INFORMATION SOCIETY TECHNOLOGIES (IST) PROGRAMME

FRICTION

FP6 - IST - 2004 - 4 - 027006

D4: User needs, application scenarios and system requirements

Dissemination	**PU** = Public
Work package	WP2 - User Needs and requirements
Authors	Matilda Ekdahl, Stefan Nord VTEC Michael Köhler IBEO Thomas Hüsemann, Christian Hartweg ika
Due date	30.11.2006
Delivery date	22.12.2006
Status	Final
This document	FRICTION_Deliverable_D4.doc
Short description	This document contains user needs, application scenarios and system requirements for the friction estimation system.

PART 0 - Preliminaries

Summary

This document defines the boundaries and specifies the requirements for the friction estimation system. Users of the friction estimation system are identified and their needs and potential benefit from a friction estimation system are analyzed.

Usecases showing the functionality in the system are identified together with functional and non-functional requirements such as interface, performance and operational requirements.

The architecture and sensor setup are presented for the development platform, an Audi A6, as well as for the demonstrator platforms, a Fiat Stilo and a Volvo FH12 truck. A subset of the usecases and related requirements are pointed out as the most relevant requirements for the demonstration of the system.

The document also provides an overview on the state of the art of strategies to determine tyre-road friction and friction measuring methods such as sensor cluster and chassis measurement.

Authors

Editor

Ms. Matilda Ekdahl	Volvo Technology Corporation	VTEC_ME

Contributors

Mr. Stefan Nord	Volvo Technology Corporation	VTEC_SN
Mr. Michael Köhler	IBEO Automobile Sensor GmbH	IBEO_MIK
Mr. Thomas Hüsemann	Institut für Kraftfahrwesen Aachen	IKA_TH
Mr. Christian Hartweg	Institut für Kraftfahrwesen Aachen	IKA_CH

Consortium participants:
Technical Research Centre of Finland, VTT (FIN)
Centro Ricerche FIAT S.C.p.A, CRF (ITA)
IBEO Automobile Sensor GmbH, IBEO (D)
Rheinisch-Westfaelische Technische Hochschule Aachen, ika (D)
Magneti Marelli Sistemi Elettronici S.p.A, MM (ITA)
Nokian tyres plc, NR (FIN)
Pirelli Pneumatici S.p.A, PI (ITA)
Siemens AG, SIEMENS (D)
Helsinki University of Technology, TKK (FIN)
Volvo Technology Corporation, VTEC (SWE)

Revision history

Version	Date	Description	Author
0.0	2006-02-21	Added headings and some initial information	VTEC_ME
0.1	2006-05-07	Added draft chapter for use cases (based on Friction_Application_Areas WP2-3_2-4.doc) Added draft chapter for requirements	IBEO_MIK
0.2	2006-09-20		VTEC_SN
0.3	2006-09-22	Added draft chapter for use cases based on WP2.2 , changed numbering and formatting	VTEC_ME
0.4	2006-09-25	Extended use case chapter extended draft chapter Functional	IBEO_MIK

		Requirements	
0.5	2006-10-17	Changed use case and requirements chapter, added use case diagram, added info in general	VTEC_ME
0.6	2006-10-26	Added ika Audi description, added infrastructure needs	IKA_CH
0.7	2006-10-27	Added input from partners	VTEC_ME
0.8	2006-11-08	Updated chapter "State of the Art" and "User needs"	IKA_CH
1.0	2006-11-14	Version finalized for internal review	VTEC_ME

Document structure

This requirements specification is based on the Volere Requirements Specification Template for requirements collection. The document is divided as follows:

PART 0 – Preliminaries
Contains meta information about the document and its contents.

PART 1 – Project Drivers
Describes the purpose of the project as well as list the stakeholders.

PART 2 – Project Constraints
Contains the relevant constraints to consider when specifying requirements.

PART 3 – Functional Requirements
Describes the scope of the system, lists the use cases as well as the functional requirements.

PART 4 – Non–functional Requirements
Lists all non-functional requirements.

PART 5 – Demonstrator System Requirements
Contains a list of the most relevant requirements for the demonstration of the system.

PART 6 – Conclusions
Contains the conclusion of the document

PART 7 – Appendices
Contains additional information and references.

Abbreviations and acronyms

ABS	Anti-lock Braking System
ACC	Adaptive Cruise Control
ADAS	Advanced Driver Assistance System
AEB	Automatic Emergency Braking
ASIC	Application Specific Integrated Circuit
BAS	Brake Assist
CAN	Controller Area Network
CAS	Collision Avoidance System
CW	Collision Warning
EMC	Electromagnetic Compatibility
ESP	Electronic Stability Program
FOV	Field Of View
GPS	Global Positioning System
HMI	Human Machine Interface
IMES	Integrated Mechanical Electronical Systems
IP	Integrated Projects
IVSS	Intelligent Vehicle Safety Systems
LED	Light Emitting Diode
LSB	Least Significant Bit
MSB	Most Significant Bit
N/A	Not Available
OEM	Original Equipment Manufacturer
PSD	Position Sensitive Detector
R&D	Research and Development
RWIS	Road Weather Information System
SAE	Society of Automotive Engineers
SRIS	Slippery Road Information System
STREP	Specific Targeted Research Project
SUV	Sport Utility Vehicle
TCS	Traction Control System
TMC	Traffic Message Channel
V2I	Vehicle To Infrastructure
V2V	Vehicle To Vehicle
VSC	Vehicle Stability Control
WP	Work Package
WT	Work Task

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PART 1 – Project drivers and user needs

1 Contents and purpose

This chapter describes the problems and objectives addressed in the FRICTION project.

1.1 Problem statement and project background

The European commission transport policy for 2010 sets a new target with respect to road safety. The FRICTION project supports the eSafety initiative for the development, deployment and use of Intelligent Integrated Safety Systems in Europe. The objective of the FRICTION project is to create an on-board system for estimating friction and road slipperiness to enhance the performance of integrated and cooperative safety systems like vehicle-to-vehicle communication and driver information.

In an earlier project, APOLLO, that were pioneering intelligent tyre systems, tyre deformation sensors were seen as the most promising technology, constructing the intelligent tyre system with batteryless power generation, wireless data transfer and tyre integration. Acceleration and strain sensors were used for deformation measurements. The tests showed that acceleration sensors can quite accurately determine the contact length of the tyre from radial velocity and tangential position signal. On snowy surface the tangential deflection signal was different on the high and low friction surfaces. On asphalt, bitumen and concrete friction potential cannot be estimated because of high signal variation. Furthermore, the tentative results of the project suggest that the detection of nascent aquaplaning would be possible. [APL03]

The FRICTION project will use the results from the APOLLO project but the aim for this project is a solution for real-time estimation of tyre-road friction using a sensor cluster in a moving vehicle, instead of using only tyre-sensors. Three kinds of sensors will be used in the FRICTION project: existing in-vehicle sensors for vehicle dynamics, environmental sensors, and tyre-based sensors. Today, the signals from these sensors are used separately for vehicle safety systems without combining them. The innovative idea is to feed the signals into a friction estimation system to estimate the tyre-road friction by using on-line mathematical methods.

1.2 Project objectives

The overall objective of the FRICTION project is:

- Create an innovative model for an on-board estimation and prediction of tyre-road friction and road slipperiness
- Build a prototype system of an intelligent low cost sensor clustering with a minimum number of generic sensors
- Verify the system benefits by means of selected vehicle applications using friction and road slipperiness information

- Enhance the functionality of preventive and cooperative safety systems applications in parallel running and upcoming Integrated Projects

2 System stakeholders

2.1 European Commission

The FRICTION project supports the eSafety initiative for the development, deployment and use of Intelligent Integrated Safety Systems in Europe.

2.2 Future system investors

- The partner Volvo Technology is willing to use FRICTION results for their heavy vehicle platform concepts.
- The partner CRF has a plan to use FRICTION results in some selected use cases such as Collision Warning/semi-autonomous Collision Mitigation emergency braking application.
- The project SAFESPOT IP investigates the possibility to use FRICTION results.

2.3 Knowledge input

The FRICTION consortium will bring input to the project as follows:

- VTT will bring their expertise to co-ordination, sensor development, wireless communication, prototyping, safety issues and validation

- CRF will bring its expertise as a developer of advanced vehicle technologies to vehicle control and dynamics and associated algorithm development, electrical systems, testing and prototyping. CRF will provide a passenger car platform for FRICTION sensor system to be demonstrated in PReVENT Integrated project

- IBEO will bring its expertise as a developer and possessor of cutting-edge technology in laser-sensors for automotive applications in obstacle and environment detection

- ika will bring its profound expertise in vehicle systems modeling, algorithm development and testing & evaluation

- MM will bring its Body Electronics Business Line including a department of Electrical and Electronic System Architectures for the definition and development of bus architectures and network design with a deep know-how in all the major automotive communication protocols and networks. Competencies in this area will apply in the system integration activity as well as telematics for co-operative systems support

- Nokian Tyres will bring its expertise in adverse road conditions, associated testing and one of the first developers of intelligent tyre technologies

- Pirelli will bring its expertise as one of the world's leading tyre manufactures with extensive facilities for tyre simulations/modeling, testing and the pioneering developers of intelligent tyre technologies.

- Siemens will bring its expertise as one of the world's leading automotive suppliers in electronics, sensors and sensor systems and related R&D with all the required facilities.

- Helsinki University of Technology will bring its expertise as an expert in tyre-road interaction and friction phenomena and associated testing & facilities.

- Volvo Technology will bring its extensive expertise in ADAS development and will also provide a commercial vehicle platform for FRICTI@N sensor system validation.

3 Users of the system

This chapter describes the users of the system. Users of the system are people or pieces of technology that interface with the system.

3.1 Key users

Key users are critical to the continued success of the system. Requirements generated by this category are of greater importance. The key users of the friction estimation system are:

- Direct driver information systems
- Vehicle Dynamic Control Systems
- Advanced Driver Assistance Systems
- External communication applications

3.2 Maintenance users

Maintenance users have requirements that are specific to maintaining and changing the system. Two different categories of maintenance users of the friction estimation system are:

- Workshop and service personnel
- Software function developers

4 User needs

Through a review of accident statistics it has become clear that adverse road conditions are often an important cause for road accidents. By some it is even argued that road condition is the most significant single parameter causing the loss of driving control.

CARE is a community database on road accidents resulting in death or injury. CARE comprises detailed data on individual accidents as collected by the member states. Road traffic accidents in the European Union annually claim more than 40 000 lives and leave more than 1.7 million people injured. The number of fatalities has steadily decreased between the years 1991 until 2004. The number of deaths varies strongly between the member countries. This is partly due to differences in traffic volume, but also other reasons can be seen. [CAR04]

In the annual statistical report from 2004, statistics over fatal accident is described with respect to the weather conditions. In Figure 1 the weather conditions are grouped into only three major groups, dry, rain or snow and other. This shows the relation between dry and adverse conditions and it can be seen that a noteworthy share of accidents take place in low friction conditions, facing a high risk of aquaplaning or slippery roads.

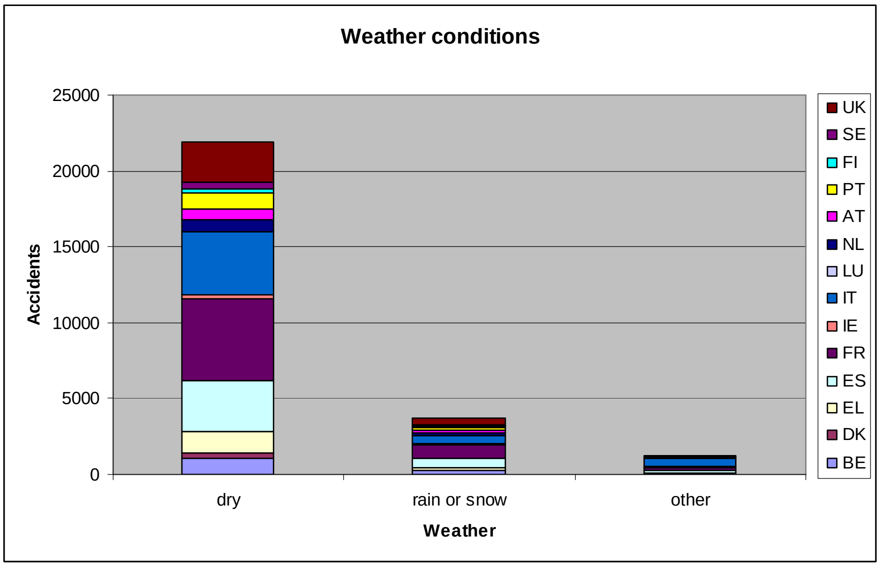


Figure 1 Accidents grouped by weather conditions

Some accidents could most evidently be prevented by an intelligent friction system and the detection of low friction is of great interest when trying to increase traffic safety.

The possibility to detect low friction depends mainly on the maximum force which can be transmitted between each wheel and the road. These forces depend on the local friction (maximum friction available) between the tyres and the road. Therefore, the maximum friction available and the wheel load at each wheel are of considerable interest for driver assistance systems operating with safe performance at any given time and driving situation.

The user needs of the friction information were discussed in the former project Apollo. In that project a tyre based sensor was developed. One benefit of this sensor is that the friction currently used by the tyre can be detected. Since this benefit is of major interest, general user needs concerning friction were analyzed. The following information, regarding possible enhancements to current systems through friction information, is partly extracted from the APOLLO analysis [APO03a].

Today it is still not possible to measure or even estimate the tyre-road-friction level in a reliable way with high precision. Recently, many research projects have mainly focused on tyre-road-friction determination rather than exploring new application areas. This is the reason why there are still many vehicle based active safety systems as well as non-vehicle based systems waiting to be enhanced by a friction sensor system. These systems can be classified in different categories:

- Direct driver information systems
- Driver assistance systems
- External systems and cooperative systems

For each of these categories different functions, systems or applications can be identified which can benefit from tyre-road-friction information.

4.1 Direct Driver Information systems

The human machine interface (HMI) gives a possibility to provide friction information directly to the driver. This could be achieved by a display message containing a certain friction level or by a digit representing a precise value. Another possibility is generating a warning sound if the friction level falls below a defined threshold. The information of interest, possibly delivered by a HMI, is listed below:

- Information on the current friction available
- Information on the road type
- Information on road conditions

Even though this is interesting information for the driver it is necessary to try to limit the total amount of driver information. Today cars are equipped with several systems which provide information to the driver. There is a risk that the driver gets overloaded with information and therefore has problems concentrating on the most important task, driving the car [APO03a].

4.2 Driver assistance systems

Modern passenger cars are equipped with several vehicle dynamics stability control systems. These systems control the transmitted tyre forces which depend on the slip ratio between the tyre and the road. The most important control systems for driving dynamics and driving safety are:

- Tyre slip control systems:
  - Antilock Braking System (ABS)
  - Traction Control System (TCS) or Anti-Skid Control (ASC)
- Electronic Stability Program (ESP)
- Active safety systems

To give a short introduction of the methods of operation, the systems are described below.

4.2.1 Tyre slip control systems

Tyre slip control systems detect a difference between the circumferential velocity of the tyre and the overall vehicle speed. The friction forces are caused by the difference between both velocities, the slip velocity. This value is defined as the tyre slip and follows this equation:

$$\lambda = \frac{v_r - v}{\max(v_r, v)} \cdot 100\% \cdot$$

In this formula λ represents the wheel slip, v the velocity of the vehicle relative to the ground, v_r the tyre velocity due to the rotation of the tyre. The wheel slip value is zero for a free rolling wheel. In case of braking the slip value becomes negative. An extreme case would be a completely locked tyre and a wheel slip value of λ = -100 %. In case of accelerating the wheel slip value becomes positive. Wheel slip control systems serve to keep the slip within the optimal range for braking and traction force transfer.

ABS - Antilock Braking System

An antilock braking system controls the brake pressure to keep the optimal tyre braking slip. Because of the direct connection between the forces and the friction coefficient the friction is estimated by the ABS controller. The ABS controller combines the control of the wheel acceleration and the slip to ensure short times of reaction. If the friction information would be known before the ABS controller detects a wheel lock situation the optimal braking force could be ensured from the beginning of the control cycle which leads to a reduced braking distance.

TCS - Traction Control System

Traction control systems are based on the same idea as the ABS. The difference is that they are used for better acceleration instead of braking. The benefit of a known friction coefficient would be an enhanced acceleration performance under bad road conditions.

[APO03a]

4.2.2 Electronic Stability Program

The aim of the electronic stability program (ESP) is to prevent over- and understeering situations. The system detects a critical side slip angle between the direction of rotation of the wheel and the direction of the speed of the contact patch between wheel and road. To distinguish between an understeering and an oversteering situation the system compares the side slip angles between the front wheels and the rear wheels. Oversteering is detected when the side slip angles at the rear wheels are larger than the front wheels side slip angle. Understeering is detected when the side slip angle at the front wheels is larger than the rear wheels slip angle.

To compensate the detected instable situations the ESP reacts with a yaw moment acting in the opposite direction. This is realized by braking one wheel to create the desired yaw torque (figure 2).

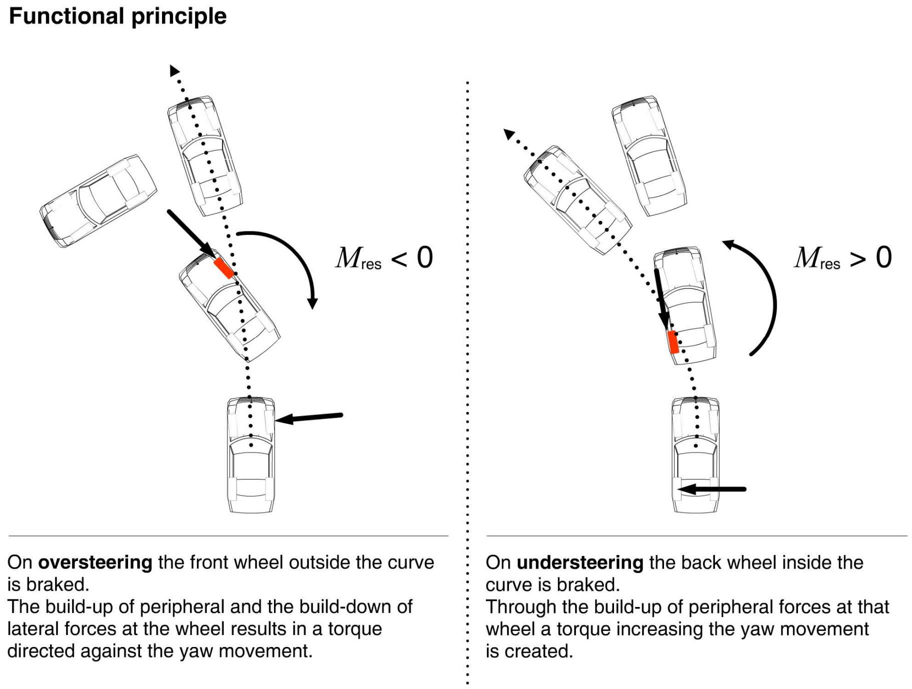


Figure 2 Mode of operation

If the yaw moment created by the braking of one wheel does not stabilize the driving situation the ESP can reduce the driving torque of the engine as well.

The ESP system usually starts to intervene when one or more tyres of the vehicle are being at or close to their friction limit. The pre-estimation of the maximum friction available would enable the ESP system to interact long before the friction limits in the tyre-road contact patches were reached and before a critical situation has occurred. This would lead to a remarkable safety benefit, especially for low friction conditions.

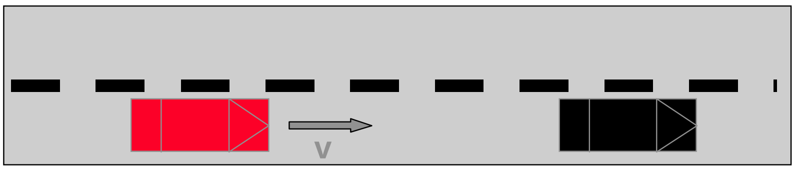
[KLI95], [PAR00], [PAU98], [SFE01], [ZAN94], [APO03a]

4.2.3 Active Safety systems

Modern cars are being equipped with more and more active systems in order to support the driver. Active steering and active braking systems have been developed and brought to market. Up until now these systems amplify the action of the driver but they do not act against the driver's intention. The next step would be that in case of an emergency the systems undertake the control of the car. First approaches have already been done with advanced driver assistance systems such as Adaptive Cruise Control (ACC). The ACC keeps the driving speed on a constant level until sensors detect an obstacle in front of the car. The system then adapts the speed so that the distance between the car and the obstacle in front stays constant. If the obstacle disappears the system increases the driving speed to the level set before. The aim is to keep a safe distance to the traffic in front of the car to be able to brake safely at any time.

If the friction information would be available the braking distance could be calculated more precisely. Figure 3 describes the connection between the braking distance and the friction coefficient.

Prediction of braking distance for stationary obstacle



Braking distance: $s_B = \dfrac{v^2}{2 \cdot \mu_x \cdot g}$

Influence of max. friction available: $1/\mu$

Max. vehicle velocity (range of radar system: 160 m)

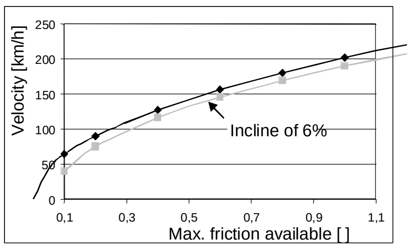


Figure 3 ACC - Prediction of minimum braking distance

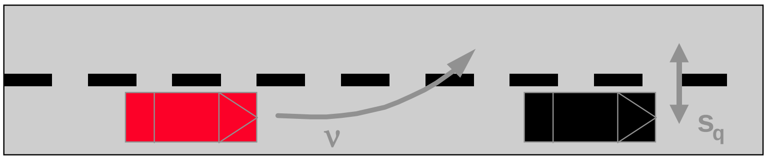
The braking distance (S) of a vehicle can be calculated by the velocity (v) and the maximum friction available (μ). Therefore besides the speed, the most influencing parameter on the braking distance is the maximum friction available (μ).

In comparison to former cruise control systems the ACC does not only control the engine torque but also activates the brakes of the vehicle. This enables another ADAS application, the automated emergency braking. While the first ACC systems gave a warning to the driver if the distance between the car and an obstacle was too small, latest versions are able to perform an automated emergency braking.

The automated emergency braking works in the same way as the ACC but the system is allowed to do an emergency braking on its own when a dangerous situation is detected. The system will decelerate the car to full stop by the maximum braking force available. This system could benefit from friction information as well.

The use of an active steering enables the development of another ADAS application called Collision Avoidance System (CAS) which combines an active braking with an active steering intervention. The idea is to avoid a collision by an active steering manoeuvre if an emergency braking is not sufficient. Figure 4 describes the relationship between the friction coefficient and the distance needed for a steering manoeuvre.

Prediction of distance for steering manoeuvre (simple model)



Distance for steering manoeuvre: $$s_A = v\sqrt{\frac{2 \cdot s_q}{\mu_y \cdot g}}$$

Influence of maximum friction available: $$1 \Big/ \sqrt{\mu}$$

Figure 4 Collision avoidance by steering actuation

The main conflict the system has to solve is the decision between braking and steering to avoid a collision. The knowledge of the friction information could help to get a higher precision of the pre-estimated distances needed [APO03a].

4.3 External communication systems

There is ongoing development concerning the distribution of online data like traffic information, local weather information or warning of dangerous road conditions. Two communication methods are to be considered.

The first method is the **vehicle-to-vehicle** communication. One scenario could be that a car detects bad road conditions or a traffic jam at one section of a road. The cars' on-board-systems could send this information to following cars to get the driver aware of the dangerous situation.

The second method is defined as **vehicle-to–infrastructure** communication. In this case the information is picked up by an individual car and transferred to the infrastructure. The infrastructure could process the data and deliver it to other road users or radio stations. An infrastructural system would be able to control traffic signs, provide data for traffic management or inform authorities about road surfaces.

Both communication methods could possibly deliver friction data and help in developing a “friction map” for short time updates [APO03a].

4.3.1 Ongoing development

The benefit for driving stability and driving safety by the knowledge of the friction information is described above. In this context current and latest investigations concentrate on friction data delivery and distribution as well as on friction level identification. This could help to publicize the friction information to every road user. There are several projects which work on communication methods. Some of the projects are described below.

FEEDMAP

The objective of the EC-supported project FeedMap is to assess the technical and economic feasibility of map data correction by providing a map data feedback loop applied to a map data updating frame-work. In the loop, the road users contribute to the improvement of the digital maps by detecting map anomalies and reporting them to the map providers. In return they benefit from a fresher map in other areas. Besides the map providers and road authorities gain a new source of map surveys. FeedMap’s main focus will be on static and semi-static changes to the road network. In addition, real-time status of reports on events such as traffic jams or accidents can be verified and returned to the information source. Also information on low friction or weather conditions can be of interest. FeedMap follows the Project ActMap which worked on the fast and flexible way to update map data. This data were given to the individual car. By the use of this system FeedMap concentrates on the data transmission from the individual car to a central database. This database may verify the collected data and is able to offer the information to various users.

The collected data are taken up by the individual car and stored in a recorder. To transmit the information, several services can be taken into accounts which are used by an infrastructure which collects the information. This system could be used to pass friction information to other road users by feeding a Friction Map. [FMP06]

WILLWARN

The PReVENT subproject WILLWARN is developing a communication-based system that extends the driver's horizon and intelligently warns the driver of dangerous situations ahead. WILLWARN provides drivers the opportunity to adapt the vehicle speed and inter-vehicle distance early-on, leading to a higher situational awareness of potential unforeseen danger. WILLWARN is developing, integrating and validating a safety application that warns the driver whenever a safety-related critical situation occurs beyond the driver's field of view. This includes the development of on-board hazard detection, in-car warning management, and decentralized warning distribution by vehicle-to-vehicle communication on a road network. One of the key issues of WILLWARN is improved safety through vehicle-to-vehicle and vehicle-to-infrastructure communication. WILLWARN will cover the following scenarios [WLW06]:

- Detection and warning of obstacles on the road, warning if one's own car is an obstacle for others
- Warning of emergency vehicles or slow vehicles
- Detection of reduced friction or reduced visibility through bad weather
- Warning of dangerous spots through electronic beacons

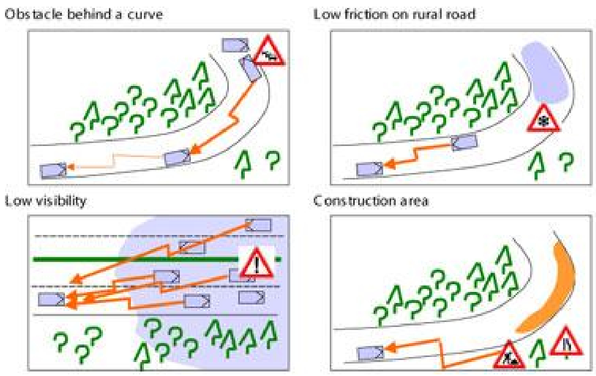


Figure 5 WILLWARN scenarios

SRIS

SRIS, Slippery Road Information System, is a project of the Intelligent Vehicle Safety System (IVSS) program driven by the Swedish Road Administration. The SRIS project aims at combining data from RWIS (weather information) and friction values from floating cars in order to improve the information to drivers and road maintenance personal about the prevailing road conditions. A model will be used where the weather data and the estimated friction values from the cars are interpreted into a high quality output suitable as information to road users. It is also analyzed how the information is best presented. [IVSS06]

SAFESPOT IP

The key aspect of the IP SAFESPOT, started in the beginning of 2006, is to expand the time horizon for acquiring safety relevant information for driving.

The incorporation of new information sources based on V2V and V2I communication has an important role. Such a cooperative approach envisages a scenario in which the vehicles and the infrastructure cooperate to perceive potential dangerous situations extended in space and time horizon that will only be limited by the range of the radio communications.

The time horizon of the SAFESPOT applications will allow an extension of the “safety margin”, namely the time in which a potential accident is detected before it can occur, from the range of “milliseconds” up to “seconds”. The availability of information about current and especially upcoming road friction condition is one very important aspect for the improvement of the „safety margin“. Thus, there can be identified potential interactions between the projects FRICTION and SAFESPOT. The following figure, taken from the SAFESPOT Technical Annex shows a possible link at SAFESPOT subproject levels.

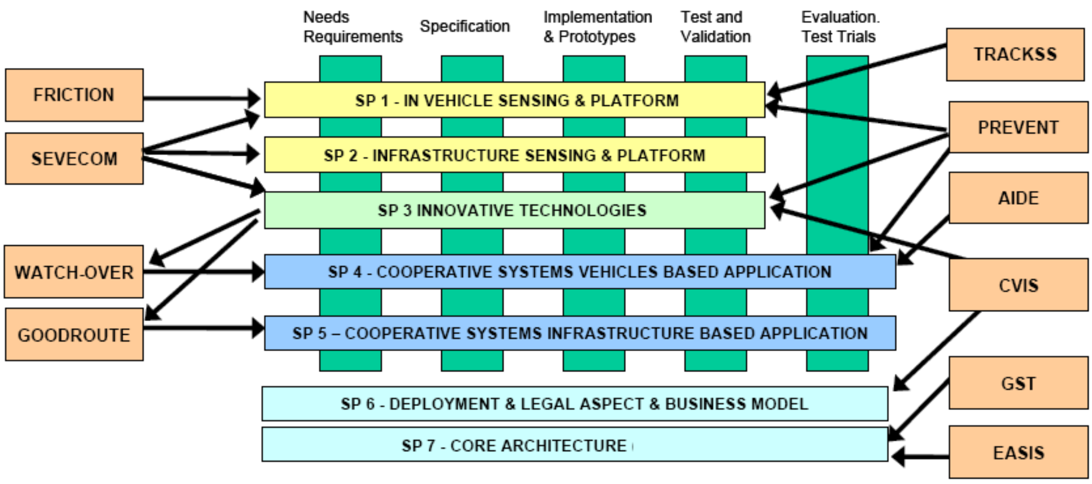


Figure 6 SAFESPOT subproject levels

PART 2 – Project constraints

5 Mandated constraints

This section describes constraints that will affect the eventual design of the product.

5.1 Solution design constraints

The project aims at a solution of real-time estimation of the tyre-road friction using a sensor cluster in a moving vehicle. The objective is to use existing and up-coming sensors - not to build new ones. A cost-effective solution is sought for that is comprised of clustering from:

- in-vehicle sensors
- environmental sensors
- tyre sensor(s) from the APOLLO-project

The target is a sensor clustering that yields tyre-road friction with a minimum number of sensors. The project seeks to employ sensors that are already used in modern vehicles or that are commercially available, cost-effective and reliable. Eventually, the principal target of the project is to develop a novel system based on sensor clustering that provides the driver and the vehicle control system with friction estimate of the road section ahead, i.e. predictive friction estimation. The target is also to promote the trend of using generic sensors for multiple purposes addressed by the PReVENT sub-project Profusion.

5.2 Implementation environment

The system will be implemented in a Rapid Prototyping hardware/software environment. This decision is made to place minimum constraints on the system developing process.

6 Naming conventions and definitions

This section lists all definitions of terms and acronyms used in project.

6.1 Friction definition

The term “friction” has different meanings. It is necessary to define three “friction-terms” in order to cope with meanings and to be able to distinguish between all of them:

6.1.1 Friction Potential

“Friction potential” $\mu_{potential}$ is defined by tyre-road contact conditions. It is the maximum potential friction $\mu_{potential}$ for a vehicle with a particular tyre on the current road. This term depends on wheel load F_Z and speed, etc. (the influence of wheel load is high; the influence of speed is low). Wheel load and speed can be used to describe the operating point of the driving situation of the certain vehicle. The term “friction potential” gives information on the current, the previous and ideally the future friction limit. Therefore, information on “friction potential” is of high importance for vehicle applications.

6.1.2 Friction Used

“Friction used” μ_{used} is defined by the current driving situation. It depends on different parameters like speed, acceleration, lateral acceleration etc. “Friction used” μ_{used} is defined as a quotient of horizontal wheel force F_H and vertical wheel force F_Z: “Friction used” $\mu_{used} = F_H / F_Z$. It can be calculated for lateral and longitudinal forces. The current road surface and road condition and the particular tyre are boundary conditions. “Friction used” does not depend on these boundary conditions, because the vehicle is driving away from these limits. Therefore this term does not supply information about the maximum friction available! “Friction used” μ_{used} can be measured using various approaches. It describes the current and the previous driving situation and does not provide information about future driving conditions.

6.1.3 Friction Available

The term “friction available” $\mu_{available}$ is defined as the difference between “friction potential” and “friction used” of the current driving state. As it is valid for “friction potential” the term “friction available” contains information about the current tyre-road contact, too. Therefore, this new term “friction available” is much more important for vehicle applications compared to data of “friction used”. “Friction available” is mainly related to up-coming, future driving situations. The “friction available” can be derived by the difference between “friction potential” and “friction used”:

“friction available” = “friction potential” – “friction used”

$\Rightarrow \mu_{available} = \mu_{potential} - \mu_{used}$

“relative friction available”

$\Rightarrow \mu_{available} = (\mu_{potential} - \mu_{used}) / \mu_{potential}$

Regarding potential automotive applications “friction available” is the most important parameter of these three types of tyre-road-friction

6.2 Communication definitions

This section contains definitions regarding network and communication.

6.2.4 Node

Every sensor/electronic device is defined as a “node” of a system.

6.2.5 Message

A message is a structured set of signals aggregated and transmitted by one module. It identifies the structure and the content.

6.2.6 Frame

A frame is the structure of a message. It identifies the message structure only and not the content.

6.2.7 Signal

A signal is a single codified piece of information, exchanged between two modules. A signal is identified by its position (MSB – LSB) and size (bits number) inside the data field:

	bit 7	bit 6	bit 5	bit 4	bit 3	bit 2	bit 1	bit 0
Byte 1	63	62	61	60	59	58	57	56
Byte 2	55	54	53	52	51	50	49	48
Byte 3	47	46	**45**	**44**	**43**	**42**	**41**	**40**
Byte 4	**39**	**38**	**37**	**36**	**35**	**34**	33	32
Byte 5	31	30	29	28	27	26	25	24
Byte 6	23	22	21	20	19	18	17	16
Byte 7	15	14	13	12	11	10	9	8
Byte 8	7	6	5	4	3	2	1	0

Figure 7 Signal data fields, the red colored signal has position [34, 45] and size 12

Signals may be either “coded” or “value” ones. Coded signals are binary values with coded information A value signal is a binary value with value information.

6.2.8 Communication matrix

A list of all messages organized in a communication matrix showing properties of each message and transmitter/receiving nodes:

ID	MESSAGE NAME	Type	Period (mSec.)	Size (byte)	RPU	NSX	NSY	...	...	...	...	...	...	NSZ
…	NSX_1	(P,E...)	t_{x1}	(1-8)	RX	TX								
…	NSX_2	(P,E...)	t_{x2}	(1-8)	RX	TX								
...	...	...	...	...	...	...								
...	NSX_m	(P,E...)	t_{xm}	(1-8)	RX	TX								
...	NSY_1	(P,E...)	t_{y1}	(1-8)	RX		TX							
…	NSY_2	(P,E...)	t_{y2}	(1-8)	RX		TX							
…	…	...	…	…	…		…							
…	NSY_n	(P,E...)	t_{yn}	(1-8)	RX		TX							
…	NSZ_1	(P,E...)	t_{z1}	(1-8)	RX									TX
…	NSZ_2	(P,E...)	t_{z2}	(1-8)	RX									TX
…	…	...	…	…	…									…
…	NSZ_p	(P,E...)	t_{zp}	(1-8)	RX									TX
…	RPU_NWM	(P,E...)	t_{rpu}	(1-8)	TX	RX	RX	…	…	…	…	…	…	RX

Figure 8 Communication matrix

6.2.9 Message map

A message map is a list of signals showing position and size:

NSX_1

Id: ... *Type:* (P,E…) *Period:* t_{x1} mSec *Size:* (1-8) bytes Sender: NSX

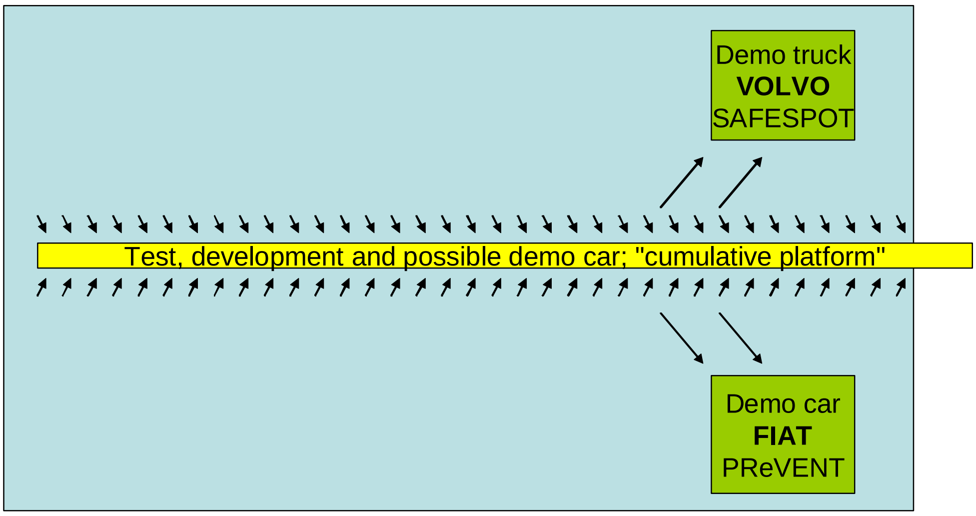
Signal Name (NSX_1)	Event trans	lsb pos	bit Size	Property	Value	NOTE	Node(s) Receiving
NSX_1_sig1	(Y, N)	(0-63)	(0-63)	Accuracy Range High Range Low Unit Signal Age Resolution Offset Startup/Default Not valid	… … … … … … … … …		RPU
…	…	…	…				RPU

Signal Name (NSX_1)	Event trans	lsb pos	bit Size	Property	Value	NOTE	Node(s) Receiving
NSX_1_sigk	(Y, N)	(0-63)	(0-63)	Accuracy Range High Range Low Unit Signal Age Resolution Offset Startup/Default Not valid	… … … … … … … … …		RPU
							RPU

Figure 9 Message map

7 Assumptions

The project intends to use a common development platform vehicle for development and test as a "cumulative platform". At a certain point in time the developed system will be transferred to the demonstrator vehicle platforms. This calls for a system that has a flexible and modular design in order to minimize the amount of work needed for integration and test.



7.1 Development platform

For first sensor tests and tests of algorithms and strategies it is useful to have a common development platform which is flexible in handling and which can be easily equipped with different types of sensors. As a development platform an Audi A6 available at ika will be used. The car is powered by a 220 kW engine and driven by a four wheel drive. The hydraulic power steering has a variable hydraulic steering torque support.

Furthermore the steering is active for variable steering ratios. This active steering can also be used as steering robot for reproducible driving maneuvers.

Figure 11 Development platform: Audi A6 4.2

The rear axle is equipped with air springs for level regulations. This feature reduces changes of the driving behavior due to load changes.

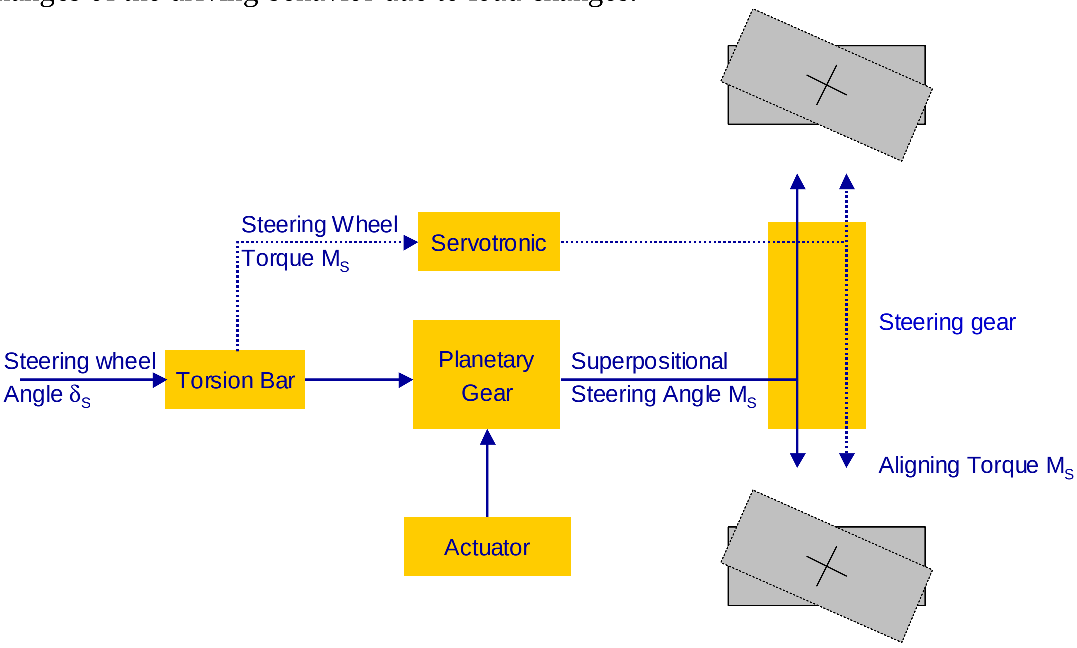


Figure 12 Steering system layout

For safety reasons main functions of the add-on systems can be controlled by the driver. The active steering can for example be terminated by an emergency power off button. There is a dSpace Autobox installed in the car which is equipped with its own CAN-bus separated from CAN-bus of the car. Information like accelerations, yaw rate, wheel speeds, car speed, engine torque and more are available on the bus. Also each brake pressure is available as analogue signals.

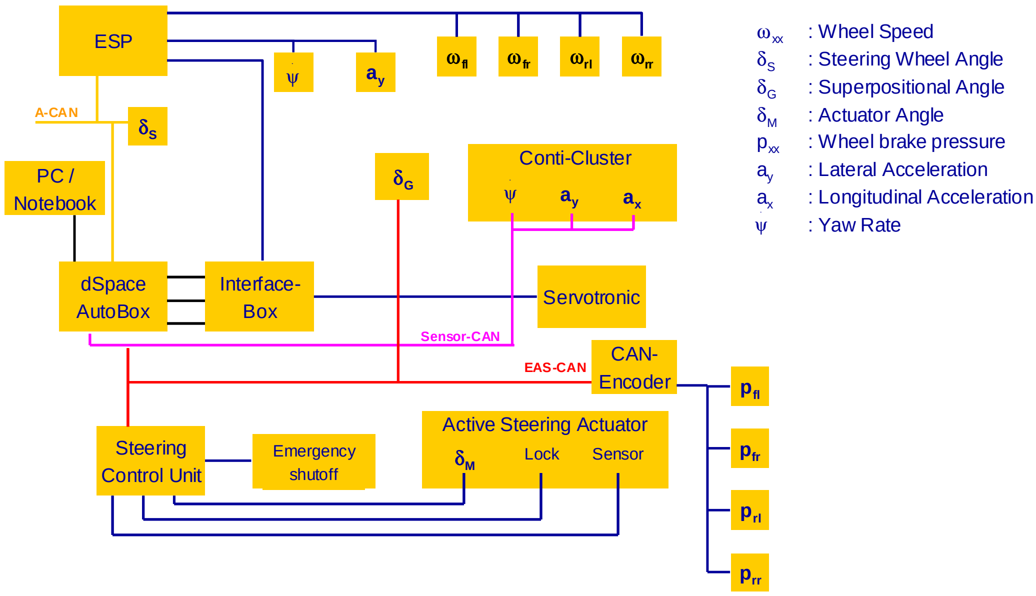


Figure 13 Information flow layout

The car is not allowed to be driven on public roads. Consequently the use for development purposes has to take place on closed proving grounds. To use the car as development platform a validated vehicle simulation model is available in Matlab / SIMULINK. By this tool any driving maneuvers can be simulated before on road test are done.

7.2 Demonstrators

7.2.1 Passenger vehicle, FIAT Stilo

A Fiat Stilo will be used as a passenger vehicle demonstrator. It is equipped with a collision warning and mitigation system. The system prevents low speed accidents involving pedestrians, by monitoring the frontal area close to the vehicle and, more generally, mitigates the severity of unavoidable collisions, by significantly reducing the kinetic impact energy and improving the control of restraint systems to enhance the protection of car passengers.

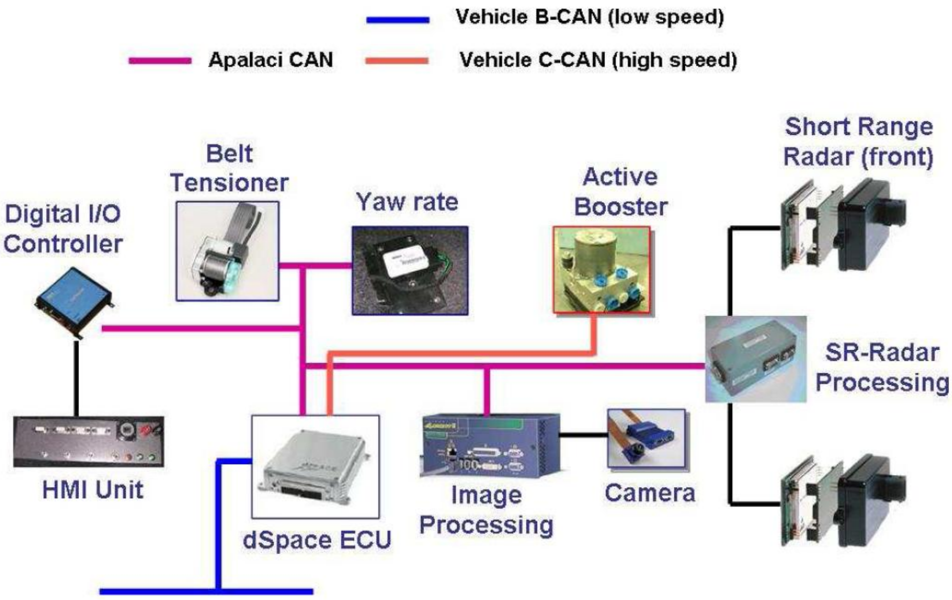


Figure 14 Demonstrator: FIAT architecture

The Fiat Stilo is equipped with the following conventional sensors:

- Wheel speed (x4)
- Lateral acceleration
- Yaw rate
- Longitudinal acceleration
- Steering wheel angle
- Steering wheel torque (EPS)
- Steering column torque (EPS)

7.2.2 Commercial vehicle, Volvo FH12

A Volvo FH12 will be used as a truck demonstrator. In addition to the conventional sensors a number of environmental sensors are mounted on the truck:

- 1 long range forward looking radar
- 2 short ranged forward looking radars
- 1 FIR camera
- 1 camera for the blind spot in front of the truck
- 1 camera for the blind spot to the right of the truck
- 1 lane tracker camera
- 1 laser scanner (225 deg FOV)

From production the truck is equipped with ABS, ESP and ACC systems. It also supports a number of applications developed in different ongoing PReVENT subprojects. These applications are:

- Active Lane Keeping Support
- Collision Mitigation by Braking
- Start Inhibit

- Curve Speed Warning
- Lane Change Assistance
- All Around Warning

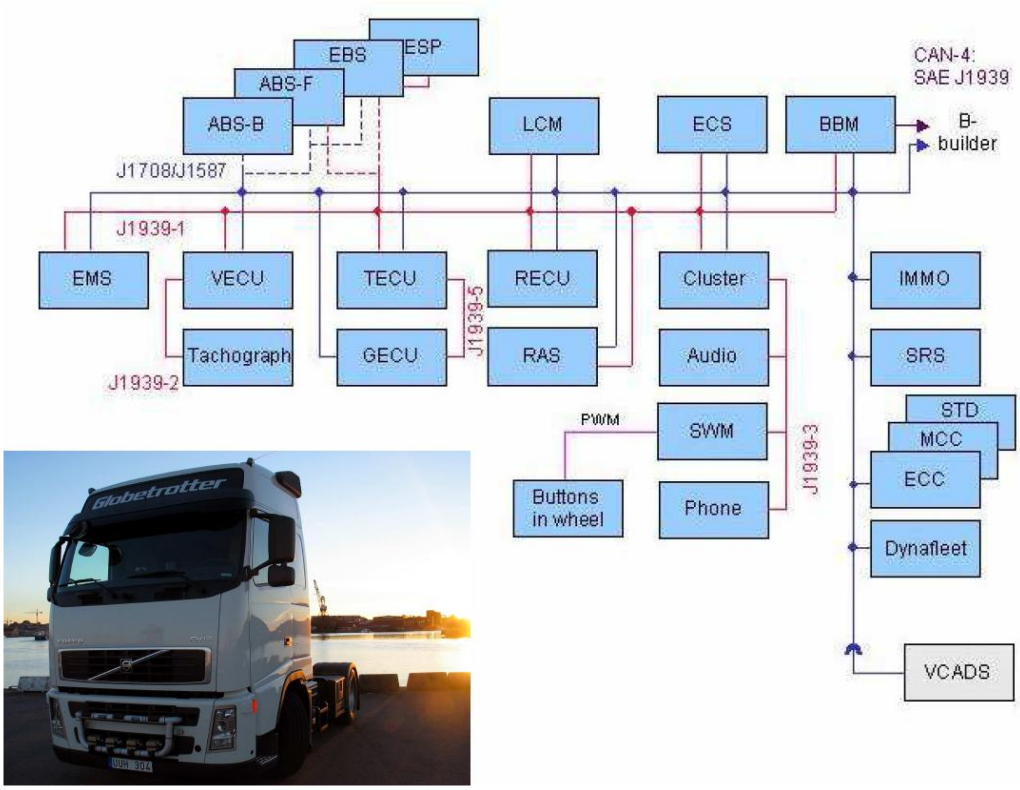


Figure 15 Demonstrator: Volvo FH12 architecture

PART 3 – Functional requirements

This part contains fundamental and essential subject matter of the friction system that are measured by concrete means like data values, decision-making logic and algorithms.

8 State of the art analysis

8.1 The tyre-road friction phenomenon

All forces, except for aerodynamic drag, that act between a vehicle and its environment have to be transmitted to the road by the tyres. This force transfer takes place by friction processes between the road surface and the tyre tread rubber. Two main phenomena are responsible for this force transfer by friction:

- Hysteresis friction and
- Adhesion friction

Adhesion describes the friction by molecular attraction while hysteresis describes friction by the interlocking of the rubber with the ground. When characterizing force transfer properties of a vehicle tyre, the two types of rubber-road friction are not separated from each other. The tyre is described by its global friction coefficient. But when taking a closer look at the processes taking place between tyre and road, it becomes obvious that adhesion friction is mainly responsible for tyre grip on dry roads while hysteresis friction assures tyre grip on wet roads.

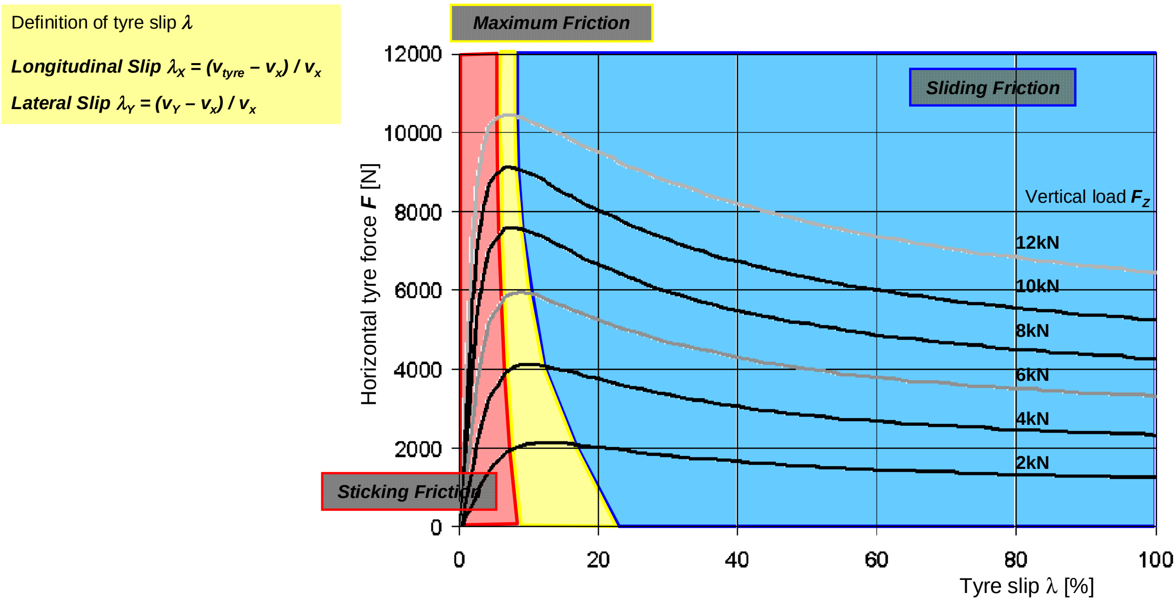


Figure 16 Friction characteristics of the overall tyre

The main outcome of friction coefficient investigations between rubber compound specimens and different road surfaces are the following facts:

- The friction coefficient decreases with increasing local pressure
- After reaching its maximum value at a very low sliding speed the friction coefficient decreases with increasing sliding velocity
- After reaching its maximum value at a characteristic temperature the friction coefficient decreases with increasing temperature
- Any liquid between rubber and road leads to a sudden drop of the friction level.

The force transfer between tyre and road is directly connected to a certain slip condition of the rolling tyre. This slip state describes the point of operation. Low slip quantities mean that there are mainly adhesive friction force transfer between tyre and road. At very high slip values, mainly sliding friction is responsible for generating tyre forces.

Besides the effects described there are other parameters that influence the force transfer behavior and therefore the friction coefficient mapping of the overall tyre. They can be classified into four main categories:

- Tyre related parameters
- The current driving state

- Road surface related parameters
- Road condition parameters

To estimate the friction available, all these parameters have to be taken into account by a friction determination system.

8.2 Strategies and concepts to determine tyre-road-friction

Different approaches can be chosen to determine friction, depending on the kind of friction ("used", "potential", "available" or "friction ahead").
"Friction used" will mainly be determined by using standard vehicle based driving dynamics sensors like those already available for ABS or ESP systems. The idea behind "friction used" measurements is to describe the current motion state of the vehicle very precisely based on standard vehicle based sensors like:

- Wheel speeds
- Vehicle speed
- Longitudinal and lateral acceleration
- Brake pressure
- Yaw rate
- Steering angle sensor
- Spring deflection

Using these online measurements of the vehicle motion to support a real-time capable vehicle dynamics calculation model, the current "friction used" can be estimated very precisely. In case of a driving maneuver where the maximum possible tyre force for this point of operation is reached, "friction potential" can also be estimated because it equals "friction used". Therefore, a rough idea of the friction limit of the road currently used can be estimated by this principle.
But to really measure "friction potential" of a tyre-road combination other efforts have to be made. Generally speaking it is still very difficult to implement a system into a car which can permanently measure the "friction potential" of the tyre-road combination. Measuring friction potential often still means applying special test equipment like e.g. a mobile tyre test bench, a tyre tread friction tester or a "skiddometer". "Friction used ahead" and "friction potential ahead" could be "measured" by vehicle-to-vehicle communication with the cars ahead. Another idea would be to implement a digital road map with online supply of the current friction levels by GPS. The measurement would be done by all vehicles using the road and transferring this data to a corresponding supplier.

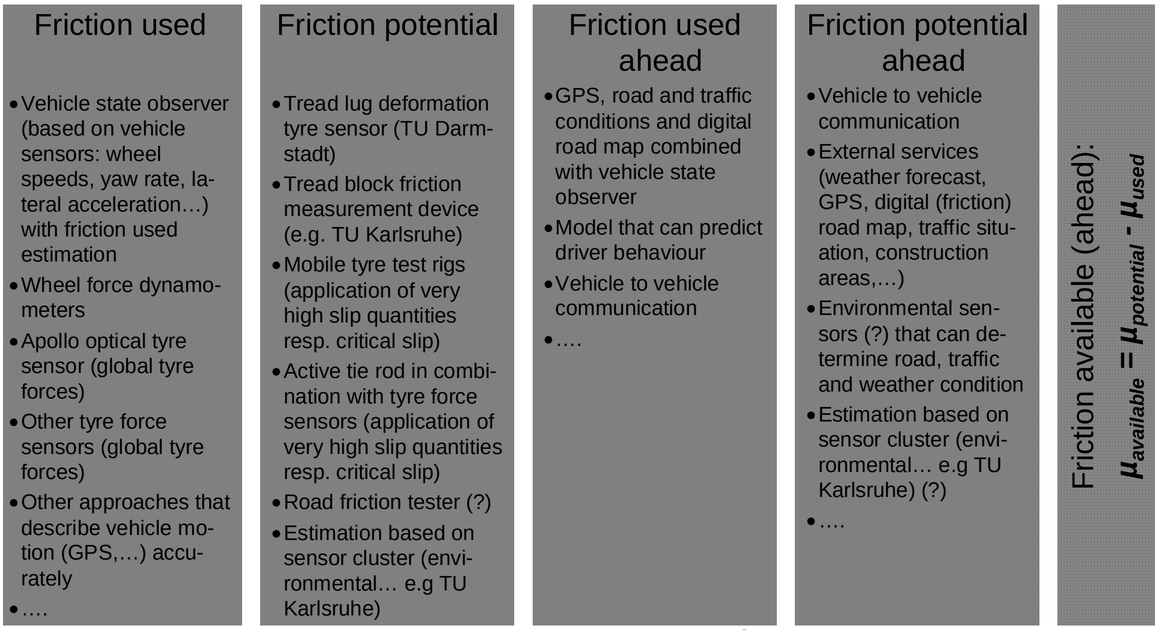


Figure 17 How to measure or estimate friction

All methods to measure tyre-road friction can be classified using three categories:

- Direct active determination
- Direct passive determination and
- Indirect determination

Technology for observing road parameters and the tyre-road contact has been a topic in a number of projects internationally - both EU-funded and others. Below, several existing systems and prototypes are listed:

- Fixed road-side monitoring systems (road segment specific)
  - Fixed road-side weather monitoring stations
  - Vaisala Remote Road Surface State Sensor DSC111 [VAI06]
  - Nagoya Electric Works Co. Ltd has developed a road surface monitoring system [NAG06]
  - Oceanor's ICECAST [OCE06]
- Direct friction characteristics measurement
  - Tyre measurement truck
  - Pendulum (Skid Resistance Tester)
  - Tread lug specimen friction test device
- Road monitoring with probe vehicles (so called floating car data)
  - Friction measuring system on public buses by Finnra (Finnish National Road Administration) [MYL03]
  - FH Konstanz: Friction determination with standard vehicles [LAU02]
- Environmental sensors
  - Optical, acoustic, ultrasonic and radio frequency-based environmental sensors utilize changes in the reflectance, polarization and absorption properties of the road surface. They can not be used for direct force measurement, but can detect road conditions.

- In-vehicle sensors for vehicle control systems
    - In-vehicle sensors monitoring vehicle state provide information about the driving state of the vehicle such as lock-up of wheels and vehicle's position on the intended trajectory. These sensors measure only changes caused by impaired friction and not directly road conditions, and are not capable of *predicting* friction ahead. The measurements must be processed and they may not be accurate or real-time enough for time critical safety applications. However, vehicle state sensors provide useful driving state information, which combined with e.g. environmental sensors, would be worthwhile in friction estimation.

8.3 Friction measuring methods

8.3.1 Estimation by sensor cluster

The University of Karlsruhe has introduced a new system for estimating “friction potential” during driving. The system is based on the detection of environmental data to determine one of six “friction potential” classes and its working principle can be classified as an “indirect” friction measurement method. The system does not depend on specific car / truck properties (type of tyre, tyre pressure, wheel load) and it allows an estimation of the friction level of the track ahead. The method is motivated by the fact that the weather and the road conditions have the most distinctive influence on the friction coefficient [ATZ04].
The described method detects these environmental conditions by several indirect sensors:

- Sensing road surface temperature
- Acoustic sensor
- Acceleration sensor at the axle
- Rain sensor
- WSE -sensor (Water, Snow, Ice)

The weather conditions are identified by using three information sources. The measured road temperature leads to the three possible situations dry road, wet road and icy conditions. At temperatures of 0°C or more a rain sensor supports by detecting dry or wet road conditions. If the temperature does not reach 0°C a newly developed sensor called WSE-sensor (water, snow, ice) provides further information about the friction coefficient by the identification of water snow or ice on the road.
Furthermore, the type of the road is detected by the use of acoustic sensors involving the measurement of the acceleration of the axle. Every type of road has an appropriate transmitted frequency band which allows the differentiation of cobblestone, asphalt or dirt road.
The data of the described sensors are analyzed and provide answers to eleven major questions. The system therefore compares the signals of the sensor to well known patterns of a data base. The answers are used to determine one of six friction classes.
This method does not provide an explicit friction coefficient but it helps to evaluate the environment of the car. This allows not only recognizing the current road conditions but

also an assumption of the conditions of the road ahead. The system can be enhanced by more sensors and more information.

8.3.2 Estimation by chassis measurement

Pasterkamp [PAS97] developed a sensor system which should measure the slip angle and the actual friction using global forces and momentums of the tyre, which are measured in the chassis.
It is known from principle tyre mechanics, that the side force is the sum of the lateral deformations of the tread blocks while the aligning torque is the distance weighted sum. The deformation shape of the tread blocks over the contact patch length mainly depends on the friction coefficient, the side slip angle and the ground pressure distribution over the whole contact patch length (whereas the G-modulus can be seen as invariant). This consideration leads to two equations with two unknown variables. At least in the linear region of the side force and aligning torque, this system of equations can be solved distinctly. The contact patch length depends on the wheel load, which is the third measured variable.
This shows that a high potential of detection possibilities is latent in the measured variables aligning torque and side force in combination with the wheel load.
The measurements of the necessary forces were solved using strain gauges in the chassis. Due to the kinematics, the forces and torques cannot be measured directly. They have to be recalculated following the chassis design; the motions due to spring travel and steering angles have to be taken into account in the recalculation.
A neuronal network was used for the calculation of the needed wheel load, side force and aligning torque using the direct measured data. Due to the structure of the neuronal network and the high number of necessary training datasets the following deficiency of the layout of this system occurs [PAS97]:

- the tyre pressure (TCP-length, contact pressure) cannot easily be considered,
- the temperature influence cannot easily be considered,
- different tyres cannot be considered,
- tyre wear cannot easily be considered,
- Ground pressure distribution changing due to uneven roads or soft underground (snow) cannot easily be considered.

In this configuration the system can only deliver friction potential, if the vehicle is cornering at the driving dynamic limits, otherwise the current friction used is obtained. Some approaches, which have not been realized, are supposed to allow active toe angle adjustments, so that side forces at the tyres can also be generated in straight line driving.

8.3.3 Darmstädter tyre sensor

The Darmstädter Tyre Sensor was developed by the University of Darmstadt since 1988 within the frame of the Sonderforschungsbereich (special research field) IMES 241 (Integrated mechanical electronic systems for mechanical engineering).
It is designed to measure the local tread block deformations in the tyre contact patch (TCP). Currently the fourth development generation is in use. The deformation is

detected by the use of inserted magnets. The change of the magnetic field while moving is detected by a Hall sensor.

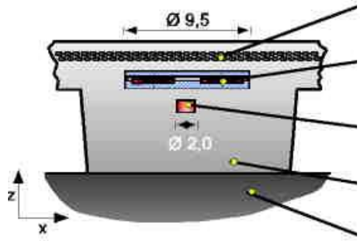


Figure 18 Fourth generation of the Darmstädter tyre sensor [STR02]

This sensor allows an estimation of the tyre forces to calculate the friction used.

8.3.4 Optical tyre sensor

An optical displacement sensor was developed and tested in the EU founded project, called Apollo. This sensor measures the displacement of the tire contact patch relative to the rim. Set up and measurements are discussed in the following.

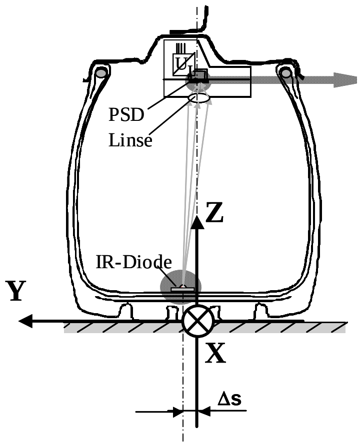


Figure 19 Axial optical sensor on inner liner

The sensor consists of a PSD, Position Sensitive Detector, a lens and a light source on the inner liner of the tire. As a light source a diode is glued to the inner liner. The PSD chip and the lens are located in housing directly on the rim. The lens between the PSD-chip and LED, Light Emitting Diode, is focusing the light to the sensor surface.

As visible in the figure to the side, the light beam, which is emitted from the IR-diode, is focused on the PSD chip. The centre of the light spot on the PSD lens is responsible for the current at the corners of the PSD chip. While higher intensity of the light beam results in an increasing current with the same ratio at all corners of the chip, a movement of the light beam changes the current at the corners with different ratios.

The relation between movement of the spot on the PSD chip and the current at the four borders can be described mathematically and can be used to get the final displacement. Appropriate tyre models can be used to calculate global tyre forces from the displacement signals [APO03].

9 Scope of the work

9.1 Context diagram

A diagram is presented to show the context of the friction estimation system:

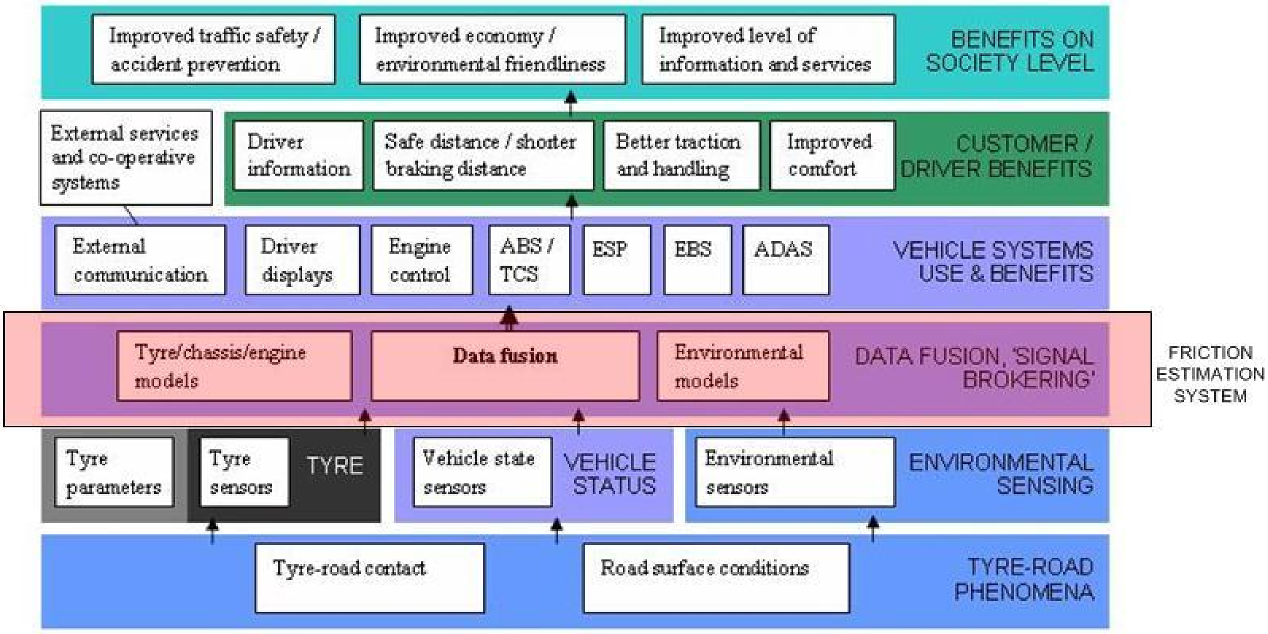
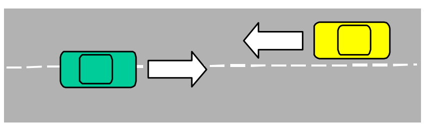


Figure 20 Context diagram

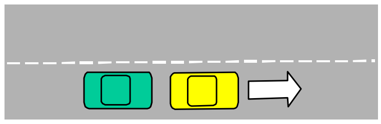
9.2 Application scenarios

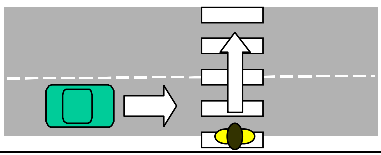
The following accident descriptions are based on accident data from Finland and correlates to the applicable accident scenarios. The accidents have been taken from the Finnish Road Accident Investigation Teams database. For each accident, a scenario is described to show how an intelligent friction system could have prevented the accident.

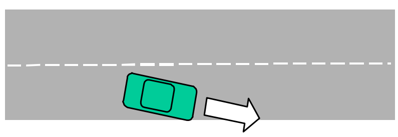
9.2.1 Passenger vehicles

Accident scenario	
Accident description	During a winter day it was -2.4°C and the sky was dark. A foreign driver was driving his middle sized passenger car equipped with summer tyres on

	a main road. Suddenly the road condition changed from dry to icy, he lost driving control and skidded into an oncoming vehicle.
Application scenario	During a winter day it was -2.4°C and the sky was dark. A foreign driver was driving his middle sized passenger car equipped with summer tyres on a main road. He was warned about the risk of icy roads, so he preventively slowed down and when road changed from dry to icy, he was able to keep the vehicle in the right lane.

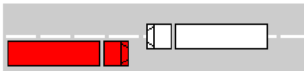
Accident scenario	
Accident description	During a summer day it was 15°C and it was raining. A young man was driving his sporty passenger car on a main road not maintaining a safe distance to the preceding vehicle. The road was wet. Suddenly the preceding vehicle slowed down and the accident was unavoidable.
Application scenario	During a summer day it was 15°C and it was raining. A young man was driving his sporty passenger car equipped with a safe speed and safe distance system. Using friction information the system warned him to adapt the distance to the preceding vehicle because of the wet road. Suddenly the vehicle in front slowed down and the young man braked in time to maintain the appropriate safe distance.

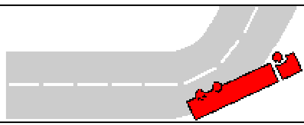
Accident scenario	
Accident description	One cold autumn day it was 0°C and it was snowing. A young driver was driving his large passenger car on a straight municipal road with a pedestrian crossing. The road was slippery. A pedestrian crossed the road and the driver decided to brake too late because he didn't take into account the road conditions and consequently the accident was unavoidable.
Application scenario	One cold autumn day it was 0°C and it was snowing. A young driver was driving his large passenger car on a straight municipal road with a pedestrian crossing. The car was equipped with a collision warning/mitigation system. The road was slippery and a pedestrian crossed the road. Using friction information the system indicated to the driver correctly when to start to brake and the driver stopped his car safely.

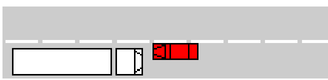
Accident scenario	
Accident	During a winter day it was 2.0°C and the sky was clear. A middle aged

description	lady was driving her small passenger car about 80km/h (speed limit 60km/h) on a local road. Suddenly the rear end of the car started sliding. The driver made a strong corrective maneuver but the car swayed to the other direction and drifted off the road.
Application scenario	During a winter day it was 2.0°C and the sky was clear. A middle aged lady was driving her small passenger car about 80km/h (speed limit 60km/h) on a local road. Suddenly the rear end of the car started sliding. The car was equipped with an ESP system improved by friction information; the driver, helped by the ESP system, made a corrective maneuver and kept the vehicle in the right lane.

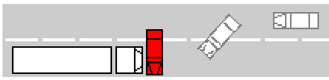
9.2.2 Commercial vehicles

Accident scenario	
Accident description	On a winter day it was -1.0°C and the sky was clear. A heavy truck was on its way to deliver its goods when it looses its path during a curve, because of the goods being unevenly loaded. In the other lane another truck is approaching and is hit when the truck enters the lane.
Application scenario	On a winter day it was -1.0°C and the sky was clear. A heavy truck equipped with an ESP system for the trailer was on its way to deliver its goods. Approaching a curve the truck's ESP system regularly gets information on the friction used and the friction available. Since the goods are being unevenly loaded the ESP system activates and prevents the truck from loosing its path in the curve. In the other lane another truck is approaching and passes without any problems.

Accident scenario	
Accident description	One cold autumn day it was 0°C and it was snowing lightly. The road was slushy and the wind was heavy. A truck was approaching a small curve when it rolls over because of the heavy side winds
Application scenario	One cold autumn day it was 0°C and it was snowing lightly. The road was slushy and the wind was heavy. A truck was approaching a small curve when the driver gets a warning on the dashboard that he needs to slow down since the car is slipping. The driver slows down and manages to keep the truck on the road

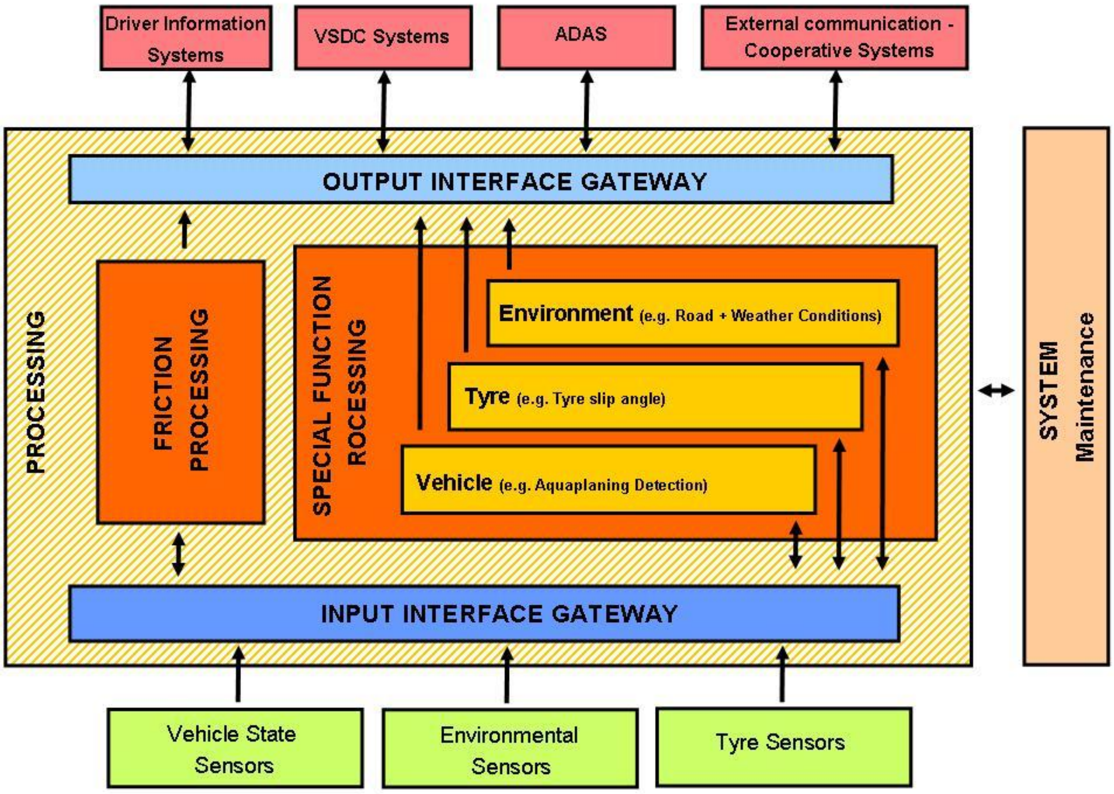
Accident scenario	

Accident description	On a late winter day the temperature was about 1°C. A middle-aged lady was driving her old small passenger car on a straight main road and came to a forested road section. In that section the ruts in the road became deeper and the ice layer thicker. The lady lost control of the car and swerved off into an oncoming truck.
Application scenario	On a late winter day the temperature was about 1°C. A middle-aged lady was driving her old small passenger car on a straight main road and came to a forested road section. She passes a traffic sign that warn her about the risk of slippery roads. The information on the traffic sign is controlled from an information center gathering data from sensor vehicles in the area. The lady slows down and keeps in the right lane.

Accident scenario	
Accident description	During a nice spring day it was 12°C and the road was dry. A young male in a sporty passenger car with retreated rear tyres was approaching a curve to the left with high speed. On the curve the car starts drifting to the right, into the gravel. The driver starts to do a strong corrective maneuver whilst he loses the control of the car and skids into an oncoming truck.
Application scenario	During a nice spring day it was 12°C and the road was dry. A young male in a sporty passenger car with retreated rear tyres was approaching a curve to the left with high speed. Since the car is equipped with an intelligent friction system together with a GPS system, the driver is warned that he is approaching a curve too fast, using all friction potential, and that he needs to slow down to stay on the road. The driver starts breaking in good time before reaching the curve.

10 Scope of the system

The following figure shows the scope and basic architecture of the intended system, whose boarders are defined by the hatched rectangle.



The input interface gateway connects to all available sensors (vehicle state, environmental, tyre) and performs the translation to a common internal system interface.

The processing part consists of two functional units:

- the friction processing, responsible for the main functionality of determine actual and oncoming “friction used” and “friction available” values
- a special function processing which uses incoming data for a dedicated subset of functions. These functions can cover special use case, which can be accomplished by the system in addition to the estimation of friction values.

The output gateway is responsible for interfacing to external systems (thus users of the system).

10.1 System boundaries

Use case diagrams can be used to describe the functionality of a system in a horizontal way. That is, rather than merely representing the details of individual features of a system, use case diagrams can be used to show all of its available functionality. Use case diagrams have four major elements: The **actors** that the system you are describing interacts with, the **system** itself, the **use cases**, or services, that the system knows how to perform, and the lines that represent **relationships** between these elements.

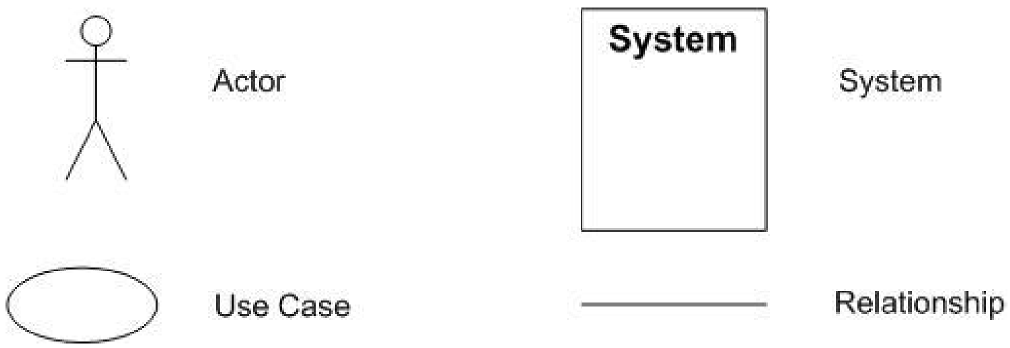


Figure 21 Use case diagram elements

In the figure below, the use case diagram for the friction estimation system is shown. The actors are the users identified in chapter 3 namely:

- Driver information system
- VSDC Systems
  - ESP
  - ABS
  - TCS
  - Rollover avoidance
  - Load Distribution Observer
  - Powertrain Management
- ADAS
  - ACC
  - CAS
  - AEB
- V2V/V2I communication interface
- Maintenance personnel
  - Workshop personnel
  - Software function developers

In addition to the users, proper use cases are displayed. The use cases are an important input to the functional requirements as they reveal the services the system shall provide.

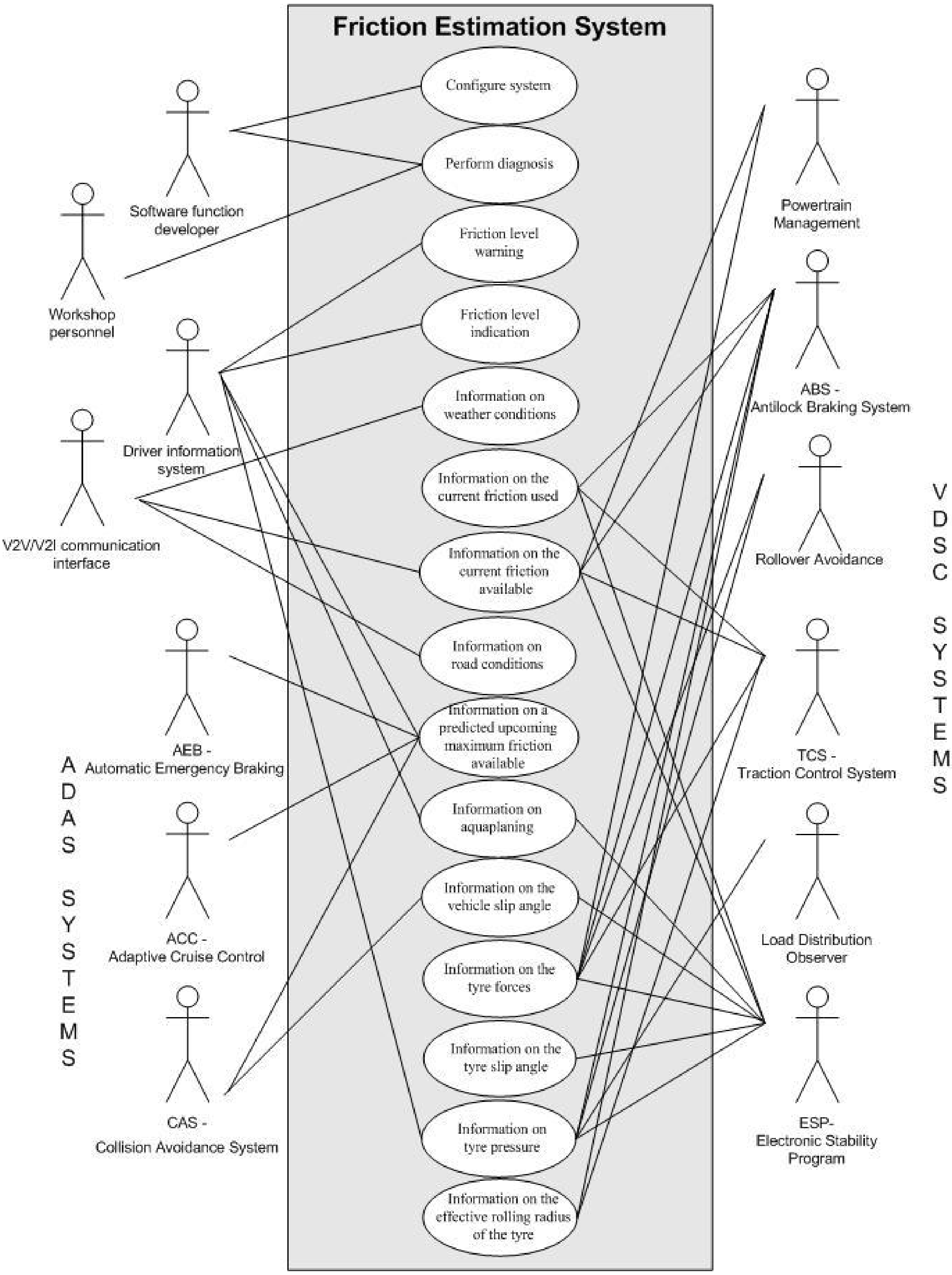


Figure 22 Use case diagram

10.2 System use cases

The use cases can be classified in different categories:

Cat_A: Friction information

Cat_B: Environmental information

Cat_C: Tyre information

Cat_D: Vehicle information

Cat_E: System maintenance

For each of the categories A - E different use cases can be identified which can benefit from tyre-road-friction information.
Each use case is described by a table with the following format

Use case ID	A unique ID
Name	A short descriptive name of the use case
Description	A longer description of the use case
User/actor	A list of the users and actors of the use case
Fit criterion	A measurement of the use case such that it is possible to test that if the solution matches the original use case
Scenario	A detailed description of the steps in the use case, a scenario description

10.2.1 Use Cases Category A: Friction information

UC A1: Friction level indication
UC A2: Friction level warning
UC A3: Information on the current friction used
UC A4: Information on the current friction available
UC A5: Information on a predicted upcoming maximum friction available

Use case ID	A1
Name	Friction level indication
Description	During non critical friction conditions information about the friction conditions is provided on request.
User/actor	Driver information system
Fit criterion	Studying data flows
Scenario	<u>Main Scenario</u> 1. The system is triggered that information on friction available level is wanted. 2. The system checks the current estimated value of friction available. 3. The system makes a decision to what level the current friction available situation corresponds. 4. The system sends the decided level to the display.

	Extensions: 4a1 The system has no valid current friction available estimate 4a2 The system sends a N/A message to the display

Use case ID	A2
Name	Friction level warning
Description	During critical friction conditions a warning is sent.
User/actor	Driver Information System, V2V/V2I communication interface
Fit criterion	Studying data flows
Scenario	Main Scenario 1. The system recognizes that a change of low-friction situation is at hand, or friction available exceeded a threshold or if friction used exceeds friction available (sliding situation). 2. The system sends a warning message.

Use case ID	A3
Name	Information on the current friction used
Description	Providing estimated values of the current friction used.
User/actor	ABS, TCS, ESP
Fit criterion	Studying data flows
Scenario	1. 1. The system estimates the friction used through wheel loads, real ground velocity and the acceleration. 2. The system broadcasts the information continuously.

Use case ID	A4
Name	Information on the current friction available
Description	Providing estimated values of current friction available.
User/actor	ABS, TCS, ESP, V2V/V2I communication interface
Fit criterion	Studying data flows
Scenario	1. The system gets information on the current friction used. 2. The system estimates the current friction available. 3. The system broadcasts the information continuously.
Use case ID	A5
Name	Information on a predicted upcoming maximum friction available
Description	Providing a value of the predicted maximum friction available in the

	upcoming driving way of the vehicle
User/actor	ACC, AEB, CAS, Driver information system
Fit criterion	Studying data flows
Scenario	1. The system gets information on the weather and road conditions. 2. The system predicts the upcoming friction available. 3. The system broadcasts the information continuously.

10.2.2 Use Cases Category B: Environmental information

UC B1: Information on weather conditions
UC B2: Information on road conditions

Use case ID	B1
Name	Information on weather conditions
Description	Providing information on weather conditions such as heavy rain, snow, fog or temperature.
User/actor	V2V/V2I communication interface
Fit criterion	Studying data flows
Scenario	1. The system gets information on the weather conditions. 2. The system broadcasts the information continuously.

Use case ID	B2
Name	Information on road conditions
Description	Providing information on road conditions such as dry, icy, snowy, slushy or wet.
User/actor	V2V/V2I communication interface
Fit criterion	Studying data flows
Scenario	1. The system gets information on the weather condition, road temperature and other road data. 2. The system estimates the road condition. 3. The system broadcasts the information continuously.

10.2.3 Use Cases Category C: Tyre information

UC C1: Information on tyre slip angle
UC C2: Information on tyre forces
UC C3: Information on the effective rolling radius of the tyre

UC C4: Information on tyre pressure

Use case ID	C1
Name	Information on tyre slip angle
Description	Providing estimated values of the tyre slip angle on each wheel turn.
User/actor	ABS, ESP
Fit criterion	Studying data flows
Scenario	1. The system gets information on the ground movement direction and wheel angle. 2. The system estimates the tyre slip angle. 3 The system broadcasts the information continuously.

Use case ID	C2
Name	Information on tyre forces
Description	Providing estimated values of tyre forces, x (longitudinal), y (lateral), z (vertical wheel load).
User/actor	TCS, ESP, ABS, Rollover Avoidance, Power train Management
Fit criterion	Studying data flows
Scenario	1. The system gets information on the relative movement between the contact patch and the rim. 2. The system estimates the tyre forces. 3 The system broadcasts the information continuously.

Use case ID	C3
Name	Information on the effective rolling radius of the tyre
Description	Providing directly measured values of the effective rolling radius of the tyre.
User/actor	TCS
Fit criterion	Studying data flows
Scenario	1. The system gets information on relative movement between the contact patch and the rim. 2. The system calculates the effective rolling radius of the tyre. 3 The system broadcasts the information continuously.

Use case ID	C4
Name	Information on tyre pressure
Description	Providing estimated values of tyre pressure
User/actor	Load Distribution Observer, ESP, Rollover Avoidance, ABS, Driver

	information system
Fit criterion	Studying data flows
Scenario	1. The system gets information on relative movement between the contact patch and the rim. 2. The system estimates the tyre pressure. 3 The system broadcasts the information continuously.

10.2.4 Use Cases Category D: Vehicle information

UC D1: Information on vehicle slip angle
UC D2: Information on aquaplaning

Use case ID	D1
Name	Information on vehicle slip angle
Description	Providing estimated values of vehicle slip angle.
User/actor	ESP, CAS
Fit criterion	Studying data flows
Scenario	1. The system gets information on yaw rate and 3D movement. 2. The system estimates the vehicle slip angle. 3 The system broadcasts the information continuously.

Use case ID	D2
Name	Information on aquaplaning
Description	Providing information on aquaplaning
User/actor	Driver information system, ESP
Fit criterion	Studying data flows
Scenario	1. The system gets information on vehicle speed, effective rolling radius of the tyre and friction available and rate and polarity of changes in friction available value. 2. The system determines if aquaplaning is at hand. 3 The system broadcasts the information continuously.

10.2.5 Use Cases Category E: Maintenance information

UC E1: Configure system
UC E2: Perform diagnosis

Use case ID	E1
Name	Configure system
Description	Provide possibility to configure the system
User/actor	Software function developer
Fit criterion	Programming interface
Scenario	1. Software upload, download, configuration.

Use case ID	E2
Name	Perform diagnosis
Description	Enable system diagnosis
User/actor	Software function developer, Workshop personnel
Fit criterion	Diagnostics interface
Scenario	1. System tests, error log readout

11 Functional requirements

11.1 High level requirements

Requirement ID	FNC_1	Requirement type	Functional	Use case ID	A1,A2
Importance	High				
Name	Enable configuration of friction available thresholds				
Description	The system must enable configuration of friction available thresholds				

Requirement ID	FNC_2	Requirement type	Functional	Use case ID	A2, D2
Importance	High				
Name	Determine the rate and polarity of changes in friction available value				
Description	The system must determine the rate and polarity of changes in friction available value.				

Requirement ID	FNC_3	Requirement type	Functional	Use case ID	A1,A2,A3
Importance	High				
Name	Determine current friction used				
Description	The system must be able to determine the current friction used				

Requirement ID	FNC_4	Requirement type	Functional	Use case ID	A1,A2,A4
Importance	High				
Name	Determine current friction available				
Description	The system must be able to determine the current friction available				

Requirement ID	FNC_5	Requirement type	Functional	Use case ID	A5
Importance	High				
Name	Predict upcoming maximum friction available				
Description	The system must be able to predict the upcoming maximum friction available				

Requirement ID	FNC_6	Requirement type	Functional	Use case ID	B1
Importance	High				
Name	Determine weather condition				
Description	The system must be able to determine the current weather condition				

Requirement ID	FNC_7	**Requirement type**	Functional	**Use case ID**	B2
Importance	High				
Name	Determine road condition				
Description	The system must be able to determine the current road condition				

Requirement ID	FNC_8	**Requirement type**	Functional	**Use case ID**	C1
Importance	High				
Name	Determine tyre slip angle				
Description	The system must be able to determine the tyre slip angle for each active tyre				

Requirement ID	FNC_9	**Requirement type**	Functional	**Use case ID**	C2
Importance	High				
Name	Determine tyre forces				
Description	The system must be able to determine the tyre force for each active tyre				

Requirement ID	FNC_10	**Requirement type**	Functional	**Use case ID**	C3
Importance	High				
Name	Determine effective rolling radius of the tyre				
Description	The system must be able to determine the effective rolling radius for each active tyre				

Requirement ID	FNC_11	**Requirement type**	Functional	**Use case ID**	C4
Importance	High				
Name	Determine tyre pressure				
Description	The system shall determine the tyre pressure value for each active tyre				

Requirement ID	FNC_12	**Requirement type**	Functional	**Use case ID**	D1
Importance	High				
Name	Determine vehicle slip angle				
Description	The system must be able to determine the vehicle slip angle				

Requirement ID	FNC_13	**Requirement type**	Functional	**Use case ID**	D2
Importance	High				
Name	Determine aquaplaning				
Description	The system must be able to determine aquaplaning is at hand				

Requirement ID	FNC_14	**Requirement type**	Functional	**Use case ID**	E1
Importance	High				
Name	Enable system configuration				
Description	The system must be configurable				

Requirement ID	FNC_15	**Requirement type**	Functional	**Use case ID**	E2
Importance	High				
Name	Enable system diagnosis				
Description	The system must enable diagnosis				

11.2 Output requirements

Requirement ID	FNC_16	**Requirement type**	Functional	**Use case ID**	A3,A4,A5, C1,C2,C3, D1,D2,D3
Importance	High				
Name	Provide timestamp to the output data				
Description	The system must tag information on timestamp to the output data.				

Requirement ID	FNC_17	**Requirement type**	Functional	**Use case ID**	A3,A4,A5, C1,C2,C3, D1,D2,D3
Importance	High				
Name	Tag information on vehicle position to the output data				
Description	The system must tag information on the position of the vehicle to the output data.				

Requirement ID	FNC_18	**Requirement type**	Functional	**Use case ID**	A3,A4,A5, C1,C2,C3, D1,D2,D3
Importance	High				
Name	Tag information on quality to the output data				
Description	The system must tag information on the quality of the taken measurement to the output data.				

Requirement ID	FNC_19	**Requirement type**	Functional	**Use case ID**	A1,A2,A3, A4,A5,B1, B2,C1,C2, C3,C4,D1, D2
Importance	High				
Name	Error handling				
Description	The system need to deliver a N/A flag when output cant be delivered for some reason				

Requirement ID	FNC_20	**Requirement type**	Functional	**Use case ID**	
Importance	High				
Name	Signal property description				
Description	In the message map each value signal should be described with following properties: *Accuracy*: The accuracy of the measured data. *Range high*: The highest Engineering value that will be transported in the signal. *Range low*: The lowest Engineering value that will be transported in the signal. *Unit*: Engineering Unit of the data. *Signal Age*: The maximum age of the signal. *Offset and Resolution*: These two parameters are used to convert bus transported value to Engineering value. Formula says that: *Engineering Value = Bus Value * Resolution + Offset* *Startup / Default* Initial value on startup or default value reported when input has not been acquired				

12 Interface requirements

12.1 Communication interface requirements

Requirement ID	IF_1	Requirement type	Interface	Use case ID	General
Importance	High				
Name	Compliancy with typical automotive communication standards				
Description	The communication interface should be compliant with typical automotive communication standards such as ISO11898, LIN.				

12.2 Hardware interface requirements

Requirement ID	IF_2	Requirement type	Interface	Use case ID	General
Importance	High				
Name	Sensor interface				
Description	The system provides an interface to sensors such as in-vehicle sensors, environmental sensors and tyre sensors.				

PART 4 – Non-functional requirements

This part contains behavioral properties of the friction estimation system.

13 Performance requirements

13.1 Speed requirements

Requirement ID	PERF_1	**Requirement type**	Performance	**Use case ID**	General
Importance	High				
Name	Speed requirement for V2I communication interface				
Description	If data is to be useful for V2I communication interface the update rate must be <10 s.				

Requirement ID	PERF _2	**Requirement type**	Performance	**Use case ID**	General
Importance	High				
Name	Speed requirement for V2V communication interface				
Description	If data is to be useful for V2V communication interface the update rate must be <1.5 s				

Requirement ID	PERF _3	**Requirement type**	Performance	**Use case ID**	General
Importance	Medium				
Name	Speed requirement for Driver information systems				
Description	If data is to be useful for Driver information systems the update rate must be <1 s.				

Requirement ID	PERF _4	**Requirement type**	Performance	**Use case ID**	General
Importance	Medium				
Name	Speed requirement for ADAS systems				
Description	If data is to be useful for ADAS systems the update rate must be <100ms.				

13.2 Safety critical requirements

Requirement ID	PERF _5	**Requirement type**	Performance	**Use case ID**	General
Importance	High				
Name	Safety critical principles				
Description	The system must use standard vehicle safety critical principles etc.				

Requirement ID	PERF _6	**Requirement type**	Performance	**Use case ID**	General
Importance	High				
Name	Safety critical level				
Description	The system must have at least the same safety critical level as the highest safety critical level of the supported users/applications.				

13.3 Robustness requirements

Requirement ID	PERF _7	**Requirement type**	Performance	**Use case ID**	General
Importance	High (Not applicable for prototype system)				
Name	Pass standard vehicle testing				
Description	The system must pass standard vehicle testing such as EMC testing, mechanical testing etc.				

Requirement ID	PERF _8	**Requirement type**	Performance	**Use case ID**	General
Importance	High				
Name	Fault tolerance				
Description	The system should ensure fault tolerance and graceful degradations if some of its component fails.				

Requirement ID	PERF _9	**Requirement type**	Performance	**Use case ID**	General
Importance	High				
Name	Single point failure				
Description	The system must handle single point failure and have a strategy for handling for example a non functioning sensor. Such a strategy could be replacing faulty sensor signals with nominal or calculated values.				

13.4 Scalability and extensibility requirements

Requirement ID	PERF _10	**Requirement type**	Performance	**Use case ID**	General
Importance	Medium				
Name	Modularity				
Description	The system must be modular and new functions should be easy to add				

Requirement ID	PERF _11	**Requirement type**	Performance	**Use case ID**	General
Importance	High				
Name	Input flexibility				
Description	The system must support adding and removing sensors				

Requirement ID	PERF _12	**Requirement type**	Performance	**Use case ID**	General
Importance	High				
Name	Configurable sensor setup				
Description	The system must support different sensors configurations with different resulting performance. Although a minimum number of sensors will be required to be able to produce the system output.				

14 Operational requirements

14.1 Expected physical environment

Requirement ID	OPER_1	**Requirement type**	Operational	**Use case ID**	General
Importance	High				
Name	Accessible placement				
Description	The system needs to be placed in an accessible place in the vehicle.				

Requirement ID	OPER_2	**Requirement type**	Operational	**Use case ID**	General
Importance	High				
Name	Temperature range				
Description	The system must function in an environment with a temperature range similar to the driver compartment. (-40°C to + 85°C)				

Requirement ID	OPER_3	**Requirement type**	Operational	**Use case ID**	General
Importance	High				
Name	Power consumption when shut down				
Description	The system must not use any power when the vehicle is shut down.				

Requirement ID	OPER_4	**Requirement type**	Operational	**Use case ID**	General
Importance	High				
Name	Power environment				
Description	The system must operate on 12 V/ 24 V power.				

PART 5 – Demonstrator system requirements

This part describes the selection of use cases and requirements that are applicable for this specific project and demonstrators. Since time and resources for the project are limited, the applications for demonstration are chosen with care. The decision is based on the following prerequisites:

- The demonstrator system implementation should not be too complex
- The validation of the demonstrator system should be easy to perform
- The access of development vehicles are limited
- Only a number of applications are available in the demonstrators

This means that not all functionality in this requirement specification will be supported by the demonstrator system. The goal is to demonstrate the system using the following applications:

- Driver Information System
- ACC
- CAS

15 Supported use cases

The following use cases are supported by the demonstrator system:

UC A1: Friction level indication
UC A2: Friction level warning
UC A5: Information on a predicted upcoming maximum friction available
UC D1: Information on vehicle slip angle

16 Prioritized requirements

The requirements that need to be fulfilled in order to support the use cases above are:

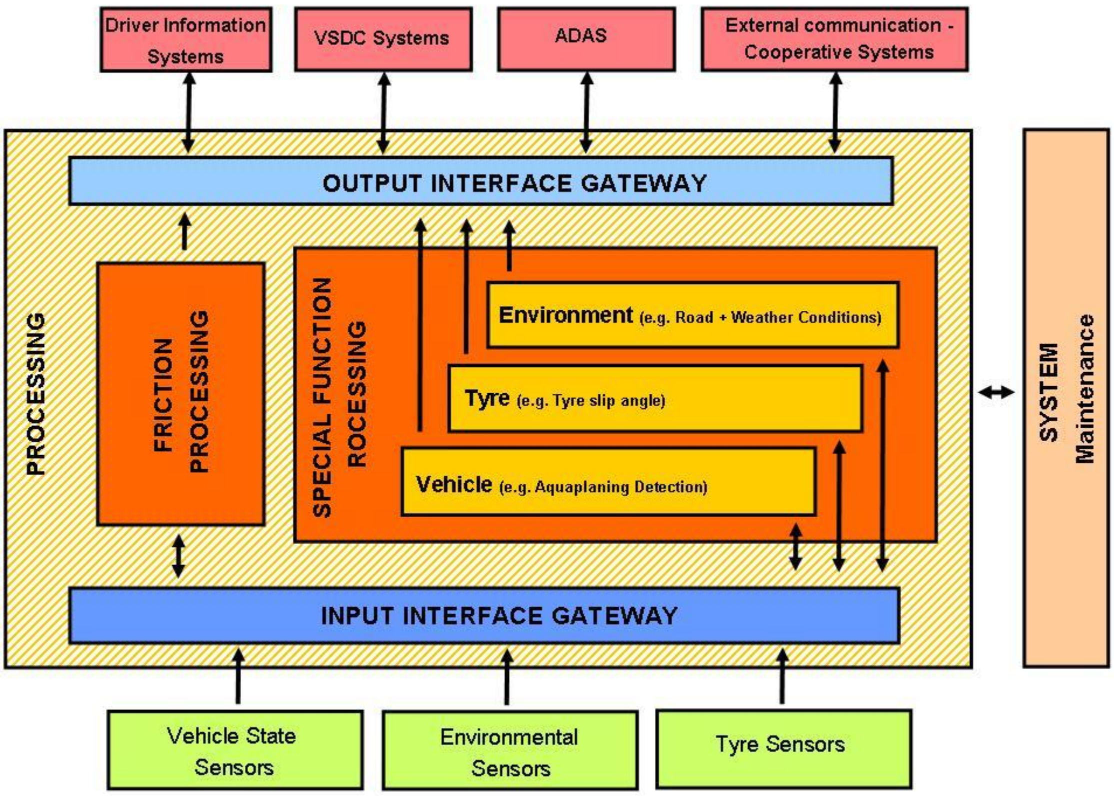
FNC_1: Enable configuration of friction available thresholds
FNC_2: Determine the rate and polarity of changes in friction available value
FNC_3: Determine current friction used
FNC_4: Determine current friction available
FNC_5: Predict upcoming maximum friction available
FNC_12: Determine vehicle slip angle
FNC_18: Tag information on quality to the output data
IF_1: Compliancy with typical automotive communication standards
IF_2: Input flexibility
PERF _3: Speed requirement for Driver information systems
PERF _4: Speed requirement for ADAS systems
PERF _10: Modularity
PERF _12: Configurable sensor setup
OPER_4: Power environment

PART 6 – Conclusions

The aim for the FRICTION project is a solution for real-time estimation of tyre-road friction using a sensor cluster in a moving vehicle. Three kinds of sensors will be used: existing in-vehicle sensors for vehicle dynamics, environmental sensors, and tyre-based sensors.

The project intends to use a common development platform vehicle for development and test as a "cumulative platform". At a certain point in time the developed system will be transferred to the demonstrator vehicle platforms. The development platform is an Audi A6. A Fiat Stilo equipped with a collision warning and mitigation system will be used as a passenger vehicle demonstrator whilst a Volvo FH12 will be used as a truck demonstrator. The Volvo truck supports a number of applications developed in different ongoing PReVENT subprojects

The following figure shows the scope and basic architecture of the intended system:



The processing part consists of two functional units:

- the friction processing, responsible for the main functionality of determine actual and oncoming "friction used" and "friction available" values

- a special function processing which uses incoming data for a dedicated subset of functions. These functions can cover special use case, which can be accomplished by the system in addition to the estimation of friction values.

The key users of the friction estimation system are:

- Direct driver information systems
- Vehicle Dynamic Control Systems
- Advanced Driver Assistance Systems
- External communication applications

All these users can potentially benefit from additional information on tyre and tyre-road contact. The control algorithms of Advanced Driver Assistance Systems (ADAS) often have to be based on the capability of the vehicle to change the driving state within a given driving situation. This capability depends mainly on the maximum force which can be transmitted between each wheel and the road. These forces depend on the local friction between the tyres and the road. Therefore, the maximum friction available and the wheel load at each wheel are of big interest for driver assistance systems. In addition to driver and vehicle applications, external users can benefit from data obtained from the tyre itself and from the tyre-road interaction.

A number of european accidents could most evidently be prevented by an intelligent FRICTION system and the detection of low friction is of great interest when trying to increase traffic safety.

PART 7 – Appendices

Volere Template

Information on the Volere template used in this requirement specification.

Use case table

Use case ID	A unique ID
Name	A short descriptive name of the use case
Description	A longer description of the use case
User/actor	A list of the users and actors of the use case
Fit criterion	A measurement of the use case such that it is possible to test that if the solution matches the original use case
Scenario	A detailed description of the steps in the use case, a scenario description

The unique ID should have the following format: <Cat><nbr> where Cat is the category of the use case (A,B,C,D,E) and nbr is a running number.

Requirements table

Requirement ID	A unique ID	**Requirement type**	Type	**Use case ID**	Use cases that need this requirement
Importance	Priority level (High, Medium, Low)				
Name	A short descriptive name of the requirement				
Description	A longer description of the requirement				

The unique ID should have the following format: <Type>_<nbr> where Type is the type of the requirement (FNC, IF, PERF or OPER) and nbr is a running number.

The requirement type shall be one of the following:

- Functional
- Interface
- Performance
- Operational

The importance shall be one of the following:

- Low – might be dropped without influence to other requirements
- Medium – if dropped, the value of the system would be reduced
- High – cannot be dropped

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