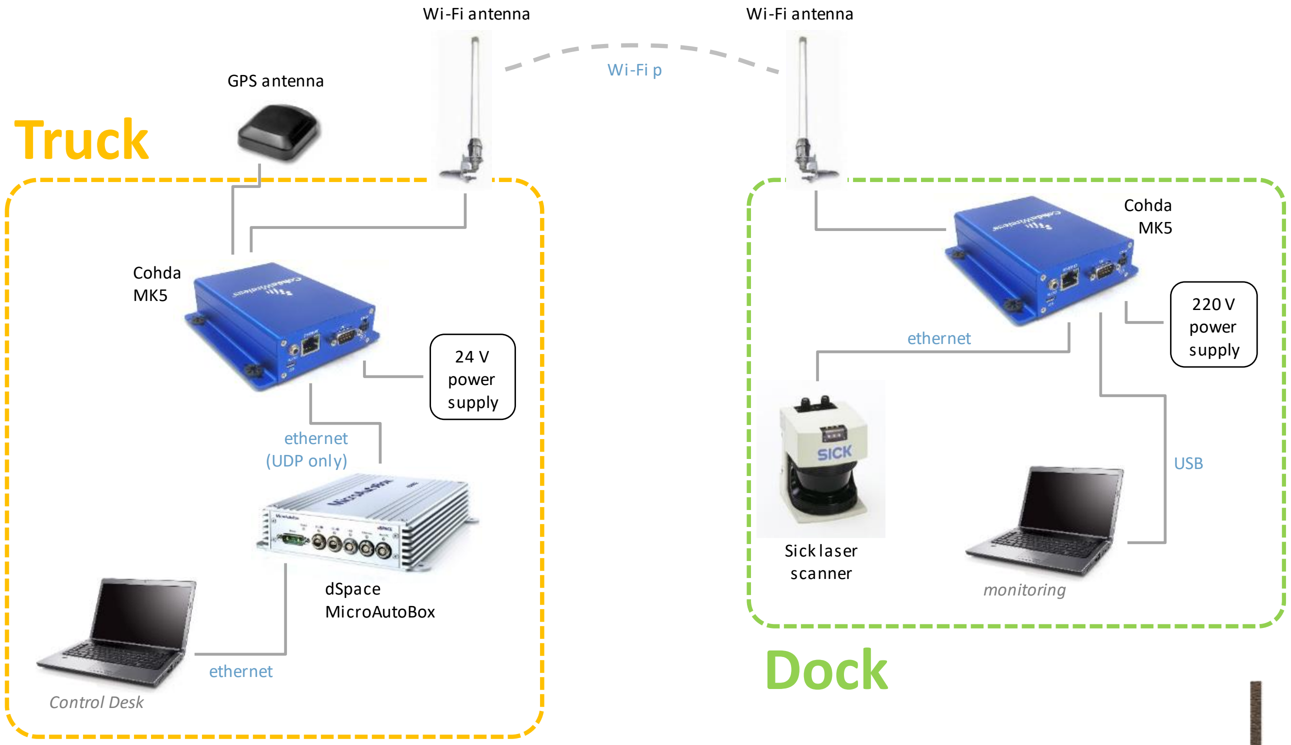
[F. Schiegg. Removing blind spots: Infrastructure-assisted collective perception. VDI ELIV conference 2021]

Building blocks for automated driving

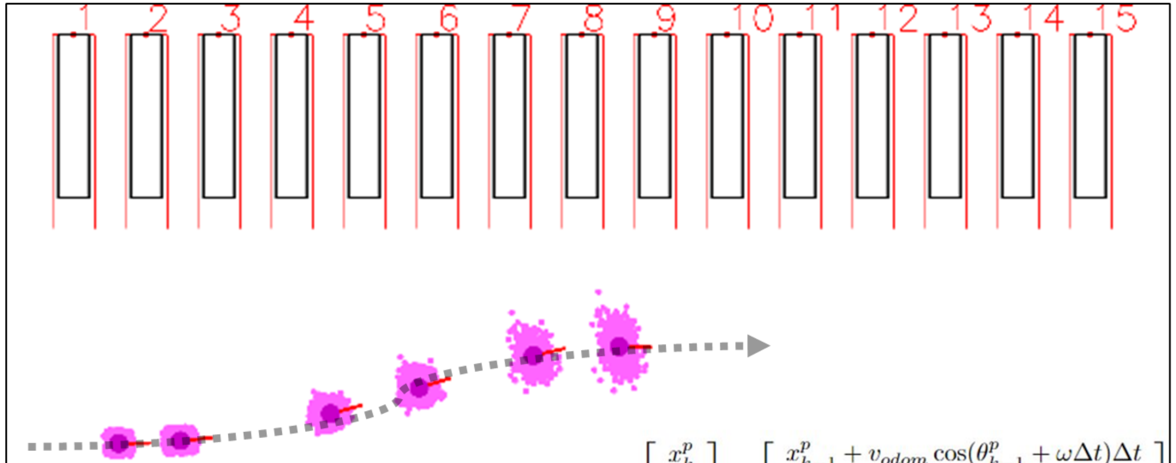


Vehicle localization
(example 1)



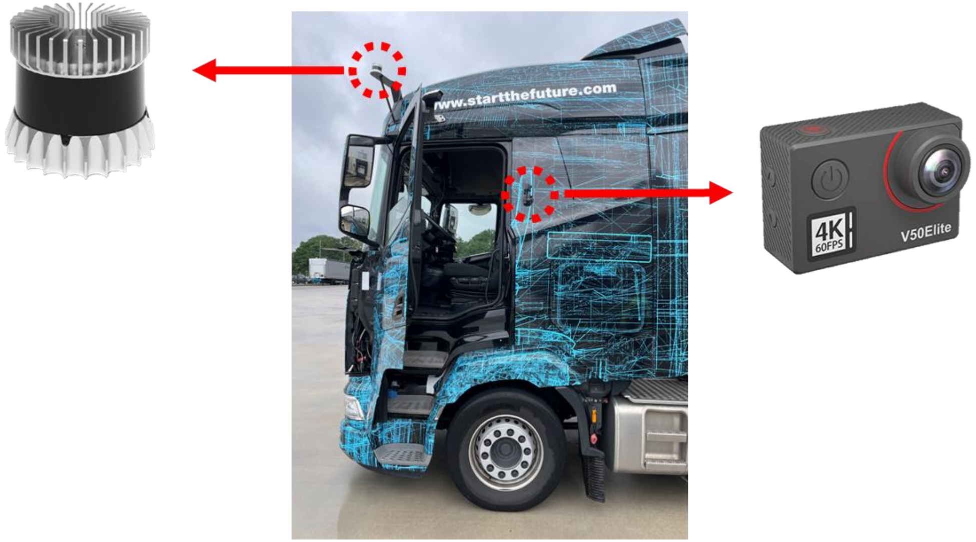


Vehicle localization (example 2)



$$x_k = \begin{bmatrix} x_k^p \\ y_k^p \\ \theta_k^p \end{bmatrix} = \begin{bmatrix} x_{k-1}^p + v_{odom}\cos(\theta_{k-1}^p + \omega\Delta t)\Delta t \\ y_{k-1}^p + v_{odom}\sin(\theta_{k-1}^p + \omega\Delta t)\Delta t \\ \theta_{k-1}^p + \omega\Delta t \end{bmatrix}$$

$$u_k = \begin{bmatrix} v_{odom} \\ \delta_{odom} \end{bmatrix}$$



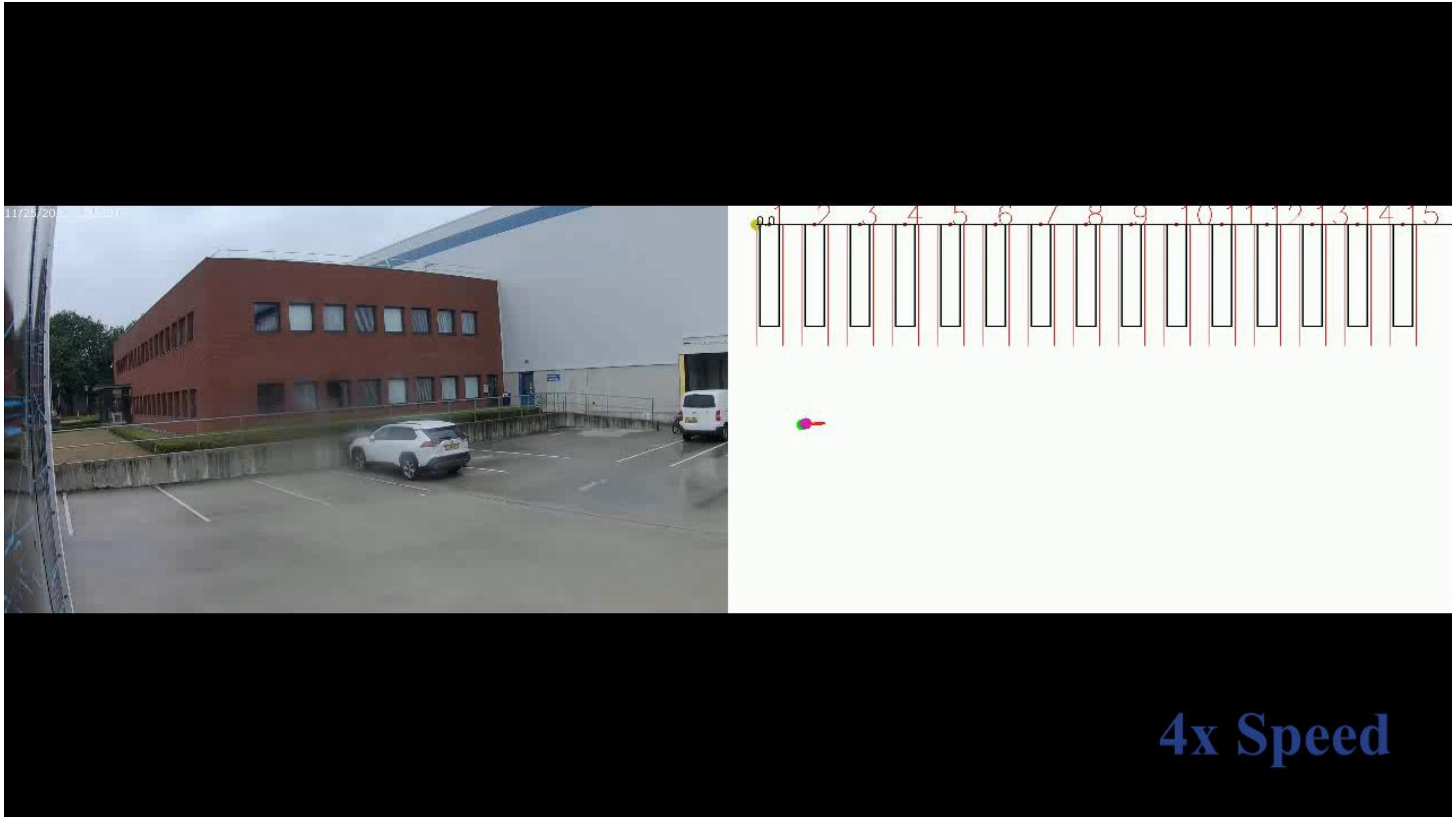
Localization using a particle filter

[Kokkelmans2022, Konings2022]

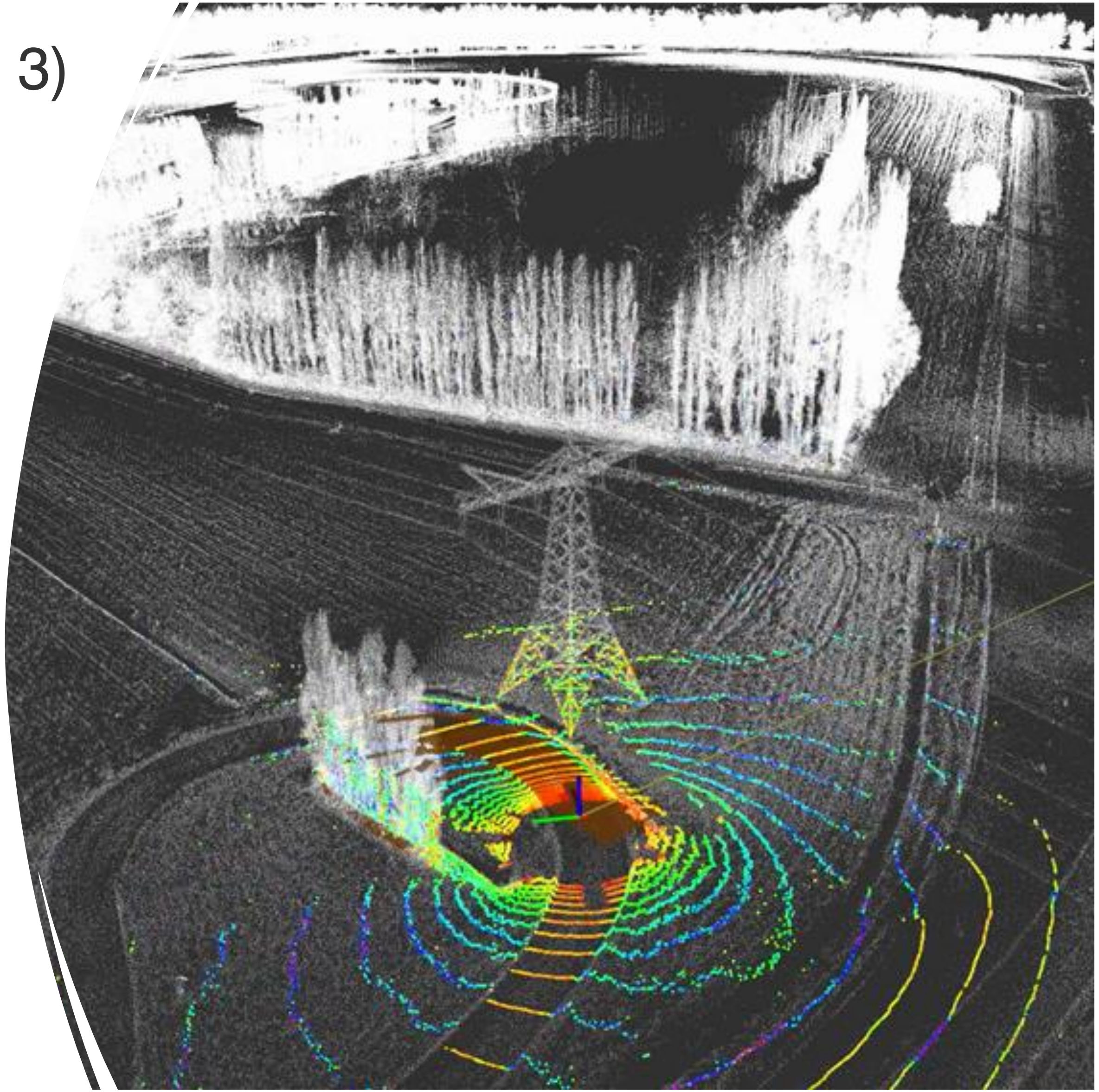
Vehicle localization (example 2)

[Konings2022]

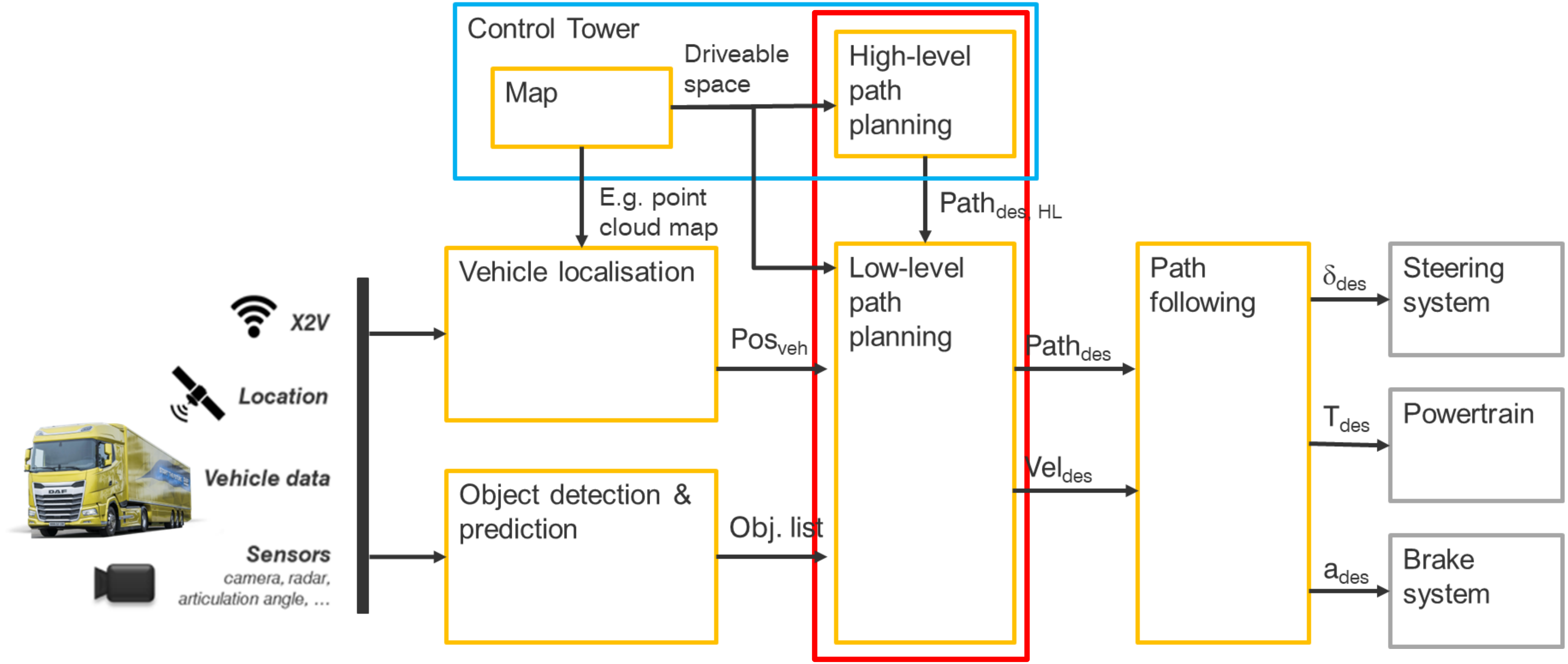
- Green: Ground Truth position
- Yellow: Camera measured position
- Pink: Particle Filter estimated position



Vehicle localization (example 3)



Building blocks for automated driving



Path planning (example high level planner: Hybrid A*)

- Use the simplified model to find a global path
- Obstacle avoidance at global level
- Decide driving direction

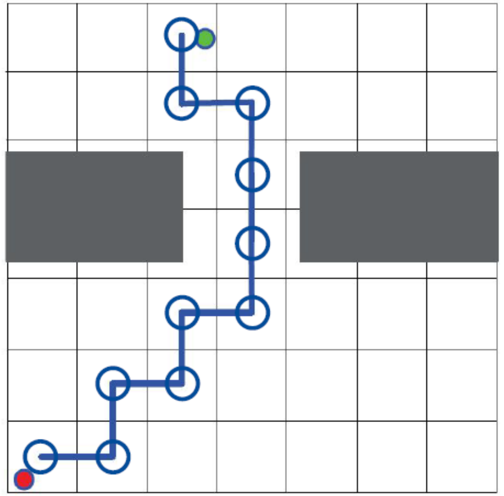


Figure 2.3: Output path of A-star algorithm with start node in red, goal node in green and intermediate nodes indicated with blue circles, obtained from [5].

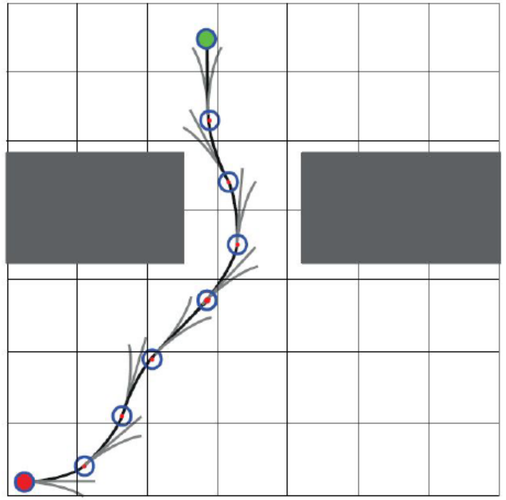
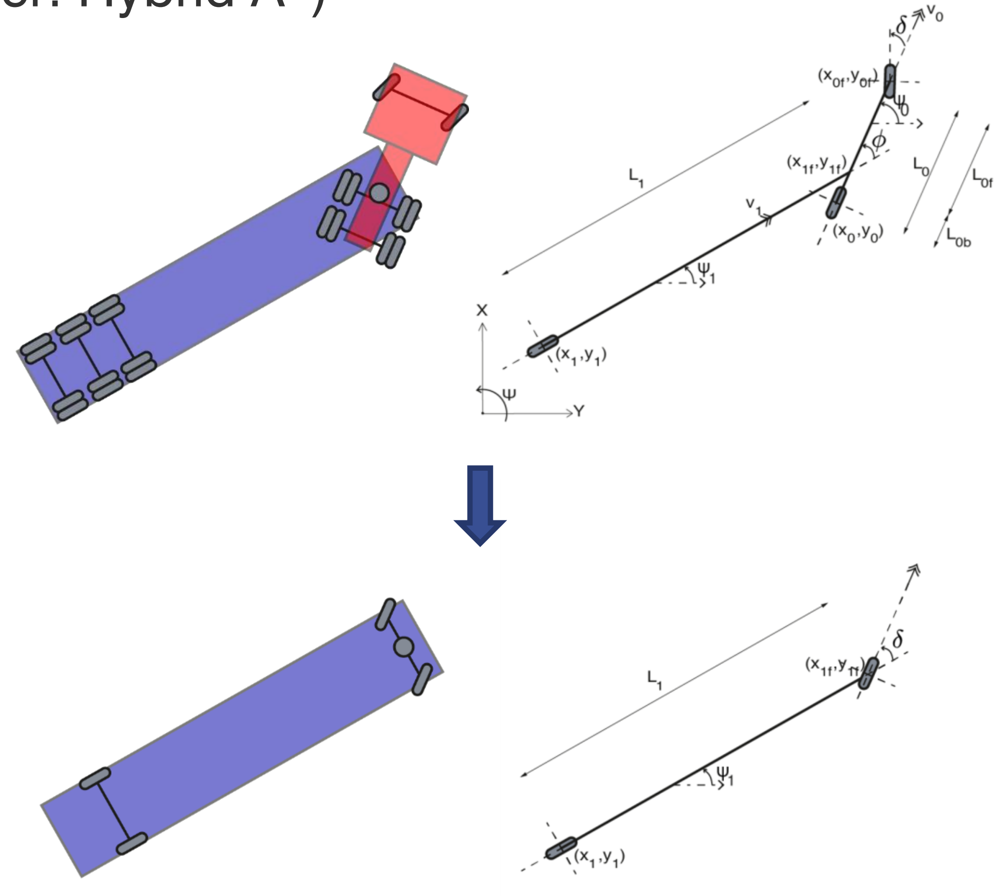


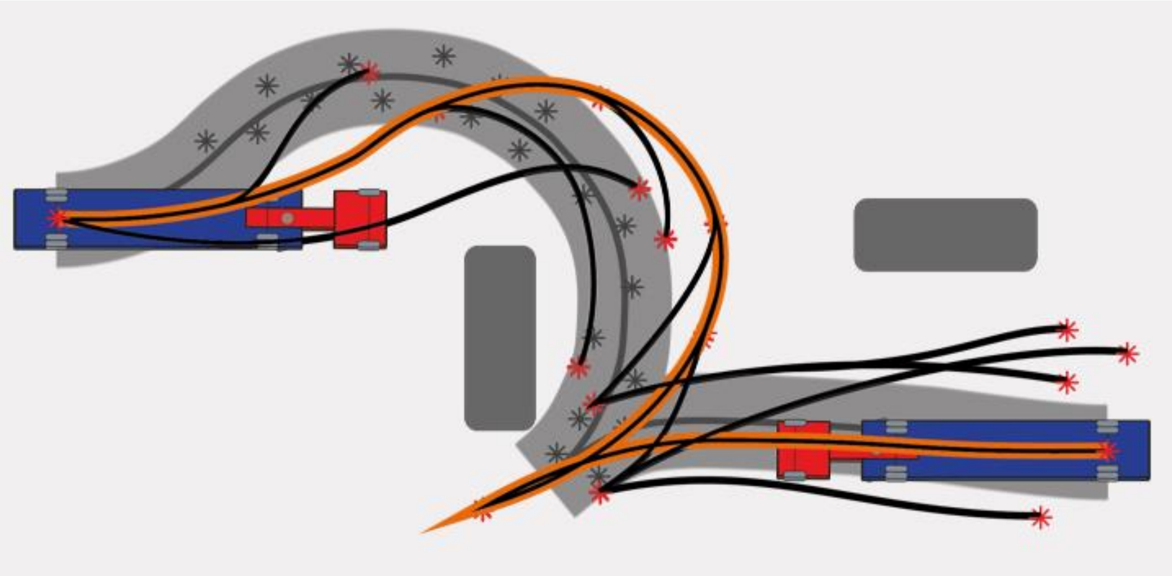
Figure 2.4: Output path of Hybrid A-star algorithm with start node in red, goal node in green and intermediate nodes indicated with blue circles, obtained from [5].

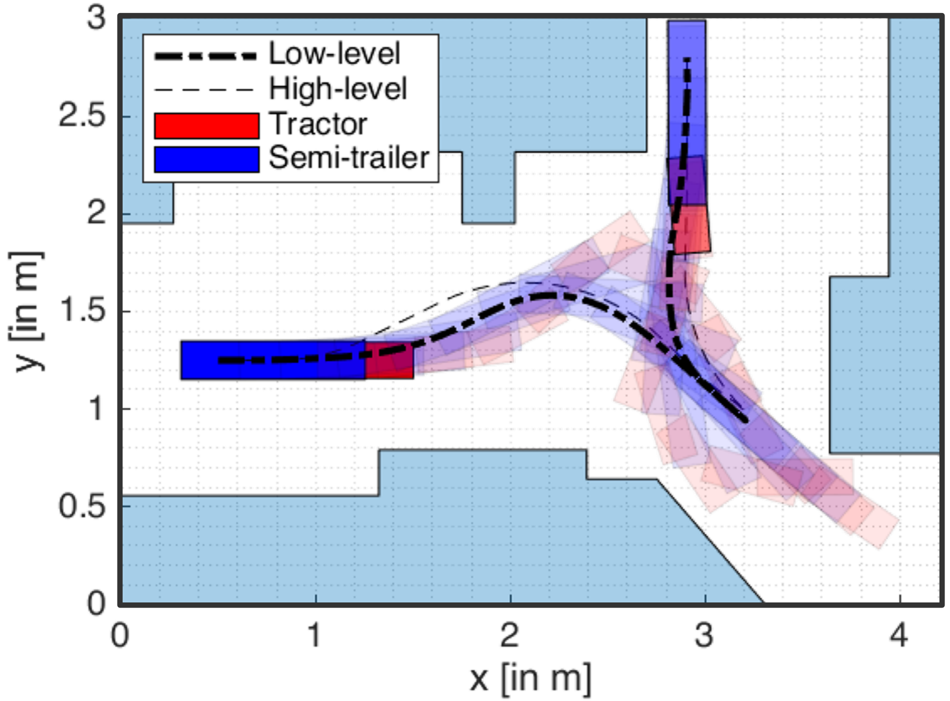


[Nair2019, Hendrix2020]

Path planning (example low level planner: CL-RRT)

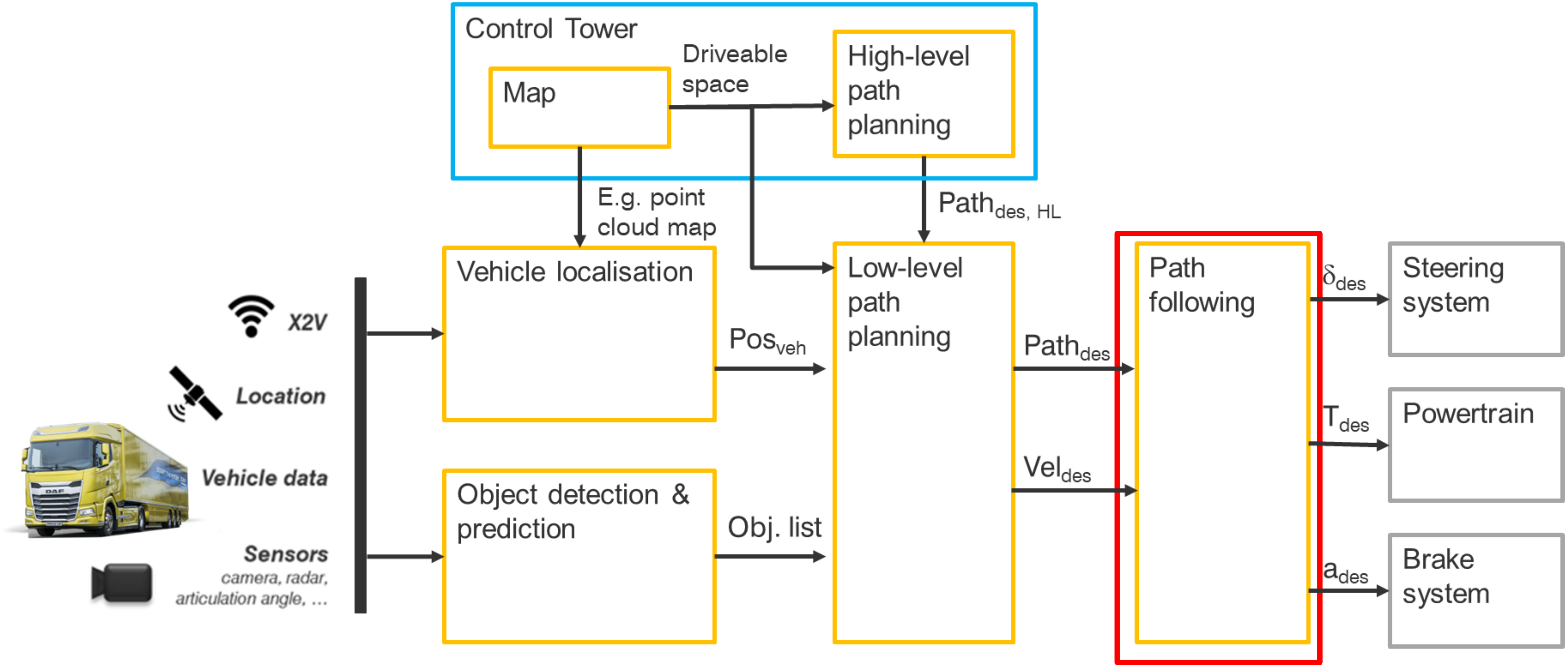
- Use the detailed model (incl. path following controller) to plan the final path around high-level path
- Ensure final docking accuracy





[Nair2019, Hendrix2020]

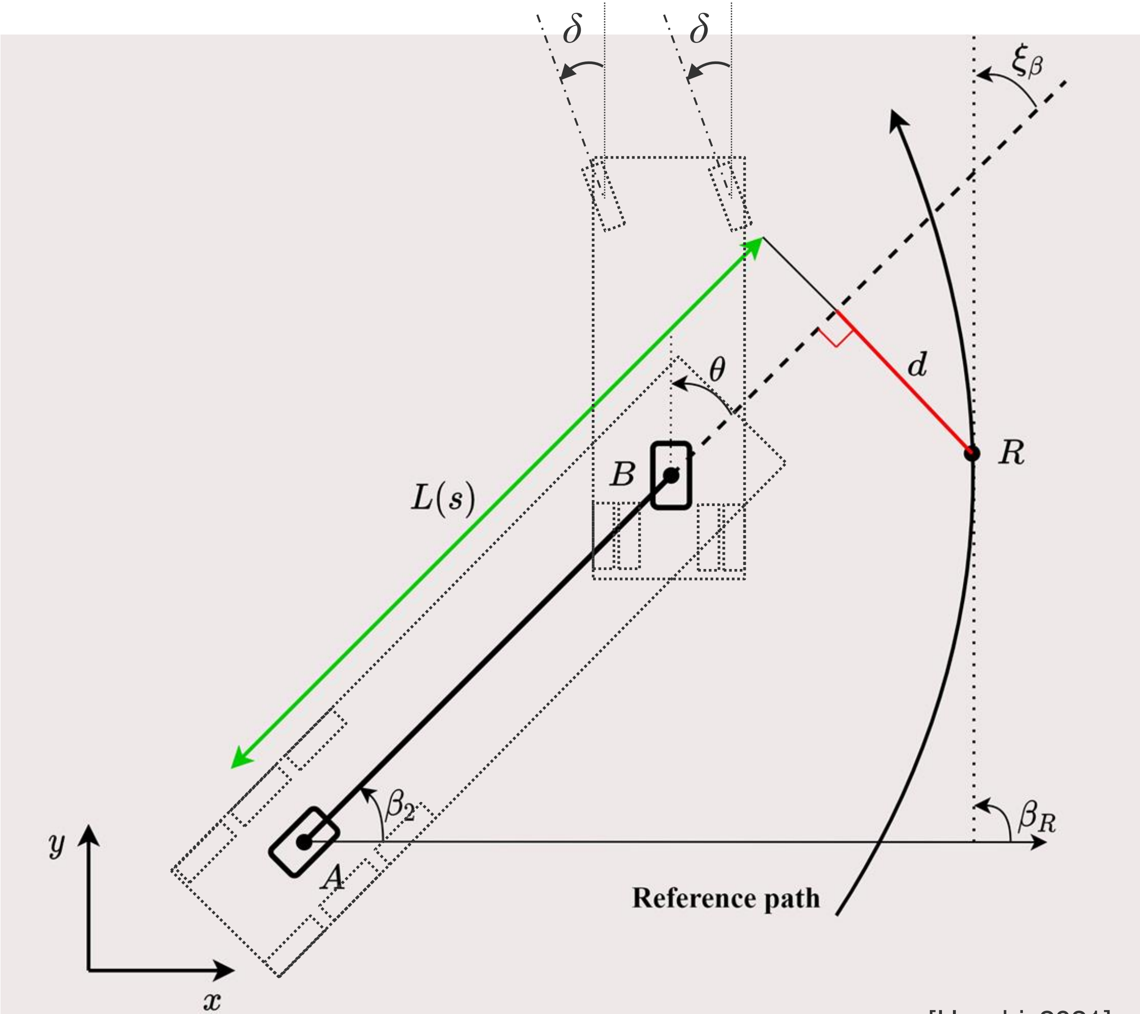
Building blocks for automated driving



Path following (example: cascaded feedback control)

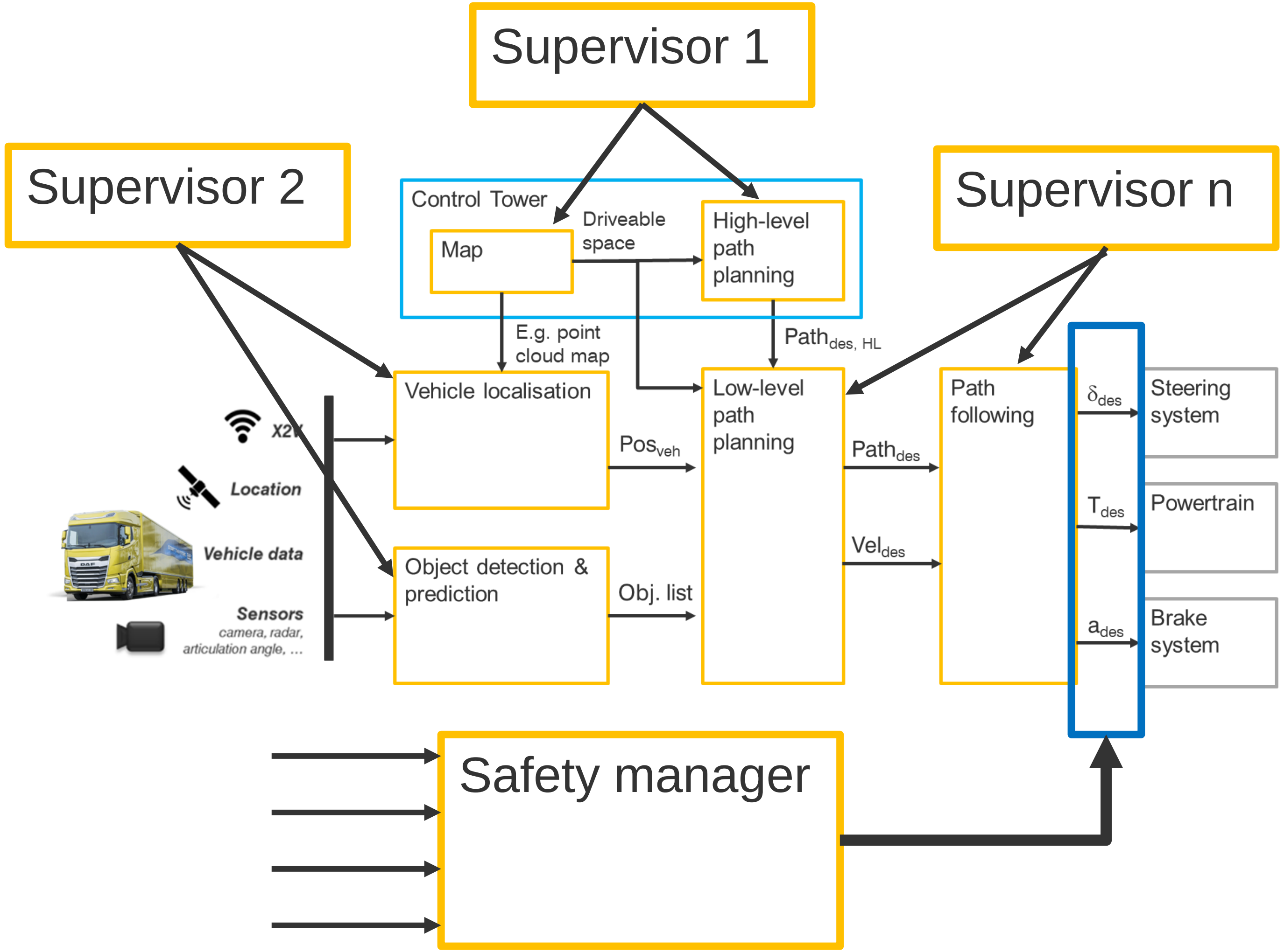
- Inner control loop
  - Fifth wheel (*B*) regarded as steerable wheel
  - Selected reference point (*R*) depends on lookahead distance (*L*)
  - Lateral (*d*) and heading (ξ_β) error
  - Desired articulation angle (θ_{des}) determined

- Outer control loop
  - Desired steering angle (δ_{des}) determined based on actual (θ) and desired articulation angle (θ_{des})



[Hendrix2021]

Supervisor(s) & Safety Manager



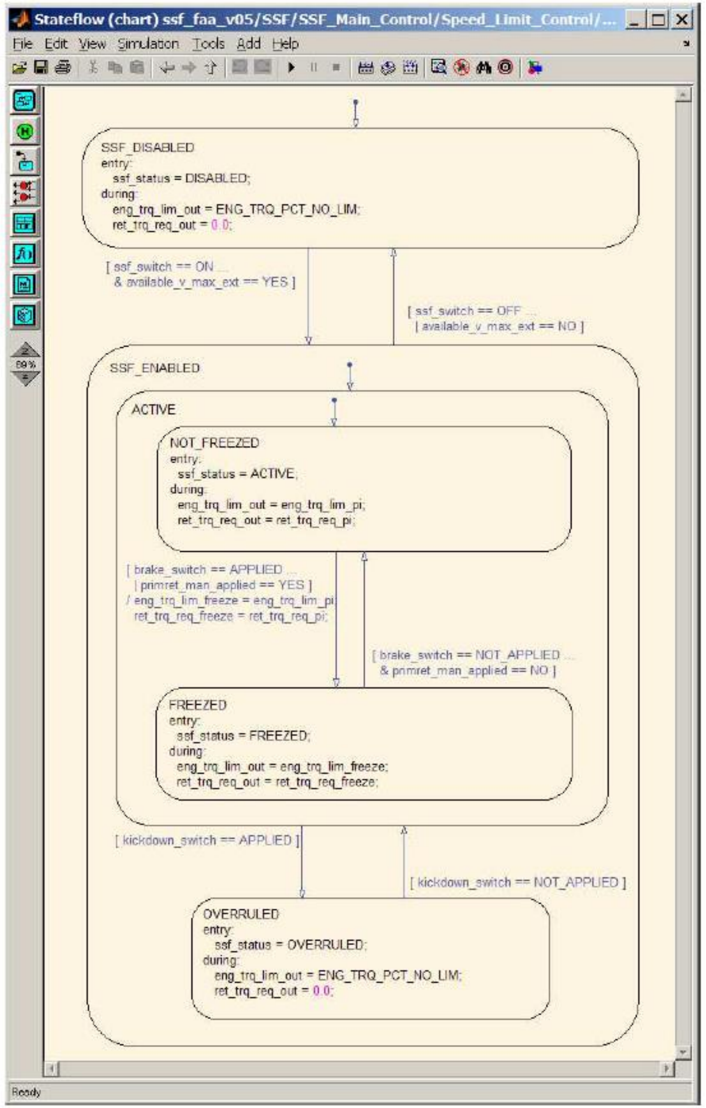
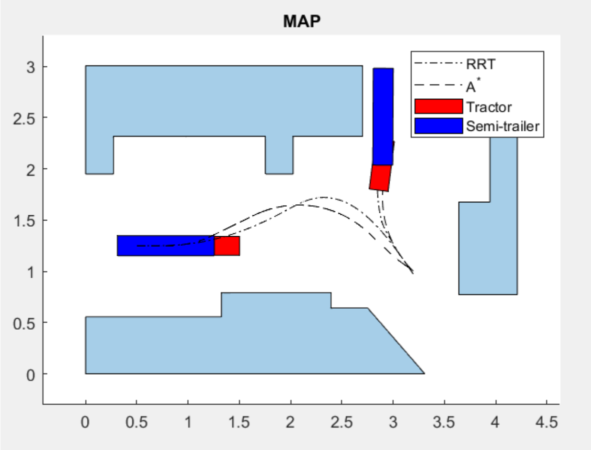


Figure 9. Example function behaviour specification of the SSF (i.e. state chart showing the SSF enable and disable logic).

Verification & Validation



Functional and failure tests

- Model-based simulations
- Software-In-the-Loop
- Hardware-In-the-Loop
- Rapid Controller Prototyping
- Vehicle tests

Concluding suggestions

- The "what":
  - Use cases
  - Requirements
- The "how":
  - First high-level architecture
  - Then detailed design
- Start simple
- Integrate & test regularly

(try to avoid "big-bang")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