Driver Chassis Control Functions in New Vehicles

Based on Steering, Suspension, and Propulsion Actuators

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Abstract

The thesis project is performed at ÅF Industry at their chassis department in Trollhättan, where their focus lay at chassis and body functions for the automotive industry. There are many functions in a car now a day, the act and function names for those functions have a huge variety between automotive brands. ÅF want a catalogue, with a collection of functions and what they do, how they act, pros and cons, and in- & output, with focus on steering, propulsion, and suspension actuators.

Through benchmarking, all functions have been collected in a list of functions for five different automotive brands. Another student from Karlstad University, worked parallel with a similar thesis, focusing on braking actuators. Some information passed through our theses to help each other during the benchmark. From the benchmark, five datasheets were made, to add to the catalogue. Out of those five functions one had to pass the elimination matrix to be tested and evaluated.

In this thesis, the function to be tested were Drive Profile with focus on suspension. The function was tested in a Saab 9-5 Aero equipped with an VBOX 3i at NEVS test track. Test method for the test was ISO 3888-2 severe lane-change, obstacle avoidance. The result for the test was that Sport profile was stiffer than Comfort and Intelligent, and therefore recovered the roll rate much quicker in hard cornering. The profile to choose, while entry a hard cornering is the Sport profile because of the fast roll rate recovery, also the steering torque felt way better for the driver with the Sport profile activated.

It is concluded that it is a problem with all variety of function names. Especial for customer who wants to compare cars when he/she is going to buy a new car.
List of important concepts as well as abbreviations

VBOX – Velocity Box
GPS – Global Positioning System
ADAS – Advanced Driver Assistance System*
SUV – Sport Utility Vehicle
ACC – Active Cruise Control
DRS – Drag Reduction System*
NEVS – National Electric Vehicle Sweden AB
IMU – Inertial Measurement Unit
ISO – International Organization for Standardization
SW – Software
CDC – Continuous Damping Control
ECU – Electrical Control Unit
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1. Introduction

The project covers car functions also called “Advanced Driver Assistance System” based on steering, levelling, and propulsion actuators. In the automotive industry, all want to make their vehicle “unique” to increase the value, therefore the automotive brands use same functions but they have different names and sometimes they even use different actuators and sensors. ÅF Industry AB is an engineering consulting company operating across the world, in all kind of industrial branches. The thesis is done at the chassis department in Trollhättan, Sweden.

1.1 Background

In new vehicles, there are more and more actuators with embedded SW for chassis system to improve performance. Also, to customize the vehicle functions to the driver. Examples of actuators are steering gear, air springs, dampers, engine and brakes.

1.2 Problem

For example, someone decides to buy a new premium SUV car and by comparing three to four types of automotive brands, he/she heads up to the point where he/she must decide what type of packets or customized function he/she wants in the car. Here comes the problem, every automotive brand is using different names and shortening. So, for a person that do not have all the knowledge about all the types of functions, it will be a mess. The information about how each function works are also very restricted.

1.3 Purpose

The purpose is to evaluate usage of steering, suspension and propulsion actuators and sensors in current production vehicles, by benchmarking several automotive brands and their functions. From the benchmark, one function is selected to be tested and evaluated. To gain more information and data about how the function works. The purpose is to gain and apply knowledge acquired during the study time at the Mechanical engineering program at Karlstads university.
1.4 Object

The goal is to make a catalogue of functions with a short explanation of the function, how it works, Pros and Cons, In- & Outputs and then evaluate one and test it with a VBOX 3i and analyse the result. To improve the knowledge in the specific area and use the current knowledge from the education should be used to receive best result.

1.5 Delimitation

Delimitation was made, for not making the thesis to big and messy. Delimitations:

- Only five automotive brands for the benchmark
- Five datasheets. Which will contain information about what each function does, how it works, pros and cons, in- and outputs.
- Only one function passes the elimination matrix
- Only looking at Suspension for the different drive profiles
- Access to test track for about 4 hours for two tests
2. Theory

This chapter will contain theory behind functions, actuators, sensors and test-equipment.

Function
Dictionary.com describes the word function as “the kind of action or activity proper to a person, thing, or institution; the purpose for which something is designed or exists; role.” [1]. A function in the automotive industry is one or more components working in a specific decided way to make something happen or change. Every component is installed for a specific reason and that reason is to deliver one or more functions to the vehicle. Some functions are created to change the characteristics of the vehicle, and some are created to make the vehicle safer for the driver and other road users. These functions are built by a system including different components. To simplify, the system that will be covered in this report has three main components, actuators, a control system and sensors.

2.1 Actuators

An actuator converts an incoming signal to mechanical movement or physical effect. This component gets activated by the regulator and executes the movement. There are different types of actuators, the four most common are; hydraulic actuators, pneumatic actuators, electric actuators and mechanical actuators.

Hydraulic Actuators
A hydraulic actuator is built up by a piston rod, a piston, a cylinder housing and in- and outlet.

The piston in the cylinder moves by applied pressure on either side depending on which direction the movement shall be. The pressure is built up by a hydraulic pump, since liquids are nearly incompressible, the exerted force is very high and distinct but very limited in acceleration. Hydraulic actuators are not very well suited for the modern automotive industry since an external hydraulic pump is needed for creating pressure. Fluid leakage must also be taken into consideration, all hydraulic actuators will most definitely leak and contaminate the area. Common application in modern vehicles is power steering and brakes. [2]

Pneumatic Actuators
The pneumatic actuators use almost the same construction as the hydraulic actuators. A cylinder works as the main body where a piston slides back and forth to create movement. Instead of using a liquid to move the piston the pneumatic actuator uses compressive gas to build up pressure on either side of the cylinder. A pneumatic actuator is simpler than a hydraulic one, they are rapid and light weight which makes them precise in repeatability. The area of use in the automotive industry is mostly in different applications in suspension systems. [2]

Electric Actuators
Electric energy is converted into rotational movement through an electric motor. This motor turns a screw which in turn moves a threaded nut, with the same threading as the screw, along the screw. The direction of the rotating screw decides the direction of the non-rotating nut. Electric actuators are extremely accurate in positioning, very simple to reprogram, quiet,
small and does not contaminate the environment that the actuator is mounted. One disadvantage for the electric actuator is its price, much higher than the pneumatic actuator. Electric actuators often replace hydraulic actuators for like steering and are used for window lifters, head light control etc. [2]

**Mechanical actuators**
There are many different types of solution of mechanical actuators, the main purpose is to convert one type of motion into different type of motion, for example rotary motion to linear motion [3]. It is often just simply mechanics, for example a chain drive, ball screw, camshaft, etc. In vehicles, it can be used for steering, transmits the steering wheel torque to linear motion to the guide shaft. In some case, the precision can be extremely good, it all comes down to how accurate the processing is. But in some case, it will depend on too many parametrises, such as weather condition, temperature, etc.

### 2.2 Control System

The control system is the functions brain. It interprets signals from one or multiple sensors monitoring different parts of the vehicle, and cross references them with its initial preprogramed conditions [4]. A signal is sent to the actuator depending on what conditions are fulfilled. Different signals can also be sent to different actuators depending on what task is set to execute. (i.e. When one wheel is slipping the ABS-actuator get activated on that wheel)

### 2.3 Sensor

There are many types of sensors measuring everything from wheel speed to body acceleration [5]. The sensors only task is to monitor an area or part, interpret what is happening and to translate that into an electric pulse that gets sent to the control system. In the new premium cars, there are often a camera and a radar in the windshield, which interacts with the other sensors in some function i.e. ACC, Collision Warning, etc.
3. Method

This chapter describes how the work has been performed during the thesis, and what method has been used.

3.1 Benchmarking

Data for functions in cars has been collected and gathered in an excel-sheet. A delimitation was set at customer selected functions only, but for some automotive brands the customer selected function was a standard function. To catch as many functions as possible one basic SUV from five premium automotive brands was studied, to see what type of actuator, sensor and parametric was used for their functions [6-10]. The reason that premium cars was selected is because they have a good reach of functions that an average person is willing to pay for.

To get more information about the brands, results from thesis Control functions based on brake actuators in combination with other actuators in new vehicles [11] Data from Combi-“Family” cars is added in table 1.

Table 1. Automotive brand and the model which have been picked for the benchmark.

<table>
<thead>
<tr>
<th>Brand</th>
<th>Model SUV</th>
<th>Model Combi [11]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volvo</td>
<td>XC 90</td>
<td>V 90</td>
</tr>
<tr>
<td>Audi</td>
<td>Q7</td>
<td>A6 Avant</td>
</tr>
<tr>
<td>Volkswagen</td>
<td>Touareg</td>
<td>Passat Sportcombi</td>
</tr>
<tr>
<td>Mercedes-Benz</td>
<td>GLS SUV</td>
<td>E-class Wagon</td>
</tr>
<tr>
<td>Toyota</td>
<td>Land Cruiser 150</td>
<td>Avensis Touring Sports</td>
</tr>
</tbody>
</table>

3.1.1 Listing

Each five SUVs were gathered together with a combi “family car” of same car brand, from thesis Control functions based on brake actuators in combination with other actuators in new vehicles [11]. Together a merged excel-sheet was made with all ten car models and their functions. The first car model that was investigated was set as a reference for the functions at the other cars in the excel-sheet.
3.1.2 Filter functions

With the information from the list of functions from different automotive brands, a screening was made to see if some of the function were the same as another function but with just a different name. Also, checked if the functions are acting the same but uses different types of actuators, sensors or parametrises. Then all the functions were divided into groups; steering, levelling, propulsion, braking, braking and others (which is functions that uses braking parallel with other actuators) and other combined (functions using steering, levelling and propulsion combined in any way). After that, a delimitation was done to actuators for steering, levelling and propulsion.

3.1.3 Define function names

After the screening of all functions in the merged excel-sheet, a definition of the remaining functions name for all the automotive brands was done, to clear the confusion with all different names.

3.2 Datasheet

The datasheets include short information about the function, how it works, Pros and Cons, In- and Output parametrises, and customer cost. All this information is assembled on maximum one A4, to keep information short and simplified for the reader.

Five datasheet of different functions that include steering, levelling and propulsion actuators is gathered with five functions based on brake actuators which has been done in thesis Control functions based on brake actuators in combination with other actuators in new vehicles [11]. Together those ten function makes a function list.

Filter functions for testing

With those five functions a new screening was made, to figure out which function should be more studied and tested. One delimitation was that the function needed to be ensured that it could be tested with the VBOX 3i and it add-ons (which can be read more about in chapter 4.2.3 VBOX 3i). The screening was done with help of a 2x2 elimination matrix with difficulty of testing with the equipment on X-axis, and on Y-axis expense for test e.g. crash risk (LDW), access to test track at night for dark environment (ALS) etc. [12].
4. Test procedure

This chapter involves information about the tested function, all equipment for the test, how the test will be executed, and which type of characteristic that will be evaluated.

4.1 Drive Profile focused on suspension

There are many names for the function drive profile, for example, Volvo calls it Drive Mode Setting, Audi, Audi Drive Select and so it goes on for every automotive brand. The test will be done with a Saab 9-5 Aero, and Saab calls their drive profiles; Drive Sense [13].

With Drive profile the driver can decide what kind of driving experience he/she wants. The different drive profiles are often pre-programmed, but in several cars, you can program your own drive profile in a simple way, just some buttons away. The most common pre-programmed profiles are:

- **ECO** – the ECO profile main object is to reduce fuel consumption.
- **Comfort** – a profile which object is to provide the driver and passengers a comfort ride. This profile fits for longer drives.
- **Off-road** – a profile focused on hard terrain driving, often for low velocity driving.
- **Dynamics (Sport)** – the dynamic profile is mainly for curvy roads like mountain climbing with a lot of acceleration points.

Adjustable characteristics for Drive profiles:

- Steering – Variable steering torque
- Dynamic steering – Variable steering ratio
- Accelerator pedal / engine – Variable characteristic
- Automatic transmission – Variable shift program
- Sport differential – Variable lateral torque split
- Adaptive air suspension – Variable shock absorber settings

4.1.1 ECO

ECO profile focusing on getting a more economic drive. Uses characteristics that have a purpose to lower the fuel consumption [14]. If it is an automatic transmission it will optimize the shifting points. If it is a manual transmission it can visualize on the instrument panel when to shift, to provide the best shifting for ECO profile. Reduced acceleration pedal response to avoid jerky driving. In some ECO profile the instrument panel will show a gauge that will promote how much the driver drives economic. Many vehicles have a self-levelling function, which means that it will lower the vehicle to receive ground clearance to improve the aero dynamics.
4.1.2 Comfort

The comfort profile provides smooth comfortable suspensions by making it lighter, to make the driver as comfortable as possible [15]. The steering is also lighter to achieve an easy handling. The shifting is also set to shift earlier, so the engine will not rev up to high revs, and make the shifting aggressive. The Comfort Profile is an ideal choice for long highway and city driving.

4.1.3 Off-road

Off-road is for heavy conditions, such as snow, sand, and rocky terrains. It will adjust the suspension depending on the road references. It is a profile that fits someone that drives in an area with tricky terrain.

4.1.4 Dynamics (sport)

The Dynamic profile is designed for a sportier drive feeling, with a stiffer suspension, and the steering torque is harder [16]. Both will help the vehicle to get a more aggressive cornering. The gearbox shifts at higher revs, and the acceleration pedal has a better response. This profile is ideal for a driver who wants a sports car experience, or driving on a way that have a very sharp cornering path [17].

4.2 Test setup

This chapter describes all needed equipment for the test such as test method, test track, test car and equipment that collects, logging and process data during and after the test.

4.2.1 Saab 9-5

The car used for the test was a 2011 Saab 9-5 Aero Turbo 4 XWD (See Figure 1), which we got access to with help of contacts through the colleagues at ÅF Industry.
“Good to know” car specification [18]:

- Weight: 1785-1945 kg
- Length: 5008 mm
- Width: 1868 mm
- Engine: 220 HP
- Gearbox: Automatic
- Propulsion: Four-wheel drive
- Drive profile: Drive Sense (Intelligent, Comfort, and Sport)
- Suspension system: ZF Sachs CDC

The car is equipped with three different drive profiles (*Drive Sense*), Comfort, Sport, and Intelligent profile [19].
The Comfort is a softer suspension alternative for a smoother driving, sport is a more aggressive alternative for such as rough cornering, intelligent is supposed to be a more standard profile in-between comfort and sport.

The *ZF Sachs CDC* is an electrical damping system that markedly enhance driving comfort, safety, and dynamics regulating damping forces for each individual wheel [20]. An ECU calculates within milliseconds the necessary damping force, and regulates the dampers in just a millisecond too. Vehicle sensors monitor values such as wheel, body, and lateral acceleration, and with those values it generates the best damping forces for each individual wheel (See Figure 2).

![Figure 2. CDC electronic damping system.](image-url)
4.2.2 NEVS test track

ÅF Industry recommended NEVS test track and helped to rent it. The test tracks location is Flygfältsvägen, Trollhättan, Sweden. (See Figure 3).

The test track is 2 284 meters long and it is divided in four sections (See Figure 4).
- **Green section** – 391 m, flat curve.
- **Red section** – A 640 m, straight line.
- **Blue section** – A 685 m, velodrome curve.
- **Cyan section** – 586 m, flat curve.

The test was executed in the red section, which is 8 meters wide.
4.2.3 VBOX 3i

Through ÅF Consulting we were handed a VBOX 3i with help from co-workers (See Figure 5). VBOX 3i is a test equipment that are logging data up to 100 Hz per seconds, received from add-ons [21] [22]. Three types of add-ons were used for this test, IMU-integration (Inertial Measurement Unit), two GPS-pucks and a VBOX Manager. For the test, a computer is also needed to be able to evaluate the result of the logged data.

![Figure 5. VBOX 3i](image)

**IMU integration:** The IMU (See Figure 6) should be mounted on a solid surface, as close to the vehicle centre point as possible. The IMU measure the vehicles attitude in three different directions (X, Y, Z) (See Figure 7). It has an accuracy of 0.06° rms for roll and pitch rate, yaw rate has an accuracy of 0.5° rms [23].

![Figure 6. IMU-Integration](image)

![Figure 7. The IMU-axis: X, Y, and Z.](image)
**GPS:** The two GPS pucks should be mounted on the roof of the vehicle, one puck in the front and one puck in the rear (See Figure 8) [24].

![GPS-Puck](image)

*Figure 8. GPS-Puck. Two of these pucks are mounted on the roof of the vehicle.*

The GPS is used to get parameters as:
- Time
- Position
- Velocity
- Heading
- Height
- Vertical velocity
- Lateral acceleration
- Longitudinal acceleration
- Radius of turn
- Centreline deviation

**VBOX Manager:** It is a small control that are used for settings and for calibration [25]. It also has a small display, that shows a live graph during the test (See Figure 9).

![VBOX Manager](image)

*Figure 9. VBOX Manager.*

### 4.2.4 Racelogic - VBOX Tools Software

*Racelogic - VBOX Tools,* is a software for Racelogic equipment, such as the VBOX [26]. The software can be used live during the test in a so called “on-line”-mode, to see live data while driving. The program also has a post-processing function, were you can evaluate and compare data from all the saved test files. By using its graph facilities and compare functions.
4.2.5 Severe lane-change manoeuvre, Obstacle avoidance

The ISO 3888-2 is a standard test method used for evaluating dynamic behaviour in passenger cars [27].

The procedure of the test: The vehicle enters section A with an engine speed of minimum 2000 r/min. After 2 m of section A, release the throttle and finish the remaining circuit in throttle-released position.

To gain a successful test, none of the cones should not have been misplaced during the lane change.

Dimensions of the track: The requirement of the track is that it shall be at least 61 m long and 7 m wide (See Figure 11).

The width between the cones are:
Section A: 1.1 x vehicle width + 0.25 m.
Section B: vehicle width + 1 m.
Section C: 1.3 x vehicle width + 0.25, but not less than 3 m.
4.3 Test execution for Drive Profiles

The test was done according to *ISO 3888-2 Severe lane-change manoeuvre, Obstacle avoidance.*
Roll- and pitch rate are the two characteristics which were evaluated. Measured with the *VBOX 3i*, which logged the pitch- and roll rate from the IMU and the position and speed from the GPS-pucks.

To see the different suspension activity between the three type of drive profiles *during severe lane-change, Obstacle avoidance.* The IMU were mounted inside the cars centre console (See Figure 12) and the two GPS-pucks were mounted on the car roof, one in the front and one in the rear with a separation of 1.4 m (See Figure 13).

Every drive profile was tested in three velocities 40 km/h, 50 km/h and 60 km/h. In total, there were 24 test performed, 40 km/h and 50 km/h was tested three times and 60 km/h which was tested two times due to the time limit at the track.
4.3.1 Pitch rate

The pitch rate was investigated, to see how the car suspension acted during the test. The pitch rate, tells how the suspension acts when the cars tilts forward or backward (See Figure 14).

![Figure 14. To see what pitch rate measure.](image)

4.3.2 Roll rate

Roll rate was the second parametric to investigate, to see how much the car was leaning during rough cornering (See Figure 15).

![Figure 15. Easy way to see how roll rate works.](image)
5. Results

5.1 Benchmarking

5.1.1 Listing

Every car model was considered to receive information about which functions that is customer selected or standard, what is the functions name, what it does, how it works and what kind of actuator(s) it uses. All collected information is assembled in an excel-sheet. The first car that was investigated was a Volvo XC 90 for reference for the function row (See Figure 16). The list contains three types of marks:

X: Customer choice.
S: Standard function.
SX: It has one function that is standard but there is also an option for the customer to upgrade the function.

<table>
<thead>
<tr>
<th>Model Function</th>
<th>Brand and Model</th>
<th>Volvo XC 90</th>
<th>Audi Q7</th>
<th>Volkswagen Touareg</th>
<th>Mercedes-Benz CLS SUV</th>
<th>Toyota Land Cruiser 150</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active Bending Light (ABL)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Park Assist Pilot (PAP)</td>
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<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Parking Camera Rear</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>S</td>
<td>S</td>
<td>S</td>
</tr>
<tr>
<td>All-Wheel Drive (AWD)</td>
<td>X</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>S</td>
</tr>
<tr>
<td>Active Lighting System (ALS)</td>
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<td>X</td>
<td>X</td>
<td>X</td>
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<td>X</td>
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<td>Parking Camera 360°</td>
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<td>Drive mode setting</td>
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<td>SX</td>
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<td>SX</td>
</tr>
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<td>Air Suspension with active four C-chassis</td>
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<td>X</td>
<td>SX</td>
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<td>Four Wheel Steering</td>
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<td>Night Vision</td>
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<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Active Cruise Control (ACC)</td>
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<td>Highbeam Assistant</td>
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<td>X</td>
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<td>X</td>
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<tr>
<td>Pilot Assist</td>
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<td>X</td>
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<tr>
<td>Lane Keeping Aid (LKA)</td>
<td>S</td>
<td>X</td>
<td>X</td>
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<td>X</td>
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</tr>
<tr>
<td>Lane Departure Warning (LDW)</td>
<td>S</td>
<td>X</td>
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<td>X</td>
</tr>
<tr>
<td>Cross Traffic Alert (CTA)</td>
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<td>Collision Warning</td>
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<td>X</td>
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</tr>
<tr>
<td>Exh. Warning Assist</td>
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<td>BLIS</td>
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<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Trailer Assist</td>
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<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

Figure 16. Customer selected functions for each brand and their basic SUV model.
The merged excel-sheet with including data and information from Thesis Control functions based on brake actuators in combination with other actuators in new vehicles (See Figure 17) [11].

<table>
<thead>
<tr>
<th>Function</th>
<th>Volvo XC90</th>
<th>Audi Q7</th>
<th>A6 Avant</th>
<th>Volkswagen Touareg</th>
<th>Passat Sportcombi</th>
<th>Mercedes-Benz CLS SUV</th>
<th>E-class Wagon</th>
<th>Toyota Land Cruiser 150</th>
<th>Avensis</th>
<th>Touring Sports</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active Bending Light (ABL)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Park Assist Pilot (PAP)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parking Camera Rear</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All-Wheel Drive (AWD)</td>
<td>X</td>
<td>$</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Active Lightning System (ALS)</td>
<td>X</td>
<td>$</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parking Camera 360°</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drive mode setting</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air Suspension with active four C-chassis</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Four Wheel Steering</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Night Vision</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Active Cruise Control (ACC)</td>
<td>$</td>
<td>$</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Highbeam Assistant</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lane Keeping Aid (LKA)</td>
<td>$</td>
<td>$</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lane Departure Warning (LDW)</td>
<td>$</td>
<td>$</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cross Traffic Alert (CTA)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Collision Warning</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exit Warning Assist</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BLIS</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trailer Assist</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Selfdriving System</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Active Curve System</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5.1.2 Filter functions

All function filtered, based on what type of actuator operates for the function. (See Figure 18).

Figure 17. Merged list of SUV and Combi cars.

Figure 18. All function divided into groups according to what type of actuator it uses.
In Figure 19 a screening for the settled actuators steering, propulsion, suspension and “other combinations”.

<table>
<thead>
<tr>
<th>Steering</th>
<th>Active Bending Light (ABL)</th>
<th>Active Lighting System (ALS)</th>
<th>Lane Departure Warning (LDW)</th>
<th>BLIS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propulsion</td>
<td>All-Wheel Drive (AWD)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other combinations</td>
<td>Drive mode setting</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Suspension</td>
<td>Air Suspension with active four C-chassi</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 19. The groups of steering, propulsion, suspension, and other combinations.

5.1.3 Define function name

All car brands different types of function name and their shortening summed in Figure 20.

<table>
<thead>
<tr>
<th>Function</th>
<th>Car brand</th>
<th>Volvo</th>
<th>Audi</th>
<th>Volkswagen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active Bending Light (ABL)</td>
<td>ABL</td>
<td>LED Headlights</td>
<td>Corning Light</td>
<td></td>
</tr>
<tr>
<td>Active Lighting System (ALS)</td>
<td>ALS</td>
<td>Audi Matrix LED headlights</td>
<td>Dynamic Light Assist (D/LSA)</td>
<td></td>
</tr>
<tr>
<td>Lane Departure Warning (LDW)</td>
<td>LDW</td>
<td>Function in Audi Side Assist (ASA)</td>
<td>Side Assist</td>
<td></td>
</tr>
<tr>
<td>Blind Spot Information System (BLIS)</td>
<td>BLIS</td>
<td>Function in Audi Side Assist (ASA)</td>
<td>Side Assist</td>
<td></td>
</tr>
<tr>
<td>All-Wheel Drive (AWD)</td>
<td>AWD</td>
<td>Quattro</td>
<td>Four Motion (Four-wheel drive system)</td>
<td></td>
</tr>
<tr>
<td>Drive Mode Setting</td>
<td>Drive Mode Setting</td>
<td>Audi Drive Select</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Four Wheel Steering</td>
<td>-</td>
<td>Four Wheel Steering</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Air Body Control</td>
<td>Air Suspension With Active C-chassi</td>
<td>Adaptive Air Suspension</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

Figure 20. A summary for all brands and their function names and shortening.

Note: All car brands do not have All-Wheel drive but have four-wheel drive instead, they are in the same category but works a bit different.
5.2 Datasheet

Following functions are assembled in a document of datasheets, *All-Wheel drive, Active Lighting System, Drive Profiles, Lane Departure Warning, and Air Body Control* (See appendix A).

5.2.1 Filter functions for detail

The result of the elimination matrix (See Figure 21).

![Diagram showing elimination matrix with functions]

*Figure 21. Elimination matrix. Elimination of functions for test. Green area = very good, yellow = ok, and red = bad.*

5.3 Test execution for Drive Profiles

**Comfort** test procedure (See Figure 22).

<table>
<thead>
<tr>
<th>COMFORT</th>
<th>TEST</th>
<th>40 km/h File &amp; comments</th>
<th>50 km/h File &amp; comments</th>
<th>60 km/h File &amp; comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>VBOX0127, Comfort 40 kmh map</td>
<td>TEST007, Comfort 50 kmh map</td>
<td>TEST000, Comfort 60 kmh map</td>
<td>Hit the last cone by mistake in section 5</td>
</tr>
<tr>
<td>2</td>
<td>VBOX0123, Comfort 40 kmh map</td>
<td>Lost the grip of the steering wheel the last part</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>VBOX0129, Comfort 40 kmh map</td>
<td>TEST009, Comfort 50 kmh map</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Figure 22. All test notes with comfort profile.*
Intelligent test procedure (See Figure 23)

<table>
<thead>
<tr>
<th>Intelligent</th>
<th>TEST</th>
<th>40 km/h File &amp; comments</th>
<th>50 km/h File &amp; comments</th>
<th>60 km/h File &amp; comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>TESTS000, Intelligent 40 kmh map</td>
<td>TESTS010, Intelligent 50 kmh map</td>
<td>TESTS002, Intelligent 60 kmh map</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>TESTS001, Intelligent 40 kmh map</td>
<td>TESTS011, Intelligent 50 kmh map</td>
<td>TESTS003, Intelligent 60 kmh map</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>TESTS002, Intelligent 40 kmh map Abit higher speed</td>
<td>TESTS012, Intelligent 50 kmh map</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Figure 23. All test notes with intelligent profile.*

Sport test procedure (See Figure 24)

<table>
<thead>
<tr>
<th>Sport</th>
<th>TEST</th>
<th>40 km/h File &amp; comments</th>
<th>50 km/h File &amp; comments</th>
<th>60 km/h File &amp; comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>TESTS003, Sport 40 kmh map Abit higher speed, more stable control.</td>
<td>TESTS011, Sport 50 kmh map Steering feels more stabilized</td>
<td>TESTS004, Sport 60 kmh map Quicker response on the steering wheel</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>TESTS004, Sport 40 kmh map Abit higher speed, more stable control.</td>
<td>TESTS014, Sport 50 kmh map Better steering response</td>
<td>TESTS005, Sport 60 kmh map</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>TESTS005, Sport 40 kmh map Abit slower speed</td>
<td>TESTS015, Sport 50 kmh map</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Figure 24. All test notes with sport profile.*

5.3.1 Pitch rate

One graph for each drive profile, maintaining all three velocities. The layout of the graphs:

- X-axis: Metres (m)
- Y-axis left: Velocity (Km/h)
- Y-axis right: Pitch rate (°/s)

See appendix B for more specific pitch rate in every velocity, for each test result for intelligent, comfort and sport profile.

Intelligent profile (See Figure 25).

*Figure 25. Pitch rate with intelligent profile for all three velocities.*
Comfort profile (See Figure 26).

![Figure 26. Pitch rate for comfort profile for all three velocities.](image)

Sport profile (See Figure 27).

![Figure 27. Pitch rate for sport profile for all three velocities.](image)
5.3.2 Roll rate

One graph for each drive profile, showing all three velocities. The layout of the graphs:
X-axis: Metres (m)
Y-axis left: Velocity (Km/h)
Y-axis right: Roll rate (°/s)
Under the graph there are an explanation of where the cars position according to the graph.

For more specific value of roll rate for every test of each velocity see appendix 1.

Intelligent profile (See Figure 28).
Comfort profile (See Figure 29).

![Comfort profile graph for three velocities](image1)

Figure 29. Roll rate for comfort profile for three velocities.

Sport profile (See Figure 30).

![Sport profile graph for three velocities](image2)

Figure 30. Roll rate for sport profile for three velocities.
**Roll rate**
Sport profile showed a different action of the suspension compared to Intelligent and Comfort (See Figure 31). The Sport profile had a better recovery of the roll rate compared to the other two. The driver could also feel a positive difference on the steering torque when Sport profile were activated during the test.

*Figure 31. Roll rate for all three profiles at 60 km/h, the marked area is of the recovery part in section five.*
6. Discussion

The project started with a pilot study about all sorts of actuators, sensors, and control units, to get an understanding of how all devices are linked to work together as a function.

6.1 Benchmark

To clear out the confusion of different naming in different brands a list of functions, with name, what included, what it does, etc. Was developed through the benchmark, it stood clear that it is a problem. Different names for each automotive brand. While benchmarking, you could see a distinction for each automotive brand, each one had their own niche. i.e. Volvo focus on safety, by having their safety packed Intellisafe Assist as standard, and an alternative packed Intellisafe Surround includes more safety functions. Audi focused more on the outside- and inside design, several more design options. For some of the cars it was quite hard to find out if they had a specific function, in some cases the function was hidden in a package with other functions.

Some automotive brand made their function more advanced compared to other brands, and in some case, they have one basic and one advanced function to choose from. For example, in Volvos advanced alternative Lane Keeping Aid there are three phases (See Figure 32), and in basic alternative Lane Departure Warning it is just the two first phases.

*Phase 1:* Alerts the driver with visible and audible warnings.
*Phase 2:* Alerts the driver with vibrations in the steering wheel.
*Phase 3:* Trying to steer it back into the lane, this is a critical moment and just in emergency.

![Figure 32. Volvos Lane Keeping Aid, with three phases.](image)

As a result, from the benchmark, a summary with all function compiled into a list with all their unique names (See Figure 20). To not confuse the reader with all those unique names, a collection name was figured out, it had to be simple and declaring the function.
The benchmark was a bit tricky, because in the car industry almost everything is confidential. No one wants to share or spread their knowledge. It was helpful to discuss the process of the evaluation of each car brands with Anton Zakariasson whom also did a similar benchmark but for combi cars for his thesis [13].

6.2 Datasheet

The datasheets are designed to simplify research about the functions. I came clear that some functions are sub-functions, functions that have been upgraded or mixed with another function. E.g. Air Body Control is a suspension function that includes in the Drive Profile function, which is a function based on several functions together. In the automotive industry, everything constantly renews and new functions develops, so it is harsh to keep-up with the industry as a customer.

Elimination matrix
In the elimination matrix three functions (2, 5, 6) were selected in the red/yellow area, because of expense and difficulty of using the VBOX 3i for the test (See Figure 33). Number two and six were clearly a to high crash risk. And number five dedicated access to test track at night and equipment to measure the lights.

For number one, (All-Wheel Drive) the expense was not the issue, but the difficulty of testing with the test equipment. Because for AWD, fuel consumption would be the value to evaluate.

Number three and four, were both in the green “very good” area, and the function to test ended up being both. Drive Mode Setting with focus on suspension.
6.3 Test result

All the velocities were supposed to be tested three times each, for every drive profile. But we only had four hours’ access to NEVS test track. During that time two types of test had to be done, therefore every 60 km/h is only tested two times. A decision was made to look at the values from the vehicles pitch- and roll rate, and not the yaw rate. The first thoughts were to also consider yaw rate, but the result would be hard to evaluate without steering torque measuring.

The weather condition for the test was good, a sunny day with dry asphalt. Consequently, the tires had better grip. It was a challenging test method; the driver was not a professional test driver, which had impact on the result. The speeds and driving path was not always ideal.

6.3.1 Verification

In appendix B we can see that the result from each velocity followed a trend for each profile, which means that the vehicle acted the same for each velocity but it does not mean that it acted the same for each profile.

6.3.2 Differences

By comparing the result with each other, some interesting things came up.

Pitch rate
For instance, the difference in pitch rate between the profiles were small (See Figure 34). It is not fair to say it is a difference, because when the difference is so small it can be all sort of things.

One source for the small differences in pitch and roll rate between the different modes could also be that the test case chosen includes high lateral acceleration. The high lateral acceleration is measured by the IMU (Inertia Measurement Unit) and the suspension system adjust the damping to control the pitch and roll for all chosen drive modes. One test for further investigation could be to disconnect the adaption of the damper system and run with a fixed setting and compare this with the adaptive setting.

The Intelligent and comfort mode are more designed to allow higher pitch and roll rates at straight forward driving to enhance the comfort and minimize the harshness (vibrations) that a sporty setting is generating. This could explain the faster recovery in sporty mode due to it keeps the high damping longer than the comfort and intelligent modes.
Roll rate
While comparing roll rate between all profiles some interesting things shown up. There was nearly no difference between Intelligent and Comfort (See Figure 35). Which means that they are like each other when it comes to suspension.

Why does Sport profile have better roll recovery?
It is a stiffer suspension profile, and designed to take sharp curves. When it recovers faster the driver will achieve a more stabilized aggressive driving. The Comfort profile is designed to provide the driver with a smoother drive on a highway and in the city traffic. The Intelligent
profile is the standard function and acted more like the Comfort profile, but it may have other characteristics that separates it from the Comfort profile.

6.3.3 Source of errors

To get a more accurate test result I think there should be a professional test driver. The velocity varies almost too much in some of the tests. A wider track should be preferred, because now the track was about 8 m wide and then a trench, which made the driver scared to fail, and end up in the trench. I believe that if there were more time to do the test, you could get about five tests for each velocity. It would end up in more accurate test results.
7. Conclusion

**Benchmark**
There is a problem with all differences of name and packages for customer, if they are choosing between two or more different types of automotive brands. It declares a proper research, and a good list of querying.

**The act of suspension for different Drive Profiles**
For *pitch rate*, there is almost no difference in the result while comparing the profiles.

There is a certain difference on the *roll rate* for Sport profile, but Comfort and Intelligent acted nearly in the same way. The suspension showed that it is stiffer for the *Sport profile* then it is for the *Intelligent* and the *Comfort profiles*. 
Acknowledgements

I would like to thank ÅF Industry who gave me the opportunity to do my bachelor project at their office. A special thanks to my supervisors at ÅF Per Bränneby and Magnus Eklund who helped me with guiding and their knowledge in the subject, and Anders Wickberg who was my supervisor at Karlstad University who support me with both guidelines and feedbacks.

I am greatly thankful for the help of the test, many thanks to Peter Dahl, Mahesh Shektar and Thomas Fritzon who made the test possible.
References


Appendices

Appendix A: Datasheets

ACTIVE LIGHTING SYSTEM

FUNCTION:
Optimize the lights for the driver during different conditions. It automatic blend on and off the high-beam, during contact with traffic in both opposite and same drive direction. It is also able to bend the light to optimize the “lights-on” during contact in traffic. The bending function works also for cornering to achieve a better sight of view.

HOW IT WORKS:
It uses the camera and radar in often placed at the top of the windshield, to adjust the headlights to the passing traffic and the traffic in front of the vehicle. For cornering it uses the steering wheels angular-position.

PROS AND CONS:
Helps the driver to focus on the driving instead of blend on and off the high beam during heavy traffic. Optimizing the sight of view for the driver. In hard conditions the camera and radar may be covered or neutralized which can cause problem for the function. And in worst case scenario it won’t work.

INPUT:
Radar
Camera
Steering wheel torque

OUTPUT:
Light system

CUSTOMER COST:
****

Sources:
LANE DEPARTURE WARNING

FUNCTION:
Warning the driver if the car is on its way out of the lane, and the driver have not used the indicators or steering wheel. In case there the driver isn’t alert of the situation.

HOW IT WORKS:
The radar and camera in the windshield senses the vehicles position and the lane-lines. And when the vehicle is on its way out of position there are different way of alert this. Often it is based on two phases. Phase one, alerts the driver with visible and audible warning. Phase two, by vibrating the steering wheel it will alert the driver.

PROS AND CONS:
It’s a safety function, that is made to prevent accidents. If the radar and camera is covered with dirt, snow or it is a rough weather outside, it may not work. Because its rely on the radar and camera.

INPUT:
Radar
Camera

OUTPUT:
Steering-wheel, vibration
Visible warning on instrument panel
Audible warning

CUSTOMER COST:
****

Audi Michelsens Bil > Audi lane assist [Internet]. Audi.se. 2017 [cited 4 April 2017]. Available from: http://www.audi.se/se_partner/p_se_michelsens_bil/sw/models/a8/a8-1-w12-quattro/equipment/assistance-systems/audi-lane-assist.html
Drive Profiles

Function:
Selectable options for the driver to receive the best driving experience for different types of driving conditions. Often there are four type of profiles: ECO, dynamic (sport), comfort and off-road. Eco, focus is to reduce fuel consumption. Dynamics (sport) is made to profit driving in curvy conditions like mountain climbing. Comfort is often a standard profile that focusing on driving silent and comfortable. Off-road, used for rough terrain such as sand-, snow- and wet landscapes.

How it works:
The driver selects one of the pre-programmed profiles, the vehicle adjusts according to the profile. Characteristics that often adjust, depending on drive profile, are: transmission, accelerator pedal response, suspension and steering wheel response. For example, the dynamic profile, there are often faster accelerator pedal response, more aggressive shifting points, stiffer suspension adaptive for fast cornering and adjusts the steering- torque and ratio to receive a more sportier driving.

Pros and Cons:
Giving the driver the option to optimize the driving for specific driving conditions.

Input:
• Chosen Drive Profile
• Wheel speed indicator
• Engine
• Body sensors
• Steering servo

Output:
• Gearbox
• Suspension
• Steering wheel
• Accelerator pedal
• Climate system

Customer Cost:
****

Drive modes* [Internet]. Support.volvocars.com. 2017 [cited 20 April 2017]. Available from: http://support.volvocars.com/uk/cars/pages/owners-manual.aspx?mc=v526&my=2016&sw=15w46&article=c9f4ae44897753f5c0a801517483a067&category=d7c8b4d1800e9959c0a801516770b1df
AIR BODY CONTROL

FUNCTION:
Provide the rides comfort for everyone in the vehicle, with adaptive damping and adjustable air springs. It will also reduce the fuel consumption by lowering the vehicle height at a pre-set speed.

HOW IT WORKS:
It is linked to the pre-programmed Drive Profile, whom the driver selects according to what type of driving he/she want. The suspension is linked to a ECU (Electrical Control Unit) which calculates values, such as wheel, body and lateral acceleration. Then depending on what profile that is selected, the suspension acts according to the settings. For example; The Comfort profile, the suspension is set to be smooth. And for the Sport profile, the suspension is set to be stiffer to get a better cornering and body control recovery.

PROS AND CONS:
Receiving a comforter ride, performance designed for different types of profiles. Reduced fuel consumption for higher speeds.

INPUT:
Body acceleration
Wheel acceleration
Lateral acceleration

OUTPUT:
Suspension

CUSTOMER COST:
18 000 – 30 000+

**ALL-WHEEL DRIVE**

**FUNCTION:**
Change automatic from normally front-wheel drive to all-wheel drive but some AWD-system change from rear-wheel drive to all-wheel drive, if any wheel start to slip. It will automatic go back to front-wheel drive or rear-wheel drive when driving on the highway under good condition, in that way it will use less fuel.

**HOW IT WORKS:**
There is a wheel-sensor on every wheel to detect wheel slippage. To determine if torque needs to be sent to just the front-wheels or all-wheels. Steering angle, lateral and longitudinal acceleration and engine torque are acquired and analysed every 10 milliseconds. The system use one controllable clutch to distribute the torque between the front and rear axles and one between the rear wheels to control the torque distribution between them.

**PROS AND CONS:**
AWD increases grip and control even for hard condition. You don’t need to activate or deactivate the AWD-system, like you must do with the four-wheel drive. Driving on the highway with FWD or RWD will lower the uses of fuel. AWD is quite expensive to install and its weight will slow down the acceleration compare to a FWD or RWD vehicle.

**INPUT:**
Wheel sensor
Lateral and longitudinal acceleration sensor
Engine torque

**OUTPUT:**
Drive on all wheels

**Customer Cost:**
20,000-35,000 SEK

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Appendix B: Detailed test data

Intelligent
40 km/h
Intelligent
60 km/h
Comfort
40 km/h

[Graph showing velocity and roll rate over distance]

Metres (m)
Comfort
50 km/h
Comfort
60 km/h
Sport
40 km/h
Sport
60 km/h