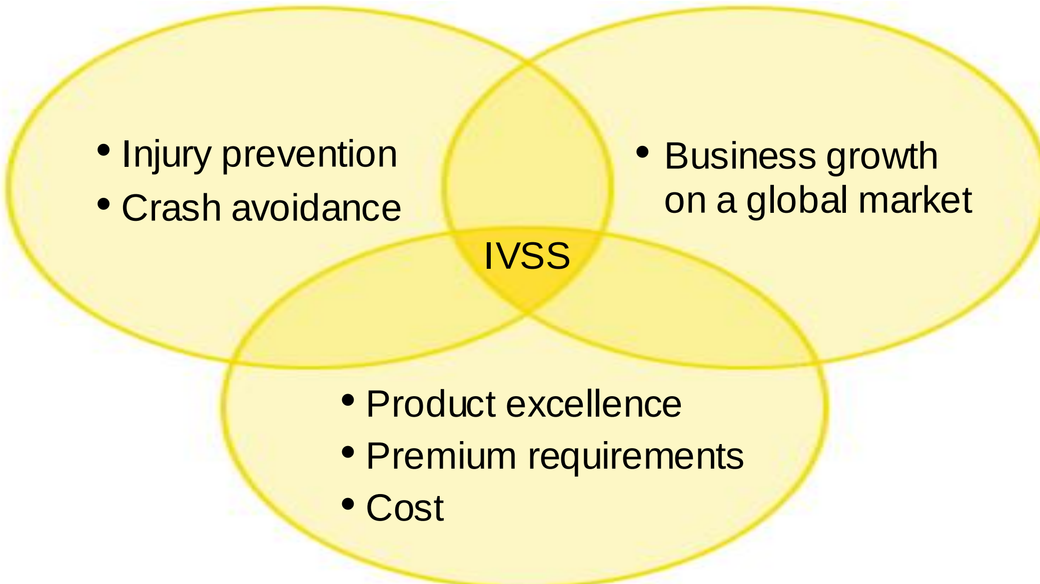
# Safety Margins and Feedback Strategies for AWD Vehicles

## IVSS Project Report

# The IVSS Programme

The IVSS programme was set up to stimulate research and development for the road safety of the future. The end result will probably be new, smart technologies and new IT systems that will help reduce the number of traffic-related fatalities and serious injuries.

IVSS projects shall meet the following three criteria: road safety, economic growth and commercially marketable technical systems.




**Three interacting components** - for better safety, growth and competitiveness:

**The human being**

Preventive solutions based on the vehicle's most important component.

**The road**

Intelligent systems designed to increase security for all road users.

**The vehicle**

Active safety through pro-active technology.

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# Summary

The vehicle industry today faces the two-fold challenge of reducing the environmental impact as well as increasing vehicle safety. Electrification of vehicles enables both of these challenges to be addressed by means of improved overall efficiency as well as providing increased possibilities to control the longitudinal forces of each wheel individually.

The objectives of this study are to increase the fundamental understanding of the influence of longitudinal forces on vehicle handling and stability. Furthermore, the study shall support the industrial development of electrical driveline systems in particular.

The results obtained in this work can be applied for analysis of the performance of current and upcoming driveline and brake systems and as components in the associated active control for these systems. Overall, the present work has expanded the fundamental framework of vehicle modeling, optimization formulations and graphical representations for analysis and optimization of a wide range of driveline system properties and vehicle level characteristics.

# Sammanfattning

Fordonsindustrin står idag inför utmaningen att både minska dess miljöpåverkan samtidigt som man ständigt vill öka trafiksäkerheten. Elektrifieringen av fordonen gör att båda dessa utmaningar kan mötas genom ökad energieffektivitet samtidigt som detta ökar möjligheterna att styra längskrafterna på varje enskilt hjul individuellt.

Syftet med denna studie är att öka den grundläggande förståelsen av den påverkan som längskrafter har på fordonets köregenskaper och stabilitet. Dessutom skall studien stödja den industriella utvecklingen av elektriska drivlinesystem i synnerhet.

Resultateten i detta arbete kan tillämpas för analysen av prestandan hos både befintliga och kommande drivline- och bromssystem och som delar i den tillhörande aktiva styrningen av dessa system. Sammantaget har detta arbete ökat det grundläggande ramverket med avseende på fordonsmodellering, optimeringsformuleringar och grafiska presentationer för analys och optimering av ett brett spektrum av system- och fordonsegenskaper.

# 1. Introduction

The vehicle industry today faces the two-fold challenge of reducing the environmental impact as well as increasing vehicle safety. Electrification of vehicles enables both of these challenges to be addressed by means of improved overall efficiency as well as providing increased possibilities to control the longitudinal forces of the vehicle individually.

Active chassis control systems, in general, and electronic stability control (ESC) systems, in particular, have significantly reduced accidents related to loss of control [36]. In [33] it is reported that ESC reduced fatal run-off-road crashes by 36 percent.

Although significant safety improvements have been made thus far, the fundamental causation of yaw instability in dynamic situations for statically stable vehicle is here seen as insufficiently described in the literature. Also, ESC systems intervene relatively late and abrupt in the unstable maneuver. Furthermore, the safety developments have been mainly focused on avoiding oversteer situations, whereas understeer situations caused by a too high curve-entry speed are much less studied.

Critical situations due to excessive understeer lead to the inability to track the desired path necessitating a path recovery that minimizes the off-tracking deviation from the intended path. This problem is illustrated in Figure 1. Currently understeer situations are addressed by means of controlling the yaw motion as in oversteer situations. However, there is reason to believe that such a strategy is not the optimal way to avoid road departures and/or avoiding collisions with road side objects caused by the off-tracking.

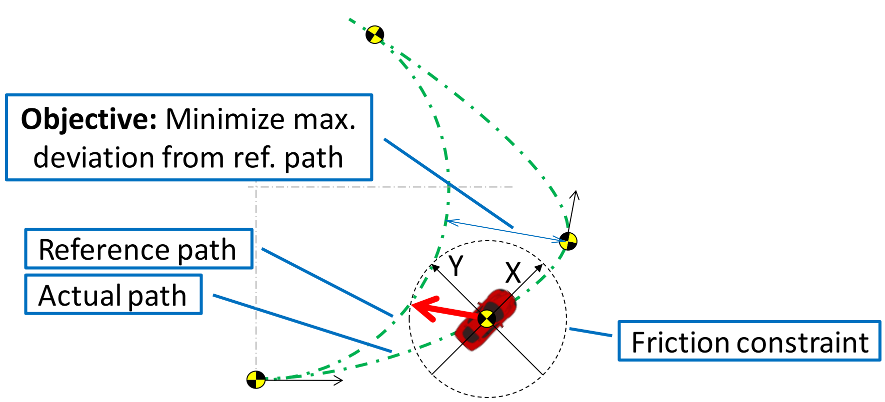


Figure 1 - Path Recovery Problem (Understeer Mitigation)

The recent developments with the convergence of active safety chassis systems and the distribution of longitudinal (brake and traction) forces through the electrification of passenger vehicles, as illustrated in Figure 2, raises the question if the above shortcomings can be addressed with these new capabilities. Therefore it is seen necessary to improve the fundamental understanding of the influence of longitudinal forces and the distribution of these longitudinal forces on the vehicle handling and stability of the vehicle.

Therefore, methods to analyze and optimize the path recovery for understeer situations as well as the optimization of the distribution of the wheel forces on each individual wheel shall be developed. Also the possibility to earlier detect excessive oversteer than in current ESC control, and thereby enabling earlier recovery from the yaw instability, by means of utilizing the increased ability to control the longitudinal forces, shall be investigated.

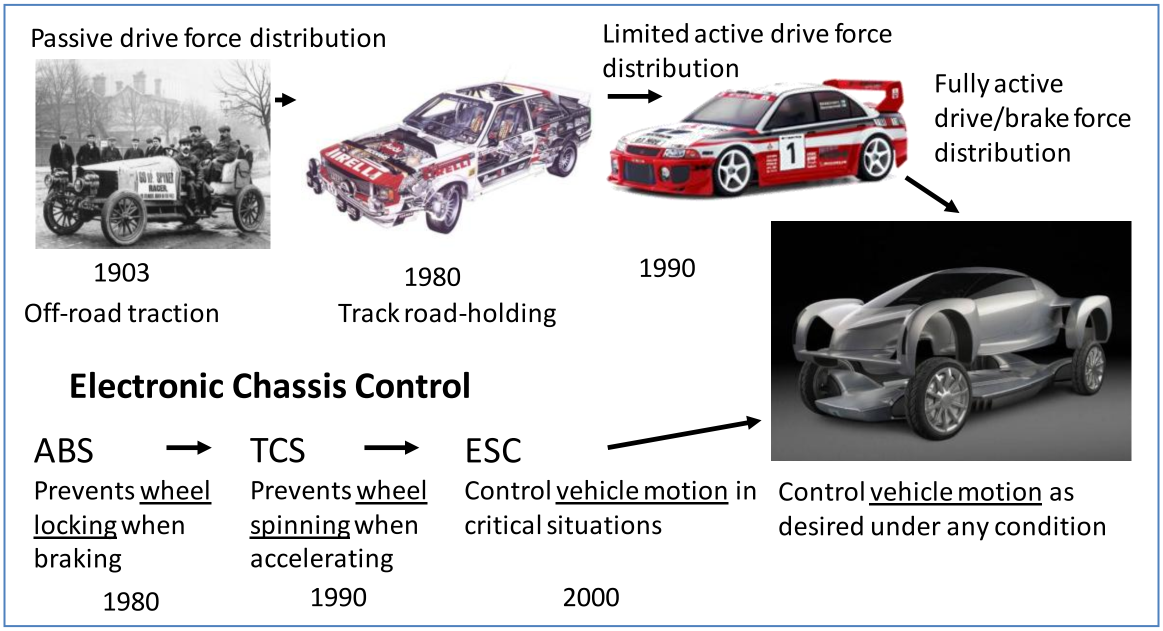


Figure 2 - Convergence of AWD Systems and Active Control

# 2. Objectives

The objectives of this study are to gain better understanding of the influence of longitudinal forces on vehicle handling and stability as well as to support industrial application of active driveline systems. The first objective is to expand the fundamental understanding of the interaction between the longitudinal force distribution and limit vehicle handling by means of simple, yet meaningful, models and improved graphical representations. This understanding should secondly support the development of actual driveline systems and feed-forward components in the associated active control.

It is suggested that the optimization of idealized driveline systems is important as reference for the development of actual systems. For this reason development of optimization formulations are part of this study.

# 3. Results

The main scientific contributions are presented in [1], which includes [13], [14], [17], [18] and [19]. A summary of the most significant findings are given below.

In [17] a new axle-level combined friction model enables a correct representation of vehicles with open front and/or rear differentials using a simple single-track vehicle model relative to the commonly used more complex two-track vehicle model. This model represents the lateral load transfer due to cornering more accurately than a standard friction circle and much simpler than the two-track model.

In [19] the objective is to develop a framework for the optimization of general driveline configurations for optimal combined grip. These problems have been addressed by using a simple load transfer model resulting in the quadratically constrained linear programming (QCLP) formulation. The QCLP formulation provides a faster and more flexible method to perform optimization of the wheel force distribution than methods currently available.

In [14] six different friction independent indicators of a critical cornering situation are evaluated. Since five of these indicators were able to identify the critical cornering situation approximately one-half to one second prior to the oversteer intervention from the ESC-system, these indicators could be used for driver warning or activation of additional yaw damping from, for instance, an electronically controlled limited slip differential (eLSD) or torque vectoring (TV).

In [18] the problem of path recovery is addressed for the case when the speed of a vehicle speed is too high to permit successful tracking of a circular reference path. The essential element of the presented approach is in the allocation of resultant vehicle forces derived from a simple particle representation. In this case the optimal path recovery results in a maximum deviation from the intended path that is only half of that of a standard ESC understeer mitigation approach of braking the inner wheels.

Apart from the above presented reports, the master thesis reports listed in Section 5.2 provide a significant broadening of the studies performed within the framework of this project. In particular in relation to the industrial relevance these studies are of interest, as is in part indicated by the number of patent applications listed in Section 5.5 generated by the contributing individuals.

# 4. Conclusions and Recommendations

This work sets out to improve the fundamental understanding of the driveline/vehicle system related to road-holding limit handling characteristics. This objective is achieved by introducing simplified mathematical models which, for instance, makes it possible to study the effects from front/rear drive force distribution using a simple single-track vehicle model. This is in contrast to the common approach of using a more complex two-track vehicle model for this purpose.

Since much information can be conveyed in graphical representations, these were developed and extensively used in this study with actual driveline systems in mind. One example of this is the dynamic square method which is successfully applied to the analysis of actual vehicle applications as demonstrated in [14], [17] and [19].

Although this study mainly focuses on longitudinal force distribution in driveline systems, the path recovery strategy shown in [18] uses a brake force distribution based on a strategy which in [19] is presented for a driveline system. This demonstrates that much of the learnings developed for traction forces can also be extended to brake forces.

Dynamic stability is studied in [9] and [14]. As with the drive force optimization, a simple bicycle model is shown to be useful to explain the phenomena that create the yaw instability that is provoked by for instance the sine-with-dwell maneuver. The understanding of these fundamentals as presented in [14] mean that interventions from, for instance, an active differentials can be activated around one second prior to the intervention of an ESC-system and thereby expanding the range within which the driver remains in control of the vehicle.

The results obtained in this work can be applied for analysis of the performance of current and upcoming driveline and brake systems and as components in the associated active control for these systems. Overall, the present work has expanded the fundamental framework of vehicle modeling, optimization formulations and graphical representations for analysis and optimization of a wide range of driveline system properties and vehicle level characteristics.

# 5. Publications

## 5.1. Dissertations

[1] Klomp, M. (2010), *Longitudinal Force Distribution and Road Vehicle Handling, Doctoral Thesis*, Chalmers University of Technology

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[18] Klomp, M.; Gordon, T. J.; Lidberg, M. (2010), *Optimal Path Recovery for a Vehicle Tracking a Circular Reference Trajectory*, submitted to the Journal of Dynamic Systems, Measurement, and Control
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