

Proceedings from 2026 Vehicle Dynamics seminar **Future directions**

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

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

VDCA is a workgroup in:



SVERIGES FORDONSTEKNISKA FÖRENING

SVEA is a member of:



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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

Vehicle Dynamics 2026 — Future directions

Registrations have closed.



Vehicle Dynamics 2026 — Future directions

👁 2109



Event registration closed.

Date And Time

2026-05-20 @ 09:00 to
2026-05-20 @ 16:30

Registration End Date

2026-05-21

The seminar has two pages, one with Swedish flag and one with English flag. The page you read now is the main page for information, registration and possible updates.

Link to proceedings: *Will come here*, some time after the seminar. We hope to be able to publish most of presentations and posters.

Fordonsdynamiksseminarium 2026 — Framtida inriktningar

Vehicle Dynamics 2026 — Future directions

This year, we have chosen a very open topic for the seminar. In engineering and vehicle development, we face significant challenges. These include energy and climate, sustainability and resilience, and the balance between global and local perspectives. At the same time, there are major opportunities. These include electric propulsion, AI in product development, AI embedded in products, and the use of big data and cloud technologies. The overall purpose of our products remains unchanged. They should provide efficient and safe road and ground transportation. However, these opportunities are likely to reshape many concepts that have evolved over decades of vehicle engineering. Many of these opportunities have existed for a long time. In recent years, global and local political developments have increased the urgency to act on them.

With this as background, the seminar will present a selection of studies/findings/proposals. Most presentations originating from Sweden, but we have a couple of international presentations also. The seminar invites engineers and technicians in and after work-life as well as young engineers under education. An important purpose with the seminar is to create and maintain networks between us.

Autoliv will present their test track but also their workplace. Hence the first presentation and the lunch demo tour on test track is also a *SVEA workplace meeting*, so we underline that also engineers outside the core vehicle dynamics are welcome.

Wednesday May 20

The seminar will be in "hybrid format", meaning that participation is possible both in-real-life and on-line.

In-real-life:

Autoliv Sverige AB
Wallentinsvägen 22, 447 37 Vårgårda, Sweden

Map: <https://maps.app.goo.gl/RriKcRFQMRnkr5ucA>
(Note, the building is new and not yet visible at Google Maps)

Parking possibilities:

- <https://maps.app.goo.gl/S2Zc7SGcMHGSB3oP9>
- <https://maps.app.goo.gl/5BHVPUN42BgvBEX96>

Location

Autoliv, Vårgårda. Map:

<https://maps.app.goo.gl/RriKcRFQMRnkr5ucA>

On-line:

Link to on-line meeting will be sent to those who register as on-line.

Registration

Registration is made on <https://www.sveafordon.com/en/event/vehicle-dynamics-2026/>

If you are SVEA member, it is easier to register for the seminar if you log in before registration.

You will get a confirmation that you are registered.

Initial seminar registration deadline is 2026-05-13, we will order light lunch and fika for those registered until then plus some in reserve.

We usually re-opens the registration after that deadline and for those who register then, we cannot promise light lunch and fika.

2026-05-14: Registration re-opened. Please continue to register. Number of seats is not yet limiting and we will try to light lunch and fika for new registrations, and send out link to on-line participation.

Seminar costs

The seminar is free for SVEA members. SVEA will sponsor food (fika and light lunch) for members (incl. pending membership applicants) who attend in-real-life.

For non-members attending in-real-life there will be a fee of 210 SEK (>membership fee!).

Presenters (incl. poster presenters) attend for free.

We encourage to apply for SVEA membership (<https://www.sveafordon.com/en/for-members/register/>). SVEA membership fee is 200 SEK/year (junior 0 SEK, senior 100 SEK). (<seminar fee!).

You will directly automatically become preliminary member.

Purpose with the seminar

- Present and discuss interesting issues on future directions for vehicle dynamics
- Create understanding and interest for vehicle dynamics
- Develop, increase, and spread competence
- Networking between engineers, 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 domestic and globally
- To build a network for efficient distribution of technological information
- To attract the next generation of Swedish vehicular engineers

Poster exhibition

There will be an exhibition of posters. It can be, e.g., master theses or PhD theses, either concluded or almost concluded. Please contact Lars Drugge larsd@kth.se or

Bengt Jacobson bengt.jacobson@chalmers.se if you would like to propose a poster.

Each poster presenter should do a poster and a 5 minute “micro presentation” with a few slides. Then the presenter should also be available for questions at the poster stands.

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 published on the SVEA web. It will include a list of seminar participants, unless you ask us to not list your name.

Agenda

09:00-09:30	Coffee and registration		
09:30-09:45	Welcome	Matthijs Klomp (Moderator), Bengt Jacobson (SVEA, VDCA), Filip Petersson (Autoliv)	
09:45-10:45	Session 1: Presentations (20+10 min each):		
	Pres1: <i>Overview and introduction to Autoliv and the Vårgårda test track</i>	Filip Petersson, Autoliv	
	Pres2: <i>Sustainability in commercial transport: the eTrailer from Trailer Dynamics</i>	Abdullah Jaber, CEO and Dr.-Ing. René Henn, Head of Vehicle Performance, Validation & Testing, Trailer Dynamics GmbH	
10:45-10:50	Short break		
10:50-11:50	Session 2:		
	Presentation (20+10 min):		
	Pres3: <i>A path-following controller for reversing tractor-trailer and A-double</i>	Zhaohui Ge, Chalmers University of Technology, Göteborg	
	Micro presentations of posters (5 min each):		
	Post1: <i>Development environments for route based functions in road vehicles</i>	Victor Andersson, Chalmers	
	Post2: <i>Turbulence signal approximation at unsimulated yaw angles</i>	William Kumlien, Chalmers & VCC	
	Post3: <i>Steer-by-wire with closed-loop yaw rate control</i>	Mohammad Faddawi and Elmer Janmark, VCC	
	Post4: <i>Experimental validation of road friction and slope estimation models for enhanced AEB performance in heavy trucks</i>	Malte Håkanson, KTH & Scania/Traton	
11:50-13:30	Light lunch with networking combined with demo tour on Autoliv's test track.		
13:30-14:30	Session 1: Presentations (20+10 min each):		
	Pres4: <i>On the performance of heavy vehicle tyres on the winter roads</i>	Miro-Tommi Tuutijärvi, University of Oulo, Uleåborg, Finland	
	Pres5: <i>Potential customer benefits</i>		

	Pres 5: <i>Potential customer benefits of Torque Vectoring in Heavy Commercial Vehicles</i>	Jolle Ikema, Scania	
14:30-15:00	Coffee with networking and manned posters		
15:00-16:00	Session 4: Presentations (20+10 min each):		
	Pres 6: <i>From Intent to Action: AI-Assisted Vehicle Dynamics Design Using Validated Modelica Libraries</i>	Johan Andreasson, Modelon	
	Pres 7: Swedish vehicle engineering education: * Pres 7a: <i>KTH, Vehicle engineering</i> * Pres 7b: <i>Chalmers, Mobility engineering & Systems, Control and Mechatronics</i> * Discussion	Mikael Nybacka, KTH Bengt Jacobson, Chalmers All	
16:00-16:15	Wrap-up • Overall technical questions from today's presentations and posters • Feedback on present years seminar. Proposals for next year's seminar. • Any other questions or proposals for VDCA or SVEA		
16:30	Seminar (latest end time)		

The seminar is hosted by Autoliv arranged by the Swedish Vehicle Dynamics Competence Area (VDCA) and Swedish Vehicular Engineering Association (SVEA, Sweden's society member of FISITA). The seminar is arranged with VDCA representatives from:

Autoliv

AFRY Automotive

AstaZero

Chalmers

KTH

Polestar

Scania

Volvo Cars

Volvo Trucks

VTI

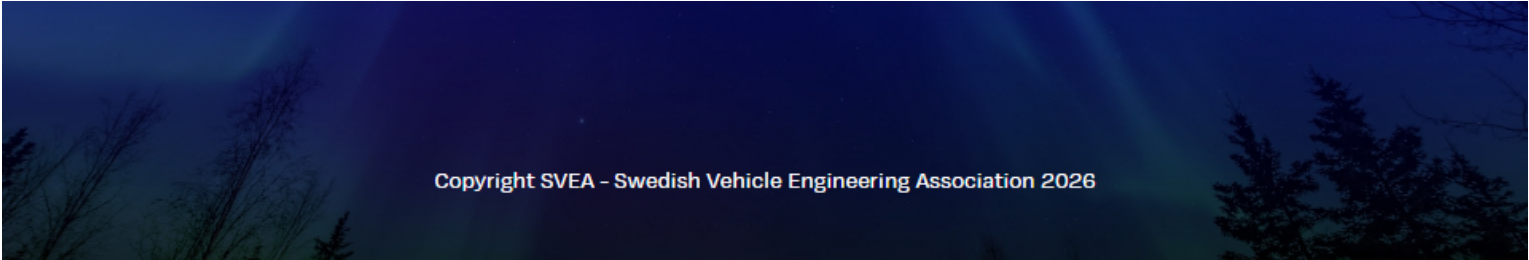
Zeekr Technology Europe

VDCA Swedish Vehicle Dynamics Competence Area



SVEA is the society member for Sweden in FISITA:





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Participations

61 participants

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Introduction to the seminar



Vehicle Dynamics 2026 — — Future directions



VDCA *Swedish Vehicle Dynamics Competence Area*

VEA SWEDISH
VEHICULAR
ENGINEERING
ASSOCIATION
SVERIGES FORDONSTEKNISKA FÖRENING



FISITA

About present year's seminar topic

Vehicle Dynamics 2026 — — Future directions

- A very open topic!
- Challenges and opportunities:

Energy and climate	Electric propulsion, AI in development and/or in vehicles, Big data, Cloud technologies, and ...
Sustainability and resilience	
Global and local perspectives	

- Many of these opportunities have existed for decades. However, in present decade, global and local political developments have increased the urgency to act on them.



Our annual Vehicle Dynamics seminars

Year	Topic	Location
2013	Vehicle Dynamics Challenges	Lindholmen, Göteborg
2014	Vehicle Dynamics in a Cooperative Environment	Scania, Södertälje
2015	Vehicle Dynamics for Energy Efficient Mobility	Chalmers, Göteborg
2016	Functional Architectures and Virtual Methods for Efficient Vehicle Dynamics Development	NEVS, Trollhättan
2017	Vehicle Dynamics for Automated Driving	Scania, Södertälje
2018	Model Fidelity for Vehicle Motion Predictions	Chalmers, Göteborg
2019	<replaced by IAVSD international conference>	Göteborg
2020	<cancelled>	Cancelled, due to pandemic
2021	Future Mobility ...and not only Lateral	On-line, due to pandemic
2022	Connected and Electric	KTH, Stockholm and on-line
2023	Testing, development, and verification	AstaZero, Sandhult and on-line
2024	Virtual verification	Linköping and on-line
2025	Model exchange for virtual pre series	Göteborg, Chalmers and on-line
2026	Vehicle Dynamics -- Future Directions	Autoliv, Vårgårda and on-line
2027	(to be discussed at the wrap-up of 2026's seminar)	

Purpose with the seminar

- **Present and discuss** interesting issues within Vehicle Dynamics and within the topic which is selected each year
- Create **understanding and interest** for vehicle dynamics
- Develop, increase, and spread **competence**
- **Networking** between engineers, organisations, and students

SVEA was formed during 1989-1990.

SVEA's objectives:

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

Enjoy the
seminar day!

VDCA “core group” has
representatives and contributions
from vehicle manufacturers,
university groups in the subject
Vehicle Dynamics, and VTI:

Autoliv

AFRY Automotive

AstaZero

Chalmers

KTH

Polestar

Scania

Volvo Cars

Volvo Trucks

VTI

Zeekr Technology Europe

Presentation 1:

***Overview and introduction to Autoliv and the
Vårgårda test track,***

Filip Petersson, Autoliv

Presentation 2:

***Sustainability in commercial transport: the
eTrailer from Trailer Dynamics,***

Abdullah Jaber, CEO and Dr.-Ing. René Henn,
Head of Vehicle Performance, Validation &
Testing, Trailer Dynamics GmbH

Sustainability in commercial transport: the eTrailer from Trailer Dynamics

Dr.-Ing. René Henn
Head of Vehicle Performance, Validation & Testing

Abdullah Jaber
CEO Trailer Dynamics GmbH

Göteborg, 2026



01

Package of the eTrailer





Our idea:
Electrification of semi-trailer



Our partners:
Krone, Jost & Thermo King



Our mission:
Contribute to decarbonization of
heavy duty transport



Our team:
90 employees



Our target:
Series-production readiness



Our location:
Eschweiler



The eTrailer

E-Kit: modular system for electrification of semi-trailer

E-Kit:

- Contains sensed king-pin, control box, electric axle and high voltage battery system
- 800V system voltage
- Modularer system approach



The eTrailer

Electric axle & motor-gearbox-unit

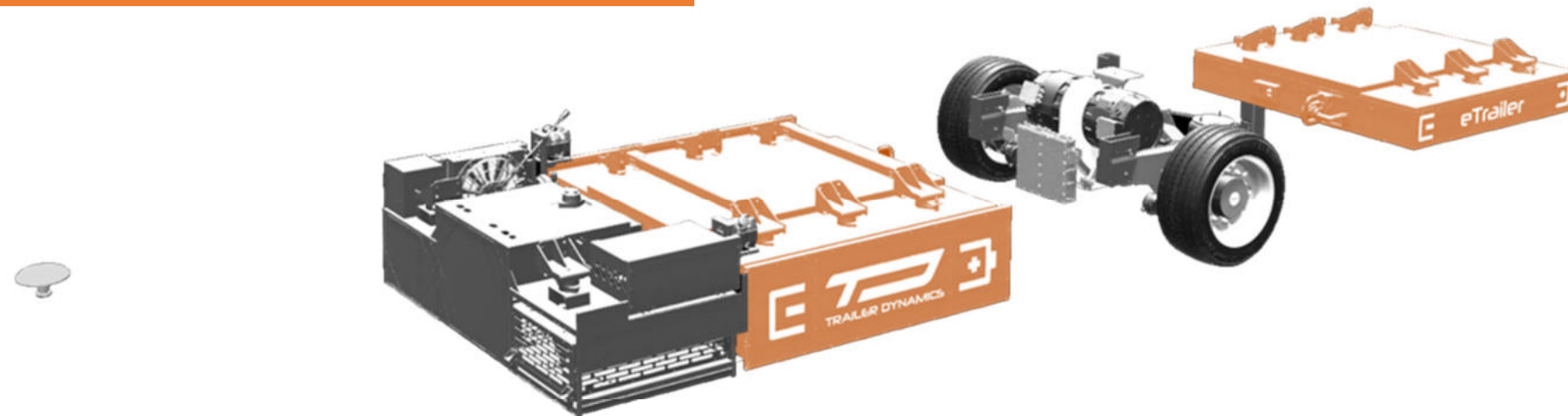
Electric axle & motor-gearbox-unit

- Two electric engines/inverter with central gearbox
- Transmission to wheel end by crank shafts
- Continuously power: 360 kW
- Peak power: 580 kW



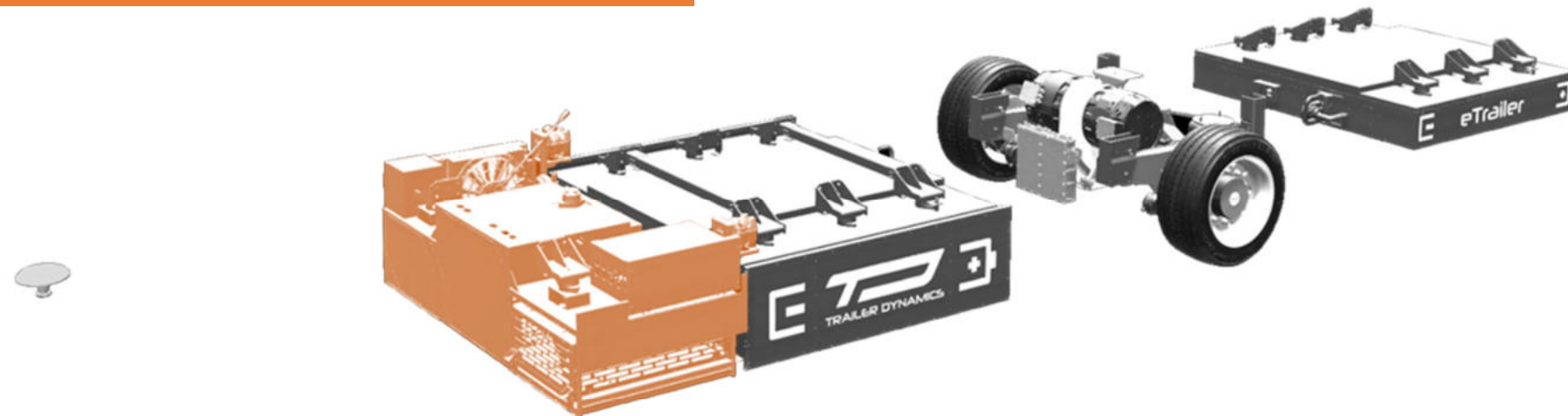
Battery system

- Charging power up to 350 kW DC
- Available in three capacity specifications:
 - 187 kWh
 - 367 kWh
 - 551 kWh
- Homologation according UN-ECE R 100



Control box

- Low voltage system & high voltage energy distribution
- Battery management system
- Vehicle control unit
- Thermal management



King-pin

- Regulation of the eTrailer by redundant sensing system
- Independent from the tractor unit
- Automatic recalibration



02

Testing of structural design



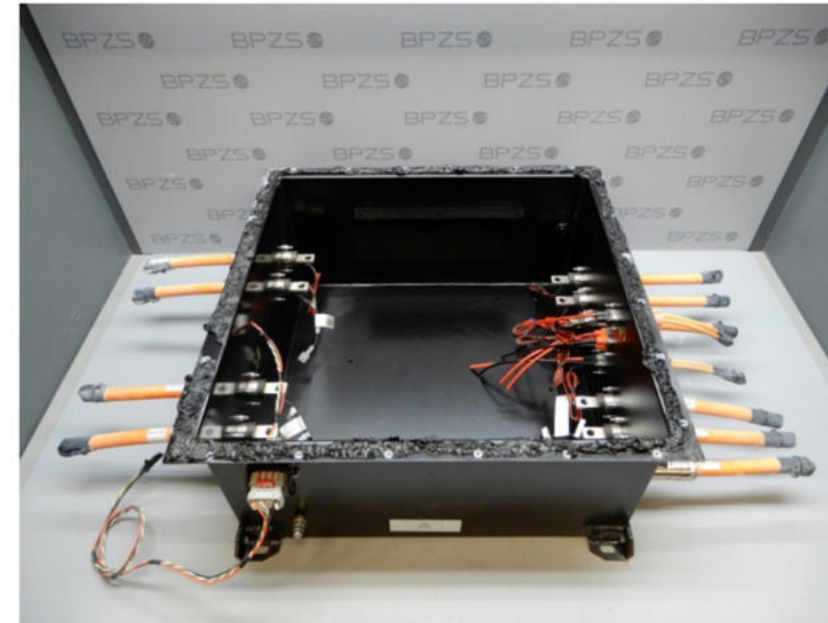
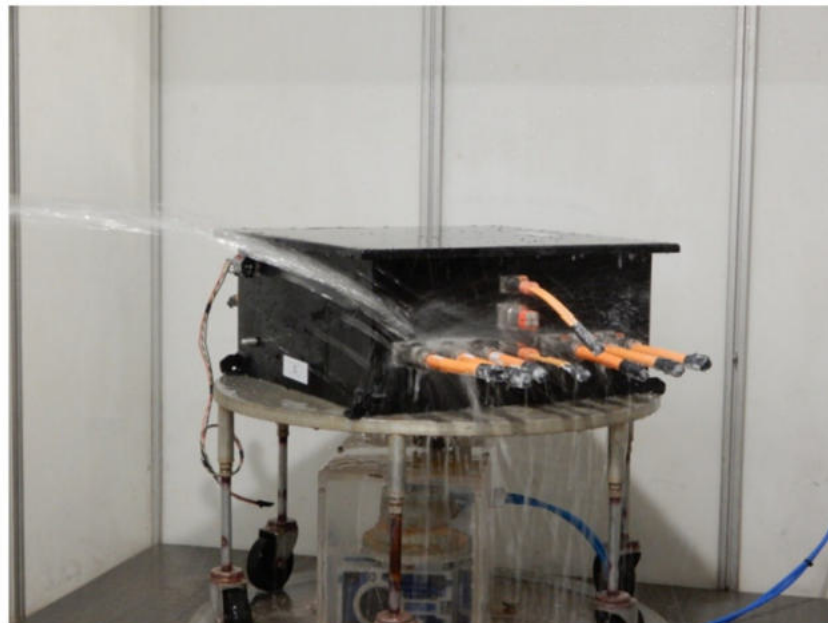
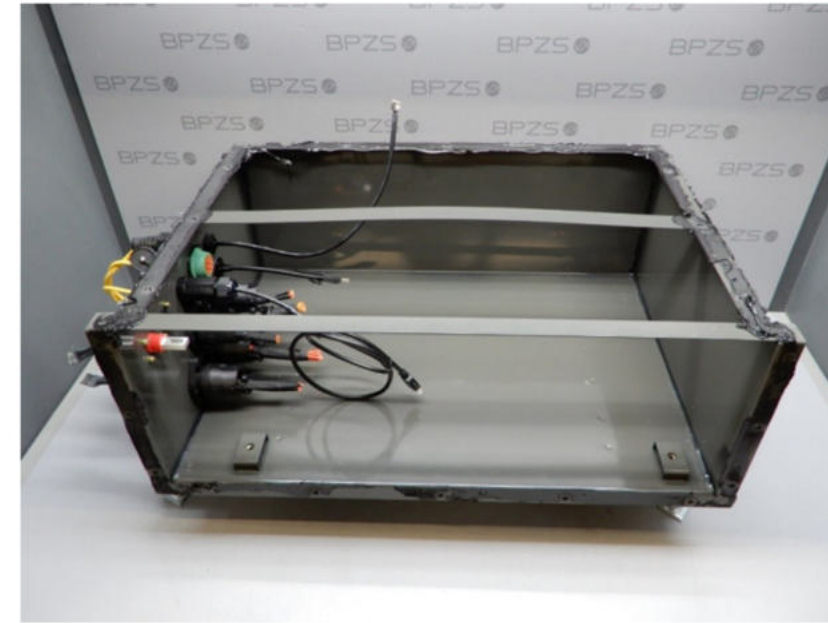
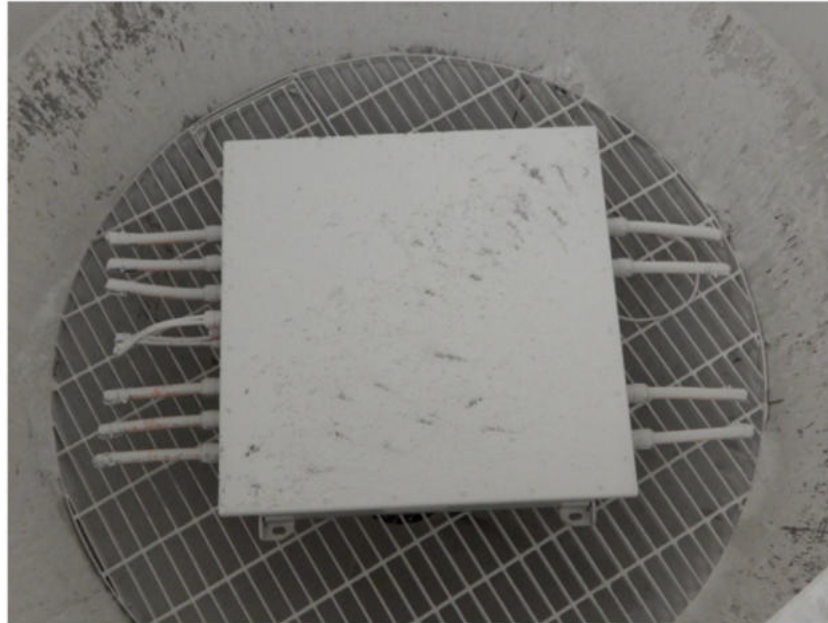
Testing for structural design

Test cases: shunting, sleeping police men, ramp crossing, square profile etc.



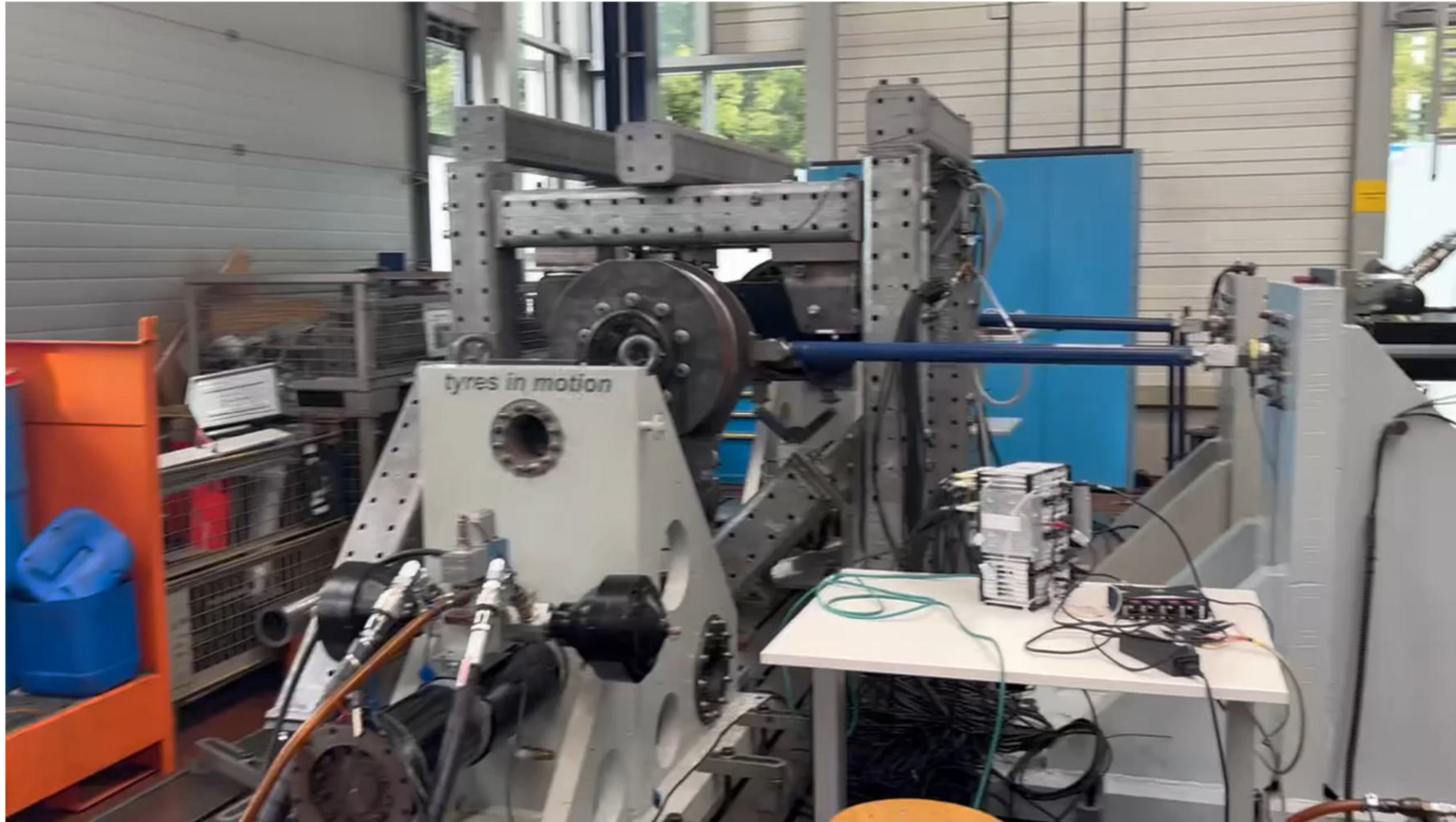
Component Tests

Dust and water intrusion at Power Distribution Unit



Component test

eAxle



Componenten Test

Control box



03

Integration tests



Homologation

UN ECE R 10 – Elektromagnetische Verträglichkeit

Setup, 30-1000 MHz, Pos-1



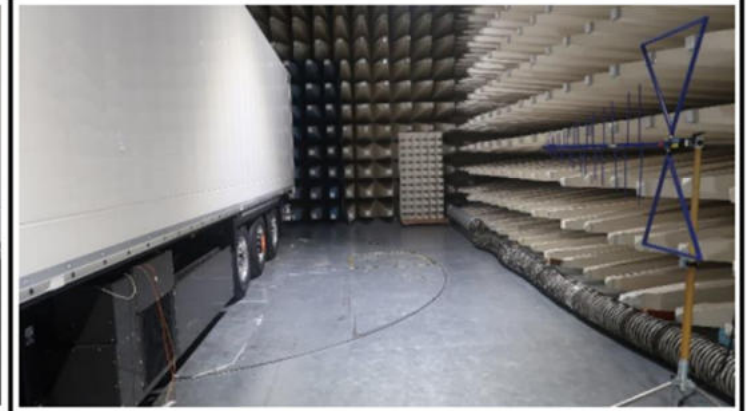
Setup, 30-1000 MHz, Pos-5



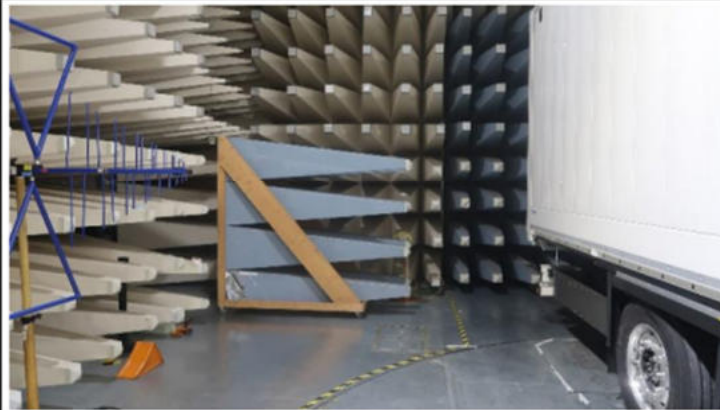
Setup, 30-1000 MHz, Pos-3



Setup, 30-1000 MHz, Pos-7



Setup, 30-1000 MHz, Pos-2



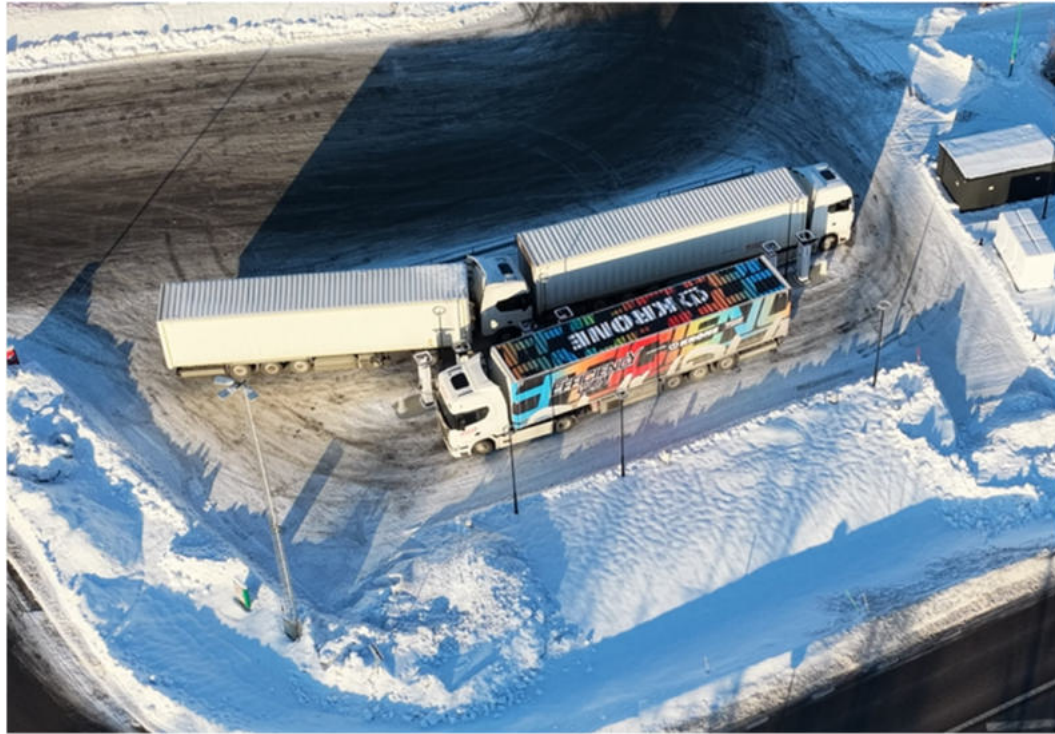
Setup, 30-1000 MHz, Pos-6



Testing on low- μ tracks

Development of Anti-Slip-Regulation (ASR)





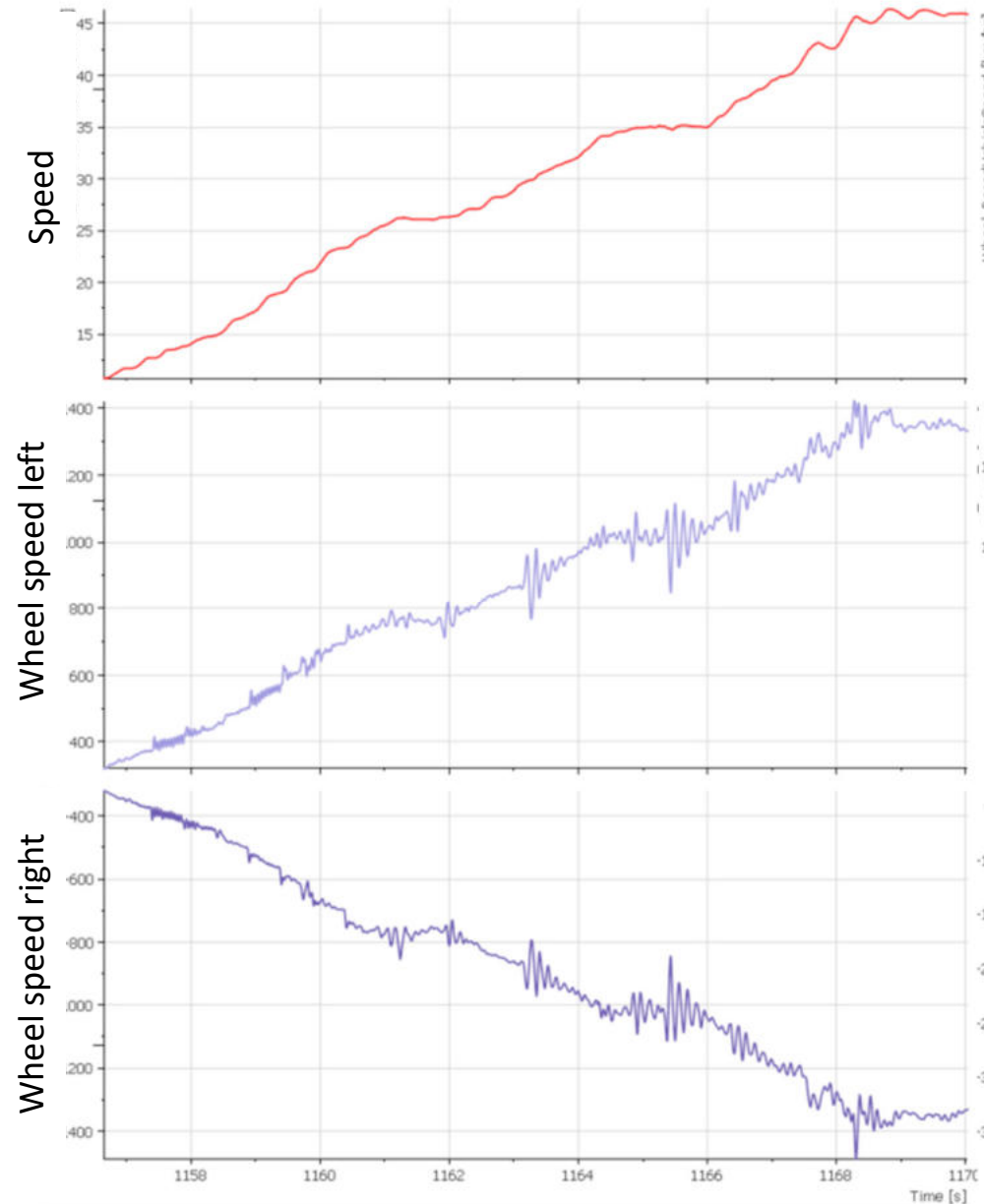
- Testing of eTrailer components during driving and charging at low temperatures (-30°C)
- Testing of Anti-Slip-Regulation (ASR) and king-pin regulation on snow and ice
- Brake testing on snow & ice
- Trip to Polar circle as long haul test on snow and ice
- Optimization of efficiency and thermal battery management for cold countries
- Testing with diesel and BEV tractor units



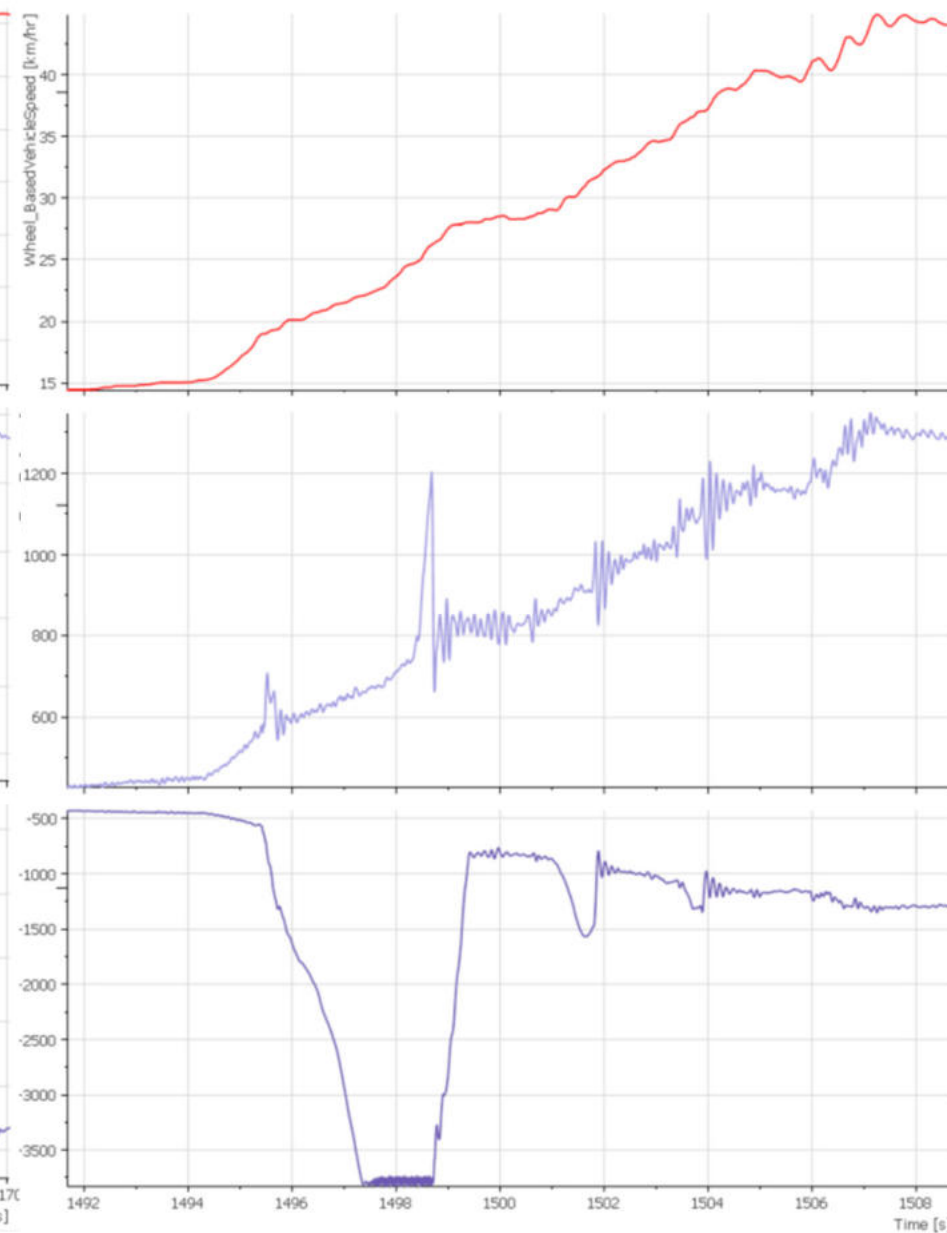
Acceleration on ice

Testing on ice patches

With usage of ASR



Without usage of ASR



- Test track contains irregular patches of ice and dry asphalt
- Control system of eTrailer needs to interact with ASR
- Result:
 - Very stable driving behavior with ASR
 - More rough behavior without ASR

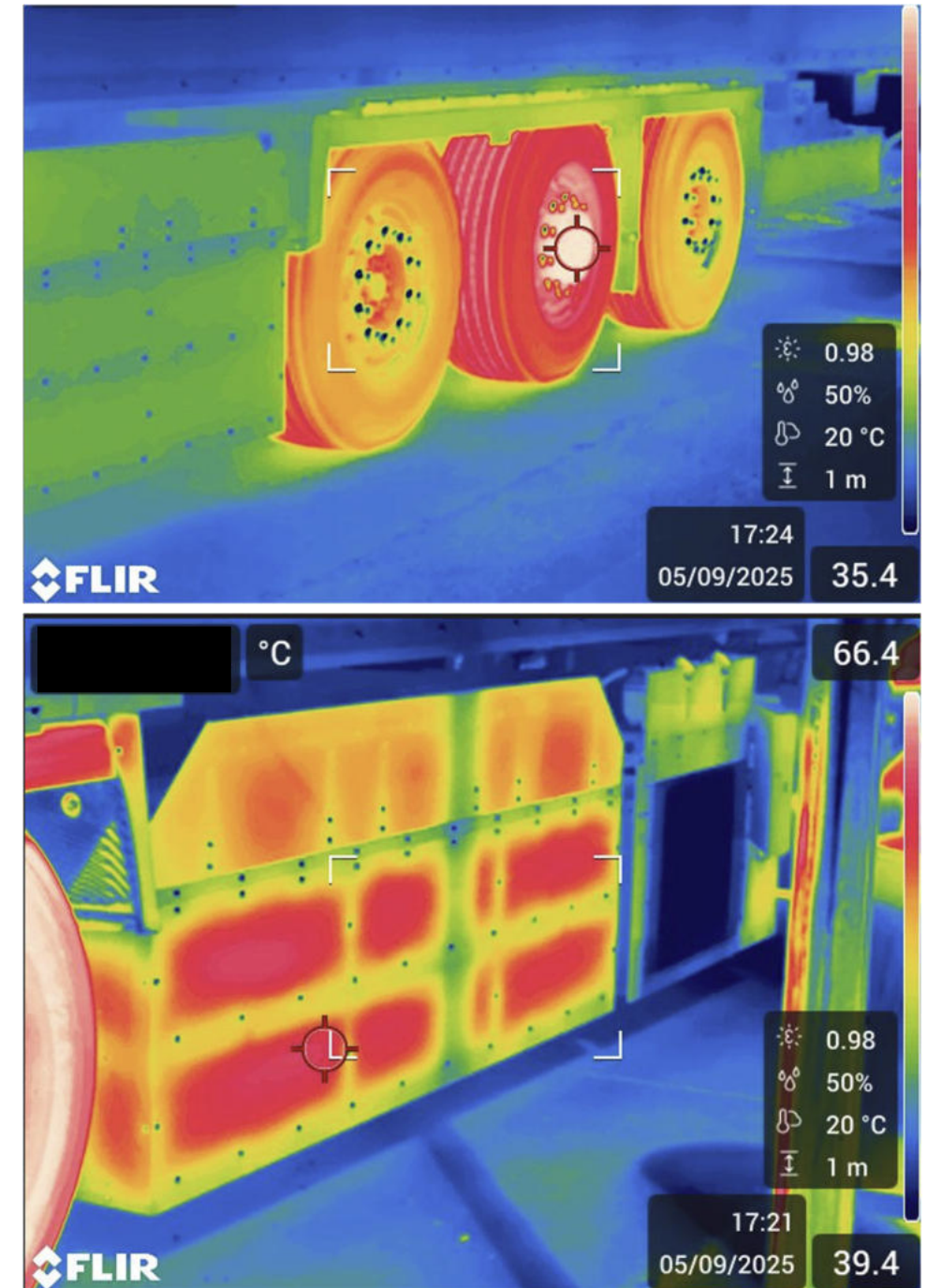


Summer Test 2025

Optimization of cooling system



- Testing of warming and cooling of eTrailer components during driving and charging at hot temperatures up to 40°C
- Up- and downhill testing in Sierra Nevada at high outside air temperatures



Development of eTrailer tires with Continental



- Tire profile and rubber specification optimized for usage in an eTrailer
- Legal for usage on public roads
- Tested in cold and hot countries (Sweden / Spain)



04

Testing with different
tractor units



Testing with different tractor units



Testing on public roads

Comparison of eTrailer with conventional trailer on reference tracks



Regulation

Vehicle classes:

Die Fahrzeuge werden in nachfolgende vier (4) Motoren-Klassen eingeteilt:

Klasse 1: Normale Verbrennungsmotoren mit Diesel oder 100 % nachhaltigem Diesel

Klasse 2: Elektrofahrzeuge mit Batterie

- B.E.V. oder reine oder vollelektrische Fahrzeuge
- Elektrofahrzeuge mit Brennstoffzellen

Klasse 3: Verbrennungsmotor mit H2

Klasse 4: Verbrennungsmotor mit (Bio-)LNG



Class 1: 10 trucks

Class 2: 3 trucks (all BEV)

Class 3: 0 trucks

Class 4: 1 truck

+ Trailer dynamics eTrailer with diesel tractor unit

Scoring:

Die Rangfolge wird in jeder Motorenklasse (Ziffer 5) anhand des Performance Index (PI) ermittelt, der sich aus dem Energieverbrauchsindex (ECI) und dem Regelmäßigkeitsindex (RI) zusammensetzt:

- a) Regelmäßigkeitsindex (RI) = Strafpunkte für jede Minute oder Bruchteil einer Minute, die das Fahrzeug zu früh ankommt (max. Geschwindigkeit = Unterschreiten der Mindestfahrzeit) und Strafpunkte für jede Minute oder Bruchteil einer Minute, die das Fahrzeug zu spät ankommt (min. Geschwindigkeit = Überschreiten der maximalen Fahrzeit).
- b) Energieverbrauchsindex (ECI) = Tatsächlicher Energieverbrauch, ermittelt mit einem FIA-Messgerät, im Verhältnis zu den offiziellen und Fahrzeug-spezifischen Werten, die von jedem Hersteller für das jeweilige Modell gem. Zulassungsunterlagen angegeben werden.

Max. vehicle mass:

Das Gewicht von Zugmaschine mit Auflieger muss mindestens 16 Tonnen betragen und darf ein Gewicht von 18 Tonnen nicht überschreiten.

TRAILER HEADS



Truck Efficiency Run

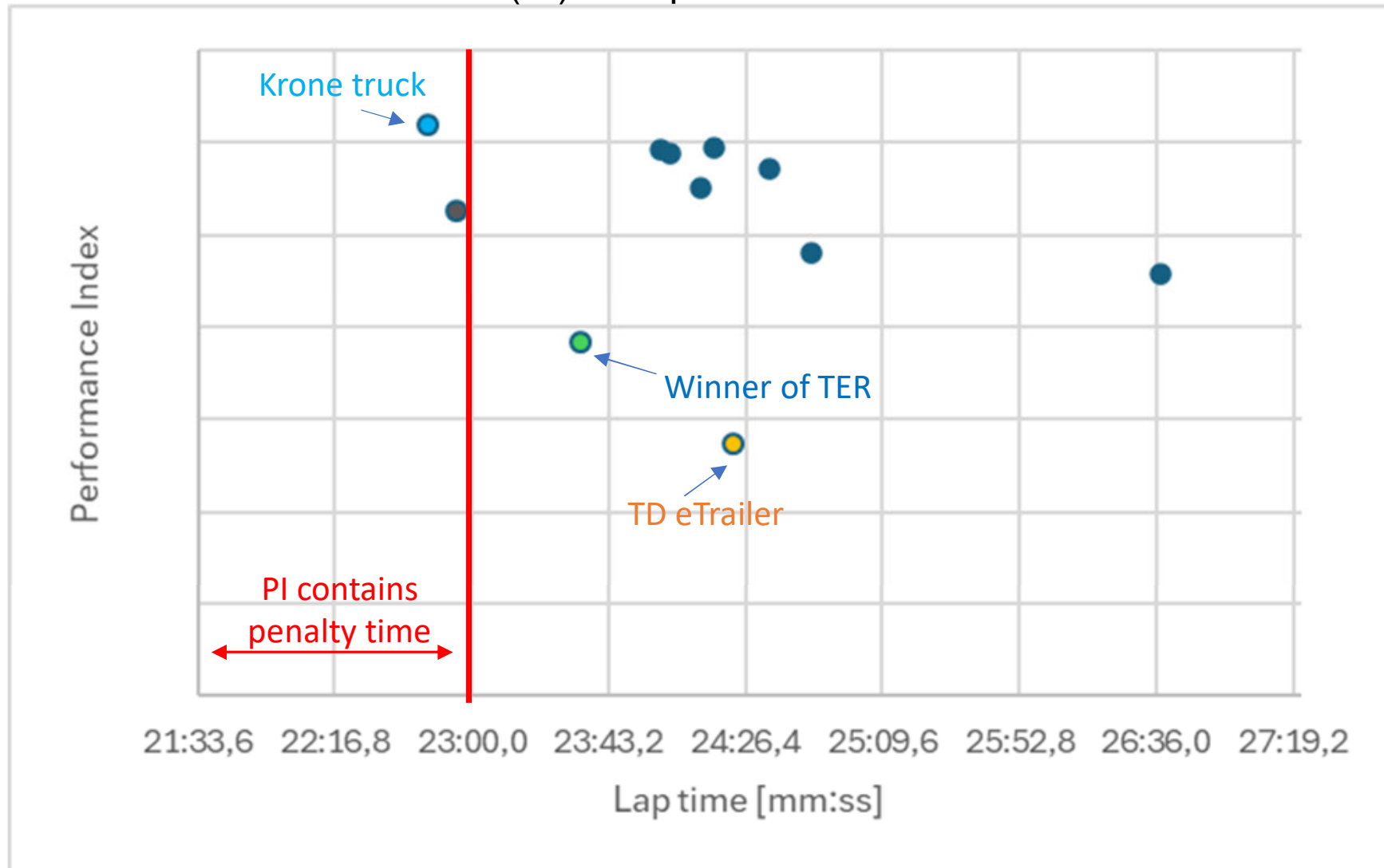
10.07.2025 Nürburgring GP-track (short) + Nordschleife

Distance	24.1 km
Average diesel consumption tractor unit	20.6 ltr. / 100 km
Total energy consumption eTrailer	24 kWh
Average energy consumption eTrailer	103,7 kWh / 100 km
SOC start	83,6 %
SOC end	79,2 %



Truck Efficiency Run (TER)

Results – Performance Index (PI) vs. lap time



Average diesel consumption (Krone truck)

33.4 ltr. / 100 km

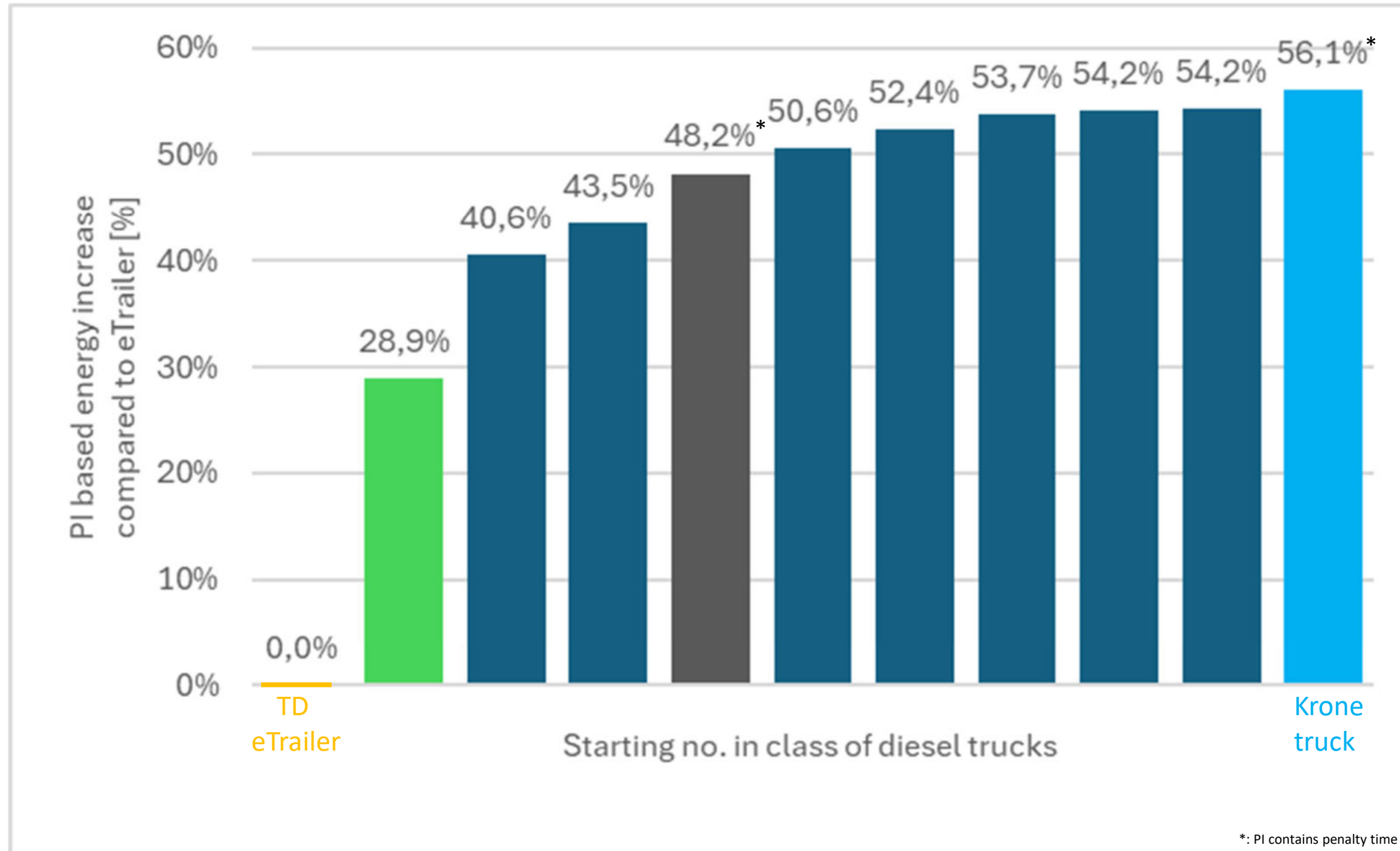
Average diesel consumption (TD eTrailer)

20.6 ltr. / 100 km
(38,3% saving)



Truck Efficiency Run

Results



Testing with electric tractor units

Field tests – customer targets

Field test „Black Forrest“

- Use electric tractor unit on a daily trip of 475 km in Black Forrest region without recharging the tractor unit during the trip
- Result: 40% SOC remaining in tractor unit at the end of the test

Field test „Long Haul“

- Elongate range of electric tractor unit
- Test charging infrastructure between the Netherlands and Hungary

Trailer Dynamics internal tests

- Winter test with electric tractor unit: testing usability in Swedish winter
 - Long haul test with testing of charging infrastructure
- Depending on usage profile very clear extension of range and reduction of travel time because tractor unit might not be charged during the trip



Many thanks for you attention!



Presentation 3:

***A path-following controller for reversing
tractor-trailer and A-double,***

Zhaohui Ge, Chalmers University of Technology,
Göteborg

A path-following controller for reversing tractor-trailer and A-double

Zhaohui Ge, Vehicle Dynamics group, Chalmers

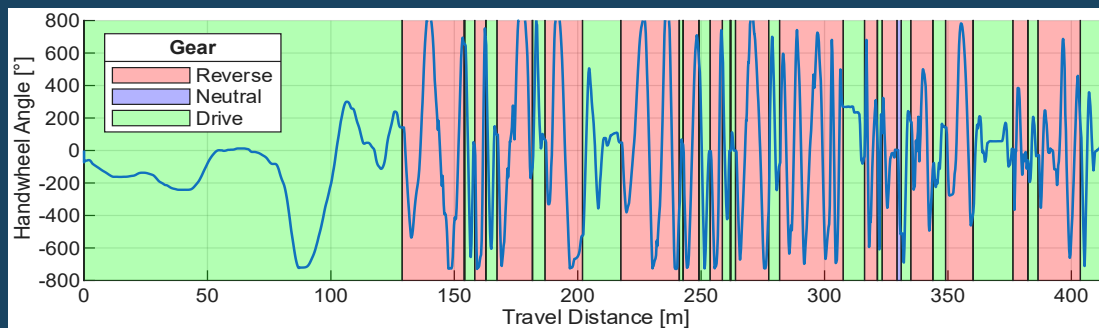
Content

1. Background
2. Test vehicle
3. Control design
4. Test results
5. Future work

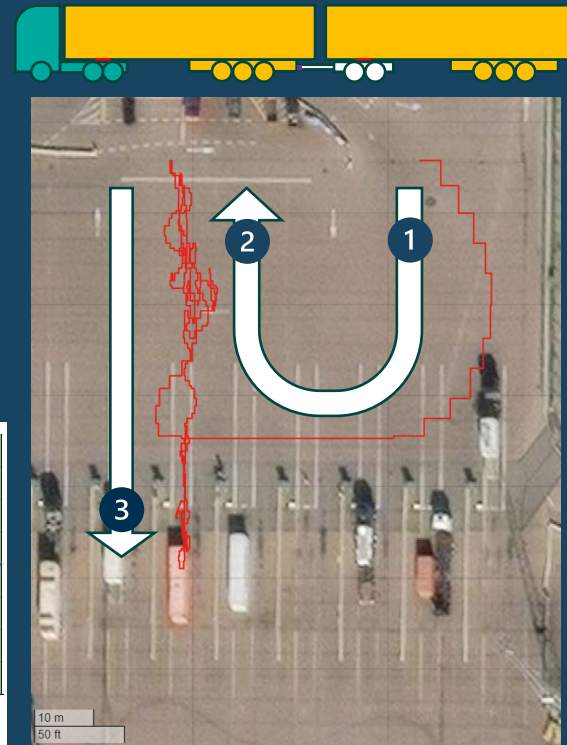
1. Background

Parking an A-double at Port of Gothenburg

- Time: ≈ 8 minutes
- Gear change: 32 times
- Handwheel travel: 8572 degrees ≈ 24 circles



Gear and handwheel steering angle



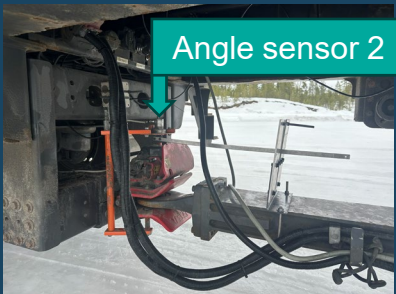
Tractor's path

2. Test vehicle

Sensing

All signals transmitted via CAN

- Articulation angle sensors
- GNSS & IMU on the last trailer
- Tractor speed



2. Test vehicle

Actuating

External steering interface via CAN

- Steering (-100~100%)
- Acceleration pedal position (0~100%)

Manual

- Parking brake
- Service brake
- Gear

VOLVO

FACT SHEET

EXTERNAL STEERING INTERFACE

EXSTER Support for external steering control via body builder module



 **PRODUCTIVITY**

- The body builder can connect a wireless remote control.
- The vehicle can be controlled and driven from the outside.

Requirements for EXSTER:

- Body builder module (ECBB-HIG or ECBB-HI2).
- Volvo Dynamic Steering (ACTST-TO)

Note! Local homologation needs to be fulfilled. The remote control is not included in the variant.

Example of how the external steering can be used.

3. Control design

Layout

Predefined inputs

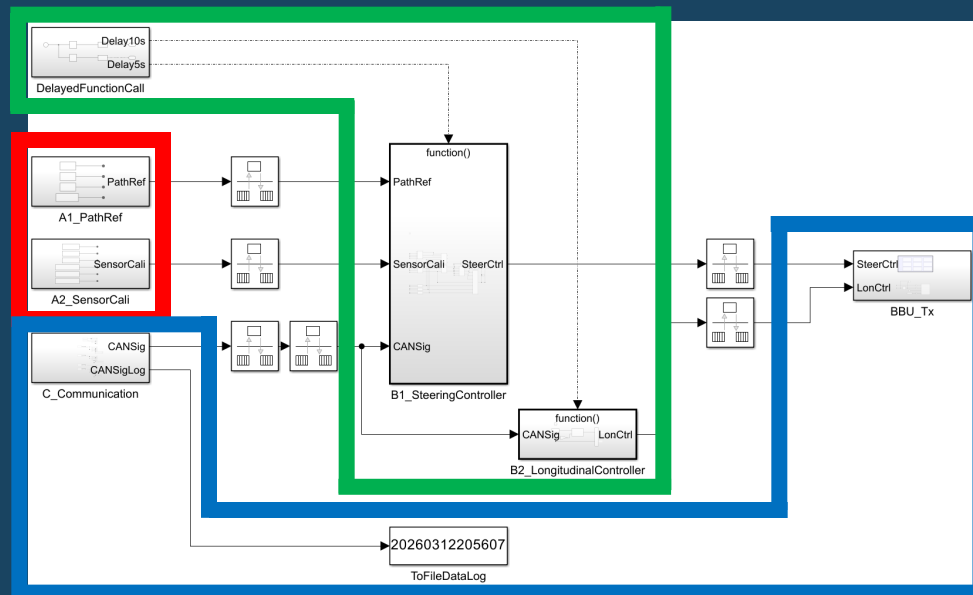
- Reference path
- Sensor offsets

Control

- Lateral control
- Longitudinal control

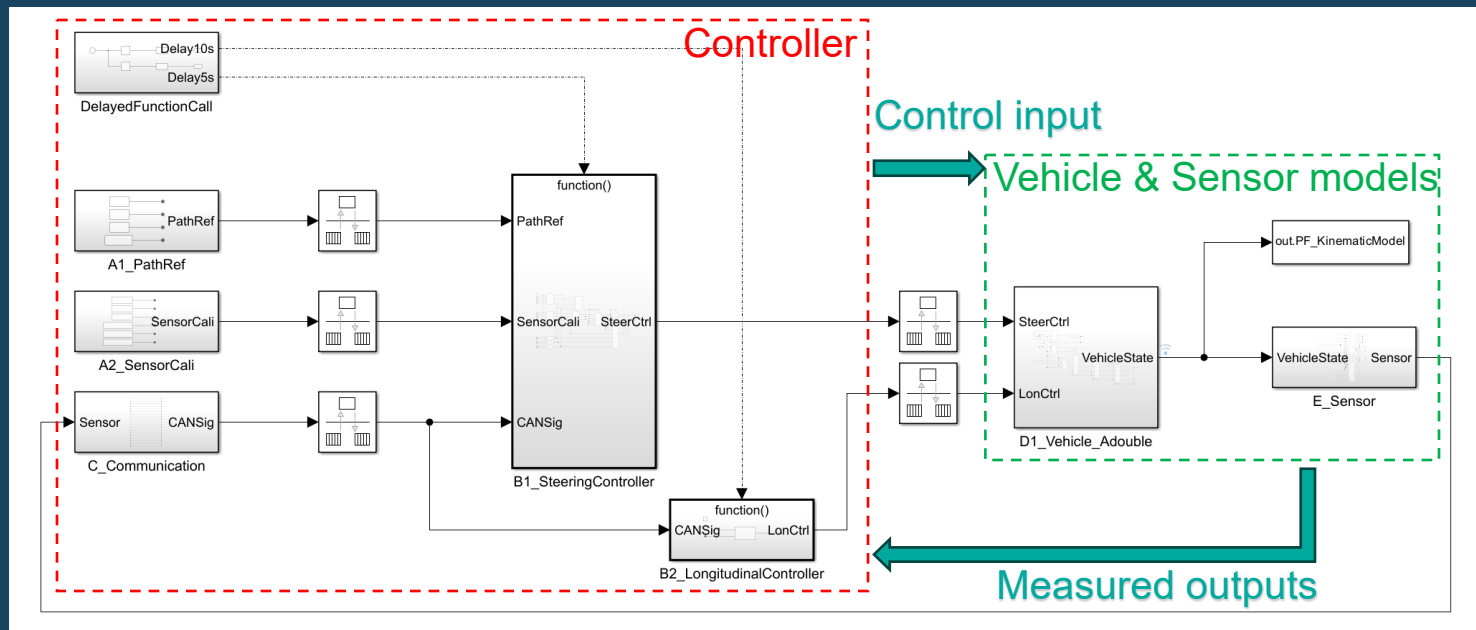
Communication

- CAN inputs (Vehicle, Articulation, GNSS)
- CAN outputs (Vehicle)
- Logger



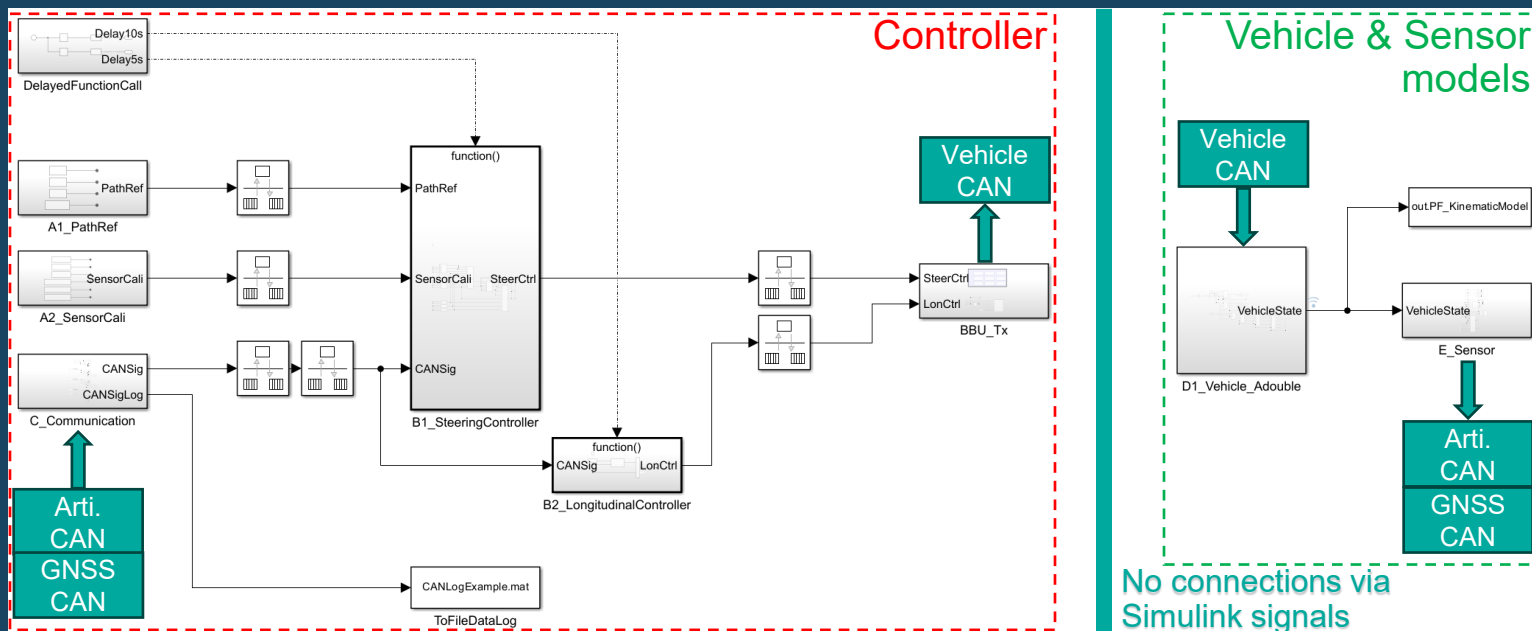
3. Control design

Simulation environment, Communicate via Simulink signal



3. Control design

Simulation environment, Communicate via virtual CAN

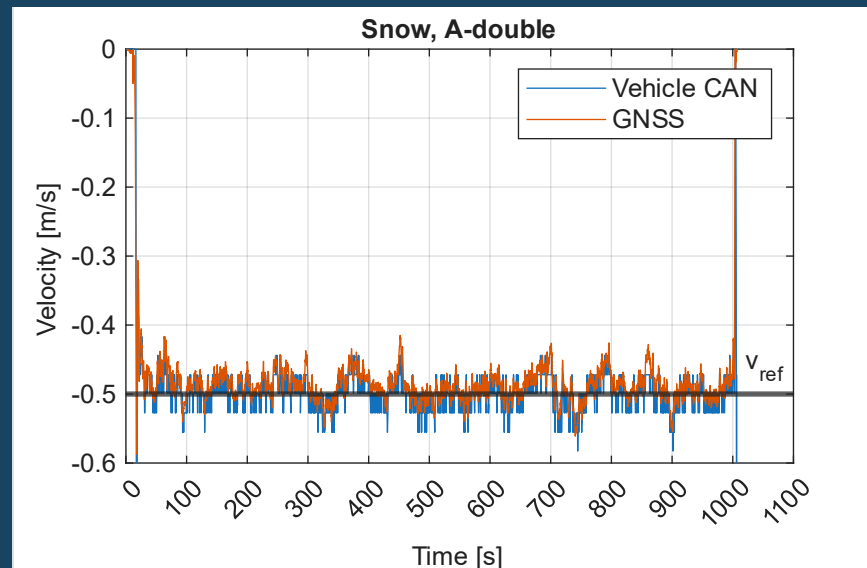


3. Control design

Longitudinal control

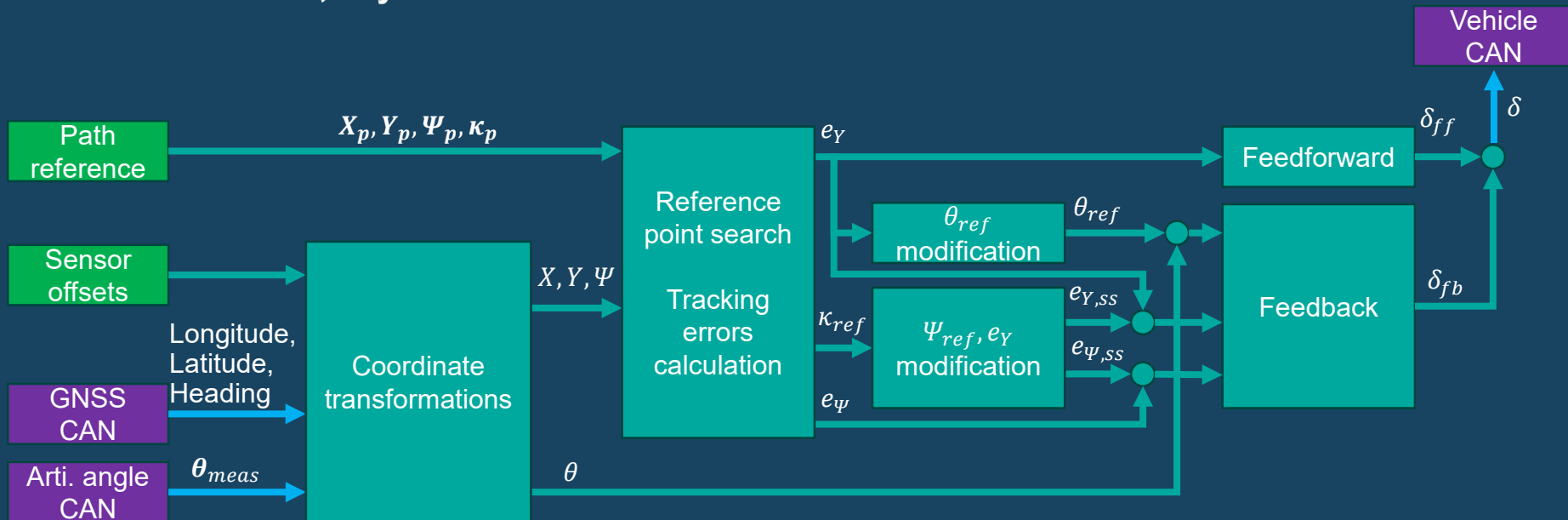
PI controller

- Output saturation applied
- Different K_p and K_I applied to different vehicles



3. Control design

Lateral control, Layout



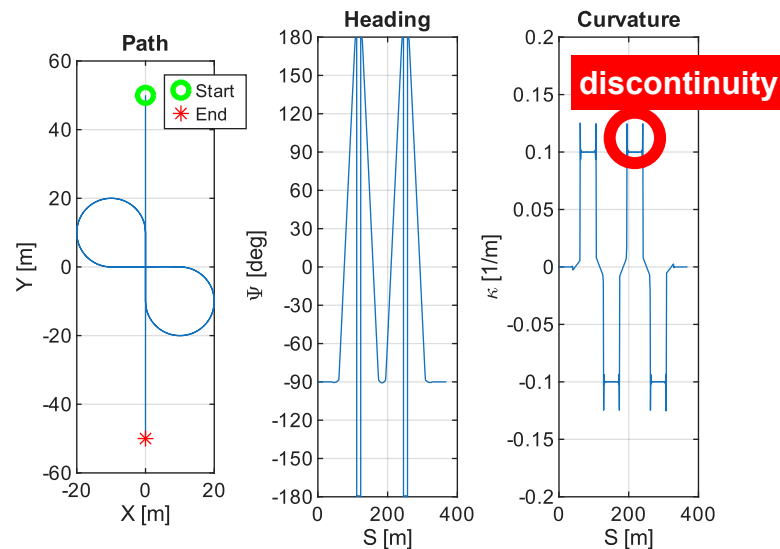
3. Control design

Lateral control, Path reference

Step 1. Define waypoints (X, Y) with a large distance (>1 m) in between.

Step 2. Reduce the distance between waypoints to a small distance (0.1 m) with spline interpolation.

Step 3. Calculate path heading and curvature based on waypoints.



3. Control design

Lateral control, Path reference with smooth curvature

Approach 1. Pseudo-continuous curvature

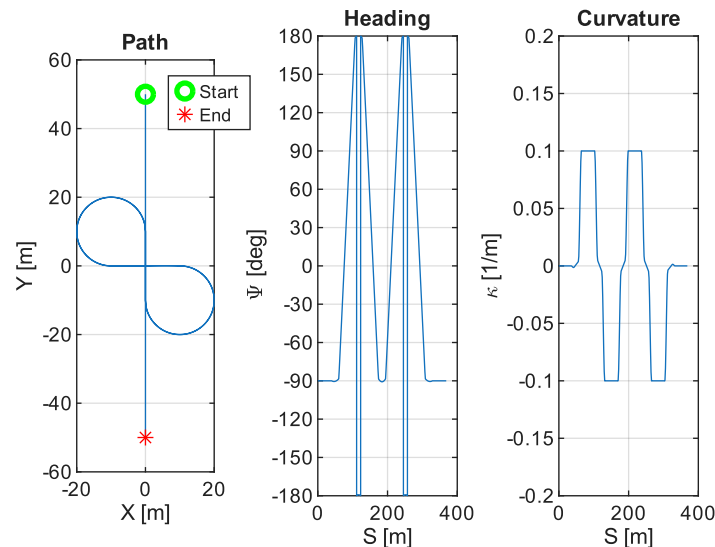
Same waypoints with smoothed curvature

Approach 2. Replan with decimated waypoints

- Decimate waypoints and heading with a large interval (20 m)
- Use existing smooth planning functions (smoothPathSpline)

Future approach, higher order continuity in curvature (for continuous steering angle)

- Tractor-trailer, continuous κ'
- A-double, continuous κ'''

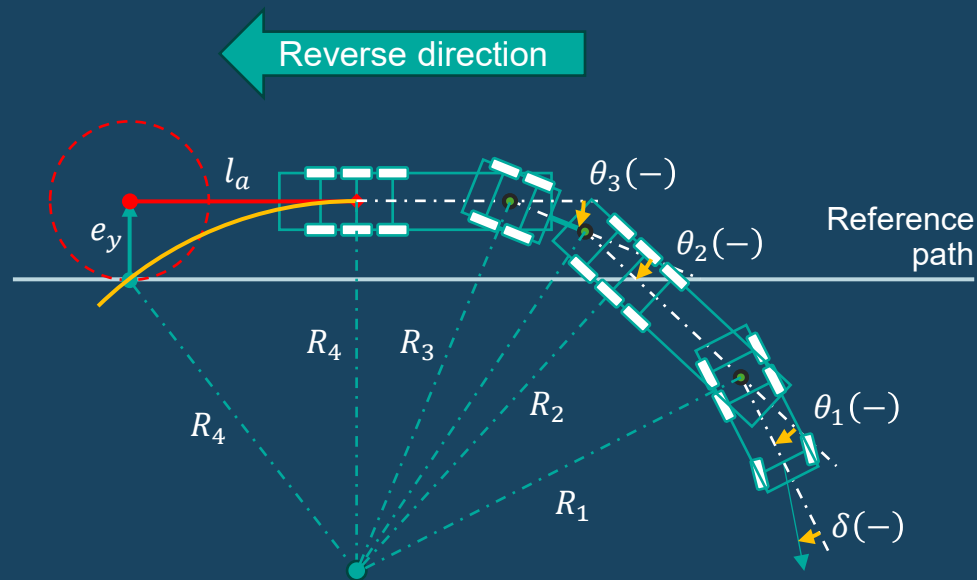


3. Control design

Lateral control, Straight line tracking

Modified pure pursuit

- Desired path radius for the last trailer
- From R_4 to the corresponding steady state based on the kinematic model
- Precompute lookup tables from e_Y to $[\theta_1, \theta_2, \theta_3]_{SS}$ and δ_{ss}



3. Control design

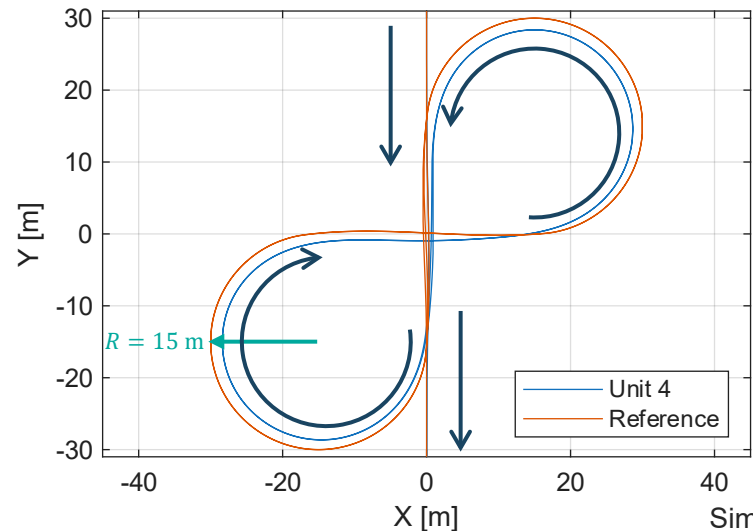
Lateral control, Straight line tracking

- Low tracking error for straight sections

$$e_y = 0.06 \text{ m at } Y = -30 \text{ m}$$

- High steady-state error for circular sections

$$e_y = 1.62 \text{ m when } R = 15 \text{ m}$$

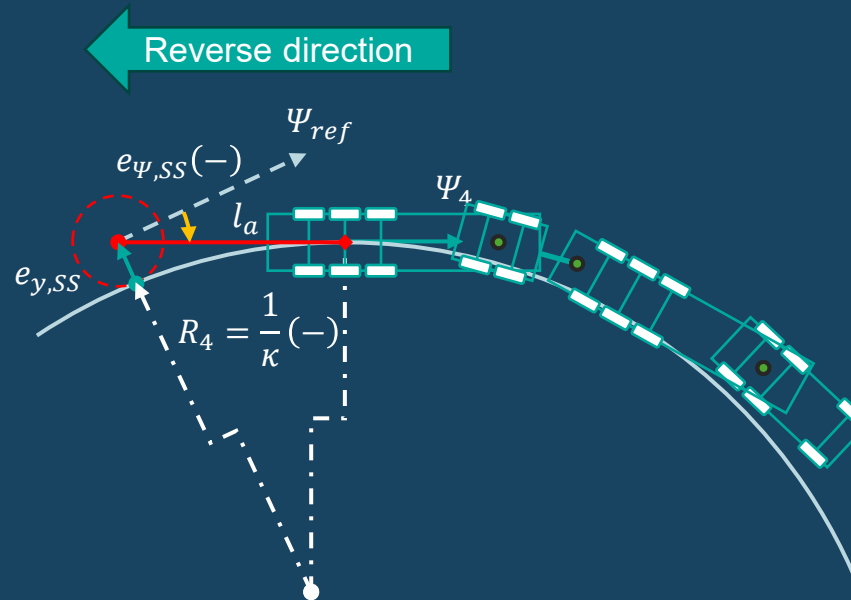


Simulation

3. Control design

Lateral control, Circular arc tracking

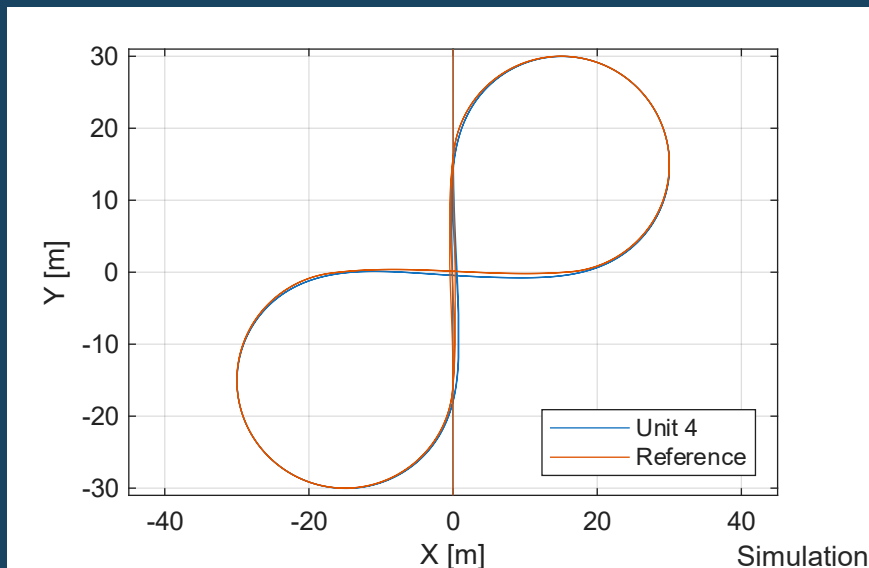
Eliminate steady-state offset by reference modification



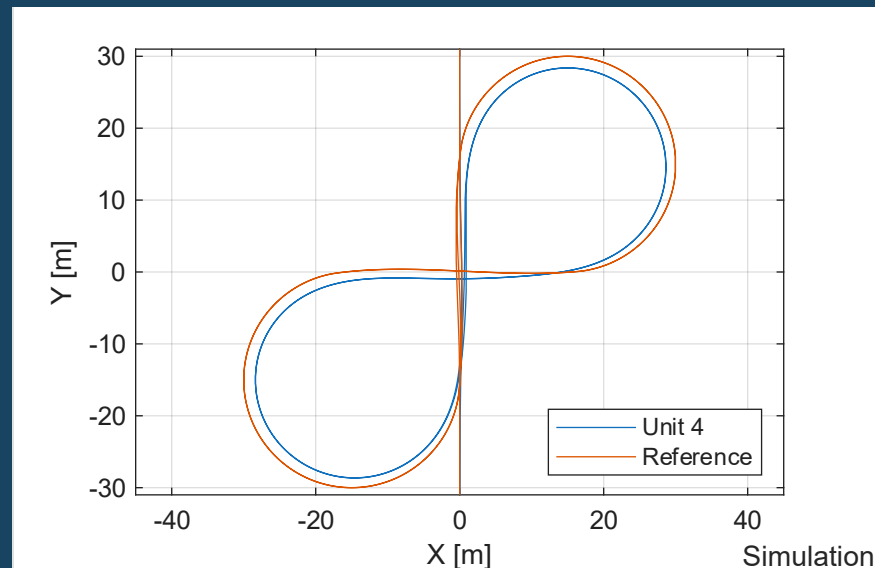
3. Control design

Lateral control, Circular arc tracking

- With reference modification



- Without reference modification

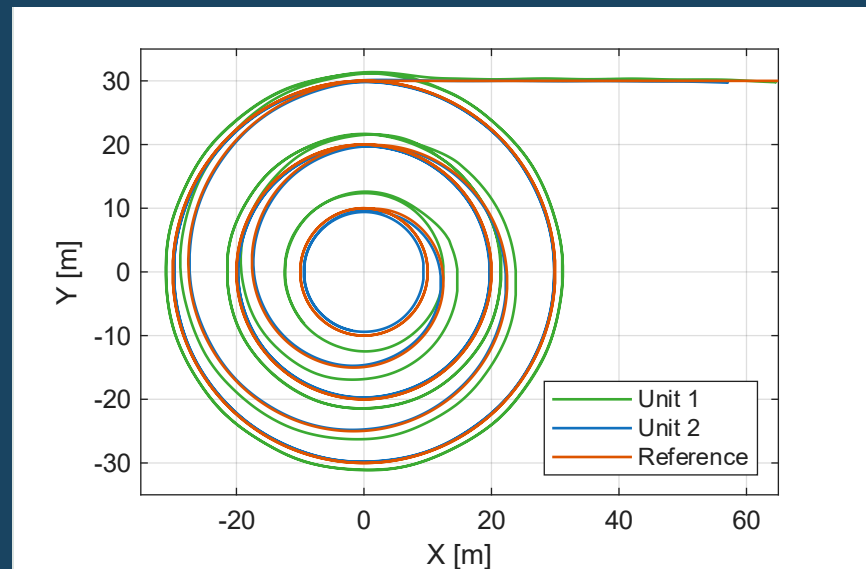
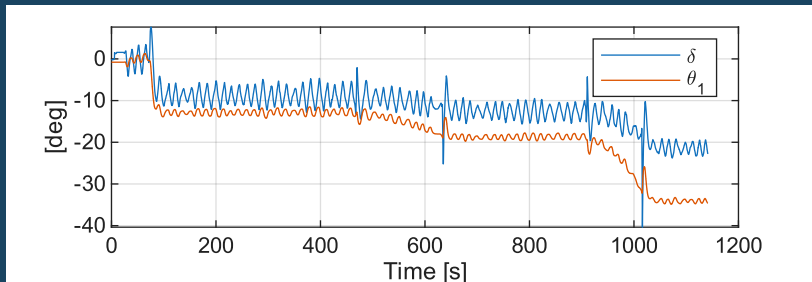


4. Test results

Tractor Trailer, Constant radii (30, 20, 10 m), 1 m/s

- Stable tracking
- Steady-state error $\uparrow$ when Radius $\downarrow$

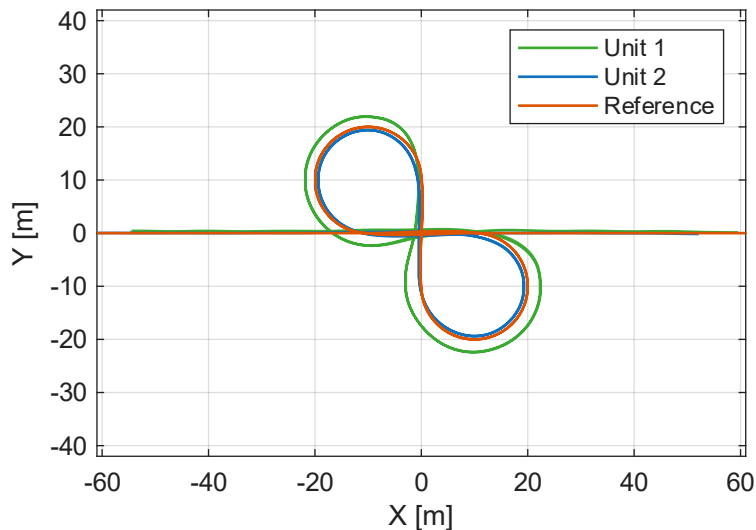
R [m]	30	20	10
e_y [m]	0.15	0.26	0.59



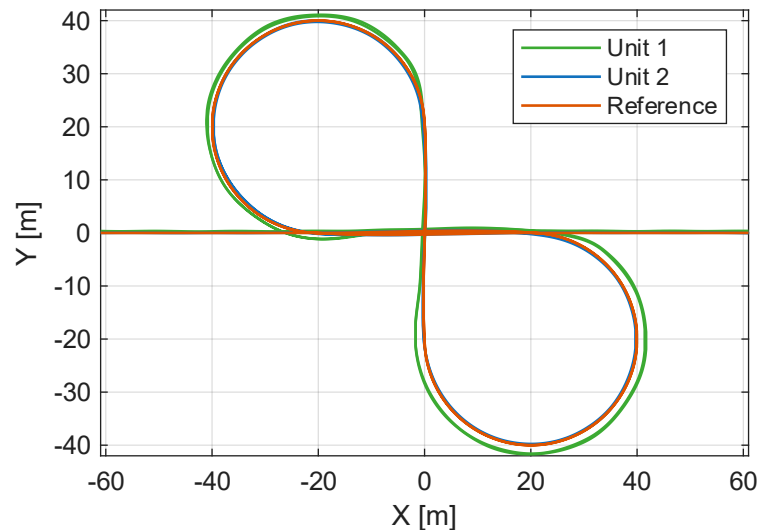
4. Test results

Tractor Trailer, Figure 8 (10, 20 m), 1 m/s

• $R = 10$ m, $e_{y,ss} \approx 0.7$ m

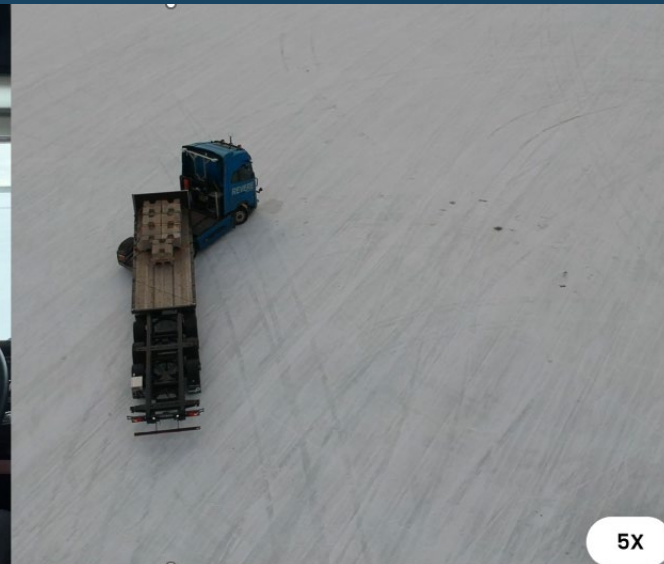
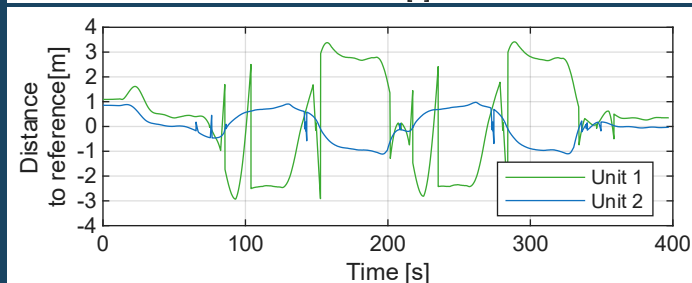
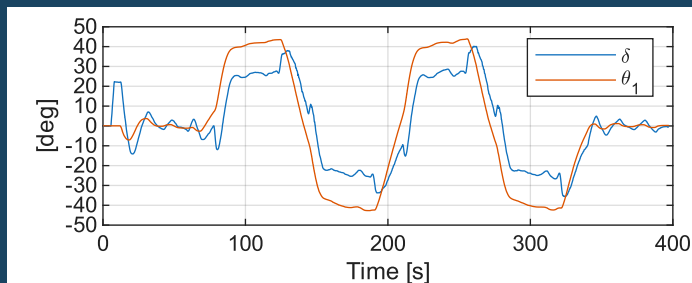
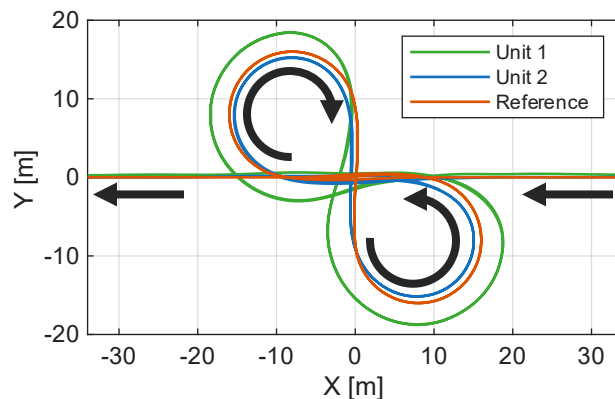


• $R = 20$ m, $e_{y,ss} \approx 0.2$ m



4. Test results

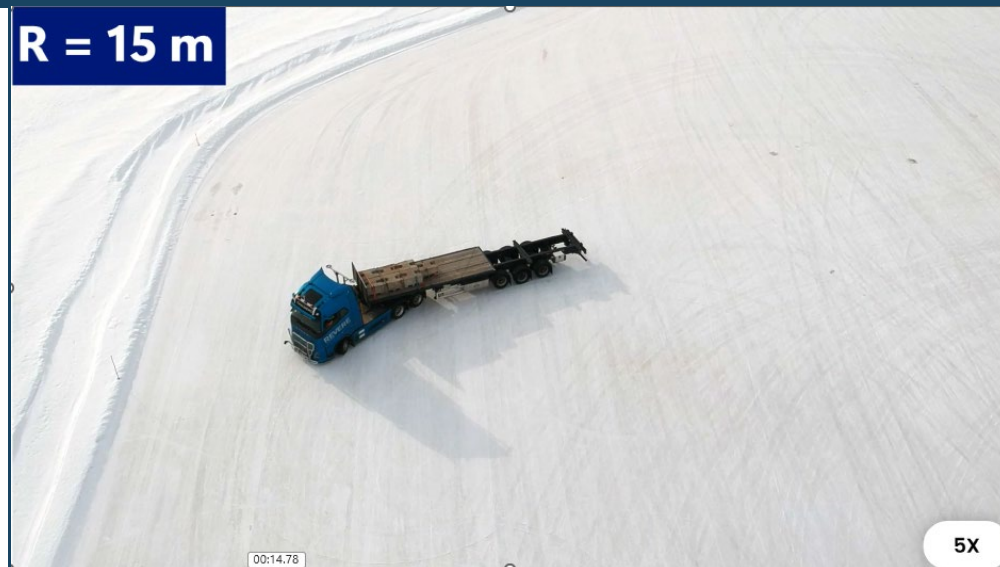
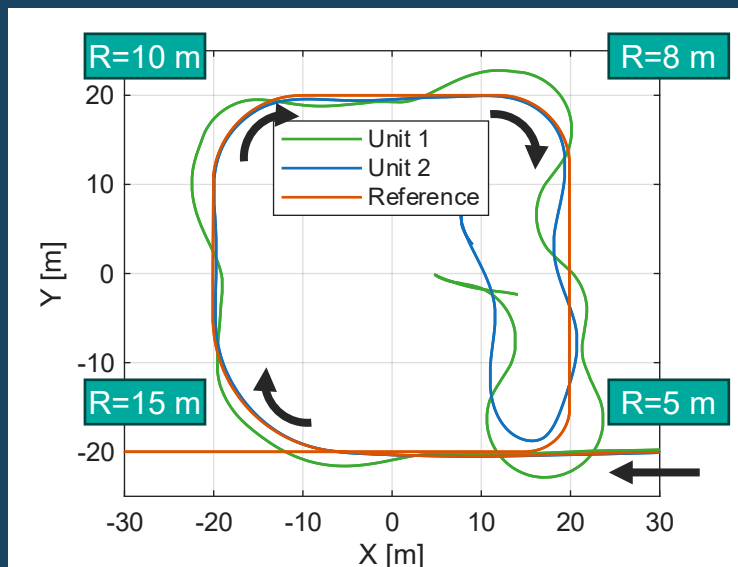
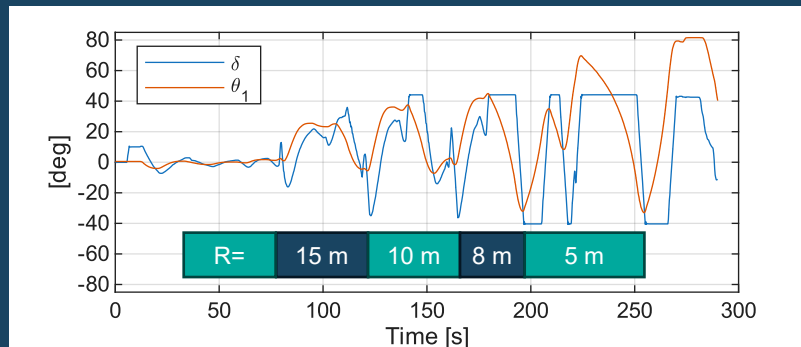
Tractor Trailer, Figure 8 (8 m), 1 m/s



5x

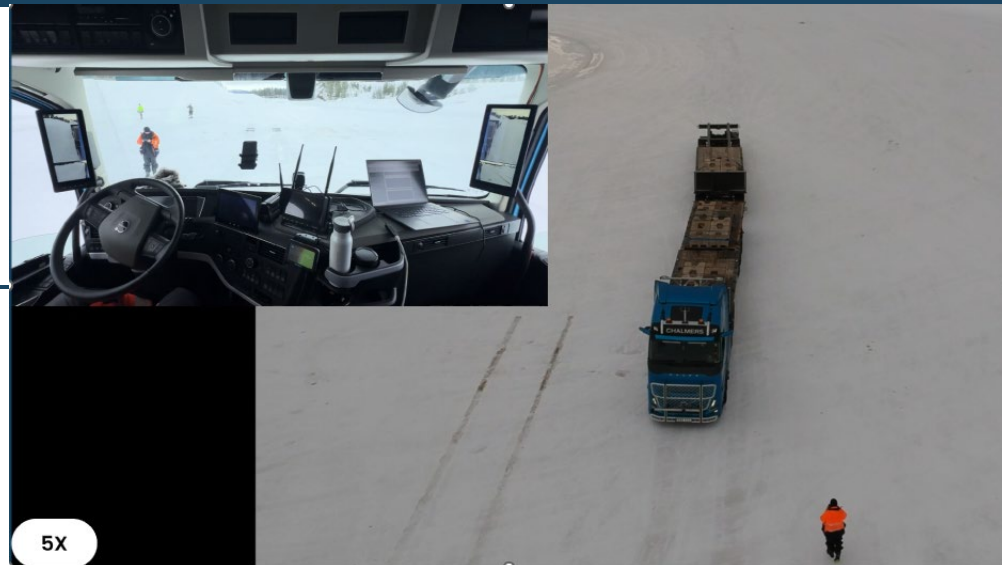
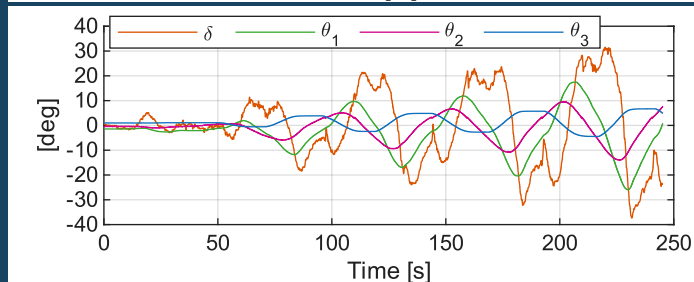
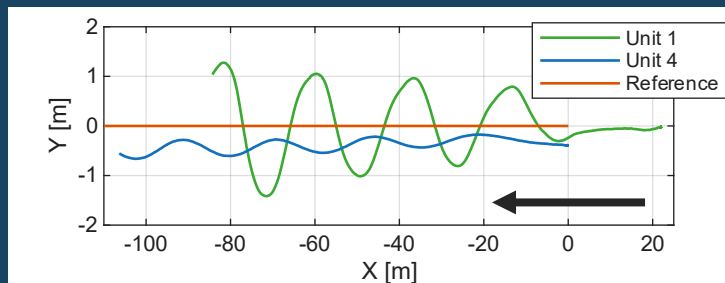
4. Test results

Tractor Trailer,
90-degree turn (15, 10, 8, 5 m), 1 m/s



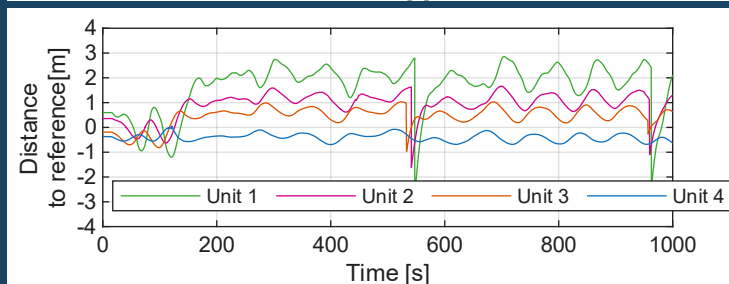
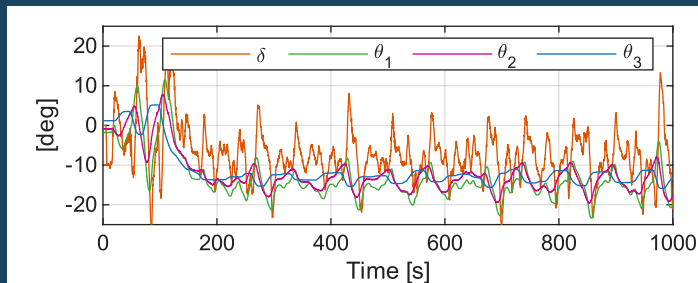
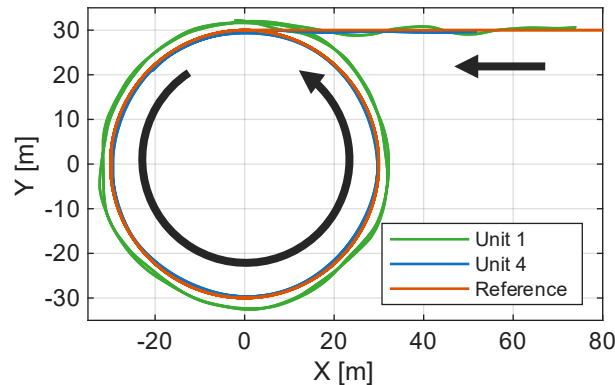
4. Test results

A-Double, Straight line, 0.5 m/s



4. Test results

A-Double, Constant radius (30 m),
0.5 m/s

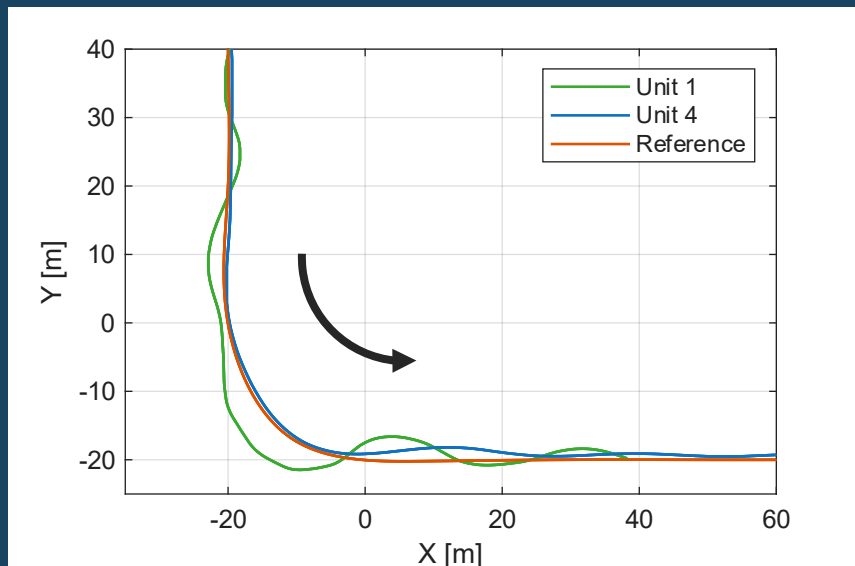


5X

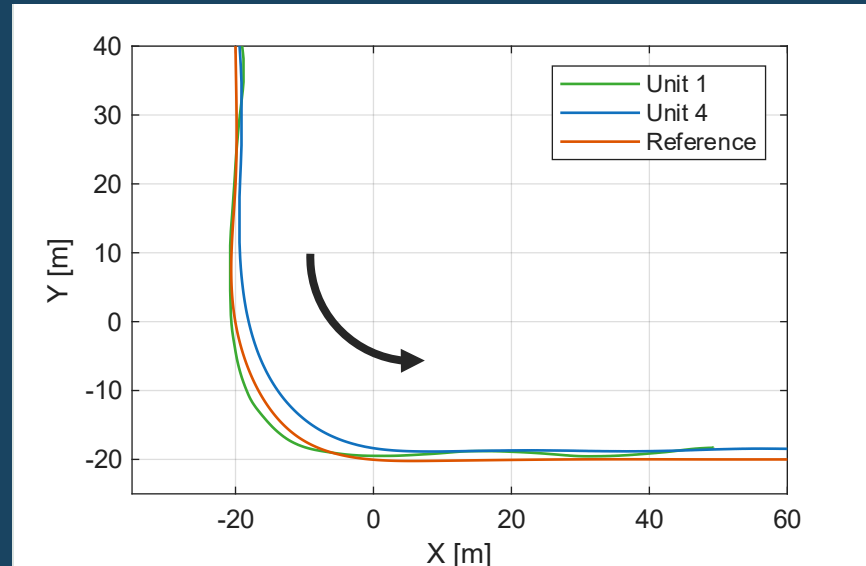
4. Test results

A-Double, 90-degree turn (20 m), 0.5 m/s

• $l_a = 11.55$ m



• $l_a = 15.40$ m

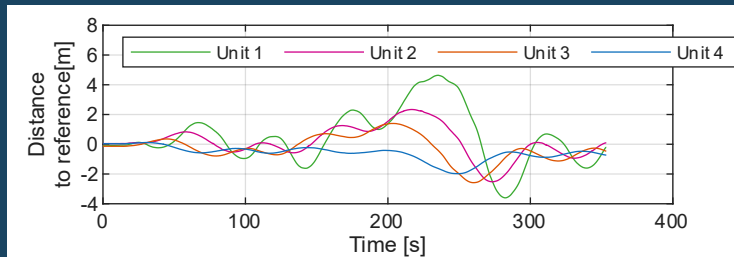


4. Test results

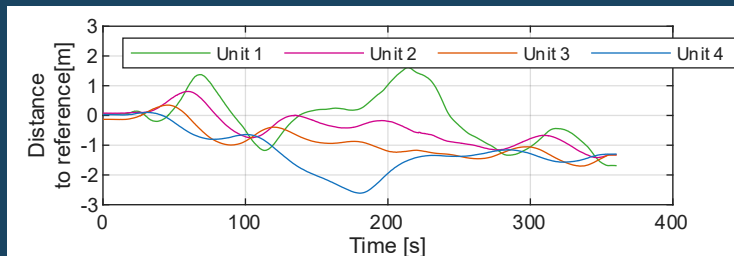
A-Double, 90-degree turn (20 m), 0.5 m/s

• $l_a = 11.55$ m

• $l_a = 15.40$ m



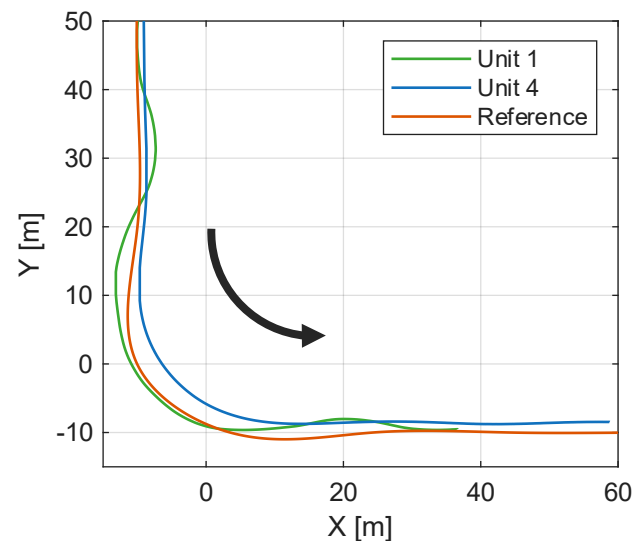
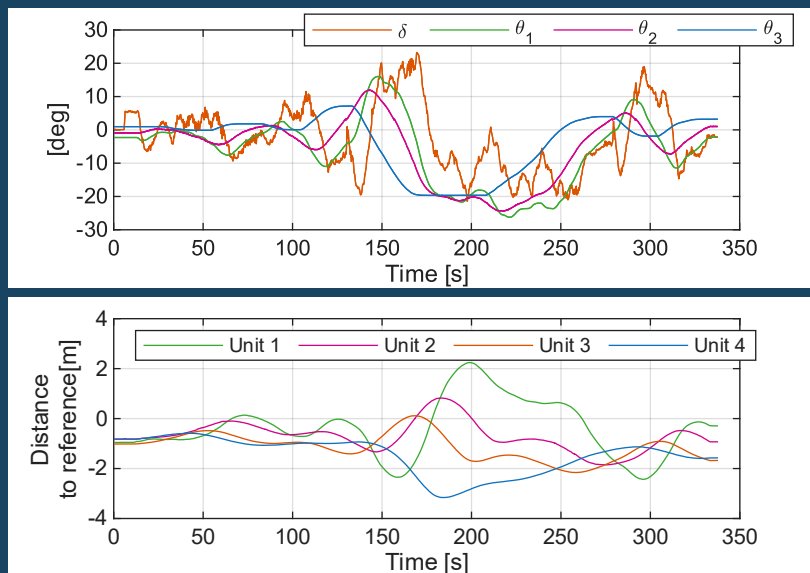
• $l_a = 15.40$ m



5X

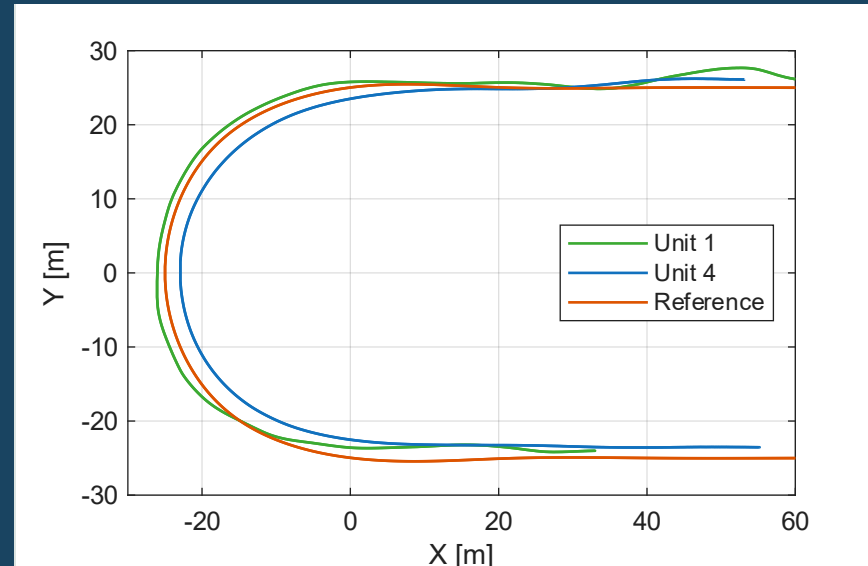
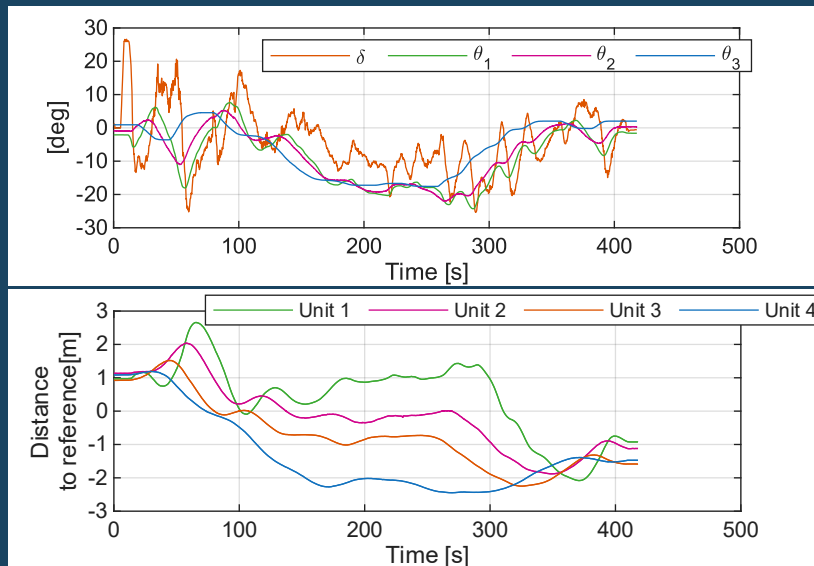
4. Test results

A-Double, 90-degree turn (10 m), 0.5 m/s



4. Test results

A-Double, U-turn (25 m), 0.5 m/s

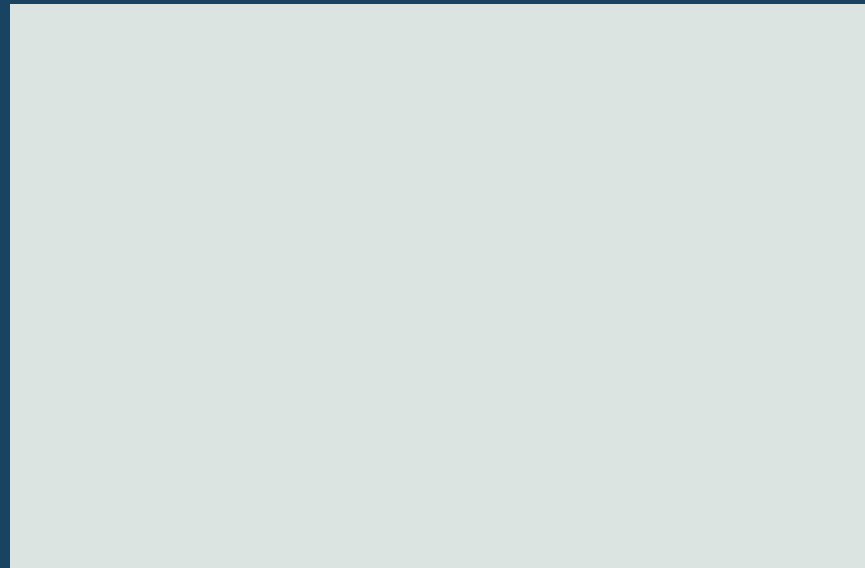


5. Future work

To be tested in June

Bi-directional controller

Performance under different conditions



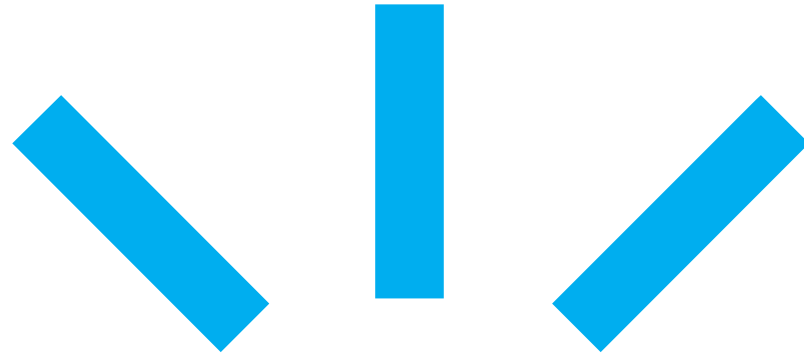


CHALMERS
UNIVERSITY OF TECHNOLOGY

Presentation 4:

***On the performance of heavy vehicle tyres on
the winter roads***

Miro-Tommi Tuutijärvi, University of Oulo,
Uleåborg, Finland



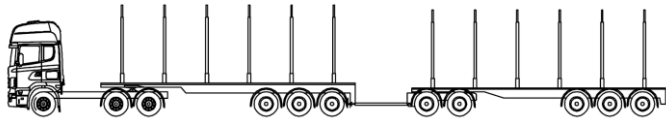
On the performance of heavy vehicle tyres on the winter roads - E! SafeTrucks tyre measurements 2024-2026

20.5.2026 – Miro-Tommi Tuutijärvi

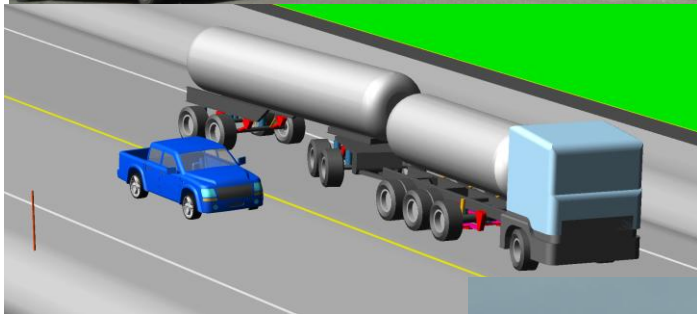
Machine and Vehicle Design (MVD) – University of Oulu



Background



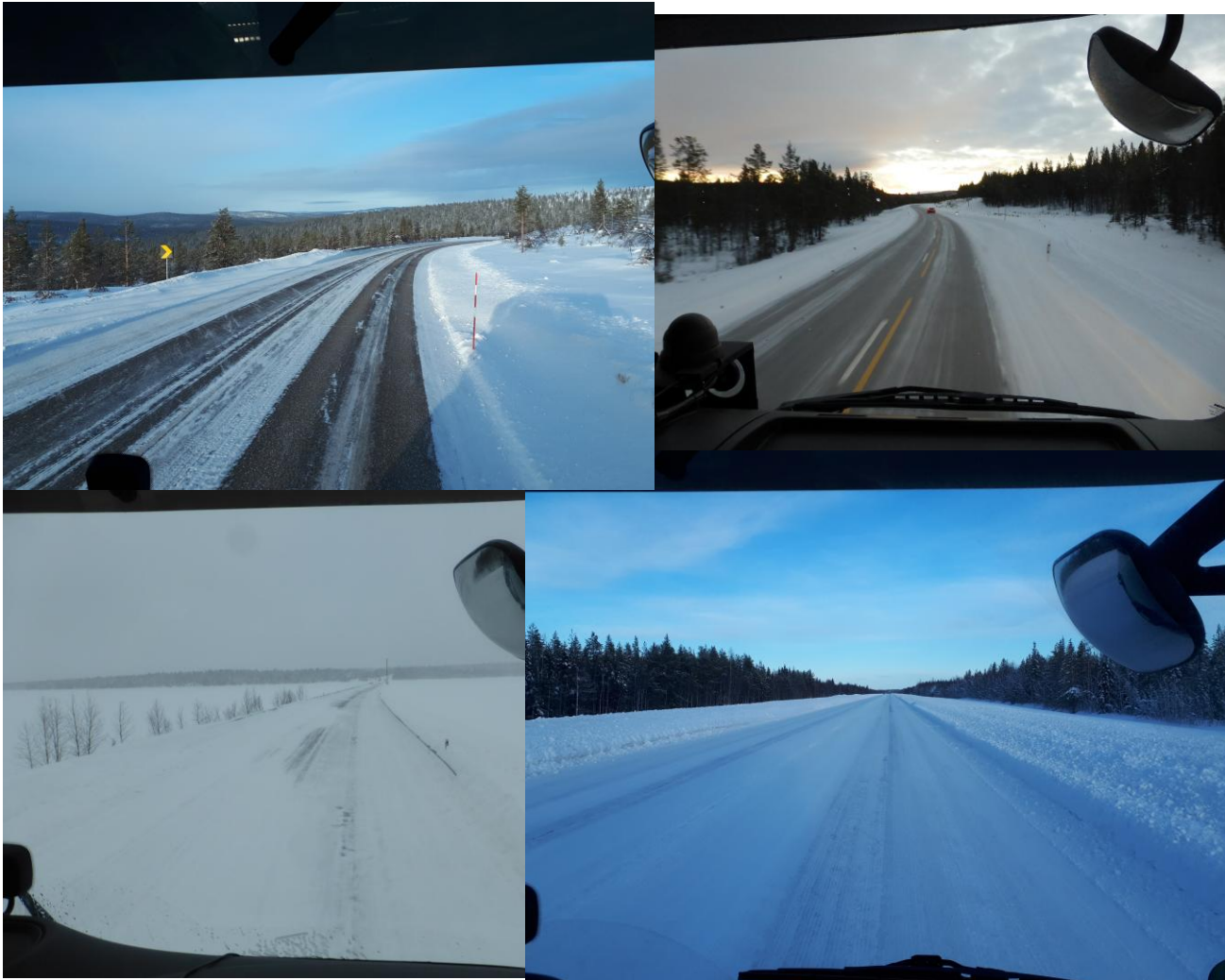
First Finnish HCT full-scale vehicle tests in Lappeenranta (2013)!



- Driving dynamics simulations started in larger scale with lateral and roll stability studies of heavy commercial vehicle (HCV) combinations with Finland's HCT trials in 2013
- First full-scale vehicle tests were followed by simulation studies when transport companies started to apply for HCT trial permits which then led to vehicle combination dimensioning studies
- Tire models were required for simulations and following first measurements done by 3rd parties and model fits, interest towards tires and their performance increased
- This resulted in the desire to develop own testing equipment capable of measuring heavy vehicle tyre forces in their typical usage



Introduction



- In northern countries, winter season brings significantly varying driving conditions
- The effect of tyre performance is emphasized with long heavy vehicle combinations due to interaction of several units with multiple axles.
- Quantifying tyre performance on various winter road conditions is not an easy task, as both are complex systems
- Considering these points, mobile approach to tyre force measurement equipment was selected and resulted in the Tyre Testing Trailer (TTT)
- In the E! SafeTrucks project, TTT has been utilized to gather tyre performance data on wide variety of road conditions



Tested Tyre set

No	Size and LI	Position	Type	Name	Rim	Inflation (bar)	Load 1 (kg)	Load 2 (kg)	Load 3 (kg)	Load 4 (kg)	Speed (km/h)	Slip [%]	Slip angle	“Nominal load [kg]”	2024	2025	2026
1	315/70R22.5 156/150L	S	Winter	S1	9.00	9.0	2000	3250	4500		15	0...-100	± 15°	4000	X	X	X
2	315/70R22.5 156/150L	S	Allseason	S2	9.00	9.0	2000	3250	4500		15	0...-100	± 15°	4000		X	X
3	315/70R22.5 154/150L	D	Winter	D1	9.00	8.0	1000	2000	3000	4000	15	0...-100	± 15°	2500	X	X	X
4	315/70R22.5 152/148M	D	Allseason	D2	9.00	8.0	1000	2000	3000	4000	15	0...-100	± 15°	2500	X	X	X
5	275/70R22.5 148/145L	T	Allseason	T1	8.25	9.0	1000	2000	3000	4000	15	0...-100	± 15°	2500		X	X
6	385/55R22.5 160K	ST	Winter	ST1	11.75	9.0	1000	2500	4000	5000	15	0...-100	± 15°	4500	X	X	X
7	385/55R22.5 160K	ST	Winter studded	ST1 S	11.75	9.0	1000	2500	4000	5000	15	0...-100	± 15°	4500	X	X	
8	385/55R22.5 160K	ST	Winter	ST2	11.75	9.0	1000	2500	4000	5000	15	0...-100	± 15°	4500		X	X
9	385/55R22.5 160K	ST	Allseason	ST3	11.75	9.0	1000	2500	4000	5000	15	0...-100	± 15°	4500			X
10	385/55R22.5 160K	ST	Allseason	ST4	11.75	9.0	1000	2500	4000	5000	15	0...-100	± 15°	4500		X	X
11	385/55R22.5 160K Worn	ST	Winter	ST1W	11.75	9.0	1000	2500	4000	5000	15	0...-100	± 15°	4500			X
12	385/55R22.5 160K Worn	ST	Allseason	ST3W	11.75	9.0	1000	2500	4000	5000	15	0...-100	± 15°	4500			X



Test location and conditions



- Tests done at Pudasjärvi airport (EFPU)
 - Full runway length 2,12 km, width 50 m
- Between weeks 6 and 10 from 2024 to 2026
- Temperature ranges from -31°C to $+3^{\circ}\text{C}$



Tyre Testing Trailer (TTT)

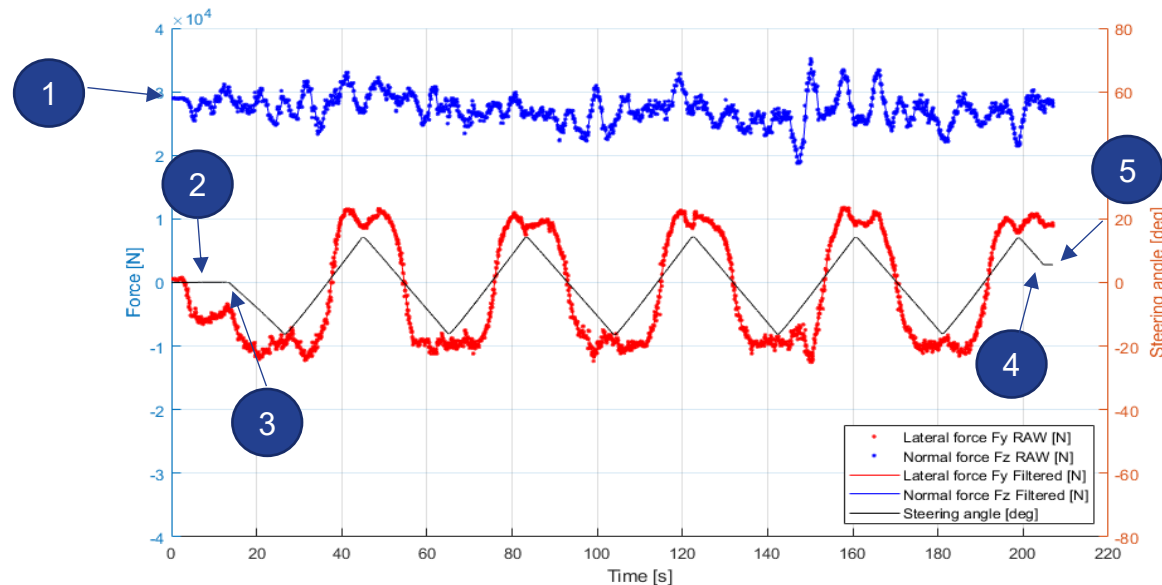
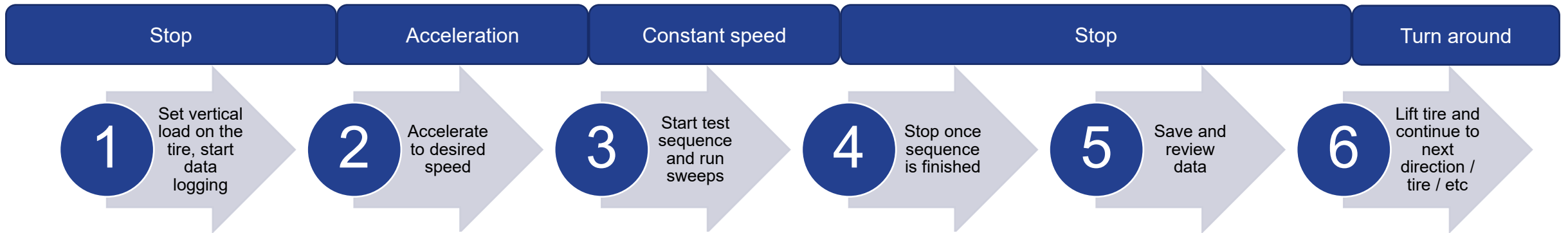


- Specifications:
 - Rim sizes 19,5" ja 22,5"
 - Wheel diameter 800-1300 mm
 - Tire width up to 455 mm
 - Wheel load up to 60 kN
 - Steering angle ± 45 degrees
 - Camber angle ± 10 degrees
 - Maximum braking moment 25 kNm
- Tire forces and moments calculated from strain gage measurements from rods holding the measuring hub
- Other measurements, including but not limited to:
 - Wheel speeds
 - Measured tire steering angle and height
 - RTK GPS for improved slip angle and trailer speed estimation
 - Sisu equipped with optical friction meter for friction estimation, surface and ambient temperature



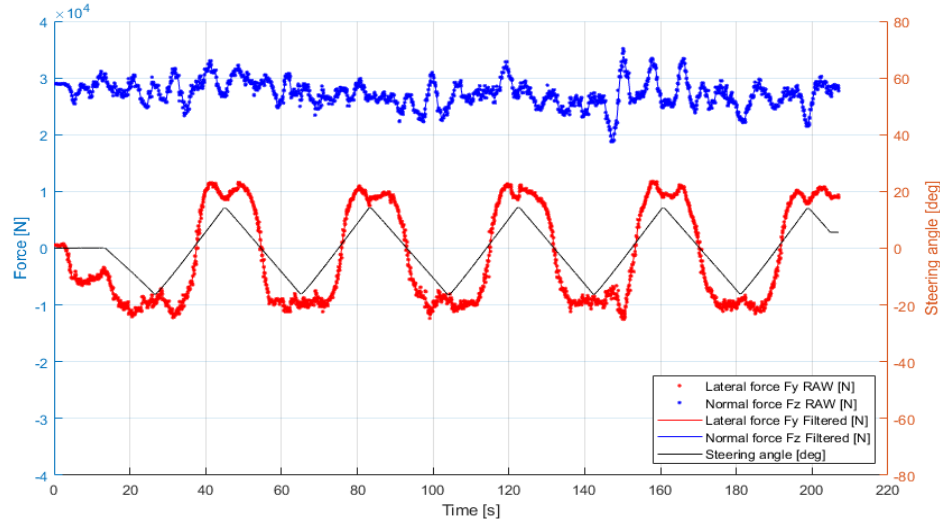
Measurement procedure (Pure lateral slip, F_y)

*Tests are usually run on two directions to use time efficiently

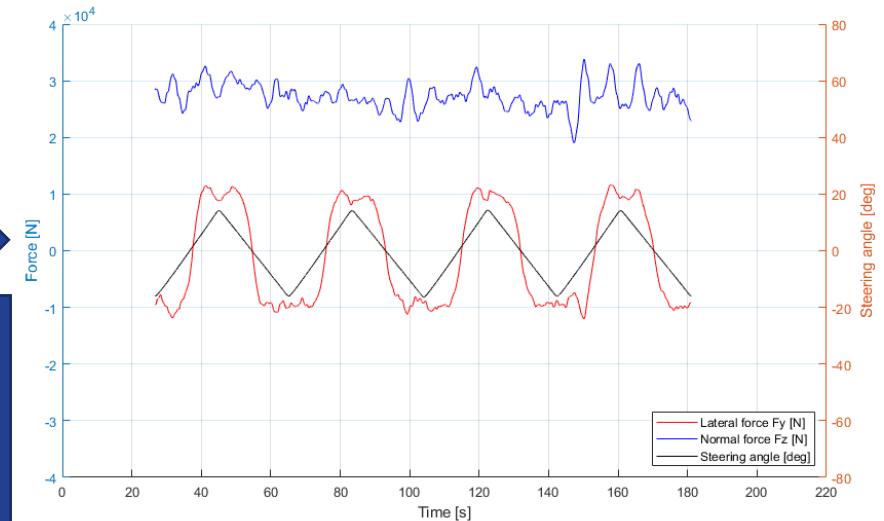




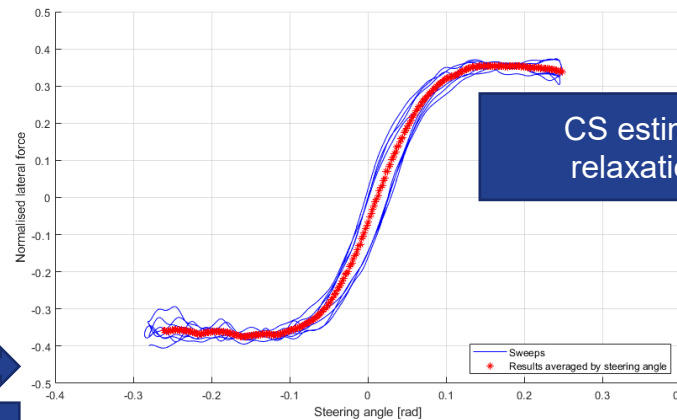
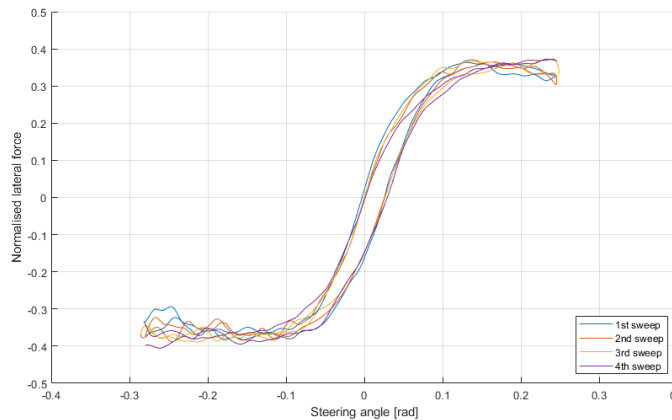
Processing F_y measurement data



- Filter raw data
- Snip filtered data from first minimum to last minimum

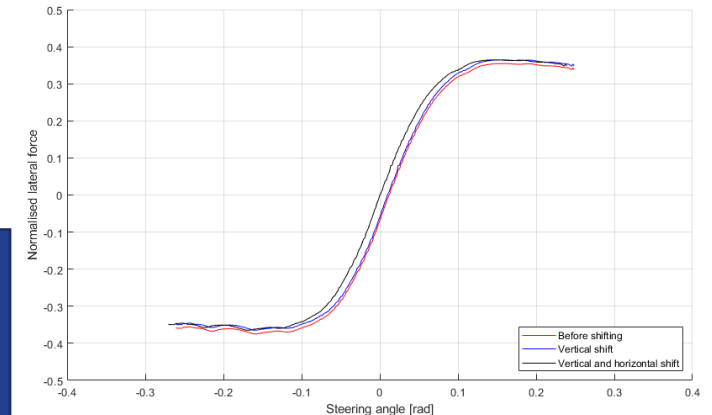


- Separate test cycle to individual sweeps
- Normalized lateral force (F_y/F_z) against steering angle



CS estimate after relaxation comp.

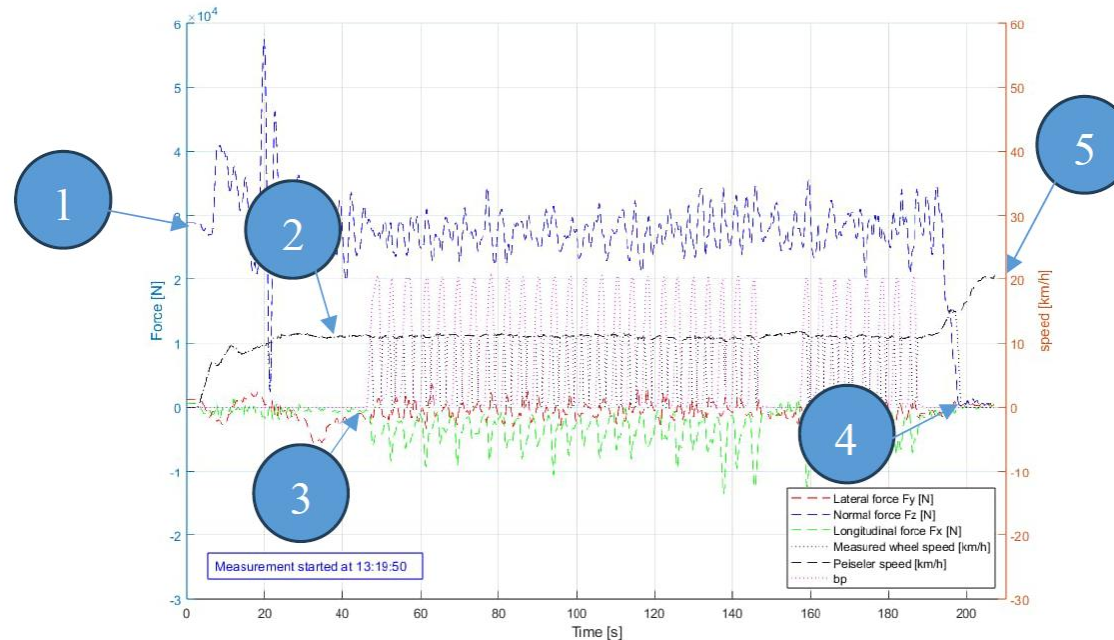
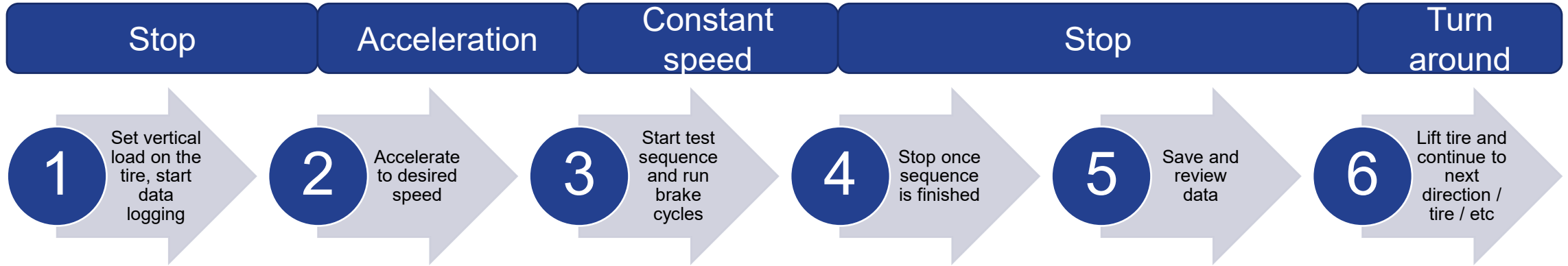
Horizontal and vertical shifts if needed



Average by steering angle to compensate the relaxation length

Measurement procedure (Pure longitudinal slip, F_x)

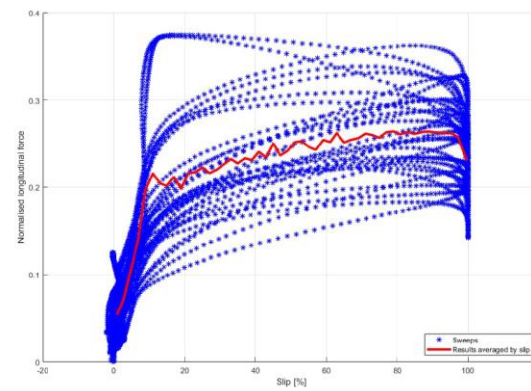
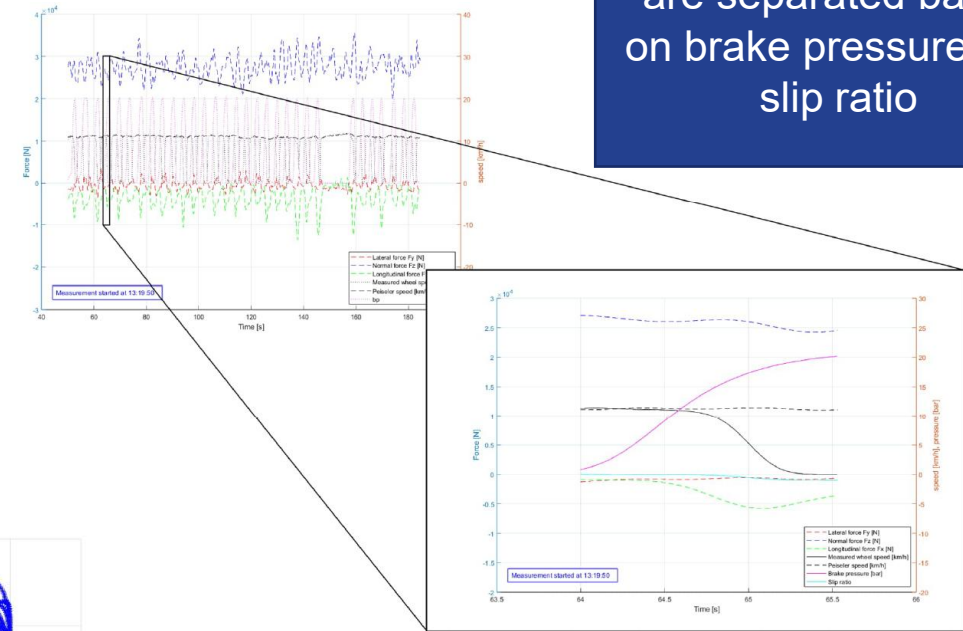
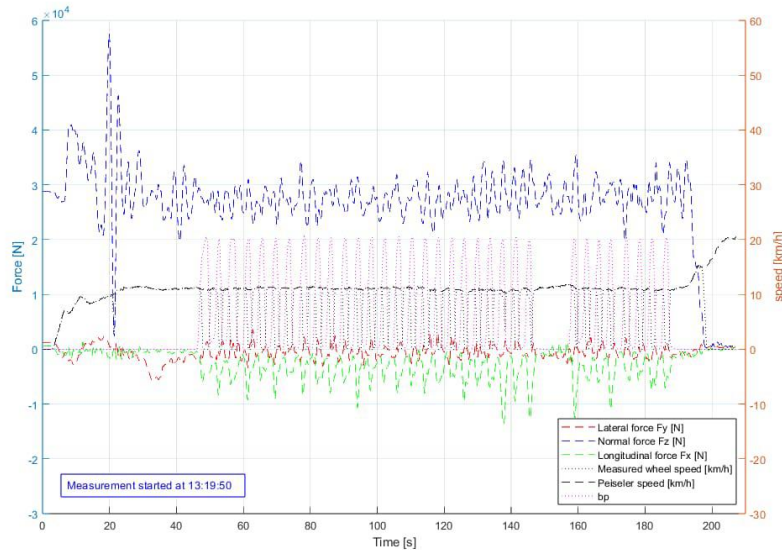
*Tests are usually run on two directions to use time efficiently



Processing F_x measurement data

Individual brake cycles are separated based on brake pressure and slip ratio

Snip filtered data from first brake pressure minimum to last minimum



- Normalized F_x (F_x/F_z) of brake cycles is plotted against slip %
- Results from individual cycles are averaged by slip ratio for longitudinal slip curve



2024 measurements and results



– Week 6

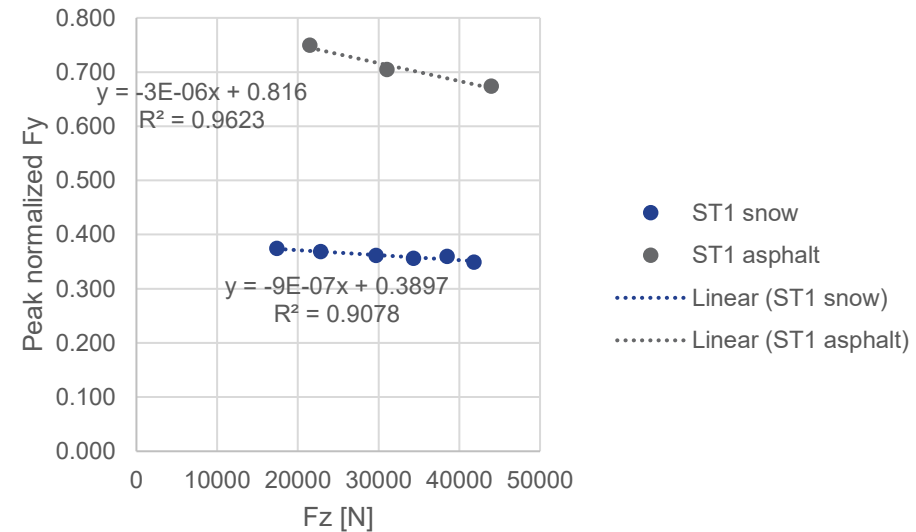
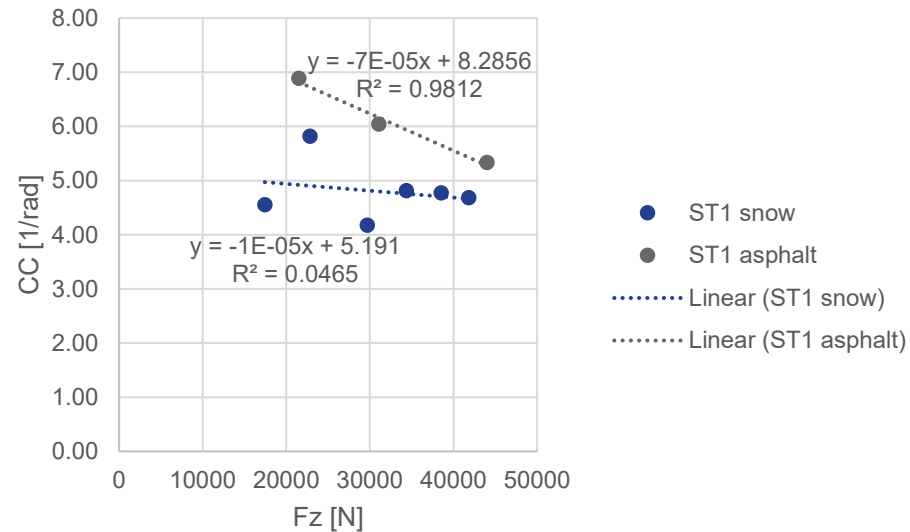
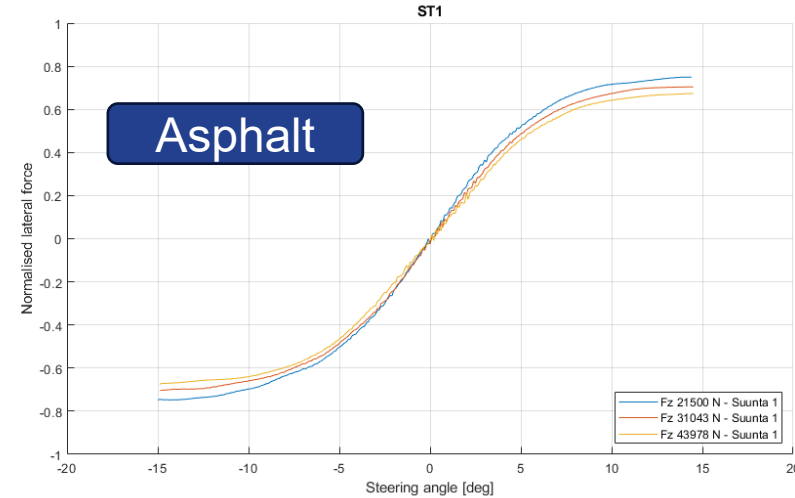
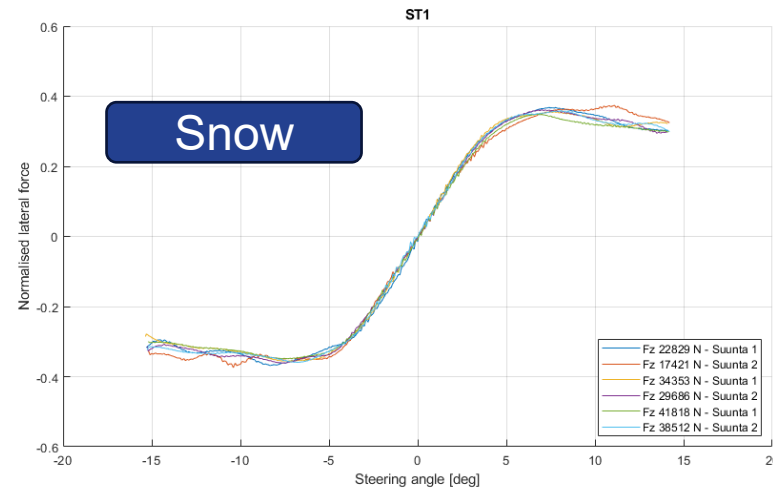
- Hard packed snow
- Limited tyre set
- First runs with updated brake setup
- Running time limited due to harsh temperatures
 - Daytime temperatures around -25°C , nighttime and morning temperatures under -30°C

– Week 10

- Asphalt
- Temperatures around 0°C , was not possible to freeze an ice surface



2024 measurements and results





2025 measurements and results



– Week 6

- Hard packed snow and icy hard packed snow
- Temperatures in suitable range
- Limited testing time due to excessive snowing
- First braking pilot with multiple heavy vehicles and vehicle combinations

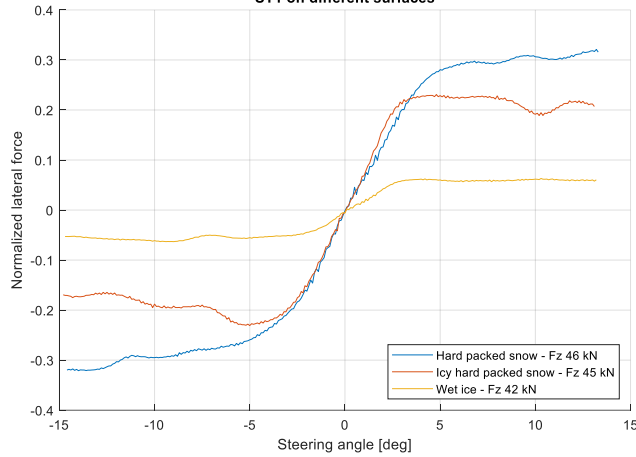
– Week 9

- Wet ice
- Temperatures above 0 °C
- Testing limited to 1½ days due to ice softening

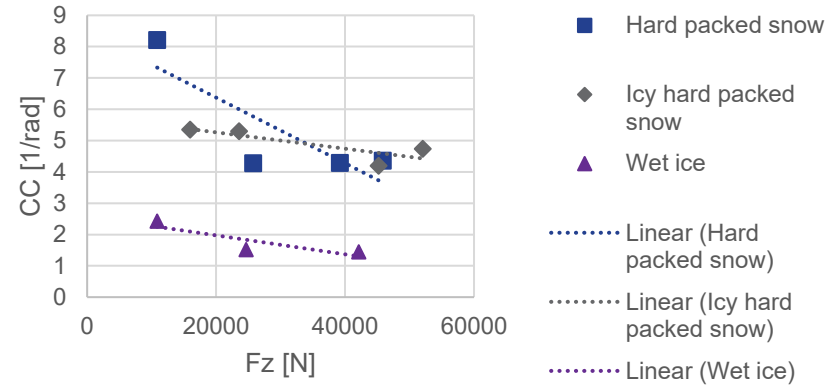


2025 measurements and results

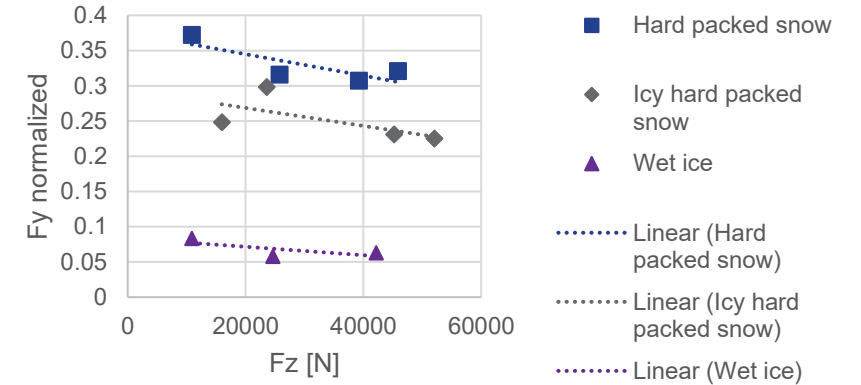
ST1 on different surfaces



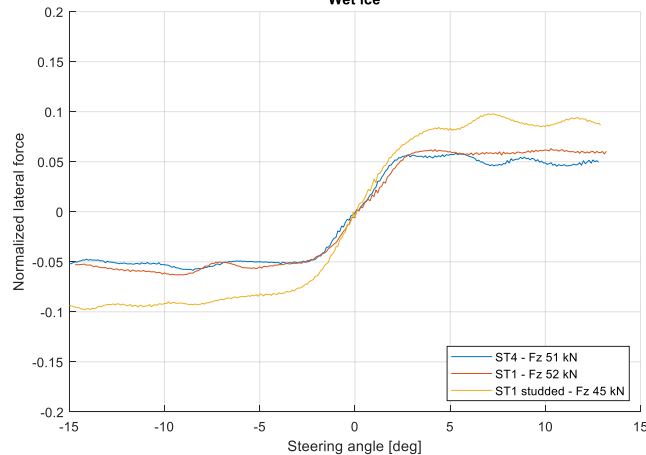
CC



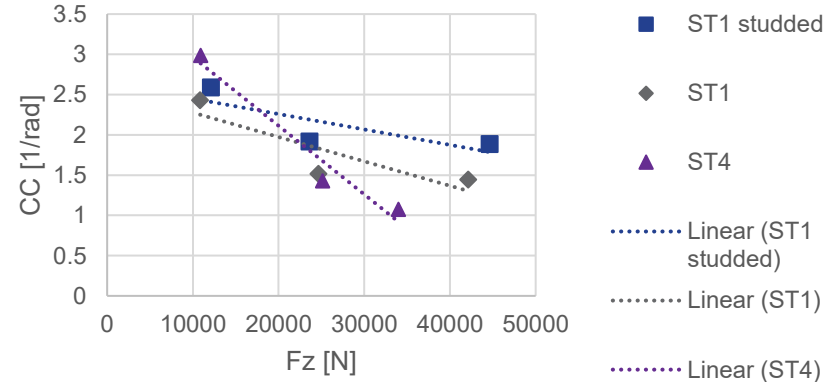
μ peak



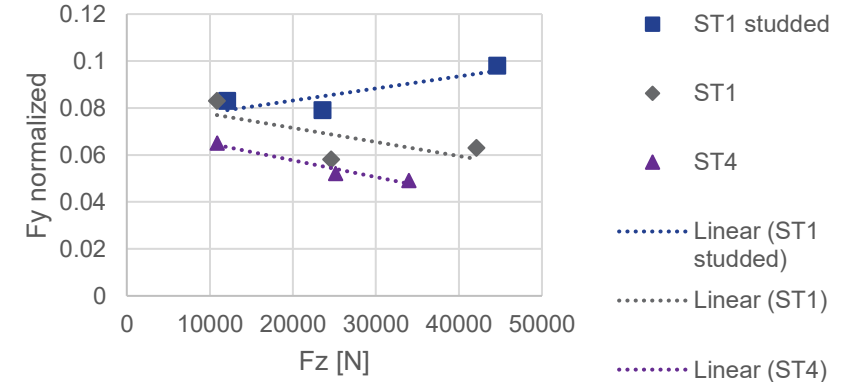
Wet ice



CC



μ peak





2026 measurements and results



– Week 6

- Hard packed snow, groomed after each day
- Good measurement conditions
- Pure lateral and longitudinal measurement for full tyre set

– Week 7

- SafeTrucks pilot demonstration with braking distance demonstrations

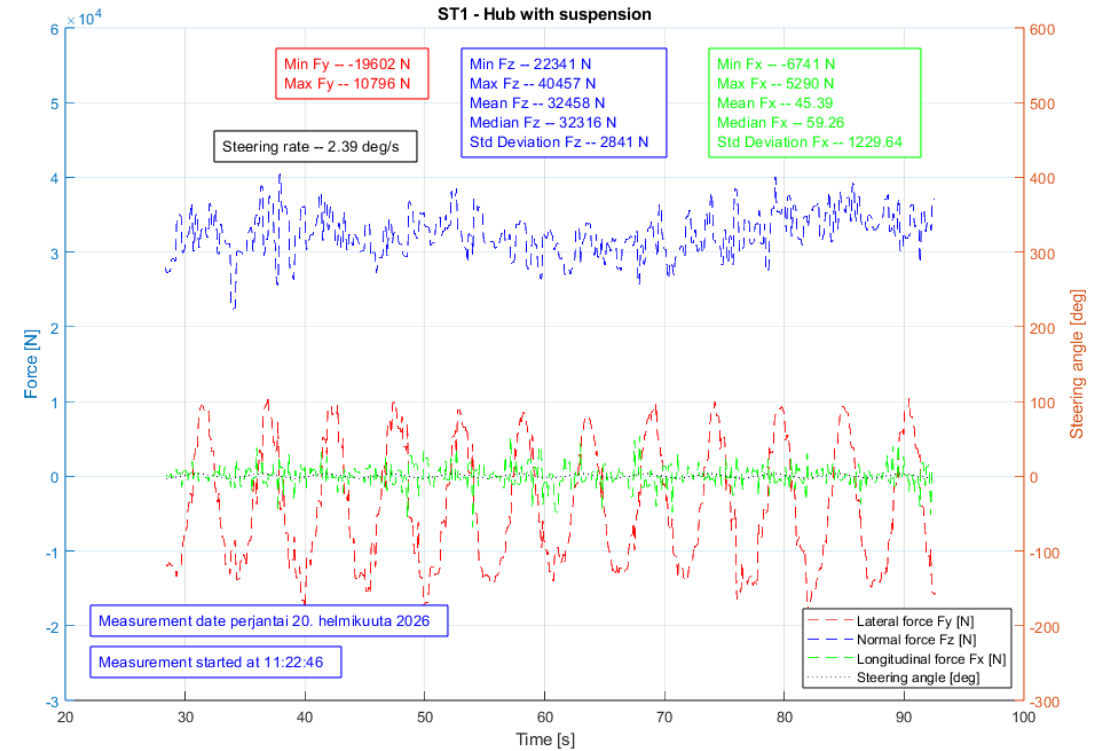
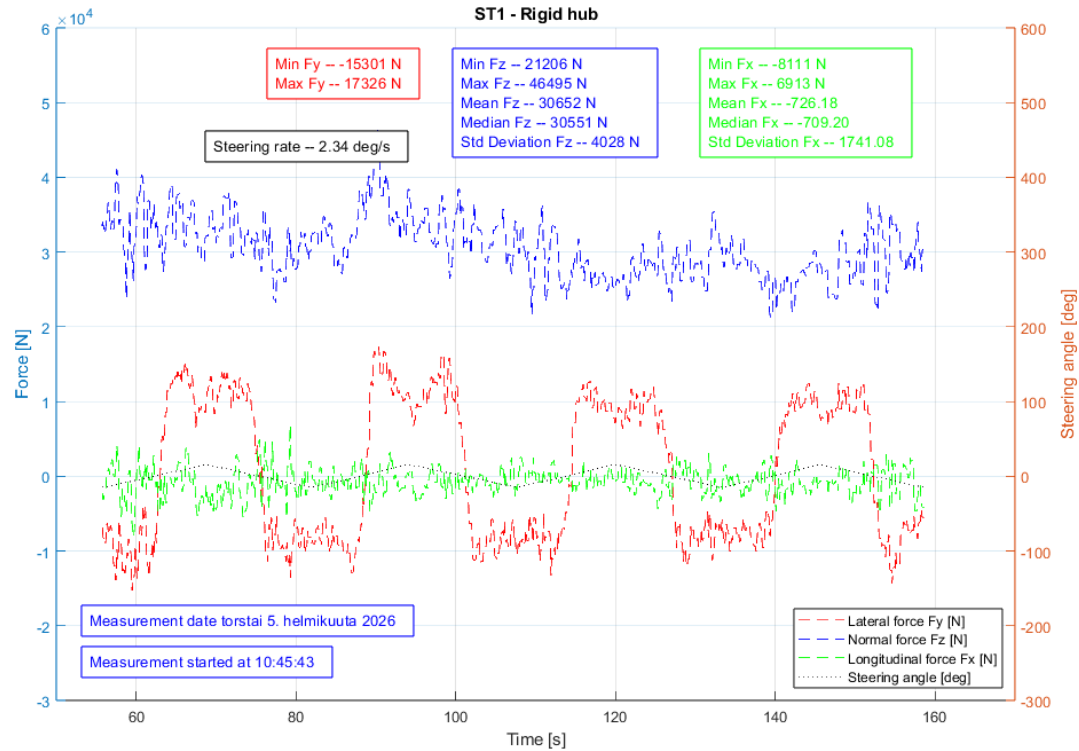
<https://www.youtube.com/watch?v=OpoZWqqDYeg>

– Week 8

- Testing new suspension setup for TTT



2026 measurements and results





Conclusions 1/2



- Winter seasons vary a lot and planning outdoor testing can be challenging and it affects road transport in general
- For these measurements, weather conditions limited testing but gave a good opportunity to measure tyres in highly varied road conditions
 - Wet Ice, icy hard packed snow, hard packed snow and cold asphalt
- Upgrades on the measuring equipment performed in satisfactory level



Conclusions 2/2



- On-going activities now:
- Reviewing all the measurement data
- Pure longitudinal slip measurement data processing and relaxation compensation
- Tyre model fitment to measurement data
 - Aim is to produce generalized tyre models for different road conditions and use cases
- Continue improving slip angle estimation with RTK GPS data



Acknowledgements



BUSINESS
FINLAND



National Research
Council Canada

Conseil national de
recherches Canada

<https://safetrucks.fmi.fi/>



**Thank you for your
attention!**



Presentation 5:
***Potential customer benefits of Torque
Vectoring in Heavy Commercial Vehicles,***
Jolle Ijkema, Scania



POTENTIAL CUSTOMER BENEFITS OF TORQUE VECTORING IN HEAVY COMMERCIAL VEHICLES

JOLLE IJKEMA, PROPERTY OWNER HANDLING & STEERING

20+10 MINUTES



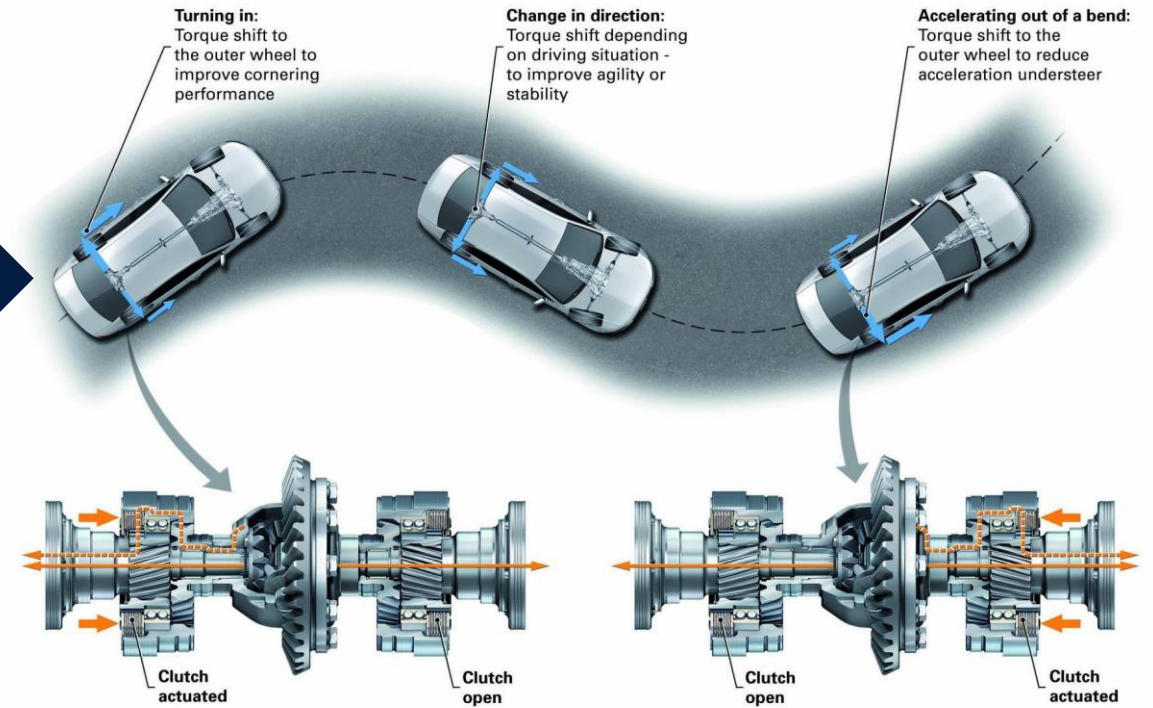
Torque vectoring



Audi S4

quattro with Sport differential: Operating principle

10/08



Elon Musk is challenging us: "Jack-knifing is impossible"



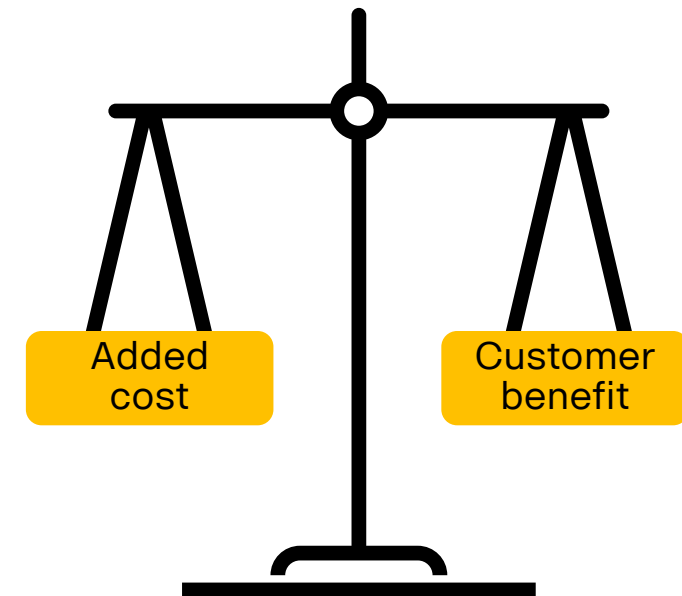


Opportunities increase with introduction of BEVs

Concept	L/R Torque Vectoring	Efficiency	Cost	Complexity
Brake-based	Yes (indirect)	Low	Low	Low
Single motor + TV diff	Yes	Medium	Medium	Medium
Dual-motor AWD	F/R only	High	Medium	Medium
Two motors per axle	Yes	High	High	High
Quad-motor	Yes (max)	High	Very High	Very High

Potential benefits?

- Improved turning radius at low speeds
- Understeer control at low friction
- Oversteer prevention (pro-active Jack-knife prevention)
- Oversteer control at low friction (reactive Jack-knife prevention)
- LKA w/o steering input
- High speed RBS for autonomy
- Side wind / road camber compensation
- Uphill driving on slippery curvy road





SIMULATION MODELS

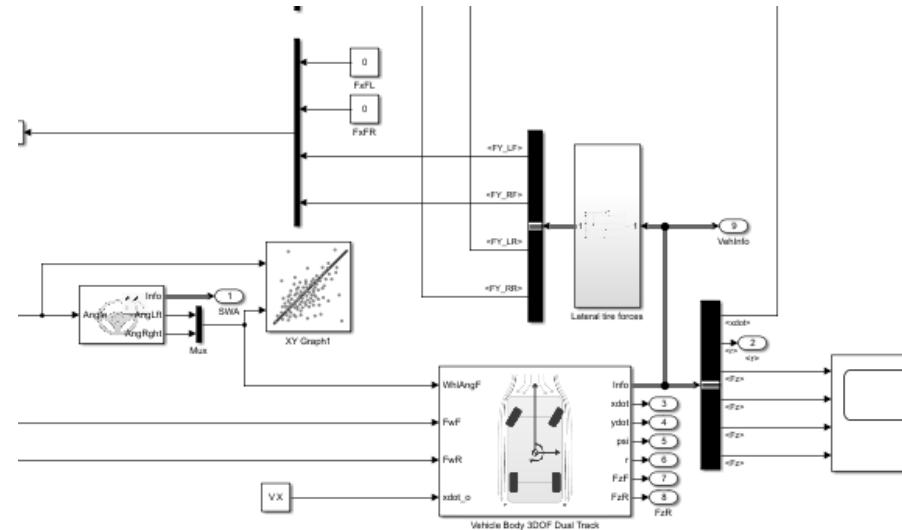
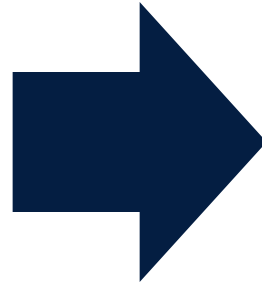
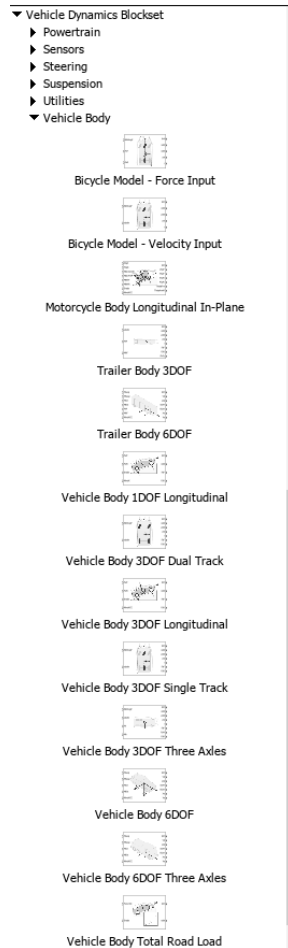


Base line vehicle

- Scania B4x2 (RWD)
- Wheelbase 4950 mm
- Axle loads:
 - 6976 kg
 - 11020 kg
- Speed range 10 km/h – 90 km/h



Simulation tools – Simulink Vehicle Dynamics blockset

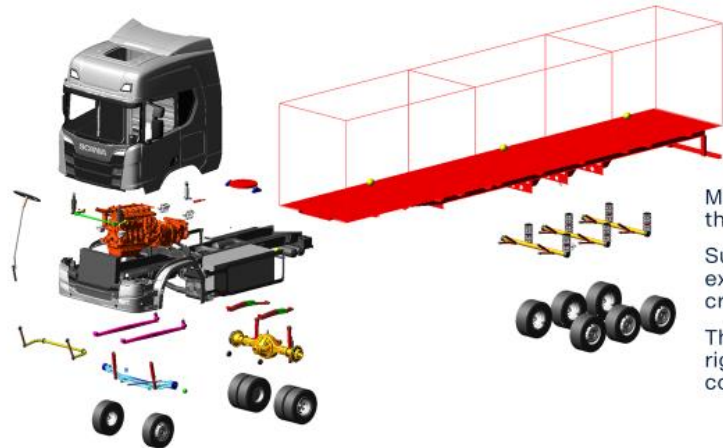


- Fast (~0.2s per second)
- Customizable
- Lo-Fi
- Generic vehicle – not a Scania

Simulation tools – Simulink with ADAMS FMU



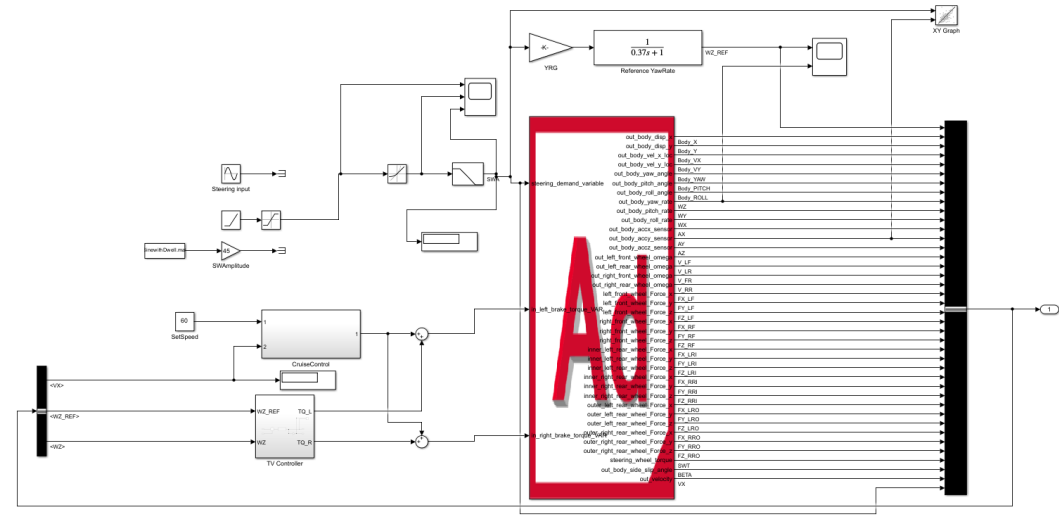
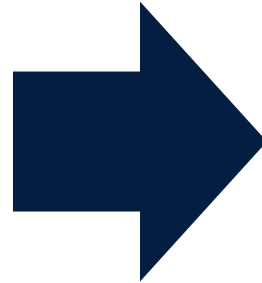
Subsystems in Adams/Car



Models are built and analysed in the software Adams/Car

Subsystems can easily be exchanged and combined to create many variants of vehicles

The models mainly consist of rigid bodies connected with constraints and force elements



- Slower (~10s per second)
- ADAMS Model parameters are fixed
- Hi-Fi
- Accurate Scania model from ADAMS



SELECTED FEATURES

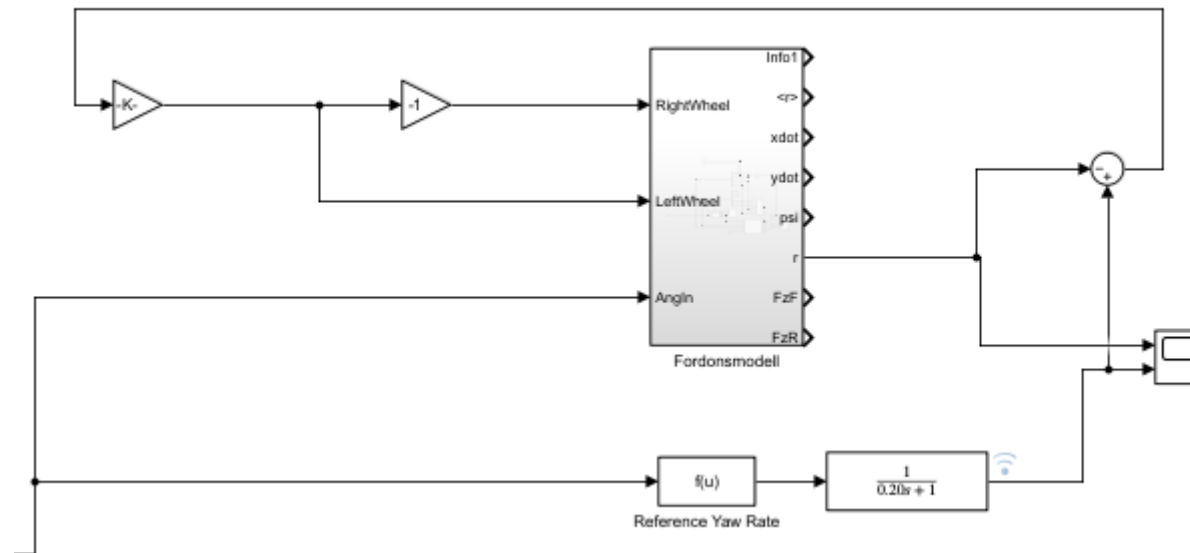


Understeer mitigation



Understeer at low- μ

- Feed-back controller TV-torque from deviation from desired reference yaw rate
- Simulink VDL model with low- μ tyres
- Open loop Sine wave input at 60 km/h and 0.2 Hz

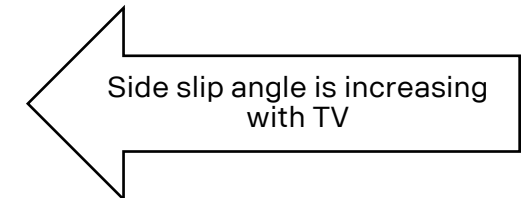
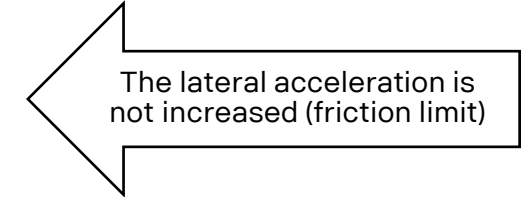
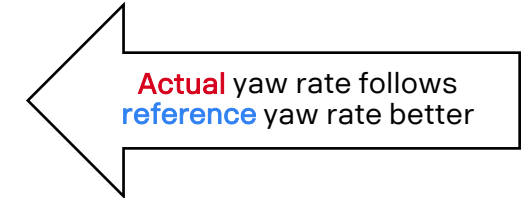


Understeer at low- μ



Base line

With Torque vectoring



- Yaw rate is improved – vehicle turns in well but is still sliding sideways
- Understeer needs speed reduction
- Friction demands at rear axle limiting factor



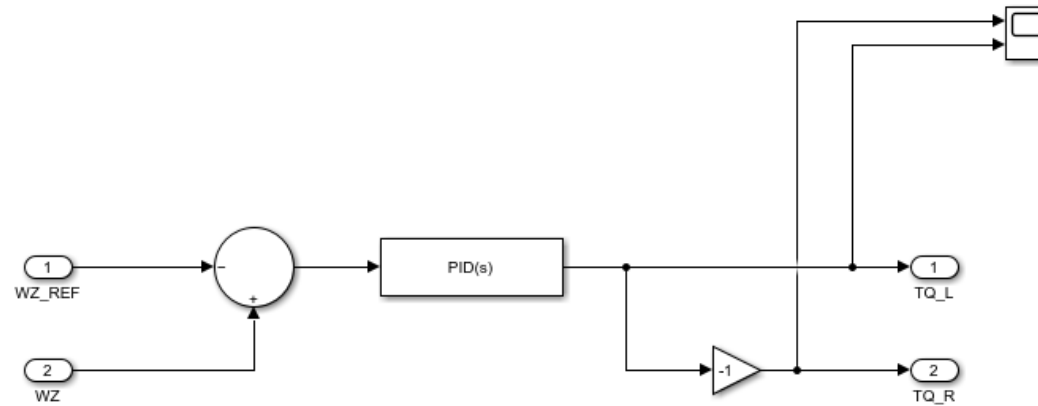
Oversteer control / Anti-jack knife (reactive)



Oversteer control at low friction

(reactive Jack-knife prevention)

- FMU model with feedback control on deviation from reference yaw rate (ESP control)
- Sine with dwell at 90 km/h





Oversteer control at low friction

(reactive Jack-knife prevention)

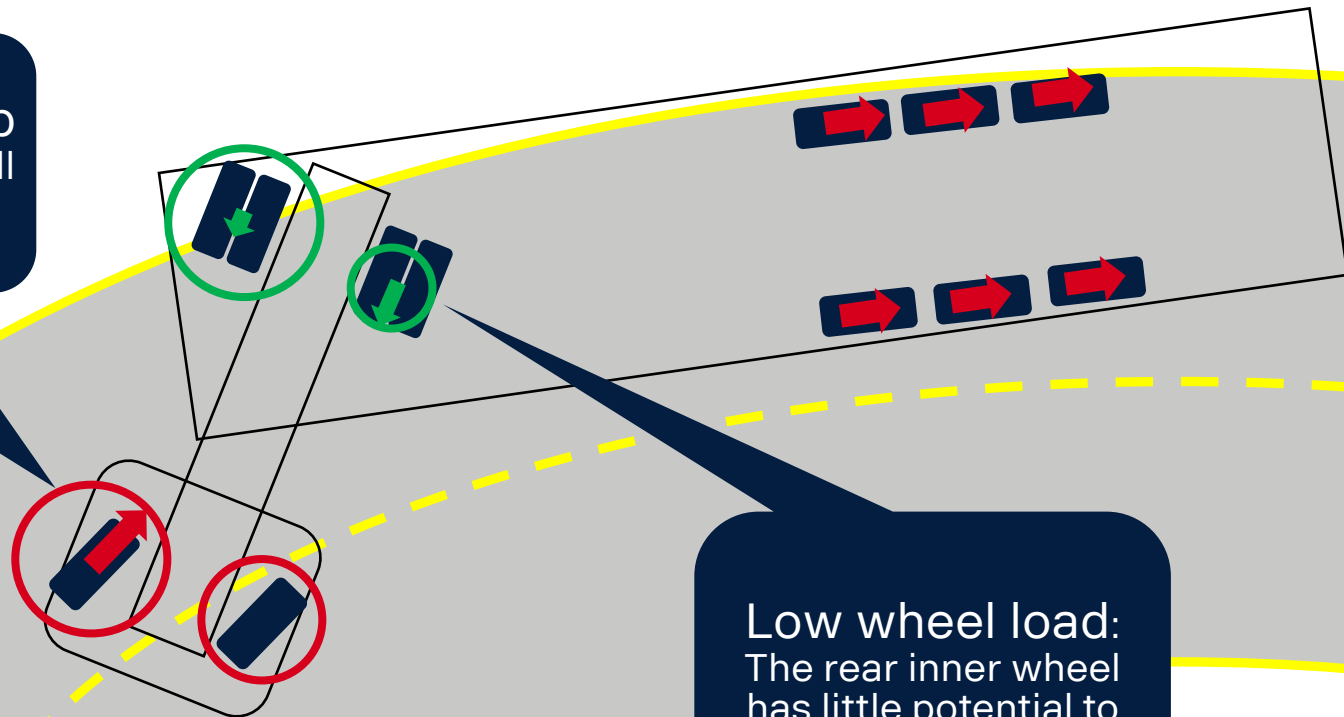
- Little benefit as inner wheel has low vertical load
- ESP that is reacting on the front axle is already effective



Oversteer control at low friction

(reactive Jack-knife prevention)

Front wheel has more grip
: ESP has better potential and will
reduce speed as a bonus



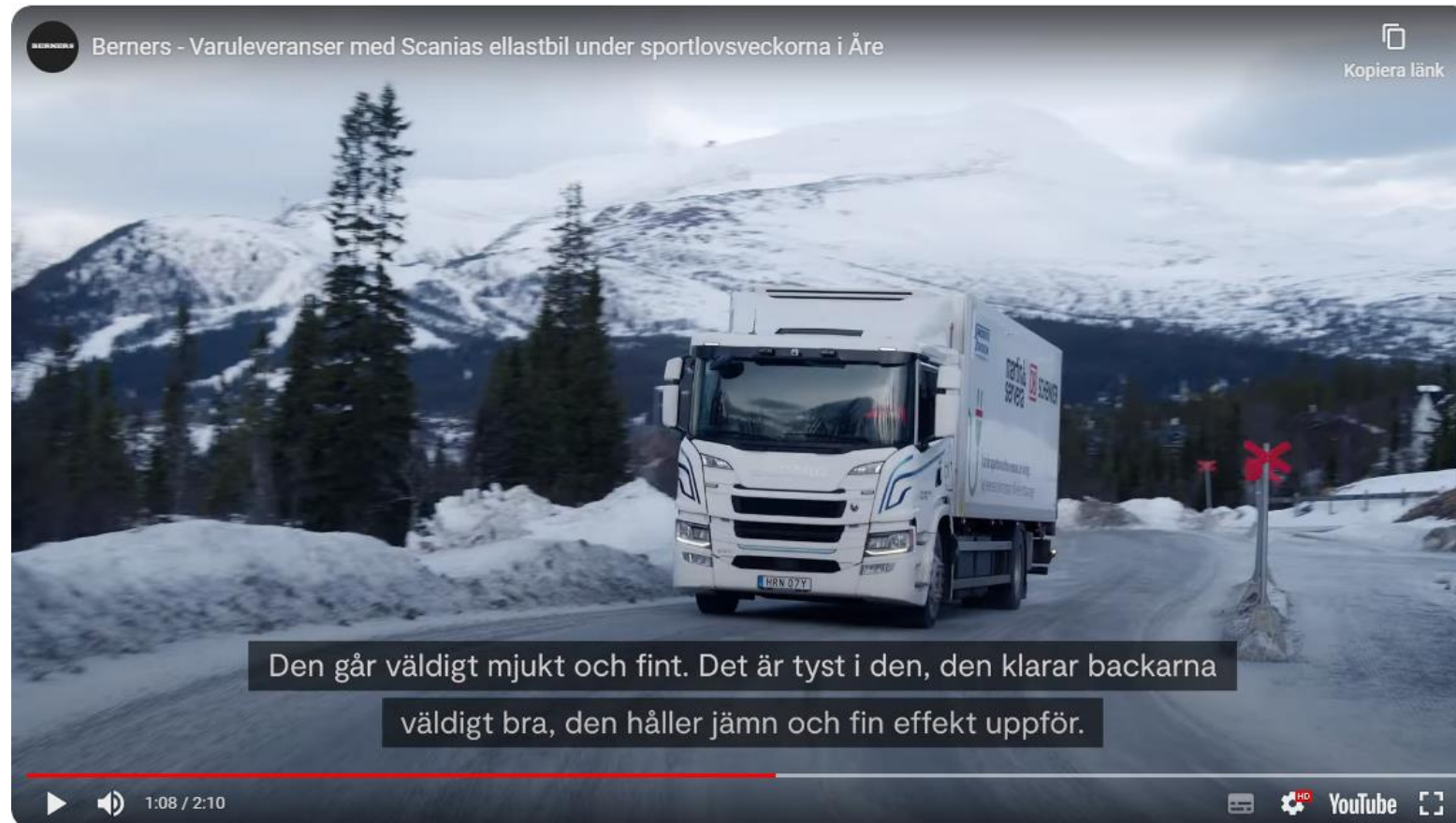
Low wheel load:
The rear inner wheel
has little potential to
generate traction
force



Slippery Slope Traction

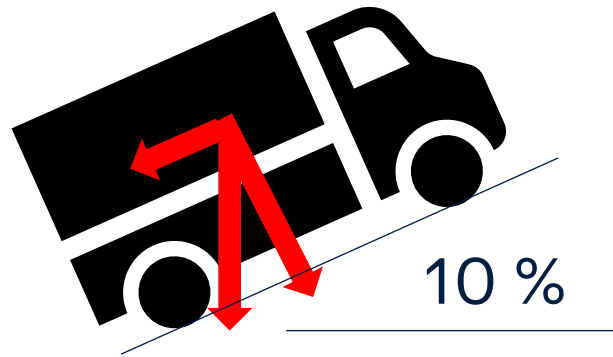


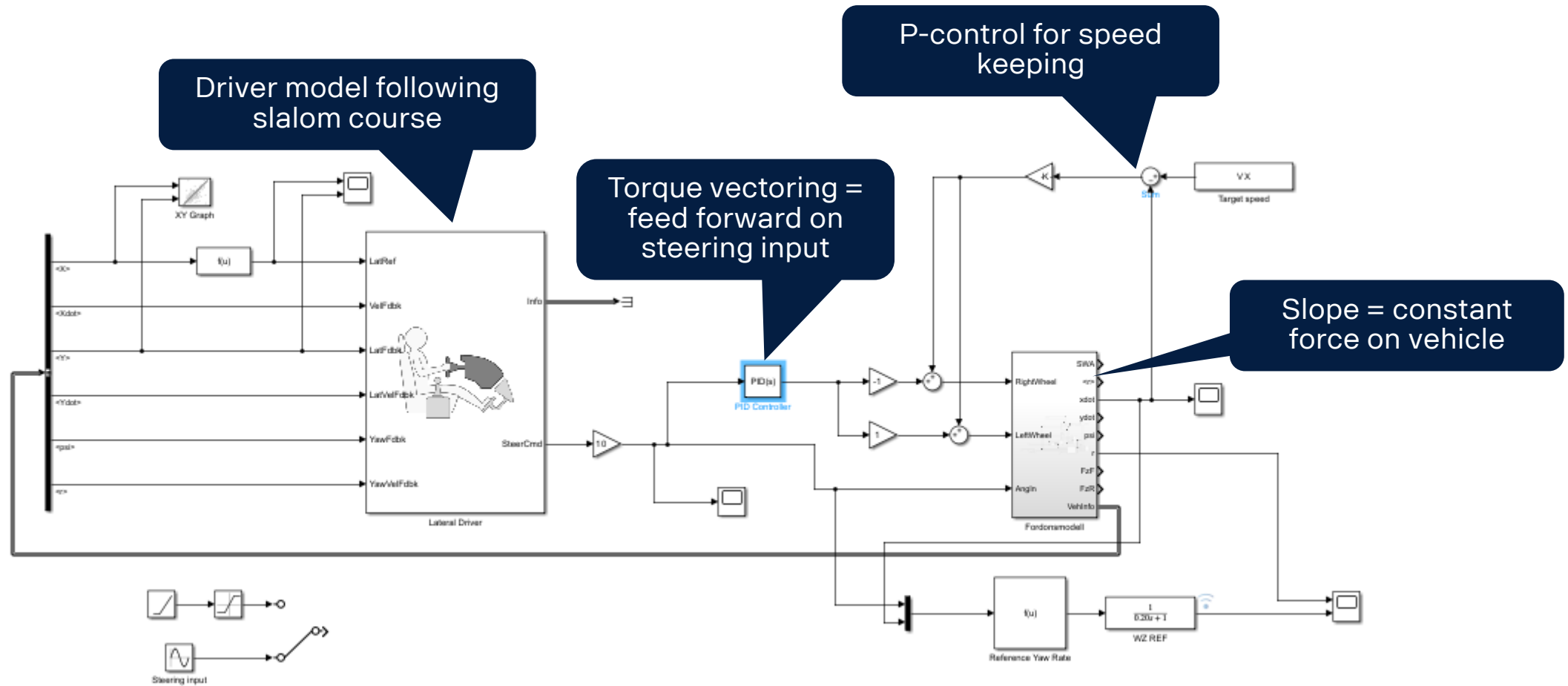
Slippery Slope





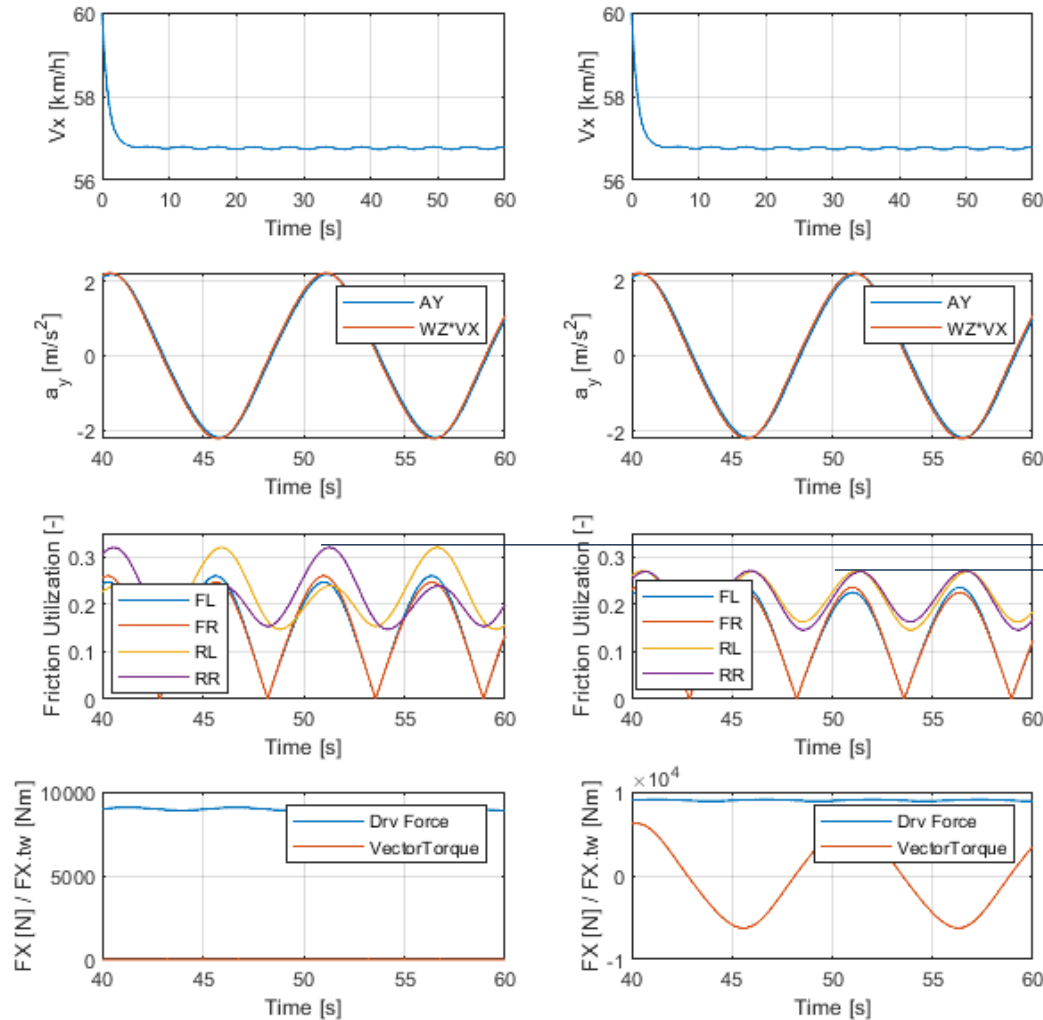
Use Case



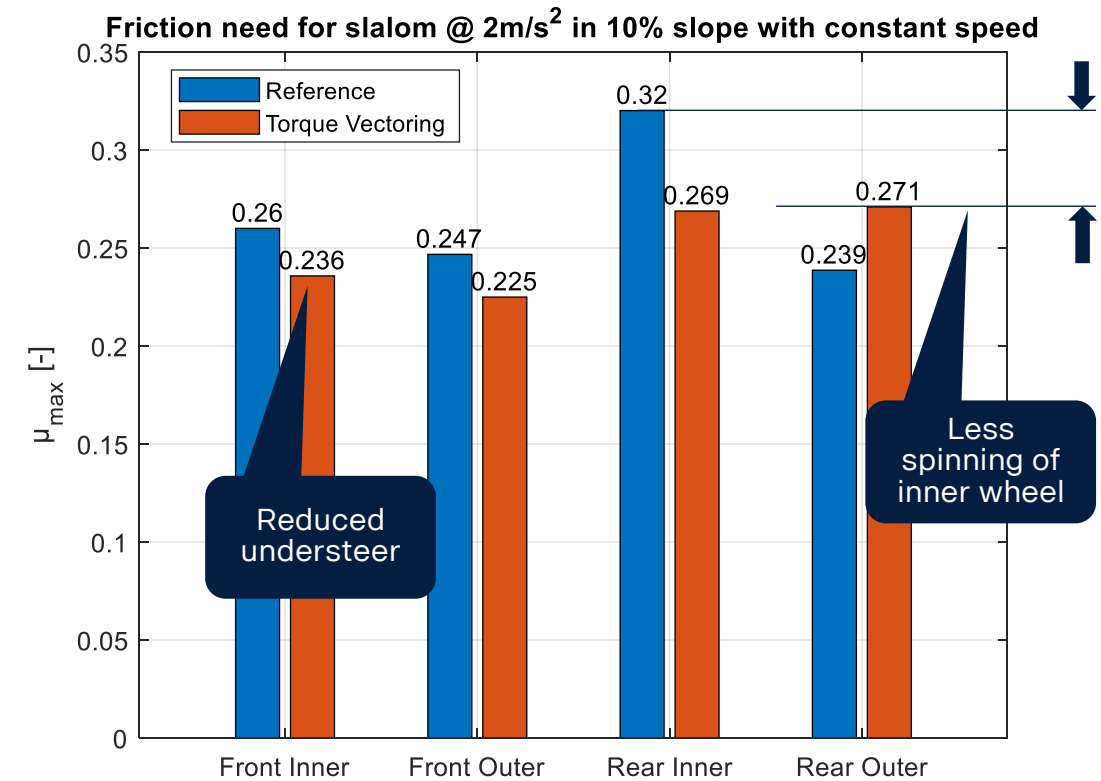




Drive torque is transferred to outer wheel



$$\mu_{max} = \frac{\sqrt{F_x^2 + F_y^2}}{F_z}$$





CONCLUSIONS



Summary

Feature	Evaluation	Comments
Turning radius at low speed	Beneficial at sufficient rear axle load and improves tyre wear on front axle	Requires good rear axle friction. Good function for 6x4
Understeer at low friction	Slides sideways anyway – like shopping cart	Requires good rear axle friction.
Oversteer prevention in DLC (pro-active)	TV could prohibit high lateral accelerations but then the object is not avoided	Stability envelope – but do we want this?
Oversteer control at low friction (reactive)	Little improvement as inner wheel at rear axle has low vertical load	ESP is more effective – reduces speed as a bonus!
LKA / RBS for autonomy	Good performance	Energy consumption?
Lateral drift compensation	See LKA	
More traction on slippery slopes	Improved traction uphill and reduced risk for understeer	Particular for high CoG

“Torque vectoring has benefits for heavy vehicles,
but ESP is more effective in preventing jack-knifing.”

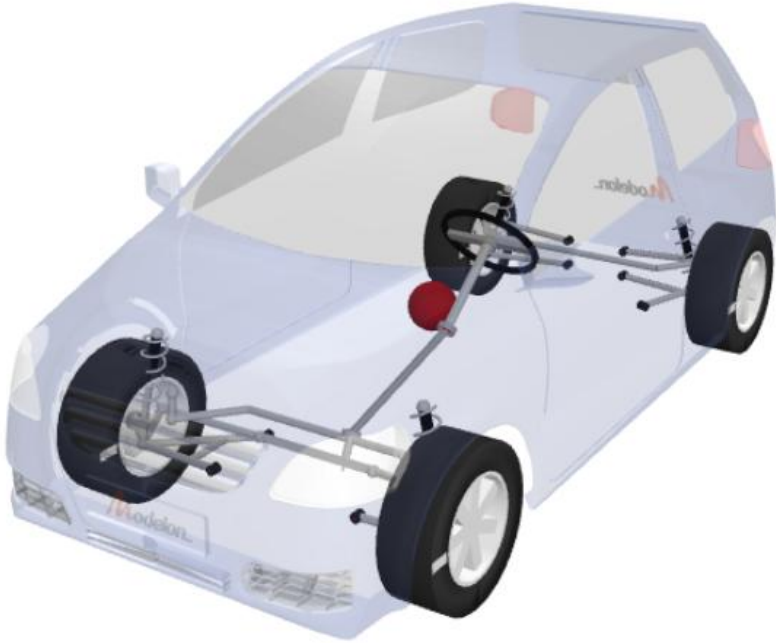
Presentation 6: From Intent to Action:
***AI-Assisted Vehicle Dynamics Design Using
Validated Modelica Libraries,***
Johan Andreasson, Modelon

From Intent to Action

AI-Assisted Vehicle Dynamics Design Using Validated Modelica Libraries

Johan Andreasson · Modelon · SVEA 2026

Intent: Improve peak lateral acceleration



Compact FWD car example
Validated physics

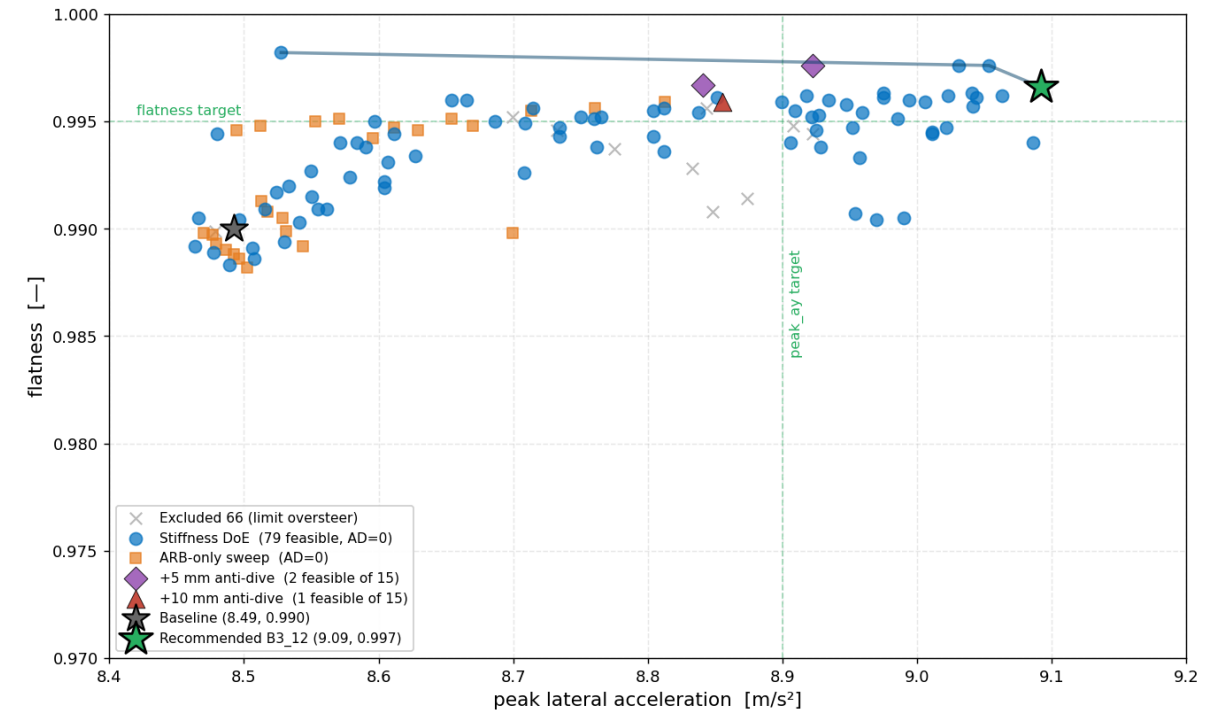
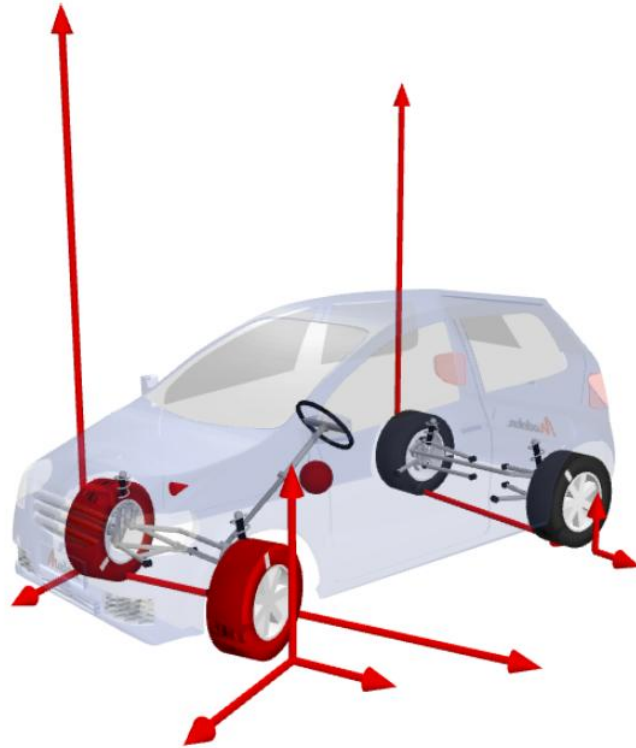
Ramp steer at constant speed

- Max lateral acceleration
- Limit flatness

Design of Experiment or Optimization

- Sensitivity study
- Scatter/pareto plot

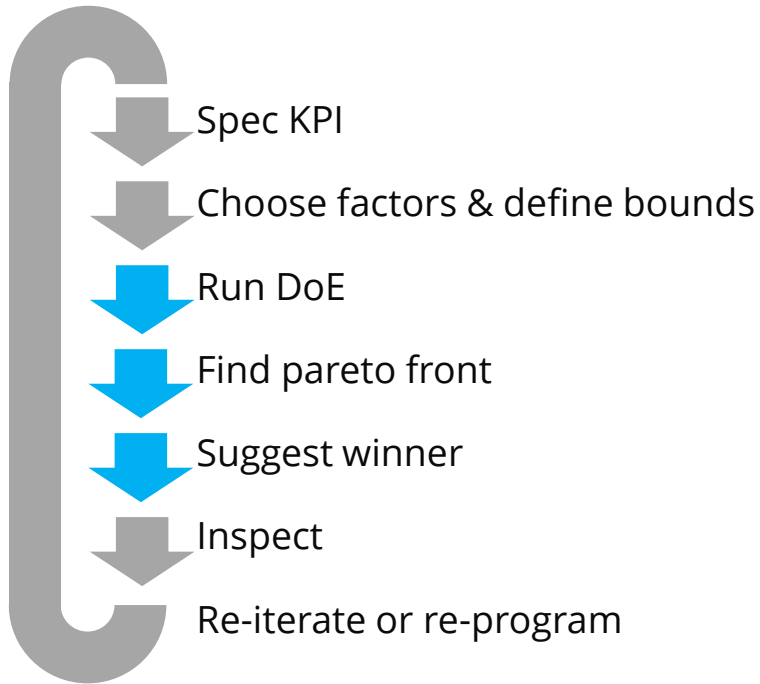
Action: DoE finds an optimum, or does it?



How AI changes the workflow

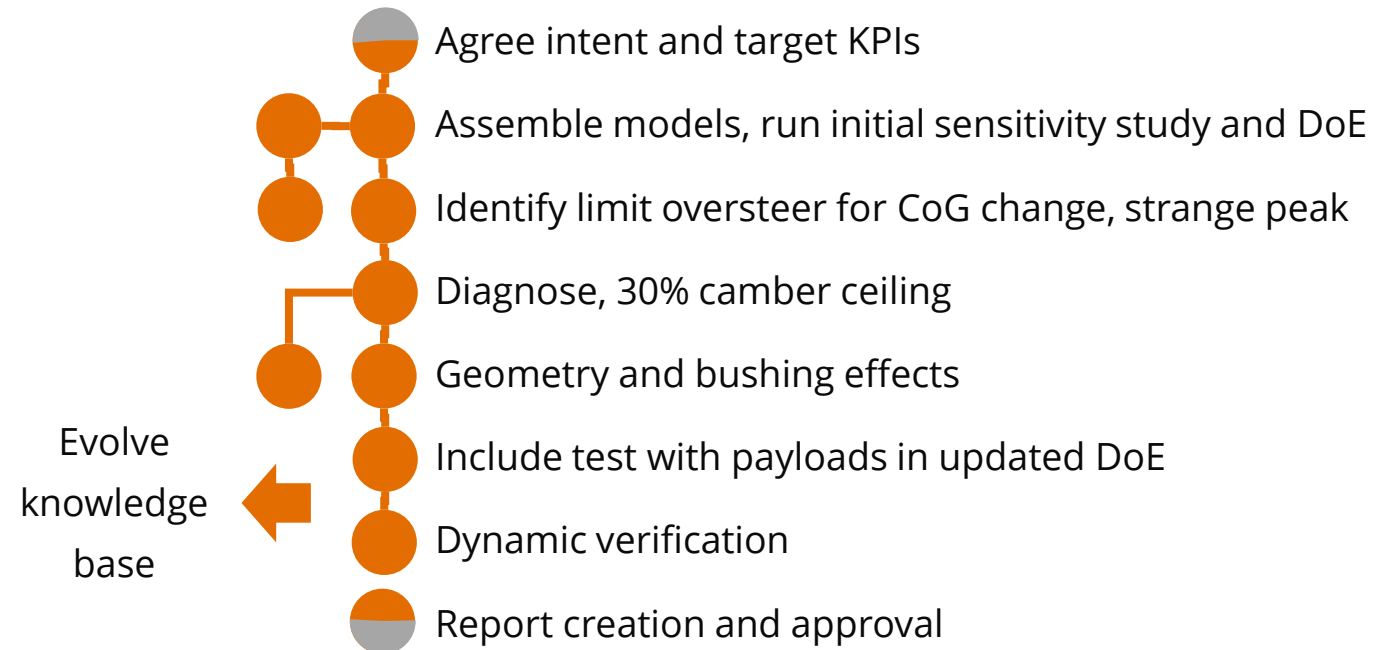
Classical way

Specify the problem, then solve it



Agentic AI

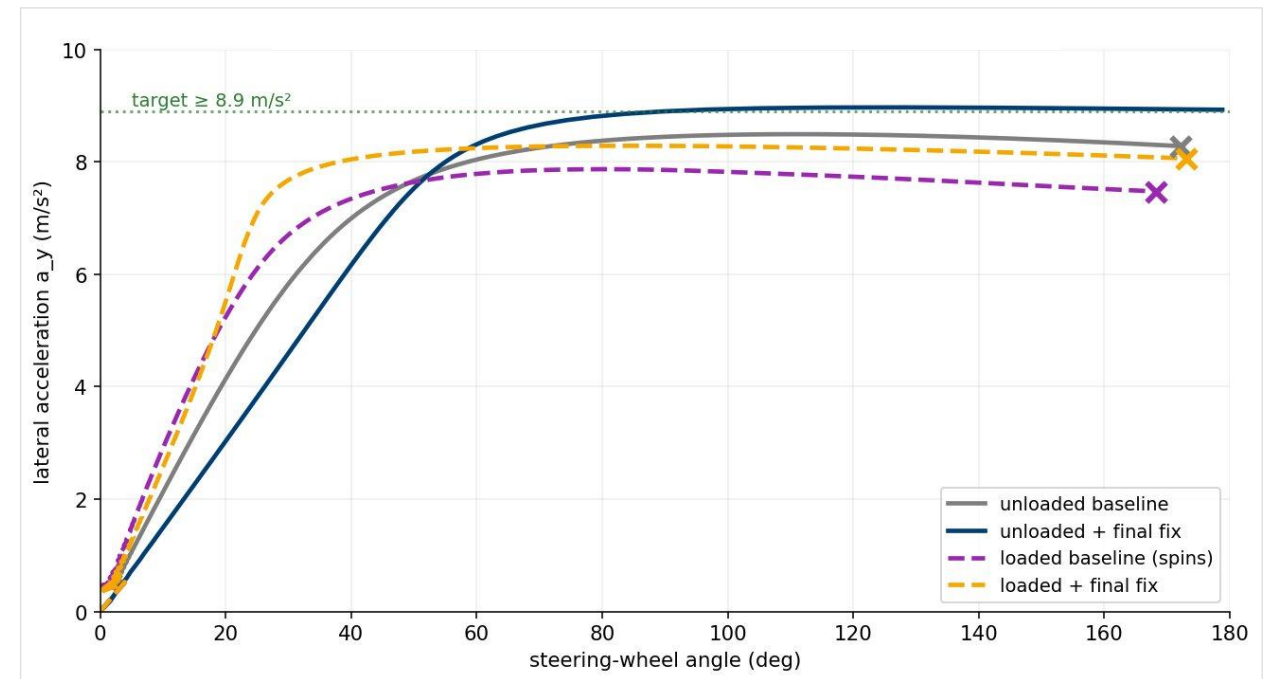
Discover the problem while solving it



Result of the AI workflow

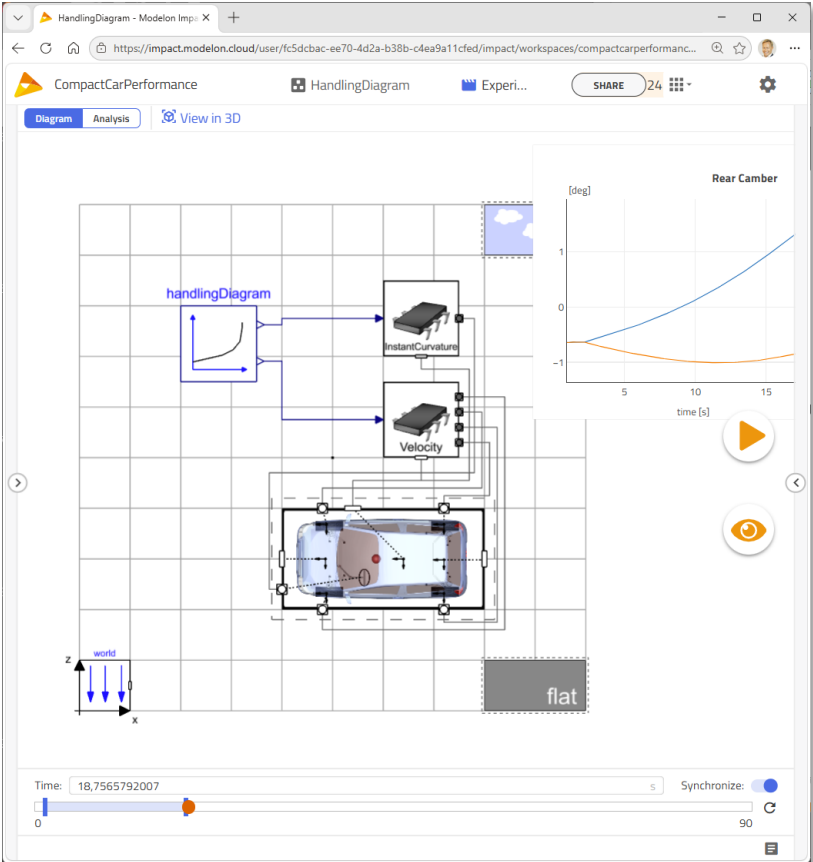
Final design:

- Trailing-arm bushing $C \times \sim 5$
- Rear ARB +25 %
- Springs, dampers, front ARB, hardpoint geometry: unchanged



The deliverables

Models and simulation data

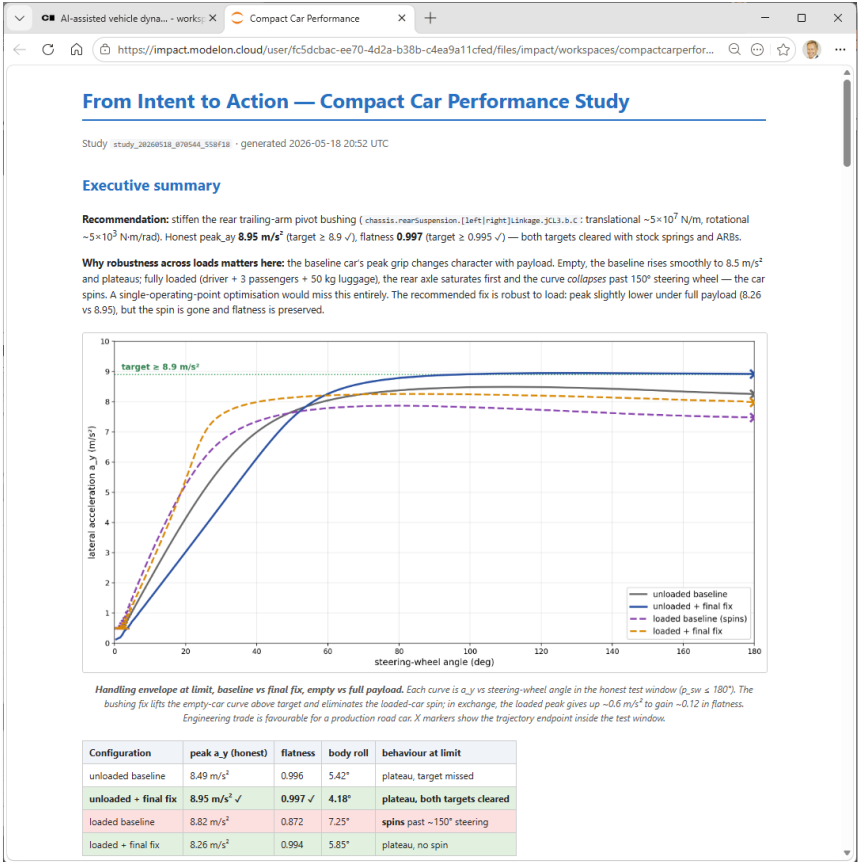


Simulation
data only



Full
reproducibility

Interactive HTML report



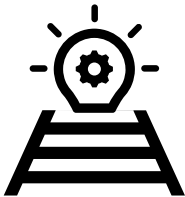
What it takes to deliver this



1. **Validated models** Physics the agent cannot drift from.



2. **Good APIs** Every action callable, not clickable.



3. **Agentic framework with knowledge** Domain context, not just tool access.



4. **Guiding autonomy** A contract up front, an audit trail after.

Takeaways

- Compared to manual work: same methodology, faster cadence
- Compared to automation: more versatile, the plan evolves with learning
- Not a replacement for simulation: still relies on validated physics
- Not a replacement for engineers: result still require human sign-off
- A replacement for scripting and automation?

Presentation 7a:
KTH, Vehicle engineering,
Mikael Nybacka, KTH

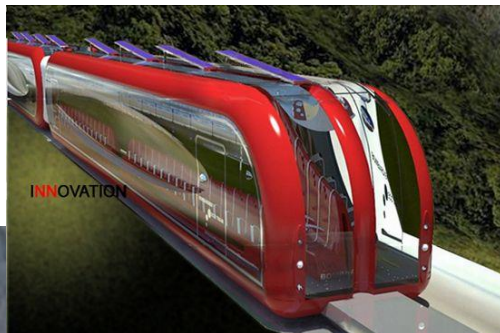


Master programme in Vehicle Engineering

Mikael Nybacka

Associate Professor in Vehicle Dynamics

Programme Director for Vehicle Engineering



Autohous



- Flexible
- Environmental friendly
- Safe
- Cheep
- Personal
- Comfortable
- Secure
- Fast
- Integrated
- Just
- ...



Master programme in 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 45 students 2024 (~**15%** acceptance rate from 1st hand applicants of int. master intake)

Total amount of student / year = **45-55**

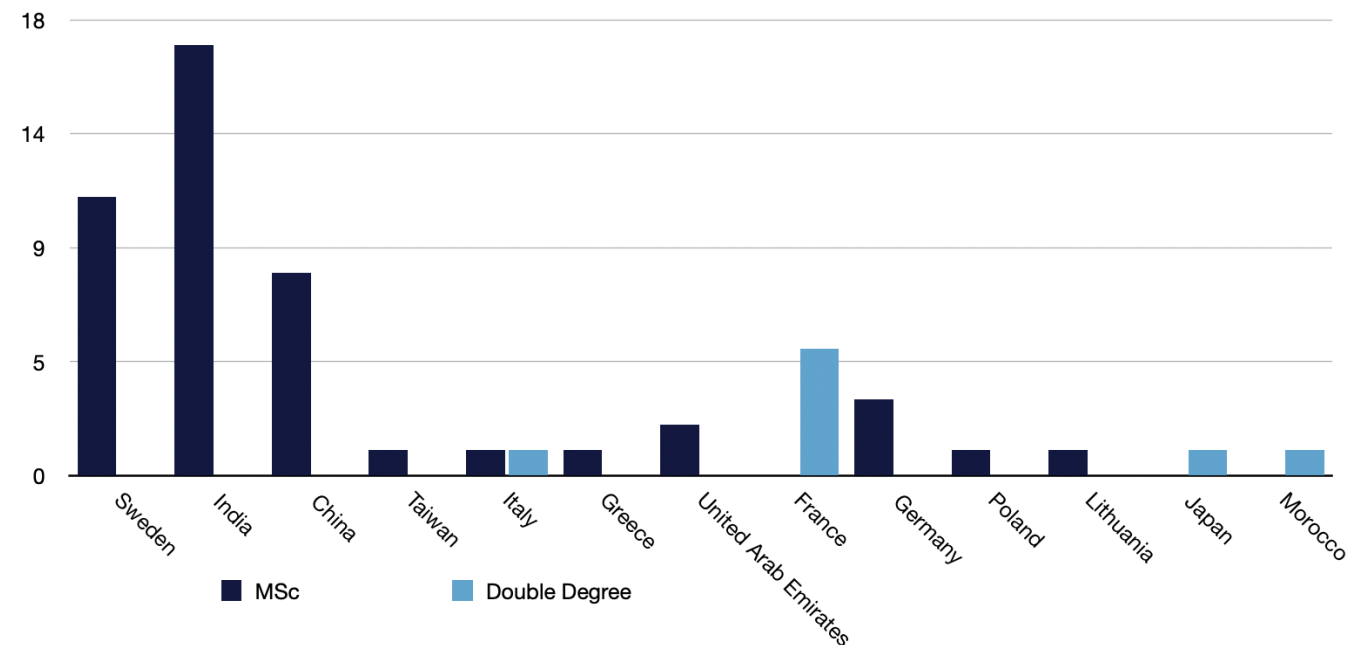
Around **1/3 Swedish** and **2/3 international** students

13 Nationalities 2024

~5 female students / year (we want more to apply!)



Students starting autumn 2024



Entry requirements

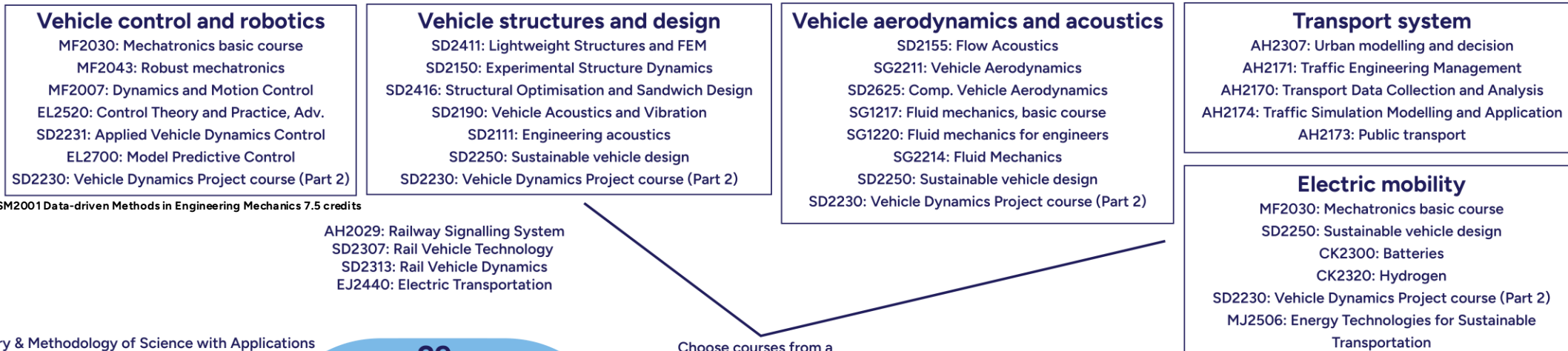
- A bachelor's degree or comparable qualification equivalent to a Swedish bachelor's degree from an internationally recognised university. 180 ECTS
- English proficiency, IELTS Academic or IELTS UKVI: An overall score of 6.5, with no selection lower than 5.5
 - Or other like TOEFL, ECPE, PTE, ESOL
- Specific documents for Vehicle Engineering
 - Summary Sheet (**IMPORTANT**)
- Selection criteria
 - Study results (grades, relevant subjects and English) motivation for studies (motivation letter) and prior education.
 - Prior education is evaluated based on the quality and suitability of the subjects that are relevant for the programme applied to. The merit rating is carried out on a scale of 1-75.
- Specific requirements:
- Mathematics and Programming, equivalent to approximately 25 ECTS credits in total, which must include courses or course modules in differential equations.
- Applied mechanics, equivalent to approximately 20 ECTS credits in total, which must include courses or course modules in solid mechanics.

Mapping of programmes at KTH and prerequisites

- Farkostteknik
 - Teknisk fysik
- } OK
- **Maskinteknik and Design & Produktframtagning:**
 - Reglerteknik grundkurs
 - (Rekommenderat att även ha läst Strömningslära och Ljud och vibrationer; kan läsas inom Masterprogrammet)



Conditional elective courses in these topic areas, choose any course from any topic area



SM2001 Data-driven Methods in Engineering Mechanics 7.5 credits

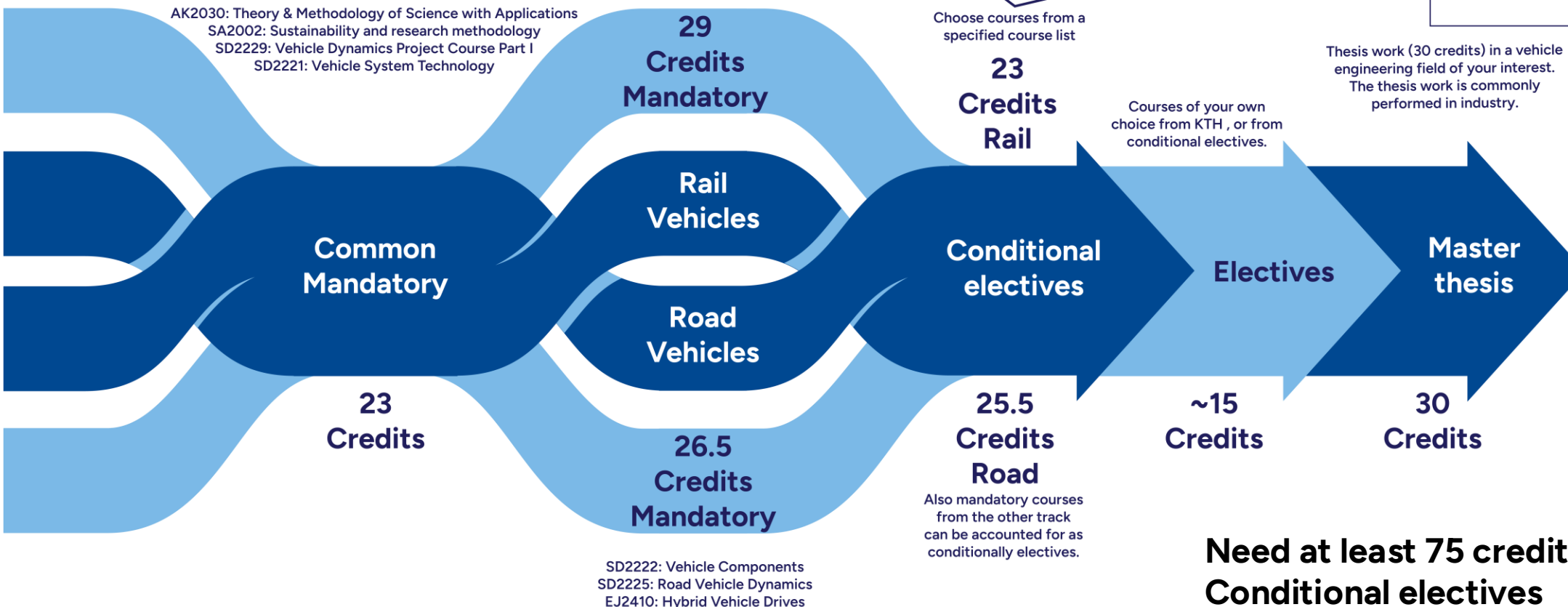
AH2029: Railway Signalling System
SD2307: Rail Vehicle Technology
SD2313: Rail Vehicle Dynamics
EJ2440: Electric Transportation

AK2030: Theory & Methodology of Science with Applications
SA2002: Sustainability and research methodology
SD2229: Vehicle Dynamics Project Course Part I
SD2221: Vehicle System Technology

Choose courses from a specified course list

Courses of your own choice from KTH, or from conditional electives.

Thesis work (30 credits) in a vehicle engineering field of your interest. The thesis work is commonly performed in industry.



Mandatory courses

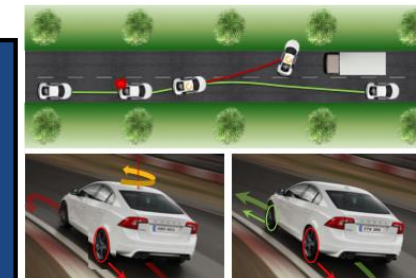
	Year 1				Year 2		
	1:1	1:2	1:3	1:4	2:1	2:2	2:3
ROAD	AK2030 Theory & science 4.5 hp	EJ2410 Hybrid vehicle drives 7.5 hp				SA2002 Sustainable dev. & research methods 3.0 hp	SD221X Master thesis 30 hp
	SD2221 Vehicle system technology 8 hp	SD2222 Vehicle components 8 hp	SD2225 Road vehicle dynamics 11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

	1:1	1:2	1:3	1:4	2:1	2:2	2:3
RAIL	AK2030 Theory & science 4.5 hp				AH2029 Railway signalling systems 7.5 hp	SA2002 Sustainable dev. & research methods 3.0 hp	SD231X 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

Road - Control focus

1:1	1:2	1:3	1:4	2:1	2:2	2:3	2:4
MF2030 Mechatronics Basic course 6hp	EJ2410 Hybrid Vehicle drives 7.5hp	EL2450 Hybrid and Embedded Control Systems 7.5hp	SD2231 Applied Vehicle Dynamics Control 7.5 hp	EL2700 Model Predictive Control 7.5 hp	MF2007 Dynamics and motion Control 7.5 hp	SD221X Master thesis 30 hp	
AK2030 Theory & science 4.5hp	SA2002 Sustainable dev. research methods 3hp						
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	SD2230 Vehicle dynamic project Part 2 7.5 hp		



	Conditionally electives
	Free course

Some examples, but can be other
Course selections and setups as well

Road - Electric powertrain focus

1:1	1:2	1:3	1:4	2:1	2:2	2:3	2:4
MF2030 Mechatronics Basic course 6 hp	EJ2410 Hybrid Vehicle drives 7.5hp	CK2320 Hydrogen 7.5 hp	EJ2400 Electric traction 6 hp	SD2250 Sustainable vehicle design 7.5 hp	SD2230 Vehicle dynamic project Part 2 7.5 hp	SD221X Master thesis 30 hp	
AK2030 Theory & science 4.5hp	SA2002 Sustainable dev. research methods 3hp						
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	CK2300 Batteries 7.5 hp		



Road - Design focus

1:1	1:2	1:3	1:4	2:1	2:2	2:3	2:4
SD2111 Engineering Acoustics 6 hp	EJ2410 Hybrid Vehicle drives 7.5hp	SD2125 Experimental structure dynamics 9 hp		SD2250 Sustainable vehicle design 7.5 hp	SD2416 Structural Optimisation and Sandwich Design 6 hp	SD221X Master thesis 30 hp	
AK2030 Theory & science 4.5hp	SA2002 Sustainable dev. research methods 3hp						
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	SD2230 Vehicle dynamic project Part 2 7.5 hp		

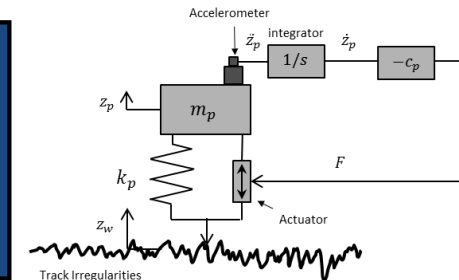


Rail - Control focus

1:1 1:2 1:3 1:4 2:1 2:2 2:3 2:4

MF2030 Mechatronics Basic course 6hp	SA2002 Sustainable dev. & research methods 3 hp	SD2313 Rail vehicle dynamics 8 hp	EJ2400 Electric traction 6 hp	EL2700 Model Pred. Control 7.5 hp	MF2007 Dynamics and motion Control 7.5 hp	SD231X Master thesis 30 hp
AK2030 Theory & science 4.5hp				AH2029 Railway signalling sys. 7.5 hp		
SD2221 Vehicle system technology 8 hp	SD2307 Rail vehicle technology 7.5 hp	EL2450 Hybrid and Embedded Control Systems 7.5hp	SD2231 Applied Vehicle Dynamics Control 7.5 hp	SD2229 Vehicle dynamic project Part I 7.5 hp	SD2230 Vehicle dynamic project Part 2 7.5 hp	

	Conditionally electives
	Free course



Rail - Traffic focus

1:1 1:2 1:3 1:4 2:1 2:2 2:3 2:4

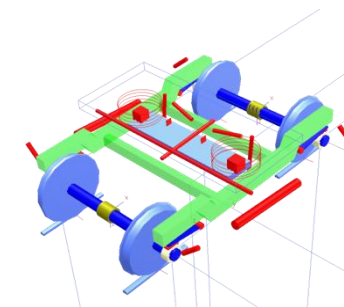
AH2170 Transport Data Collection and an. 7.5 hp	AF2901 Road and Rail. Track Engine. 7.5 hp	SD2313 Rail vehicle dynamics 8 hp	EJ2400 Electric traction 6 hp	AH2029 Railway signalling system 7.5 hp	AH2028 Railway traffic market and planning advanced course 7.5 hp	SD231X Master thesis 30 hp
AK2030 Theory & science 4.5hp	SA2002 Sustainable dev. research methods 3hp					
SD2221 Vehicle system technology 8 hp	SD2307 Rail vehicle technology 7.5 hp	AH2301 Transport Policy and Evaluation 7.5 hp	AH2173 Public Transport 7.5 hp	SD2229 Vehicle dynamics project Part I 7.5 hp	AH2171 Traffic Engineering Managem. 7.5 hp	



Rail - Dynamics focus

1:1 1:2 1:3 1:4 2:1 2:2 2:3 2:4

AK2030 Theory & science 4.5 hp	SA2002 Sustainable dev. & research methods 3 hp	SD2313 Rail vehicle dynamics 8 hp	EJ2400 Electric traction 6 hp	AH2029 Railway signalling system 7.5 hp	MF2007 Dynamics and motion Control 7.5 hp	SD231X Master thesis 30 hp
SD2221 Vehicle system technology 8 hp	SD2307 Rail vehicle technology 7.5 hp	SD2125 Experimental structure dynamics 9 hp		SD2229 Vehicle dynamics project Part I 7.5 hp	SD2230 Vehicle dynamics project Part 2 7.5 hp	



Experimental vehicles, equipment and test tracks



Volvo V60 Plug-in Hybrid



Roller rig



RCV-Dynamic

Research
Concept Vehicles

RCV-E



Driving simulators

Arlanda test track
Drive Lab 1 and 2

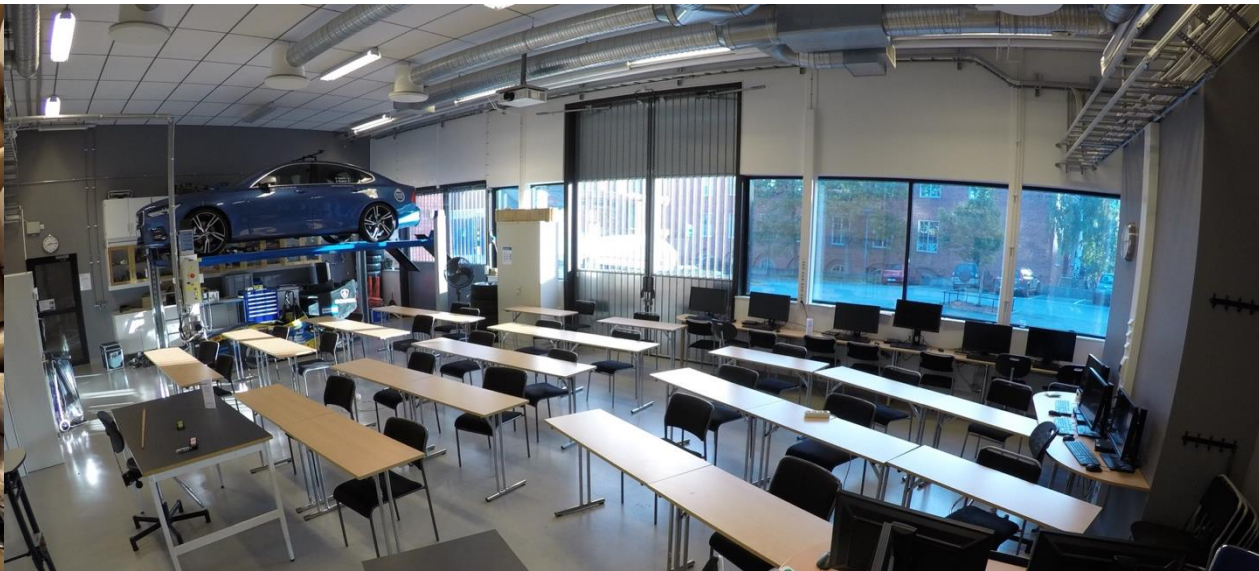


Lunda flygfält

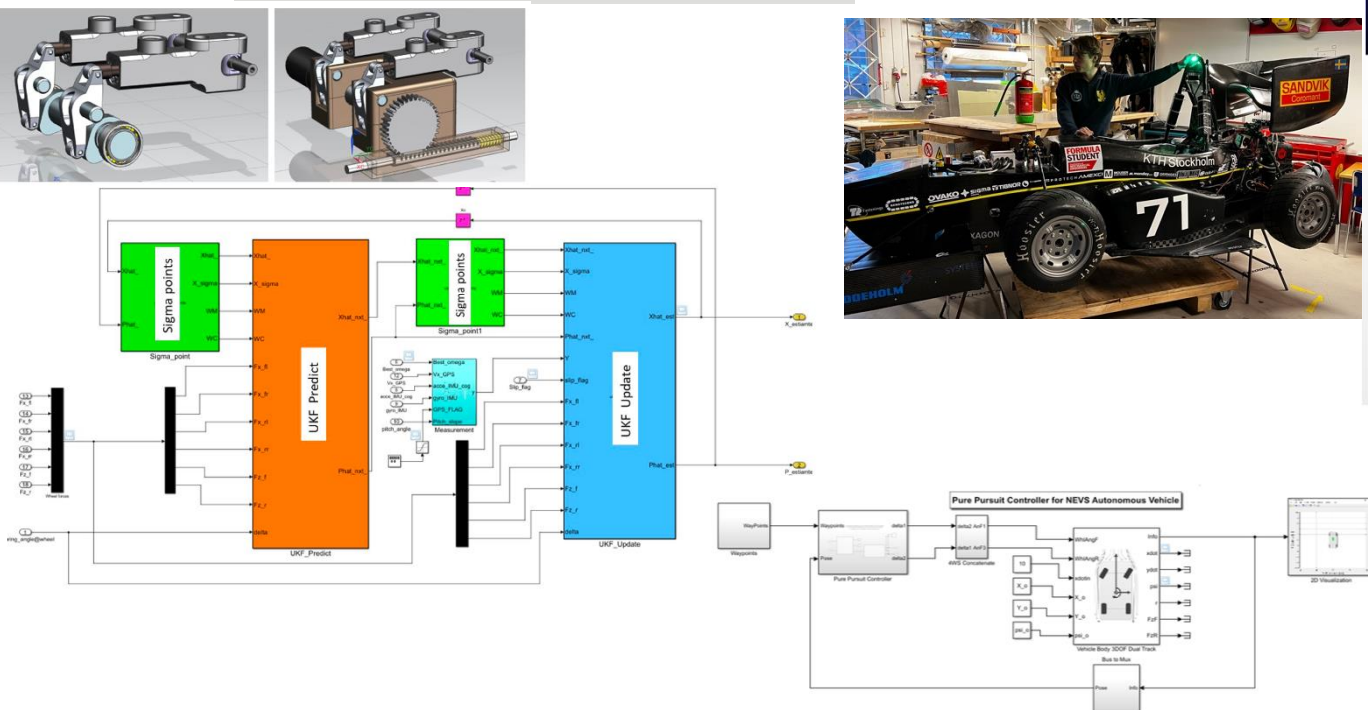
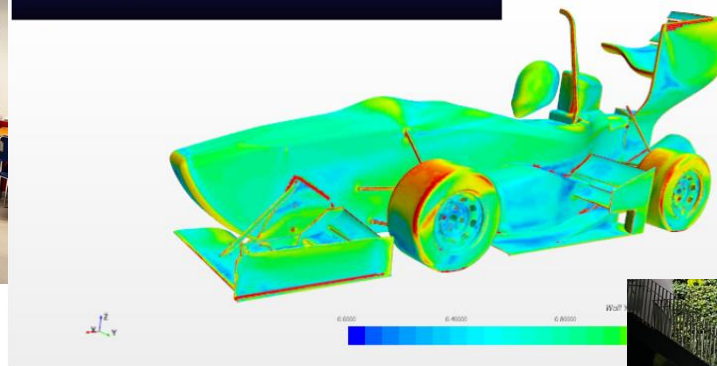
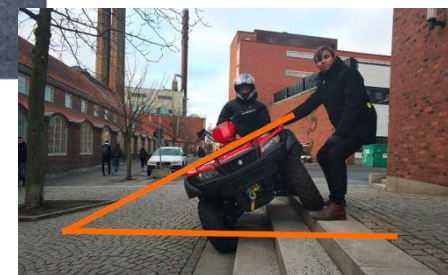
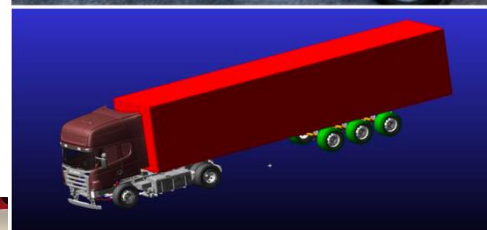


Vehicle Engineering Lab

- Education
- Experiments
- Computer exercises
- Studies on your own



The diagram illustrates a closed-loop system for a driving simulator. On the left, a silhouette of a car is labeled "Vehicle". On the right, a car seat mounted on a motion platform is labeled "Driving simulator with motion cues". A central box labeled "Motion cueing" contains a graph titled "Linear acceleration, rotations" showing a blue curve over time. Two arrows connect the vehicle and the simulator: one from the vehicle to the motion cueing box, and another from the motion cueing box to the simulator. A feedback arrow points from the simulator back to the vehicle, labeled "Steering angle, throttle pos. Brake pressure....etc". In the top right corner, a small inset shows a red arrow pointing up and a black arrow pointing down, with the Greek letter θ between them, representing a rotational angle.



Exchange

- There are several universities around the world you can choose from on the link below, but you need to check that they have courses that are similar to the programme courses that period:
 - <https://www.kth.se/student/studier/utlandsstudier/utbyte/utbytesuniversitet-skolan-for-teknikvetenskap-1.590700>
- Best period for exchange is autumn second year.
- Best period for exchange is Autumn in second year.
 - Austria: Technische Universität Graz
 - Netherlands: Technische Universiteit Delft
 - Netherlands: Technische Universiteit Eindhoven: Universitat Politècnica de Catalunya
 - Italy: Politecnico di Torino
 - Spain: Universitat Politècnica de Catalunya
 - Tyskland: Technische Universität Berlin
 - Tyskland: Technische Universität Braunschweig
 - Tyskland: Technische Universität München
 - Tyskland: Universität Stuttgart
 - USA: University of Illinois at Urbana-Champaign
 - USA: University of Texas at Austin
 - ...
- New double degree exchange programme with Beijing Jiaotong University (BJTU)
 - One year at KTH and one year at BJTU
- Contact: exchange-out@sci.kth.se



Questions?



Mikael Nybacka
Programme director

mnybacka@kth.se

Research groups ***Rail vehicles, Vehicle dynamics, Aero dynamics*** and ***Conceptual vehicle design***
At the division of Vehicle Engineering and Solid Mechanics

info@kth.se – accommodation, KTH user account, anything else.

master@sci.kth.se – study plans, courses, etc.

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

Presentation 7b:
***Chalmers, Mobility engineering & Systems,
Control and Mechatronics,***
Jonas Bärghman and Jonas Fredriksson,
presented by Bengt Jacobson, Chalmers

Chalmers gives 2 MSc programmes

These slides and presentation is by Bengt Jacobson,
based on some relatively new presentations from: **Dag Henrik Bergsjö** and **Jonas Fredriksson**

Presentation scope:

- for Chalmers' MSc programme update for starters **from autumn 2027**
- with **explicit automotive (road & ground vehicle) contents.**

MSc programmes:	Mobility engineering, MSc 120 credits	Systems, control and mechatronics, MSc 120 credits
		
*Specializations:	Aerospace engineering Automotive engineering Specialization: Marine technology Specialization : Railway technology	 Vehicle Dynamics Control ...

**) Formalized (!) from 2027*

MPMOB and MPSYS with Compulsory courses

year 1 (or 3)				year 2 (or 5)			
period 1	2	3	4	1 (sept-oct)	2	3	4 (apr-may)
MPMOB Systems and mechatronics for mobility engineering Introduction to propulsion and energy systems for transport MPSYS Modelling and learning for dynamical systems Applied signal processing						Master Thesis	
	Linear control systems		Design of cyber-physical systems			Master's thesis	

Courses for MPMOB.Automotive

Compulsory

Systems and mechatronics for mobility engineering

Vehicle Motion Engineering

Elective

Elective

Elective

Elective

Introduction to propulsion and energy systems for transport

Vehicle and traffic safety

Elective

Elective

Elective

Elective

Master Thesis

Examples of “**Elective**” from MPMOB:
(Note: also course from MPSYS are Elective for MPMOB)

Vehicle Motion and Control

Powertrain mechanics

Road Vehicle Aerodynamics

Electric and Hybrid Vehicles

Chalmers formula student

Automotive Engineering Project

Courses from MPMOB in red



Reserve slide: Courses for MPMOB.Automotive

Course code	Course Name (linked)	Examiner	In specialisation:	credits
MMS196	Introduction to propulsion and energy systems for transport	Tomas Grönstedt	MPMOB Compulsory	7,5 hp

Course code	Course Name (linked)	Examiner	In specialisation:	credits
MMS196	Introduction to propulsion and energy systems for transport	Tomas Grönstedt	MPMOB Compulsory	7,5 hp
EEN130	Systems and mechatronics for mobility engineering	Jonas Fredriksson	MPMOB Compulsory	7,5 hp

TME180	Automotive engineering project	Alexey Vdovin	Automotive Engineering	15,0 hp
TME047	Chalmers formula student	Björn Pålsson	Automotive Engineering	15,0 hp
TME095	Electric and Hybrid Vehicles	David Sedarsky	Automotive Engineering	7,5 hp

MMS210	Connected fleets in data-driven engineering	Ola Benderius	MPMOB Generic	7,5 hp
EEN140	Electric drive systems for vehicles and vessels	Stefan Lundberg	MPMOB Generic	7,5 hp
EEN135	Electric machines for vehicles and vessels	Sonja Lundmark	MPMOB Generic	7,5 hp
IMS105	Fundamentals of systems engineering	Dag Bergsjö	MPMOB Generic	7,5 hp

MMA169	Structural engineering	Jonas Ringsberg	Naval Architecture	7,5 hp
SJO747	Wave loads and seakeeping	Martin Schreuder	Naval Architecture	7,5 hp

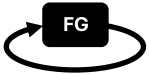
TME192	Active safety	Marco Dozza	Automotive Engineering	7,5 hp
TME180	Automotive engineering project	Alexey Vdovin	Automotive Engineering	15,0 hp
TME047	Chalmers formula student	Björn Pålsson	Automotive Engineering	15,0 hp
TME095	Electric and Hybrid Vehicles	David Sedarsky	Automotive Engineering	7,5 hp
TME196	Impact biomechanics	Johan Davidsson	Automotive Engineering	7,5 hp
MTF242	Internal combustion engines	Petter Dahlander	Automotive Engineering	7,5 hp
TME170	Powertrain mechanics	Petter Dahlander	Automotive Engineering	7,5 hp
MTF236	Road vehicle aerodynamics	Simone Sebben	Automotive Engineering	7,5 hp
TME202	Vehicle and traffic safety	Jonas Bärghman	Automotive Engineering	7,5 hp
TME102	Vehicle motion and control	Mats Jonasson	Automotive Engineering	7,5 hp
MMF062	Vehicle motion engineering	Bengt Jacobson	Automotive Engineering	7,5 hp

Reserve slide 1(of2): MPSYS.VehicleDynamicsControl

Specialisations



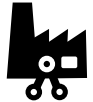
Communication and sensing - Create reliable, high-performance systems that sense the world and communicate information seamlessly.



Decision and control - Master the methods that power high-performance control and real-time decision-making in dynamic systems.



Electromobility - Shape the future of electric transportation by mastering battery systems, electric drives, and vehicle control.



Intelligent automation - Develop advanced automation solutions using high-level planning, simulation, and optimisation for modern industry.



Mechatronics - Design smart electro-mechanical systems by integrating mechanics, electric drives, control, and energy storage.



Robot learning - Build intelligent robots that can sense, plan, and act autonomously in real-world environments.



Vehicle dynamics control - Engineer safe, stable, and intelligent vehicles through advanced modelling, estimation, and control of vehicle dynamics.

Reserve slide 2(of2): MPSYS.VehicleDynamicsControl

The specialisation focuses on applying control to vehicle dynamics, a key foundation for designing modern automotive systems such as active safety functions and automated driving. This includes how sensing, decision-making, and actuation work together to ensure safe and stable vehicle motion. The courses provide in-depth knowledge of vehicle modelling, estimation, and control methods used in applications ranging from stability control to autonomous driving.

Compulsory courses:

- Model predictive control (SSY286)
- Sensor fusion and nonlinear filtering (SSY345)
- Vehicle motion engineering (MMF062)

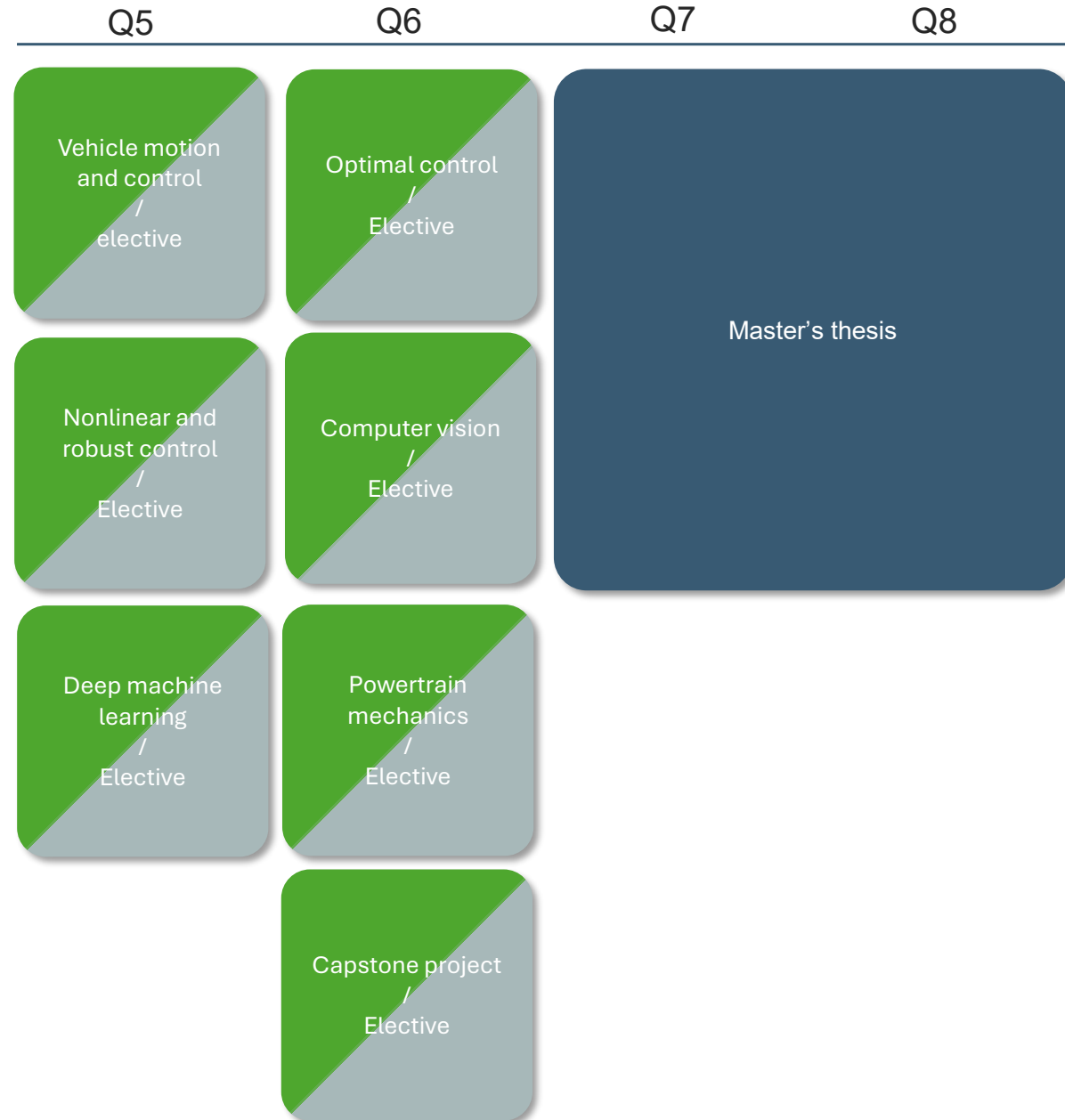
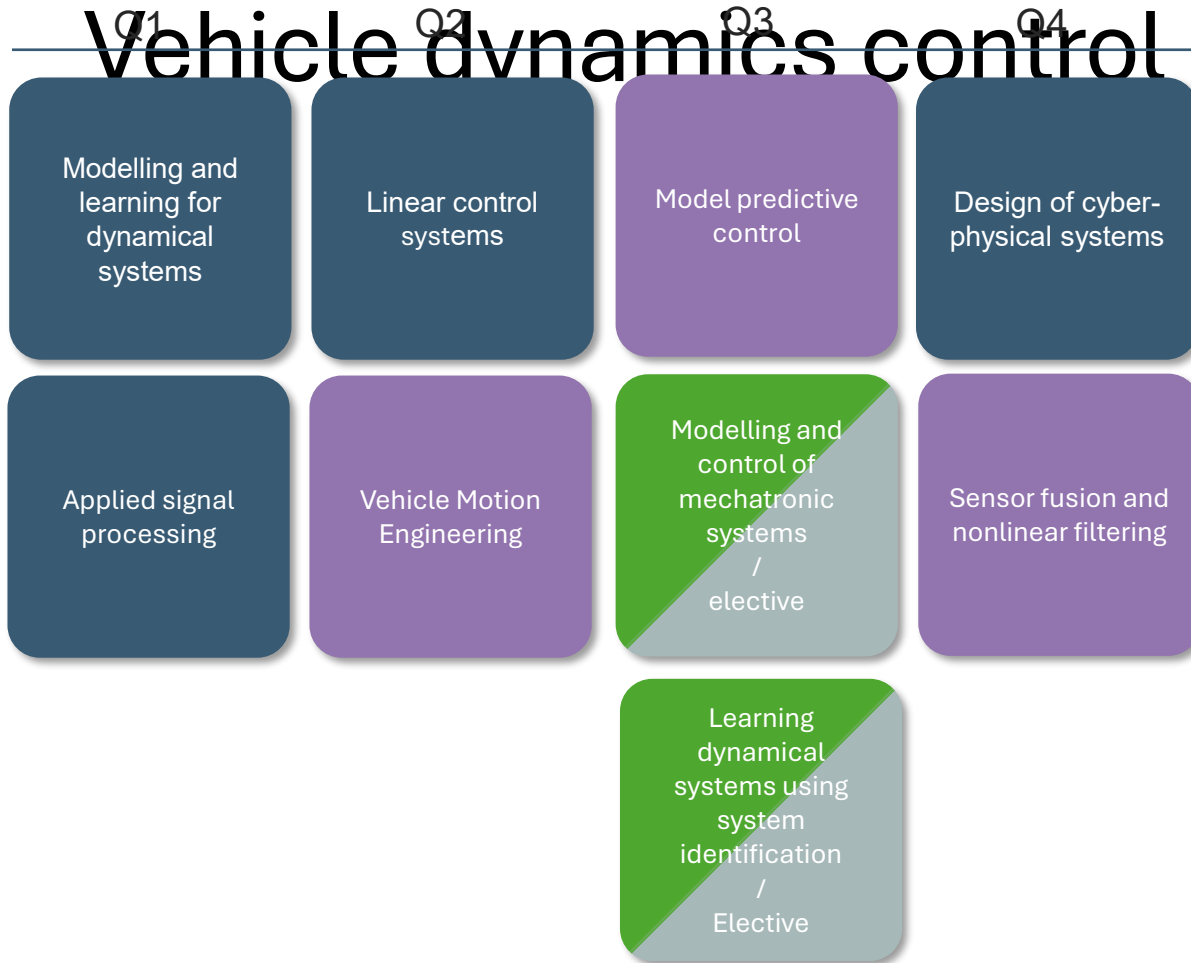
Compulsory elective courses (at least 1 out of):

- Capstone project in Systems, Learning and Control (SSY226, new name)
- Computer vision (EEN020)
- Deep machine learning (SSY340)
- Learning dynamical systems using system identification (SSY230)
- Modelling and control of mechatronic systems (SSY156)
- Optimal control (new course)
- Powertrain mechanics (TME170)
- Vehicle motion and control (TME102)

Year 1

Year 2

Vehicle dynamics control



Slide not planned for presentation; maybe input to Q&A

Automotive outside MSc programmes:

- **First 3 years** in civilingenjör's education does hardly contain any automotive
 - Even if we try to dedicate some **BSc thesis** (kandidatarbeten) to automotive
- **PhD** graduate schools (e.g. Machine and Vehicle Systems)
- **PhD** courses
- Courses given **for industry in industry**
- **Stand-alone/single courses** can be taken by engineers in industry
- **Double degree**, mainly MSc degree, but also PhD degree exists
- Master theses can be ways to cooperate (or “steal” students) **between universities**.
 - Examples (from Chalmers.VehDyn):
 - KTH.VehDyn and Chalmers.VehDyn
 - HAN.Automotive and Chalmers.VehDyn
 - TU Delft and Chalmers.VehDyn

Poster 1:

***Development environments for route based
functions in road vehicles,***

Victor Andersson, Chalmers

Development environments for route based functions in road vehicles



CHALMERS

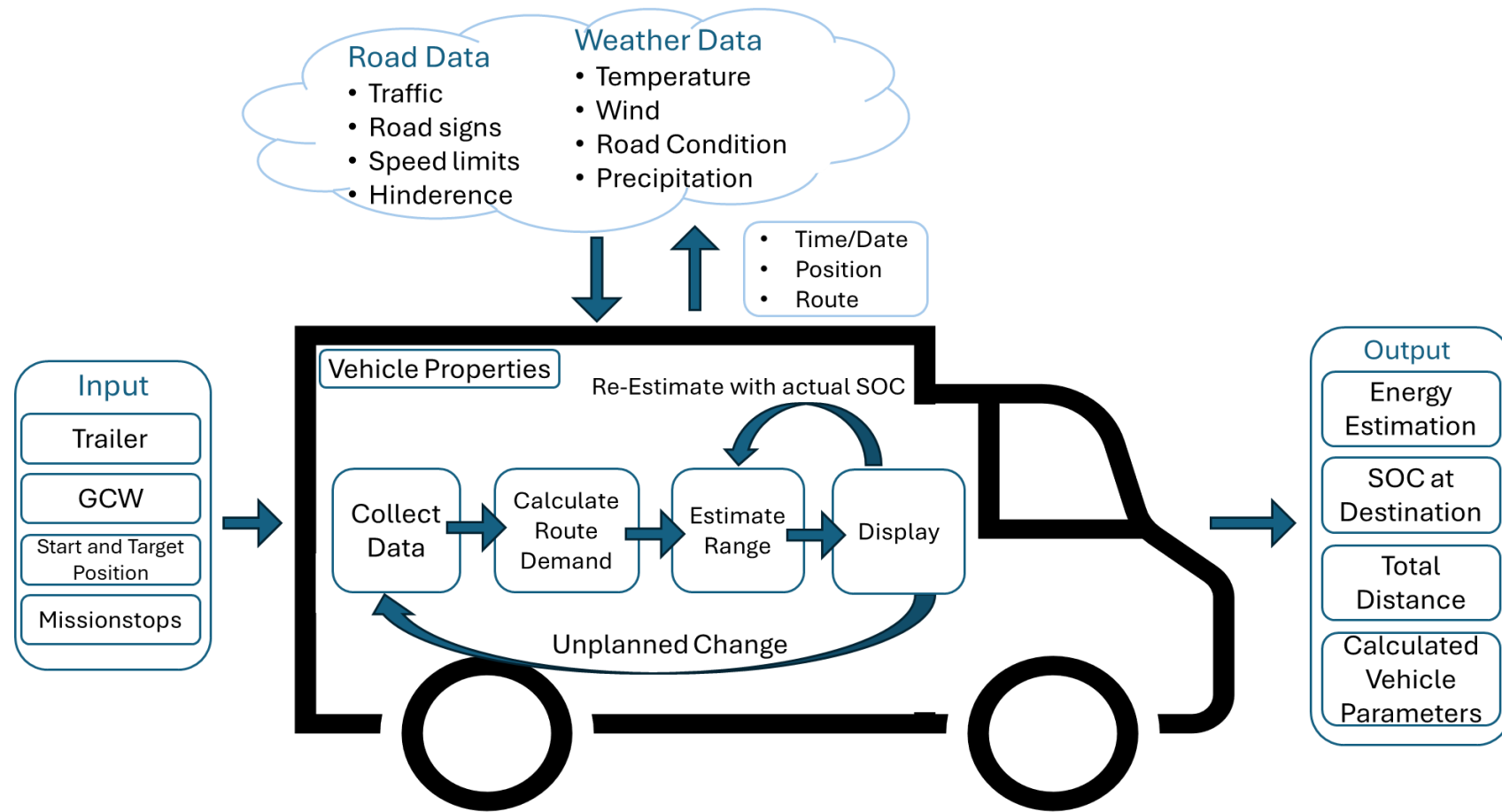
Victor Andersson
Master's Programme in Mobility Engineering
Chalmers university of technology

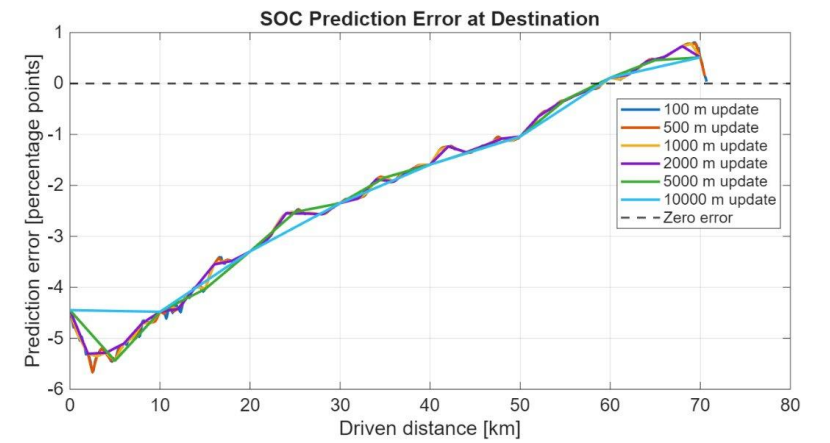
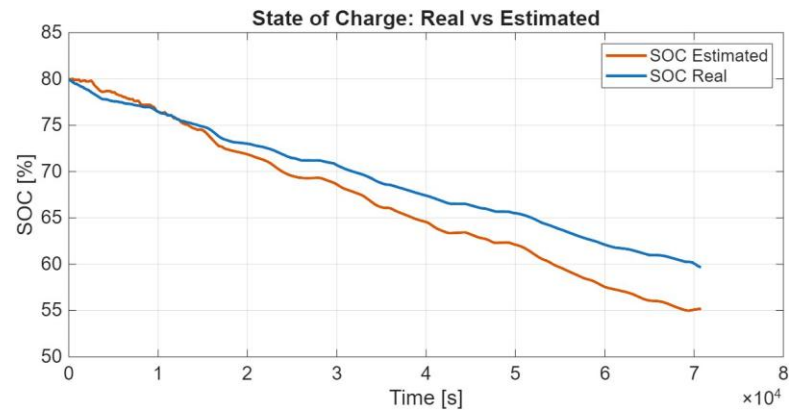
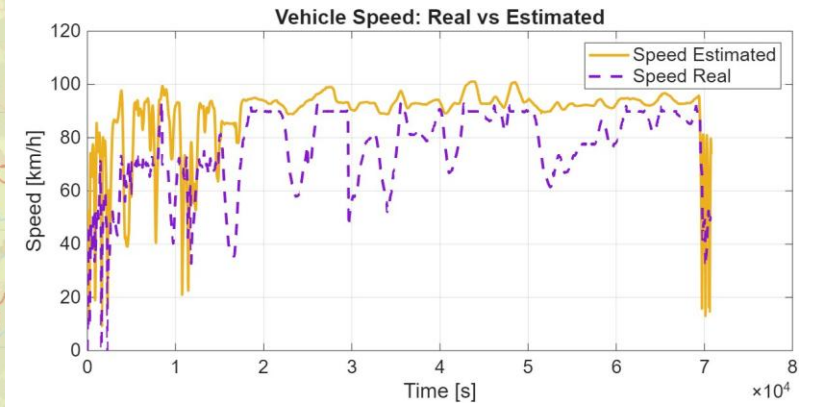
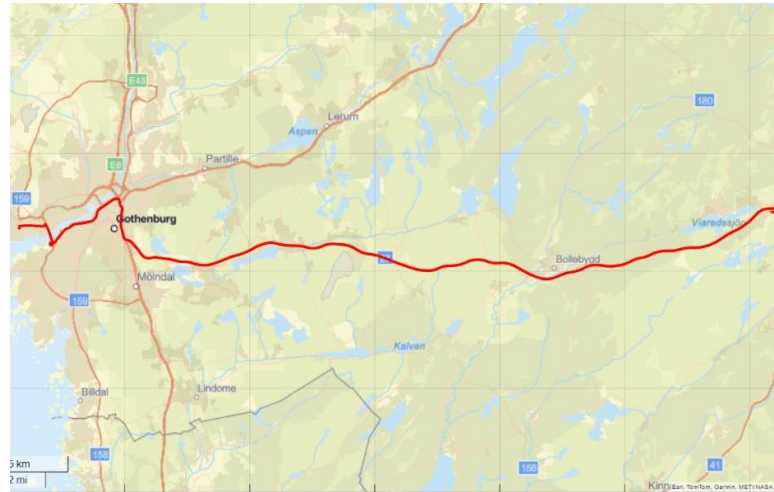
Short Description

- Uses road data from HERE
- Simulation environment in TruckMaker for route-based energy prediction
- Predicts vehicle range and state of charge (SoC) from road data
- Analyzes impact of re-estimation frequency on accuracy
- Investigates effects of parameter changes
- Develop testbench for real vehicle



Considerations for range estimators







CHALMERS

Background

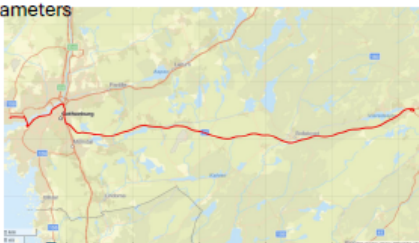
The transition to battery-electric heavy-duty trucks is accelerating, but adoption remains limited due to concerns about range, charging infrastructure, and operational reliability. Haulage companies face uncertainties regarding charging availability, battery capacity, and vehicle performance, creating significant "range anxiety" and slowing the shift toward sustainable freight transport.

Problem Definition

Accurate range prediction is essential for planning electric truck operations and reducing perceived risk. Energy consumption depends on factors such as payload, topography, weather, driving behavior, and auxiliary systems, making prediction difficult with simple models. This project aims to develop and evaluate a predictive, data-driven range estimation framework and test environment for battery-electric heavy-duty trucks, supporting more reliable and efficient transport operations.

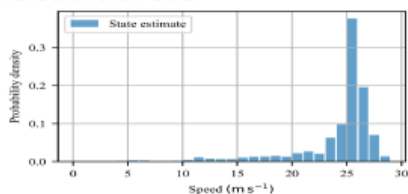
Aim/Objective

- Developed a simulation environment in TruckMaker for route-based energy prediction
- Integrated road and map data from HERE Technologies
- Predicted vehicle range and battery state of charge (SoC)
- Evaluated how re-estimation frequency affects prediction accuracy
- Investigated the impact of varying vehicle and environmental parameters



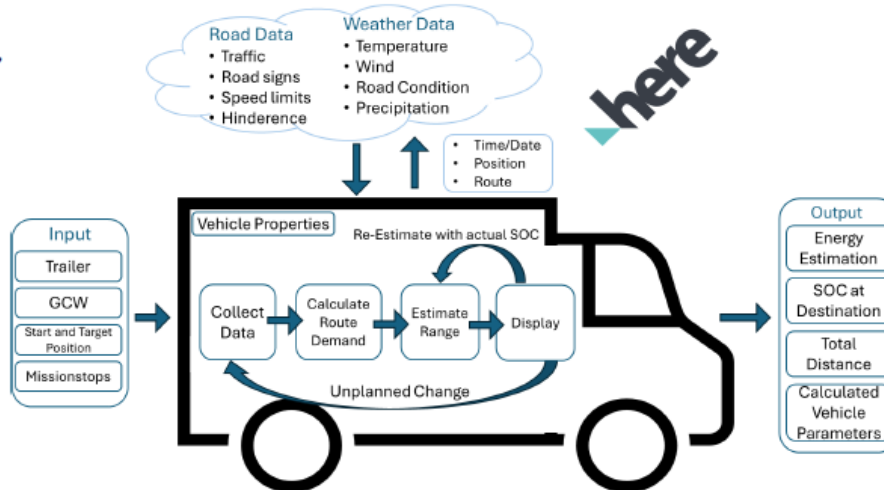
Chosen Route

The chosen route is Gothenburg harbour to Viared near Borås. This route is chosen since it is a common driven route that is not too long to simulate, but also long enough to get different conditions and valid results



Development environments for route based functions in road vehicles

Examiner: Bengt Jacobson Supervisor: Carl Emvin



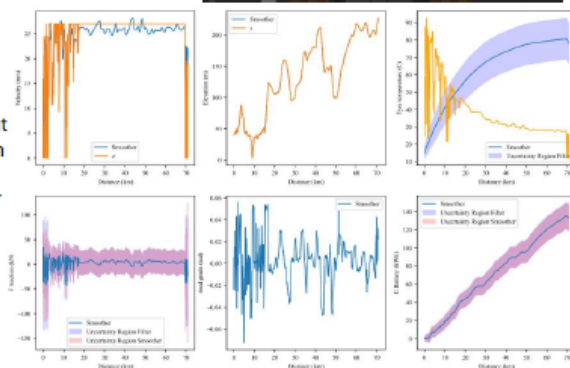
Simulation Platform (TruckMaker)

A predictive range estimation framework was developed in TruckMaker using a Simulink-based heavy-duty vehicle model. The environment enabled route-based energy prediction using road and mission data from HERE Technologies under varying operating conditions.



Range Estimator

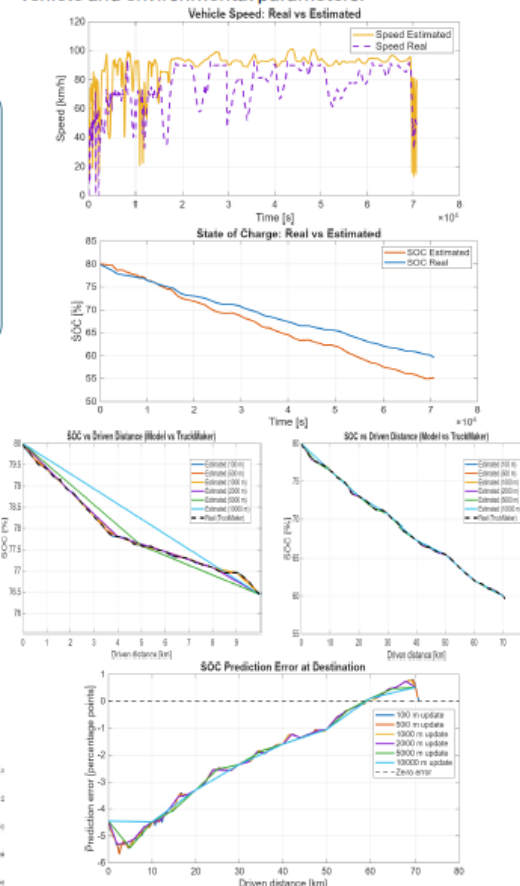
The predictive range estimator was developed based on research conducted within the U-Feel project at Chalmers University of Technology. The main estimation framework and algorithms build upon previous work by PhD student Carl Emvin on energy consumption estimation for battery-electric heavy-duty vehicles. The estimator predicts vehicle energy consumption and remaining state of charge along a planned route using route, vehicle, and environmental data.



Victor Andersson
Chalmers Tekniska Högskola
Mobility Engineering
Contact:
Victoand@chalmers.se
Tel: 072 310 61 93

Results

The results show that estimation accuracy is influenced by re-estimation frequency, route conditions, and varying vehicle and environmental parameters.



Future Work

- Compare with log from Revere
- Validate both simulation model and Range Predictor, Try different routes
- Possibly try real truck at REVERE
- Changing parameters mid route, ex. Stops, GCW etc.
- Add real weather data



CHALMERS

Development environments for route based functions in road vehicles

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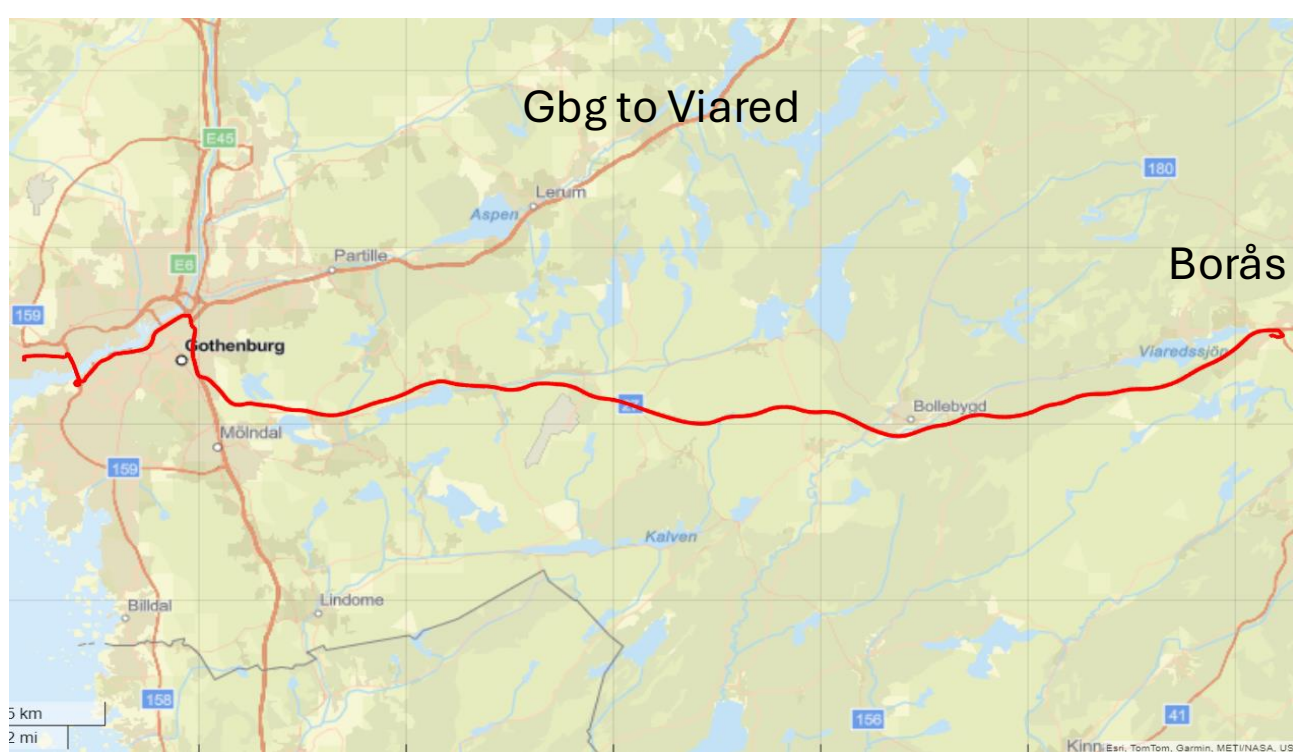
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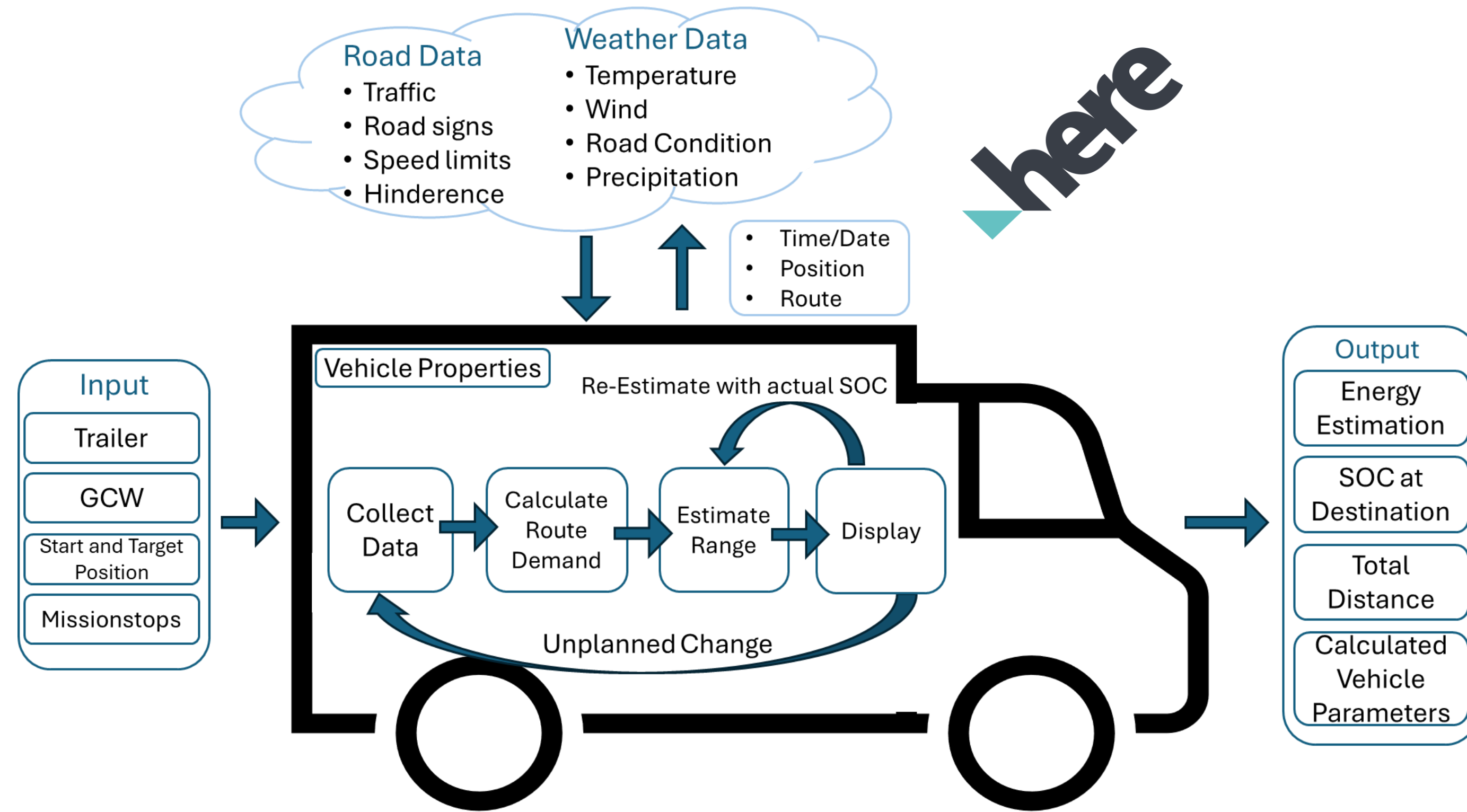
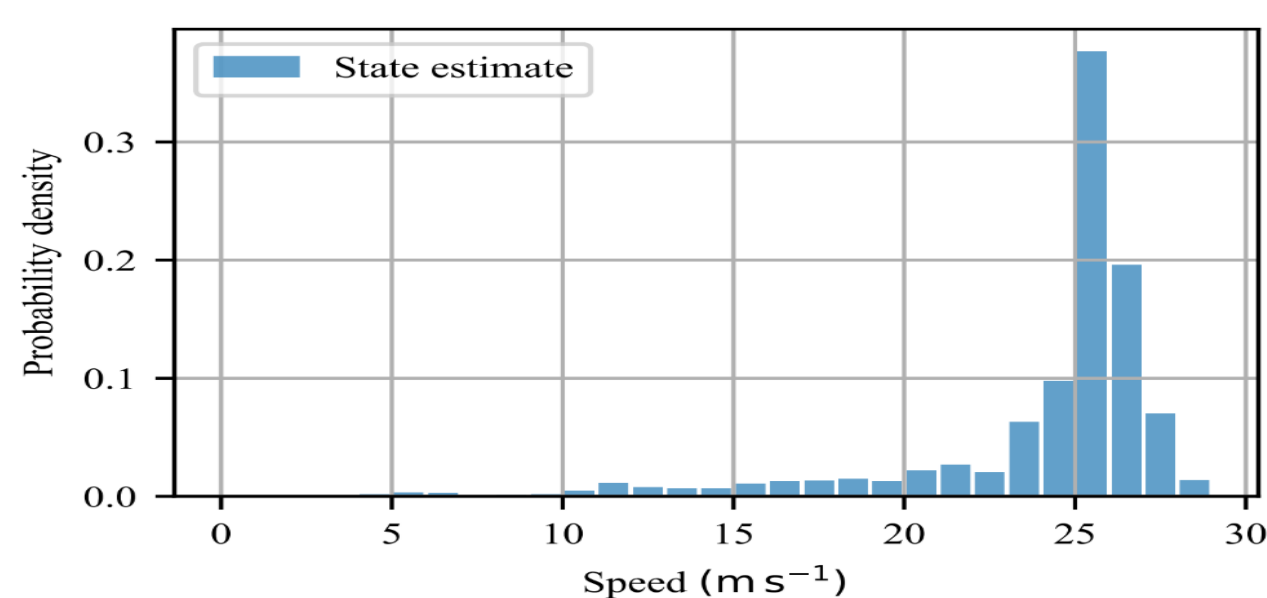
Aim/Objective

- Develop a simulation environment in TruckMaker for route-based energy prediction
- Road and map data from HERE Technologies
- Vehicle range and battery state of charge (SoC)
- Evaluate how re-estimation frequency affects prediction accuracy
- Investigate the impact of varying vehicle and environmental parameters



Chosen Route

The chosen route is Gothenburg harbour to Viared near Borås. This route is chosen since it is a common driven route that is not too long to simulate, but also long enough to get different conditions and valid results



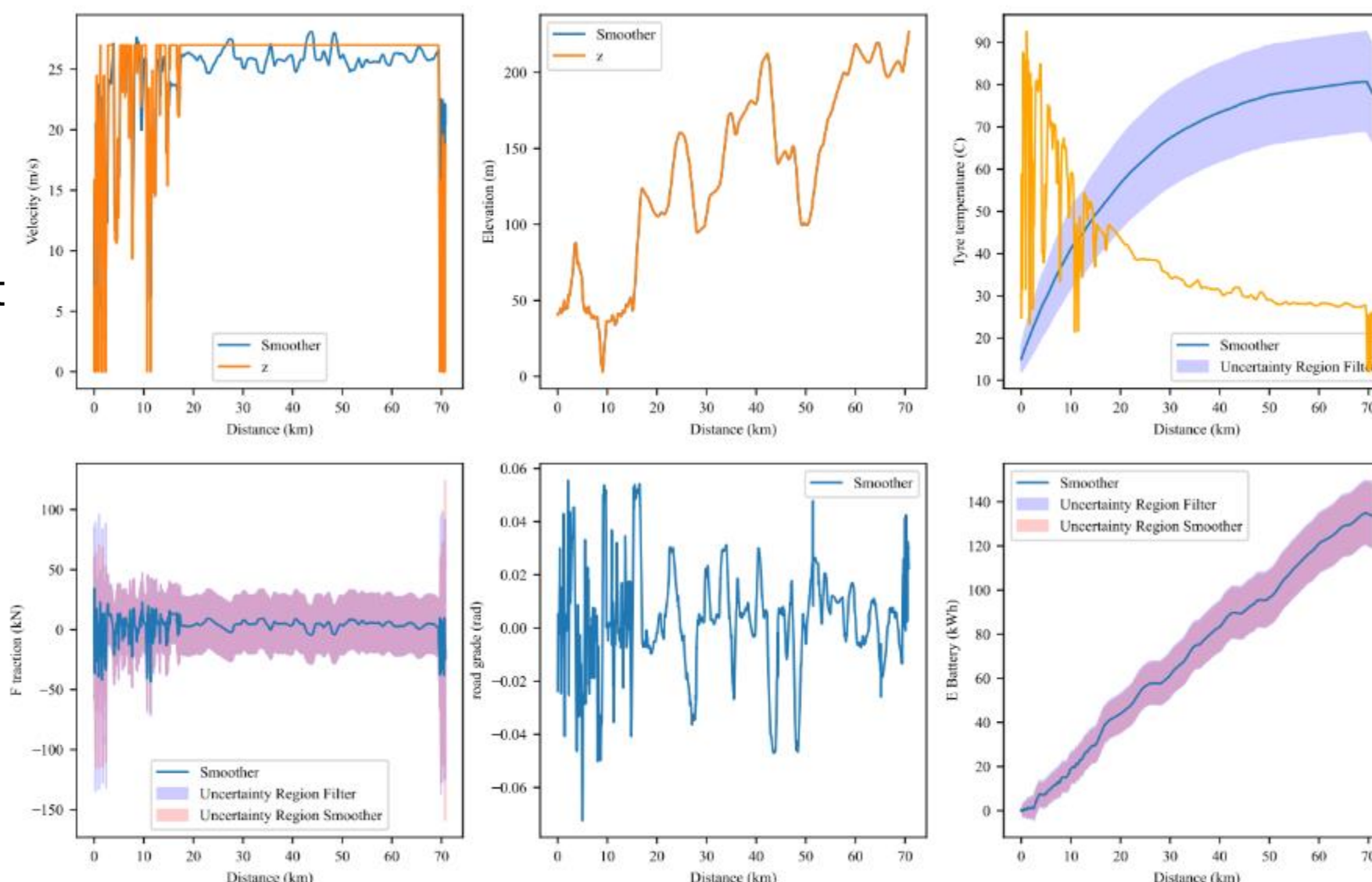
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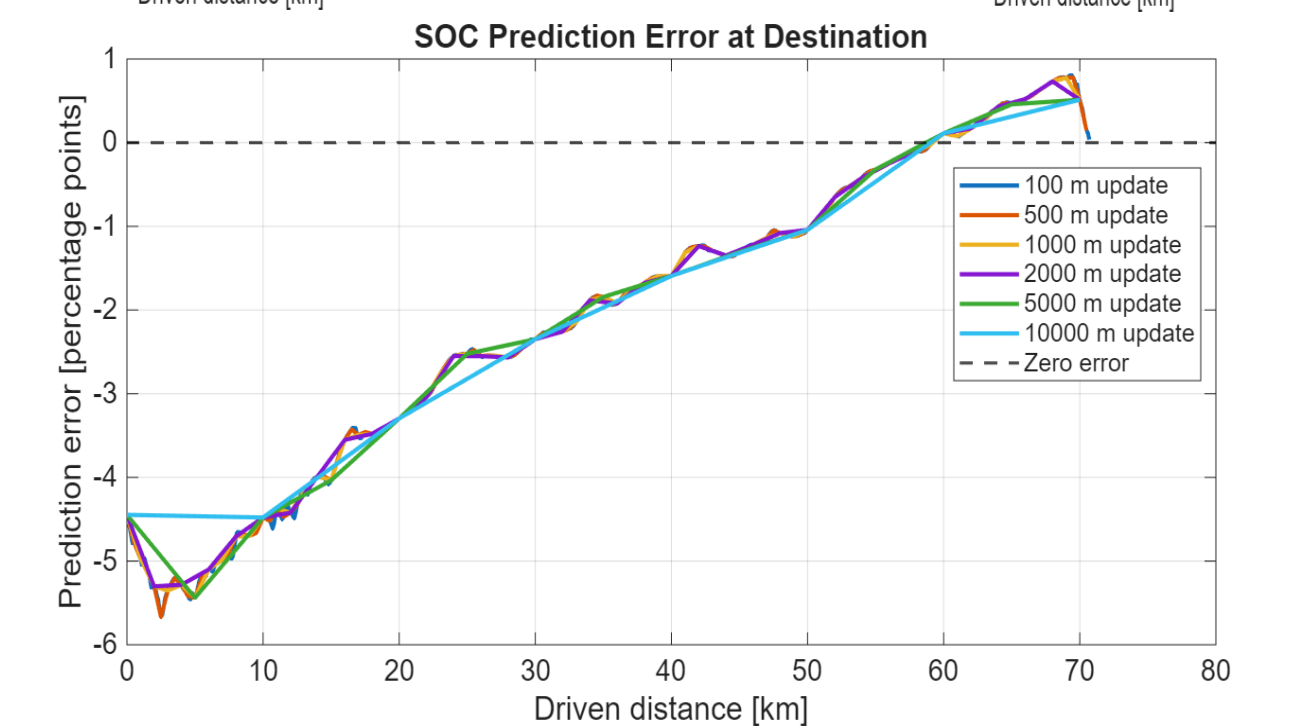
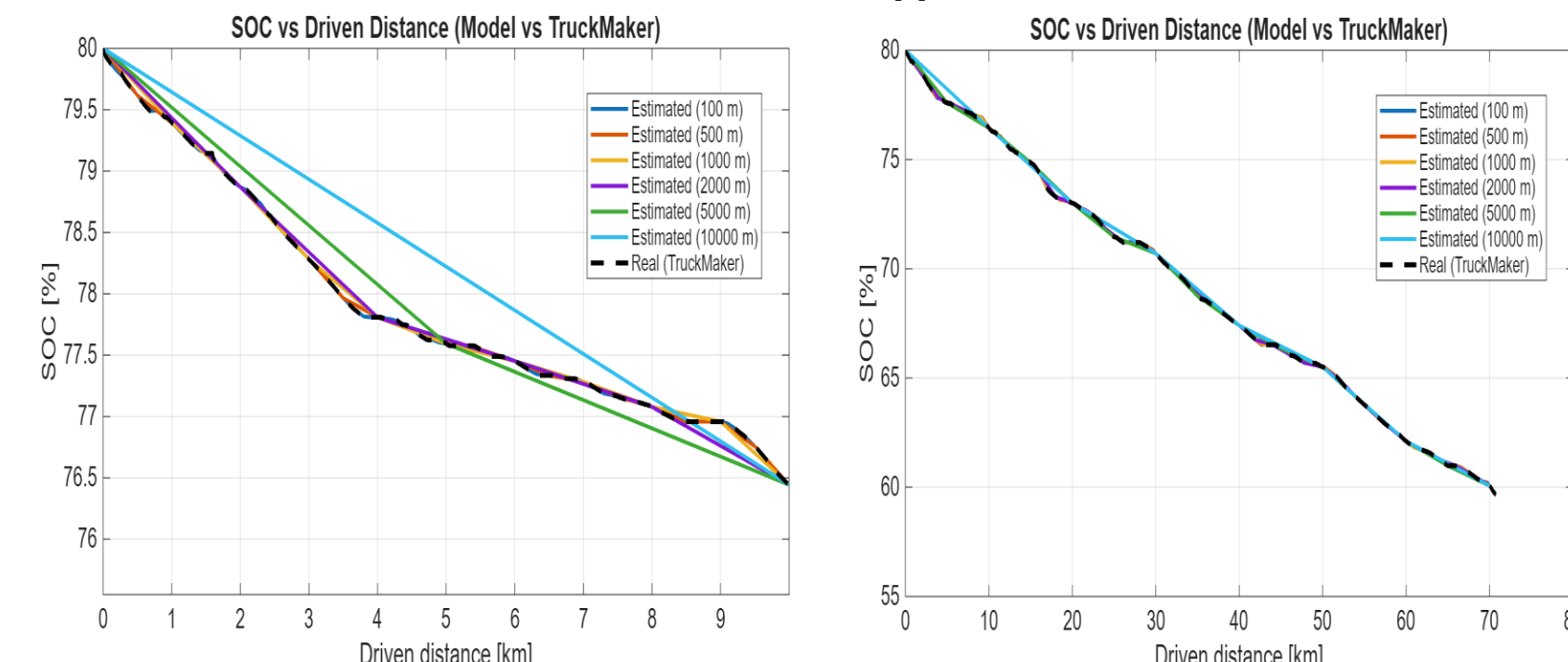
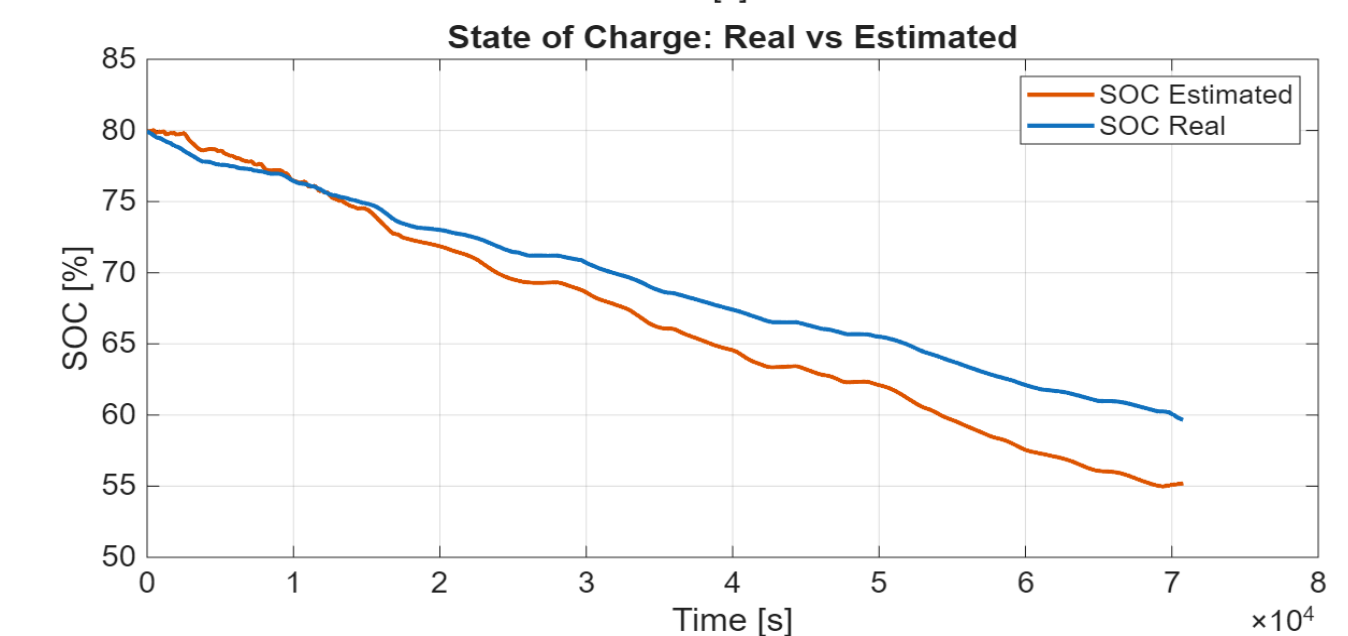
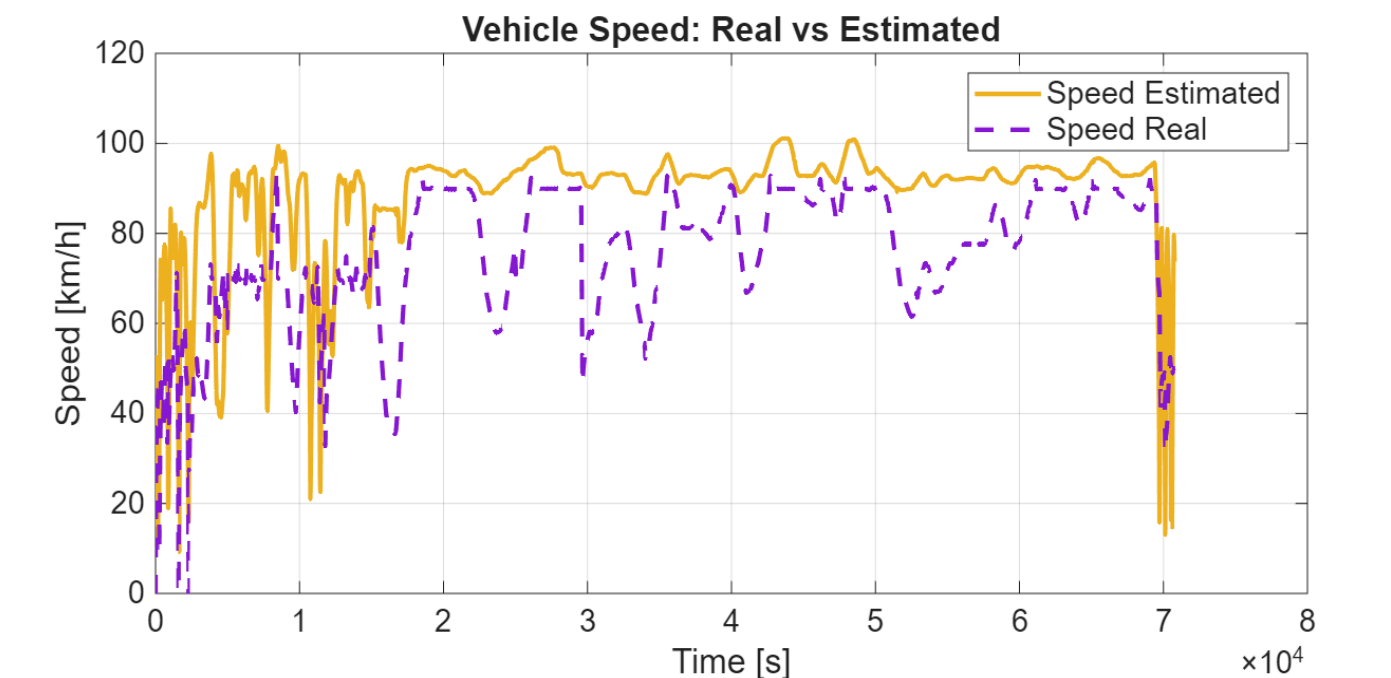
Range Estimator

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Results

The results show that estimation accuracy is influenced by re-estimation frequency, route conditions, and varying vehicle and environmental parameters.



Future Work

- Compare with vehicle log files from for instance Revere test lab.
- Validate both simulation model and Range Predictor, Try different routes
- Possibly try real truck at REVERE
- Changing parameters mid route, ex. Stops, GCW etc.
- Add real weather data

Poster 2:

***Turbulence signal approximation at
unsimulated yaw angles,***

William Kumlien, Chalmers & VCC

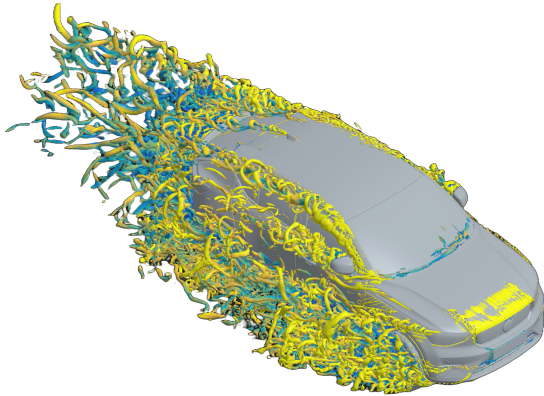
Simulating Transient Crosswind Aerodynamics

Enhancing Realism in the Volvo Cars Driving Simulator

William Kumlien

Lund University & Volvo Cars

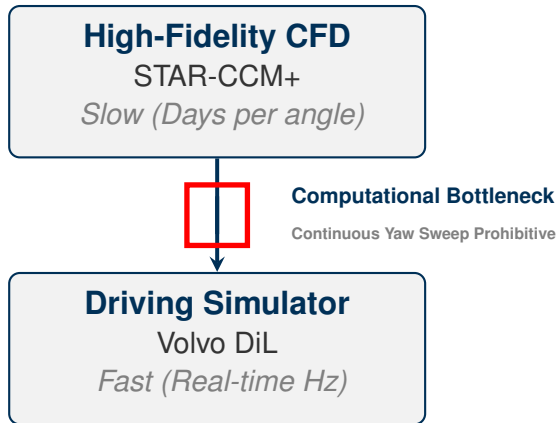
The Reality of Crosswinds



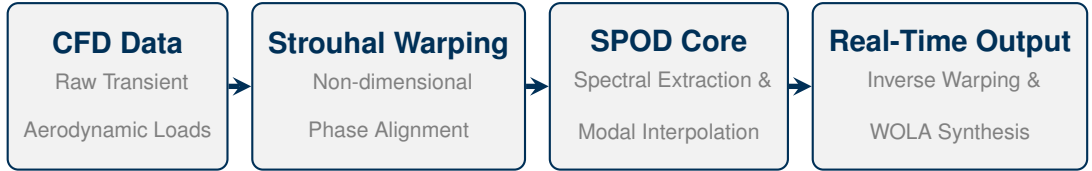
- Flow separation
- Coherent vortex shedding
- **Transient load shocks**

The Computational Bottleneck

- **High-fidelity CFD**
Accurate but prohibitively slow
- **Driving Simulator**
Requires instantaneous data
- **The Gap:**
Continuous Yaw Angles



Bridging the Gap: Data-Driven SPOD



Result: Computationally inexpensive, continuous turbulence synthesis.

Impact: The Volvo Cars Simulator



- Driver-in-the-Loop validation
- True transient stability analysis
- **Safer, predictable handling**

Thank You

Questions?

Data-Driven Reduced Order Modeling of Transient Vortex Shedding Across Continuous Yaw Angles

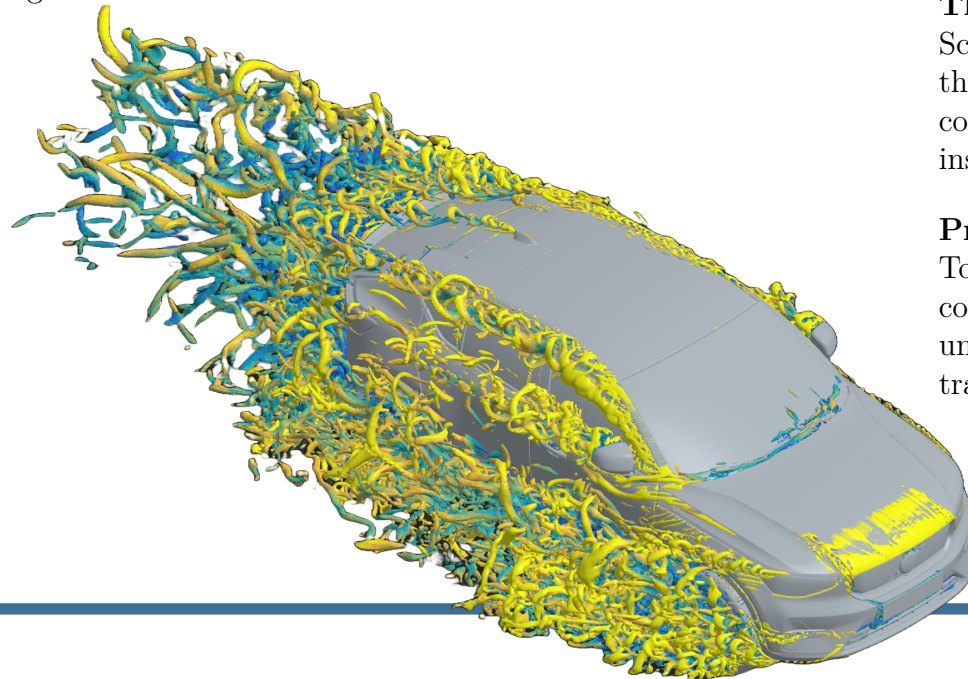
William Kumlien

Lund University & Volvo Cars

The Simulator Challenge

Vehicle aerodynamic restrictions traditionally rely on time-averaged (“mean”) forces due to the extreme difficulty of measuring high-frequency turbulence in physical wind tunnels.

However, real-world crosswinds cause bluff-body flow separation, resulting in highly periodic and energetic vortex shedding. These transient forces and moments heavily impact vehicle stability and steering feedback.



The Computational Barrier

Scale-resolving CFD (e.g., STAR-CCM+ DES/LES) captures these physics accurately but is computationally prohibitive for continuous yaw sweeps. Real-time driving simulators require an instantaneous, continuous aerodynamic surrogate model.

Project Objective

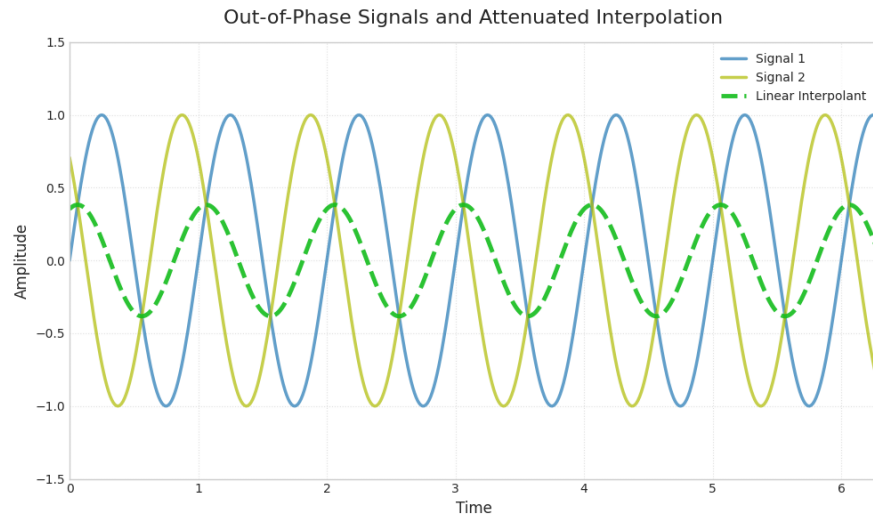
To develop a data-driven Reduced Order Model (ROM) that reconstructs full time-history turbulence signals at any continuous, unsimulated yaw angle, empowering engineers to evaluate true transient stability in real-time.

The Frequency-Yaw Dependency

Vortex shedding frequencies shift non-linearly with the vehicle's yaw angle due to the changing effective bluff-body width (L). This is governed by the Strouhal relationship:

$$St = \frac{f_{St}L}{U_{\infty}}$$

The Phase Barrier: Direct temporal interpolation between discrete yaw angles averages mismatched phases (e.g., combining a peak with a trough), causing destructive interference and artificial amplitude attenuation.



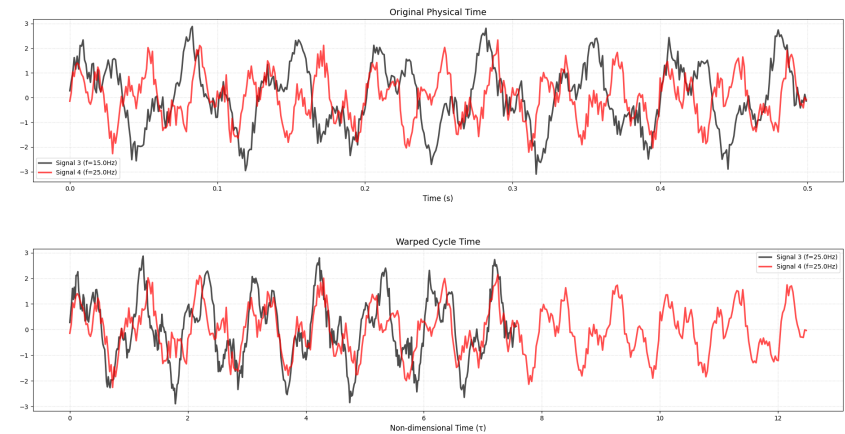
Amplitude Attenuation due to Phase Mismatch.

Dynamic Time Warping

To synchronize the shedding cycles, the physical time vector t is non-dimensionalized into a phase variable τ (Strouhal Scaling):

$$\tau = f_{St}(\theta)t \implies \tilde{y}(\tau, \theta) = y\left(\frac{\tau}{f_{St}(\theta)}, \theta\right)$$

Independent CFD training runs are first cross-correlated to a 0° reference angle to ensure all arrays commence at the identical shedding phase.



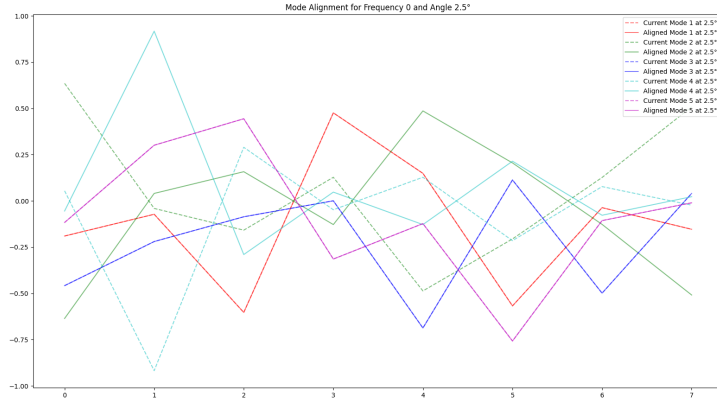
Frequency alignment via Strouhal scaling.

Spectral Proper Orthogonal Decomposition

Unlike spatial POD, SPOD enforces strict temporal coherence by operating on Welch frequency-domain blocks ($\hat{\mathbf{Q}}_f$). Because the system is bounded by 8 macroscopic aerodynamic coefficients, the spatial cross-spectral density matrix is a tractable 8×8 system. The spatial modes ($\mathbf{U}_f$) and temporal coefficients ($\mathbf{A}_f$) are extracted via the economy SVD for numerical stability:

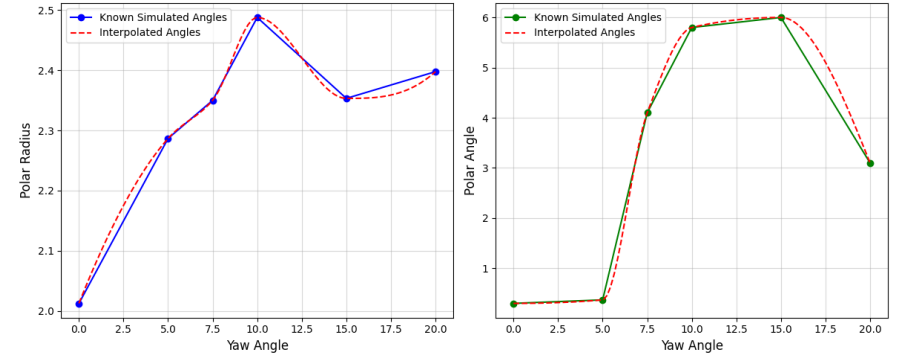
$$\frac{1}{\sqrt{K-1}}\hat{\mathbf{Q}}_f = \mathbf{U}_f \mathbf{\Sigma}_f \mathbf{V}_f^*$$

Eigenmodes are globally phase-aligned to prevent polar interference, and then interpolated across yaw in polar coordinates.



Eigenmodes before and after phase-alignment.

These modes represent a coherent coupling pattern between forces and moments at a given frequency.



Interpolation of the 1st singular value across yaw.

Weighted Overlap-Add (WOLA)

To prevent boundary discontinuities caused by modal truncation, the reconstructed Inverse-FFT blocks are double-windowed. The global signal is normalized by the squared window envelope (satisfying the COLA constraint) to strictly conserve physical kinetic energy:

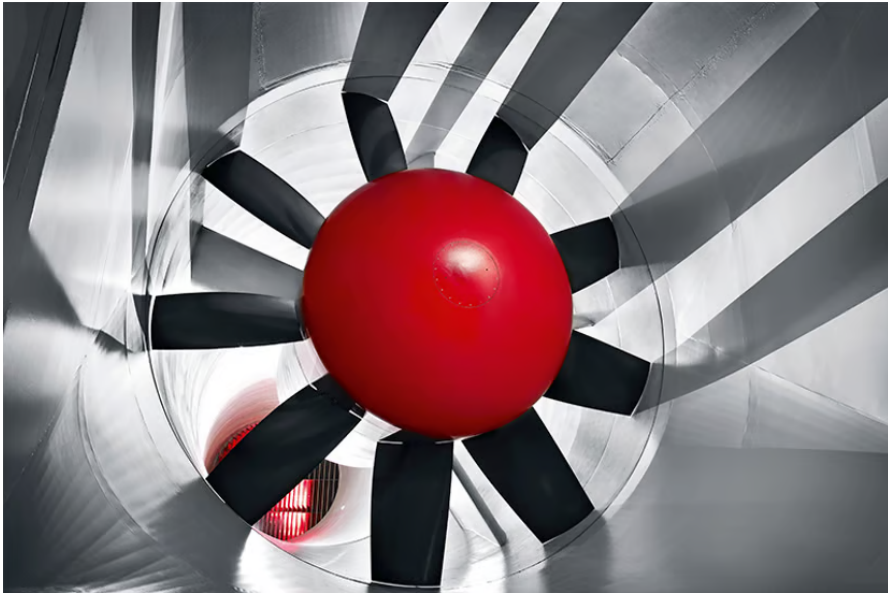
$$y_{final}(\tau, \theta^*) = \frac{\sum \mathbf{q}_b(\tau, \theta^*) w(\tau - \tau_b)}{\sum w^2(\tau - \tau_b)}$$

The Real-Time Reconstructor Algorithm

To deploy the generated aerodynamic signals into the Volvo Cars' Driving Simulator, a real-time explicit time-stepping algorithm—the *Reconstructor*—was developed.

While the dynamic signals could theoretically be implemented using multi-dimensional lookup tables, storing and querying massive arrays of time-series data is highly memory-intensive and computationally prohibitive for real-time hardware.

To circumvent this, the Reconstructor synthesizes continuous time-domain aerodynamic coefficients (C_l, C_d, C_{mz} , etc.) directly from the predicted signal frequency parameters (A, ϕ, f_k). To preserve physical stability during continuous yaw maneuvers, it utilizes a time-dependent linear cross-fading mechanism that enforces continuity between states. Optimized for deterministic execution, the module strictly uses pre-allocated static arrays to satisfy rigid simulator constraints.



Driver-in-the-Loop Evaluation

Because mathematical error does not always map linearly to human perception, ultimate validation is performed by a professional test driver.

The driver will evaluate the following methodologies:

1. Direct Temporal Interpolation
2. Direct Spectral Interpolation
3. Strouhal-Scaled Temporal
4. Harmonic Component Extraction
5. Standard Snapshot POD
6. Spectral POD

Conclusion

By effectively bridging high-fidelity computational fluid dynamics with real-time hardware constraints, this data-driven framework successfully captures the fundamental mechanics of transient vortex shedding without sacrificing spatio-temporal coherence.

Coupled with the Reconstructor algorithm, the system synthesizes highly realistic aerodynamic buffeting across continuous, unsimulated yaw angles. This novel approach circumvents the reliance on static mean loads and memory-intensive lookup tables, ultimately empowering engineers to evaluate true transient vehicle stability and steering feedback in a dynamic simulation environment.

Poster 3:

***Steer-by-wire with closed-loop yaw rate
control,***

Mohammad Faddawi and Elmer Janmark, VCC

Steer-by-wire yaw rate disturbance rejection

Mohammad Faddawi – MPSYS Chalmers

Elmer Janmark – MPSYS Chalmers

Supervisor: Matthjis Klomp



Biography

- Master thesis students from Systems, Control & Mechatronics (MPSYS) at Chalmers
- Currently doing our master thesis at Volvo Cars, dept Steering
- We will present the results and findings from our thesis work on SbW yaw rate control.

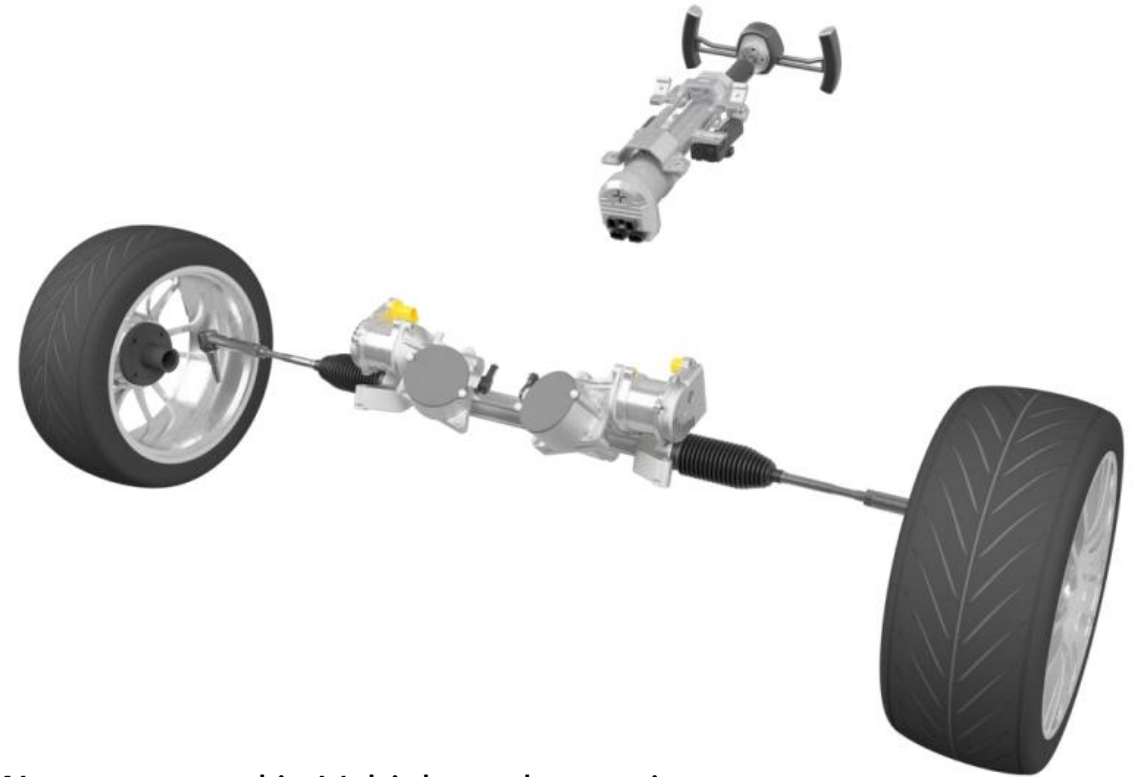
Elmer Janmark
ejanmark@volvocars.com

Mohammad Faddawi
mfaddawi@volvocars.com



Steer-by-Wire (SbW)

- No mechanical connection between steering wheel and the road wheels.
- Road wheels can be steered independently from the steering wheel
- Using Angle overlay



SbW system used in Vehicle and test-rig

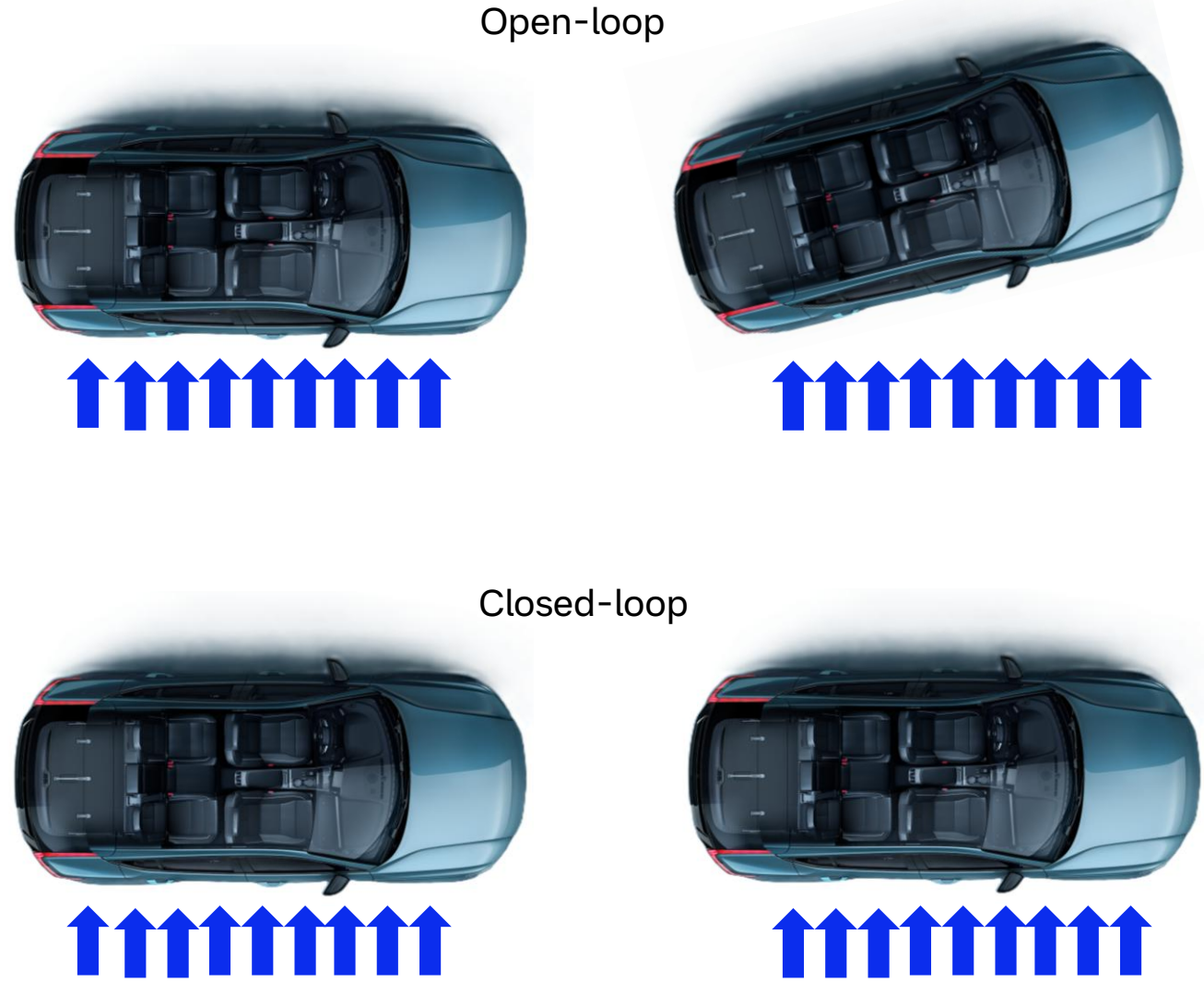
Challenge

Problem:

- Current open-loop lack ability to filter out body disturbances on the car (e.g, crosswinds)

Solution:

- Design a **closed-loop yaw rate controller** to apply corrective steering action (without affecting the steering wheel angle) to **counteract disturbances**



Reference model

- Based on the linear single track (bicycle) model
- System identification
- Model validation

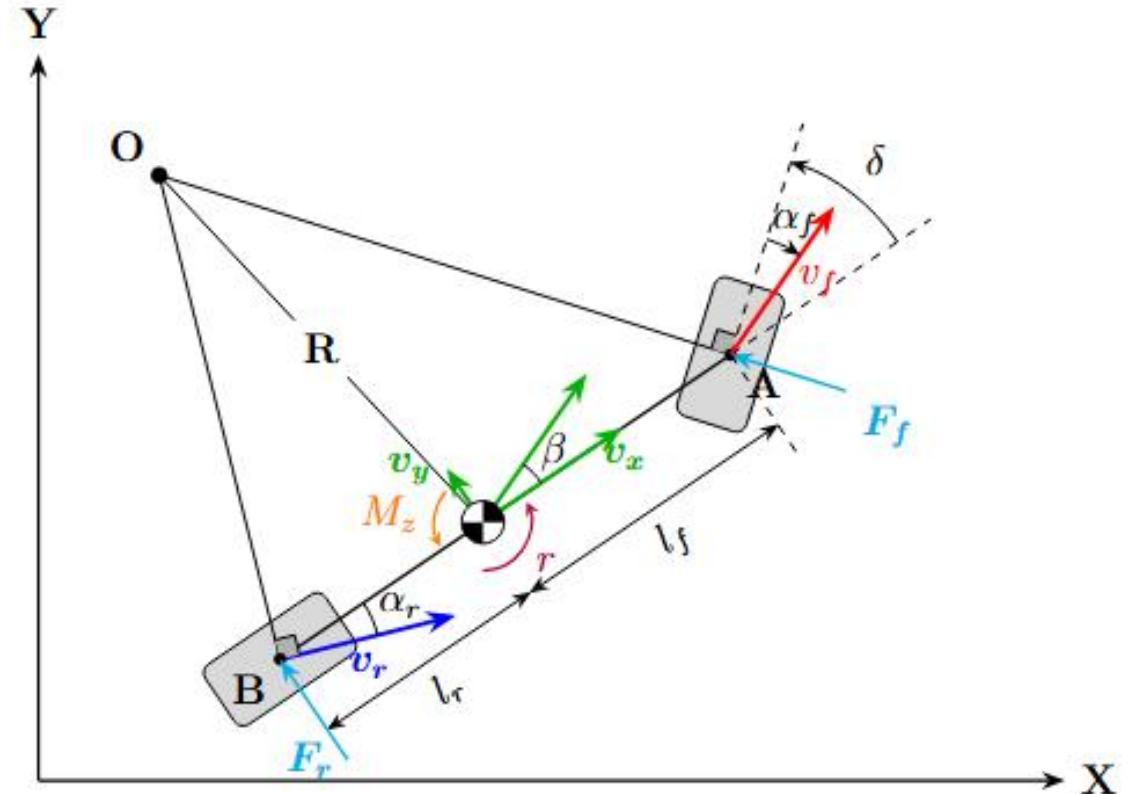
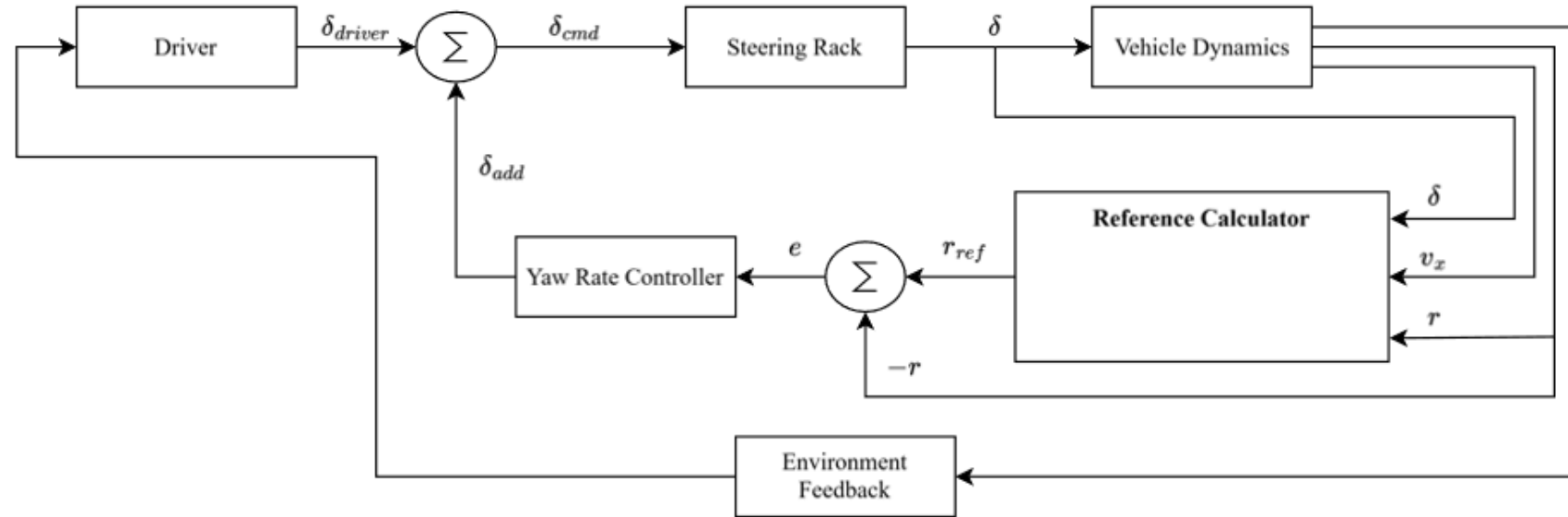


Figure 2.1: Linear Bicycle Model

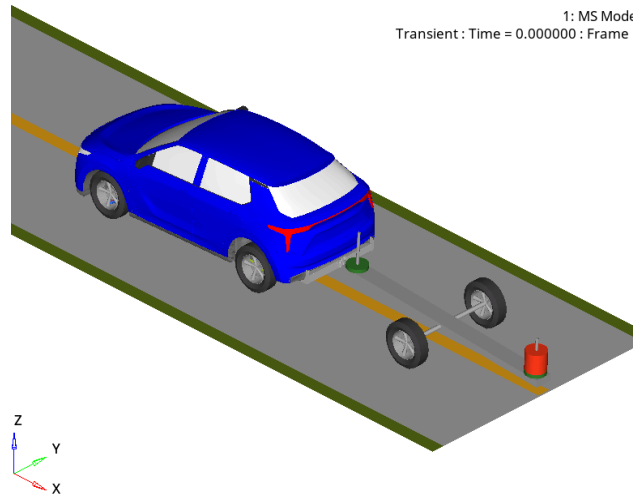
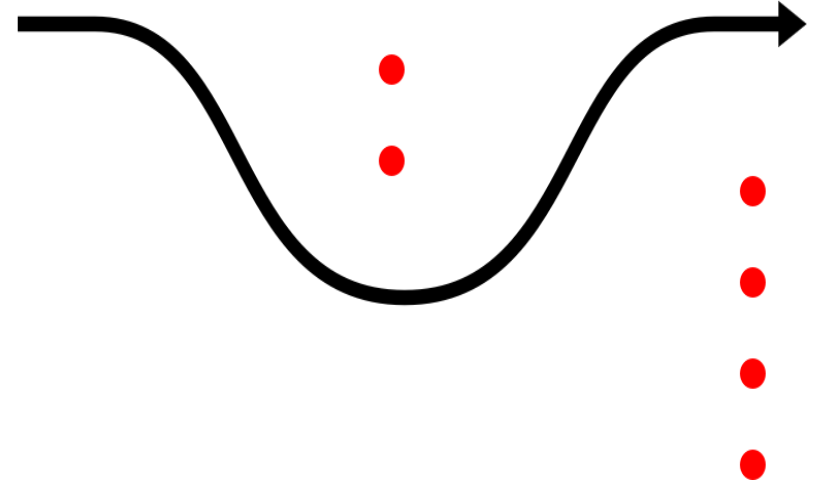
Controller design

- P-controller using steady state as reference and IMU measurements to calculate error.
- Controller will add steering angle overlay based on calculated error
- Implemented using CANoe

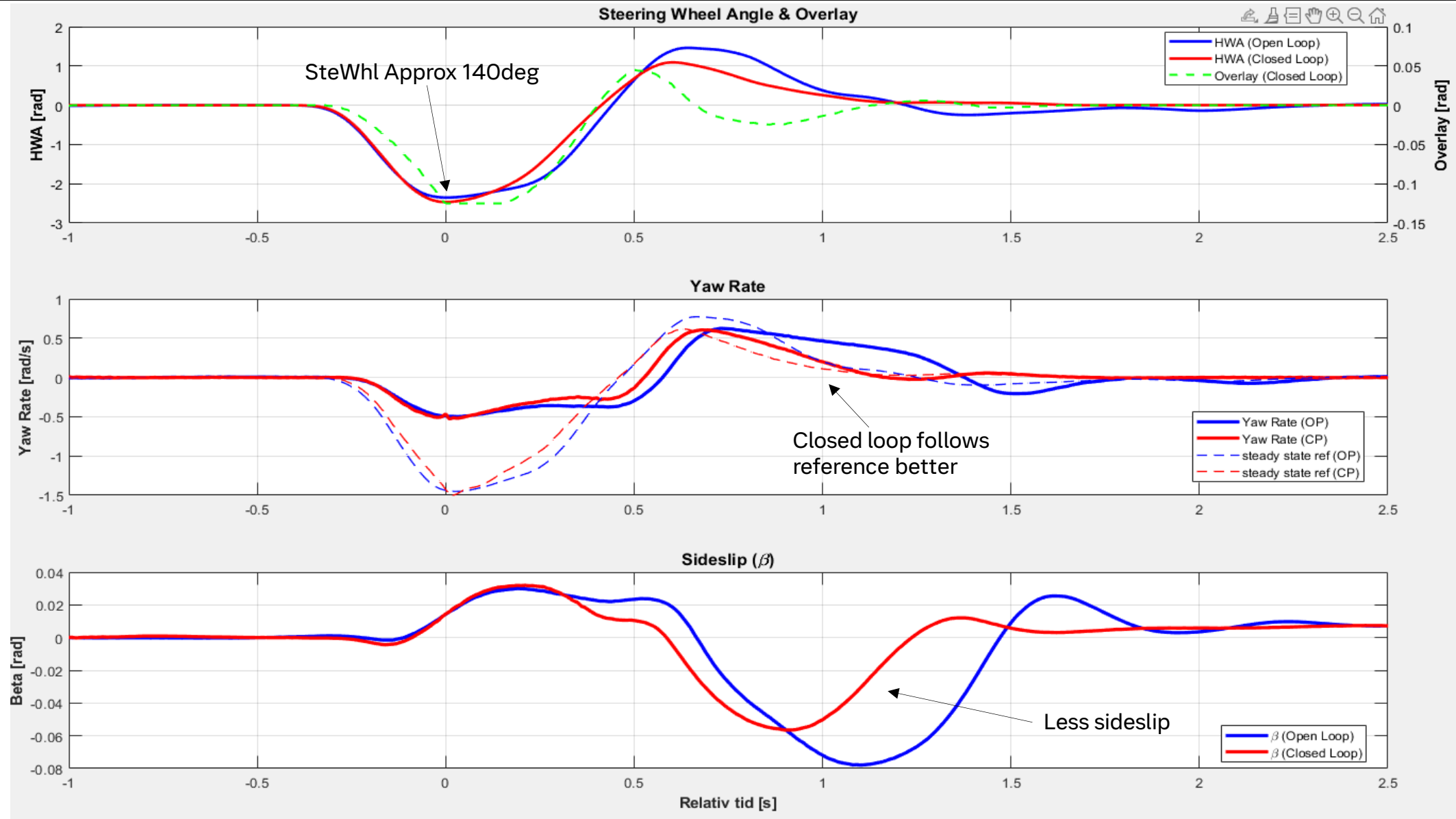


Open-loop vs Closed-loop evaluation

- Lane changes
- Step-steers
- Phase-delay comparison
- Unstable trailer



Aggressive Lanechange 80km/h

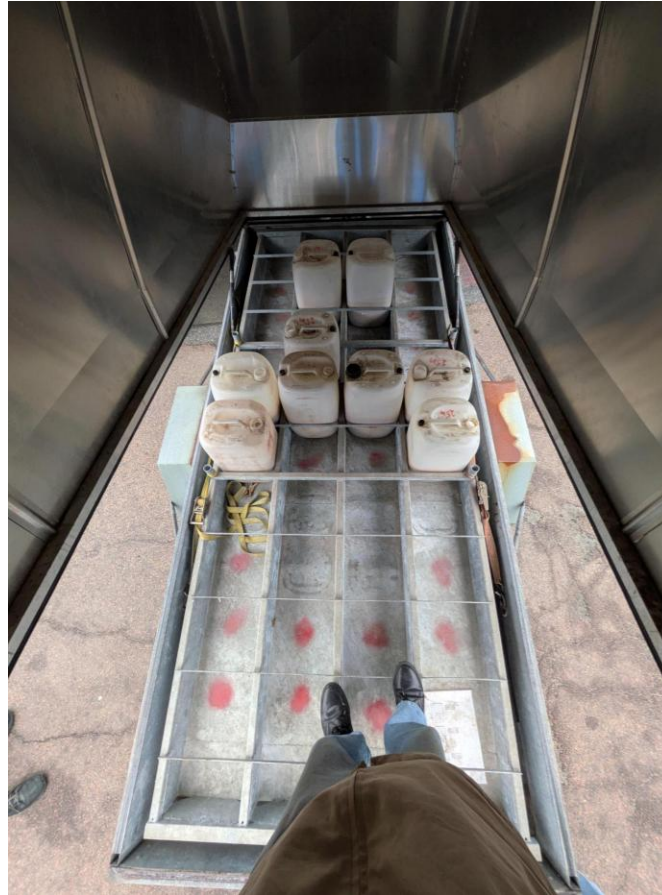


Trailer test setup

- Weight of trailer with cage and weights: 750kg
- Driving on TT-track 80km/h doing random input maneuvers
- Trailer acts as a disturbance

Two test cases:

- Normal loaded
- Back heavy load, negative tow hook pressure



Normal load



Back heavy load

Table 3.9: Quantitative performance comparison between the open-loop baseline and the active closed-loop controller during the dynamic trailer towing maneuvers.

Performance Metric	Open-Loop	Closed-Loop	Improvement
Load Configuration 1 (Standard Load)			
Mean RMS Error (rad/s)	0.01944	0.01466	24.6 %
Mean Peak Error (rad/s)	0.04208	0.04393	-4.4 %
Mean Phase Delay (s)	0.091	0.058	37.0 %
Load Configuration 3 (Rear-Biased Load)			
Mean RMS Error (rad/s)	0.0252	0.0159	36.8 %
Mean Peak Error (rad/s)	0.0815	0.0593	27.2 %
Mean Phase Delay (s)	0.098	0.056	42.5 %

Thank you for your attention, see you at our poster!

V O L V O

Steer-by-wire yaw rate disturbance rejection

Mohammad Faddawi – MPSYS Chalmers (mfaddawi@volvocars.com)

Elmer Janmark – MPSYS Chalmers (ejanmark@volvocars.com)

Supervisor - Matthjis Klomp



Problem:

- Current open-loop lack ability to filter out body disturbances on the car (e.g, crosswinds)

Aim:

- Design a **closed-loop yaw rate controller** to apply corrective steering action (without affecting the steering wheel angle) to **counteract disturbances**

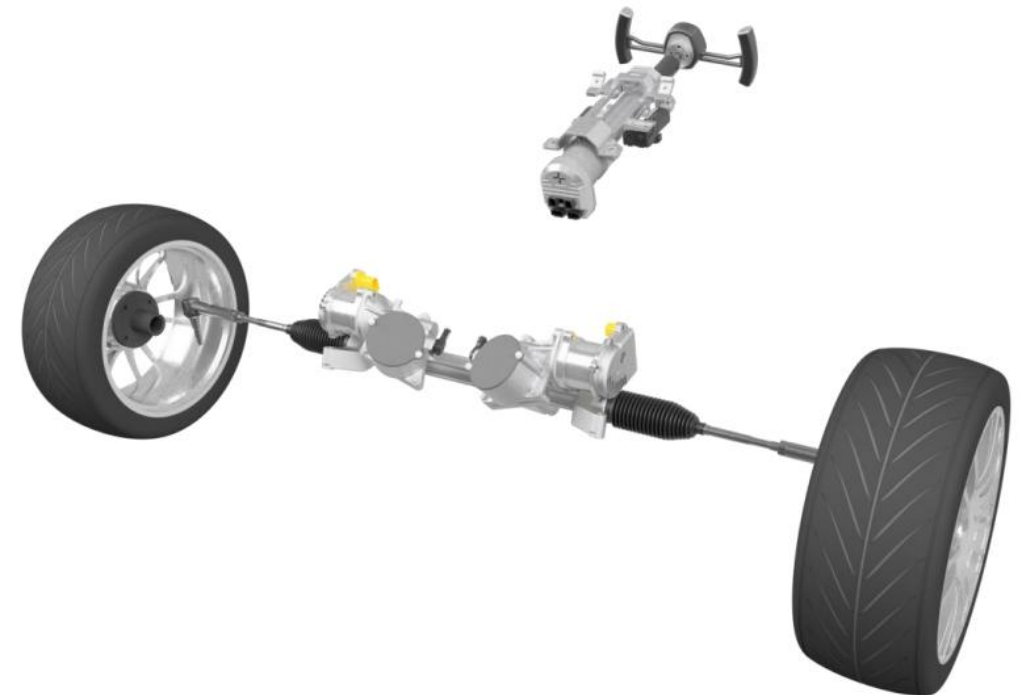
Open-loop



Closed-loop



SbW system used in Vehicle and test-rig



- No mechanical connection between steering wheel and the road wheels.
- Road wheels can be steered independently from the steering wheel
- Using angle overlay

Modelling and System Identification

Reference model: Linear single track model

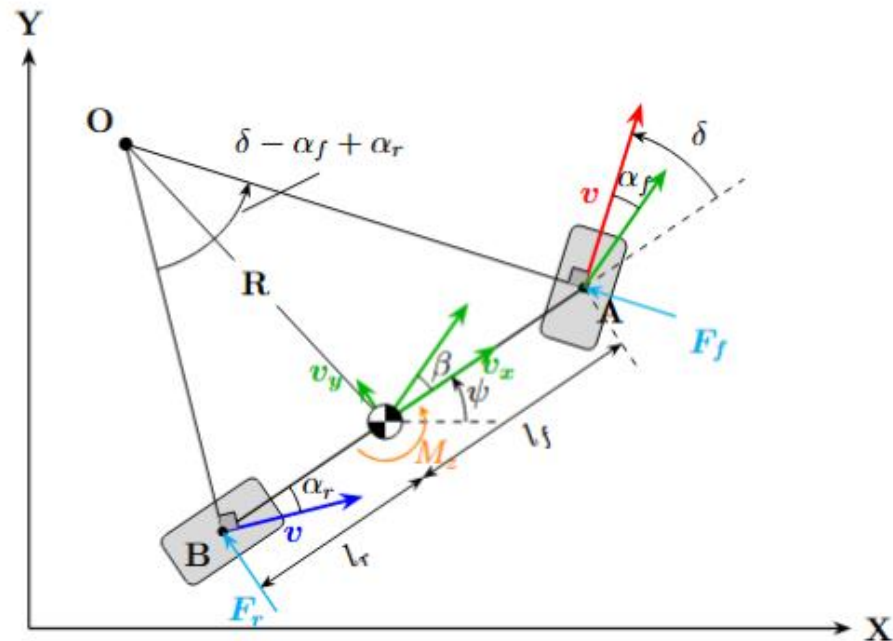
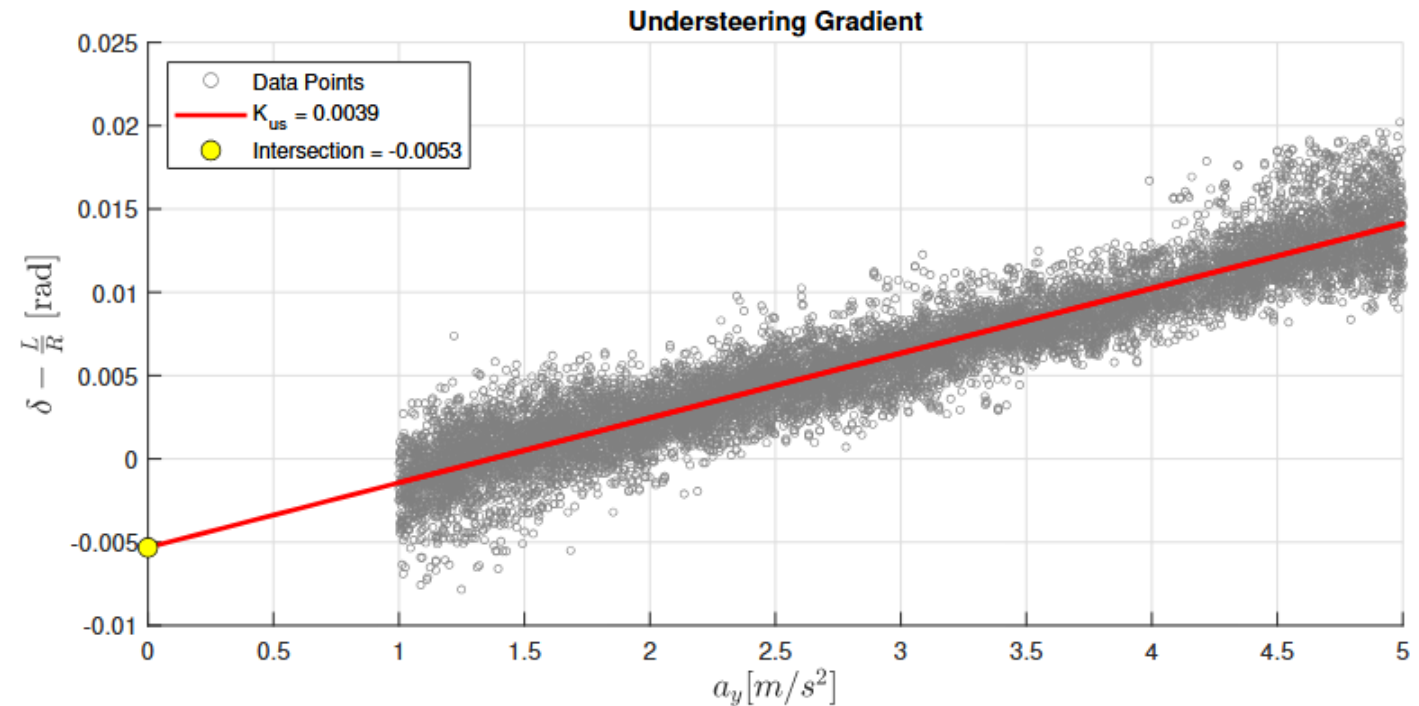
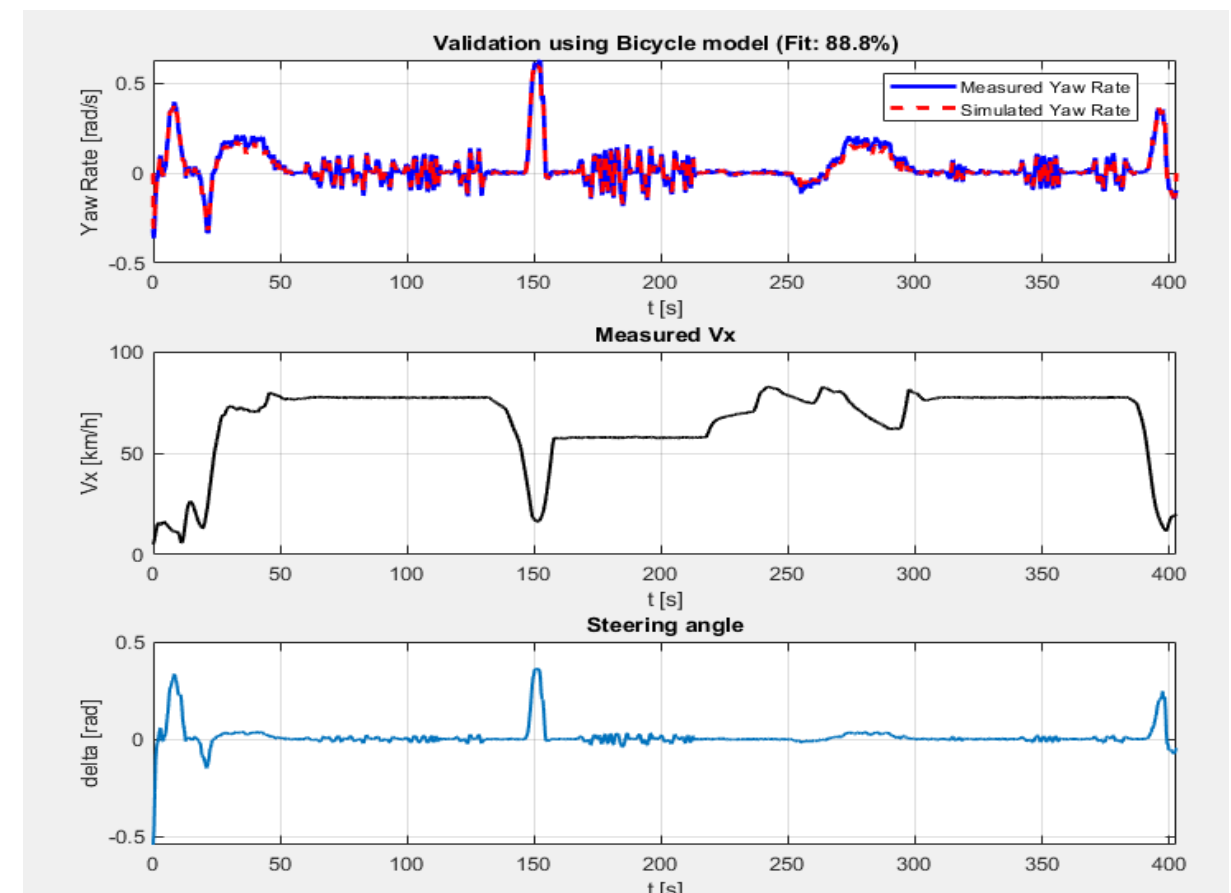


Figure 2.1: Linear Bicycle Model



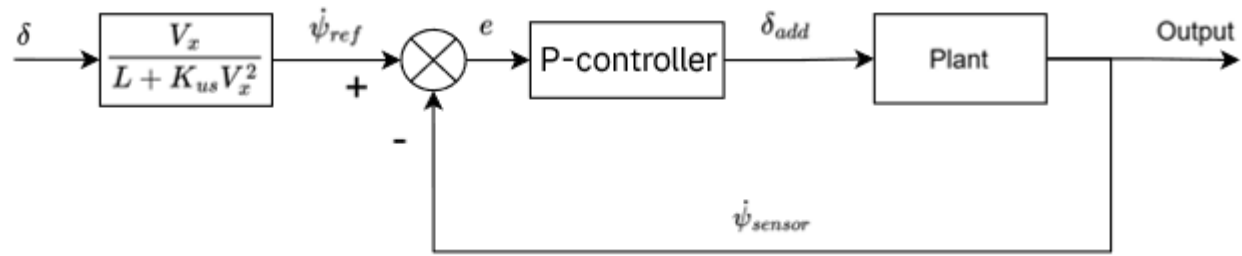
Validation of model:

- Reference model: Linear single track model
- Steady-state circular driving to find Understeer Gradient
- Sinus-Sweep Driving to find the vehicle parameters for cornering stiffness (C_f , C_r). To be used in simulation and tuning.
- Independent data-set for validation



Steady-state yaw rate
as reference

Closed-Loop



Aggressive lane change
80km/h test

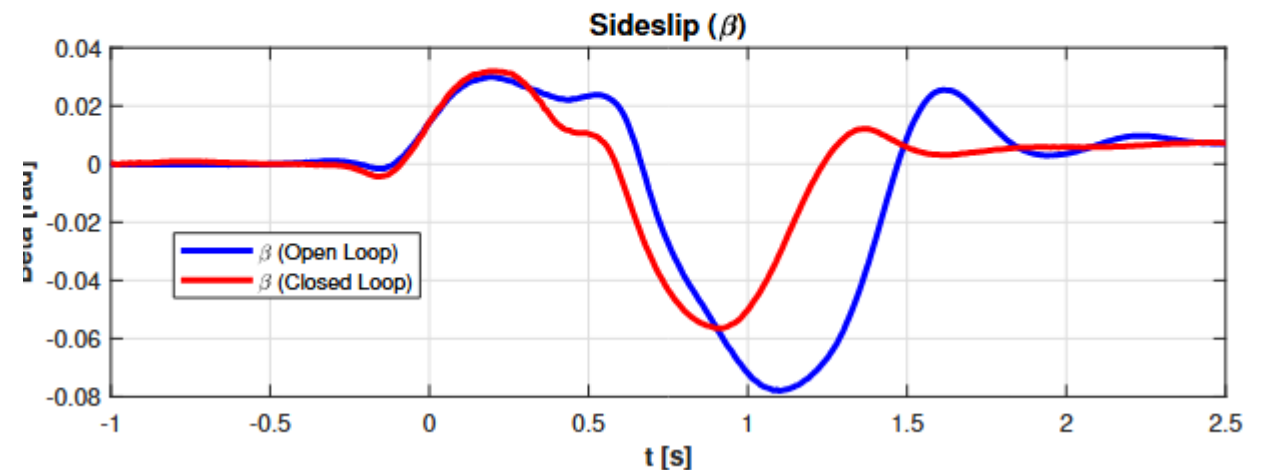
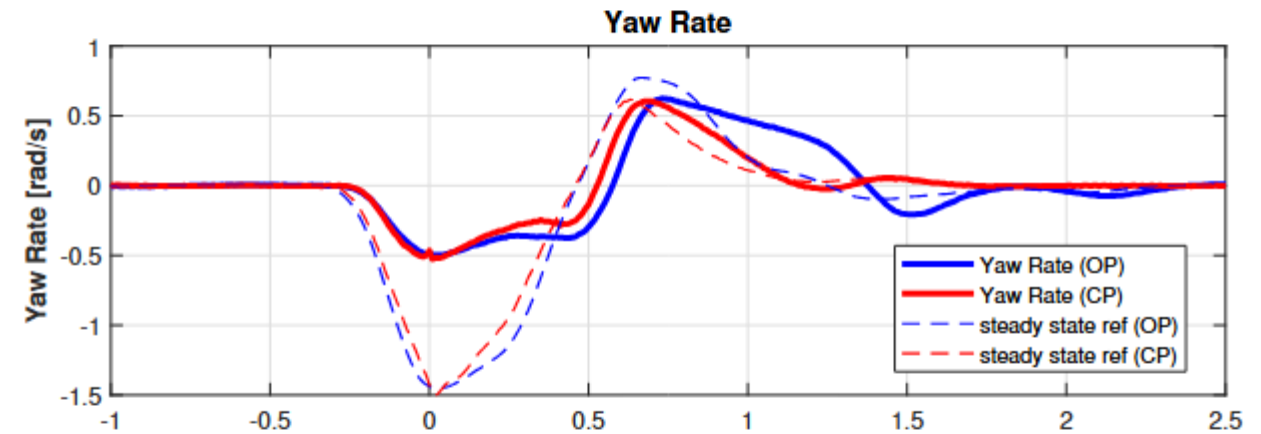
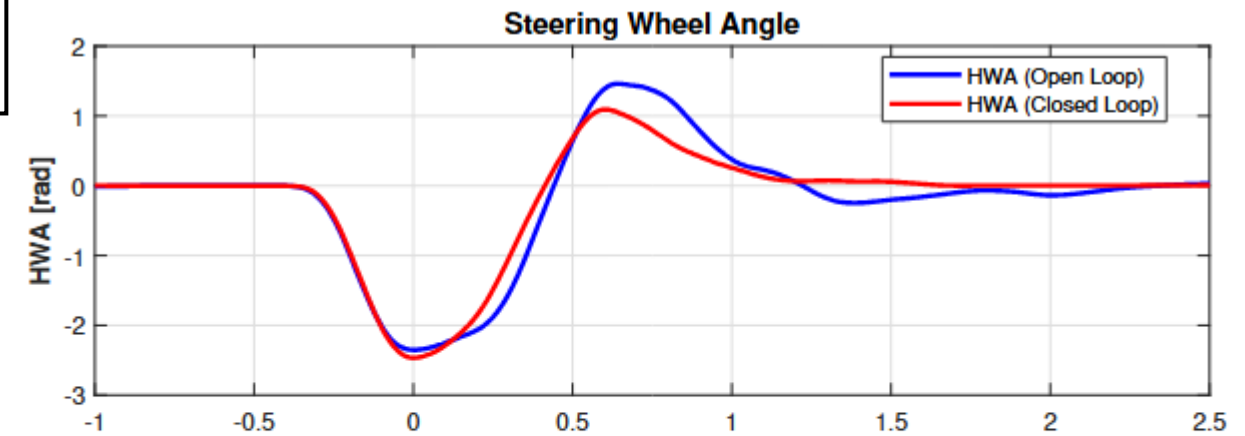
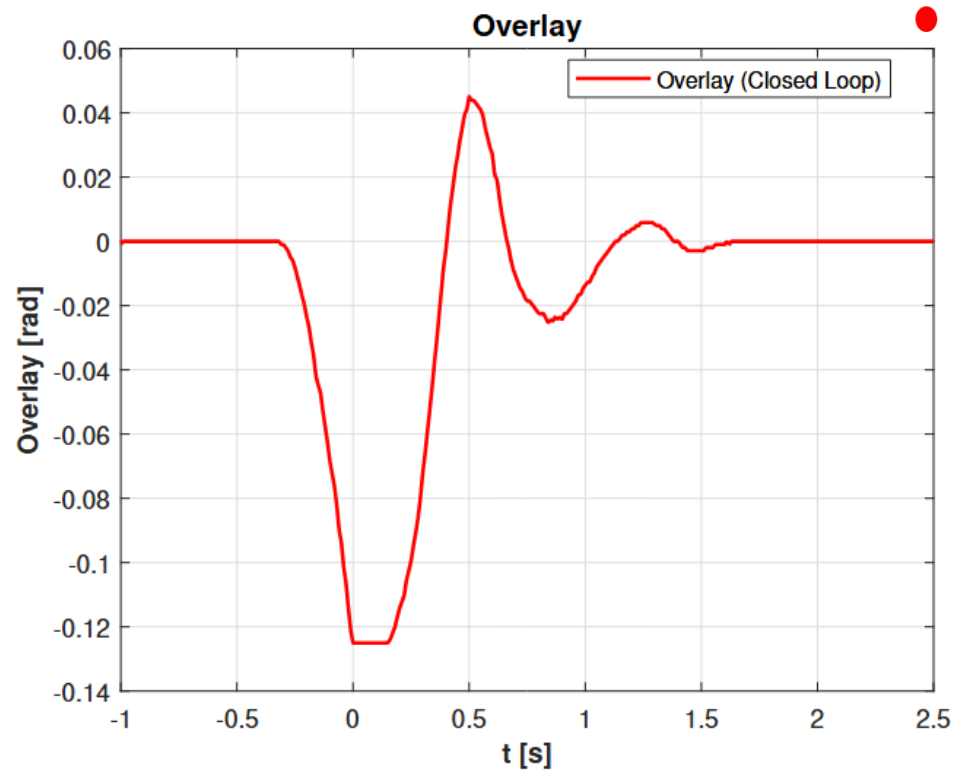


Figure 3.18: Active steering overlay (δ_{add}) applied by the controllers during the lane change maneuver demonstrating strict compliance with the $\pm 7^\circ$ hardware limit.

Trailer as yaw rate disturbance test

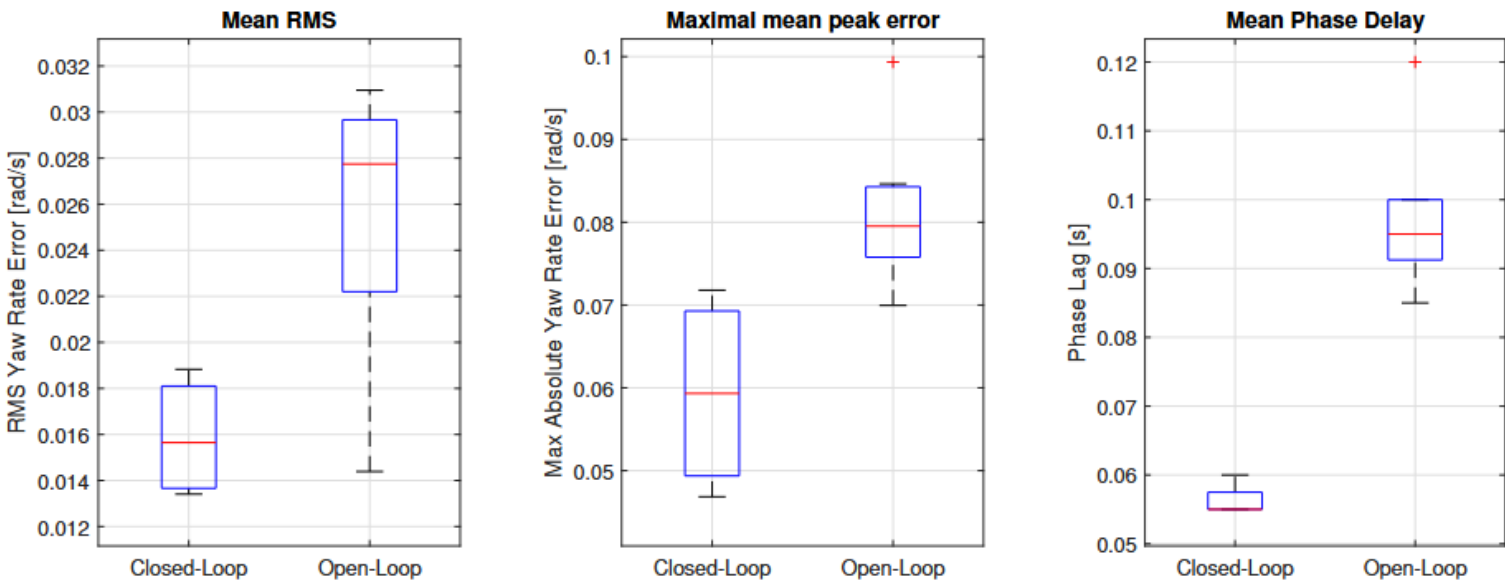
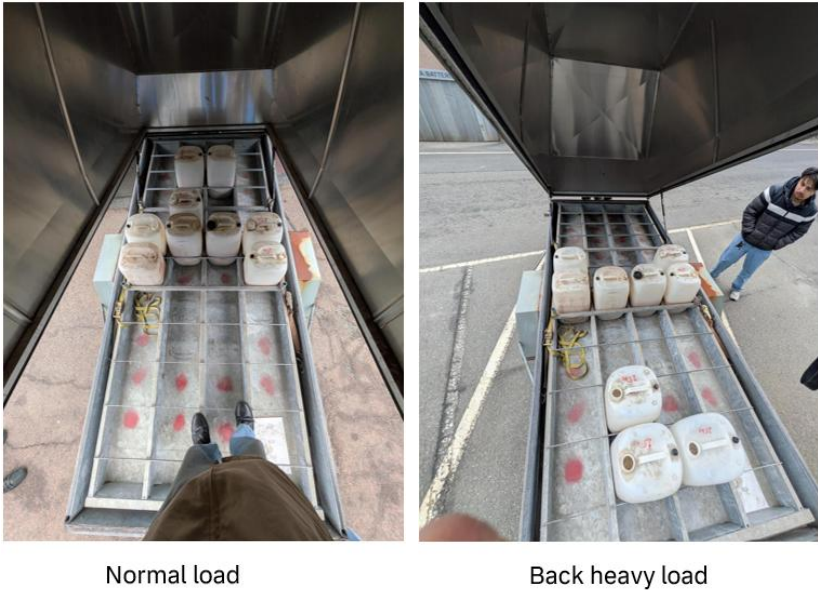


Figure 3.20: Boxplots illustrating the performance metrics when subjected to severe trailer sway induced by the negative tow hook weight (Configuration 2).

Conclusion

- SbW controller can be used to minimize disturbances on vehicle
- Limited to linear single track model but still improvement outside linear region
- Parameters Variations: The controller was able to compensate for the variations by providing a suitable reference

Table 3.9: Quantitative performance comparison between the open-loop baseline and the active closed-loop controller during the dynamic trailer towing maneuvers.

Performance Metric	Open-Loop	Closed-Loop	Improvement
Load Configuration 1 (Standard Load)			
Mean RMS Error (rad/s)	0.01944	0.01466	24.6 %
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Mean Peak Error (rad/s)	0.0815	0.0593	27.2 %
Mean Phase Delay (s)	0.098	0.056	42.5 %

Poster 4:

***Experimental validation of road friction and
slope estimation models for enhanced AEB
performance in heavy trucks,***

Malte Håkanson, KTH & Scania/Traton



Road friction and slope estimation in a heavy truck

For improved Advanced Emergency Braking system performance with experimental validation

Degree project, in Vehicle Engineering, second level

Who am I?

- Malte Håkanson
- Degree Programme in Vehicle Engineering at KTH Royal Institute of Technology
 - Master in Vehicle Engineering
- Degree project, in Vehicle Engineering
 - In collaboration with TRATON R&D/Scania



TRATON

Advanced Emergency Brake system (AEB)

What is the AEB?

- Detects potential forward collision
- Full emergency braking
- Mandatory since 2013

Limitations

- Assumes perfect conditions
- Risk of braking too late when slippery/downhill

Scope of thesis

- Implement friction and slope estimation model in heavy truck
- Validate during real-world driving
- Investigate threshold parameter for potential adaptive AEB system

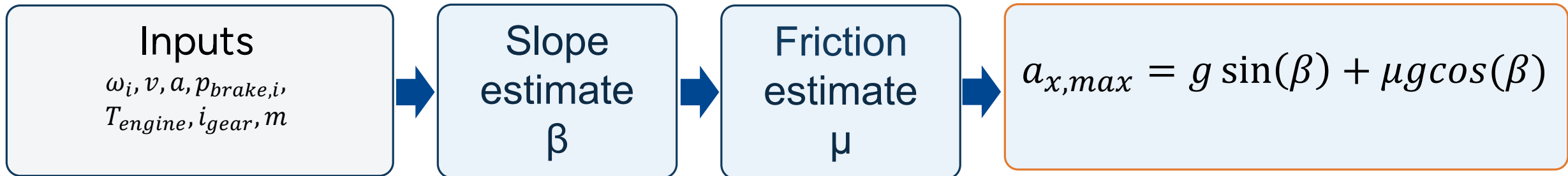
Model implementation

Estimator inputs

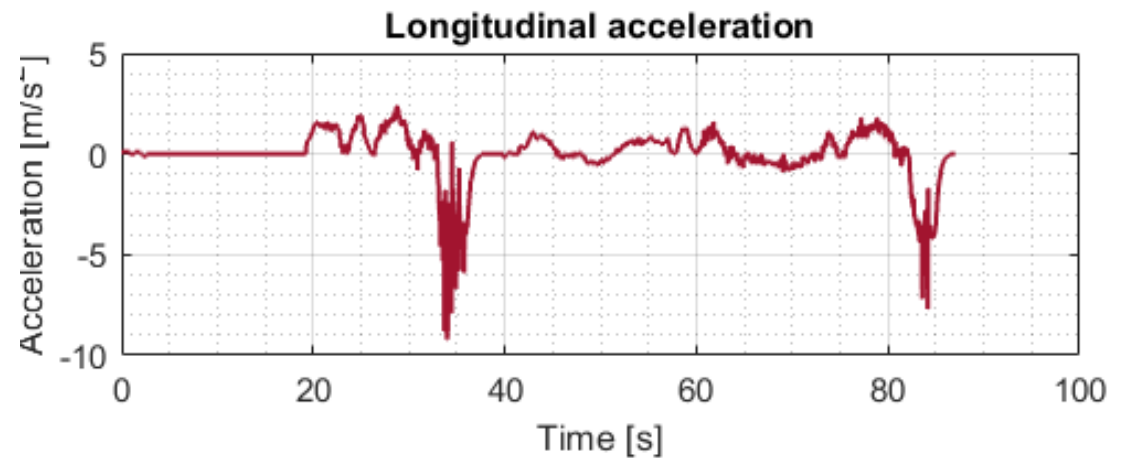
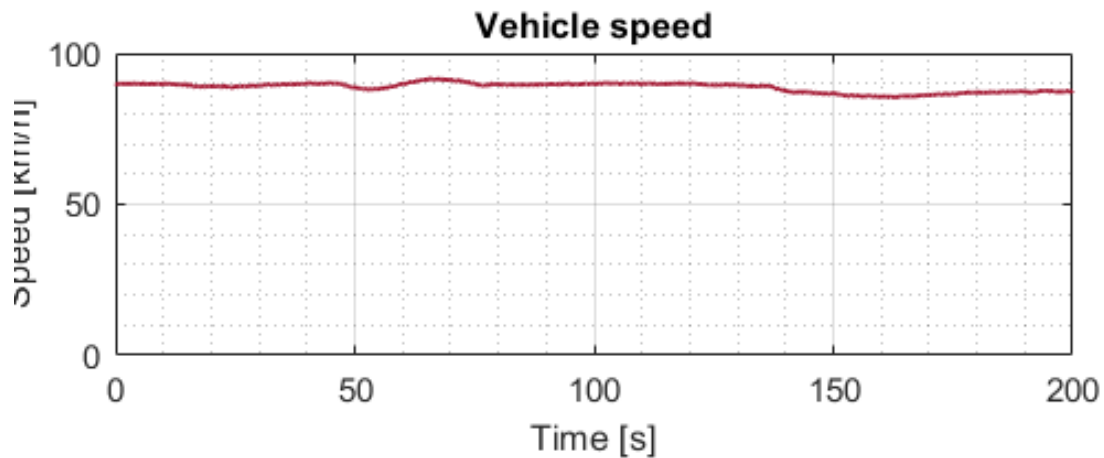
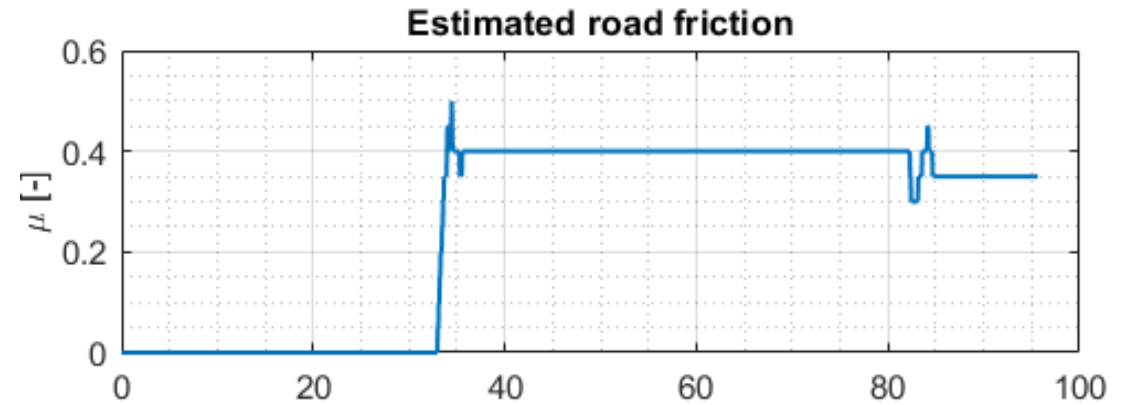
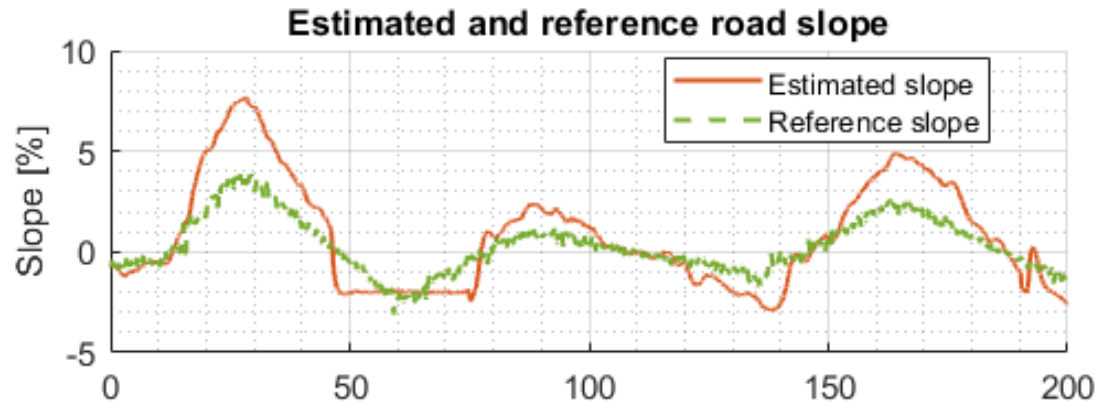
- Vehicle speeds and acceleration
- Brake cylinder pressures
- Engine torque and gear
- Mass

Model framework

- $\sum F = ma$
- Dugoff tire model
- Recursive Least Square (RLS)
- Kalman filter



Result highlights



System performance and conclusion

Slope estimation error

Driving case	Slope MAE [percentage points]
Mixed driving	1.319
Highway driving	1.120

Acceleration estimation error

Surface	Braking level	Peak a_x [m/s ²]	Estimated $a_{x,max}$ [m/s ²]	Δa_x [m/s ²]
Gravel	Full	4.0	3.0	1.0
Gravel	Almost full	3.8	3.4	0.4
Cobblestone	Full	5.0	4.0	1.0
Cobblestone	Almost full	4.5	4.0	0.5
Asphalt	Full	6.0	7.8	-1.8
Asphalt	Full	5.8	6.0	-0.2
Asphalt	Soft	0.5	6.0	0*
Asphalt	Soft	1.8	7.5	-1.5*

* Error calculated using the peak acceleration from the full braking event on asphalt (6.0 m/s²).

Limitations

- Adaptive AEB system not yet implemented
- Robustness needs improvement

Conclusion

- Friction and slope estimation validated in real-world driving
- Promising results for AEB implementation
- Relevant for use in other vehicle dynamics areas

Experimental validation of road friction and slope estimation models for enhanced AEB performance in heavy trucks

Advanced Emergency Braking system (AEB)

- Detects targets with radar and lidar
- Automatically brakes if collision is unavoidable
- AEB has been mandatory for new trucks in the EU since 2013

Problem

- Assumes ideal conditions

Presenter: Malte Håkanson

- Degree Programme in Vehicle Engineering at KTH
- Master Thesis in collaboration between Scania/Traton and KTH



TRATON

Objectives

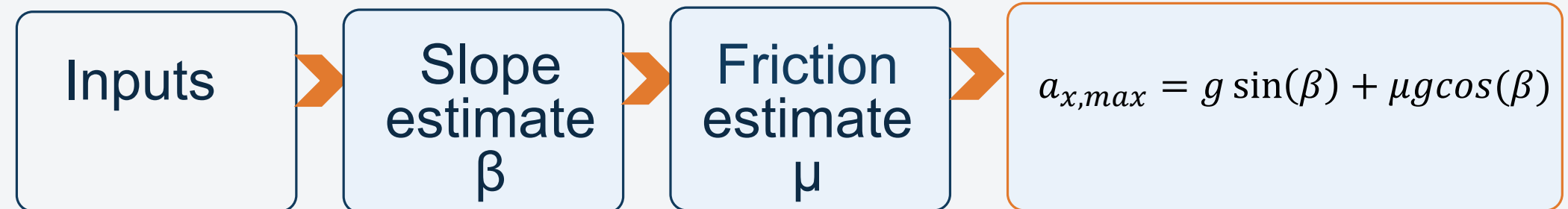
- Implement friction and slope estimation in a heavy truck.
- Use the estimates to calculate maximum available longitudinal acceleration
- Evaluate the signals as potential inputs to adaptive AEB

Key takeaway: The work focuses on making road condition information available for a potential adaptive AEB decision logic.

Estimator inputs

- Vehicle speed and acceleration
- Brake cylinder pressures
- Engine torque and gear
- Mass

Implementation flow

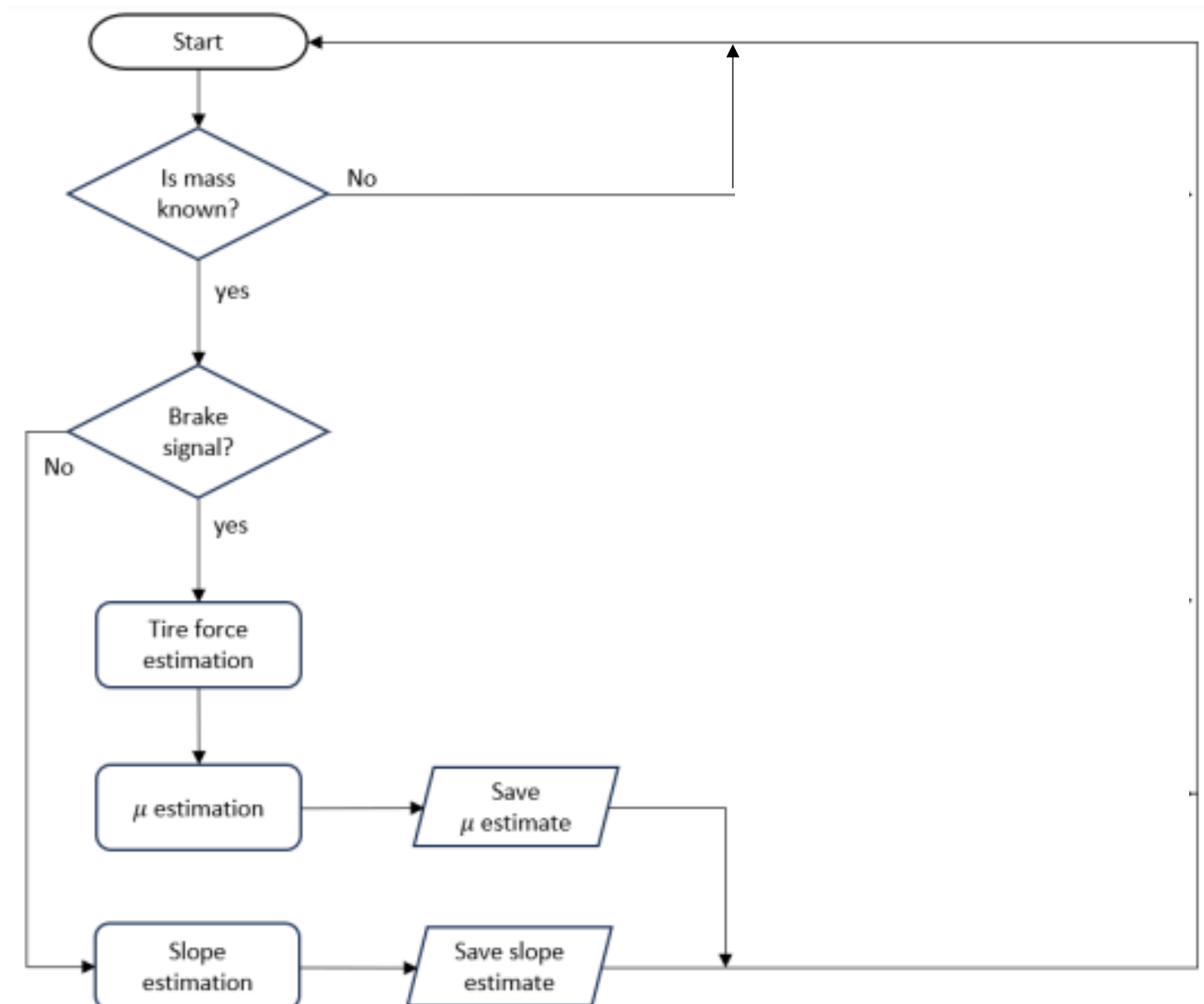


Model framework

- $\sum F = ma$
- Dugoff tire model
- Recursive Least Square
- Kalman filter

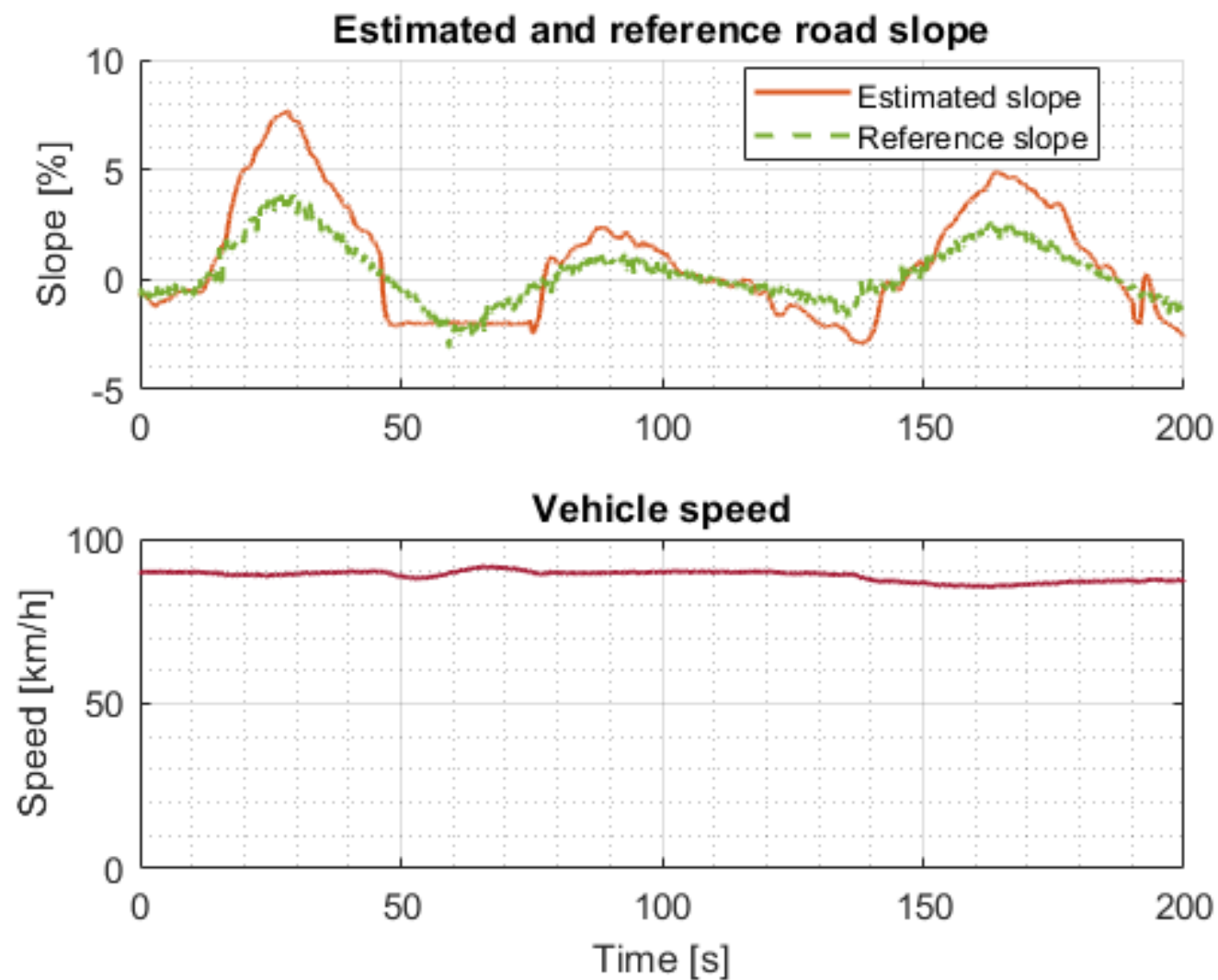
Test setup

- Models deployed on heavy truck
- Signals logged during real-world driving.
- Controlled braking events on asphalt, gravel, and cobblestone
- Mixed surfaces: asphalt, cobble stone, gravel

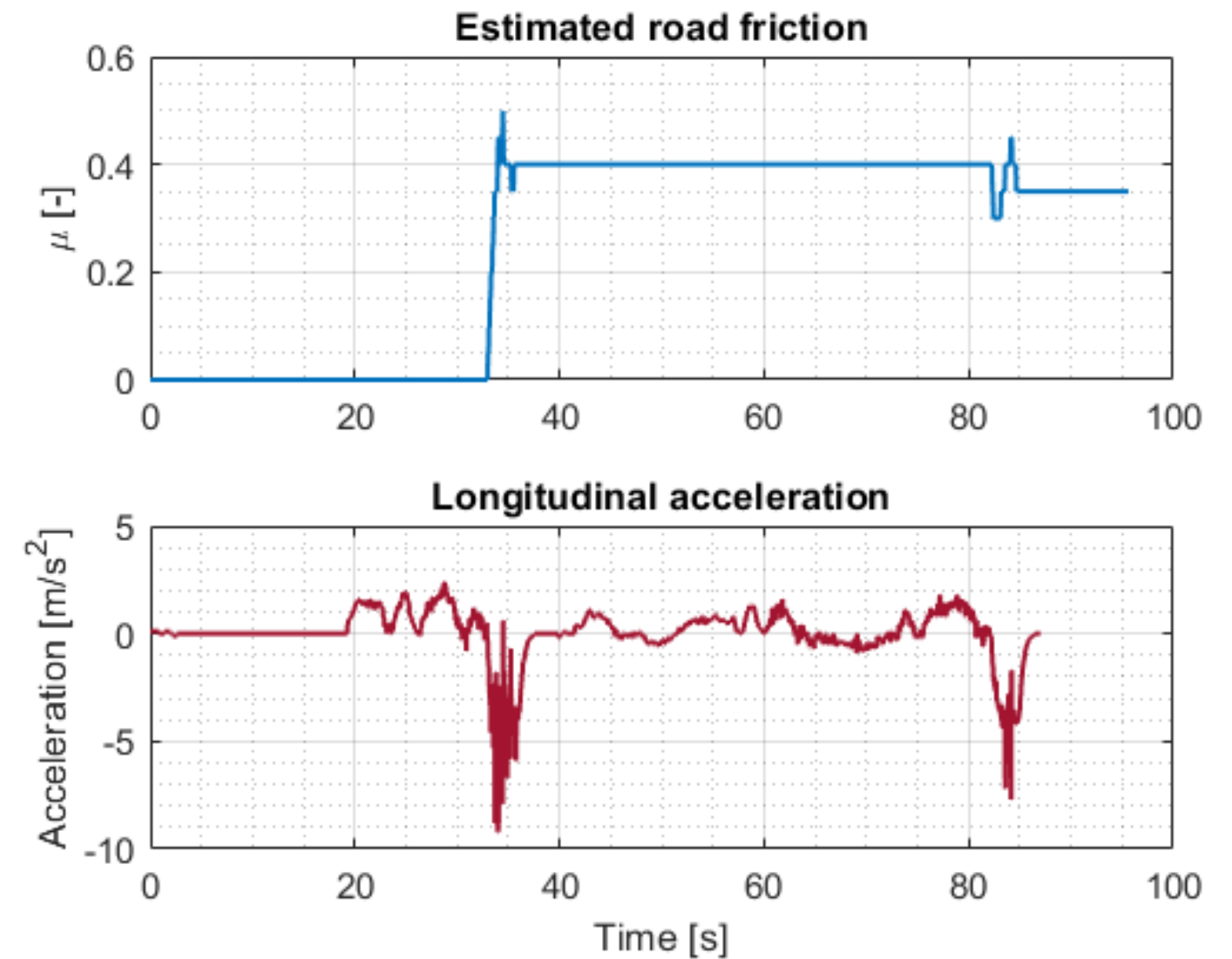


Key takeaway: The implemented on a truck ECU

Slope estimation on highway



Friction estimation on low friction surface (gravel)



The estimated slope Mean Average Error (MAE) for both highway and mixed driving

Driving case	Slope MAE [percentage points]
Mixed driving	1.319
Highway driving	1.120

Key takeaway: Both friction and slope estimation models are validated in real-world conditions

System performance

- The right column shows how close the estimation is to the measured peak acceleration
- System shows good accuracy but robustness is relatively low

Surface	Braking level	Peak a_x [m/s ²]	Estimated $a_{x,max}$ [m/s ²]	Δa_x [m/s ²]
Gravel	Full	4.0	3.0	1.0
Gravel	Almost full	3.8	3.4	0.4
Cobblestone	Full	5.0	4.0	1.0
Cobblestone	Almost full	4.5	4.0	0.5
Asphalt	Full	6.0	7.8	-1.8
Asphalt	Full	5.8	6.0	-0.2
Asphalt	Soft	0.5	6.0	0*
Asphalt	Soft	1.8	7.5	-1.5*

* Error calculated using the peak acceleration from the full braking event on asphalt (6.0 m/s²).

Conclusions

- Friction and slope estimation works in certain conditions
- Estimated maximum acceleration ($a_{x,max}$) could be used as threshold variable in adaptive AEB system

Future work

- Tuning of parameters for improved performance
- Improve robustness during low-excitation driving.
- Implement adaptive AEB system

Summary

This master thesis implements and evaluates road friction and slope estimation on a heavy truck, with the estimates used to calculate the maximum available braking acceleration in real time. The results indicate that this signal can be used as the threshold variable for a potential adaptive AEB system, although full AEB intervention testing was outside the scope of the work.

Key takeaway: Final message: road-condition-aware braking information can support future adaptive AEB decisions.