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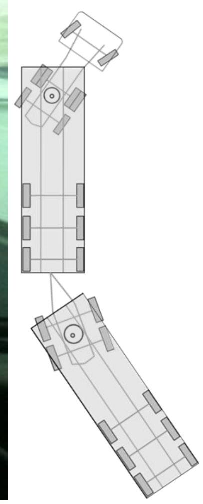
SafeCorridors

High Speed Control of Long Combination Heavy Commercial Vehicles within Safe Corridors



Project within: Fordonsstrategisk Forskning och Innovation, Fordonsutveckling, Dnr:2011-04411

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Content

FFI in short

FFI is a partnership between the Swedish government and automotive industry for joint funding of research, innovation and development concentrating on Climate & Environment and Safety. FFI has R&D activities worth approx. €100 million per year, of which half is governmental funding. The background to the investment is that development within road transportation and Swedish automotive industry has big impact for growth. FFI will contribute to the following main goals: Reducing the environmental impact of transport, reducing the number killed and injured in traffic and Strengthening international competitiveness. Currently there are five collaboration programs: **Vehicle Development, Transport Efficiency, Vehicle and Traffic Safety, Energy & Environment and Sustainable Production Technology.**

For more information: www.vinnova.se/ffi

1. Executive summary

Sweden has historically used long vehicle combinations in order to improve road transport and its productivity. Further development of how future long modular vehicle combinations for road transport can be designed and controlled with respect to both energy efficiency and safety is planned by Volvo. It is predicted that longer combinations than those agreed upon in EU directive 96/53, European modular system, will be realized to meet upcoming environmental goals and emission legislations on transported goods kg CO_2/(ton*km). The predicted combinations range typically between 25-35 m in length and have at least two articulated joints. Productivity of these combinations is seen to improve by approximately 30 percent. To assure traffic safety of these foreseen transports, the objective of this project is to address how driver assistance functionality for high speed control, ranging from 0 to 90 km/h could be designed and realized when the complete combinations are considered.

The envisioned realization of future motion functionality road transport vehicles would have different prediction horizons containing a transport mission mgmt with a prediction horizon of days. Next layer is foreseen to be route situation mgmt with a prediction horizon of hours. The next following functionality layer route segment mgmt has a prediction horizon of minutes. This is foreseen to be followed by traffic situation mgmt layer with a horizon of 10-20 s and has a clear interface with vehicle motion mgmt layer with up to1-2 s prediction horizon. The result from this project shows how traffic situation management functionality can be realised to support driving assistance functionality with autonomous driving with automation level 4 in single way multiple lane highway traffic for long combination vehicles, i.e. lengths of 25-35 m containing at least two articulated joints. Function development and experimental validation have been conducted by using the large movement simulator SIM4 at VTI Lindholmen. In the simulator experiments the professional drivers conducted different driving tasks manually and back to back got to try out the first solution for automated driving. This gave crucial insights in how the automated functionality in traffic situation mgmt could be improved when comparing how the manual professional drivers of these long combination vehicles drove.

The project has produced knowledge to the heavy vehicle industry to produce world-leading safe transport solutions especially for longer and more productive combination vehicles. Several publications and a licentiate thesis have been published. A public simulator demonstration is planned in September 2016. PhD defence is planned to September 2017.

2. Background

Here follows a short version of the background for the project. For a longer version see [XX].

The easiest way to improve vehicle productivity and environmental impact with conventional technology in long haul applications is to extend the lengths and number of units per combination vehicle. The extended length and added articulation angles of long combination vehicles (LCVs) will directly affect vehicle performance of both the longitudinal and lateral vehicle dynamics. Electro mobility and automation are two key enablers in the advancement of vehicle productivity. These will drive the tremendous functionality increase in future road transport systems in order to meet customer satisfaction, traffic safety, sustainability, and security.

To meet the functionality increase when it comes to automation of road transports it is necessary to start to discuss what is the fundamental functionality needed in conducting safe automated road transports. This project has targeted this in combination by selecting the most productive vehicle combinations.

3. Objective

The overall objective of the project was to build up knowledge and develop functionality for automated driving of long combination vehicles. The focus was on the traffic situation management (TSM) functionality domain, shown in Figure 1.

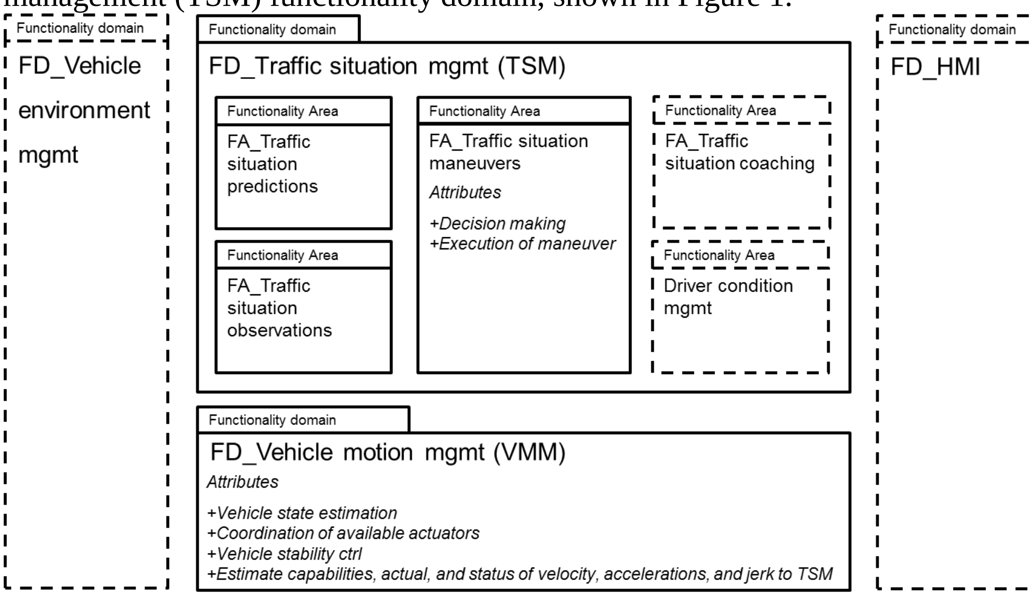

Figure 1. Part of motion functionality reference architecture with focus on traffic situation mgmt

The project was divided into several work packages together forming a technical solution, which should make it possible to better ensure what functionality is crucial within TSM. Some work packages were accompanied with a research question (RQ) in order to clarify what to prioritize. The work packages and research questions were (for more details see [XX]):

WP1: Interface to Traffic Sensing

RQ1: How shall observed objects (movable, fixed, road segments, traffic rules) be prioritized, represented, and valued?

WP2: Find Safe Corridors

RQ2: How can safe corridors be identified and represented? Including defining what abilities is needed from motion layer for long vehicle combinations for prediction of safe corridors?

WP3: Select best corridor and path

RQ3: Research question: How can the best corridors be chosen and represented? The focus shall be on designing one that assures a best corridor and path solution at all times in real time?

WP4: Arbitrate with Transport Planner

RQ4: How can requests from Traffic Layer be realised and be arbitrated with requests from Transport Planner so that arbitration result is realizable for Vehicle Motion Controller? This includes formulating the requests from traffic planner to vehicle motion layer for long vehicle combinations.

WP5: Arbitrate with Requests from Driver

RQ5: How can seamless transition be realised between autonomous driving and driver? How can requests from driver be arbitrated with requests from Traffic Layer and Transport Planner? How is the arbitration with autonomous type of functions realised?

WP6: Function development and Verification

WP7: Academic Lic. degree

WP8: Academic PhD degree

(**WP5** and **WP8** were initially defined, but not in scope for this project.)

4. Project realization

The project ran according to what was planned. All partners have also contributed as intended in total. Content wise, the project group has developed and verified functionality for automated driving on automation level 3 of one way multiple lane highway for long combination vehicles. The developed functionality includes traffic situation predictions, traffic observations, traffic situation manoeuvres with decision making and execution of the most feasible predicted plan, see Figure 1.

Here are some of the important actions that were performed in the project

- Thorough literature reviews were conducted in all areas researched to gather relevant state of the art material.
- Function development was conducted both by computer simulations and large movement simulator testing.
- Collaboration with TU-Delft to receive high performing one year MSc students within model predictive control, optimization, and realtime systems [1],[5],[13],[14].
- Three clinical tests in VTI/SIM4 were set-up with professional truck drivers of long combination vehicles to analyse human driving and compare with automated driving, in addition of objective comparison, the drivers gave subjective feedback.
- The involved Phd candidate took part in relevant courses at Chalmers.
- Several conferences were visited to exchange ideas with other researchers.
- Internal project steering group meetings were held.
- Public demonstration is planned at VTI/SIM4 in September 2016.

5. Results and deliverables

The project has developed dedicated functionality and knowledge to meet the intended outcomes from the project. The different research questions have also been answered to the best extent possible; most of the answers have indirectly been formulated in publications according to:
RQ1 [1,3]; RQ2 [2-5,8]; RQ3 [5,6,7,9,10]; RQ4 [6]; WP6 [4,11,12], WP7 [10]

5.1 Delivery to FFI-goals

The project aimed on vehicle development of functionality that needs to be in place for meet customer demands 2025 of innovative functionality, such as automation level 3-4, within commercial heavy vehicles. This has been conducted long before it has been tested on road. The opposite way with first developing physical long combination vehicle with

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surrounding sensors would have focused on the environment sensor platform fusion and would have dominated the focus to first succeed with this before starting to develop the motion functionality within traffic situation mgmt. To use large movement simulator experiments changed to focus instead on the function development and back to back comparison how experience commercial drivers solves the different tasks gave invaluable answers on how the automated functionality should be realised.

This will contribute to that Volvo AB will remain world leading in developing productive and safe commercial heavy vehicles.

6. Dissemination and publications

6.1 Knowledge and results dissemination

This project have initiated the aim of reaching automation level 4 for commercial heavy vehicles on one-way multiple lane highway driving. This will be followed up with a larger research programme, called “Highly Automated Road Freight Transports” this will share knowledge between customers of container transport between Borås Viared and Göteborg Harbor, and sensor suppliers to realise the physical sensor platform for long combination vehicles. It will also incorporate connected vehicle technology to improve productivity in the harbour and the dry port for containers at Borås Viared. A large share of the achieved results has furthermore also been spread outside the partner constellation in form of publications and participation in several conferences, see 6.2 publications. It is aimed to file patents of some parts that have been found as core knowledge before publication.

6.2 Publications

[1] Disse M.W., Real-time path planning for long heavy vehicle combinations, a receding horizon optimization approach, Master thesis, TU-Delft, Netherlands, 2012

[2] Nilsson, Peter, and Kristoffer Tagesson. Single-track models of an A-double heavy vehicle combination. Chalmers University of Technology, 2014.

[3] Nilsson P., Laine L., Benderius O., and Jacobson B. “A Driver Model Using Optic Information for Longitudinal and Lateral Control of a Long Vehicle Combination”, IEEE 17th International Conference on Intelligent Transportation Systems (ITSC), p. 1456-1461, October 8-11 Qingdao, China, 2014.

[4] Nilsson P., Laine L., and Jacobson B., ”Performance Characteristics for Automated Driving of Long Heavy Vehicle Combinations Evaluated in Motion Simulator”, 25th IEEE Intelligent Vehicles Symposium, IV 2014, Dearborn, MI, U.S.A. 8-11 June 2014.

[5] van Duijkeren N., Realtime receding horizon trajectory generation for long heavy vehicle combinations on highways, Master thesis, TU-Delft, Netherlands, 2014

[6] Nilsson P., Laine L., Jacobson B., and van Duijkeren N., “Driver Model Based Automated Driving of Long Vehicle Combinations in Emulated Highway Traffic”, IEEE 18th International Conference on Intelligent Transportation Systems (ITSC), September 15-18, Las Palmas, Spain, 2015.

[7] Nilsson P., Laine L., van Duijkeren N., and Jacobson B., “Automated highway lane changes of long vehicle combinations: A specific comparison between driver model based control and non-linear model predictive control”, 2015 International Symposium on Innovations in Intelligent SysTems and Applications (INISTA), September 2-4, Madrid, Spain, 2015.

[8] Sandin J., Augusto B., Nilsson P., and Laine L., “A Lane-Change Gap Acceptance Scenario Developed for Heavy Vehicle Active Safety Assessment: A Driving Simulator Study”, Future Active Safety Technology Towards zero traffic accidents, FAST Zero 2015, September, Göteborg, 2015.

[9] van Duijkeren N., Keviczky T., Nilsson P., and Laine L., “Real-Time NMPC for Semi-Automated Highway Driving of Long Heavy Vehicle Combinations”, 5th IFAC Conference on Nonlinear Model Predictive Control, NMPC'15, September 17-21, Seville, 2015

[10] Nilsson P., On Traffic Situation Predictions for Automated Driving of Long Vehicle Combinations, Licentiate thesis, Chalmers University of Technology, 2015

[11] Augusto B., Nilsson P., Sandin J., and Laine L., "Using large moving base simulators as tools when designing future automated functionality for commercial heavy vehicles: A case study og highway auto-piloting for high capacity transport". Submitted to conference HVTT14: Rotorua, New Zealand, 15 – 18 November, 2016

[12] Nilsson P., Laine L., and Jacobson B., “A simulator study on comparing characteristics of manual and automated driving during lane change of long combination vehicles”, journal article submitted to IEEE transactions on Intelligent Transportation systems.

[13] Mattsson Persson B., Predictions of surrounding traffic for autonomous long combination vehicle driving in dense highway traffic, Master thesis, Chalmers Technical University, 2016.

[14] Baktovic I., Real-time optimization of driver model parameters for long combination vehicles, Master thesis, Chalmers Technical University, 2016.

7. Conclusions and future research

The suggested hypothesis that a traffic situation mgmt functionality domain with prediction horizon of up to 10s is necessary to realise safe automation level 4 for productive commercial heavy vehicles have been found be necessary. This will include some traffic situation prediction part either by optimization based methods such as model predictive control or simulations with driver model including optimization or deep learning. All predictions need to consider the vehicle dynamics that a long combination vehicle is limited by.

Future research is how to realise the sensor platform for vehicle environment and how to have unit to unit communication to fuse the traffic observation to a complete view. Next part is to develop the automation and adapt it to real customer usage and how the transport could be conducted partly driverless. This last step is a big step from just automate the commercial heavy vehicle with driver still in the transport but would also reduce transport costs and improve safety by reducing tired drivers on long highway/freeway drives.

8. Participating parties and contact person

A. Volvo Lastvagnar AB – Project Leader: Leo Laine
B. Chalmers tekniska högskola – Contact: Bengt Jacobson

9. References (other than those listed in Section 6)

[XX] Application to FFI: "SafeCorridors High Speed Control of Long Combination Heavy Commercial Vehicles within Safe Corridors", FFI Project, 2012 Dnr:2011-04411.