

Proceedings from 2022 Vehicle Dynamics seminar

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The seminar is held annually. The full title of this year's seminar was "2021 Vehicle Dynamics seminar -- Connected and Electric".

The contents of these proceedings include both **presentations and poster material** and are published at <https://research.chalmers.se/en/publication/532686>. It will also be available at <https://kth.diva-portal.org/> and <https://www.sveafordon.com/>.

The seminar was arranged by Vehicle Dynamics Competence Area and Swedish Vehicular Engineering Association (SVEA, <https://www.sveafordon.com/>).

The seminar was very appreciated and held both "in-real life" at LTH in Stockholm and remotely via "Teams". There were 75 registered participants from around 20 organisations, 8 presentations, and 4 poster presentations.

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Presentation: *Road surface identification and tyre-road property estimation using camera data*, Will Midgley, Loughborough University and Volvo Trucks

Presentation: *Vehicle as a sensor*, Bas Oremus, Scania

Presentation: *Path following and lateral stability of automated vehicles*, Wenliang Zhang, KTH

Presentation: *Towards automating High Capacity Transport vehicles*, Abhijeet Behera, VTI and LIU

Presentation: *Vehicle Engineering Master programme*, Mikael Nybacka, KTH

Presentation: *Mobility Engineering Master programme*, Giulio Bianchi Piccinini, Chalmers

Poster: *A study on the energy consumption impact of environmental parameters on heavy vehicles*, Manish Raathimiddi, Chalmers and HAN

Poster: *Heavy duty EPS and its theoretical requirements*, Christopher Essén and David Wikman, KTH and Scania

Poster: *Variable steering ratio design for steer-by-wire system*, Jakob Roempke and Gustav Lindahl, KTH and Volvo Cars

Poster: *Driving simulator study on Crosswind Aerodynamics*, Anup Garje Mohan Kumar and Sai Kishan Sawanth, CEVT and Chalmers

Note that the pdf file is generated with these “headings as pdf bookmarks”, so you can also navigate via the “bookmark pane” in your pdf reader.

Announcement of the Seminar



Seminars

2022 Vehicle Dynamics -- Connected and Electric (2022-05-18 09:00)

Seminarie: 2022 Vehicle Dynamics -- Connected and Electric



ENDORSED BY



FISITA

Vehicle Dynamics -- Connected and Electric

Wednesday May 18, 2022, 9-15

Lecture hall (Hörsal) D3, Lindstedtsvägen 9, KTH, Stockholm, Sweden

Hybrid seminar: Both in-real-life and on-line.

Please fill in the registration form to the right. Our appologies for that the registration form is in Swedish:

- "För- och Efternamn" means "First and Last Names"
- "Postadress" means "Mail address"
- "Postnummer" means "Zip code"

- "Stad" means "City"
- "Land" means "Country"
- "Telefonnummer" means "Phone number"
- "E-postadress" means "E-mail address"
- "Jag vill bli medlem" means "I want to apply for membership"
- "Anmäl dig till seminarie" means "Register to seminar"

You will get a confirmation e-mail when you are registered.

Additionally, if you will participate in-real-life, please send an e-mail to info@sveafordon.com. If you do not inform us that you will participate in-real-life, we will assume that you participate on-line.

We will order food (sponsored by SVEA) and send directions to "in-real-lifers".

We will send link to "on-liners".

Note 2022-05-03: We have experienced problems with registration. If you get an error message please ask to be registered in an e-mail to info@sveafordon.com. In that case, please remember to also tell if you participate in-real-life.

Purpose with the seminar

- Present and discuss interesting issues within and challenges for **Vehicle Dynamics -- Connected and Electric**
- Develop and increase competence
- Create understanding and interest for vehicle dynamics
- Networking between engineers and organisations and students

SVEAs objectives

- To make vehicular technology's voice heard in an increasingly more challenging debate among different vehicle types and transport modes both domestically and globally.
- To build a network for efficient distribution of technological information
- To attract the next generation of Swedish vehicular engineers

Agenda

[Times stated are in Swedish time]

09:00-09:15 Registration and coffee & Poster session

09:15-09:30 Intro

- *Welcome from SVEA and Vehicle Dynamics Competence Area,*
Ingemar Johansson & Bengt Jacobson

Moderator: Lars-Gustaf Hauptmann

09:30-10:30 Lecture session 1

09:30-10:30 Lecture session 1

- *Using maps and location data to improve vehicle dynamics*, Petter Djerf, HERE Technologies
- *Predictive energy management for heavy duty vehicles*, Olof Lindgärde, AB Volvo
- Micro-presentations of posters, part 1
 - *A study on the energy consumption impact of environmental parameters on heavy vehicles*, Manish Raathimiddi, Chalmers
 - *Heavy duty EPS and its theoretical requirements*, Christopher Essén and David Wikman, KTH and Scania

10:30-10:50 Coffee

10:50-11:50 Lecture session 2

- *Road surface identification and tyre-road property estimation using camera data*, Will Midgley, Loughborough University & Volvo Trucks
- *Vehicle as a sensor*, Bas Oremus, Scania
- Micro-presentations of posters, part 2
 - *Variable steering ratio design for steer-by-wire system*, Jakob Roempke and Gustav Lindahl, KTH and Volvo Cars
 - *Driving Simulator Study on Crosswind Aerodynamics*, Anup Garje Mohan Kumar and Sai Kishan Sawanth, CEVT and Chalmers

11:50-12:50 Lunch, mingel

12:50-13:30 Lecture session 3

- *Path following and lateral stability of automated vehicles*, Wenliang Zhang, KTH
- *Towards automating High Capacity Transport vehicles*, Abhijeet Behera, VTI and LiU

13:30-14:00 Coffee

14:00-14:45 Lecture session 4: Automotive education

- *Vehicle Engineering MSc prog*, Mikael Nybacka, KTH
- *Mobility engineering MSc prog*, Giulio Bianchi Piccinini, Chalmers
- Questions and discussion about the automotive education

Poster exhibition

There will be an exhibition of posters. It can be, e.g., master thesis or PhD thesis projects, both concluded and almost concluded such. Please contact Lars Drugge <larsd@kth.se> or Bengt Jacobson <bengt.jacobson@chalmers.se> if you would like to propose a poster.

Each poster should do a "5 minutes micro-presentation with 2-4 slides". These slides will be printed also on paper and displayed at seminar site.

Proceedings

There will be proceedings from the seminar. This means that the presenters, including poster presenters, are welcome with a paper, or at least a public version of their presentation material. The proceedings will be available as a report on web; at www.sveafordon.com. It will include a list of participants.

Registration

Please fill in the registration form to the right on the top. (Translation in the first section of this page.)

Additionally, if you will participate in-real-life, please send an e-mail to info@sveafordon.com. If you do not inform us that you will participate in-real-life, we will assume that you participate on-line.

We want registration:

- latest Thursday 2022-05-12 (for "in-real-lifers", in order to order food)
- latest Monday 2022-05-16 (for "on-liners", in order to send out link).

Membership in SVEA

If you are not a member, we welcome you as a member.

Member fee in SVEA is 200 SEK/year (free for "junior 26-", 100 SEK for "senior 65+").

Membership application through: <http://www.sveafordon.com/bli-medlem/vill-du-bli-medlem/medlemsansokan>

Questions via e-mail to: info@sveafordon.com

The seminar is arranged by the Swedish Vehicle Dynamics Competence Area and hosted by SVEA with representatives from:

- AstaZero
- CEVT
- Chalmers
- KTH
- VTI
- NEVS
- AFRY Automotive
- Scania
- Volvo Cars
- Volvo GTT

VDCA Swedish Vehicle Dynamics Competence Area



Plats	KTH, Lecture hall (Hörsal) D3, Lindstedtsvägen 9 Stockholm, Sweden
Pris (medlem)	0 kr
Pris (junior/senior)	0 kr
Pris (ej medlem)	0 kr
Start	2022-05-18 09:00
Slut	2022-05-18 15:00

Anmälan





Land



Telefonnummer



bengt.jacobson@chalmers.se

☐ Jag vill bli medlem

Anmäl dig till seminarie

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Registered participations

75 registered

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Presentation:
*Using maps and location data to improve
vehicle dynamics,*
Petter Djerf, Here Technologies



Using maps and location data to improve vehicle dynamics

SVEA Seminarie: 2022 Vehicle Dynamics -- Connected and Electric

Petter Djerf, HERE Technologies





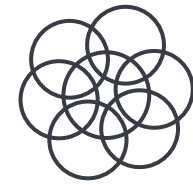
Global trends in Location Technology today...



**AI &
Machine
Learning**



**Increasing
Regulations &
Public Scrutiny**



**Converging
Industries**



**Transport
& Mobility
Revolution**



**Changing
Consumer
Demands**



**Platform
Scale**



Creating a **DIGITAL** **REPRESENTATION**

35+

Years in
mapmaking

8,000

Employees

#1

Location platform in
analyst evaluations⁽¹⁾

2m+

Developers in our
ecosystem

of the **PHYSICAL** **WORLD**

190+

Countries & territories for
which we provide data

200m+

Points of interest

160m+

Vehicles with HERE on
board

15b+

Real-time probe data
points ingested daily

Road Attributes



Slope 43°



Height 1220m

6.10 m

Road Attributes

Curvature 935m

Radius 605



374.8 cm

388.2 cm

W-Sonnborn
-Vohwinkel

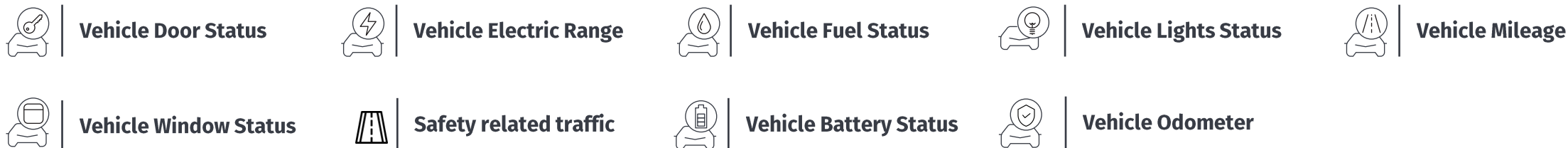
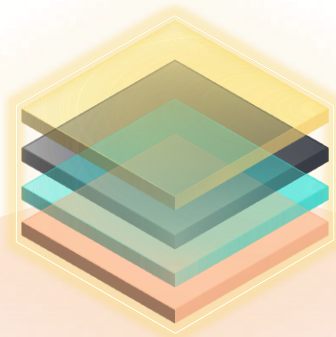
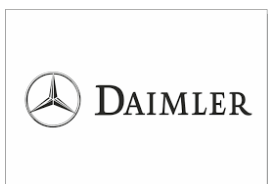
Ausfahrt



W SW 1414



Daimler became the first customer to provide access to vehicle sensor data via HERE Neutral Server



Examples of services, "virtual" sensors & use cases

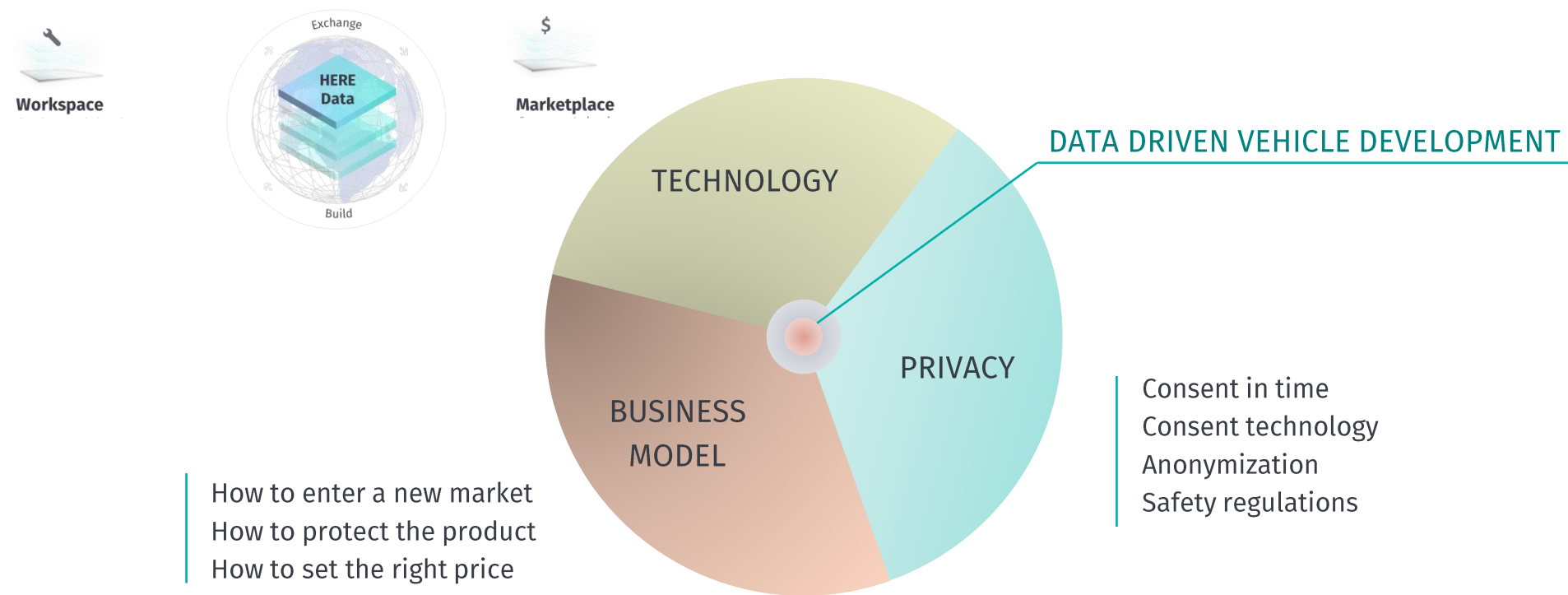
- Road speed
- Probe data
- EV
- Friction / Grip
- Roughness
- Speedbump
- Pothole
- Aquaplaning
- Road resistance
- ...

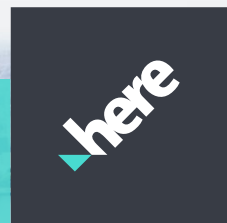


- Speed assist
- ADAS all kinds
- Traffic info
- Parking services
- Truck parking
- EV
- Friction alert
- Road hazards
- ...



Overview vehicle dynamics – digital challenges





THANK YOU!

Petter Djerf

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Presentation:

***Predictive energy management for heavy
duty vehicles,***

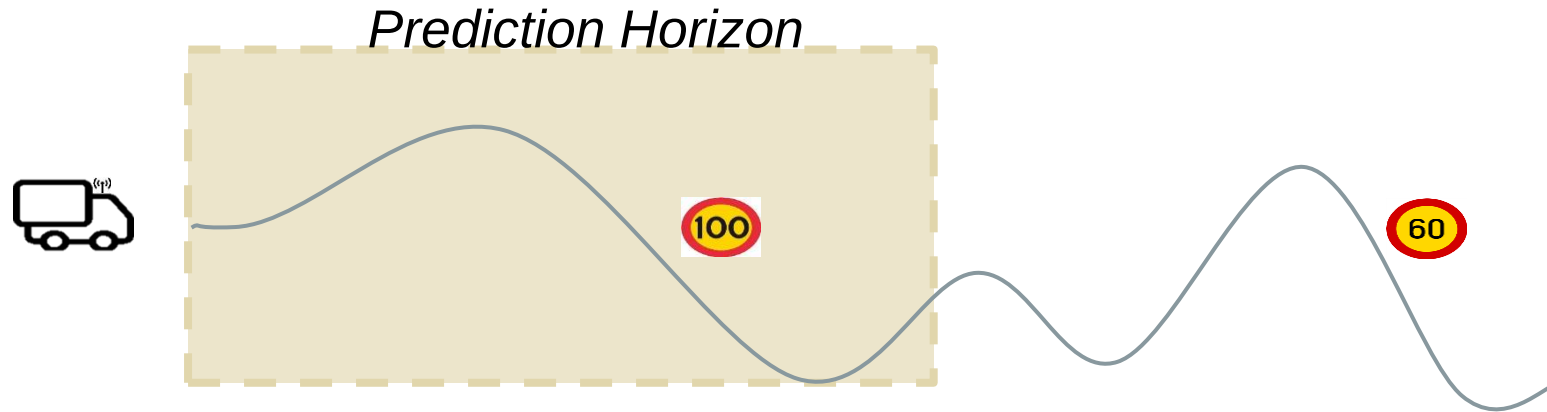
Olof Lindgärde, AB Volvo



Predictive Energy Management for Heavy Duty Vehicles

Olof Lindgärde

Presenting the idea



Task: Minimize fuel consumption

Constraints: Speed within upper and lower bounds

Output: Speed, gear and eco roll (engine off)

Approach:

- Model based **optimal** control using **prediction**

Goal:

- Improve performance
- Improved variant handling and reduce calibration effort

Optimize the propulsion over a predicted horizon

Minimize fuel (or losses)
+ penalties (e.g. using disk brake)

$$\min_{u_c, u_d} \int_{t_0}^{t_f} J(x, u_c, u_d) dt$$
$$\dot{x} = f(x, u_c, u_d)$$

States (vehicle kinetic energy
& battery state of charge)

Prediction Models

Continuous actuators (engine
& EM torque)

$$x^{\min} \leq x \leq x^{\max}$$

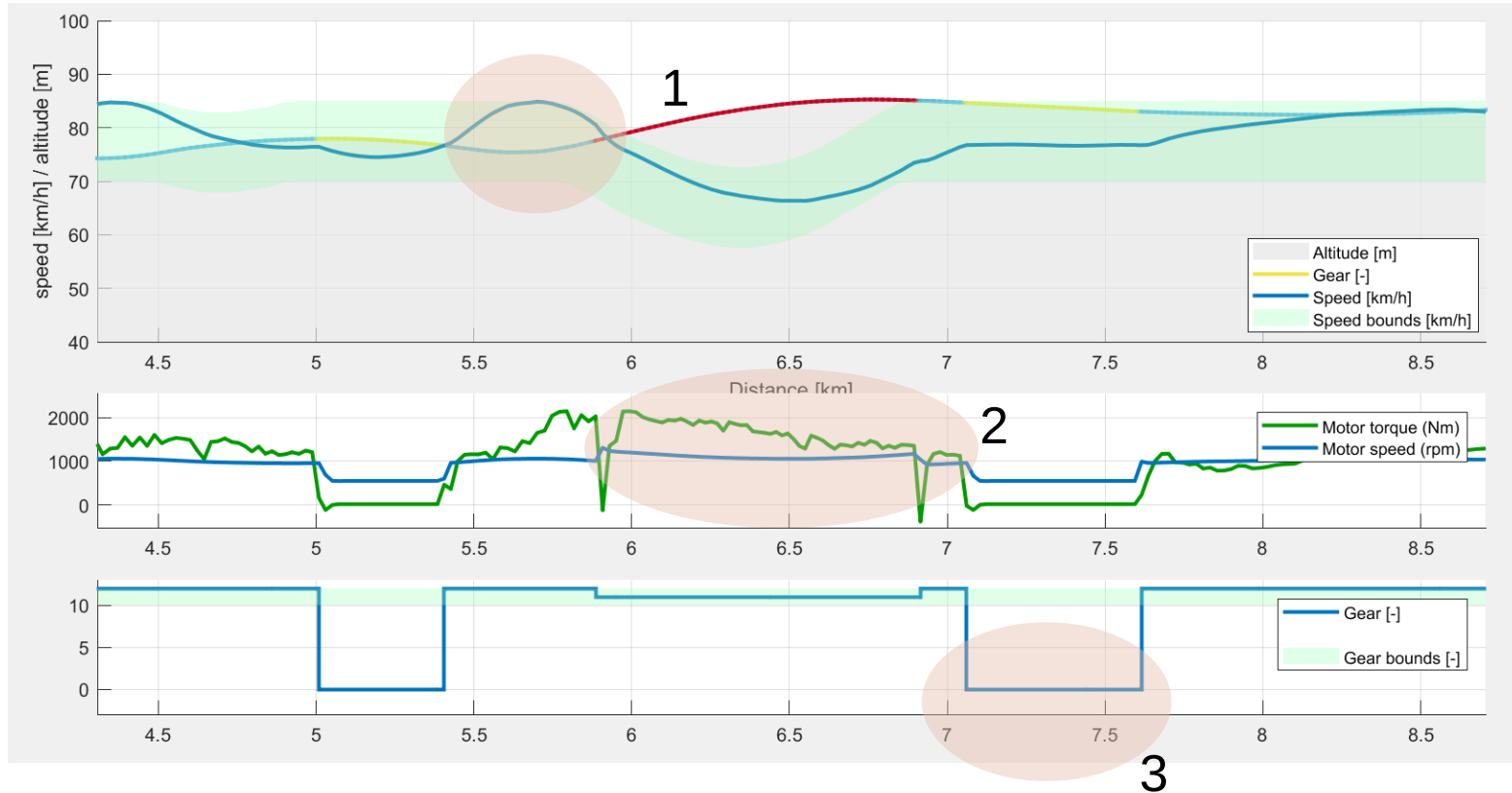
State Bounds

Discrete actuators (gears and
clutches)

$$u_c^{\min} \leq u_c \leq u_c^{\max}$$
$$u_d^{\min} \leq u_d \leq u_d^{\max}$$

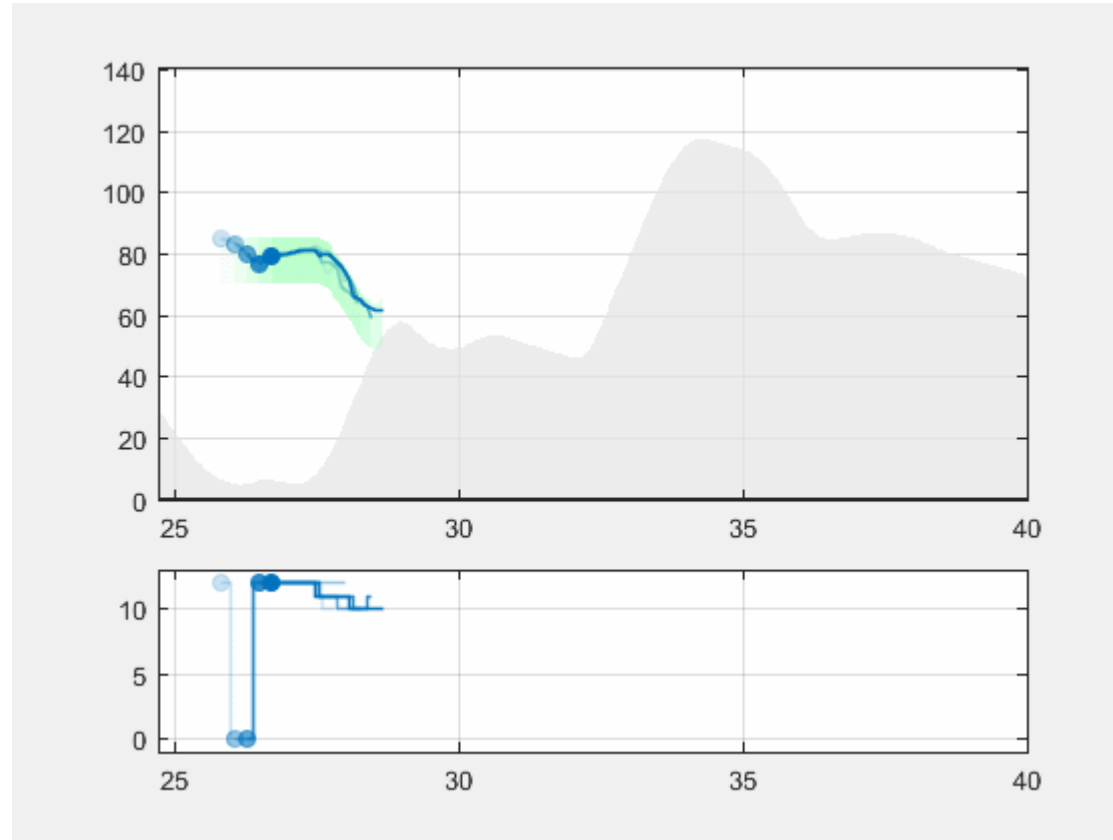
Actuator Bounds

A simulation example

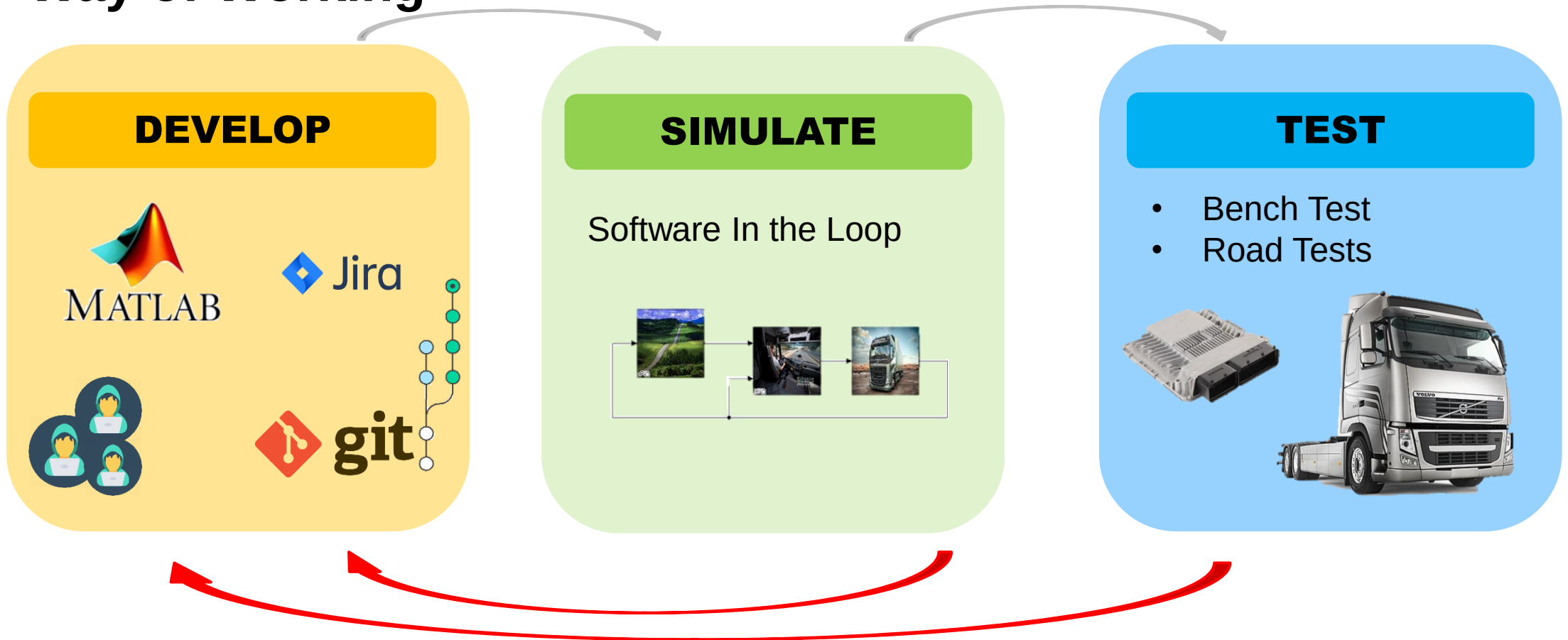


1. Pre-speed;
2. Gradual torque reduction on crest;
3. Eco roll.

Speed/Gear Trajectories



Way of Working



Some learnings

Strengths

- Modularity, easy to adapt to various configurations
- Reduces calibrations effort
- Adapt to requirements

Challenges and potential weaknesses

- Debugging
- Formulate correct model and cost function
- Computational effort/Memory footprint

Some Learnings:

- Mix discretes/continuous: difficult
- This approach also valuable on electrified vehicles:
 - more focus on life than on energy consumption

Presentation:

***Road surface identification and tyre-road
property estimation using camera data,***

Will Midgley, Loughborough University and
Volvo Trucks



Loughborough
University

Road surface identification and tyre-road property estimation using camera data

Mohammad Otoofi, Will Midgley & Laura Justham – Loughborough University

Leo Laine, Leon Henderson – Volvo Trucks

- 5th in the UK for Mechanical Engineering (Guardian)
- Top 100 in the world for Mechanical, Aeronautical and Manufacturing Engineering
- Awarded 7 Queen's Anniversary Prizes for higher and further education
- Largest engineering activity in the UK
- 93% of research outputs “internationally excellent” or “world-leading” (REF2021)
- WhatUni Top University for Facilities 2020
- QS Rankings 5*+ university



The Project

Motivation



- Friction coefficient is important for:
 - Active safety systems (ASS)
 - Emergency collision avoidance (ECA)
 - Anti-lock braking system (ABS)
 - ...
 - Advanced driver-assistance systems (ADAS)
 - Autonomous navigation systems
- Current methods:
 - Effect-based methods
 - Estimating dynamic parameter response of the vehicle
 - Cause-based methods
 - Identifying the factors affecting friction, e.g. surface type
- What if we can use computer vision?



Previous experimental investigations using thermal imaging [1]

[1] Jonsson, Patrik, Johan Casselgren, and Benny Thörnberg. "Road surface status classification using spectral analysis of NIR camera images." IEEE Sensors Journal 15, no. 3 (2014): 1641-1656.

Our Approach



- Use machine learning and computer vision:
 - Determine the properties ahead in a similar way to a human driver

This breaks down into two tasks:

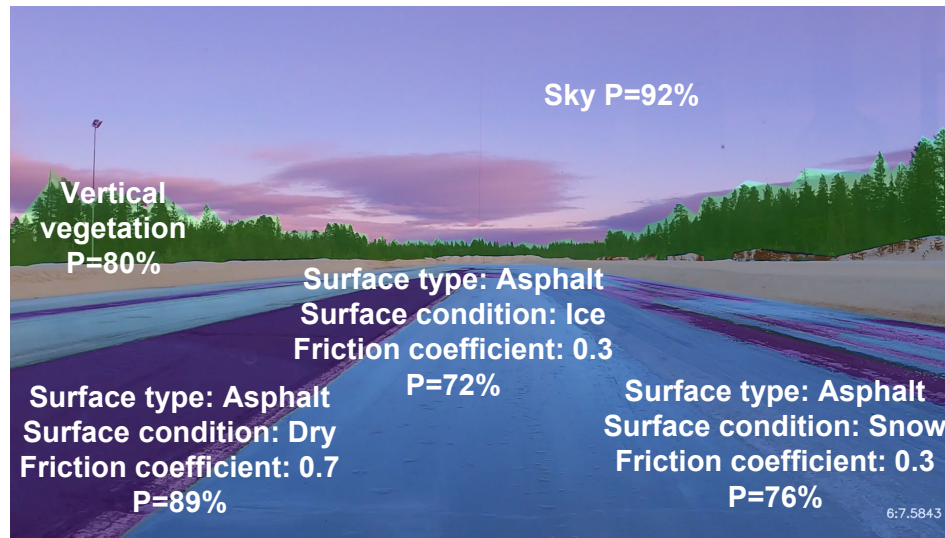
1. Surface detection/categorisation
2. Friction coefficient estimation

1. Surface detection/Categorisation:

- *Semantic segmentation*: pixel-by-pixel classification of image into surface types and surface condition

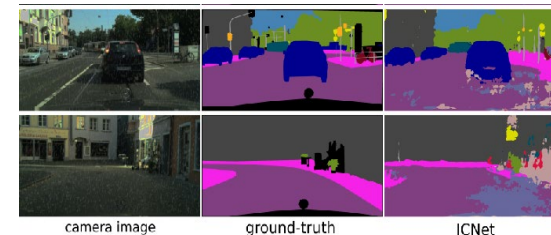
2. Friction

- Detected regions are fed to a second function to provide an estimate of friction coefficient



Challenges

- Producing a scalable solution:
 - Performing in real-time
 - Using a *monocular* dashcam
- Ambiguous situations
 - Inherent noise in environment
 - Sun glare
 - Shadows
 - Poor visibility
 - Fog
 - Rain
 - Snow
 - **Solution:** *multiple hypotheses*



Previous work on semantic segmentation [1]



Example of difficult operating conditions [2]

[1] Pfeuffer, Andreas, and Klaus Dietmayer. "Robust Semantic Segmentation in Adverse Weather Conditions by means of Fast Video-Sequence Segmentation." In 2020 IEEE 23rd International Conference on Intelligent Transportation Systems (ITSC), pp. 1-6. IEEE, 2020.

[2] Valada, Abhinav, Johan Vertens, Ankit Dhall, and Wolfram Burgard. "Adapnet: Adaptive semantic segmentation in adverse environmental conditions." In 2017 IEEE International Conference on Robotics and Automation (ICRA), pp. 4644-4651. IEEE, 2017.

Challenges II

- Lack of data
 - No visual data for friction estimation
 - Desired categories cannot be found in any dataset
 - Rural environment
 - **Solution:** Vehicle testing with Volvo Trucks on a range of surfaces

Dataset	Real	Location Accuracy	Diversity	Annotation			
				3D	2D	Video	Lane
CamVid	✓	-	day time	no	pixel: 701	✓	2D / 2 classes
Kitti	✓	cm	day time	80k 3D box	box: 15k pixel: 400	-	no
Cityscapes	✓	-	day time 50 cities	no	pixel: 25k	-	no
Toronto	✓	cm	Toronto	focus on buildings and roads exact numbers are not available ¹			
Mapillary	✓	meter	various weather day & night 6 continents	no	pixel: 25k	-	2D / 2 classes
BDD100K	✓	meter	various weather day 4 regions in US	no	box: 100k pixel: 10k	-	2D / 2 classes
SYNTHIA	-	-	various weather	box	pixel: 213k	✓	no
P.F.B.	-	-	various weather	box	pixel: 250k	✓	no
ApolloScape	✓	cm	various weather day time 4 regions in China	3D semantic point 70K 3D fitted cars	pixel: 140k	✓	3D / 2D Video 27 classes

¹ database is not open to public yet.

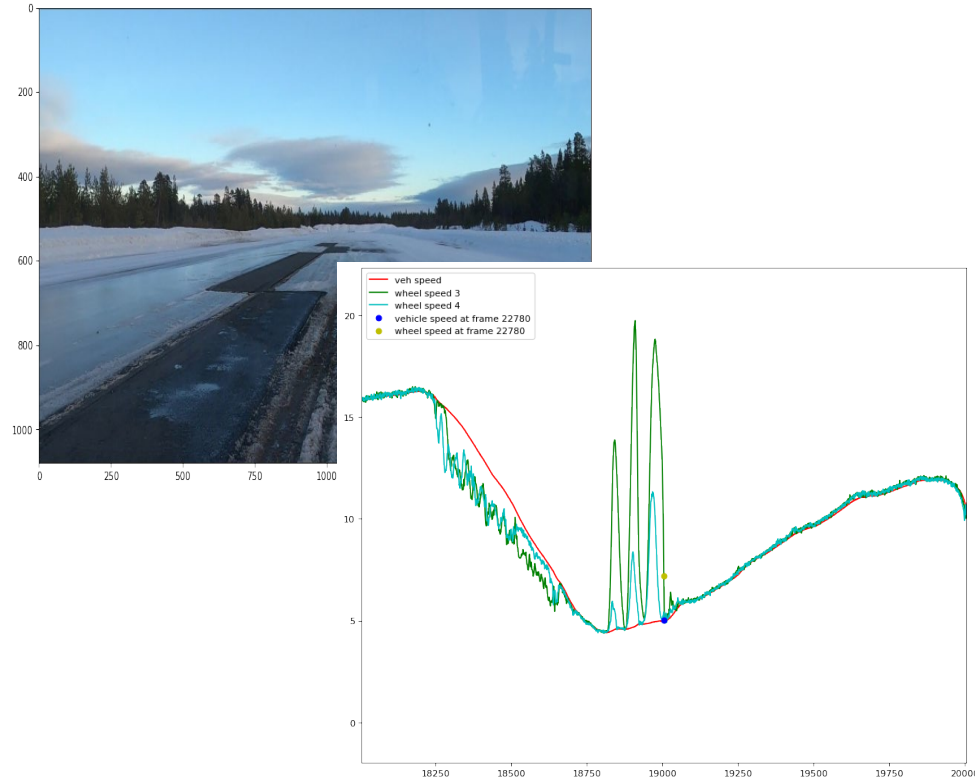
Summary of available data sources [1]

[1] Huang, Xinyu, Xinjing Cheng, Qichuan Geng, Binbin Cao, Dingfu Zhou, Peng Wang, Yuanqing Lin, and Ruigang Yang. "The apolloscape dataset for autonomous driving." In Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition Workshops, pp. 954-960. 2018.

Current Progress

Results from Winter Testing

- Data gathering for friction coefficient estimation
- Measuring friction ground truth using GPS, vehicle data, and dashcam
- Building our own dataset for friction estimation



Semantic Segmentation

- INPLACE-ABN trained on Mapillary dataset [Meta AI]
- Doesn't cover all the categories we are interested in
- Generates point estimate not probabilistic outputs
- No friction estimate



Semantic Segmentation

- UNet architecture
- Trained on Mapillary dataset [by Mohammad]

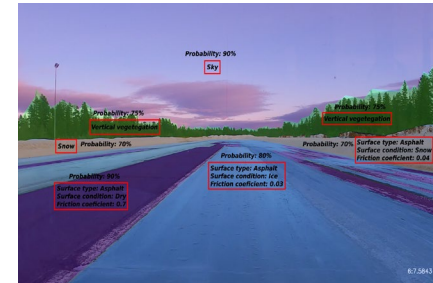
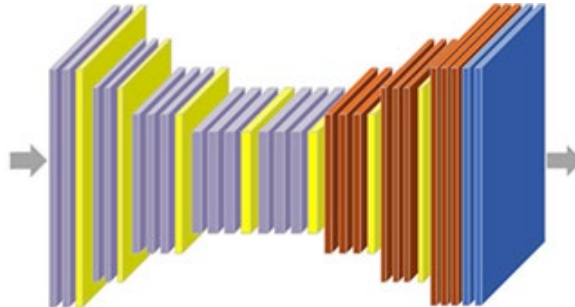


Solution Architecture

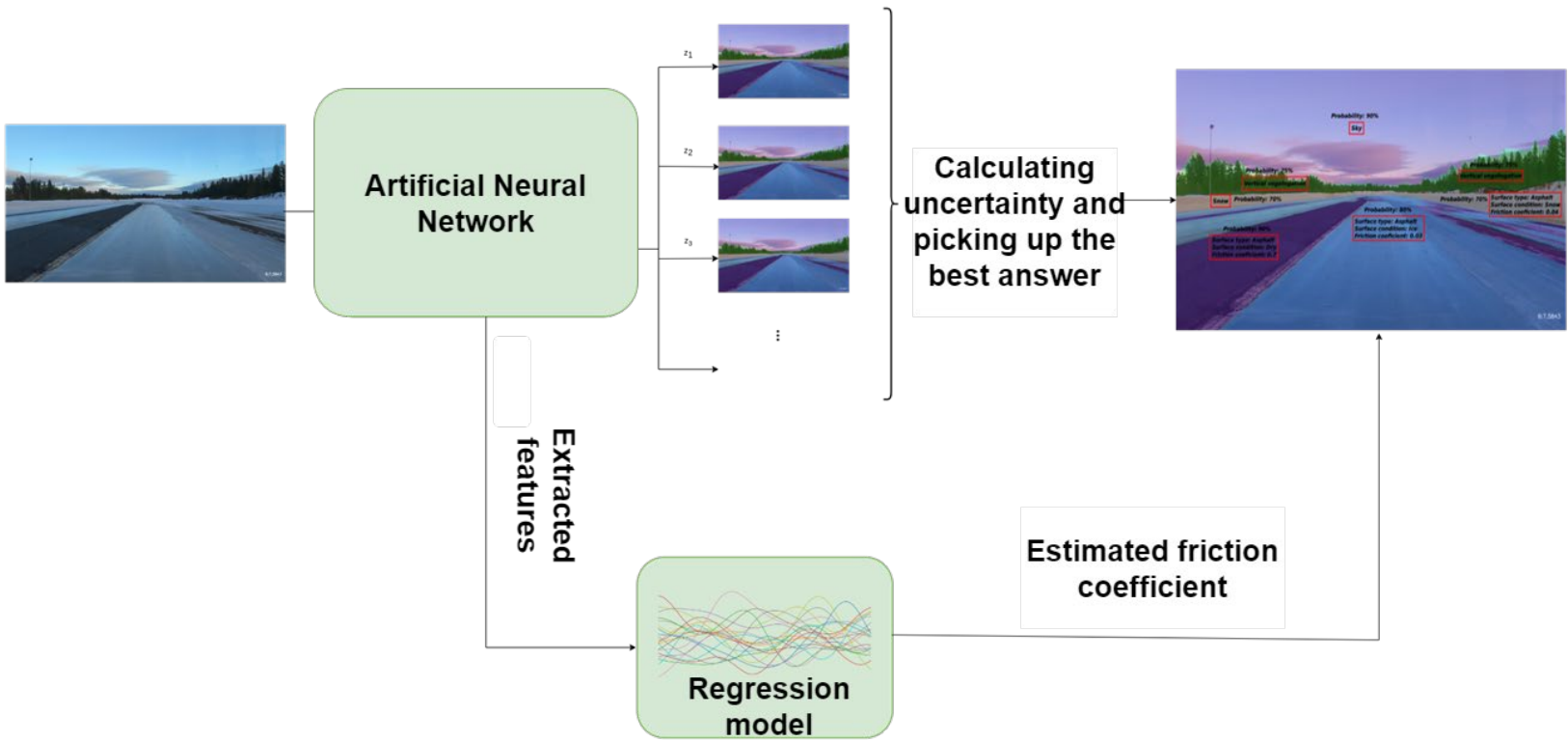
Proposed Solution:



- Detecting surface characteristics
 - Semantic segmentation
 - Probabilistic method
- Estimate friction coefficient
 - Regression
- Synthetic data
 - Generating samples for the desired categories
- Winter testing 2022
 - Gathered more samples for friction estimation



Method – System Overview





Loughborough
University

Questions?

Presentation:
Vehicle as a sensor,
Bas Oremus, Scania



BAS OREMUS

VEHICLE AS A SENSOR

SCANIA



BAS OREMUS

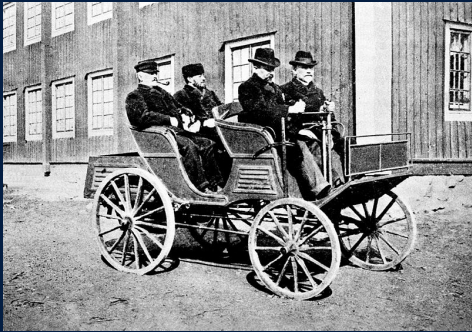
STARTED AT SCANIA 2003

- TEST ENGINEER VEHICLE DYNAMICS
- SW DEVELOPER WITHIN DRIVER SUPPORT
- MANAGER CONNECTED PLATFORM
- MANAGER ONLINE LOCATION INTELLIGENCE
- RESEARCH ENGINEER AUTONOMOUS SYSTEMS



SCANIA

THE TRUCK, AN ISOLATED SYSTEM <2011



1897



1923



0-series
1970



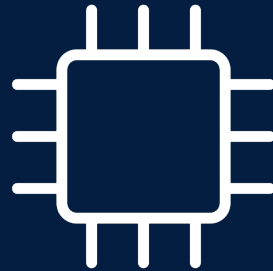
4-series
1995



PGRS-series
2004



A FUNCTION





IN 2011 WE STANDARDISED CONNECTIVITY





550.000+ CONNECTED VEHICLES





CONNECTED FUNCTION

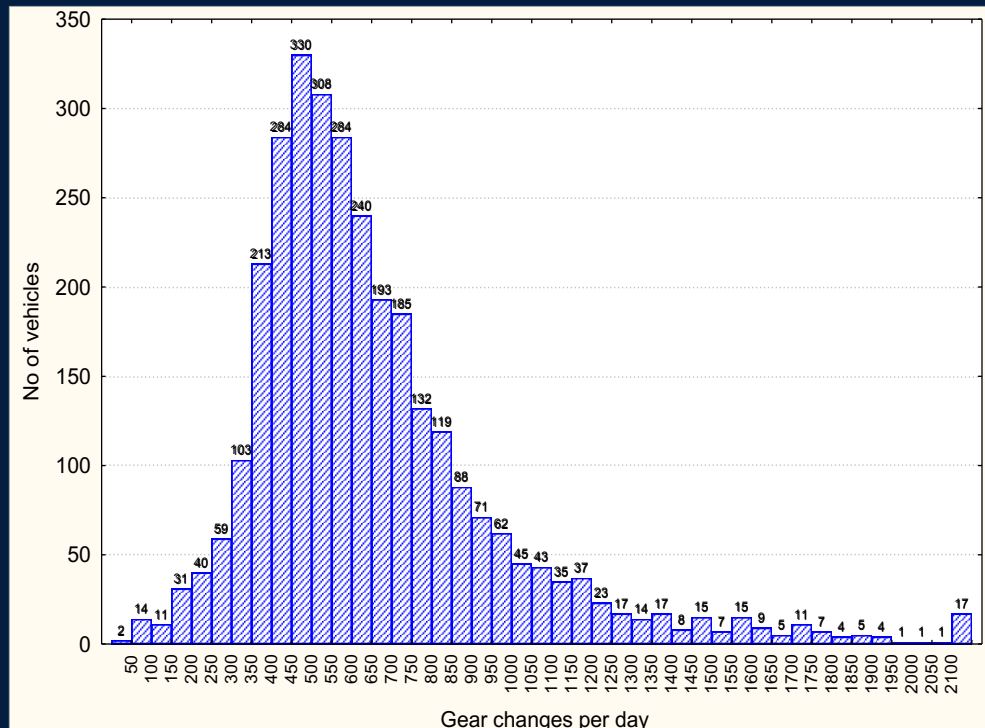


- Daily contact with factory
- Data collection
 - Digital twin
 - Vehicle is sensor for itself
- Data analytics

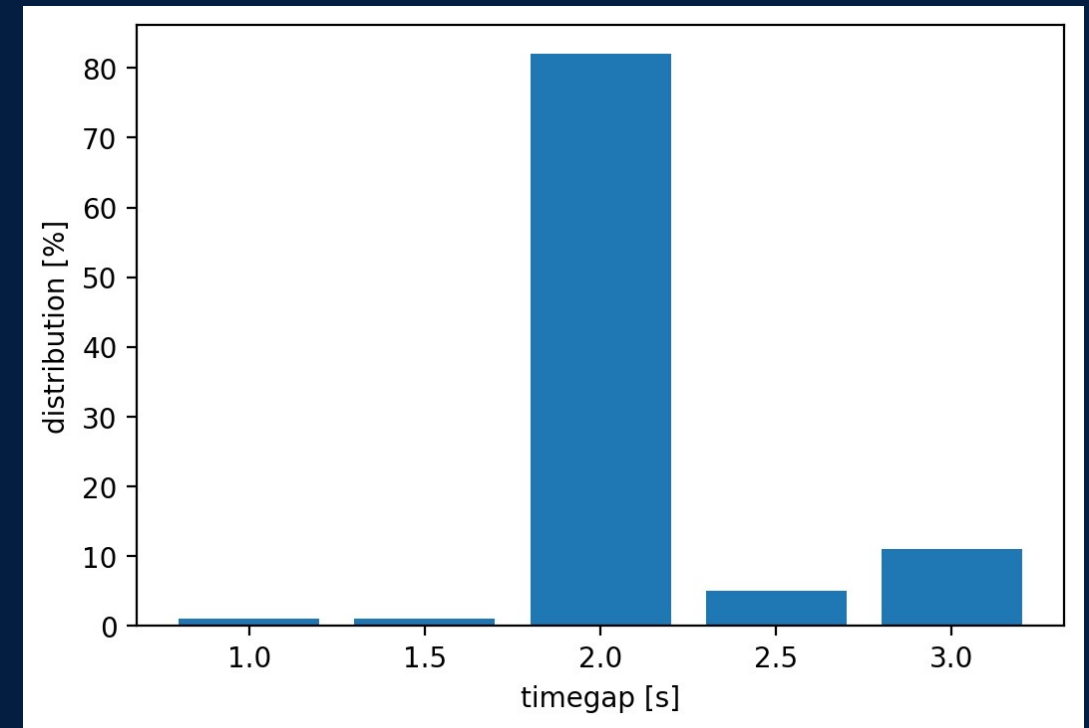


DATA DRIVEN PRODUCT DEVELOPMENT

Dimension the hardware:
Automatic clutch



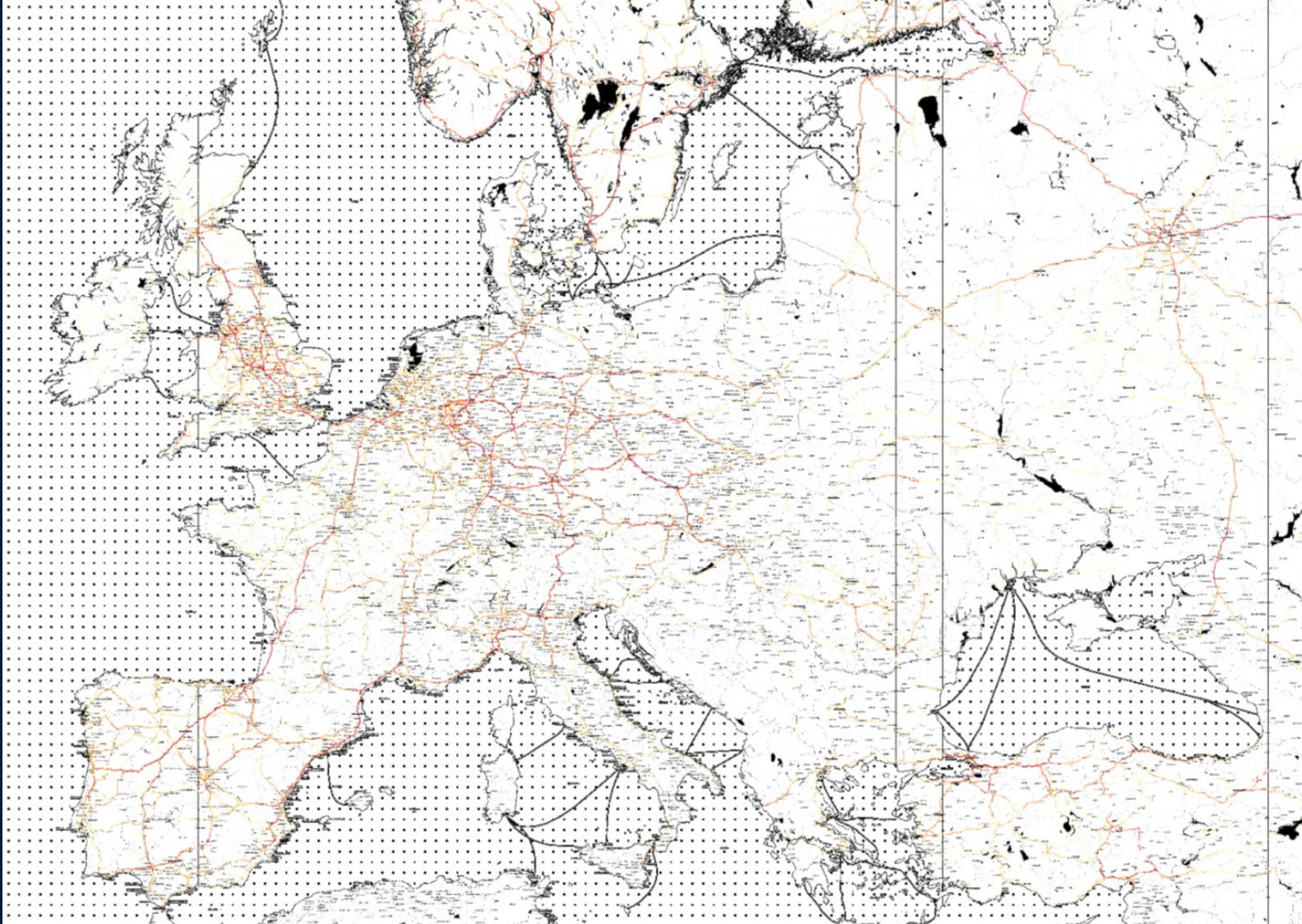
Decide a parameter setting:
Timegap for adaptive cruise control



Most people use default (2) or higher, let's make it longer



CONNECTIVITY ENABLES GEOSPATIAL ANALYTICS



Fuel Consumption
on Motorway



MACHINE LEARNING





DRIVER IS RESPONSIBLE

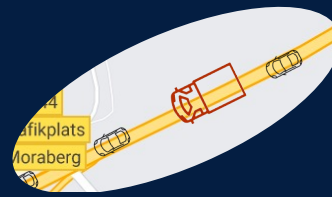


- Functions to assist the driver
- Compromise between safety and drivability



AUTOMATED VEHICLES & CONNECTIVITY





Range with vehicle sensors
(also the case for manual
driver)

CONNECTED AWARENESS BEYOND SENSOR RANGE



Manual vehicles can *benefit from* being connected to and cooperating within the transport system while automated/autonomous will be *dependent* on it to operate efficiently.

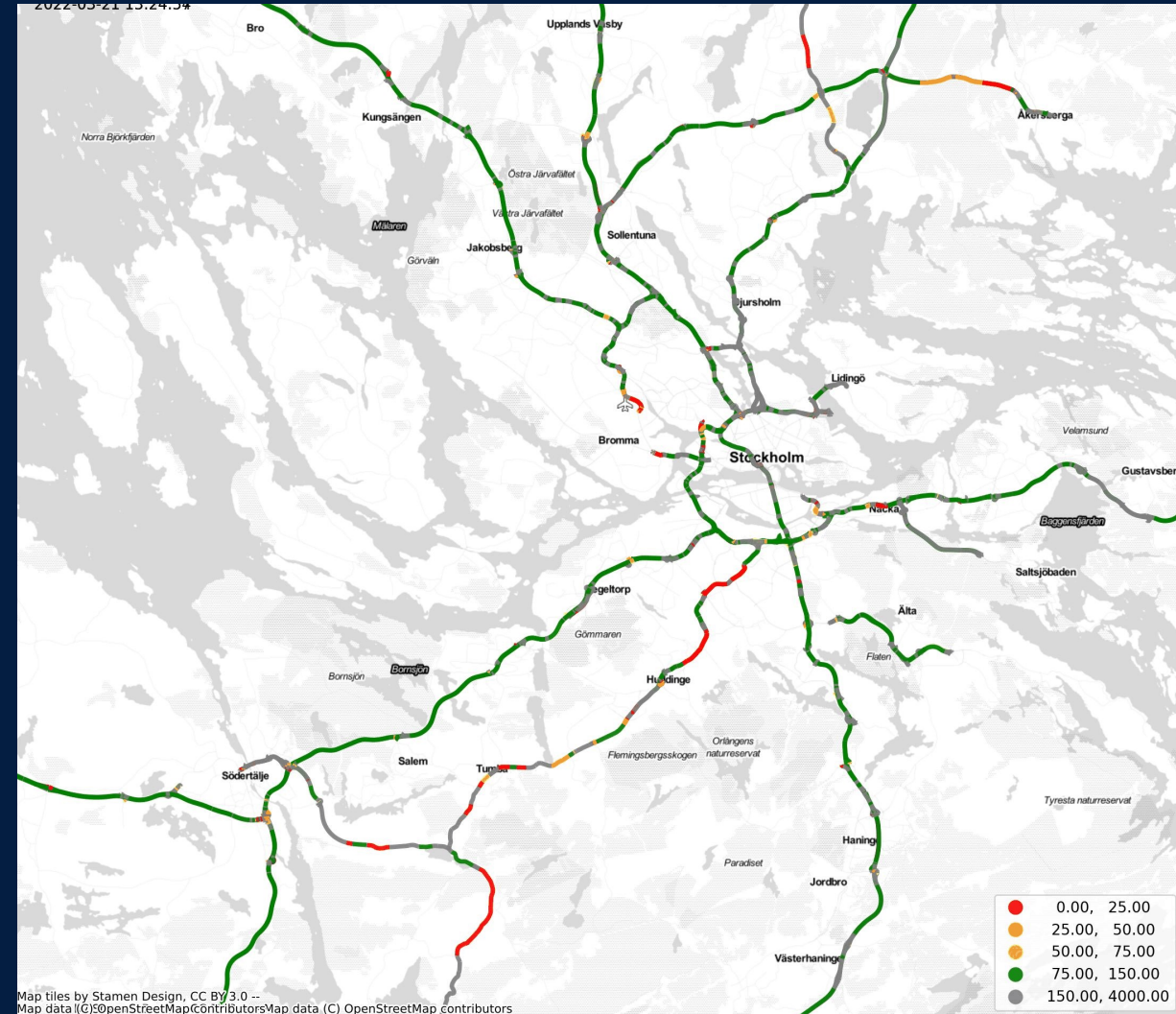
VEHICLES DETECT ROAD STATUS



- Scania connected fleet
 - Relative to legal speed
- Yes it is like google maps
 - New to OEM
 - Access to more vehicle sensors

Joining forces for traffic safety

Mercedes-Benz & Ministry of Infrastructure and Water Management, Netherlands



VEHICLES -> SENSORS FUNCTIONS -> SERVICES



- Dependency
 - On external data
 - On connectivity
- Evolve over time
 - Information sharing
 - Correct map data



QUESTIONS ?

bas.oremus@scania.com

Presentation:

***Path following and lateral stability of
automated vehicles,***

Wenliang Zhang, KTH



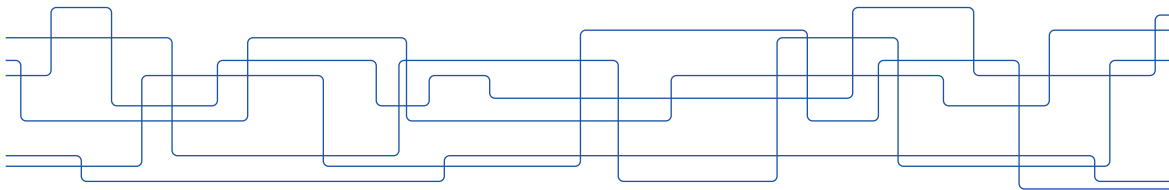
Active safety of autonomous electric vehicles

Wenliang Zhang

Ph.D. Candidate

KTH Vehicle Dynamics

May 18, 2022



Outline

Introduction

Research topic

Research questions

Vehicle dynamics modelling

Controller formulation

Results and discussion

Conclusions

Bibliography

Introduction

Road safety

- ▶ Traffic accidents $\rightarrow \approx 1.3$ million deaths every year [1]
- ▶ Road accident injuries $\rightarrow \approx 3\%$ of most countries' GDP
- ▶ Vehicle occupant deaths $\downarrow 14\%$ in 2018 (vs. 2010) [2]
 - ▶ Safer roads
 - ▶ Passive safety devices, e.g., airbags and seat belts
 - ▶ Active safety systems, e.g., electronic stability control (ESC) [3]

Introduction

Electronic stability control

- ▶ A closed-loop system to improve vehicle handling and braking response
- ▶ Helps prevents the vehicle from over- or under-steering



Figure 1: Car in an obstacle-avoidance manoeuvre [4].

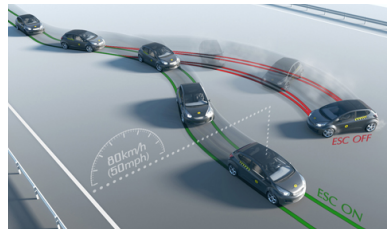


Figure 2: ESC in an obstacle-avoidance manoeuvre [5].

Introduction

Over-actuation

- ▶ Production vehicles with more motion actuators
 - ▶ BYD Han: one electric motor (EM) on each axle [6]
 - ▶ Polestar 1: one ICE in the front axle + two EMs in the rear [7]
 - ▶ Tesla Model S Plaid and Audi e-tron S: one EM in the front axle + two EMs in the rear [8, 9]



Figure 3: Tesla Model S Plaid [8].

- ▶ Over-actuated vehicle platforms
 - ▶ Zoox: individual traction + all wheel steering + active suspension [10]
 - ▶ KTH RCV: individual steering + camber + drive [11]

Research topic

KTH Research Concept Vehicle (RCV)

- ▶ Individual steering + drive + camber



Figure 4: KTH Research Concept Vehicle (RCV) [11].

Benefits of over-actuated electric vehicles

- ▶ Improved vehicle dynamics control
- ▶ Fast and accurate motor torque generation

Means of over-actuation studied

- ▶ Active front steering (AFS)
- ▶ Torque vectoring (TV)
- ▶ Active camber (AC)
- ▶ Integrated control

Research questions

Path following and yaw stability control strategies using over-actuation

- ▶ How can **path following** and **yaw stability** performance be improved in critical conditions?
- ▶ How would different means of **over-actuation** influence path following and yaw stability performance?

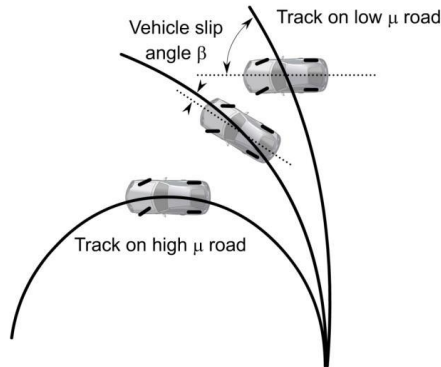


Figure 5: Path following and yaw stability control [12]

Vehicle modelling

- ▶ Double-track dynamic vehicle model
- ▶ Seven degrees of freedom

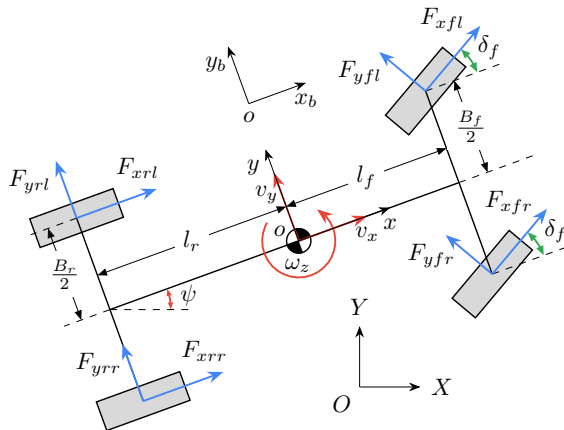


Figure 6: Double-track dynamic vehicle model.

Tyre modelling

Dugoff tyre model

- Combined slip conditions
- Uniform vertical load distribution

Camber effect modelling

$$F_{y\gamma i} = C_{\gamma i} \gamma_i \quad (1a)$$

$$C_{\gamma i} = \begin{cases} C_{\gamma 0i} + C_{\gamma \alpha i} |\alpha_i|, & \text{if } |\alpha_i| < \alpha_{lim} \\ C_{\gamma fi}, & \text{if } |\alpha_i| \geq \alpha_{lim} \end{cases} \quad (1b)$$

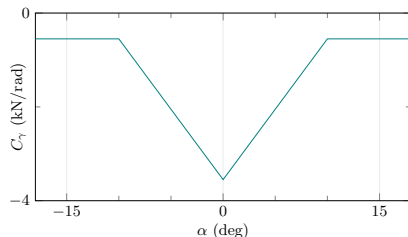


Figure 7: Tyre camber stiffness variation with respect to slip angle.

Tyre modelling

Camber effect modelling – Lateral tyre forces and camber gains

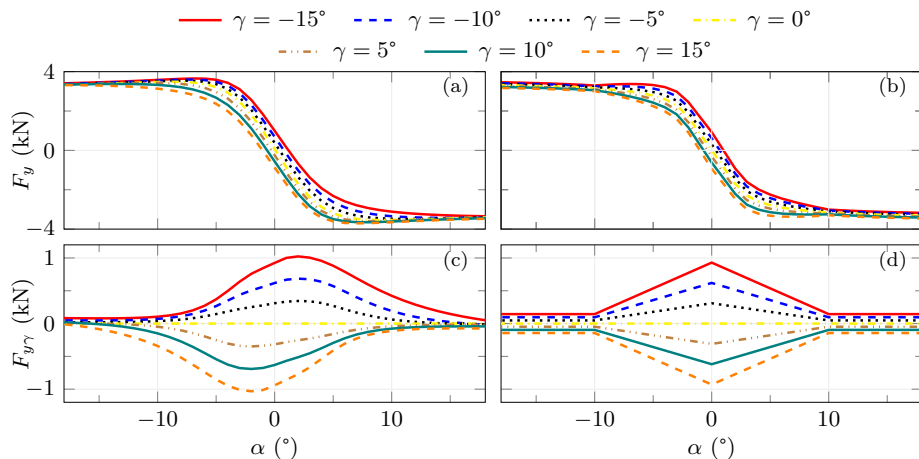


Figure 8: The Magic Formula [13] [(a) and (c)] and the Dugoff model with camber effect [(b) and (d)].

Vehicle plant modelling

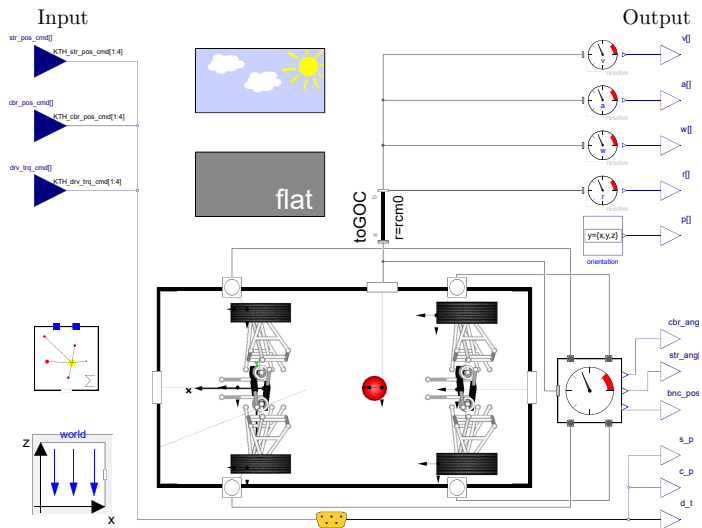


Figure 9: Dymola vehicle plant model.

Controller formulation

Formulation considerations

- ▶ Concurrent path following and yaw stability control
- ▶ Explicit constraints on sideslip angle and yaw rate
- ▶ Transient limits on reference yaw rate

$$\omega_{zmax} = \frac{\mu g}{v_x} - \dot{\beta} \quad (2a)$$

$$\omega_{zmin} = -\frac{\mu g}{v_x} - \dot{\beta} \quad (2b)$$

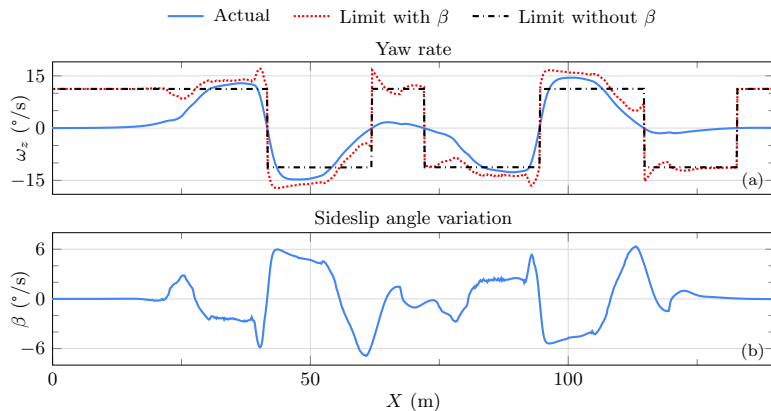


Figure 10: Reference yaw rate limits.

Controller formulation

Model predictive control

$$\begin{aligned}
 \min_{\mathbf{x}_p, \mathbf{u}_p, \Delta \mathbf{u}_p, \mathbf{s}} & \underbrace{\sum_{i=0}^{N_p-1} \|y_{k+i|k} - y_{k+i|k}^{ref}\|_{Q_y}^2}_{\text{tracking error}} + \underbrace{\sum_{i=0}^{N_p-1} \|u_{k+i|k}\|_{R_u}^2}_{\text{control action}} + \underbrace{\sum_{i=0}^{N_p-1} \|\Delta u_{k+i|k}\|_{R_{du}}^2}_{\text{change of control action}} \\
 & + \underbrace{\|y_{k+N_p|k} - y_{k+N_p|k}\|_{Q_{yf}}^2}_{\text{terminal cost of tracking error}} + \underbrace{\sum_{i=0}^{N_p-1} \|s_{k+i|k}\|_{Q_s}^2}_{\text{slack term}} + \underbrace{\|s_{k+N_p|k}\|_{Q_{sf}}^2}_{\text{terminal cost of slack variable}}
 \end{aligned} \tag{3a}$$

$$\text{s.t. } x_{k+i+1|k} = f(x_{k+i|k}, u_{k+i|k}) \tag{3b}$$

$$y_{k+i|k} = h(x_{k+i|k}), \quad i \in \{0, 1, \dots, N_p\} \tag{3c}$$

$$\Delta u_{k+i|k} = \begin{cases} u_{k+i|k} - u_{k+i-1|k}, & \text{if } i \geq 1 \\ u_{k|k} - u_{k-1|k-1}, & \text{if } i = 0 \end{cases} \tag{3d}$$

$$u_{min} \leq u_{k+i|k} \leq u_{max} \quad \Delta u_{min} \leq \Delta u_{k+i|k} \leq \Delta u_{max} \tag{3e}$$

$$\mathcal{H}_p(x_{k+i|k}, u_{k+i|k}, s_{k+i|k}) \leq 0 \tag{3f}$$

$$s_{k+i|k} \geq 0 \tag{3g}$$

Results and discussion

Why concurrent path following and yaw stability control?

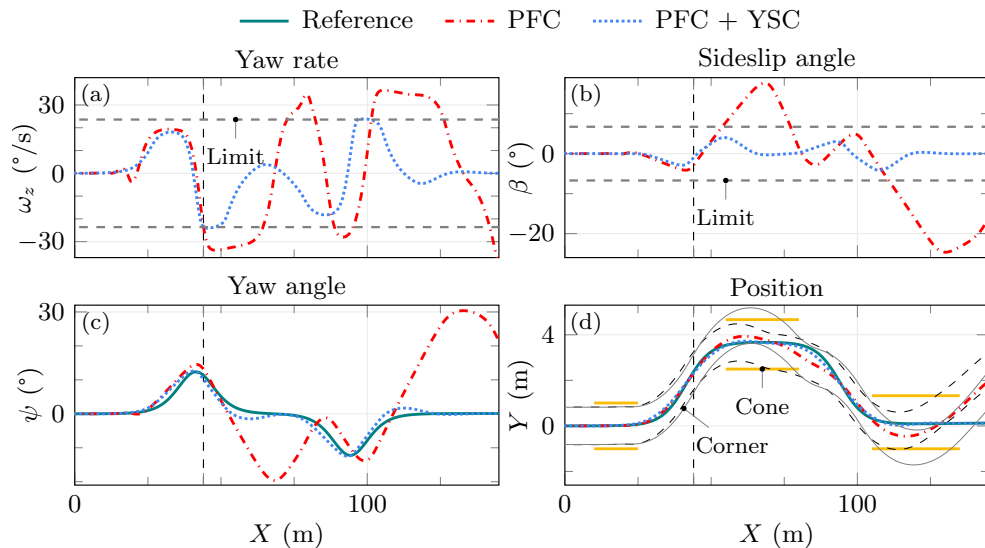


Figure 11: Tracking performance with and without yaw stability control ($\mu = 0.6$, $v_{xref} = 76$ km/h).

Results and discussion

Torque vectoring

- ▶ Aim
 - ▶ Evaluate the effects of **torque vectoring** and **controller structure** on control performance¹
- ▶ Comparison items

One-level controllers		Two-level controllers	
OLTV	OLEA	TLOA	TLRA
Torque vectoring	Equal allocation	Optimisation-based	Rule-based

¹Wenliang Zhang, Zhenpo Wang, Lars Drugge and Mikael Nybacka. Evaluating model predictive path following and yaw stability controllers for over-actuated autonomous electric vehicles, IEEE Transactions on Vehicular Technology, vol. 69, no. 11, 2020.

Results and discussion

Torque vectoring

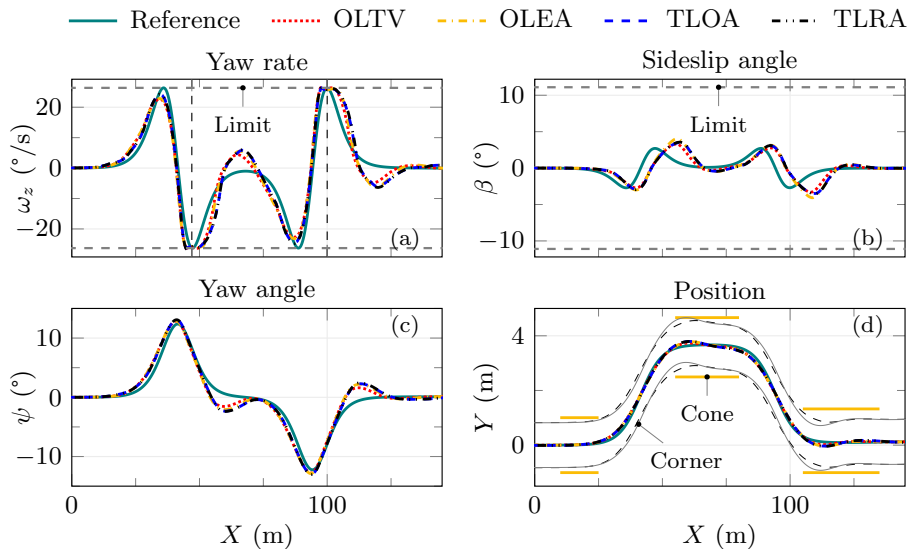


Figure 12: Tracking performance of the four controllers ($\mu = 1$, $v_{xref} = 85$ km/h).

Results and discussion

Torque vectoring

Table 1: Tracking accuracy of the four controllers ($\mu = 1$).

Ref. velocity (km/h)	Controller	ω_z ($^{\circ}/s$)	Y (m)
		e_{rms}	e_{rms}
85	OLTV	4.1	0.08
	OLEA	4.6	0.10
	TLOA	4.4	0.10
	TLRA	4.6	0.10
86	OLTV	4.3	0.08
	OLEA	4.8	0.10
91	OLTV	5.2	0.11

^a The colour red indicates the highest value, whilst the colour blue indicates the lowest.

Results and discussion

Active camber

- ▶ Aim
 - ▶ Evaluate the effects of **active camber** and **camber rate** on control performance²
- ▶ Comparison items
 - ▶ No camber control
 - ▶ Camber controllers with various camber rates

²Wenliang Zhang, Lars Drugge, Mikael Nybacka and Zhenpo Wang. Active camber for enhancing path following and yaw stability of over-actuated autonomous electric vehicles, Vehicle System Dynamics, vol. 59, no. 5, 2020.

Results and discussion

Active camber

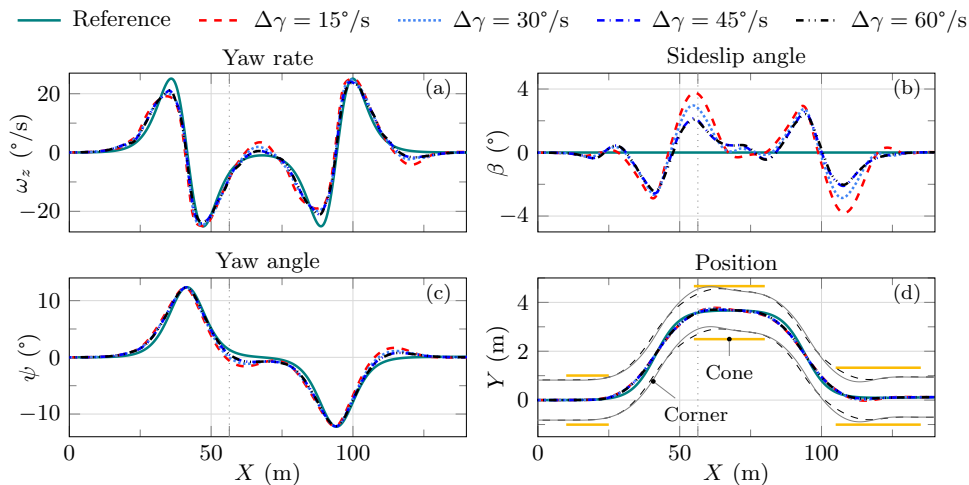


Figure 13: Tracking performance of the camber controllers ($\mu = 0.6$, $v_{xref} = 81$ km/h).

Results and discussion

Active camber

Table 2: Tracking accuracy with ($\Delta\gamma = 15 - 60^\circ/\text{s}$) and without (—) camber control ($\mu = 1$).

Ref. velocity (km/h)	Camber rate ($^\circ/\text{s}$)	ω_z ($^\circ/\text{s}$)	Y (m)
		e_{rms}	e_{rms}
84	—	3.64	0.09
91	15	3.47	0.11
	30	3.68	0.13
	45	3.03	0.12
	60	2.95	0.12

^a The colour red indicates the highest value, whilst the colour blue indicates the lowest.

Results and discussion

Integrated control

- ▶ Aim
 - ▶ Evaluate the effects of **over-actuation configurations** on control performance³
- ▶ Comparison items

Controller	Configuration
S	Active front steering (AFS)
ST	AFS + torque vectoring (TV)
SC	AFS + active camber (AC)
STC	AFS + TV + AC

³Wenliang Zhang, Lars Drugge, Mikael Nybacka, Jenny Jerrelind and Zhenpo Wang. Integrated control of motion actuators for enhancing path following and yaw stability of autonomous electric vehicles, Submitted for publication, 2022.

Results and discussion

Integrated control

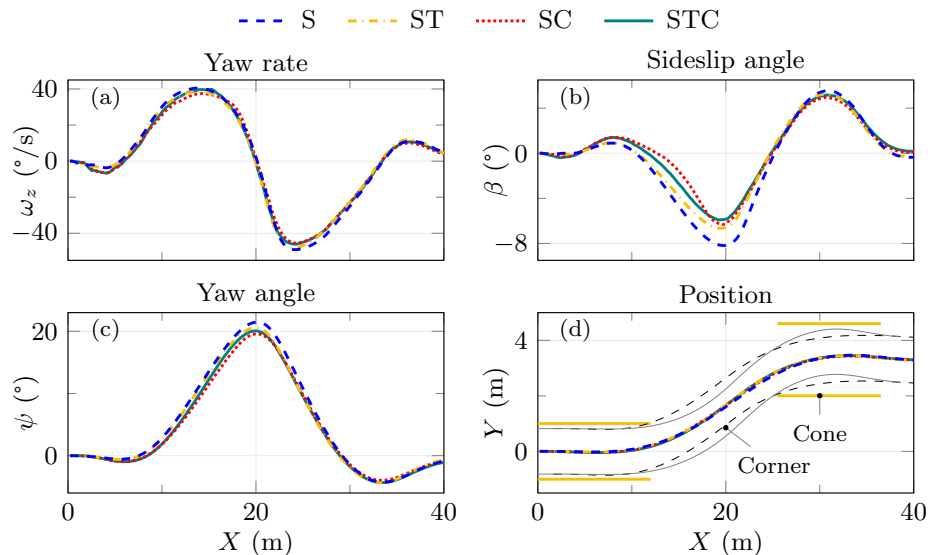


Figure 14: Tracking performance of the four over-actuation configurations ($v_{x0} = 76$ km/h).

Results and discussion

Integrated control

Table 3: Tracking accuracy of the four over-actuation configurations.

Initial velocity (km/h)	Controller	β (°)	ψ (°)
		e_{rms}	e_{rms}
73	S	0.6	0.9
	ST	0.5	0.8
	SC	0.3	0.6
	STC	0.2	0.5
76	ST	0.6	0.9
	SC	0.4	0.6
	STC	0.2	0.6
79	STC	0.5	0.8

^a The colour red indicates the highest value, whilst the colour blue indicates the lowest.

Results and discussion

Integrated control

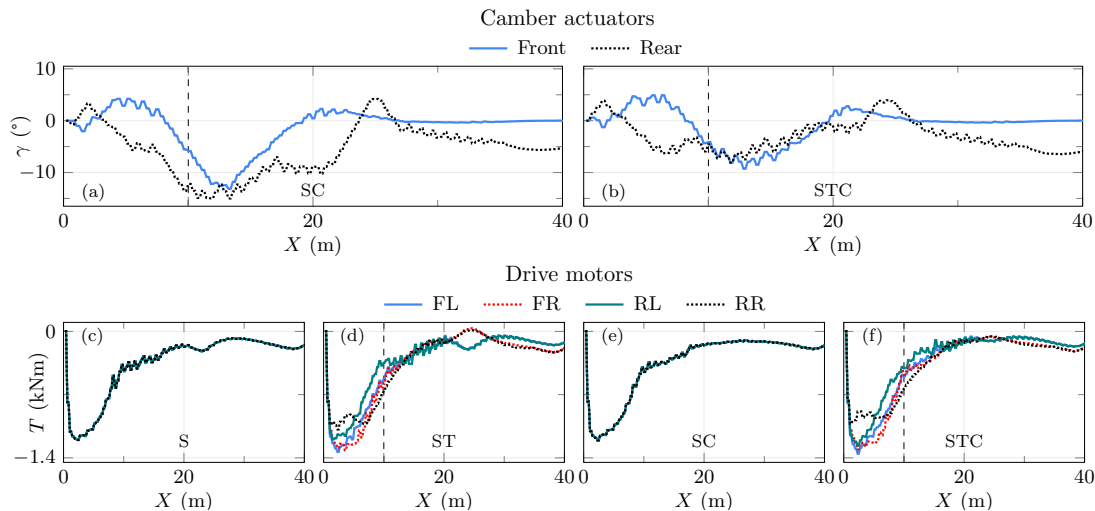


Figure 15: Control actions of the four over-actuation configurations ($v_{x0} = 76$ km/h).

Conclusions

Torque vectoring⁴

- ▶ Improved passing velocity + tracking accuracy
- ▶ One-level controller structure:
 - ▶ Torque vectoring → highest passing velocity
- ▶ Two-level structure:

Optimisation-based	Rule-based
+	Same passing velocity
+	Comparable tracking accuracy
More degrees of freedom in design and tuning	-

⁴Wenliang Zhang, Zhenpo Wang, Lars Drugge and Mikael Nybacka. Evaluating model predictive path following and yaw stability controllers for over-actuated autonomous electric vehicles, IEEE Transactions on Vehicular Technology, vol. 69, no. 11, 2020.

Conclusions

Active camber⁵

- ▶ Improved path following + yaw stability + passing velocity
- ▶ Desired camber rate at different friction levels

High and medium	Low
Wide effective camber region	Narrow effective camber region
$\Delta\gamma = 45^\circ/\text{s}$	$\Delta\gamma = 30^\circ/\text{s}$

- ▶ Required peak power and consumed energy

	Camber actuators	Wheel motors
Required peak power	↓↓↓	↑↑↑
Consumed energy	↓↓↓	↑↑↑

⁵Wenliang Zhang, Lars Drugge, Mikael Nybacka and Zhenpo Wang. Active camber for enhancing path following and yaw stability of over-actuated autonomous electric vehicles, Vehicle System Dynamics, vol. 59, no. 5, 2020.

Conclusions

Integrated control⁶

- ▶ AFS + TV + AC outperformed the other configurations
 - ▶ Increased **passing velocity**
 - ▶ Decreased peak values and tracking errors for **sideslip angle**
 - ▶ Enlarged **safety distance** in the most critical location
 - ▶ Improved response to reference **trajectory variations**
- ▶ AFS + AC outperformed AFS + TV
 - ▶ More effective **tyre utilisation** of active camber over torque vectoring
- ▶ AFS and AFS + TV
 - ▶ Not robust to reference **trajectory variations**

⁶Wenliang Zhang, Lars Drugge, Mikael Nybacka, Jenny Jerrelind and Zhenpo Wang. Integrated control of motion actuators for enhancing path following and yaw stability of autonomous electric vehicles, Submitted for publication, 2022.



 <https://www.researchgate.net/profile/Wenliang-Zhang-3>

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- [13] H. Pacejka, *Tire and Vehicle Dynamics*, 3rd ed. Oxford, UK: Elsevier, 2012.

Presentation:
***Towards automating High Capacity
Transport vehicles,***
Abhijeet Behera, VTI and LIU

An aerial photograph of a city street, likely in Stockholm, Sweden. The image shows a mix of old and new buildings, a river, and a bridge. The text is overlaid on a white rectangular background in the center of the image.

TOWARDS AUTOMATING HIGH-CAPACITY TRANSPORT VEHICLES

Abhijeet Behera

Supervisors: Sogol Kharrazi (VTI), Erik Frisk (LiU)

18 May 2022

About me

1st year Institute PhD Student at VTI and LiU

- HCT vehicles

Past experience

- M.Sc in Automotive Technology (Vehicle Dynamics and Control), TU Eindhoven, The Netherlands
- B.Tech in Mechanical Engineering, NIT Rourkela, India



Objectives (1)

Automated Vehicles

- Motion Planning
- Control Systems
- Software and Hardware Architecture
- etc.



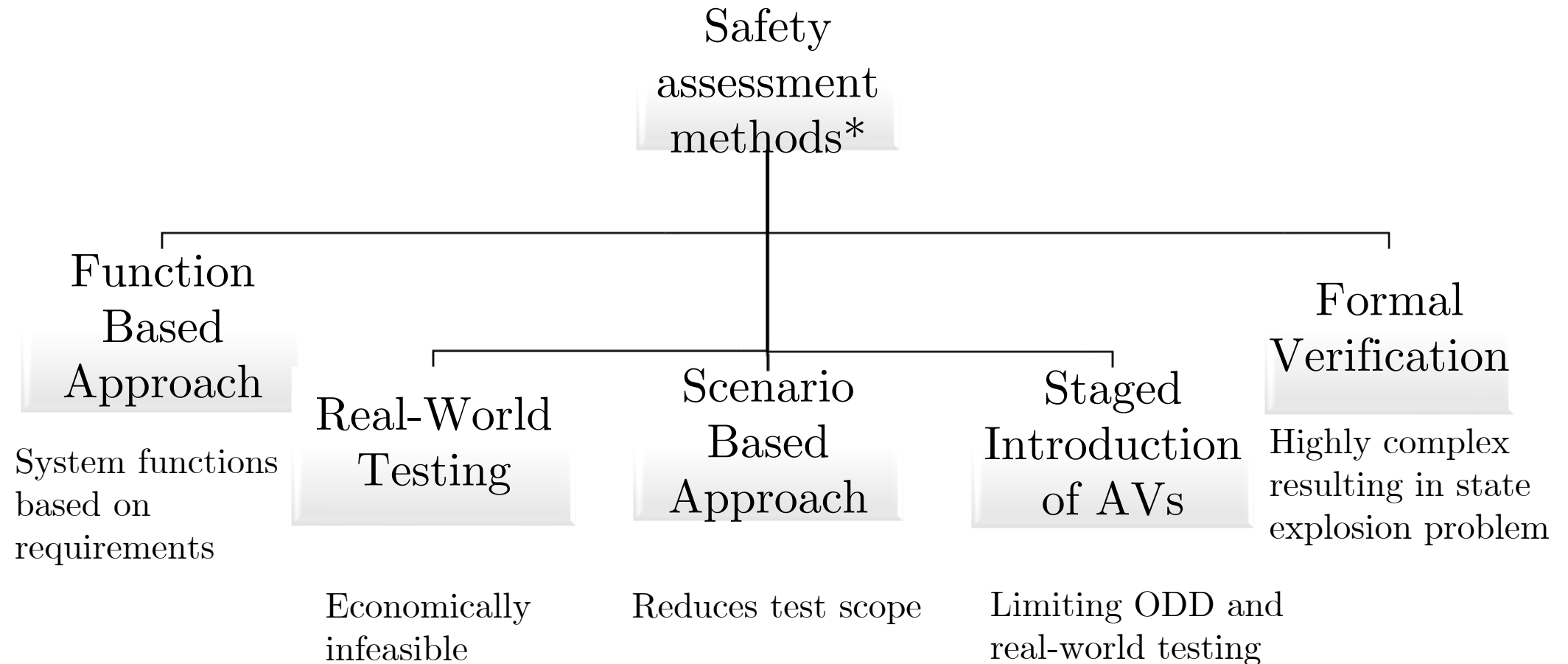
Safety of vehicles must be thoroughly tested before introducing to the market !

Primary objective: Safety assessment of automated vehicles (HCT Vehicles)

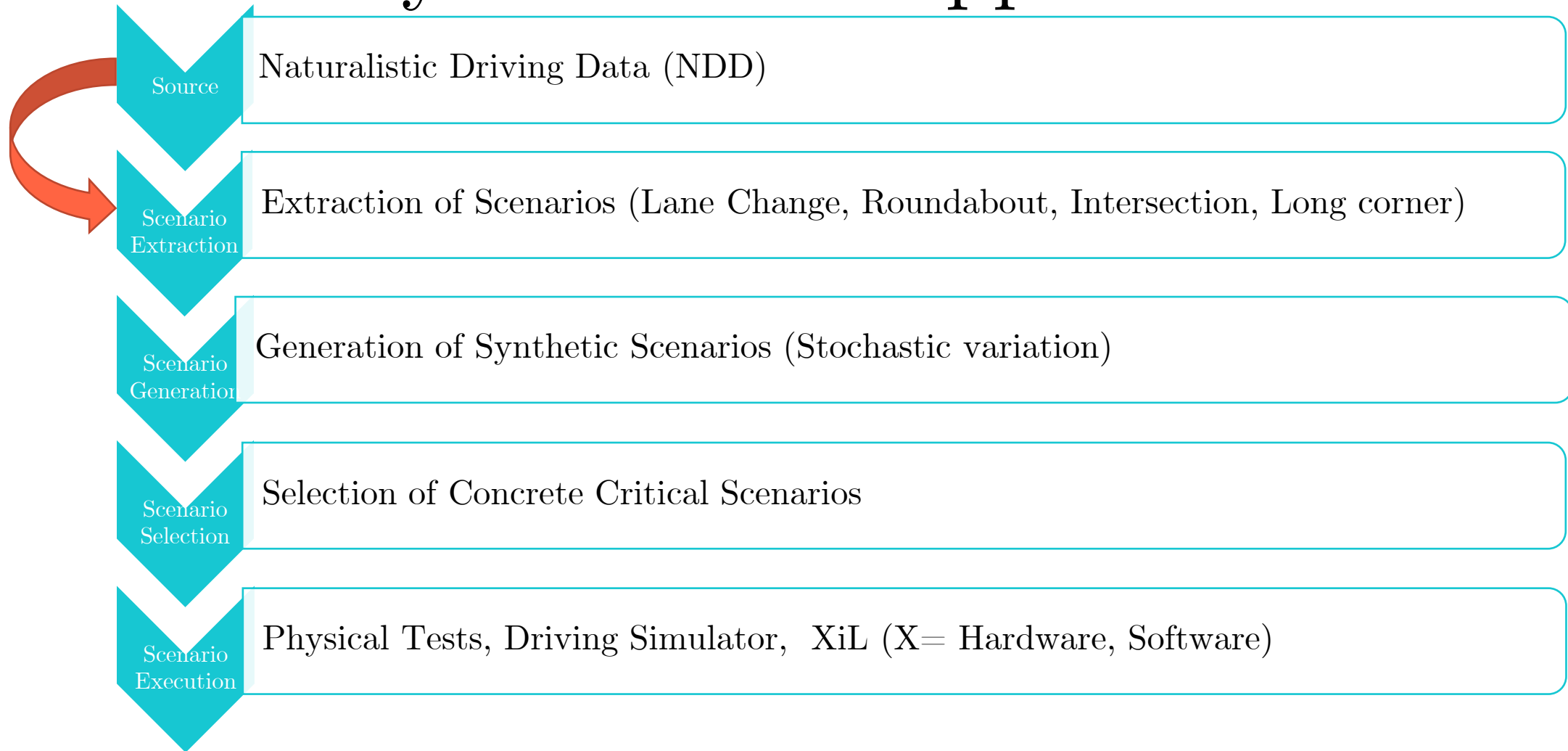


Adouble combination

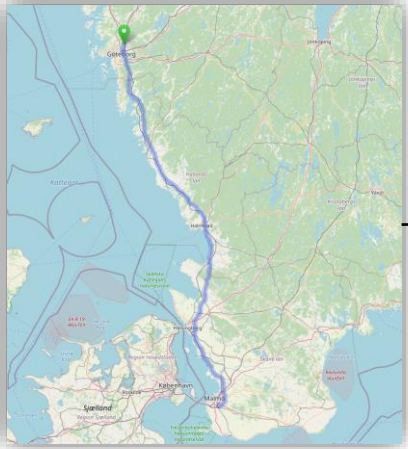
Objectives (2)



Taxonomy of followed approach



NDD: Scenario Extraction

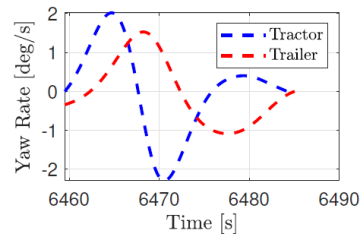


ND data

- Gothenburg-Malmö (Adouble)
- Trips ≈ 12
- Positions, translational and angular velocities, and corresponding accelerations

Data processing

Lane change: Based on yaw rate

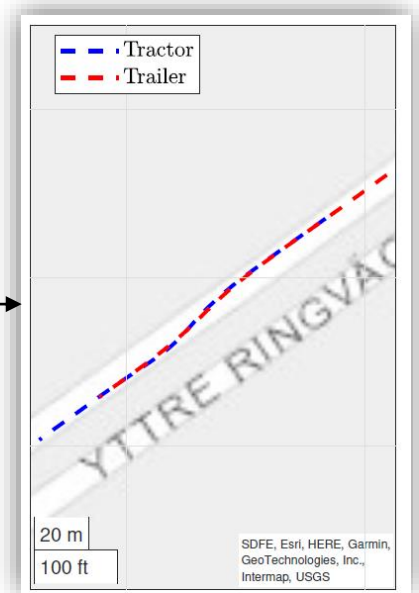


Roundabout: Using open street maps

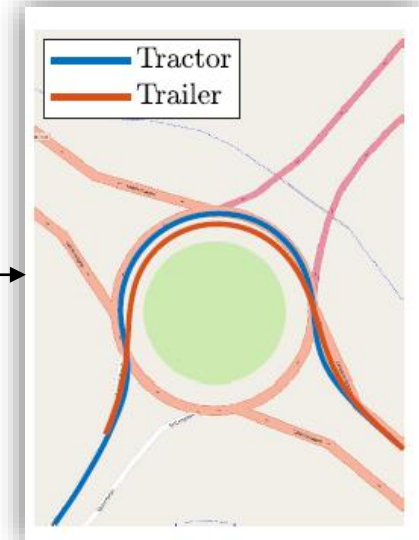
- Fixed in real world
- Crop the roundabouts in OSM
- Segregate data when truck enters the cropped area

Detection Algorithms

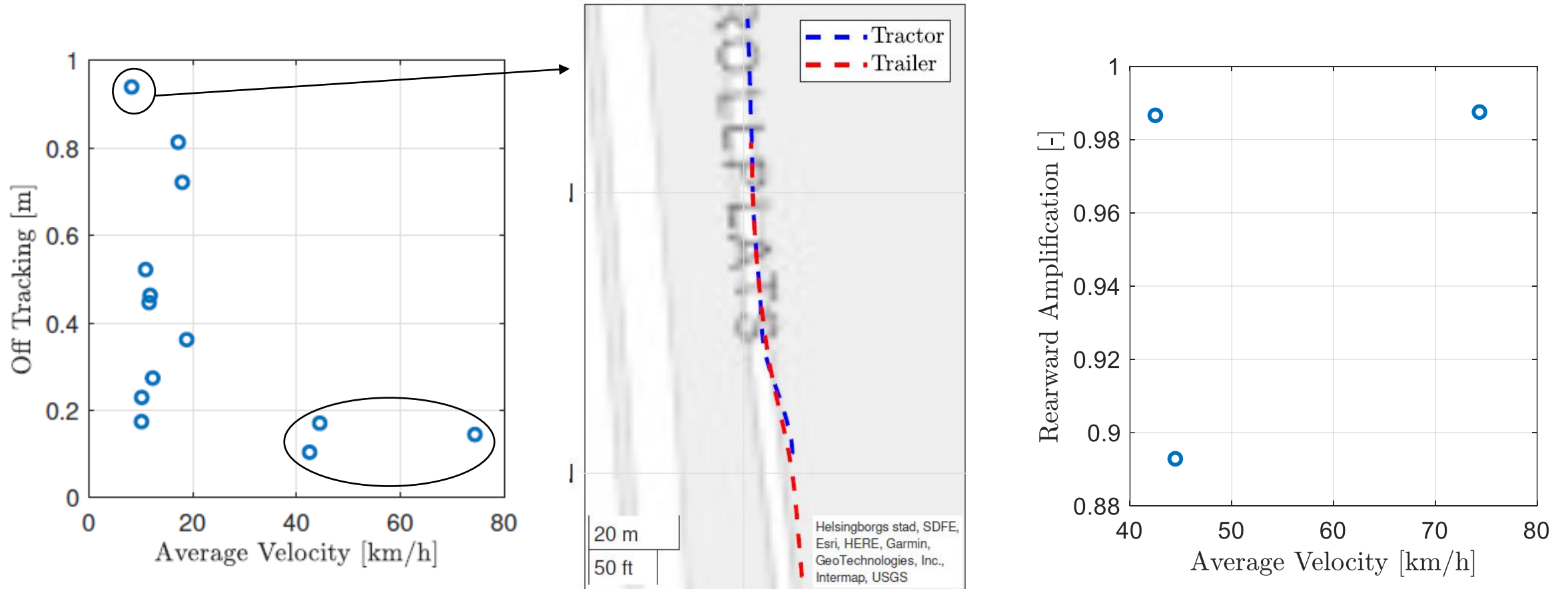
Lane change



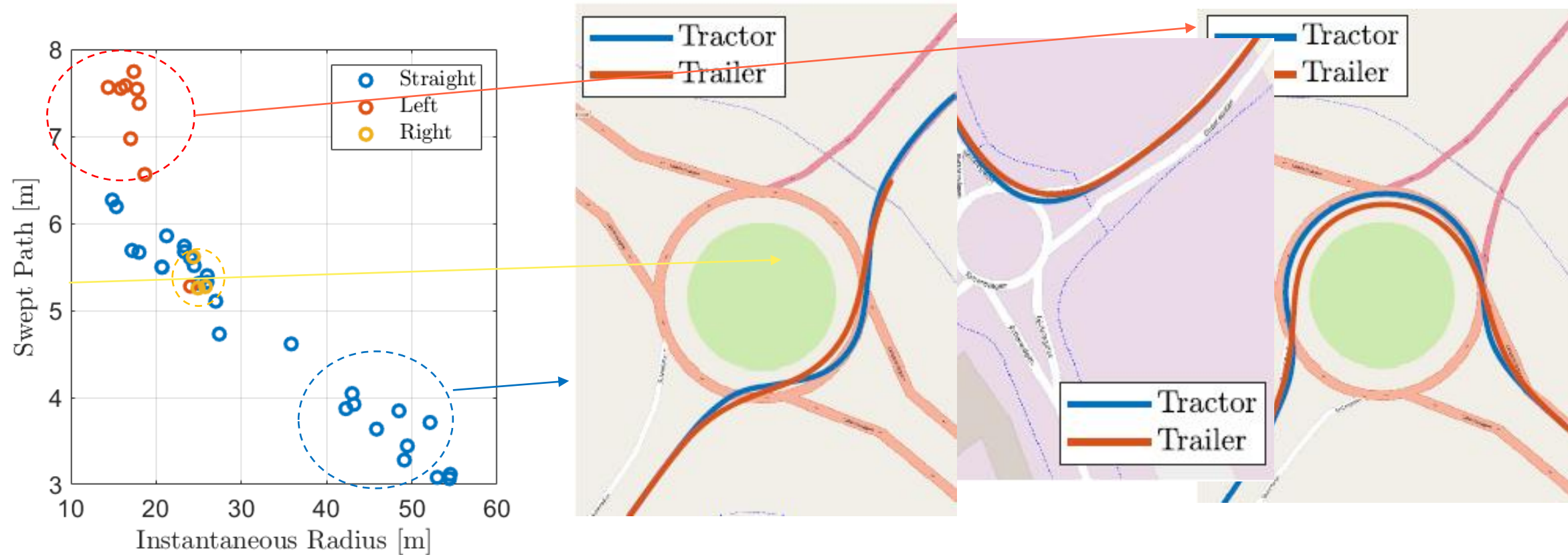
Roundabout



Lane change analysis



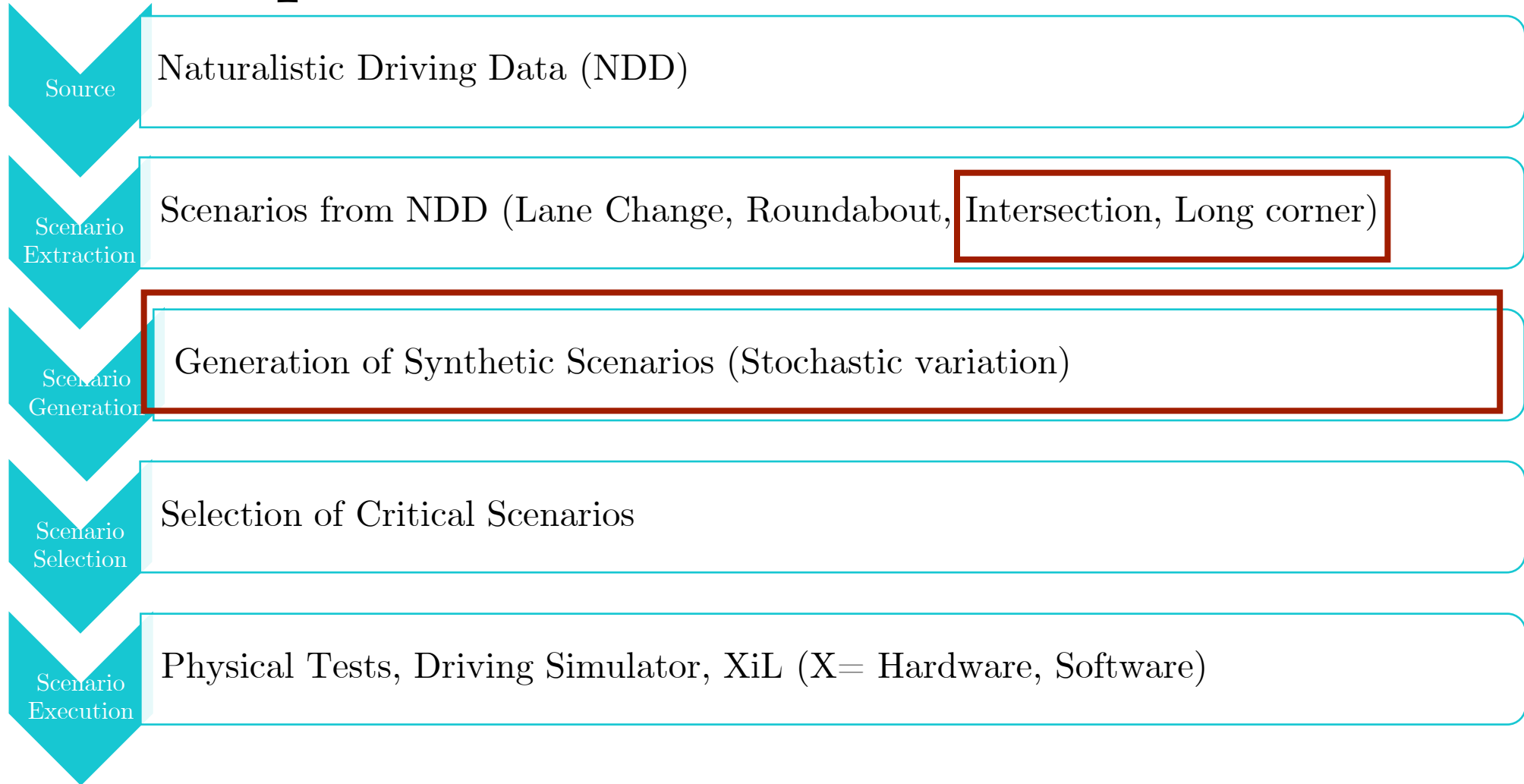
Roundabout analysis



Conclusions (Until now)

- Trucks are driving safe (in Roundabouts and Lane changes)
- Critical scenarios (Merging !)

Next Steps?



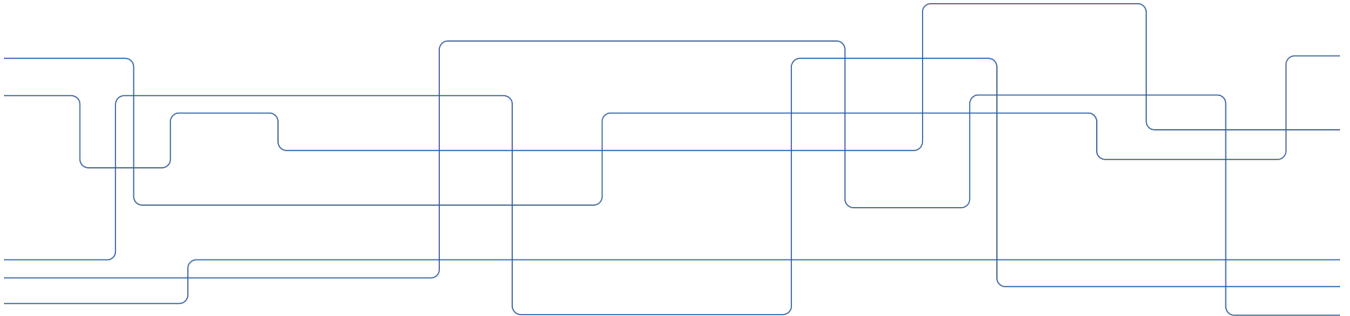
THANK YOU
QUESTIONS ?

Presentation:
Vehicle Engineering Master programme,
Mikael Nybacka, KTH

Master program in Vehicle Engineering

Program director:

Mikael Nybacka, KTH Vehicle Engineering and Solid Mechanics





ROYAL INSTITUTE
OF TECHNOLOGY

Master program in *Vehicle Engineering*

Program responsible:

Mikael Nybacka, KTH Vehicle Engineering and Solid Mechanics



Road vehicle



Rail vehicle



Vehicle engineering

- some quick facts



Two-year programme (120 ECTS credits) given in English

Two tracks, road and rail vehicles

600-700 applicants and 300 1st hand applicants over the last 5 years

Admitted 53 students 2021 (14% acceptance rate)

Around 1/3 Swedish and 2/3 international students



Specific entry requirements

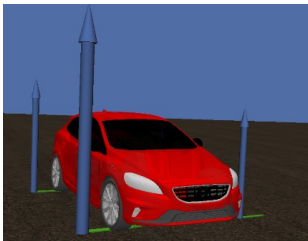
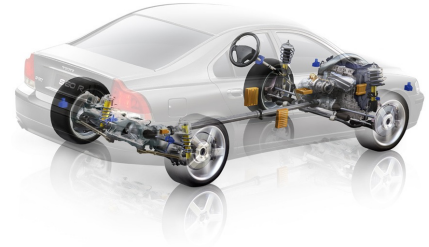
- A bachelor's degree, or equivalent, corresponding to 180 ECTS credits, with courses in
 - **Mathematics and programming:** must include
 - > (i) differential and integral calculus in several variables,
 - > (ii) linear algebra,
 - > (iii) numerical analysis),
 - > (iv) ordinary and partial differential equations and integral transforms,
 - > (v) basic control theory,
 - > (vi) mathematical statistics and
 - > (vii) basics of programming in a higher programming language
 - > equivalent to at least 25 ECTS credits in total.
 - **Applied mechanics:** must include
 - > (i) rigid body mechanics,
 - > (ii) solid mechanics,
 - > (iii) fluid mechanics and
 - > (iv) thermodynamics,
 - > equivalent to at least 20 ECTS credits in total.



Learning goals

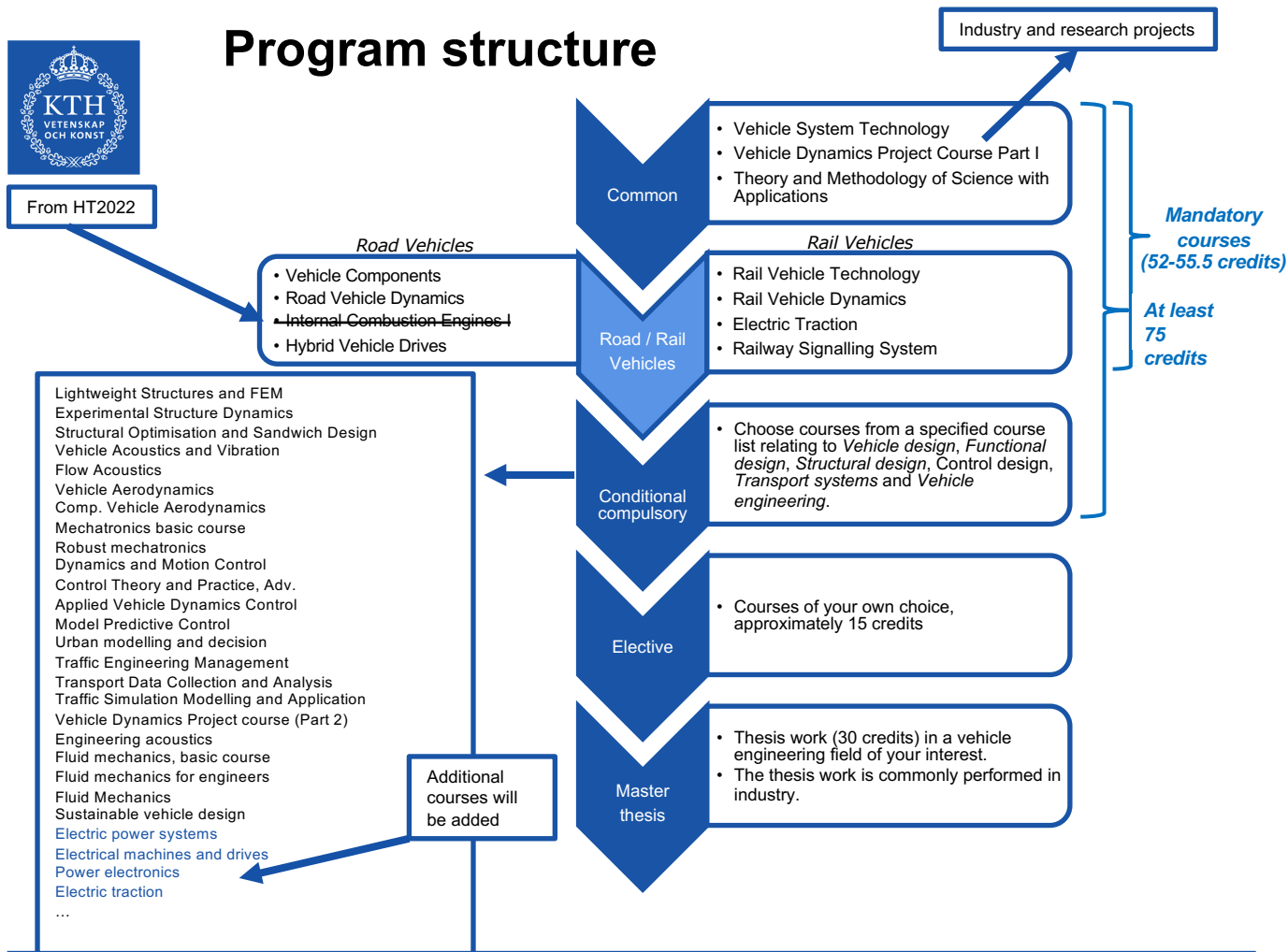
Students will learn about:

- future *demands* and *challenges*,
- vehicles *components* and *functions*,
- vehicles *dynamic properties* and *interaction with its environment*,
- *active vehicle systems* for safety, monitoring and comfort,
- vehicles *role in the transport system and in society*.





Program structure



Mandatory courses

ROAD

1:1	1:2	1:3	1:4	2:1	2:2	2:3	2:4
	EJ2410 Hybrid vehicle drives 7.5 hp			AK2030 Theory & science 4.5 hp	SA2002 Sustainable dev. & research methods 3.0 hp	SD221X Master thesis 30 hp	
SD2221 Vehicle system technology 8 hp	SD2222 Vehicle components 8 hp	SD2225 Road vehicle dynamics 11 hp		SD2229 Vehicle dynamic project Part I 7.5 hp			

RAIL

1:1	1:2	1:3	1:4	2:1	2:2	2:3	2:4
AK2030 Theory & science 4.5 hp				AH2029 Railway signalling systems 7.5 hp	SA2002 Sustainable dev. & research methods 3.0 hp	SD221X Master thesis 30 hp	
SD2221 Vehicle system technology 8 hp	SD2307 Rail vehicle technology 7.5 hp	SD2313 Rail vehicle dynamics 8 hp	EJ2400 Electric traction 6 hp	SD2229 Vehicle dynamic project Part I 7.5 hp			

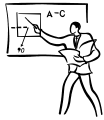
	mandatory
	mandatory, but can be read during 1 st or 2 nd year
	mandatory, can be read in any study period

Vehicle Engineering Lab

- Teknikringen 8

Our common laboratory:

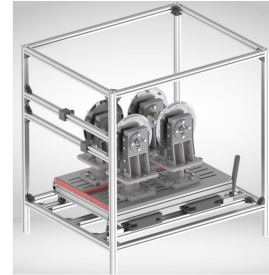
- Teaching
- Experiments
- Computer exerc.
- Own studies



Experiment vehicles, equipment and test tracks



Volvo S90 D5 AWD Geartronic



Roller rig

Arlanda test track



Renault Twizy

RCV

Research
Concept Vehicles

RCV-E



Driving simulator

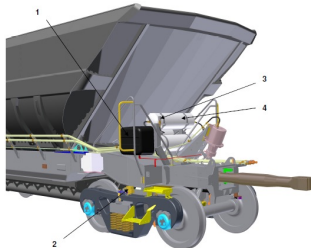
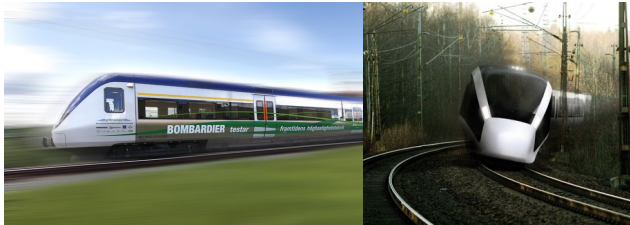
Lunda flygfält



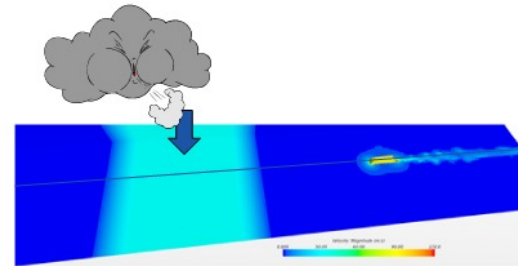
MSC thesis examples

Advertise Thesis proposals in October
For double degree in March

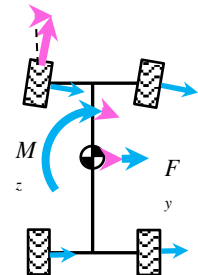
Develop new body tilting for Regina 250



Simulation model of a iron ore carriage



*Side wind
sensitivity of
vehicles*



Energy efficient propulsion with in-wheel motors



Vehicle Engineering

- Fordonsteknik



Mikael Nybacka
Programme responsible

mnybacka@kth.se

Research groups ***Rail vehicles, Vehicle dynamics, Aero dynamics*** and ***Conceptual vehicle design***

At the division of Vehicle Engineering and Solid Mechanics

Teknikringen 8

www.kth.se/en/studies/master/vehicleengineering

Presentation:
Mobility Engineering Master programme,
Giulio Bianchi Piccinini, Chalmers



Mobility engineering, MSc (MPMOB)

Giulio Bianchi Piccinini,

Associate professor & Director of master's programme,

Department of Mechanics and Maritime sciences (M2)

MPMOB: programme in a nutshell



Broad knowledge on mobility

- Mechatronics for mobility
- Propulsion for mobility
- Connected fleets and automated data collection
- System engineering

In-depth knowledge in one of these profiles

- Aerospace engineering
 - Fluids
 - Structural
 - Artificial intelligence
- Automotive engineering
 - Active and passive safety
 - Powertrain and propulsion systems
 - Vehicle engineering and aerodynamics
- Marine technology and naval architecture
 - Structures
 - Fluid
 - Systems engineering
- Railway technology
 - Railway mechanics
 - Structural deterioration
 - Asset management

MPMOB: study plan



Year 1

LP1

LP2

LP3

LP4

Systems and mechatronics for mobility engineering (EEN130)

Elective /
Compulsory elective

Elective /
Compulsory elective

Connected fleets in data-driven engineering (MMS210)

Introduction to propulsion and energy systems for transport (MMS195)

Elective /
Compulsory elective

Elective /
Compulsory elective

Elective /
Compulsory elective

Year 2

LP1

LP2

LP3

LP4

Elective /
Compulsory elective

Elective /
Compulsory elective

Master thesis

Elective /
Compulsory elective

Elective /
Compulsory elective

- Compulsory courses for 52.5 ECTS
- Compulsory elective courses for 37.5 ECTS (to be chosen among 32 different courses)
- Elective courses for 30 ECTS (to be chosen from 12 different Master programmes)

MPMOB: project work



- Project in aerospace (Aerospace engineering)
- Automotive engineering project (Automotive engineering)
- Marine design project (Marine technology)
- Project in railway technology (Railway technology)
- Chalmers formula students (Automotive engineering)

MPMOB: industrial connections



- Abetong
- Autoliv
- Alstom
- Consulting companies (Alten, Altran, ÅFRY, Atkins)
- China Euro Vehicle Technology (CEVT)
- GKN Aerospace
- Green Cargo
- Heart Aerospace
- Lucchini
- SAAB
- SSPA
- Stena Line
- SJ
- SweMaint
- Trafikverket
- Volvo Group
- Volvo Cars
- Wabtec

MPMOB: research-based education



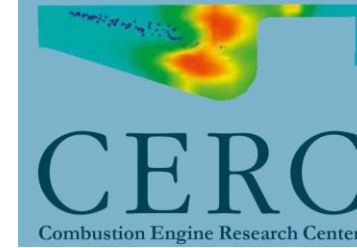
<http://www.charmec.chalmers.se/>



<https://emobilitycentre.se/>



<https://lighthouse.nu/>



<https://www.chalmers.se/en/centres/cerc/Pages/default.aspx>

TechForH2 – Hydrogen Centre

<https://www.chalmers.se/en/departments/m2/news/Pages/TechForH2---for-a-sustainable-hydrogen-economy-of-tomorrow.aspx>



<https://www.saferresearch.com/>

MPMOB: international opportunities

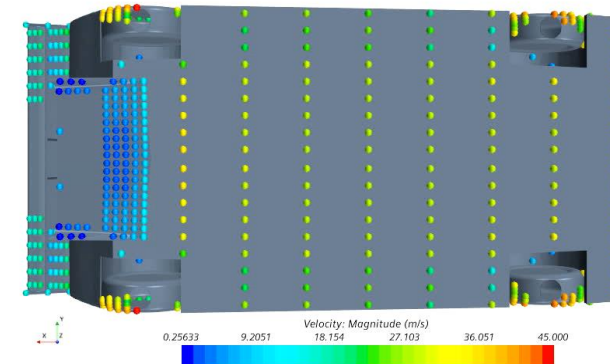
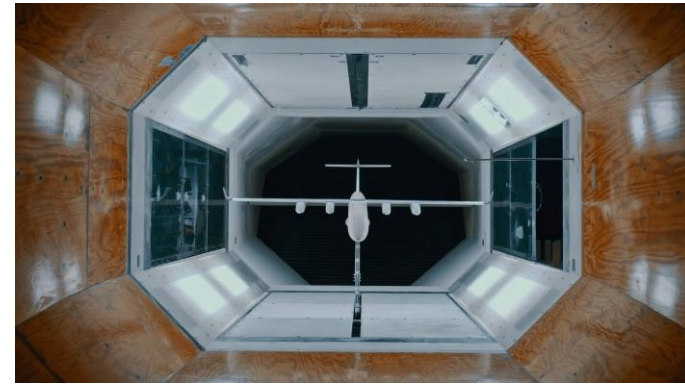


- Double degree with University of Stuttgart (automotive engineering)
- Nordic Master in Maritime engineering, within Nordic Five Tech (marine technology)
- Erasmus exchanges (<https://cth.moveon4.de/publisher/1/eng#>)

MPMOB: job opportunities



- Design of parts and systems (e.g., yacht designer, powertrain integration engineer)
- Simulation engineer (e.g., crash simulation engineer, vehicle dynamics CAE engineer)
- Asset management (e.g., asset management railway engineer, maintenance engineer)
- Technical sales engineer
- Project manager
- Research & development (e.g., railway technical specialist, traffic safety research specialist)
- Academia (e.g., PhD student)
- Other (e.g., offshore engineer)



MPMOB: facilities for education



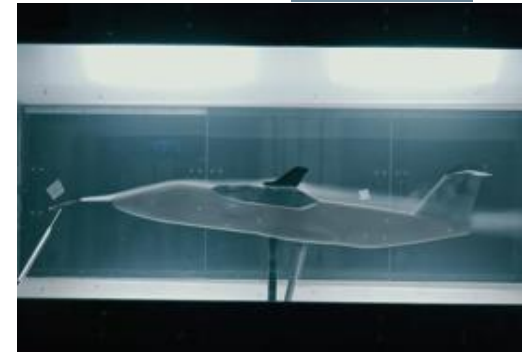
Hybrid powertrain lab



Driving simulator



Brake rig for rail



Low-speed wind tunnel



Resource for vehicle research
(REVERE)



Maritime simulator



Low-pressure compressor rig



CHALMERS
UNIVERSITY OF TECHNOLOGY

Poster:

A study on the energy consumption impact of environmental parameters on heavy vehicles,

Manish Raathimiddi, Chalmers and HAN



CHALMERS

A study on the energy consumption impact of environmental parameters on heavy vehicles

Manish Varma Raathimiddi, MSc student | Division of Vehicle Engineering and Autonomous Systems (VEAS), Mechanics and Maritime Sciences

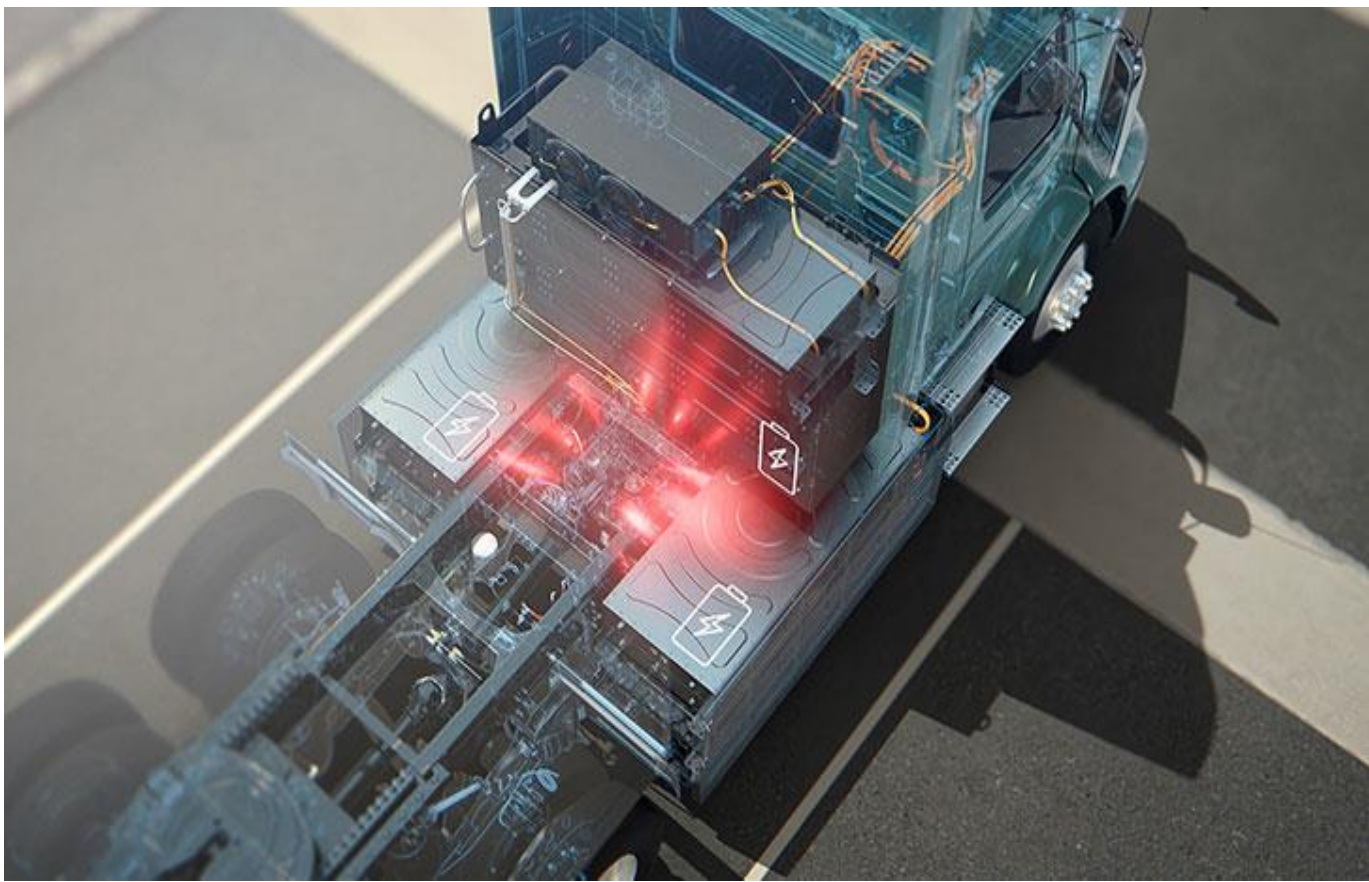
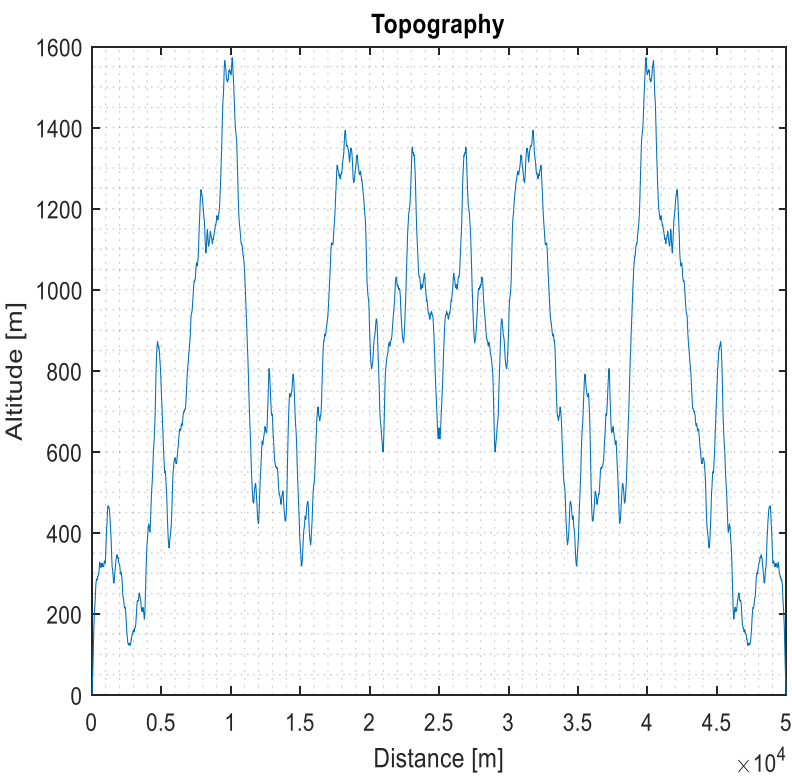
1. BACKGROUND

Analysing the various powertrain parameters that affect energy consumption is the most crucial step during drivetrain design (for example, battery weight, motor efficiencies, or engine operating point). Thereby one can predict and optimize these crucial factors.

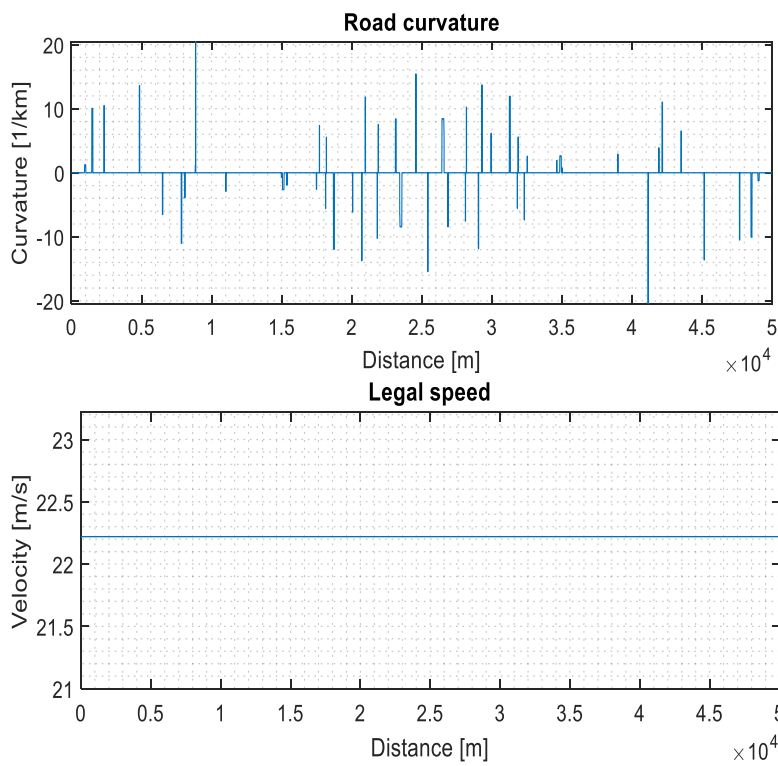
Environmental parameters	Powertrain parameters
Topography	Battery mass
Legal speed	Motor efficiencies
Curvature	Engine operating points

3. GENERATING ENVIRONMENTAL PARAMETERS

• Topography



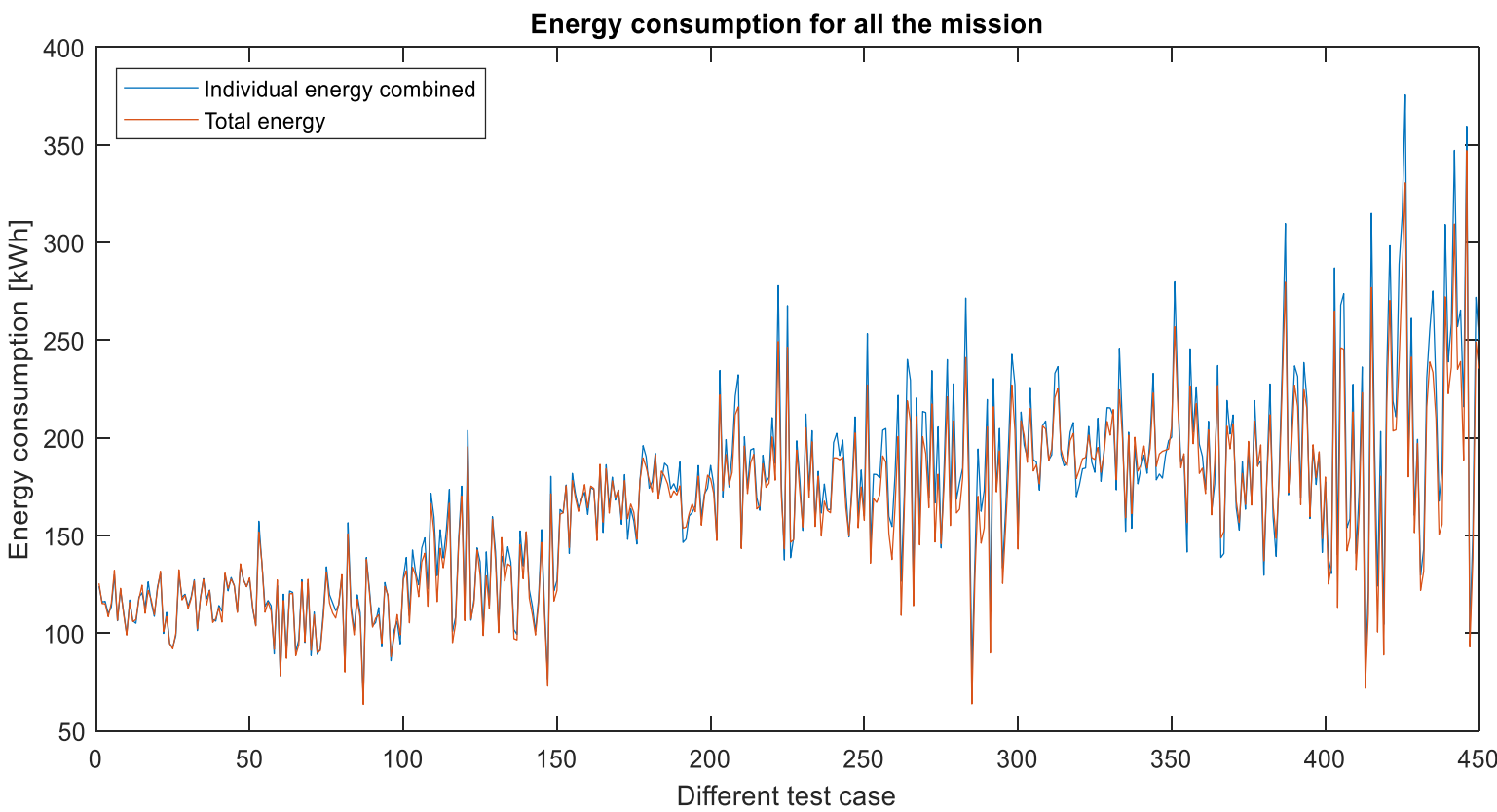
• Curvature & legal speed



4. RESULTS

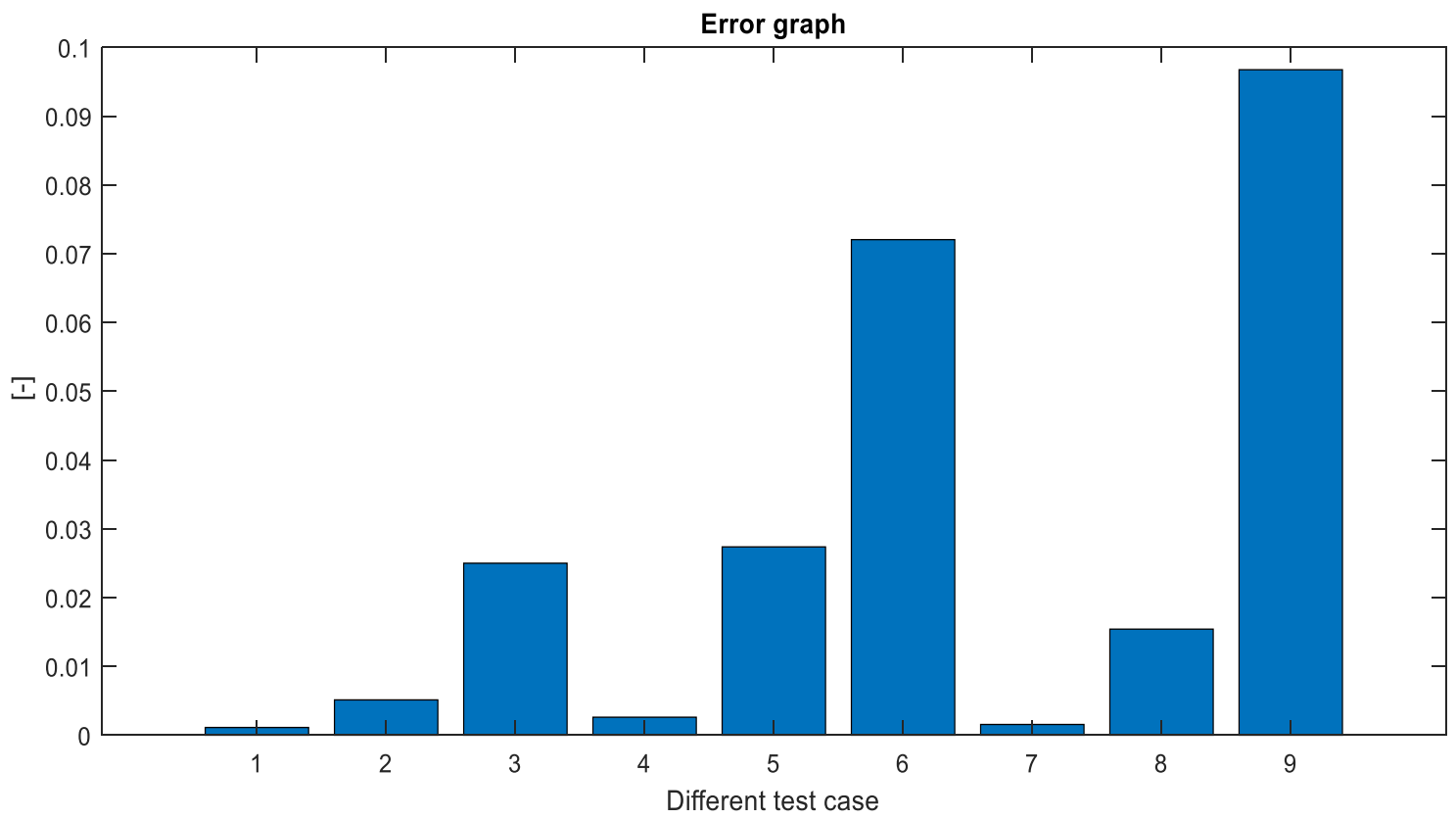
- Hill length(L_h) and variance (σ_y) are the parameters which are required for the topographical model to be parametrized. Variance shows a quadratic influence on energy use. The length of the slope has a minor influence since the driver's condition is such that the vehicle will travel at the same pace up and down the hill.
- The curviness model requires a total of 6 parameters to be parametrized. Analysis was conducted on the intensity of curves (λ_C) and log-normal mean of (shifted) radius (μ_C). The outcome is a logarithmic trend that never reaches a maximum, but the rate of energy consumption begins to level off at a certain point.
- A predicted total energy consumption (E_{tot}) was generated to evaluate how much this differs from the individual contributions of each environmental parameter (i.e., E_{topo} , E_{curv}).

$$E_{tot} = E_0 + E_{topo} + E_{curv}$$



2. REASONS FOR PARAMETER SELECTION

- Heavy vehicles possess higher mass, high drag coefficient, deceleration, and accelerations. These have a significant impact on energy consumption, making it an ideal choice to evaluate topography, legal speeds, and road curvature parameters.
- Battery mass: An increase in the range can be done by adding the number of battery cells which eventually leads to an increase in weight.
- Motor efficiencies: Electric machine losses at various torque and speed working points show a significant impact on machine efficiency.
- Engine operating points: Engine efficiency fluctuates greatly depending on the route, driving style, and other factors, which causes engine operating points to deviate significantly from their optimal point.



4. CONCLUSION

- Simulation data demonstrate a developing trend of energy usage as anticipated, based on powertrain factors such as battery mass, motor efficiency, and engine operating points.
- Curvature yielded higher energy consumption compared to other parameters due to curve clustering.
- The combined energy efficiency was lower than individual energy distribution due to the predetermined threshold value for lateral acceleration provided to the driver model
- Finally, a relation has been established between external variables and drivetrain characteristics in order to determine which parameter affects energy usage.



Poster:

***Heavy duty EPS and its theoretical
requirements,***

Christopher Essén and David Wikman, KTH and
Scania

Heavy Duty EPS and its Theoretical Requirements

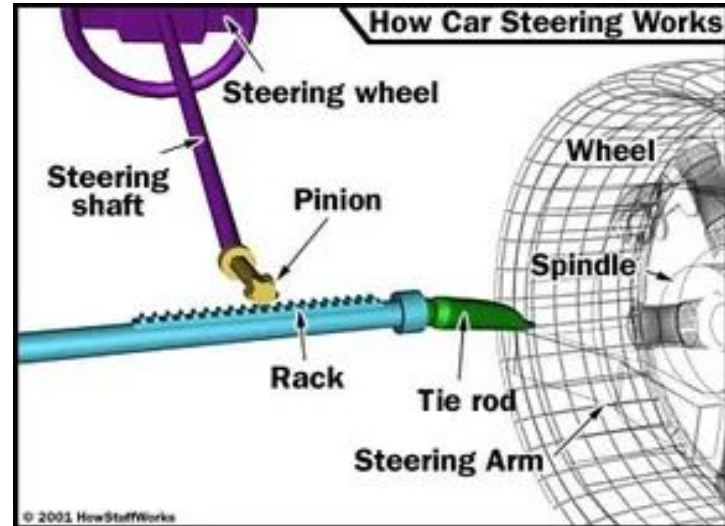
Christopher Essén and David Wikman

Supervised by Malte Rothhämel

13 maj 2022

Introduction

- Steering
- EPS
- HPS och E-HPS
- History



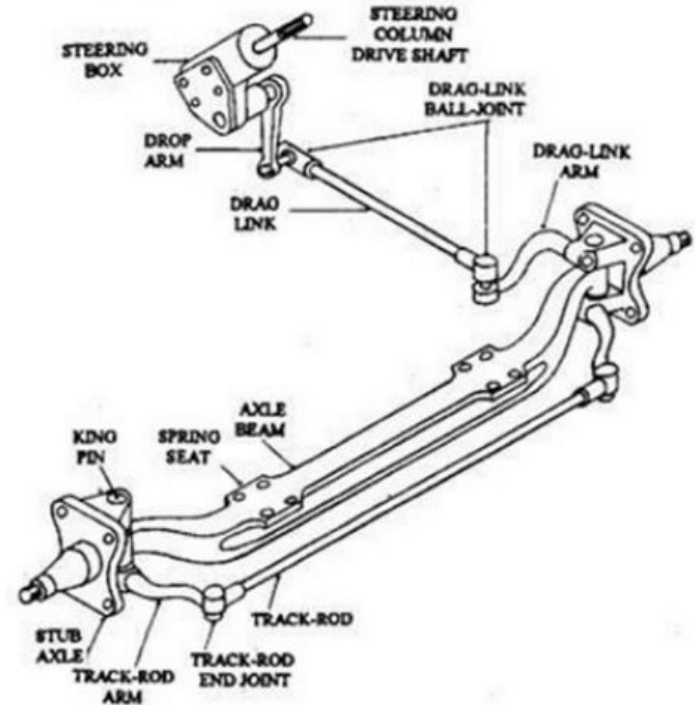
Purpose

- Starting Point
- Specification, EPS
 - Dimensions 25x25x50 cm
 - Steering velocity 600 °/s
 - Input Torque 8 Nm
 - Output Torque 8000 Nm



Steering Systems

- EPS and no gearbox
- Steering column mounted EPS
- Drop arm mounted w/ variants

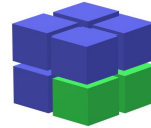


Specifications of the electric motor

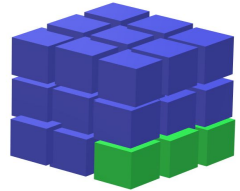
- Resistance, voltage and current, $U=RI$
- Volume vs surface area
- Correlation between torque and RPM



1 cm cell	
SA	6 cm ²
V	1 cm ³
SA:V	6:1



2 cm cell	
SA	24 cm ²
V	8 cm ³
SA:V	3:1



3 cm cell	
SA	54 cm ²
V	27 cm ³
SA:V	2:1

Joules Heating Law:

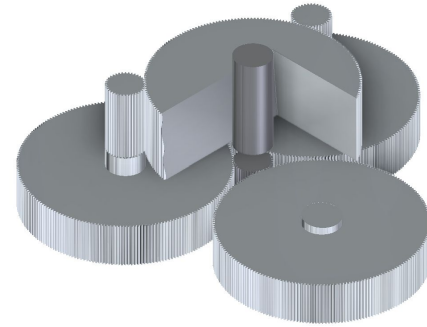
$$P = RI^2$$

$$[P] = W = J/s = Nm/s = [\tau\omega]$$

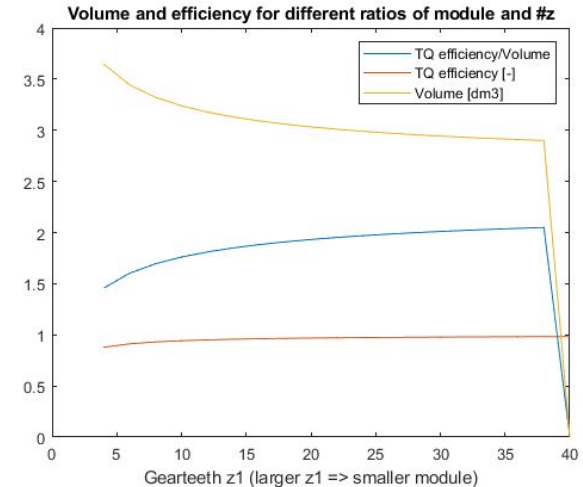
$$\tau = \eta P / \omega$$

$$\omega = \pi RPM / 30 \Rightarrow \tau = 30P\eta / \pi RPM$$

Gearbox

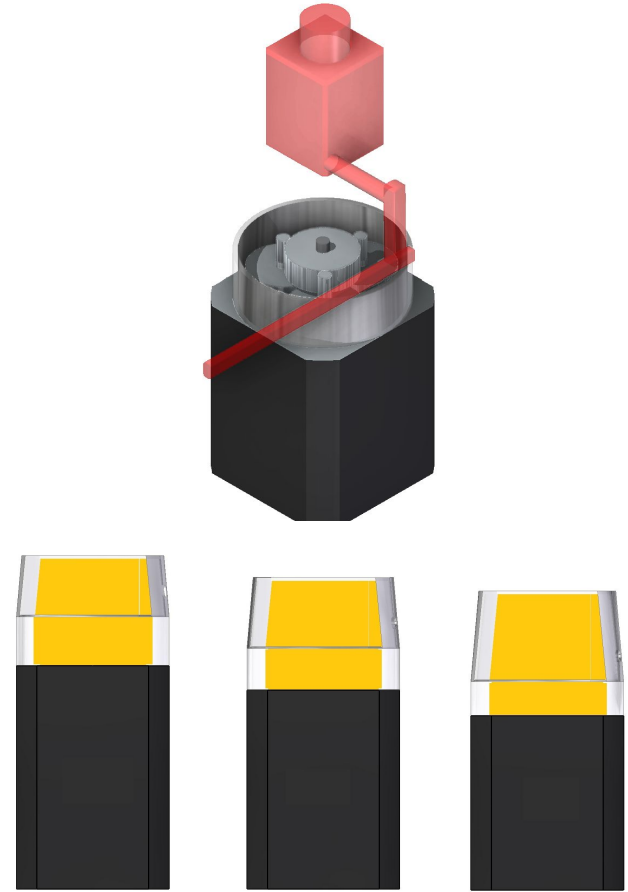


- 4-wheel planetary gearbox
- Exchange limits
- Optimization
 - Cog count vs cog size
 - Efficiency
 - Dimensioning => cog width (SS1871)



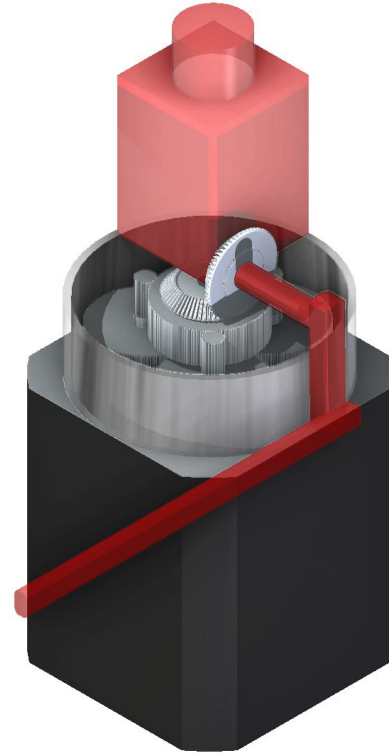
Gearbox

- 90° bevel final gear
- Calculated as a “virtual” spur gear
- Different ratios for different EM's



Results

- Specification
 - 165Nm EM -> 48.4:1 gearbox
 - 8400Nm reach the front axle
 - Steering velocity 530 vs demand 600 °/s
 - Measurements: 25x25x49cm
- Future iterations
 - Unified gearbox for steering wheel and electric motor
 - Weaker electric motor, higher exchange
 - Utilize maximum torque



Discussion

- Space constraints
- Costs
- Time

Honorable Mentions:

- Malte Rothhämel
- Mats Leksell
- Study visit: Scania trucks
- Annika Stensson Trigell

Poster:

Variable steering ratio design for steer-by-wire system,

Jakob Roempke and Gustav Lindahl, KTH and
Volvo Cars

Design of Variable Ratio for Automotive Steer-by-wire Systems



Bachelor thesis in Fordonsteknik SA115X

Gustav Lindahl and Jakob Roempke

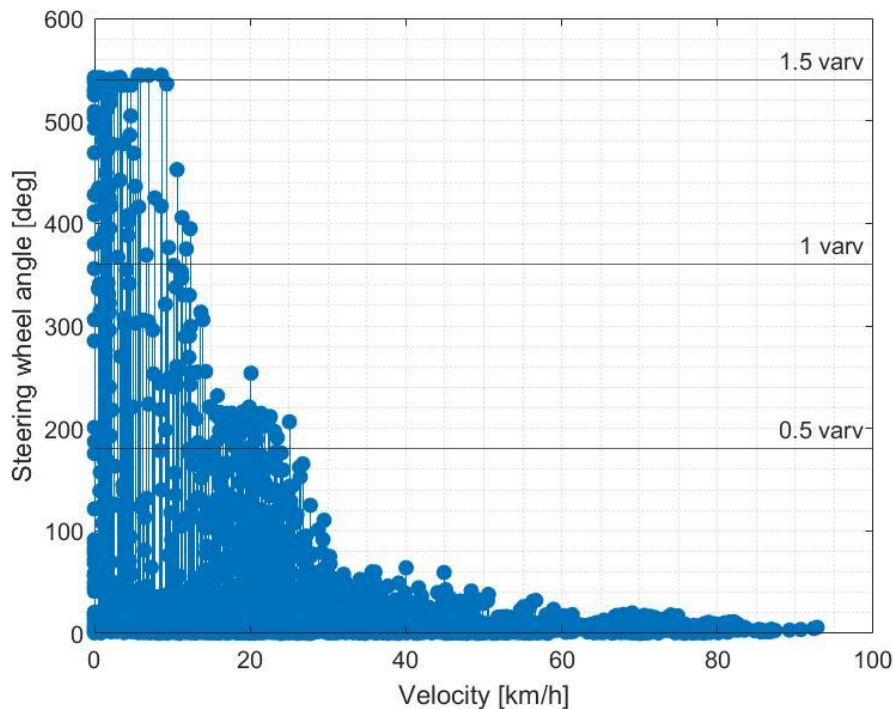
Supervisor:

- Lars Drugge, KTH
- Matthijs Klomp, Volvo Cars



Results

Physical tests and comfort



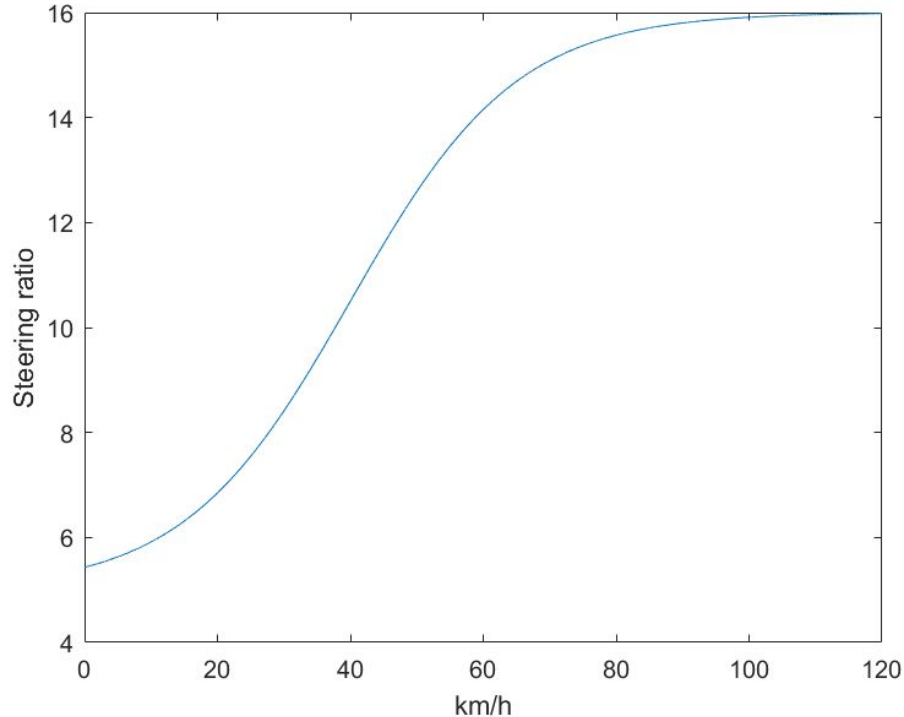
Two hands

Test person	Comfortable	Maximum
1	$-145^{\circ} \leq \theta_{sw} \leq 143^{\circ}$	$-189^{\circ} \leq \theta_{sw} \leq 170^{\circ}$
2	$-154^{\circ} \leq \theta_{sw} \leq 159^{\circ}$	$-167^{\circ} \leq \theta_{sw} \leq 178^{\circ}$
3	$-145^{\circ} \leq \theta_{sw} \leq 154^{\circ}$	$-226^{\circ} \leq \theta_{sw} \leq 231^{\circ}$
4	$-120^{\circ} \leq \theta_{sw} \leq 130^{\circ}$	$-213^{\circ} \leq \theta_{sw} \leq 180^{\circ}$
5	$-140^{\circ} \leq \theta_{sw} \leq 143^{\circ}$	$-258^{\circ} \leq \theta_{sw} \leq 248^{\circ}$
Average	$-141^{\circ} \leq \theta_{sw} \leq 146^{\circ}$	$-210^{\circ} \leq \theta_{sw} \leq 201^{\circ}$

One hand

Test person	Maximum
1	$-208^{\circ} \leq \theta_{sw} \leq 250^{\circ}$
2	$-265^{\circ} \leq \theta_{sw} \leq 187^{\circ}$
3	$-245^{\circ} \leq \theta_{sw} \leq 195^{\circ}$
4	$-266^{\circ} \leq \theta_{sw} \leq 190^{\circ}$
5	$-250^{\circ} \leq \theta_{sw} \leq 236^{\circ}$
Average	$-247^{\circ} \leq \theta_{sw} \leq 212^{\circ}$

Variabel steering ratio



Different sections

- Dependent on speed
- Low speeds - Maneuverability and stability
- Predictable in between
- High speed - Stability

Conclusions

- A variable steering ratio should in some way be dependent on the speed of the vehicle.
- The steering wheel can comfortably be rotated about $\pm 145^\circ$ and the maximum rotation possible is about $\pm 200^\circ$ with two hands on the steering wheel.
- A yoke design is possible to implement with variable steering ratio and also open up the possibility to move the interface of the gear selection and turn signals to the steering wheel.

Poster:

***Driving simulator study on Crosswind
Aerodynamics,***

Anup Garje Mohan Kumar and Sai Kishan
Sawanth, CEVT and Chalmers

DRIVING SIMULATOR STUDY ON CROSSWIND AERODYNAMICS

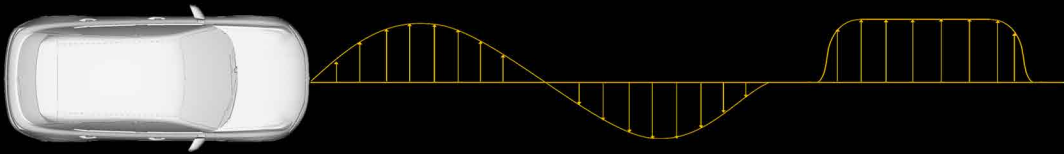
Anup Garje Mohankumar, Sai Kishan Sawanth
anup.mohankumar@cevt.se, sai.sawanth@cevt.se

Supervisor: Adam Brandt
adam.brandt@cevt.se

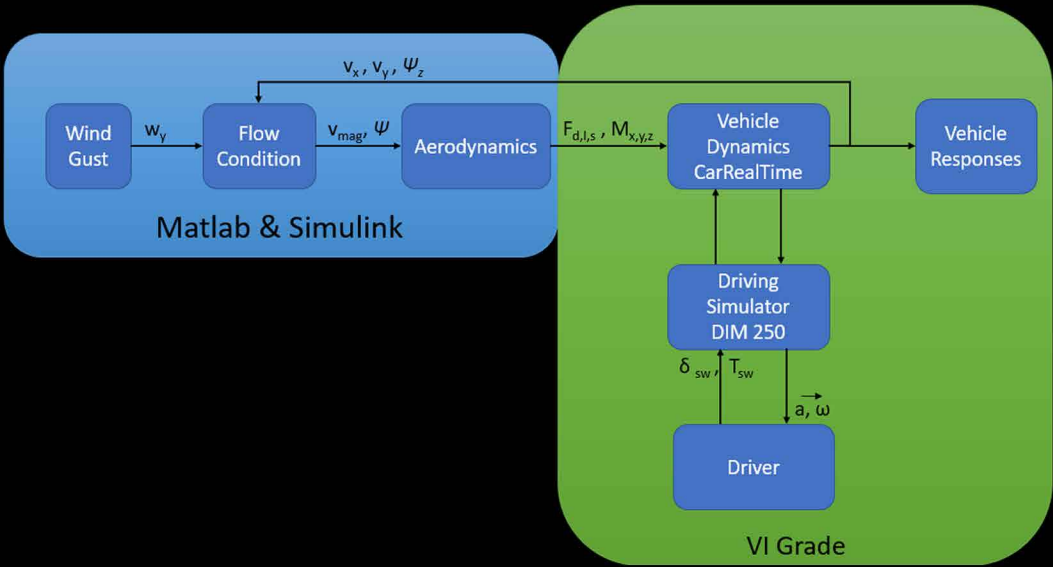


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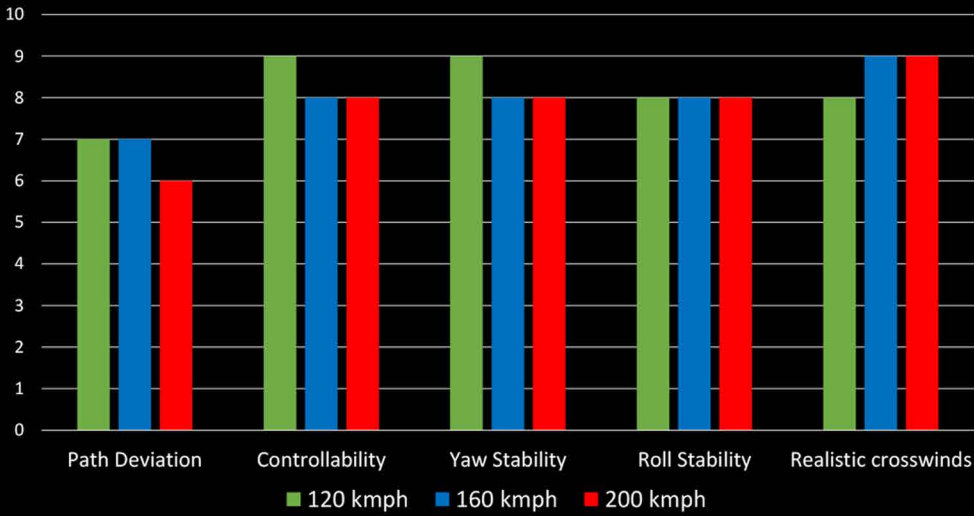
A method to study a SUV's crosswind gust sensitivity at high speed driving on a moving base driving simulator.



The crosswind gust are parameterised based on Hällared proving ground crosswind data.



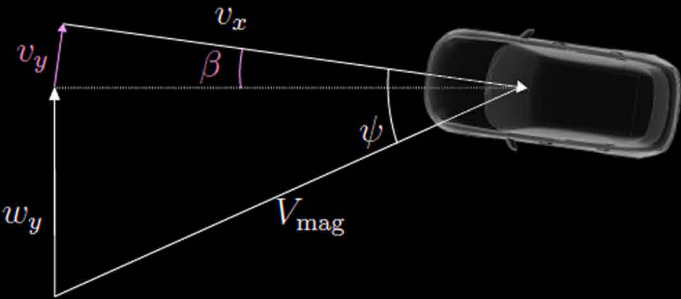
Subjective Assessment



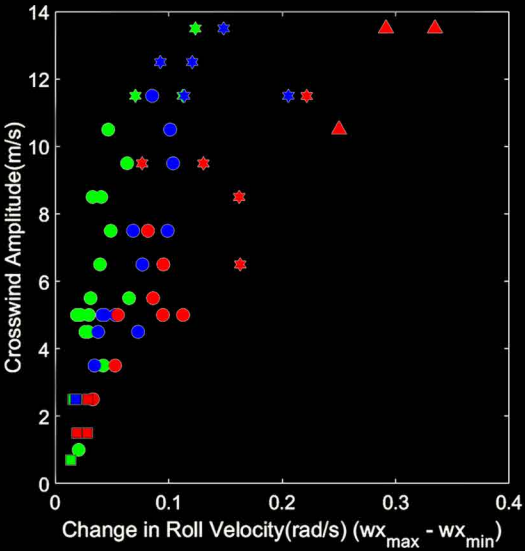
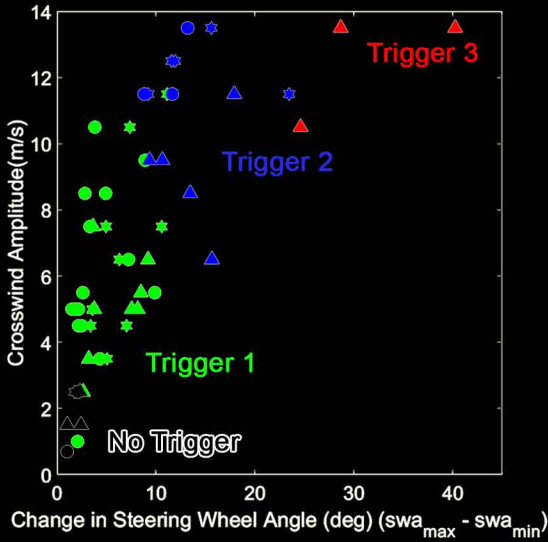
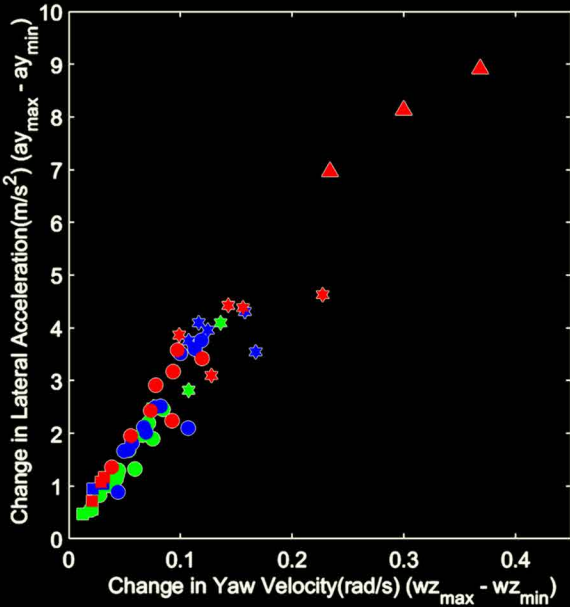
Legend	No Trigger	Trigger 1	Trigger 2	Trigger 3
120 kph	■	●	★	▲
160 kph	■	●	★	▲
200 kph	■	●	★	▲

No Trigger - driver did not respond to the crosswind gust
Trigger 1 - felt the crosswind gust, straight line tracking with little or no effort
Trigger 2 - felt the crosswind gust, straight line tracking with some effort
Trigger 3 - felt the crosswind gust, straight line tracking with excessive effort

The crosswind flow velocity and flow angle define the flow condition and are used as inputs to implement aerodynamic forces and moments on the vehicle reference point.



The crosswinds are implemented by using 2 way coupling method between aerodynamics and vehicle dynamics, the aerodynamic forces and moments are dictated by the flow angle and magnitude, which varies with change in wind angle and body slip.



The objective metrics shows the change in vehicle response at different crosswind amplitudes. The subjective assessment and subjective trigger correlates with the change in vehicle response.

The sensitivity of the vehicle to crosswind is studied by comparing the change in lateral acceleration with the change in yaw velocity of the vehicle during the crosswind gust.

A driving clinic was conducted which involved common and experienced drivers, a total of 39 drivers and each driver completed 4 driving sessions of 6 minutes each. While, no driver reported motion sickness during the driving clinic.

