

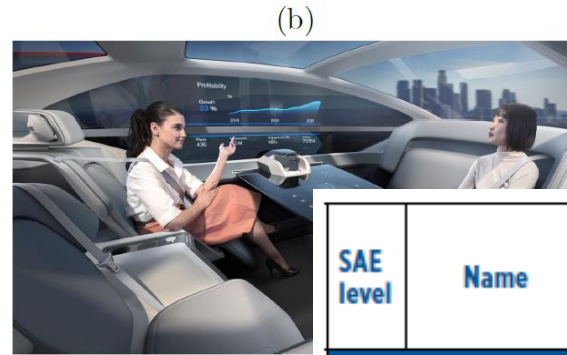
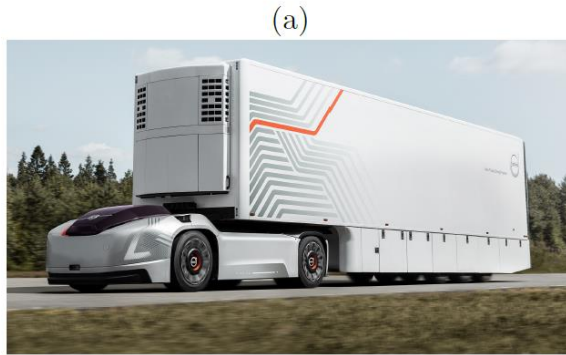
Needs for Physical Models and Related Methods for Development of Automated Road Vehicles

*Professor in Vehicle Dynamics, PhD **Bengt Jacobson** (Chalmers University of Technology; Sweden)*

*Industrial researcher, PhD **Peter Nilsson** (Volvo Global Trucks Technology; Sweden)*

*Senior researcher, PhD **Mats Jonasson** (Chalmers University of Technology; Sweden)*

Automated Driving



SAE J3016

SAE level	Name	Narrative Definition	Execution of Steering and Acceleration/Deceleration	Monitoring of Driving Environment	Fallback Performance of Dynamic Driving Task	System Capability (Driving Modes)
Human driver monitors the driving environment						
0	No Automation	the full-time performance by the <i>human driver</i> of all aspects of the <i>dynamic driving task</i> , even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a
1	Driver Assistance	the <i>driving mode</i> -specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the <i>human driver</i> perform all remaining aspects of the <i>dynamic driving task</i>	Human driver and system	Human driver	Human driver	Some driving modes
2	Partial Automation	the <i>driving mode</i> -specific execution by one or more driver assistance systems of both steering and acceleration/deceleration using information about the driving environment and with the expectation that the <i>human driver</i> perform all remaining aspects of the <i>dynamic driving task</i>	System	Human driver	Human driver	Some driving modes
Automated driving system ("system") monitors the driving environment						
3	Conditional Automation	the <i>driving mode</i> -specific performance by an <i>automated driving system</i> of all aspects of the <i>dynamic driving task</i> with the expectation that the <i>human driver</i> will respond appropriately to a <i>request to intervene</i>	System	System	Human driver	Some driving modes
4	High Automation	the <i>driving mode</i> -specific performance by an automated driving system of all aspects of the <i>dynamic driving task</i> , even if a <i>human driver</i> does not respond appropriately to a <i>request to intervene</i>	System	System	System	Some driving modes
5	Full Automation	the full-time performance by an <i>automated driving system</i> of all aspects of the <i>dynamic driving task</i> under all roadway and environmental conditions that can be managed by a <i>human driver</i>	System	System	System	All driving modes

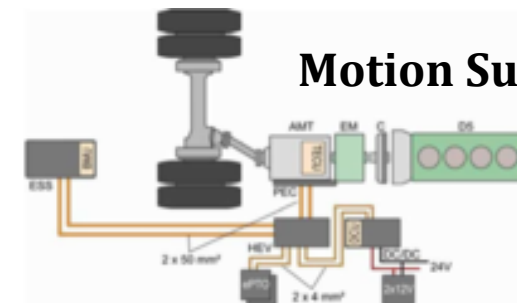
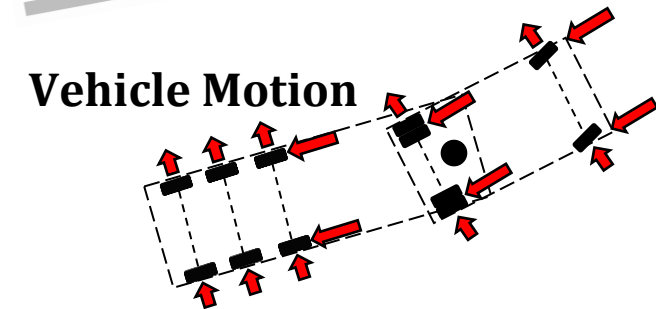
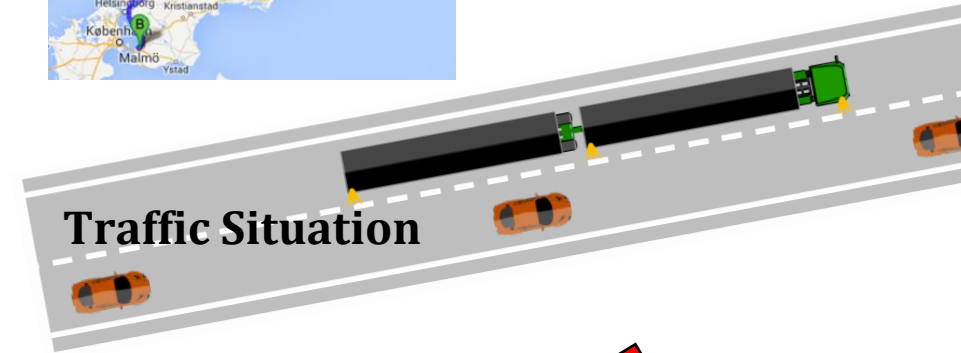
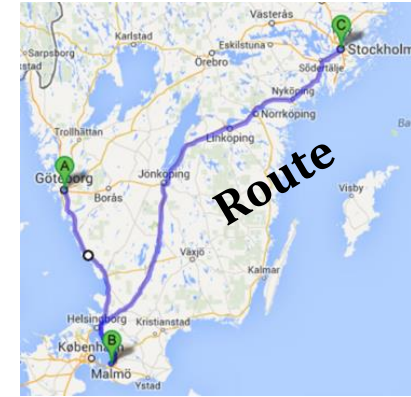
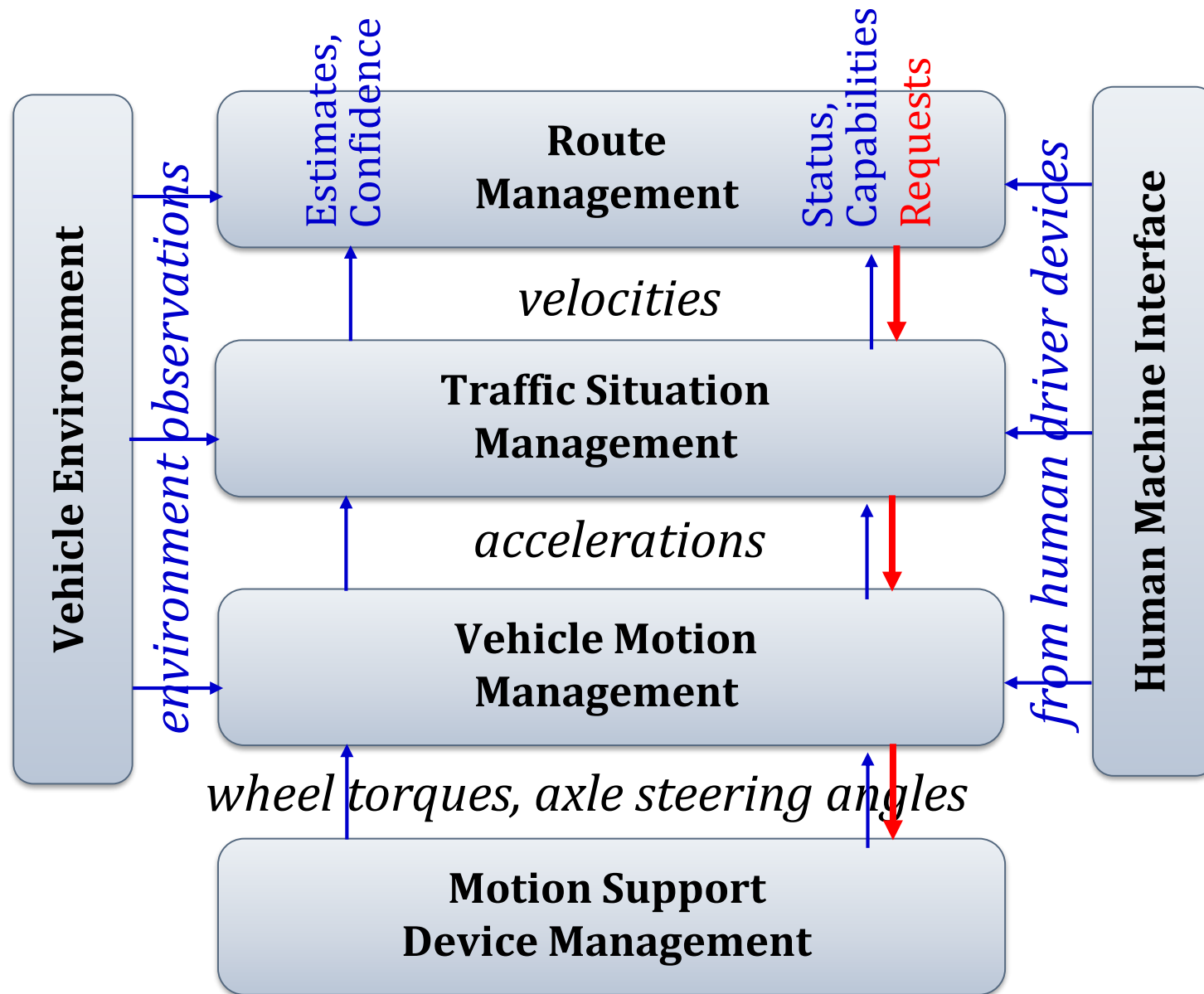


Figure 2.: Volvo external steering [22]

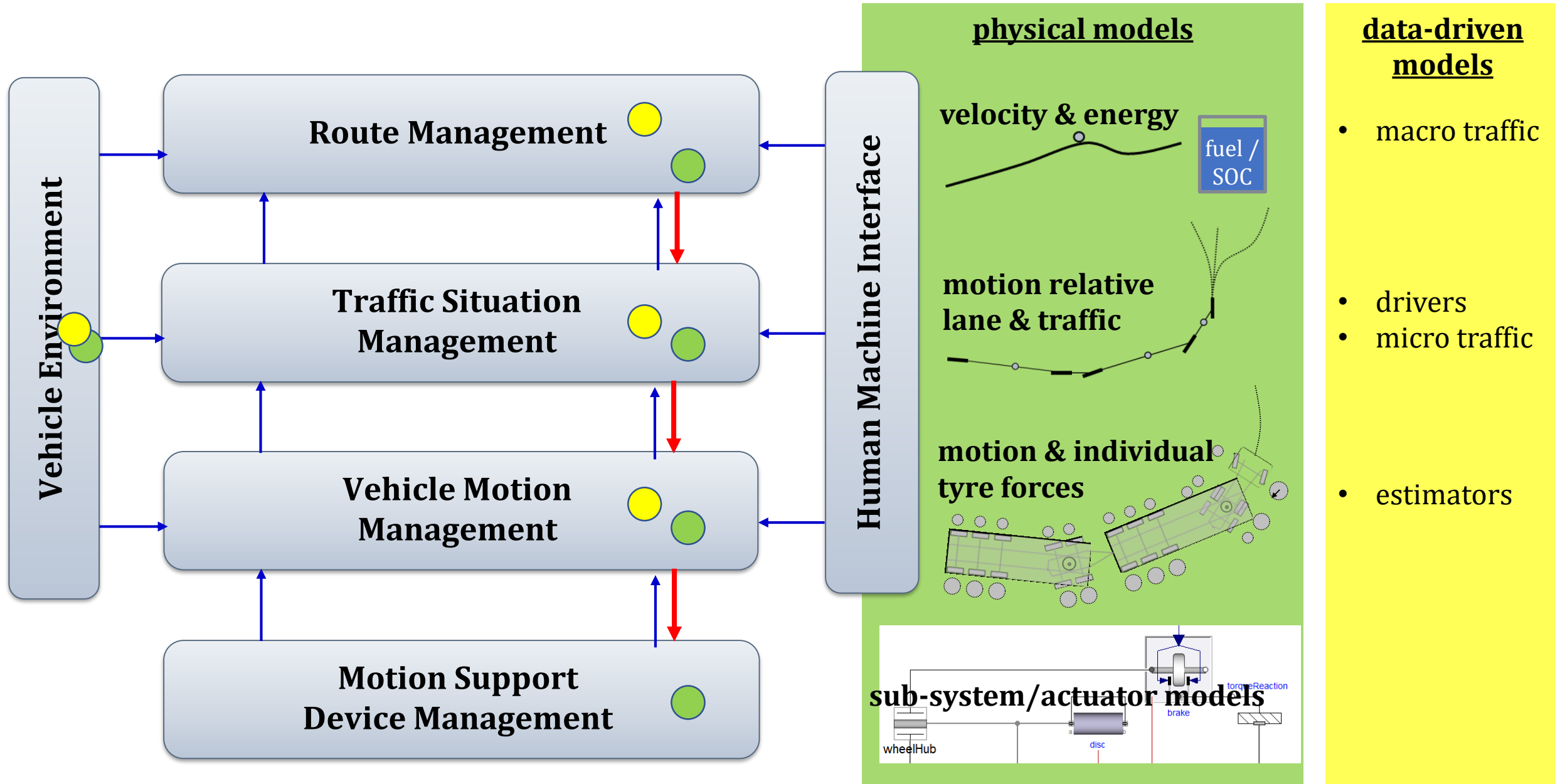
Reference: [Matthijs Klomp, et al, 2019]

Reference: [SAE, 2014]

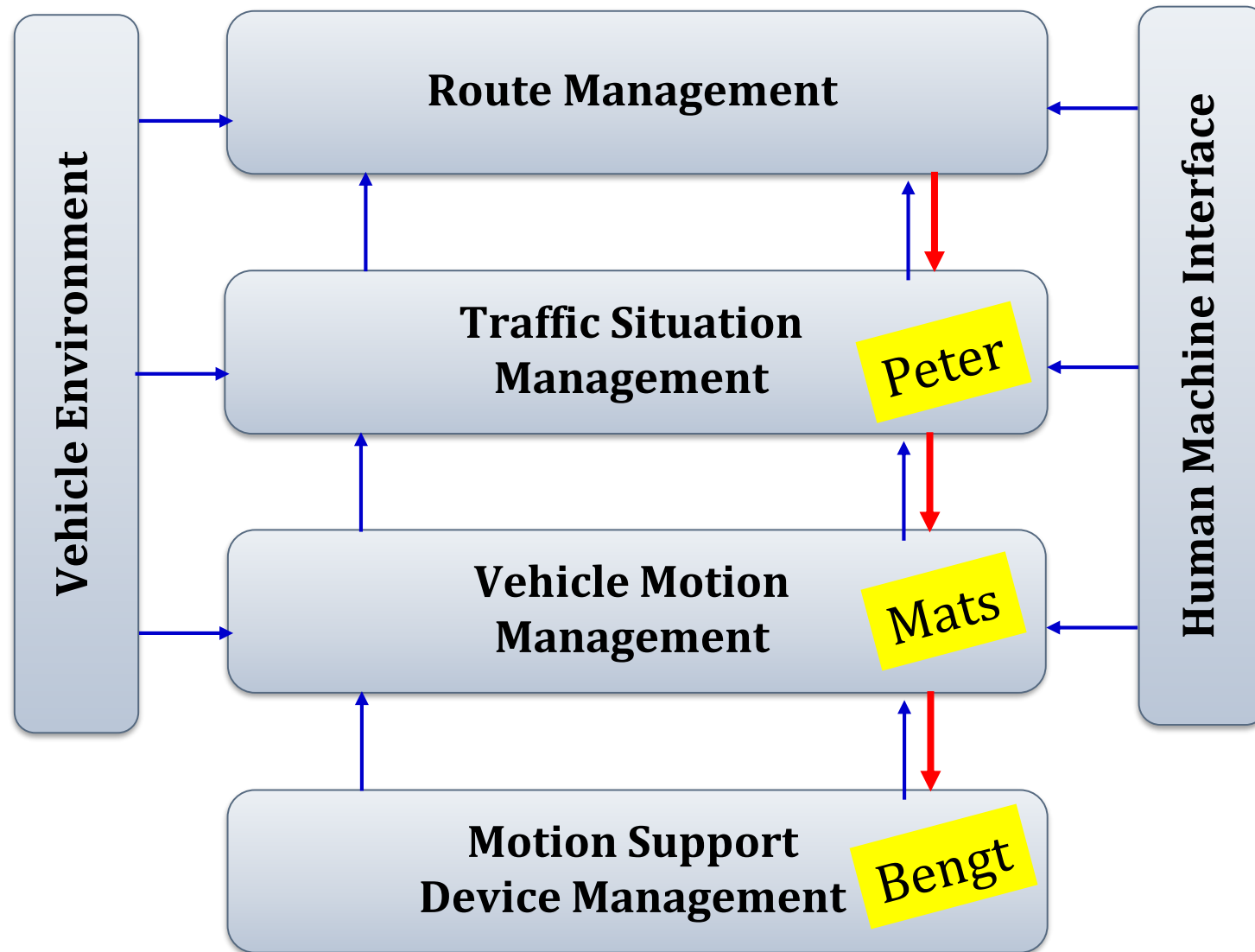
“Function Architecture” for vehicle motion & energy



Models for vehicle motion and energy control design



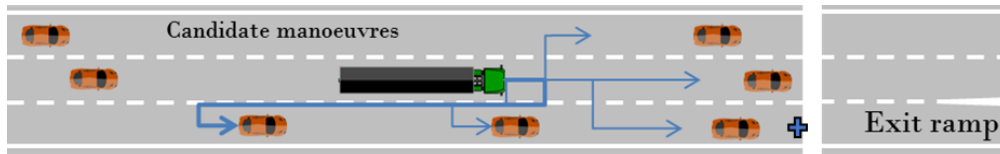
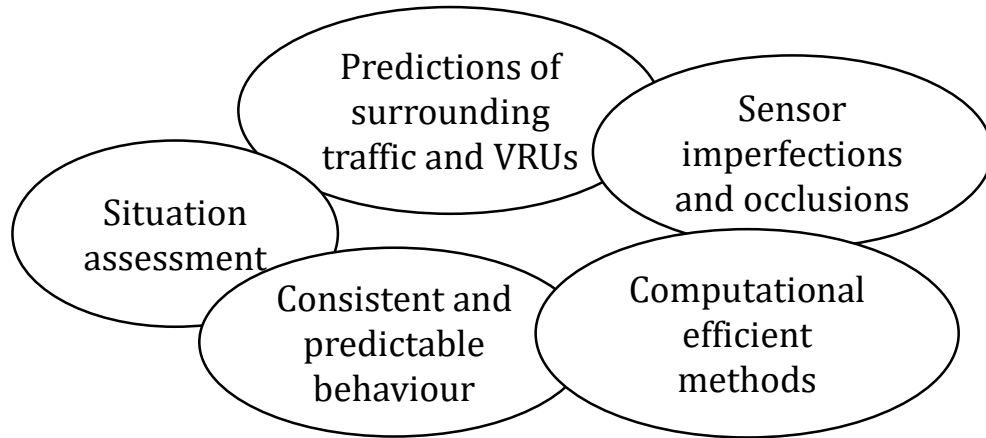
Next speakers



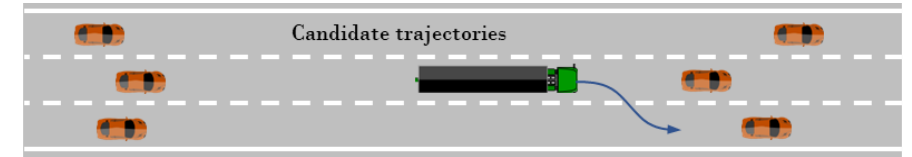
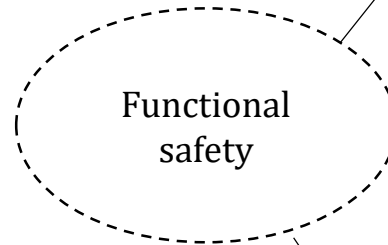
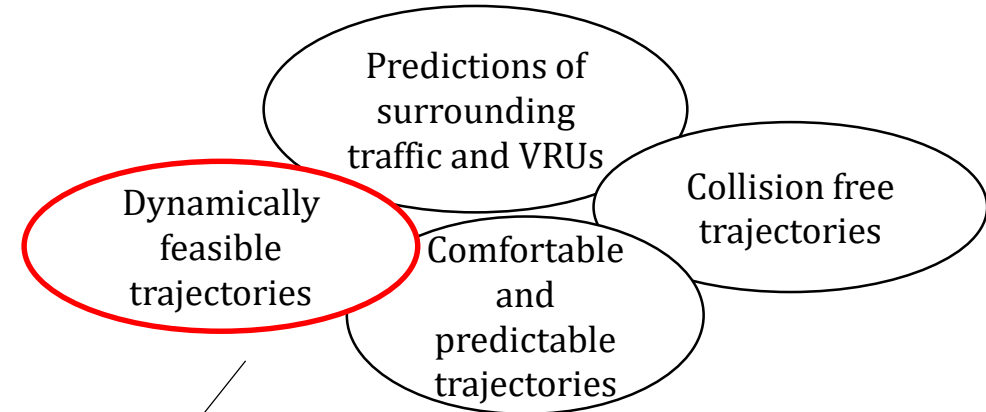
Traffic Situation Management,
Dynamically Feasible Trajectories,
Peter Nilsson, Volvo Trucks

Examples of challenges for TSM

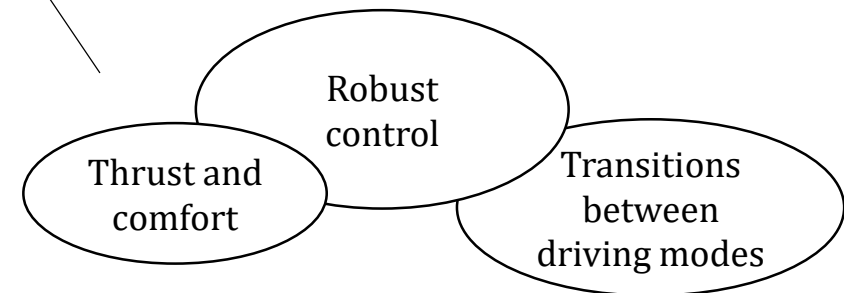
Behaviour planning (Tactical decision)



Motion Planning (Trajectory planning)



Vehicle Longitudinal and Lateral Control

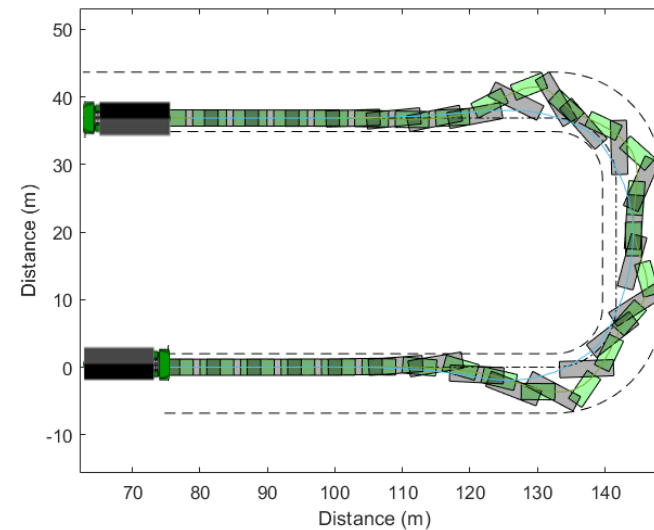
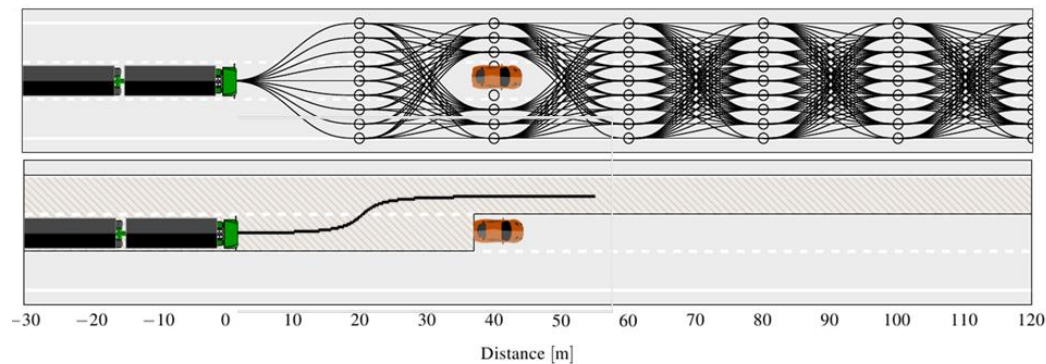


Trajectory planning

“Trajectory planning is a generalization of path planning, involved with planning the state evolution in time while satisfying given constraints on the states and actuation”

Commonly used methods:

- Numerical optimization (e.g. MPC)
- Graph search (e.g. A*)
- Neural network (e.g. Nvidia PilotNet)
- ...

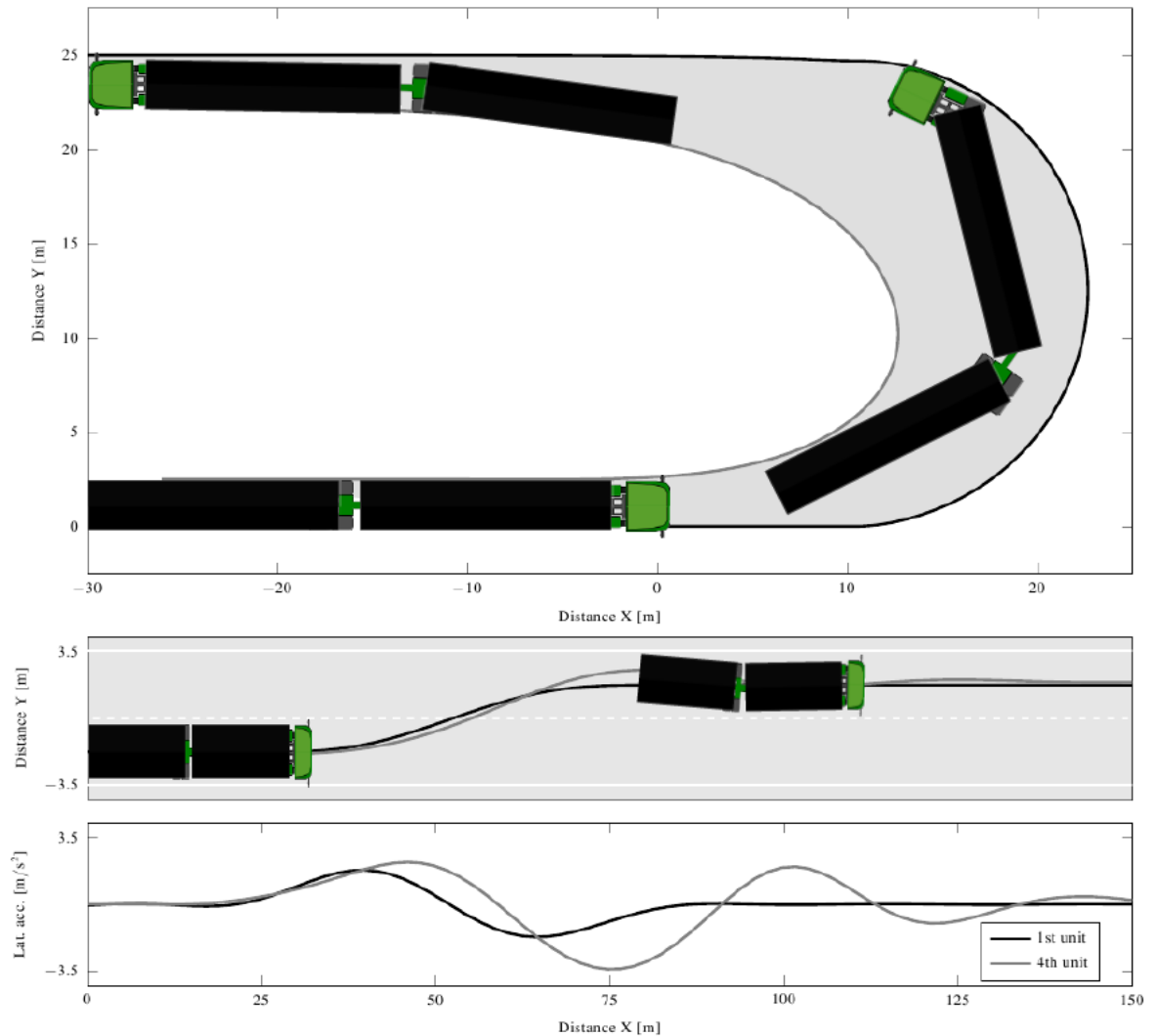


Trajectory planning example:
left curve, tractor semi-trailer

Heavy duty combination vehicles

Example of motion constraints:

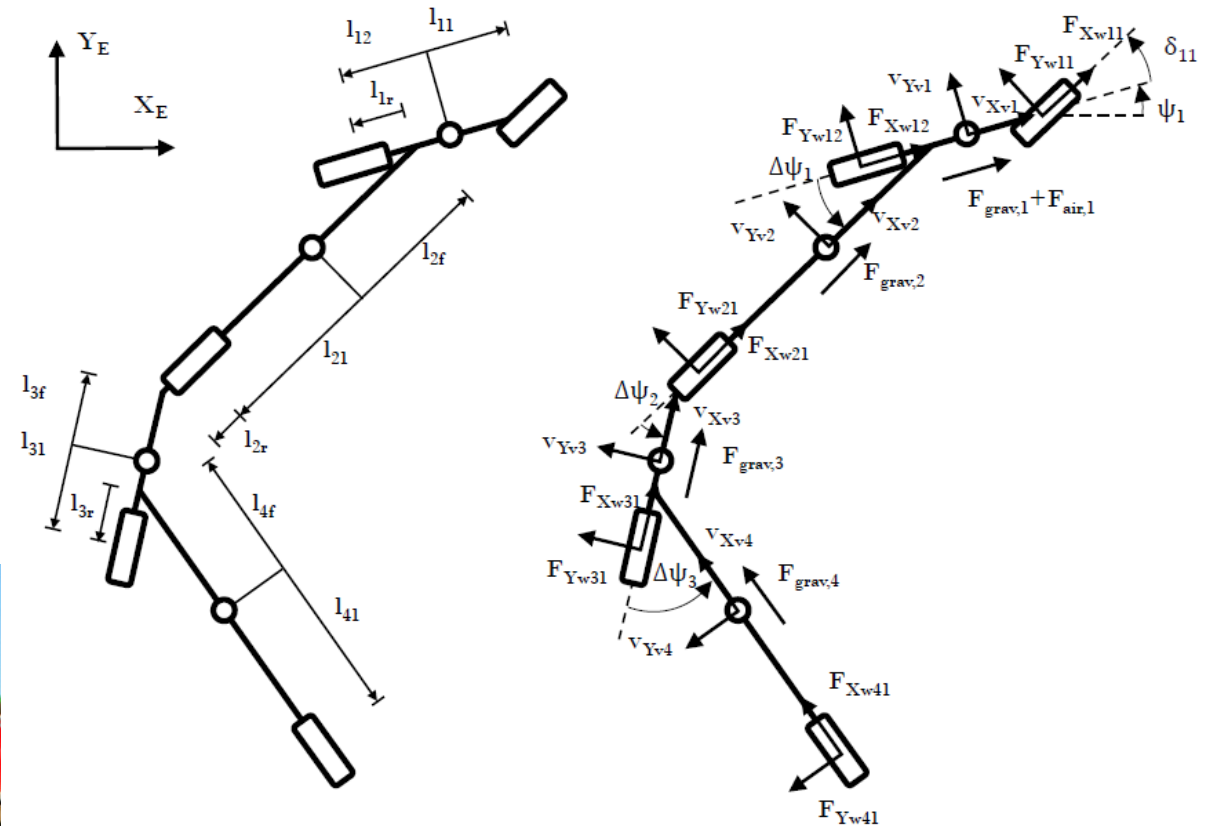
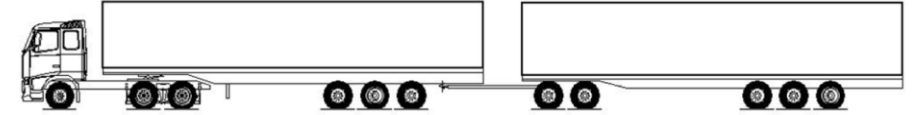
- Position of first unit
- Position of trailer units (off-tracking)
- Roll-over threshold (rearward amplification)
- ...



Trajectory planning modelling

Example of modelling:

- One-track models : $\dot{x} = f(x, u, w)$
- Possible states for A-double
 - 1st unit (tractor) : $v_x, v_y, \dot{\psi}_1$
 - 2nd unit (trailer) : $\Delta\psi_1, \Delta\dot{\psi}_1$
 - 3rd unit (dolly) : $\Delta\psi_2, \Delta\dot{\psi}_2$
 - 4th unit (trailer) : $\Delta\psi_3, \Delta\dot{\psi}_3$



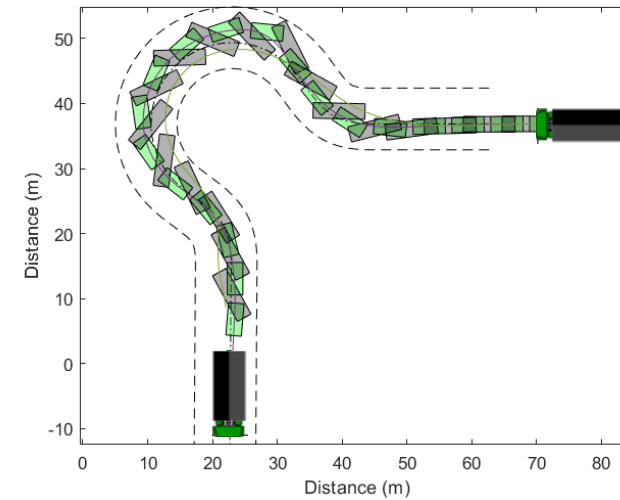
Vehicle variants and trajectory planning challenges

Vehicle variant combinatorics:

- Powertrain : $\approx 10^2$ variants
- Chassis : $\approx 10^3$ variants
- Vehicle load $\approx 7 - 120\text{t}$ (incl. different heights to CoG)
- Vehicle units : 1-4

Challenge:

Trajectory planning methodology needs to be scalable and robust with respect to variant combinatorics

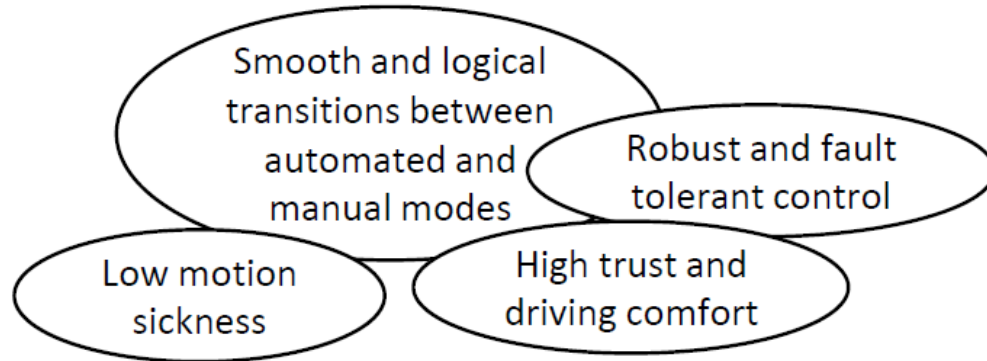


Trajectory planning example:
Roundabout, tractor semi-trailer

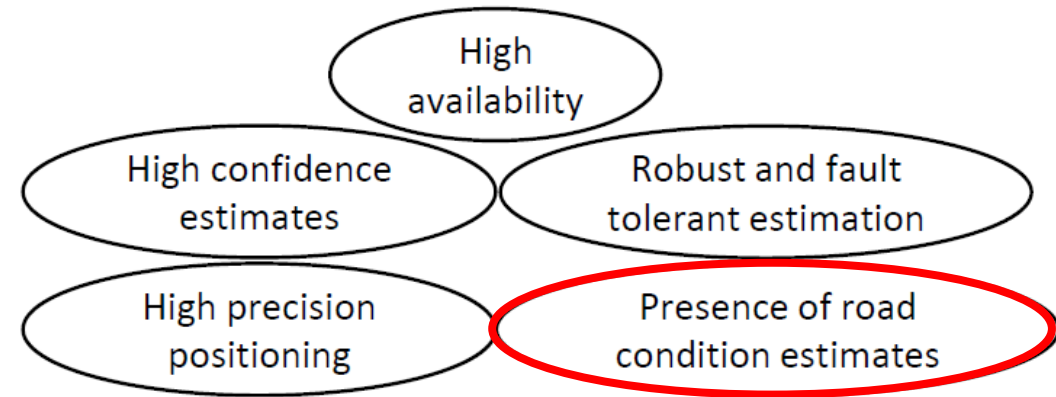
Vehicle Motion Management, Road friction estimation, Mats Jonasson

Challenges for VMM

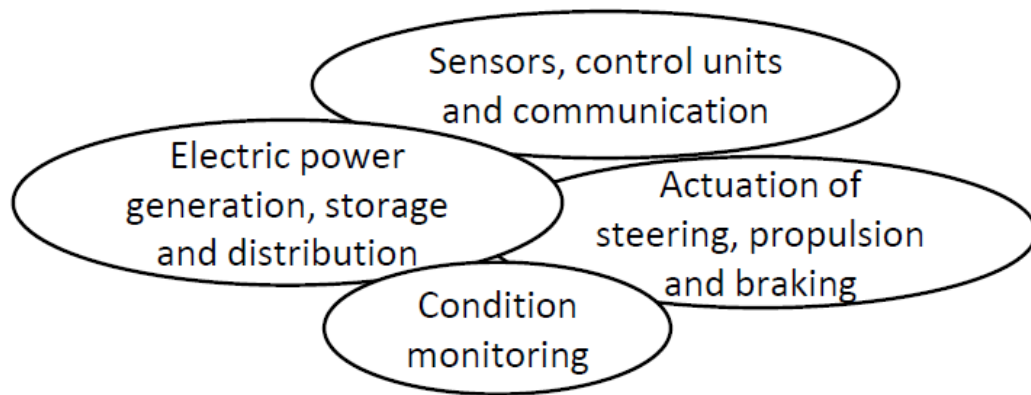
Vehicle Longitudinal and Lateral Control



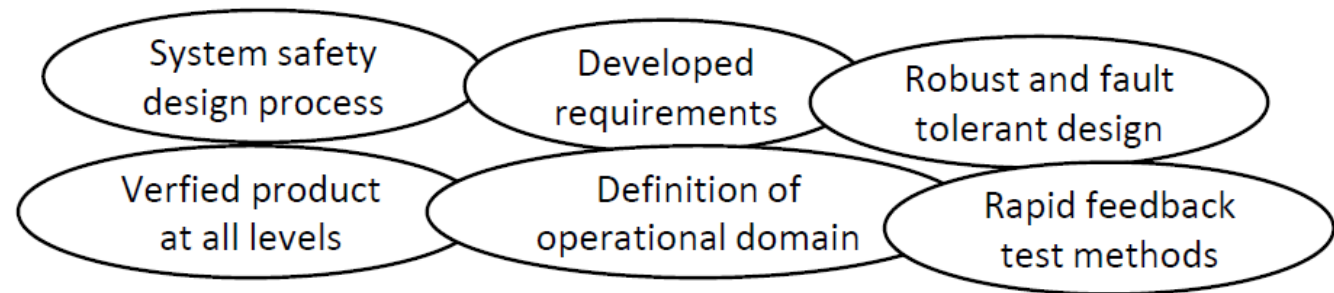
Vehicle Motion State Estimation



Robust, Independent and Fault Tolerant Vehicle Systems



Development Processes



Road condition – road friction



Lateral force f_y

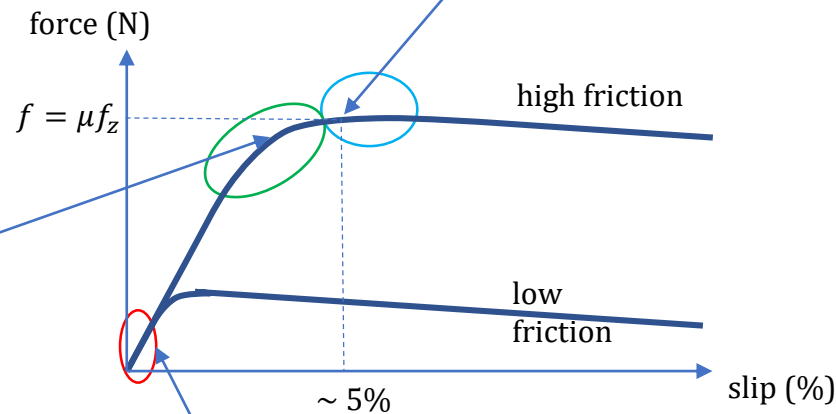
Longitudinal force f_x

Normal force f_z

More than 10% of all accidents occur because of slippery conditions*

In the US: yearly approx 500 000 accidents of which 1800 are deadly*

ABS activation, friction can be found $\mu \approx \frac{f}{f_z}$



To estimate friction the tyre must at least be excited to the nonlinear region at “the bend”

Definitions:

Low friction

$$0 < \mu \leq 0.4$$

Mid friction

$$0.4 < \mu \leq 0.7$$

High friction

$$0.7 < \mu$$

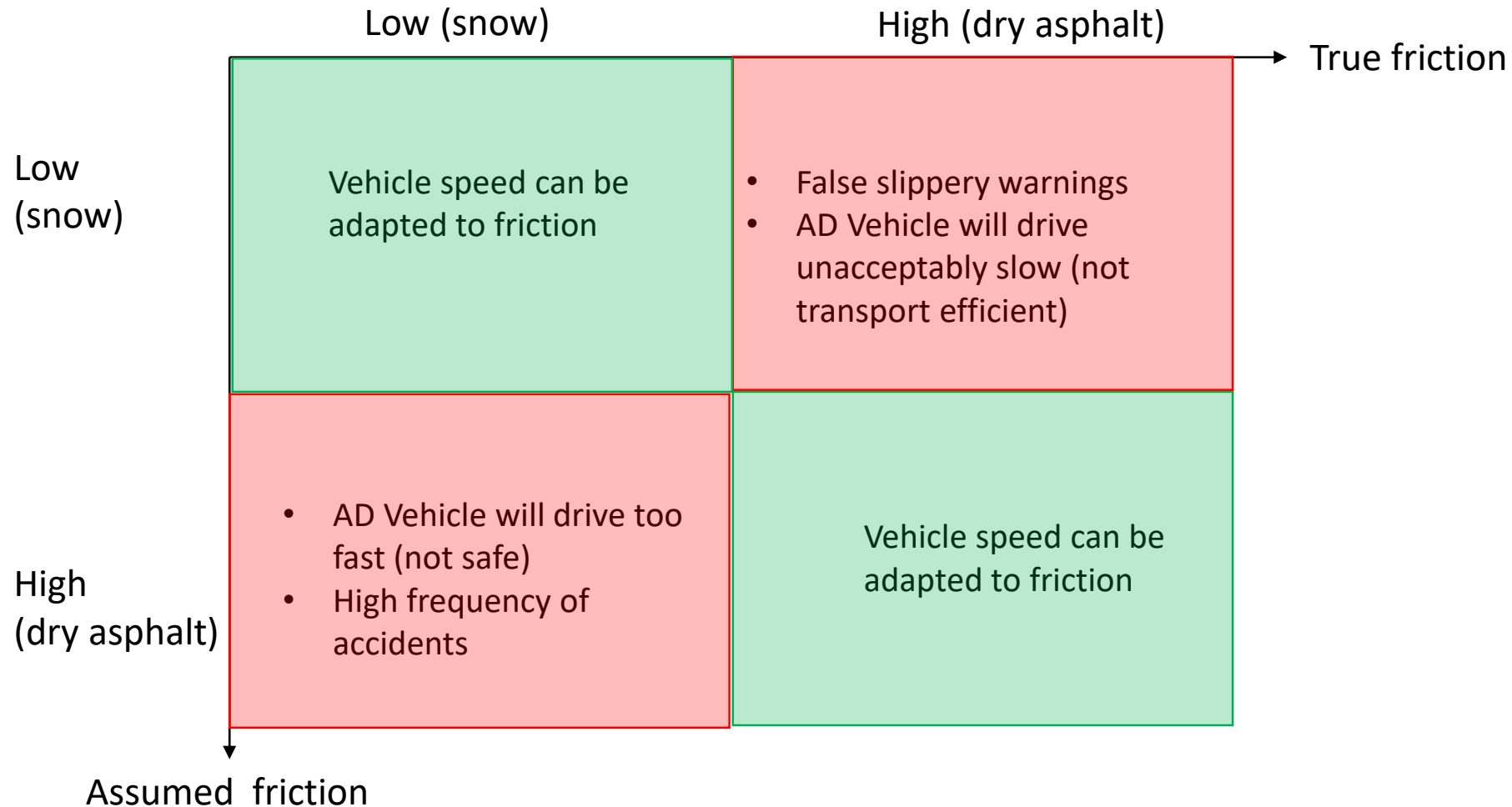
Most driving take place here, not possible to distinguish between low or high friction

* Reference: [IVSS Road Friction Estimation Part II]

* Reference: [US Department of Transportation – Federal Highway Administration]

** Reference: [Wallman. Tema vintermodell – olycksrisker vid olika vinterväglag]

Confusion matrix of road friction



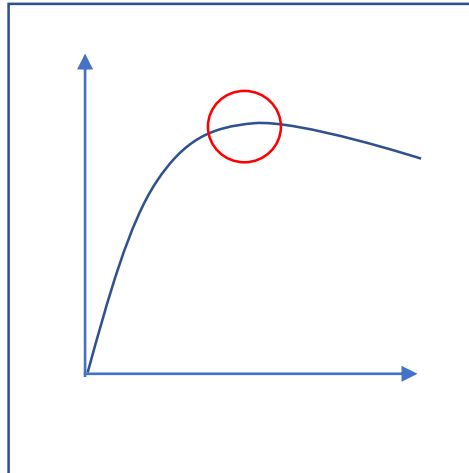
Methods for road friction estimation

Optical measurement device



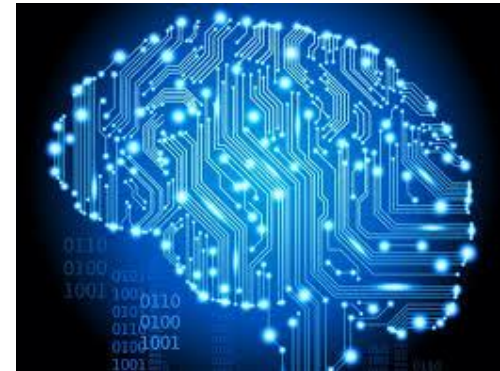
- Contactless
- Requires a map from texture to friction

Model-based estimator



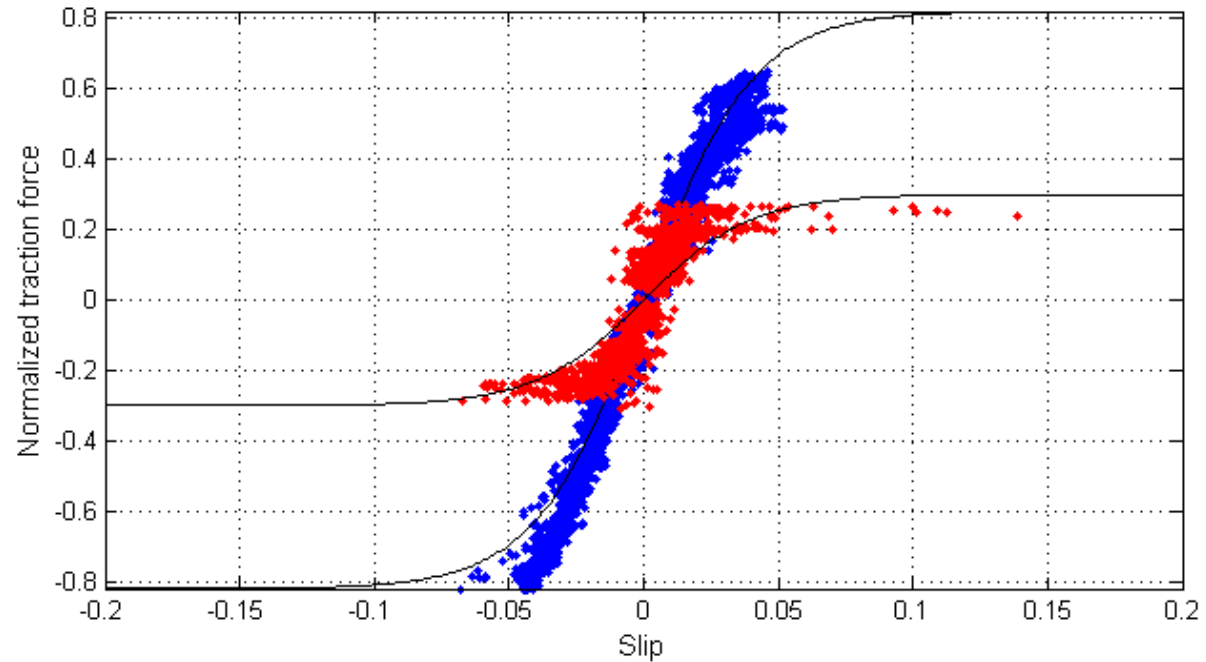
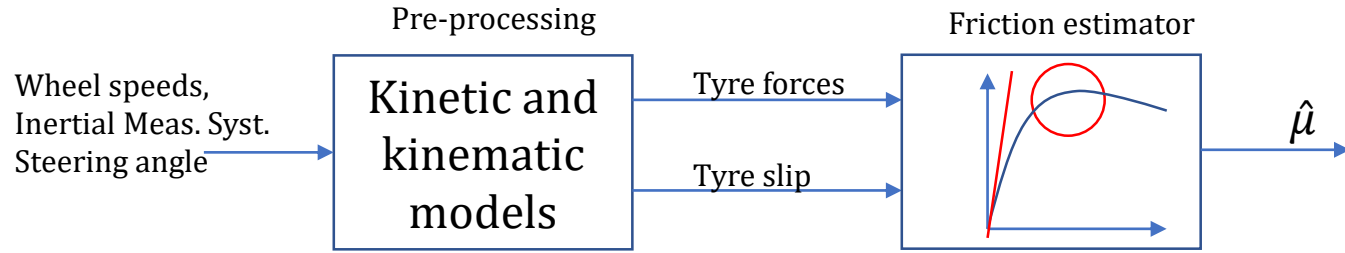
- Use the tyre as the sensor
- Requires knowledge about tyre physics

Machine learning estimator



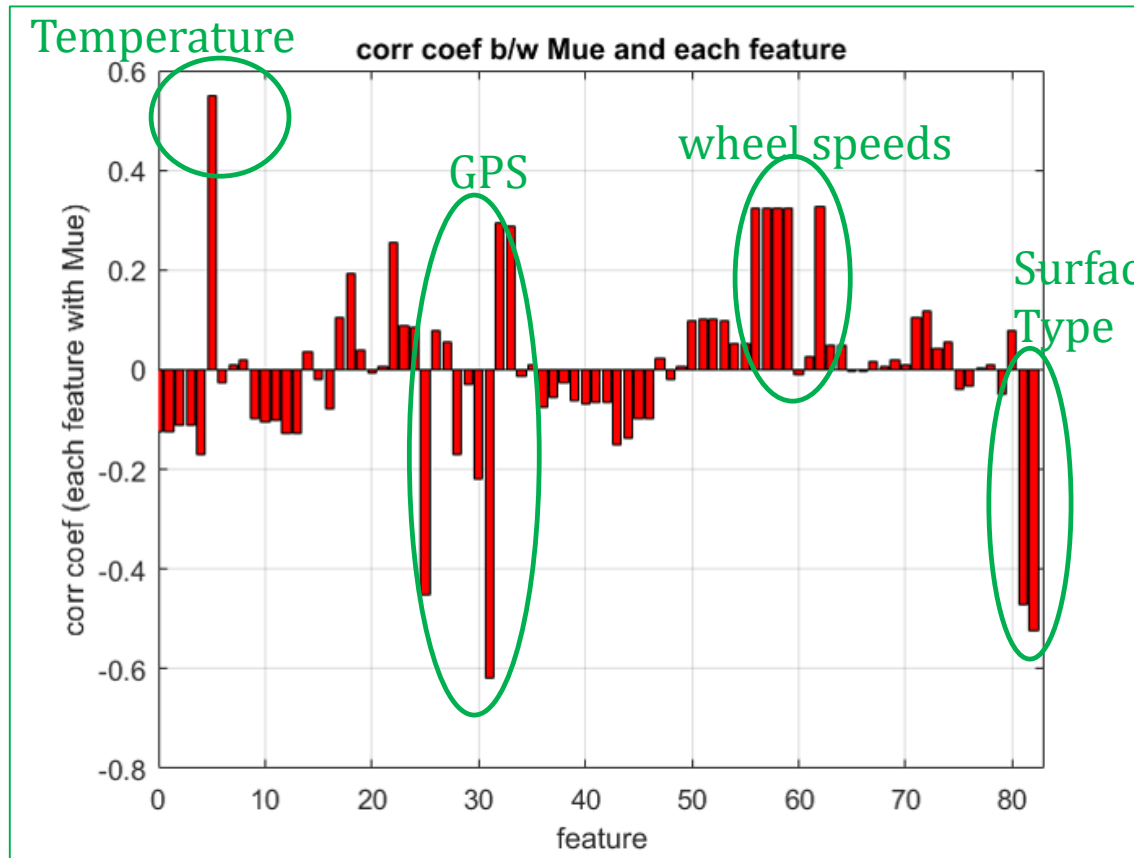
- Use features without knowledge of physics
- Requires training

State-of-the art model-based estimator



Features and correlation to friction

Correlation to
true friction



Surface & road type are not available
in the sensor suite -> important to
use a new sensor e.g. a camera

Temperature, GPS, vehicle speed,
surface and road type are
important features for friction
estimation

Features 1...86

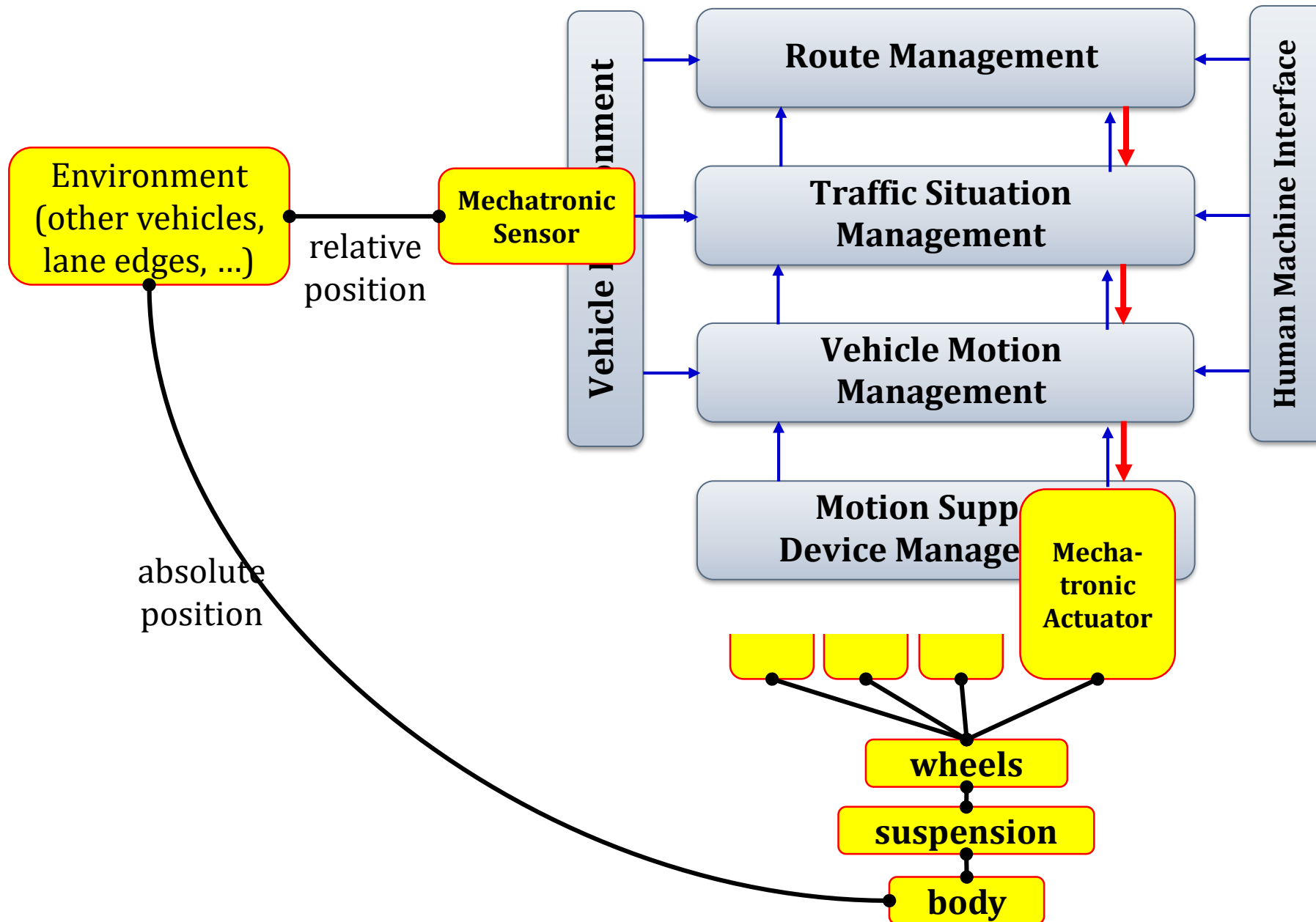
Challenges road friction estimation

- General:
 - Difficult to identify friction for normal driving (low friction utilization)
- Model-based:
 - Model uncertainties for different tyres - the physics is hard to model
 - The pre-processing is not accurate enough
- Machine learning:
 - Generalizability of machine learning algorithms to various situations
 - Generalizability would require large testing
 - Training of machine learning algorithms require ground truth – road friction is hard to measure

Reference [Jonasson, et al] 2018

Motion Devices,
Virtual Verification, Wheel Model,
Bengt Jacobson

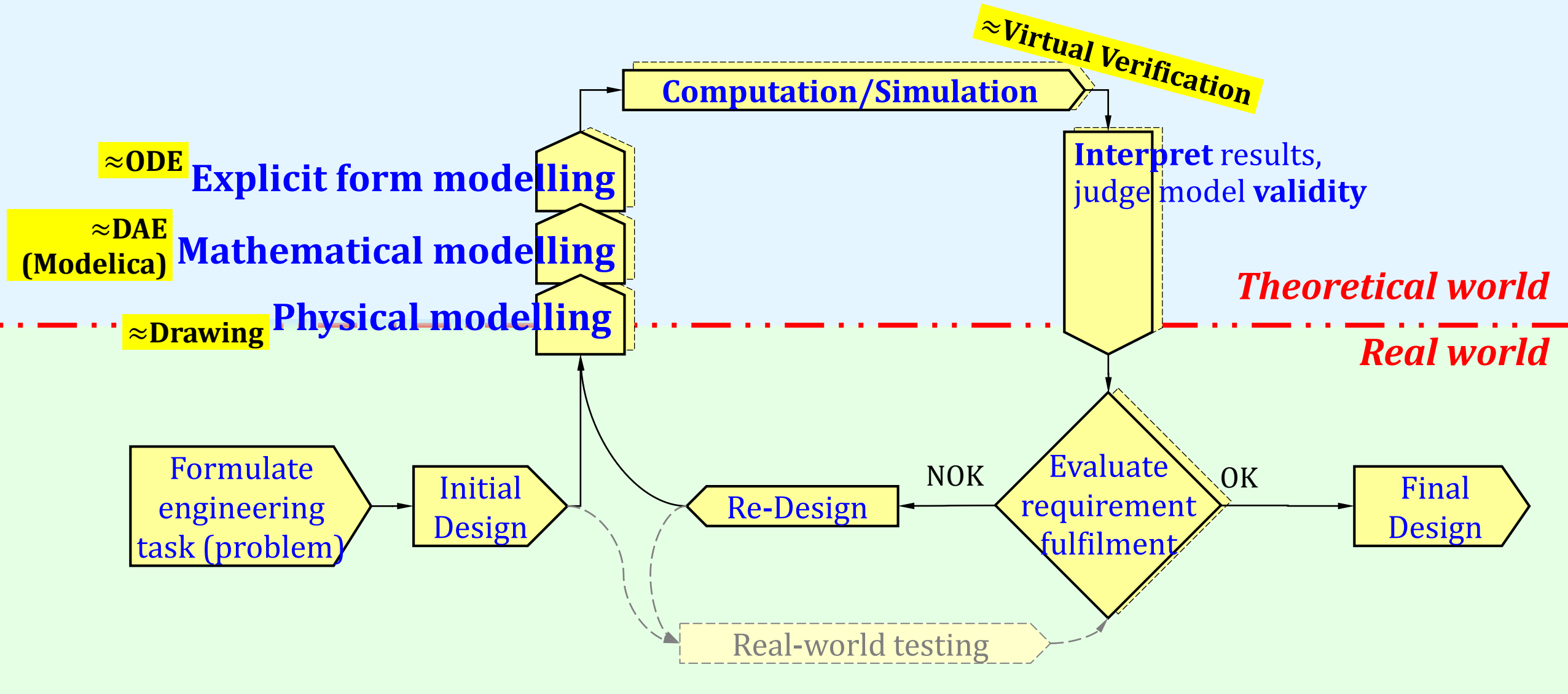
Models for Virtual Verification



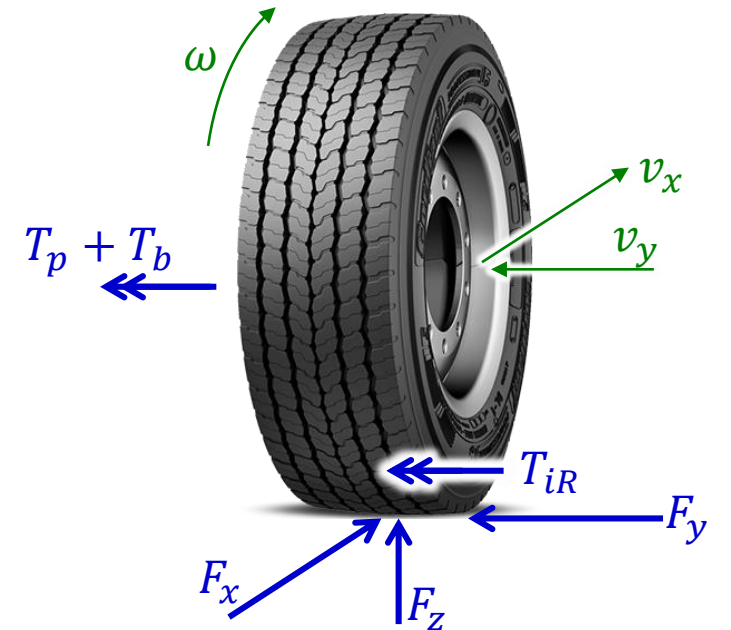
For Virtual Verification:

- Higher **accurate** and larger **validity** range than for control design.
- But **only simulate-able**, no need for linearized, inversion, etc.

...one view of model based engineering

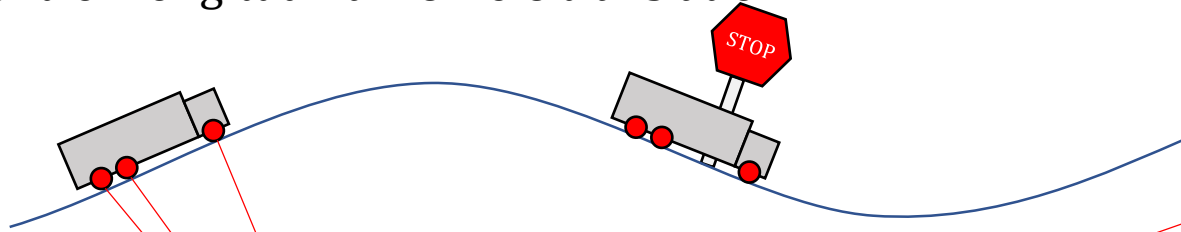


Wheel model as example

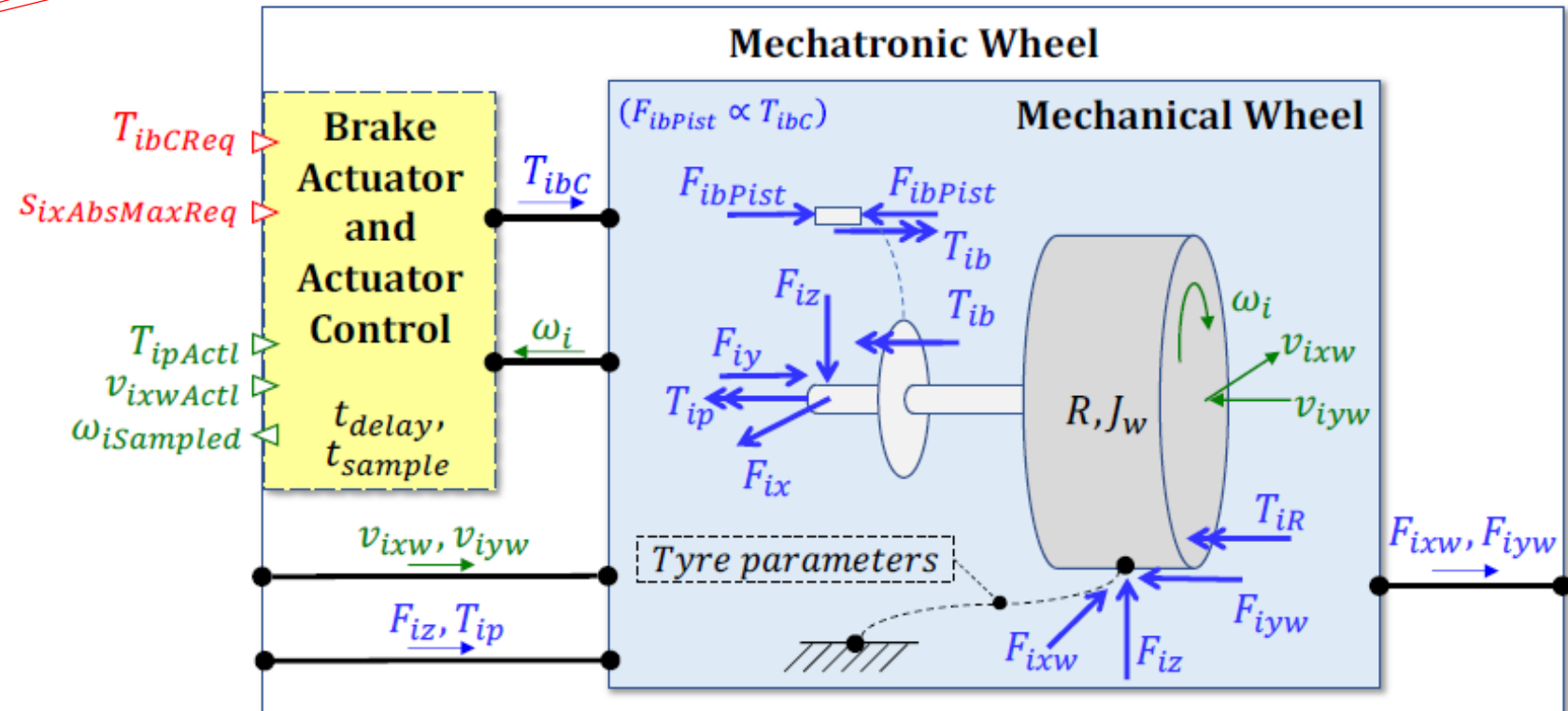
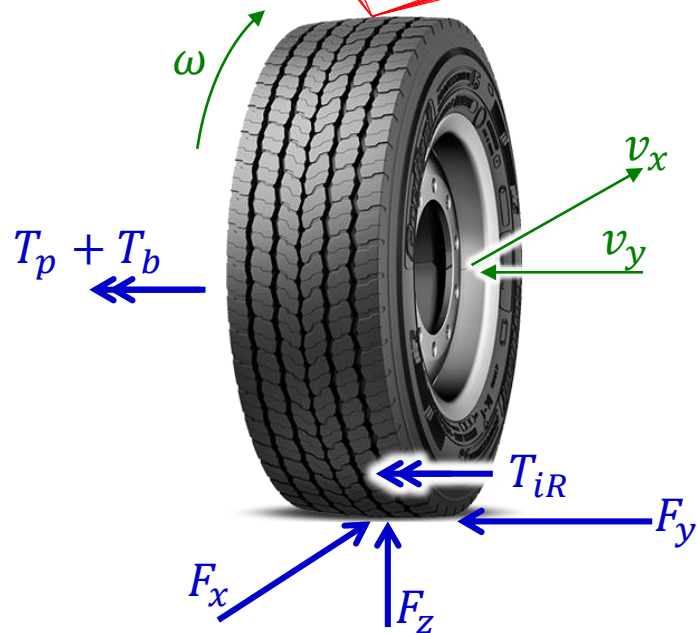
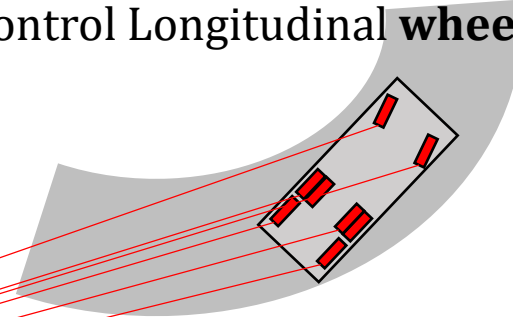


Wheel model use cases

Control Longitudinal **vehicle** translation

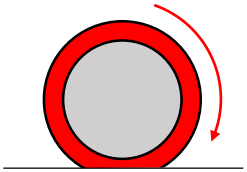


Control Longitudinal **wheel** rotation



Wheel model, Mechanical challenges

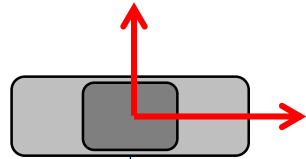
Continuously Renewed Friction Surfaces



$$F_x = C_x \cdot s_x;$$

$$s_x = \frac{R \cdot \omega - v_x}{|R \cdot \omega|};$$

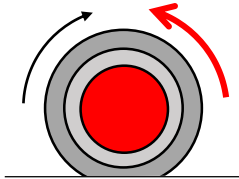
Relative Velocity Direction



$$[F_x, F_y] = \min(C_{xy} \cdot s_{xy}, \mu \cdot F_z) \cdot [\sin(\theta_{Fxy}), -\cos(\theta_{Fxy})];$$

$$s_{xy} = \frac{\sqrt{(R \cdot \omega - v_x)^2 + v_y^2}}{|R \cdot \omega|}; \theta_{Fxy} = \arctan2(-v_y, \underline{R_w \cdot \omega - v_x});$$

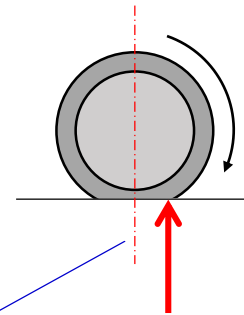
Dry Friction in Brake



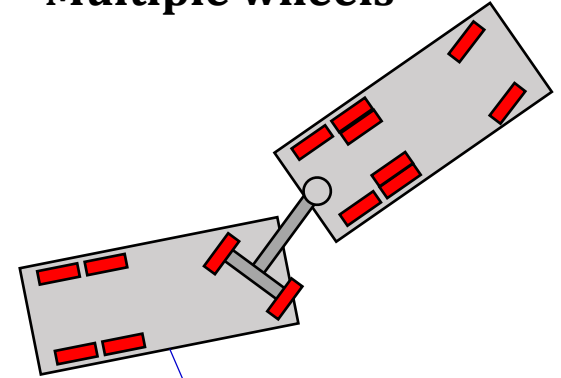
$$J \cdot \dot{\omega} = T - F_x \cdot R - T_R;$$

$$T_R = -\underline{\text{sign}(\omega)} \cdot (T_{bc} + RRC \cdot R \cdot F_z);$$

Rolling Resistance

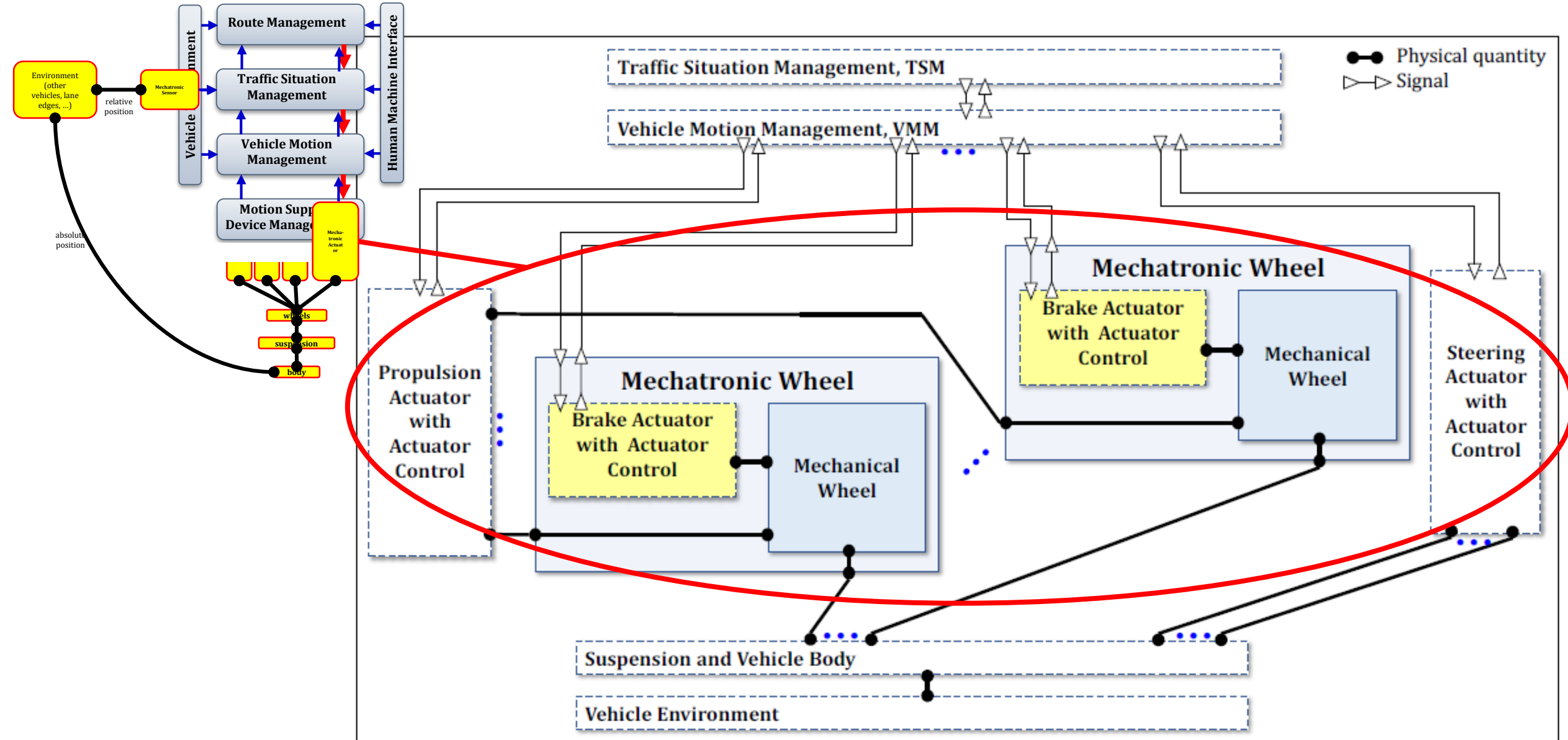


Multiple wheels



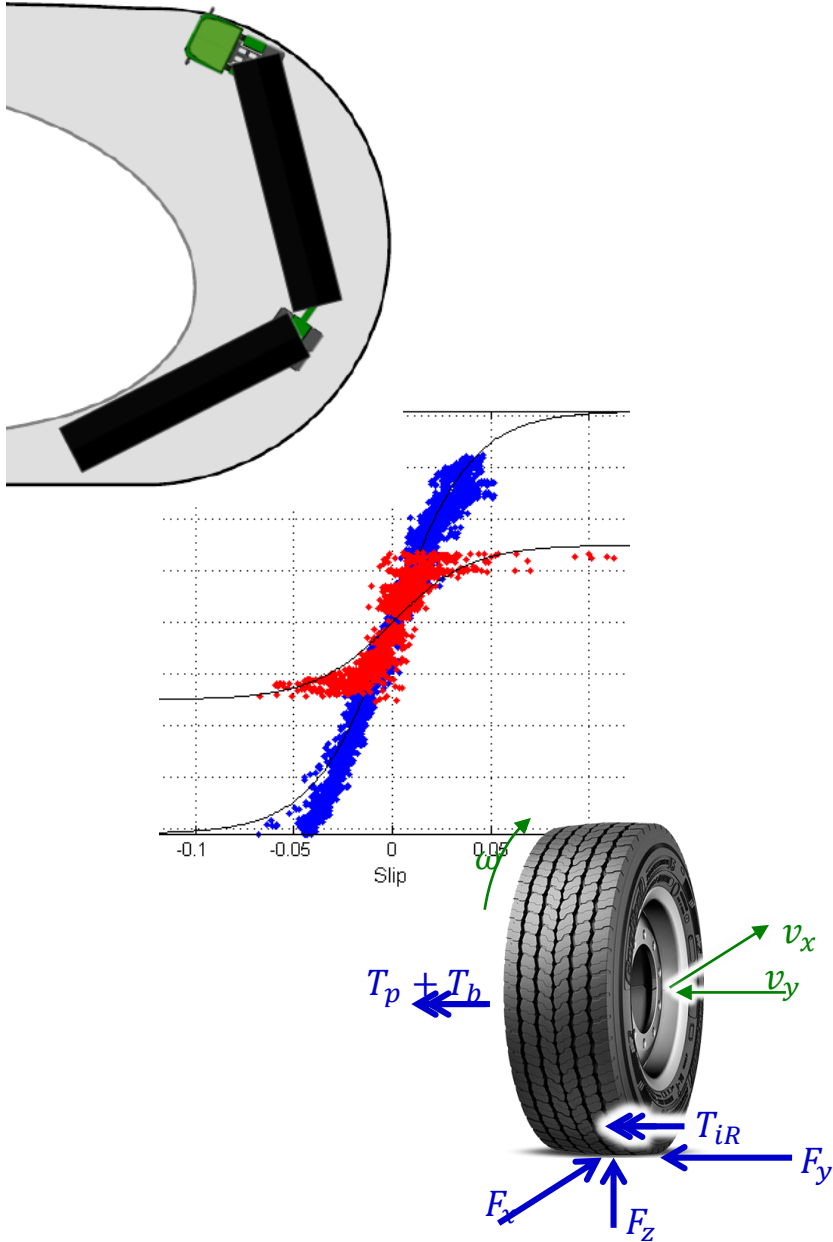
If vehicle standstill and two or more wheels locked:
Statically underdetermined

Wheel model in its model context



Conclusions

You have seen:



Automated driving needs modelling in many aspects:

- TSM and VMM needs Physical modelling for **“Control/algorithm design”**.
- **“Virtual verification”** drives Physical modelling, incl. exchange of models between organisation.

References

Matthijs Klomp, et al, *Trends in vehicle motion control for automated driving on public roads*, 2019.

<https://www.tandfonline.com/doi/full/10.1080/00423114.2019.1610182>

Nilsson, Peter, *Traffic Situation Management for Driving Automation of Articulated Heavy Road Transports - From driver behaviour towards highway autopilot*, PhD thesis, Chalmers, 2017. <https://research.chalmers.se/publication/251872>

Weitao Chen et al, *Integration and Analysis of EPAS and Chassis System in FMI-based co-simulation*, 2019.

<http://www.ep.liu.se/ecp/article.asp?issue=157%26article=74>

SAE, *Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems*, Standard J3016, 2014.

https://saemobilus.sae.org/content/j3016_201401

IVSS Road Friction Estimation Part II Report, <http://www.ivss.se>

US Department of Transportation – Federal Highway Administration

C.-G Wallman. Tema vintermodell – olycksrisker vid olika vinterväglag. Technical Report N60-2001, VTI, 2001.

S. Roychowdhury, M. Zhao, A. Wallin, N. Ohlsson, M. Jonasson, 'Machine learning models for road surface and friction estimation using front-camera images', International Joint Conference on Neural Networks (IJCNN 2018), Rio, Brazil, 2018.

M. Jonasson, N. Olsson, S. R. Chowdhury, S. Muppirisetty, Z. Minming, *Automated Road Friction Estimation using Car-sensor Suite: Machine Learning Approach*, Autonomous Vehicle Software Symposium, Stuttgart, Germany, 2018

Thanks for your attention