PEDRO LIMA

PREDICTIVE CONTROL FOR AUTONOMOUS DRIVING

SCANIA

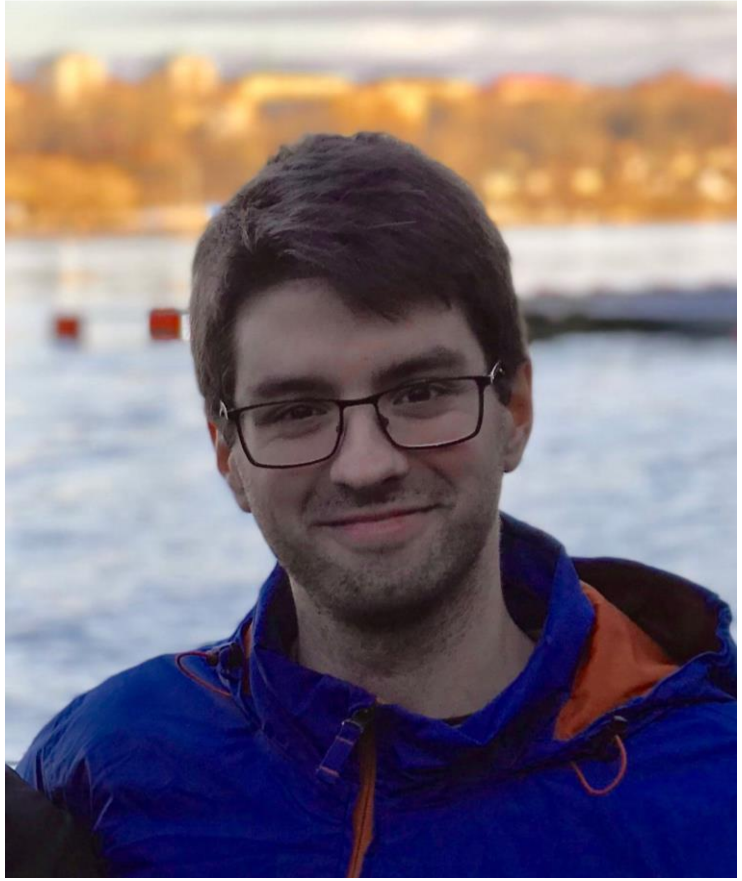
OUTLINE

- About me
- About Scania
- Mining applications
- Urban applications
- Reversing with trailers
- Remaining challenges

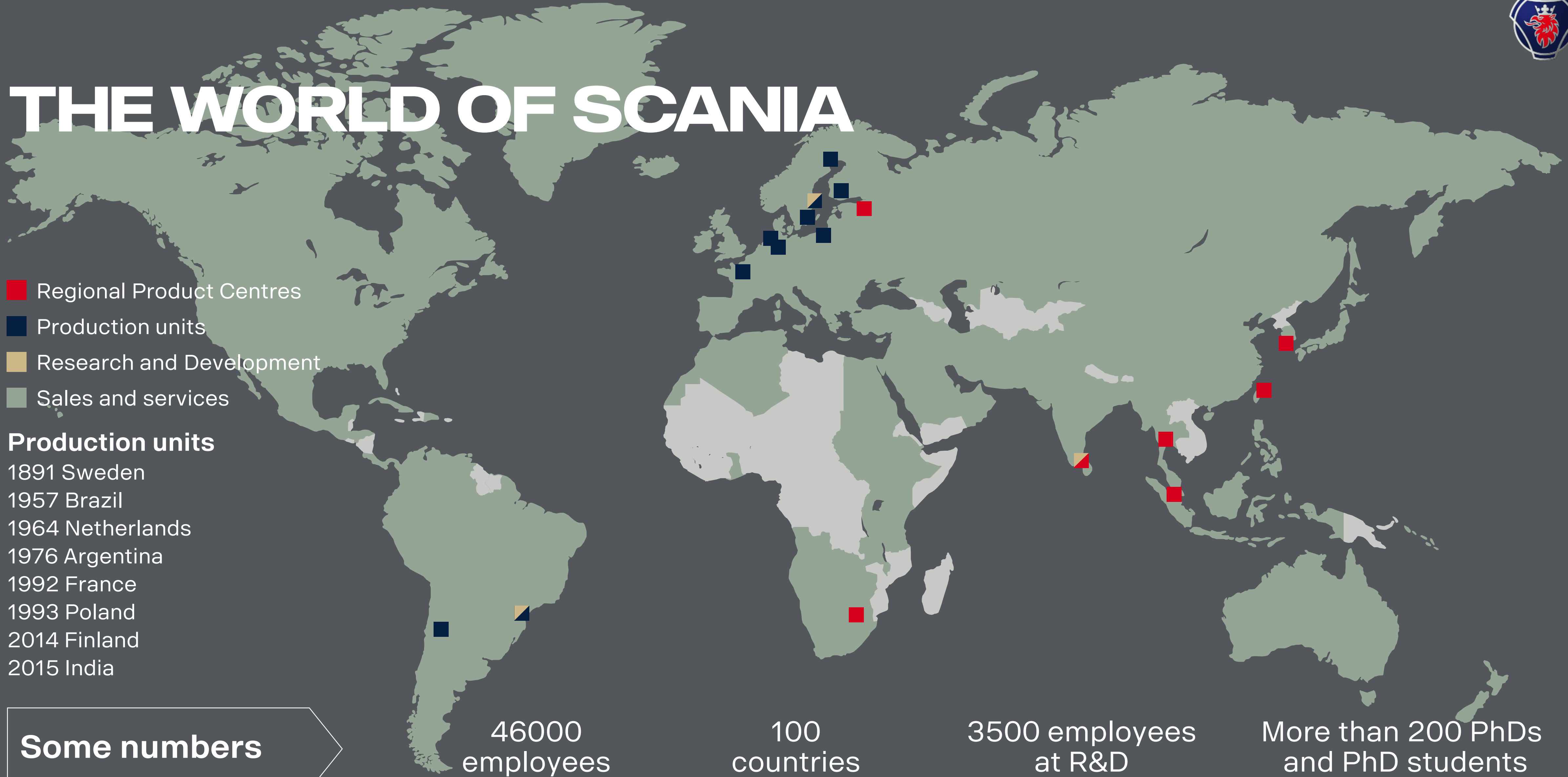
ABOUT ME – PEDRO LIMA

- Master of Science in Electrical Engineering
  - KTH Royal Institute of Technology, Sweden
  - IST, University of Lisboa, Portugal
- Doctor of Philosophy in Electrical Engineering
  - Automatic Control department (2013-2018)
  - KTH Royal Institute of Technology, Sweden

  "Optimization-Based Motion Planning and Model Predictive Control for Autonomous Driving"
- Product Owner at Scania CV AB (2018-2019)
  - ECPM – Autonomous motion
  - Pre-development & Research
- Development Engineer at Scania CV AB (since May 2019)
  - EADM – Motion Planning & Control
  - Product development



THE WORLD OF SCANIA



Production units

1891 Sweden
1957 Brazil
1964 Netherlands
1976 Argentina
1992 France
1993 Poland
2014 Finland
2015 India

Some numbers

46000 employees

100 countries

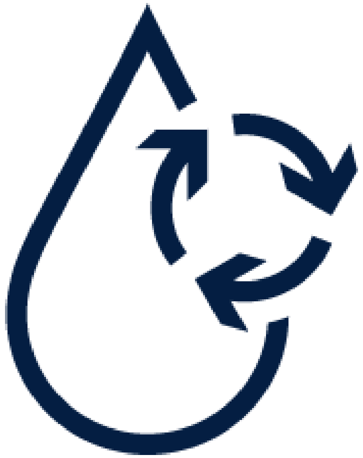
3500 employees at R&D

More than 200 PhDs and PhD students

Scania is part of TRATON

SCANIA APPROACH TO SUSTAINABLE TRANSPORT

Energy efficiency

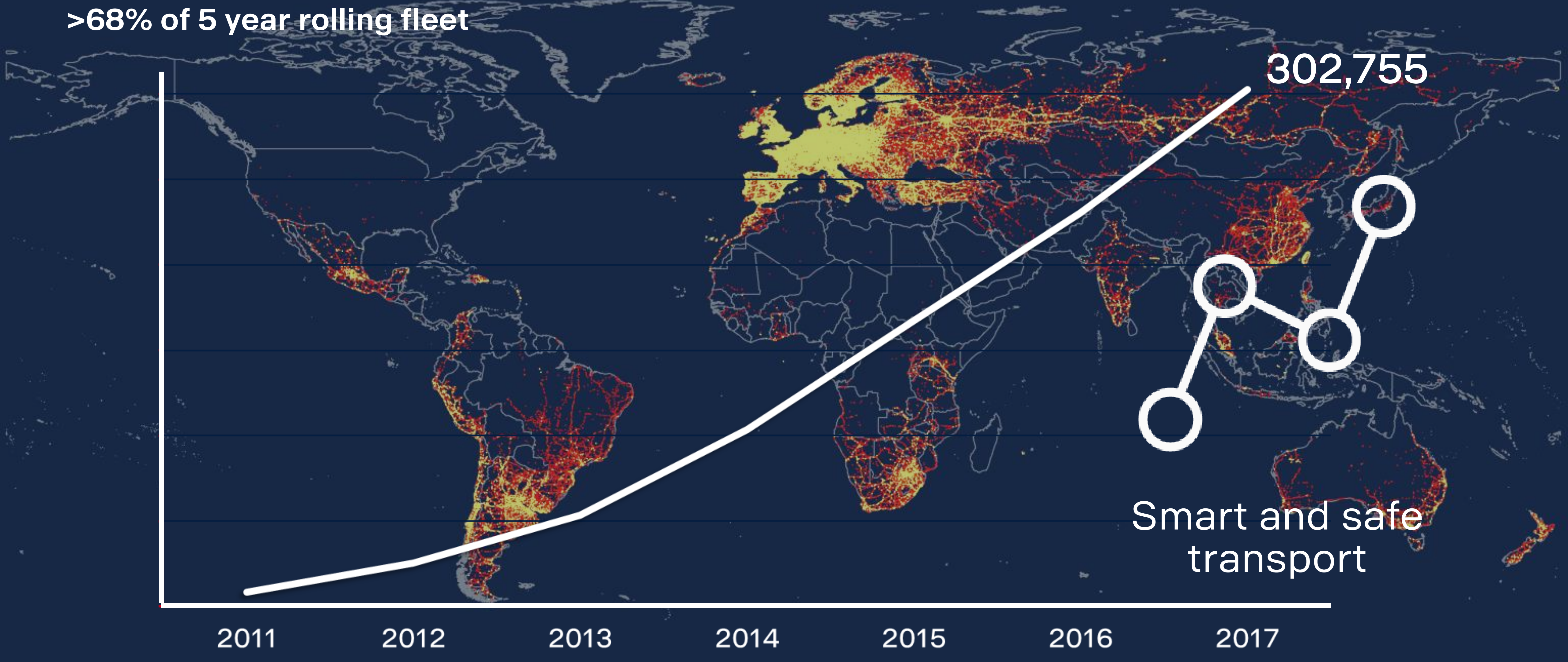


Alternative fuels
and electrification

Smart and safe
transport

CONNECTED VEHICLES

>68% of 5 year rolling fleet



PLATOONING

Smart and safe transport

PLATOONING

https://www.youtube.com/watch?v=lpuwG4A56r0&

AUTONOMOUS VEHICLES

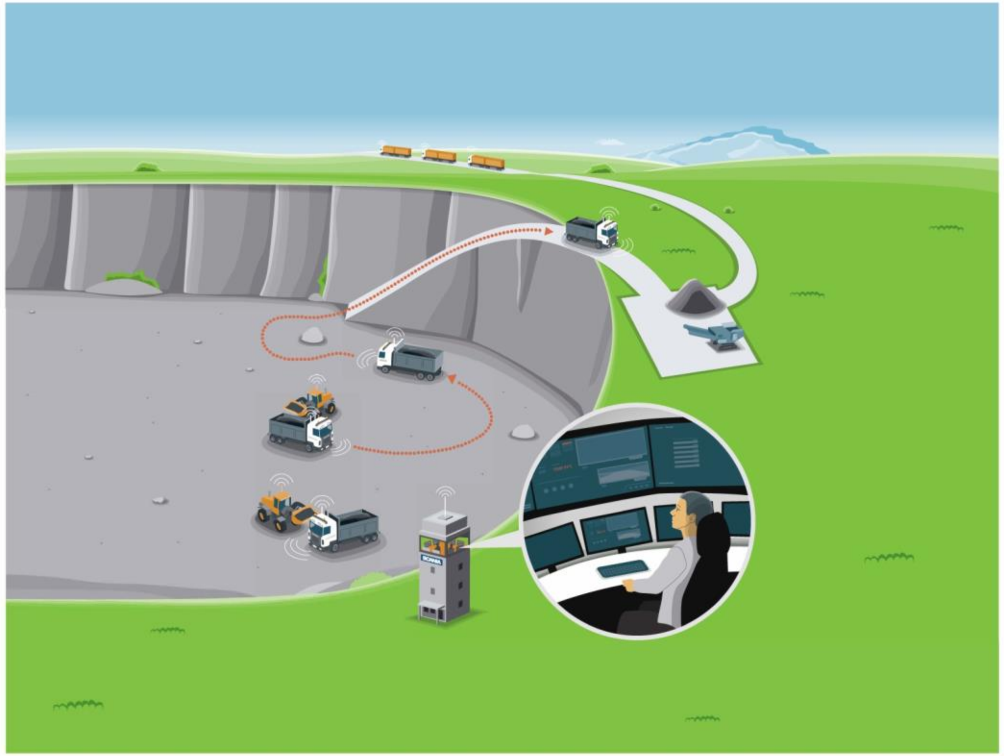
Smart and safe transport

AUTONOMOUS VEHICLES

https://www.youtube.com/watch?v=-X5CLeKDxrQ&

MINING TRUCKS - IQMATIC

- Develop fully autononomous heavy-duty vehicles for mining applications;
- Autonomous vehicles in closed, special environments (e.g., mining areas):
  - easier to implement comparing to urban environments;
  - eliminate repetitive jobs.
- Need of a motion controller that
  - minimizes “wear and tear” of the vehicle;
  - maximizes accuracy to drive on tight roads.



MINING TRUCKS – RIO TINTO TRIALS

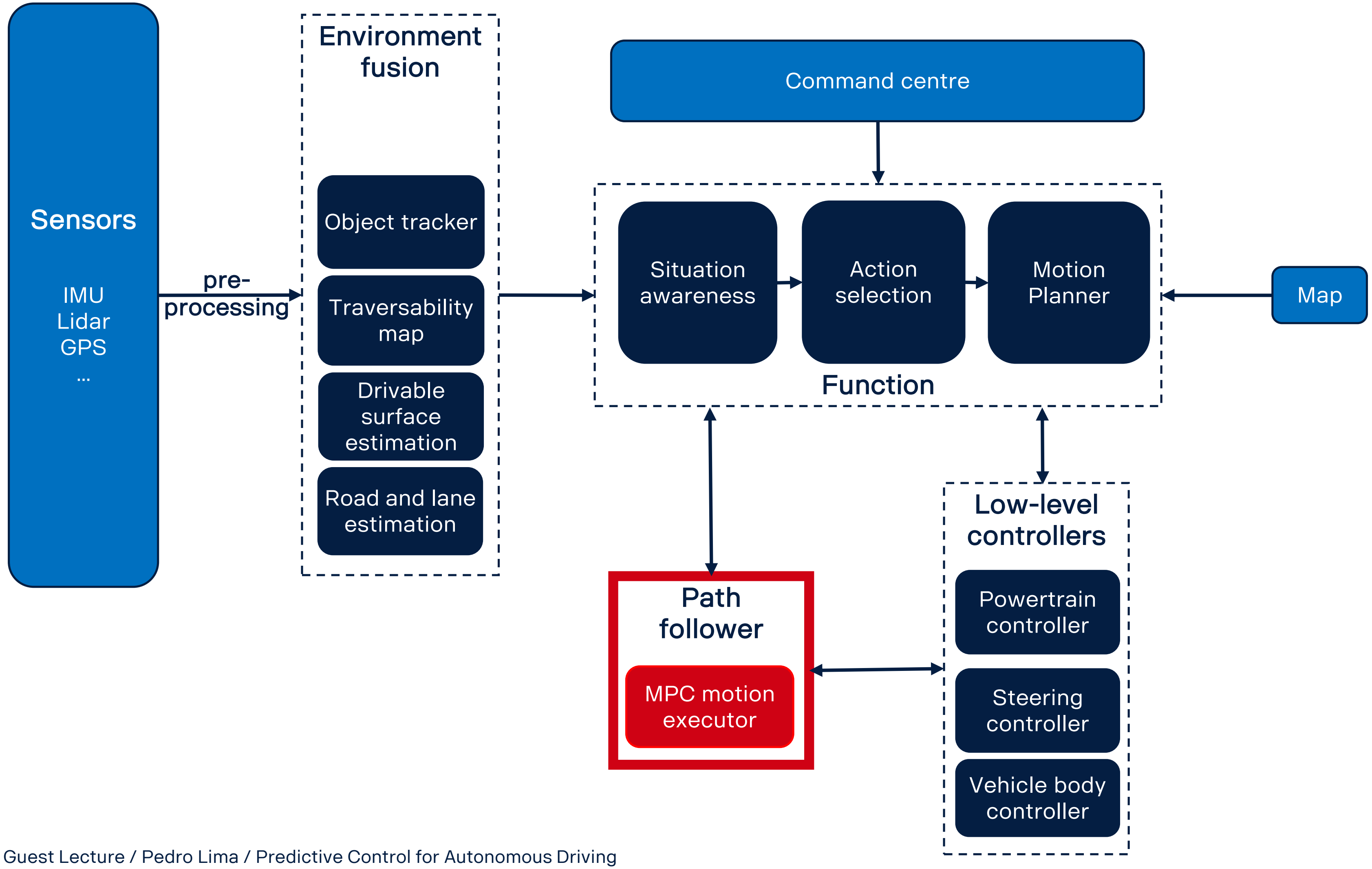
Read more at https://www.scania.com/group/en/scania-and-rio-tinto-trialling-autonomous-truck-in-western-australian-mine/

SCANIA AXL - CABLESS

https://www.youtube.com/watch?v=0WN9xvAvEls

https://www.youtube.com/watch?v=8bX48KVeN2U

SYSTEM OVERVIEW (SIMPLIFIED VERSION)



MODEL PREDICTIVE CONTROLLER (MPC)

- MPC predicts the vehicle behavior for a given set of inputs using a vehicle model;
- Minimizes a chosen cost function computing an optimal sequence of inputs;
- Methodical handling of nonlinear time-varying models and constraints.

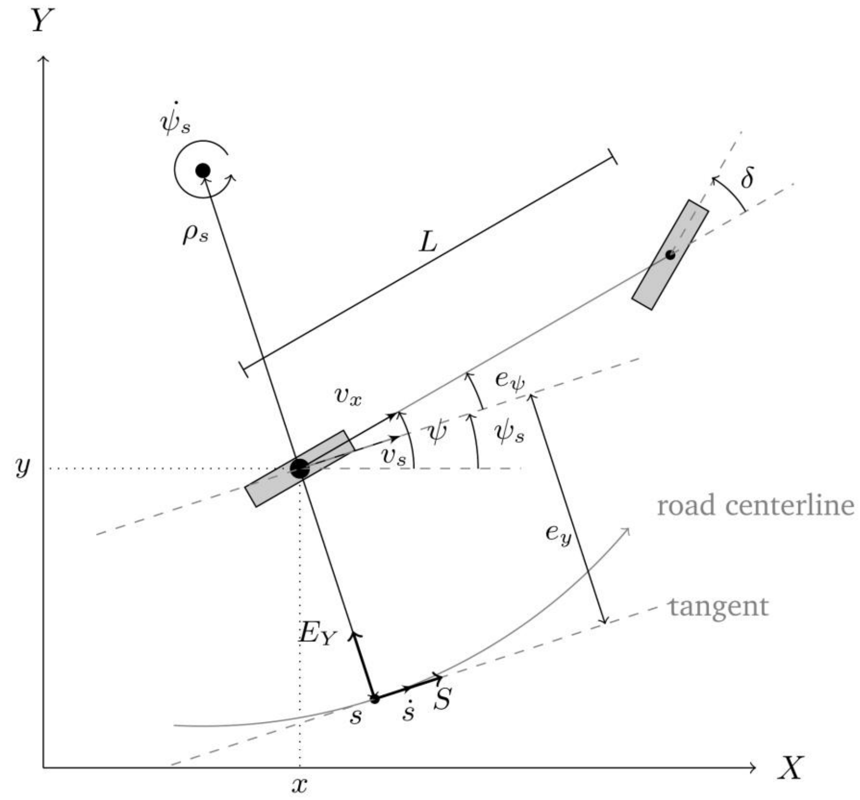
SMOOTH AND ACCURATE MPC

- The cost function is related to the driving smoothness;
- The driving smoothness is related to the steering wheel change rate;
- Driving smoothly decreases the "wear and tear" of the vehicle;
- Trade-off between accurate path tracking and smooth driving.

max	Tracking accuracy + Driving smoothness
subject to	Vehicle dynamics
	Input constraints
	State constraints

PREDICTION VEHICLE MODEL

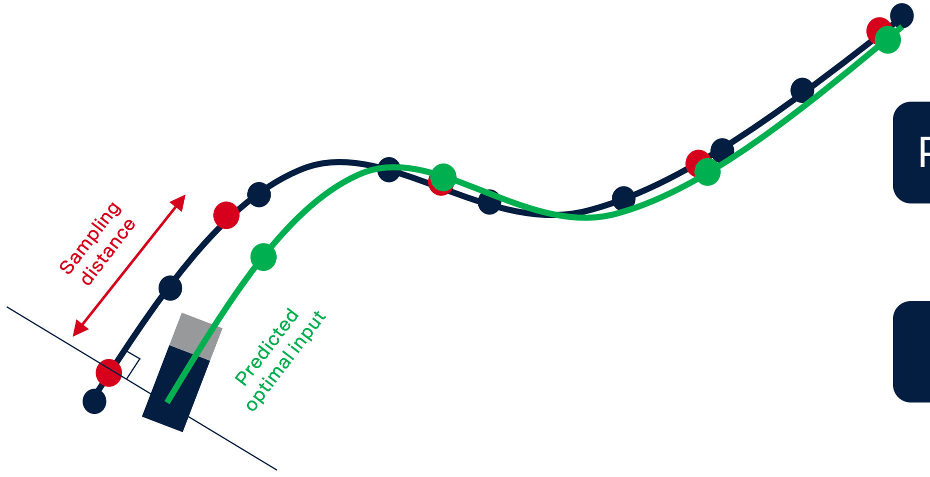
- Nonlinear kinematic vehicle model;
- Modeled in the space-domain and in a road-aligned coordinate frame;
- Linearized around the reference path, leading to linear time-varying (LTV) model;
- Constraints on the steering and steering rate;
- Constraints on the maximum lateral deviation allowed.



SIMULATION VEHICLE MODEL

- Nonlinear 4-axles dynamic bicycle model;
- Steering wheel angle to steering angle dynamics;
- Cruise-controller and powertrain dynamics;
- System identification using a real vehicle;
- Used to validate the controller before deploying it in the vehicles.

SOME IMPLEMENTATION DETAILS



Vehicle ego position
Planned path

Path sampling and treatment

Reference path

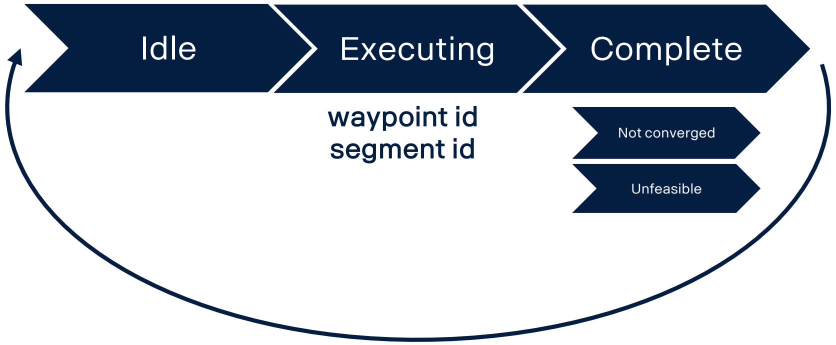
Model Predictive Controller

MPC predicted input

State Machine

Controller state
Vehicle input

50Hz



MAIN RESULTS

- Currently implemented on Scania's autonomous tucks and buses.
- Very accurate, deviations are maximum: <30 cm and average: ~6cm from the path.
- Performs well both at high- and low-speeds.
- Stability guarantees.

https://zenodo.org/record/1292422#.XZyjlEYzaUk

https://zenodo.org/record/1292426#.XZyjl0YzaUk

LTV-MPC STABILITY

- What can go wrong with MPC?
  - Feasibility: no control sequence exists that satisfies the constraints;
  - Stability: state does not converge to the reference.
- Reason: a poorly tuned and/or designed MPC controller is too short-sighted.

- Solution?
  - increase the prediction horizon;
  - add a terminal cost;
  - add a terminal state constraint set.

LTV-MPC STABILITY

- For LTI-MPC, stability and feasibility can be proved if:
  - The terminal cost is a quadratic term depending on the solution of the algebraic Riccati equation;
  - The terminal state set is the maximal positive invariant set for the closed-loop system, when using a control law associated with the LQR.

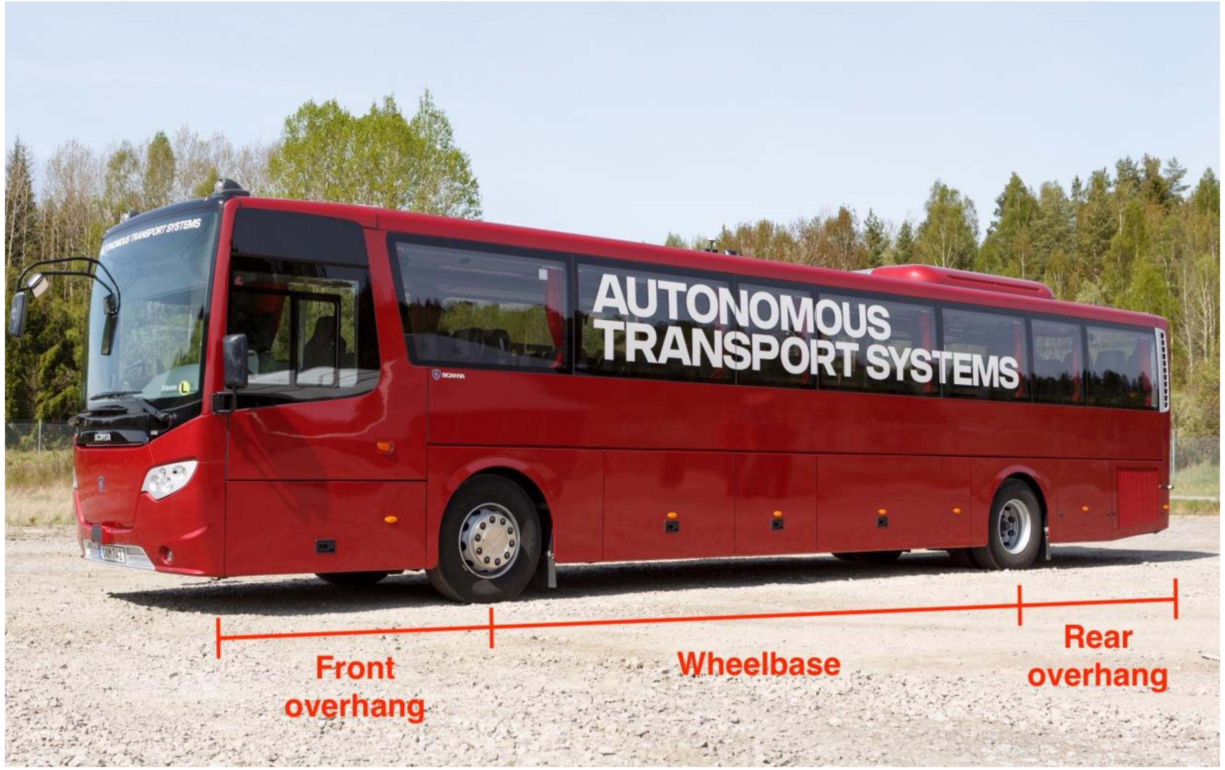
- For LTV-MPC, we proposed:
  - Representing the LTV model using a multi-plant model consisting of a set of LTI models;
  - The terminal cost is then a quadratic term depending on the solution of the algebraic Riccati equation of the worst time-invariant model if used as prediction model;
  - The terminal state set is the maximal positive invariant set that is invariant for all LTI systems.

EXPERIMENTS - STABILITY

https://zenodo.org/record/1292428#.XZyj20YzaUk

PUBLIC TRANSPORTATION - IQPILOT

- Main reasons for not using public transport are:
  - expensive tickets;
  - irregular travel times.
- Autonomous buses would lead to:
  - reduced expenses (no driver, higher fuel efficiency);
  - more predictable running times.
- However, buses are:
  - long and wide;
  - difficult to maneuver in tight roads.



BUSES OVERHANGS MINIMIZATION

- Buses often have to leave their lanes due to their large dimensions;
- Experienced drivers make use of the vehicle overhangs to maneuver the vehicle.

BUSES OVERHANGS MINIMIZATION

- Multi-classification of the environment:
  1. The vehicle wheelbase must be inside the drivable region;
  2. Overhang can go over the sweepable region;
  3. Vehicle body cannot intersect the obstacle region.
- Formulate the problem as an optimization problem
  - Minimize the amount of overhang outside the drivable surface;
  - Formulate the constraints related to the three different regions.

BUSES OVERHANGS MINIMIZATION

Centerline following

Overhang minimization

https://sites.google.com/view/rui-oliveira/work

Obstacle avoidance

SCANIA NXT

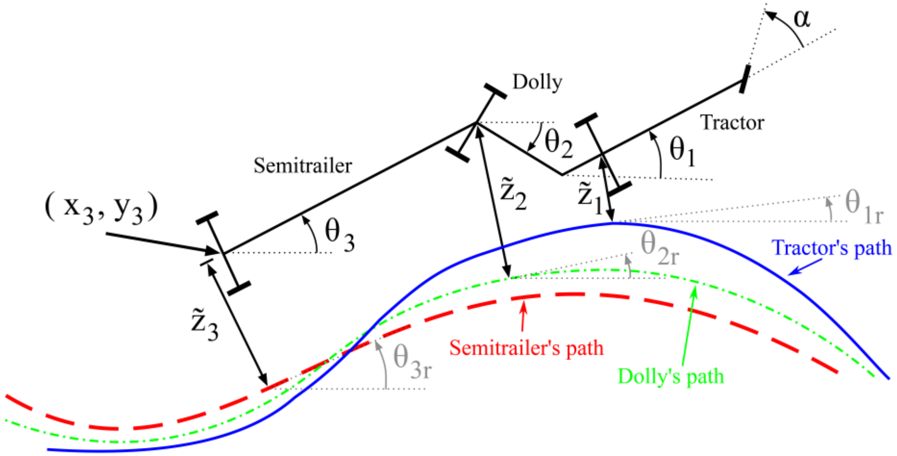
https://www.youtube.com/watch?v=7N3eIygeUA4

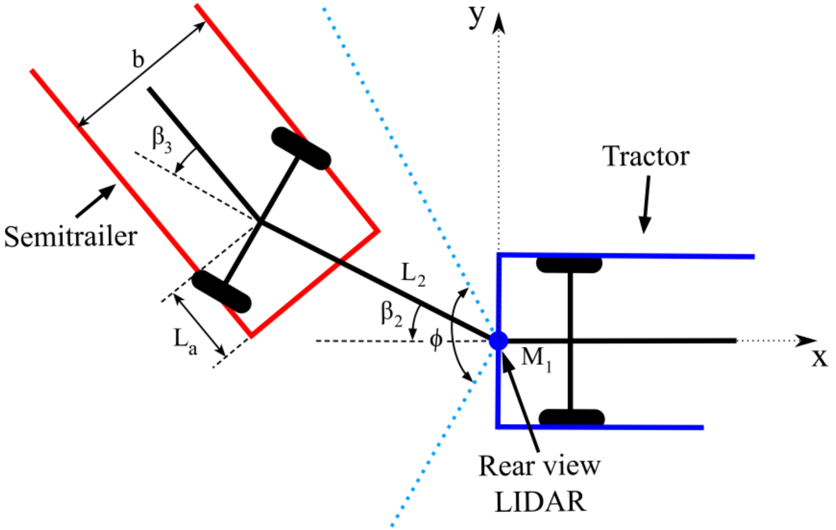
REVERSING WITH A TRAILER

- Hard problem:
  - Complex configurations;
  - Jackknife;
  - Tight parking.

REVERSING WITH A TRAILER

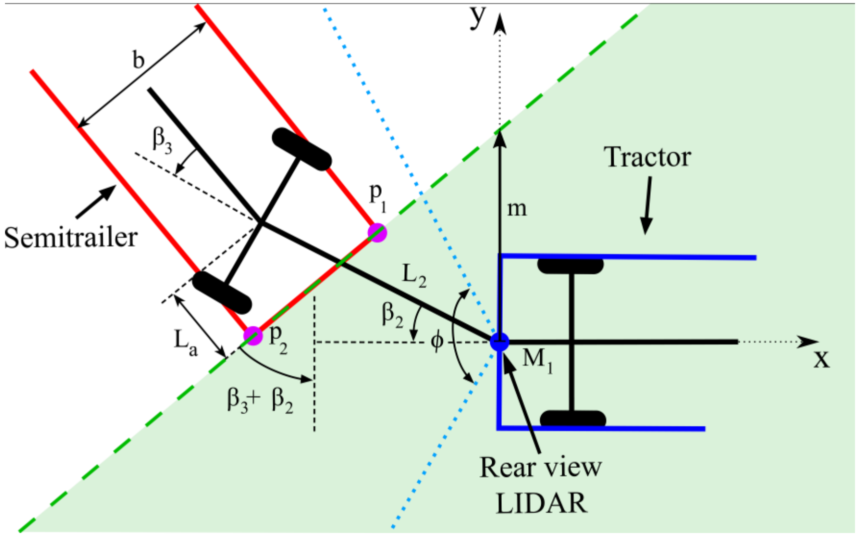
- LQR controller based on:
  - Kinematic vehicle model;
  - Road-aligned coordinate frame;
  - Linearized around the reference path.
- Trailer(s) states estimation:
  - Extended Kalman filter (EKF);
  - LIDAR measurements.

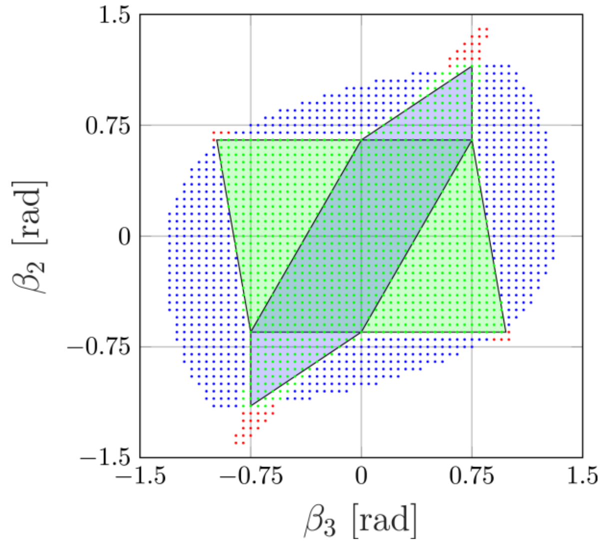




REVERSING WITH A TRAILER

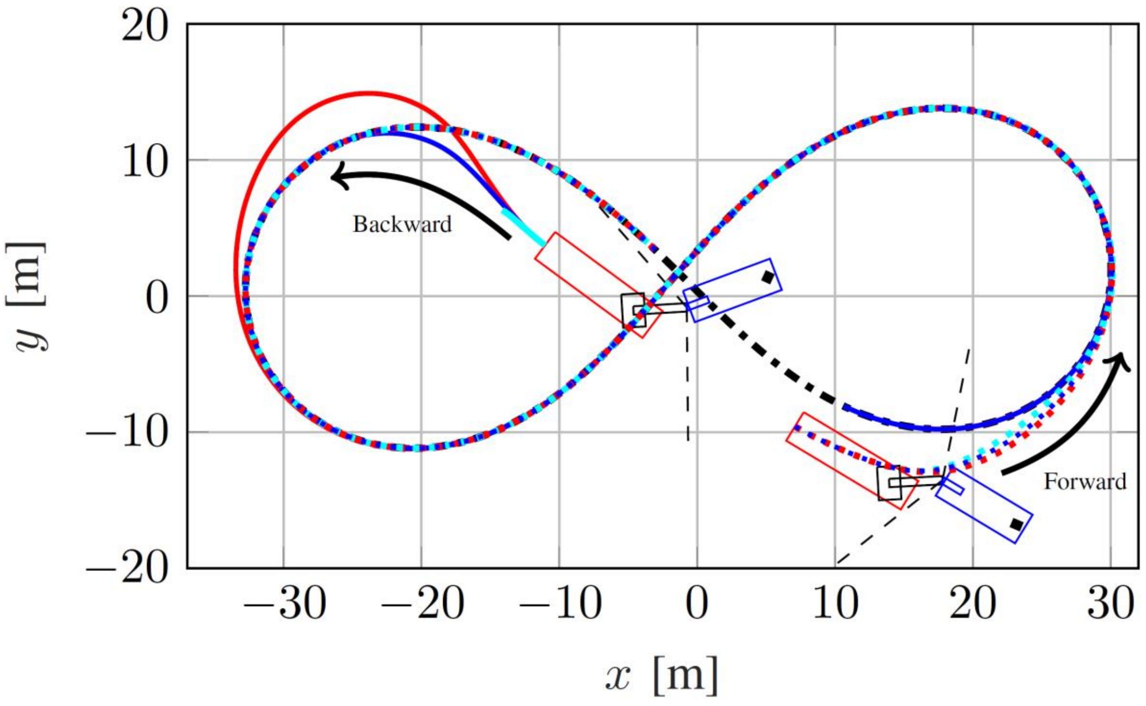
- LQR controller assumes that the constraints are handled at the motion planning layer;
- If the path following errors are sufficiently large, how to deal with:
  - input saturation and rate limit?
  - jackknifing?
  - joint angles being inside regions where they cannot be estimated accurately?
- Solution: Model predictive control!

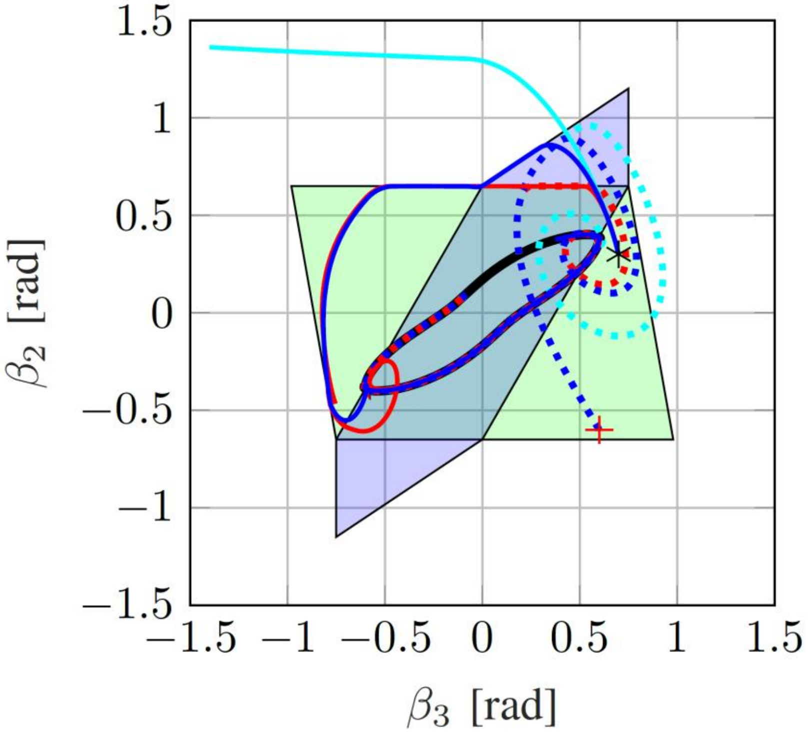




REVERSING WITH A TRAILER

- Forward and reverse 8-figure motions using MPC (MIQP, QP) and LQR.





REVERSING WITH A TRAILER

https://www.youtube.com/watch?v=IBA-8wom5zQ&

REMAINING CHALLENGES

- In the area of motion control:
  - Robustness to uncertainty (different road surfaces, noisy positioning…)
  - Vehicle modeling:
    - how complex does the vehicle model used in the control design need to be?
    - how do we estimate the vehicle parameters (online)?
  - Controller accuracy:
    - how to stop in a specific spot? (important in the case of buses or for parking)
- In general:
  - How to ensure redundancy?
  - How to perceive the environment?
  - How to determine other vehicles/pedestrians/cyclists intentions?

MASTER'S THESES

Predevelopment and research (EARM): Motion planning and control, and situation awareness

- https://www.scania.com/group/en/available-positions/?job_id=15220&kw=
- https://www.scania.com/group/en/available-positions/?job_id=15221&kw=
- https://www.scania.com/group/en/available-positions/?job_id=15222&kw=
- https://www.scania.com/group/en/available-positions/?job_id=15223&kw=
- https://www.scania.com/group/en/available-positions/?job_id=15224&kw=

Development (EADM): Motion planning and control

- https://www.scania.com/group/en/available-positions/?job_id=15099&kw=
- https://www.scania.com/group/en/available-positions/?job_id=15100&kw=
- https://www.scania.com/group/en/available-positions/?job_id=15101&kw=

LIST OF PUBLICATIONS

Smooth and accurate model predictive controller:

- "Experimental Evaluation of Economic Model Predictive Control for an Autonomous Truck",
  P. F. Lima, M. Nilsson, M. Trincavelli, J. Mårtensson, B. Wahlberg, IEEE Intelligent Vehicles Symposium, 2016.
- "Spatial Model Predictive Control for Smooth and Accurate Steering of an Autonomous Truck",
  P. F. Lima, M. Nilsson, M. Trincavelli, J. Mårtensson, B. Wahlberg, IEEE Intelligent Vehicles Transactions, 2017.
- "Stability Conditions for Linear Time-Varying Model Predictive Control in Autonomous Driving",
  P. F. Lima, J. Mårtensson, B. Wahlberg, IEEE Conference on Decision and Control, 2017.
- "Experimental Validation of Model Predictive Control Stability for Autonomous Driving",
  P. F. Lima, G. Collares Pereira, J. Mårtensson, B. Wahlberg, Control Engineering Practice, 2018.

Buses overhangs minimization:

- "Minimizing Long Vehicles Overhang Exceeding the Drivable Surface via Convex Path Optimization",
  P. F. Lima, R. Oliveira, J. Mårtensson, B. Wahlberg, IEEE Intelligent Transportation Systems Conference, 2017.
- "Path Planning for Autonomous Bus Driving in Urban Environments"
  R. Oliveira, P. F. Lima, G. Collares Pereira, J. Mårtensson, B. Wahlberg, IEEE Intelligent Transportation Systems Conference, 2019.

Reversing with a trailer:

- "Path Following Control for a Reversing General 2-trailer System"
  O. Ljungqvist, D. Axehill, A. Helmersson, IEEE Conference on Decision and Control, 2016.
- "Lattice-based Motion Planning for a General 2-trailer system"
  O. Ljungqvist, N. Evestedt, M. Cirillo, D. Axehill, O. Holmer, IEEE Intelligent Vehicles Symposium, 2017.
- "On Model Predictive Path Following Control for a General 2-trailer With a Car-like Tractor"
  O. Ljungqvist, D. Axehill, submitted to the International Conference on Robotics and Automation, 2020.

SCANIA. IT STARTS WITH YOU.

scania.com/career