

**CS445 / ECE 451 / CS645**  
**Electronic Stability Control - Project Deliverable 3**



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## 1.0 Introduction

### 1.1 Purpose

This document describes the software requirements and specification for an electronic stability control (ESC) system for automobiles. The document is intended for the customer and the developer (designers, testers, maintainers). The document also specifically describes the four constituents of the ESC which are a collection of active-safety features namely, Anti-Lock Braking System, Brake Assist, Traction Control, and Skid Control. The reader is assumed to have basic knowledge of automobile architecture and mechanisms. Knowledge and understanding of UML diagrams is also required.

## 1.2 Scope

The software supports basic electronic stability controls for any automobile. The ESC and its four core components focus on avoiding or lessening the severity of loss-of-control accidents. The ESC takes effect when the driver is losing control or about to lose control of the vehicle. The Anti-Lock Braking System is activated when rotation speed of any wheel is rapidly decelerating in order to prevent the wheels from locking when the driver brakes hard. The Brake Assist takes effect when the driver is performing an emergency stop. Its purpose is to apply maximum braking power to the wheels and reduce the time and distance needed to stop the car. The Traction Control takes effect when it senses that any wheel is slipping. It takes corrective action by subsequently keeping the wheels from slipping. The Skid Control is activated when the car is stopping or turning too quickly. It takes corrective action by preventing the car from steering away from the turn. The ESC software must make sure that all these four systems are running in parallel.

## 1.3 Definitions, Acronyms, Abbreviations

### **Definitions:**

- brakePressure: the pressure applied to the brake pedal
- brakeThreshold: the threshold to determine if emergency braking is engaged. Based on the acceleration of the pedal.
- curPressure: the current pressure built up in the actuator pump
- curSpeed: the speed of the vehicle

### **TRAC specific definitions:**

- state: the state of the vehicle (forward, reverse, stationary)
- acceleration: the pressure applied to the acceleration pedal

### **SC specific definitions:**

- steerAngle: the angle of the steering wheel
- safeSteer: the range to determine if turning is safe or over/under. Determined by using the yaw sensor to calculate the yaw rate.
- SCLights: the indicator for the SC on/off
- SCErrorLights: the error indicator of the SC

### **BA specific definitions:**

- BALights: the indicator for the BA on/off
- BAErrorLights: the error indicator of the BA
- maxPressure: 100% pressure for braking

### **ABS specific definitions**

- pulseRate: the pulse rate of ABS system
- ABSLights: the indicator for the ABS on/off
- ABSErrorLights: the error indicator of the ABS

### **Acronyms/Abbreviations:**

- Electronic Stability Control (ESC)
- Brake Assist (BA)
- Anti-lock braking system (ABS)
- Traction Control (TRAC)
- Skid Control (SC)
- Electronic Control Unit (ECU)

## 1.4 References

### **Existing Documentation:**

Stability Control - Project Definition, Accessed from:

<http://www.student.cs.uwaterloo.ca/~cs445/Winter2012/Project/stability.pdf>

### **Stakeholder Documentation:**

Communication with David Dietrich:

[Date: 02/04/12]

Communication regarding first meeting and minutes. Made note of systems are checked at startup to make sure they are functioning, if not then lights are turned on by the dashboard.

[Date: 02/08/12]

Communication regarding second meeting and minutes. David pointed out the 2 micro-processors for ABS may be there for redundancy but not necessarily.

[Date: 02/14/12]

Emails regarding TRAC calculation and latitudinal slippage and requiring both longitudinal and latitudinal sensors in the case when 4 wheels are slipping simultaneously.

Only 1 speed sensor is needed per vehicle.

Sensors are connected to ECUs and not to one another. The ECUs perform calculations and apply effects to the actuators.

Brake Assist Actuator pump retains constant max pressure.

The throttle actuators exist for for each wheel to apply/remove power from wheel.

Discussion regarding use case diagram and concerns of the diagrams being too low level.

[Date: 02/16/12]

Email regarding length of deliverable.

[Date: 03/13/12]

Communication regarding third meeting and minutes.

[Date: 03/20/12]

Variant discussions and sample variants.

[Date: 03/22/12]

Deliverable 2 formatting issues.

### **Sources:**

[ref1] Stability Regulation, CBC. Accessed from:

<http://www.cbc.ca/news/story/2009/03/13/stability-regulation.html>

[ref2] Electronic Stability Control, Transport Canada. Accessed from:  
<http://www.tc.gc.ca/eng/roadsafety/tp-tp14651-vs200701-menu-738.htm>

[ref3] Electronic Stability Control, National Highway Traffic Safety Administration. Accessed from:  
[http://www.nhtsa.gov/Laws+&+Regulations/Electronic+Stability+Control+\(ESC\)](http://www.nhtsa.gov/Laws+&+Regulations/Electronic+Stability+Control+(ESC))

[ref4] Electronic Stability Control to be Standard On All Vehicles From 2014, Carscoop. Accessed from:  
<http://carscoop.blogspot.ca/2008/05/eu-electronic-stability-control-to-be.html>

[ref5] Electronic Stability Control to Improve Safety of Trucks and Coaches, European Union. Accessed from:  
<http://europa.eu/rapid/pressReleasesAction.do?reference=IP/07/1710&format=HTM>

[ref6] United Nations Group Action on Electronic Stability Control Helps Advance Auto Safety Worldwide, Continental. Accessed from:  
[http://www.conti-online.com/generator/www/com/en/continental/pressportal/themes/press\\_releases/3\\_automotive\\_group/chassis\\_safety/press\\_releases/vereinte\\_nationen\\_07\\_07\\_08\\_en.html](http://www.conti-online.com/generator/www/com/en/continental/pressportal/themes/press_releases/3_automotive_group/chassis_safety/press_releases/vereinte_nationen_07_07_08_en.html)

### **Minutes**

Minutes are provided within the appendix at the end of the document

## 1.5 Overview

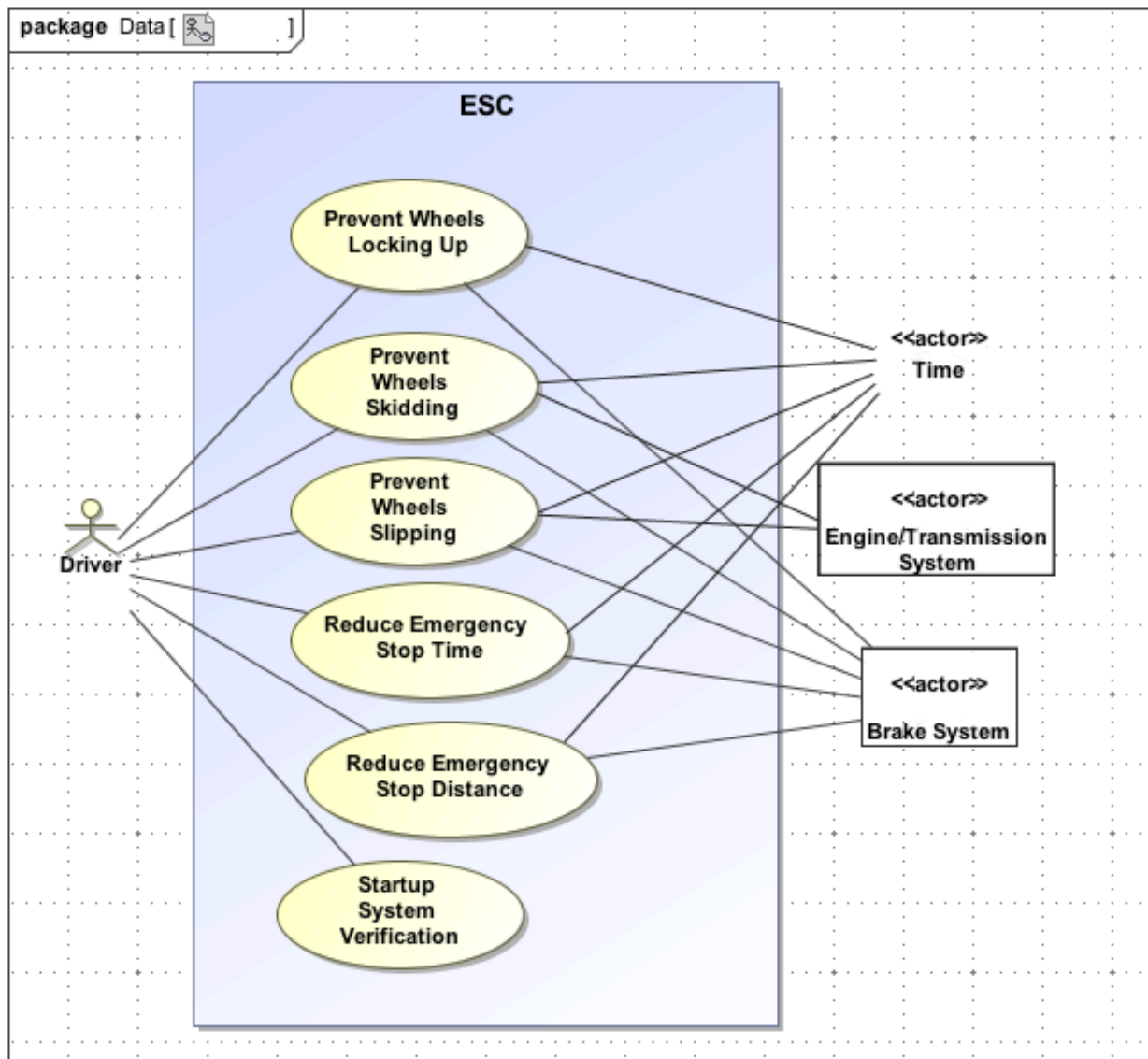
The rest of this document is organized as follows. Section 2 contains a general description of the ESC software requirements. Section 3 identifies the specific requirements, including external interfaces, use cases, functional requirements, and behavioral requirements. The document concludes with an appendix of meeting minutes. The appendix does not constitute additional requirements of the software; all requirements arising from these minutes have been incorporated into the specific requirements in Section 3.

## 2.0 Overall Description

### 2.1 Product Perspective

Here's a use-case diagram that illustrates how the ESC works in relation to its actors and actuators.

### Use-Case Diagram



The ESC system operates concurrently with various components of the vehicle including the acceleration and brake system, the engine and transmission, and the steering system.

### **Brake Interface**

The brake system detects the driver's application of pressure to the brake pedal. The brake sensors pick up the degree of pressure applied and communicates with the ESC system and the actuator pumps to make the necessary adjustments.

### **Engine and Transmission Interface**

The transmission controls the power usage from the engine. The power output is determined by the gear the user is currently in (variations:HERE) and the acceleration/brake state of the vehicle. The ESC interacts with the transmission and engine to make the necessary adjustments.

### **Steering Interface**

The steering system is controlled by the driver through the use of the steering wheel and controls the steer direction and degree of the vehicle. The steering sensors pick up the degree of turning of the wheel and communicates with the ESC system to make the necessary adjustments.

### **User Interfaces**

Driver - The driver is responsible for operating the vehicle. The driver user interface should be uniform across vehicles such that drivers with the proper license can operate the vehicle and locate the necessary functionality. The electronic stability control system is initiated through the driver in certain situations as detected by the appropriate sensors, but the system does not require driver input and makes automatic adjustments.

Manufacturer - The manufacturer is responsible for installing and adjusting the electronic stability control system. The installed system should operate properly and within the constraints defined through testing, but the system does not provide any guarantees and is sometimes optional and can even be turned off. The manufacturer designates dealerships to make any future adjustments needed to the individual parts of the system including updates and maintenance.

## 2.2 Product Functions

The ESC system is a collection of safety features that activate when sensor inputs determine that the driver is about to lose control of the vehicle: such as when the driver is turning too sharply or braking too hard. The main goal of the ESC is to make the necessary adjustments for the driver to maintain control of the vehicle in such detected emergencies. The ESC contains 4 main features:

### **Anti-Lock Braking (ABS)**

ABS is a safety feature that helps to prevent the wheels from locking when the driver brakes hard. ABS is a passive system that is turned on at all times. ABS sensors monitor the speed and deceleration of each wheel to determine locking of wheels. ABS applies pulsing to the brake pressure to prevent wheels skidding and locking.

### **Brake Assist (BA)**

BA is a safety feature that helps to reduce the time and distance needed to stop a car. BA sensors monitor the amount of pressure applied to the brake pedal to determine emergency braking. BA applies maximum braking through the use of BA actuator pumps to reduce stopping time and distance.

### **Traction Control (TRAC)**

TRAC is a safety feature that helps to prevent the wheels from slipping. TRAC sensors monitor and calculate the speed differential of the wheels to determine if a wheel is slipping. TRAC applies corrective action to the engine and brakes to adjust for slippage.

### **Skid Control (SC)**

SC is a safety feature that helps prevent the wheels from slipping or skidding during a turn. SC sensors monitor the angle of the steering wheel and the yaw differential to determine if the vehicle is in an understeer or an oversteer situation. SC applies corrective actions to the engine and brakes to adjust for the turn.

ESC and its features are engaged in the following use cases:

- Prevent wheels from locking up
- Prevent wheels from skidding
- Prevent wheels from slipping
- Reduce stop time
- Reduce stop distance

## 2.3 User Characteristics

The ESC system consists of two main users, drivers and manufacturers:

### **Drivers:**

- Drivers are simply owners and drivers with the proper licence to operate the vehicle.
- Drivers have read the owner's manual but it is not necessary for the functionalities provided by the ESC system.
- Drivers must not have any disability or under are under special circumstances that prevents safe operation of the vehicle.

### **Manufacturers:**

- Manufacturers must be experienced to properly install and setup the ESC system initially.
- Manufacturers must provide updates and maintenance of the ESC system for the vehicle.

## 2.4 Constraints

### **Regulatory Policies and Laws**

The ESC system is a required feature that must be installed on all vehicles with a gross vehicle weight rating of 4536 kg or less, effective on all models September 1st, 2011 in Canada [ref1] [ref2].

The ESC system is also a required feature that must be installed on all vehicles with a gross vehicle weight rating of 4536 kg or less, effective on all 2012 models in the USA [ref3].

The ESC system is also being introduced as a mandatory feature on all new vehicles sold in the EU from 2012 with all new cars being equipped by 2014 [ref4][ref5].

### **Hardware Limitations**

The ESC system is mostly automatic and activation is dependent on driver actions and sensor inputs. Therefore hardware limitations exist in sensors to collect the correct data and determine the correct situation in which if ESC features are required and what corrections need to be made to the vehicle for the driver to remain in control. The sensor measurements must be extremely accurate to several significant figures. The measurements must also be collected and processed quickly to maintain a constant stream of inputs for the ESC system to analyze.

Other hardware limitations may exist in the application of corrective measures, for example if it is possible for the BA actuator pumps to apply a certain sufficient pressure to stop a vehicle moving at a high speed safely.

These hardware limitations define the threshold on some of the performance specifications determined from testing and can be improved with new technology.

### **Parallel Operations**

The ESC system and the separate features must operate in parallel. In each of the use cases provided for the separate features, interaction exists between the systems. For example when TRAC and SC applies braking for corrective actions, BA or ABS can activate depending on the braking. When BA activates, the differential on the wheels also triggers ABS, so both systems must work in parallel to achieve both safe stopping distance and time and prevent skidding.

Because of parallel operations there exists an order of precedence among the 4 systems. Because BA and sometimes ABS cannot be turned off, these system retain precedence over TRAC and SC, which can both be turned off by the driver.

### **Criticality of Application**

Since certain features of ESC are still optional and can be turned off by the driver (BA and sometimes ABS are the exception), ESC is not considered critical in the operations of the vehicle.

### **Safety and Security Considerations**

The ESC system has been proven to effectively help the driver maintain control of the vehicle in emergencies. The ESC system does not provide any guarantees in safety, only helps perform adjustments to help the driver stay in control of the vehicle. The only guarantee the ESC system provides is that it will not be detrimental in the driver retaining stability during an emergency (BA or ABS will not prevent the driver from crucial functionality like braking).

### **Standards**

Currently ESC is a generic term and each vehicle manufacturer uses its own system within their vehicles. A proposed Global Technical Requirement for ESC will aim to establish a single regulatory standard for the ESC system instead of the various products available for the different manufacturers [ref6].

## 2.5 Assumptions and Dependencies

### **Assumptions about input/environmental behaviour:**

- Weather conditions are reasonable and safe to drive in
- Hardware never fails

### **Conditions that could cause the system to fail:**

- Damaged sensors
- Wear of tires
- Improper pressure of tires
- Weak car battery

### **Changes to the environment that could lead to changes in the software requirements:**

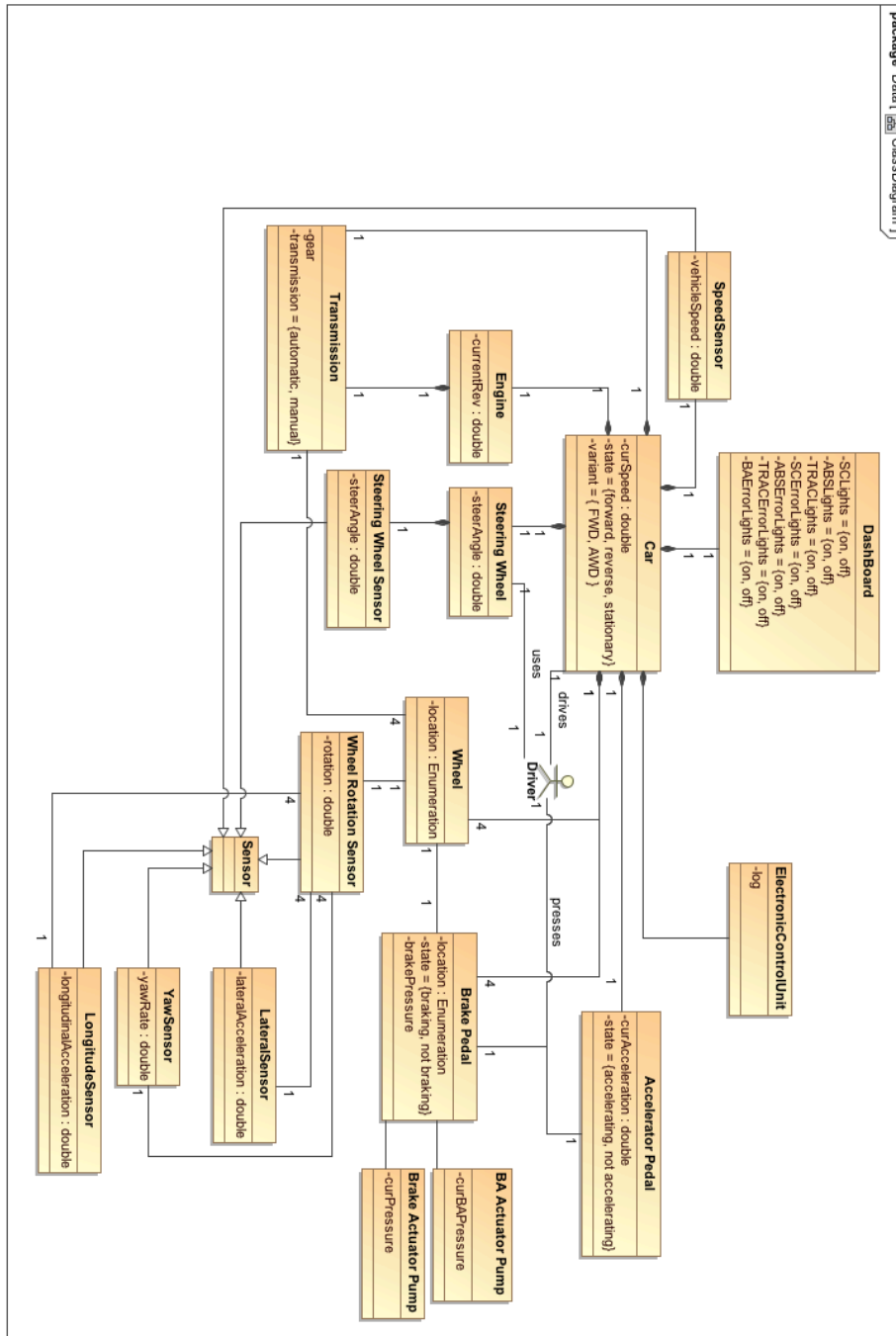
- Climate conditions such as temperature and weather (TRAC requirements might be different for Canada versus Brazil)
- Changes to road conditions such as potholes and cracks
- Rugged terrain
- Steep roads

### 3.0 Specific requirements

### 3.1 External Interfaces

Here's the domain model of the ESC that illustrates what parts of the automobile are involved in the system and how they interact based on the input.

#### Domain Model



## **Inputs**

Name: Braking

Description: The driver presses the brake pedal and the force applied and total compression is measured

Source: Brake Pedal

Range, Accuracy and Tolerance: The compression of the pedal is measured with a percentage, range from 0% to 100%, and the pressure applied with force

Unit of Measure: Percentage and Pound Per Square Inch

Timing: Can occur concurrently with steering wheel inputs but not accelerator pedal inputs (braking is given priority)

Name: Accelerating

Description: The driver presses the accelerator pedal and the force applied and total compression is measured

Source: Accelerator Pedal

Range, Accuracy and Tolerance: The compression of the pedal is measured with a percentage, range from 0% to 100%, and the pressure applied with force

Unit of Measure: Percentage and Pound Per Square Inch

Timing: Can occur concurrently with steering wheel inputs but not brake pedal inputs (braking is given priority)

Name: Steering

Description: The driver turns the steering wheel and the angle of steering is measured

Source: Steering Wheel

Range, Accuracy and Tolerance: The range is the full range of rotation of the steering wheel, which is 2 full rotations in both directions

Unit of Measure: Degree

Timing: Can occur concurrently with accelerator pedal and/or braking inputs (braking is given priority)

Name: Toggle System Switch

Description: The driver toggles the switch for SC and/or TRAC to turn the system on or off

Source: System Switch

Range, Accuracy and Tolerance: Boolean, on or off

Unit of Measure: None

Timing: Can be turned on and off at any time regardless of other inputs

Name: Change Gears

Description: The driver shifts gear to change the transmission

Source: Transmission

Range, Accuracy and Tolerance: States as defined by the vehicle

Unit of Measure: None

Timing: Can be shifted concurrently with other inputs

## **Outputs**

Name: Brake Pressure Applied

Description: The brake system is engaged and the actuator pumps engage based on the pressure and compression from the brake pedal input

Destination: Brake System

Range, Accuracy and Tolerance: Pressure applied is based on the brake pedal input

Unit of Measure: Pound Per Square Inch

Timing: Can not be applied the same time as the emergency brake pressure (precedence given to emergency braking)

Name: Emergency Brake Pressure Applied

Description: The BA actuator pumps are engaged because of emergency braking and the maximum pressure is released

Destination: Brake System

Range, Accuracy and Tolerance: Pressure applied is the maximum pressure on the brakes

Unit of Measure: Pound Per Square Inch

Timing: Can not be applied the same time as normal brake pressure (precedence given to emergency braking)

Name: Brake Pulsing Applied

Description: The brake system applies pulsing action to the brake pressure to based on the pulse rate

Destination: Brake Actuator

Range, Accuracy and Tolerance: Pulsing is based on the predefined pulse rate

Unit of Measure: Pounds Per Square Inch/Second

Timing: Can be applied concurrently with emergency and normal braking pressures as well as other action with engine/transmission

Name: Engine Power Throttled

Description: The engine is throttled to reduce power to the wheels because of emergencies

Destination: Engine

Range, Accuracy and Tolerance:

Unit of Measure: Horsepower (hp)

Timing: Can be applied concurrently with braking actions

Name: Toggle System Lights

Description: The dashboard lights of the system is turned on or off

Destination: Dashboard Lights

Range, Accuracy and Tolerance: Boolean, on or off

Unit of Measure: None

Timing: Can be turned on and off at any time regardless of other outputs

## 3.2 Functions

### Use Case Descriptions

Use Case 1

Name: Make a turn

System: Skid Control

Actors: Driver(initiator), Wheel, SC sensor

Trigger Event: Driver initiates a turn with the steering wheel outside the defined ranges for safe turn (classified to be oversteering or understeering)

Driver	Wheel	SC sensor
1. Driver oversteers or understeers the steering wheel		
	2. Wheel turns according to steering wheel	
		3. SC sensor detects oversteering or understeering
<b>Alternative: Safe turn</b> 1. Driver initiates a turn with the steering wheel inside the defined ranges for a safe turn		
	2. Wheel turns according to steering wheel	
		3. SC sensor does not detect oversteering or understeering
<b>Alternative: SC is turned off</b> 1. Driver initiates a turn		
	2. Wheel turns according to steering wheel	
<b>Alternative: Car is under 20km/h</b> 1. Driver oversteers or understeers the steering wheel, but SC does not activate under 20km/h		
	2. Wheel turns according to steering wheel	

Use Case 2

Name: Detect under-steering or over-steering

System: Brake Assist

Actors: SC sensor, ECU

Trigger Event: Driver initiates a turn with the steering wheel outside the defined ranges for a safe turn (classified to be understeering or oversteering). Skid control gets triggered.

SC sensor	ECU
1. SC sensor polls the lateral acceleration, yaw rate and steering angle to determine oversteering and understeering	
	2. Signalled by the SC sensor that skid control action is required, signals the engine and the brake pad
Exception: SC malfunction 1. SC sensor polls the data and detects discrepancies in the range of data or is not reporting the correct statistics	
	2. ECU logs the error, take the recovery actions, and turns on the “check SC light” on the dashboard.

Use Case 3

Name: Take corrective actions

System: Brake Assist

Actors: Brake Pad, Engine

Trigger Event: Driver initiates a turn with the steering wheel outside the defined ranges for a safe turn (classified to be oversteering or understeering). Skid control gets triggered, signalling the engine and the brake pad. Depending on the situation, brakes are applied to the outside(oversteer) or the inside(understeer) wheels and the engine is throttled.

Engine	Brake Pad
1. Engine is throttled to compensate for oversteering or understeering	
	2. Braking system engages the brake pad on the wheels to slow down the car. Brakes on the outside are applied for oversteering. brakes on the inside are applied for understeering.

Use Case 4

Name: Press accelerator

System: Traction Control

Actors: Driver(initiator), Engine, TRAC sensor

Trigger Event: Driver presses the accelerator to increase the speed of the vehicle with slippage.

Driver	Engine	TRAC sensor
1. Driver presses the accelerator and slippage occurs		
	2. Engine provides power to wheels to accelerate the vehicle	
		3. TRAC sensor detects slippage
<b>Alternative: No slippage</b> 1. Driver presses the accelerator to increase the speed of the vehicle without slippage		
	2. Engine provides power to wheel to accelerate the vehicle	
		3. TRAC sensor does not detect slippage
<b>Alternative: TRAC is turned off</b> 1. Driver presses the accelerator		
	2. Engine provides power to the wheels to accelerate the vehicle	

Use Case 5

Name: Detect slipping

System: Traction Control

Actors: TRAC Sensor, ECU

Trigger Event: Driver presses the accelerator to increase the speed of the vehicle with slippage.

TRAC control gets triggered.

TRAC Sensor	ECU
1. TRAC sensor polls the speeds of the individual wheels to determine if the individual wheels are slipping and lateral/longitudinal sensors if all four wheels are slipping	
	2. Signalled by the TRAC sensor that traction control action is required, and signals the engine and the brake pad
<b>Exception: TRAC malfunction</b> 1 TRAC sensor polls the data and detects discrepancies in the range of data or is not reporting the correct statistics	
	2. ECU logs the error, takes recovery actions, and turns on the “check TRAC light” on the dashboard.

#### Use Case 6

Name: Take corrective actions

System: Traction Control

Actors: Brake Pad, Engine

Trigger Event: Driver presses the accelerator to increase the speed of the vehicle with slippage.

TRAC control gets triggered, signalling the engine and the brake pad. TRAC control reduces the power transferred to the wheel(s) and applies the brake(s) appropriately.

Engine	Brake Pad
1. Engine reduces power transferred to the wheel(s)	
	2. Braking system engages the brake pad on the wheels to slow down the car. Brakes are applied to the wheel(s).

#### Use Case 7

Name: Press brake pedal

System: Anti-lock braking system

Actors: Driver(initiator), Brake Pad, ABS sensor

Trigger Event: Driver presses on the brake with the intention of slowing down the car, causing the wheels to lock up

Overview: Driver presses on the brake pedal

Driver	Brake Pad	ABS sensor
1. Driver presses the brake pedal which causes the wheels to lock up		
	2. Braking system engages the brake pad on the wheels to slow down the car	
		3. ABS sensor detects the wheel getting locked up
<b>Alternative: Wheel does not get locked up</b> 1. Driver presses the brake pedal without causing the wheels to lock up		
	2. Braking system engages the brake pad on the wheels to slow down the car	
		3. ABS sensor does not detect the wheel locking up
<b>Alternative: ABS is turned off</b> 1. Driver presses the brake pedal		
	2. Braking system engages the brake pad on the wheels to slow down the car	

Use Case 8

Name: Detect locking up

System: Anti-lock braking system

Actors: ECU, ABS sensor

Trigger Event: Driver presses brake with the intention of slowing down the car, causing the wheels to lock up. ABS sensor gets triggered.

ABS sensor	ECU
------------	-----

1. ABS sensor pools the speed of the wheel, which determines if the wheels are being locked up.	
	2. Signalled by the ABS sensor that the wheels are being locked up, which will initiate pulsing braking.
<b>Exception: ABS malfunction</b> 1. ABS sensor detects that the hardware has malfunctioned, or is not reporting the correct statistics.	
	2. ECU logs the error, take recovery actions, and turns on the “check ABS light” on the dash board.

#### Use Case 9

Name: Pulse Braking

System: Anti-lock Braking System

Actors: Brake Pad, Time

Trigger Event: Driver presses brake with the intention of slowing down the car, causing the wheels to lock up. ABS sensor gets triggered, signalling ABS to pulse the brake pad to ensure that the wheels do not get locked up.

Time	Brake Pad
1. The timer will apply the brake pad on and off several times in a second	
	2. Braking system pulses the brake pad on the wheels to slow down the car, without locking up the wheels.

#### Use Case 10

Name: Press brake pedal

System: Brake Assist

Actors: Driver(initiator), Brake Pad, BA sensor

Trigger Event: Driver presses on the brake with the intention of slowing down the car, surpasses the threshold for BA sensor.

Overview: Driver presses the brake pedal

Driver	Brake Pad	BA sensor
--------	-----------	-----------

1. Driver presses the brake pedal with the intention of emergency braking		
	2. Braking system engages the brake pad on the wheels to slow down the car	
		3. BA sensor detects emergency braking
<b>Alternative: Safe braking</b> 1. Driver presses the brake pedal within the threshold for BA sensor		
	2. Braking system engages the brake pad on the wheels to slow down the car	
		3. BA sensor does not detect emergency braking, system brakes as normal

#### Use Case 11

Name: Detect emergency braking

System: Brake Assist

Actors: BA sensor, ECU

Trigger Event: Driver presses on the brake with the intention of slowing down the car, surpasses the threshold for the BA sensor. The BA gets triggered.

BA sensor	ECU
1. BA sensor pools the braking pedal, which determines an emergency brake	
	2. Signalled by the BA sensor that an emergency braking action is required, which will signal the Brake Assist Actuator
<b>Exception: BA malfunction</b> 1. BA sensor detect that the hardware has malfunctioned, or is not reporting the correct statistics.	
	2. ECU logs the error, takes recovery actions, and turns on the "check BA light" on the dashboard.

<b>Exception: ABS malfunction</b> 1. BA sensor polls the braking pedal, which determines an emergency brake.	
	2. ECU logs the error, takes recovery actions.

## Use Case 12

Name: Apply maximum braking force

System: Brake Assist

Actors: Brake Assist Actuator, Brake Pad

Trigger Event: Driver presses on the brake with the intention of slowing down the car, surpasses the threshold for the BA sensor. The BA gets triggered, signalling brake assist actuator to inject maximum pressure to the brake pad.

Brake Assist Actuator	Brake Pad
1. Inject additional reserved pressure to the brake pad to increase braking pressure	
	2. Braking system engages the brake pad on the wheels to slow down the car

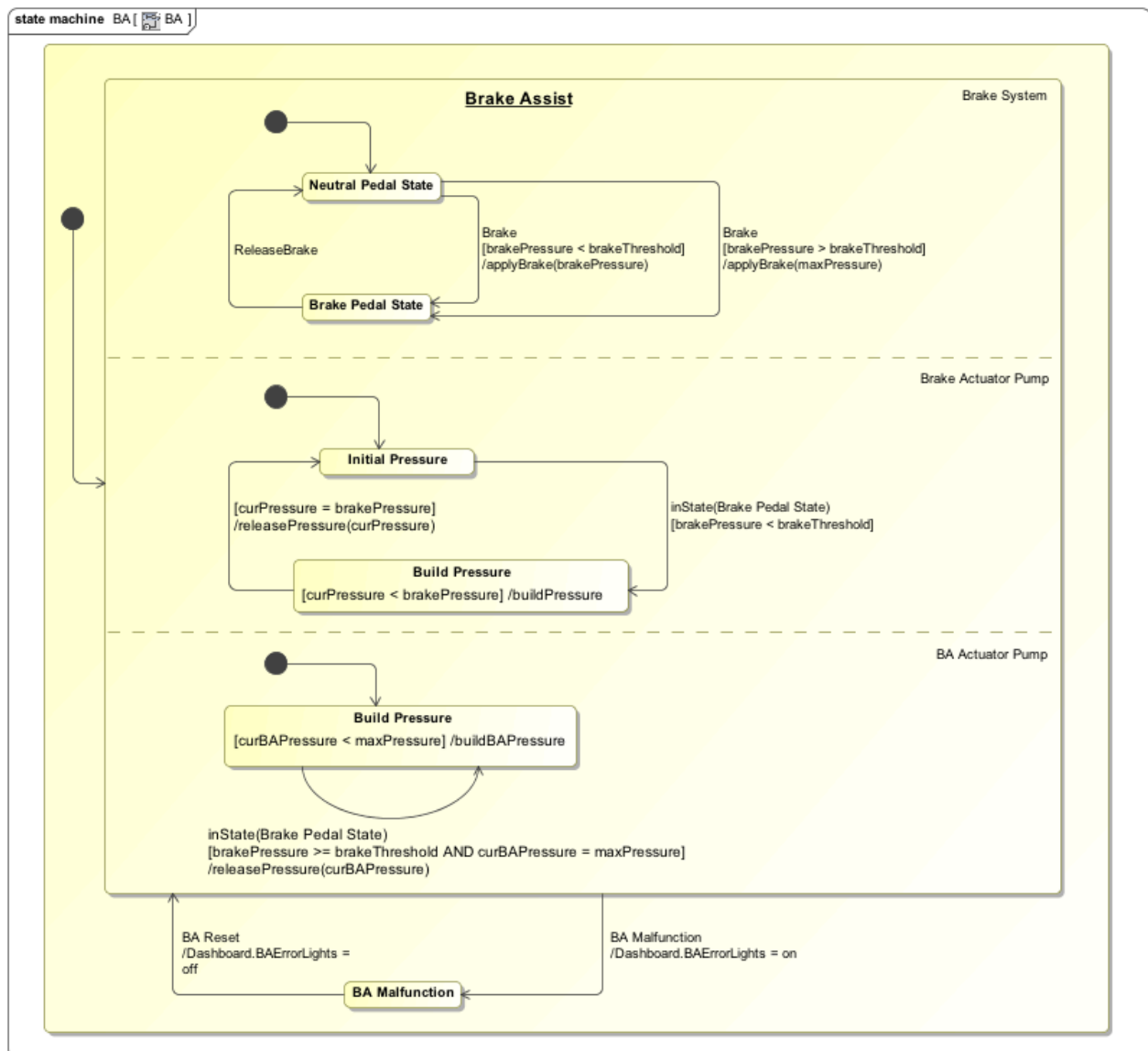
## Use Case Variants

- SC can only be turned off only if you have AWD and Off-Road mode.
- ABS malfunction activates the general warning light except the dashboard is complex in which case, it activates the ABS specific warning light.
- In BA, if the car has radar and it is telling you if you are close to a car, if you do not press the brake, then the car will press on brake on itself, some cars may not.
- High end cars may adapt the brake threshold according to driving habits. Others cars may just have a constant brake threshold.
- For ABS, some cars have diagnostics, attach machine to core to tell you where ABS is failing (if it is). Like ECU, battery, sensor, etc.
- Variation in number of actuator pumps (most have 1/wheel, some old ones have 2 in front and 1 in back). This would affect how ABS can be applied.
- For TRAC, some cars may have AWD, in which case, the corrective action will take place on each separate wheel. FWD or RWD cars will take corrective actions on both front wheels or both rear wheels.
- High end cars may have options to turn off all the systems except ABS. However, most cars have all four systems turned on at all times.

## State Machine Models

Here's the BA state machine model that illustrates the different states/stages of a BA operation.

### Brake Assist (BA)



### Variables:

brakePressure: the pressure applied to the brake pedal

brakeThreshold: the threshold to determine if emergency braking is engaged, which is based on the acceleration and pressure on the pedal

curPressure: the current pressure built up in the actuator pump

BALights: the indicator for the BA on/off

BAErrorLights: the error indicator of the BA

maxPressure: 100% pressure for braking

**Events:**

Brake: driver brakes by stepping on the brake pedal

ReleaseBrake: driver releases brakes completely off the brake pedal

BA Malfunction: BA system is determined to be malfunctioning by the sensors, also alert other systems since BA is necessary for other systems to function

BA System Reset: BA system is diagnosed and reset

**Functions:**

applyBrake(pressure): applies the brakes at pressure

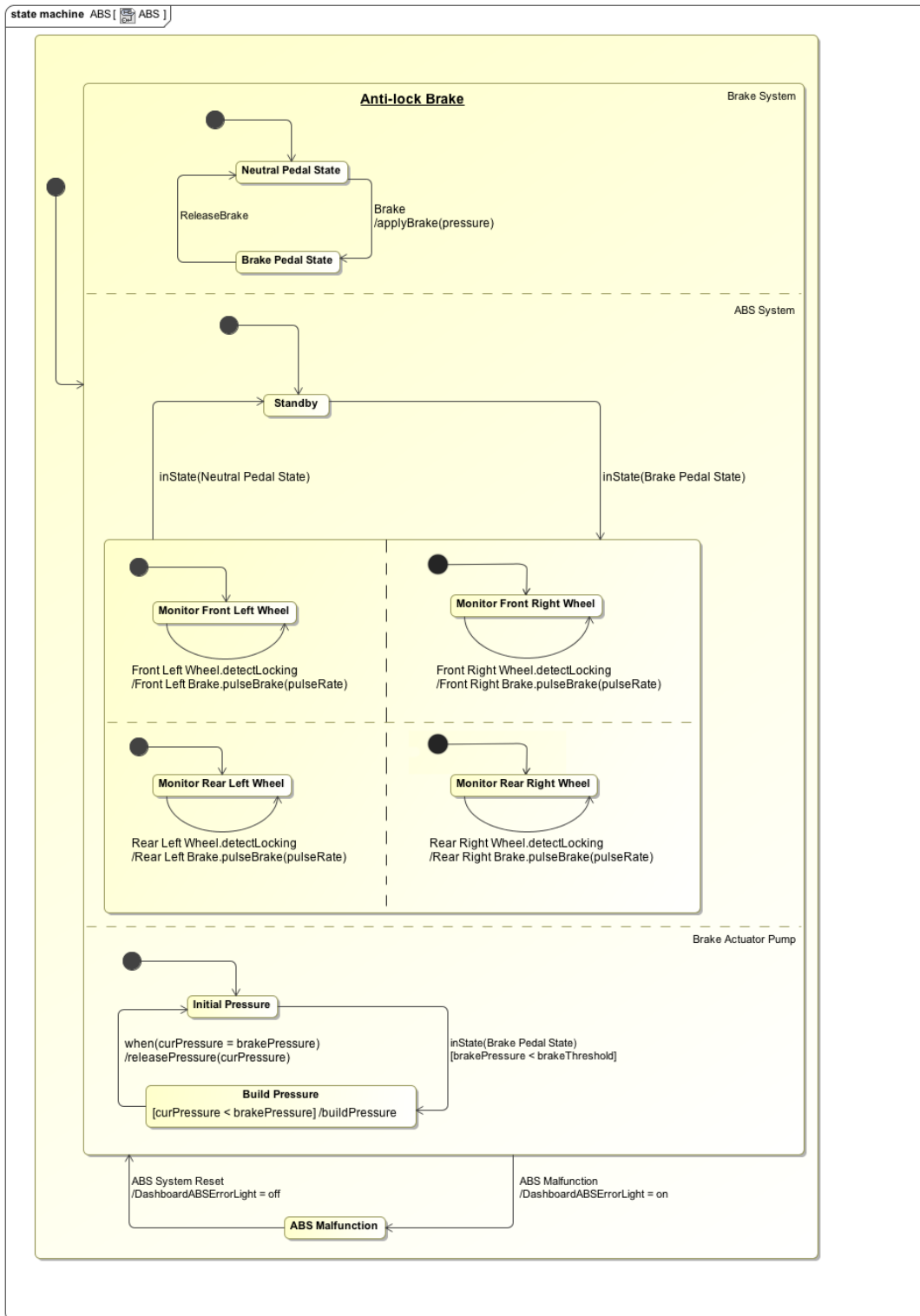
releasePressure(pressure): releases the built up pressure of the actuator pump

buildPressure: build up the current pressure curPressure of the brake actuator pump

buildBAPressure: build the current pressure of curBAPressure of the BA actuator pump

Here's the ABS state machine model that illustrates the different states/stages of a ABS operation.

### Anti-Lock Braking System (ABS)



**Variables:**

pulseRate: the pulse rate of ABS system

brakePressure: the pressure applied to the brake pedal

brakeThreshold: the threshold to determine if emergency braking is engaged, which is based on the acceleration and pressure on the pedal

curPressure: the current pressure built up in the actuator pump

ABSErrorLights: the error indicator of the ABS

**Events:**

Brake: driver brakes by stepping on the brake pedal

ReleaseBrake: driver releases brakes completely off the brake pedal

detectLocking: triggers when a wheel is locking up - determined by the rotation of the wheel relative to other wheels

ABS Malfunction: ABS system is determined to be malfunctioning by the sensors

ABS System Reset: ABS system is diagnosed and reset

**Functions:**

pulseBrake(rate): applies pulsing (alternate/ease of braking) to the specified brake at rate

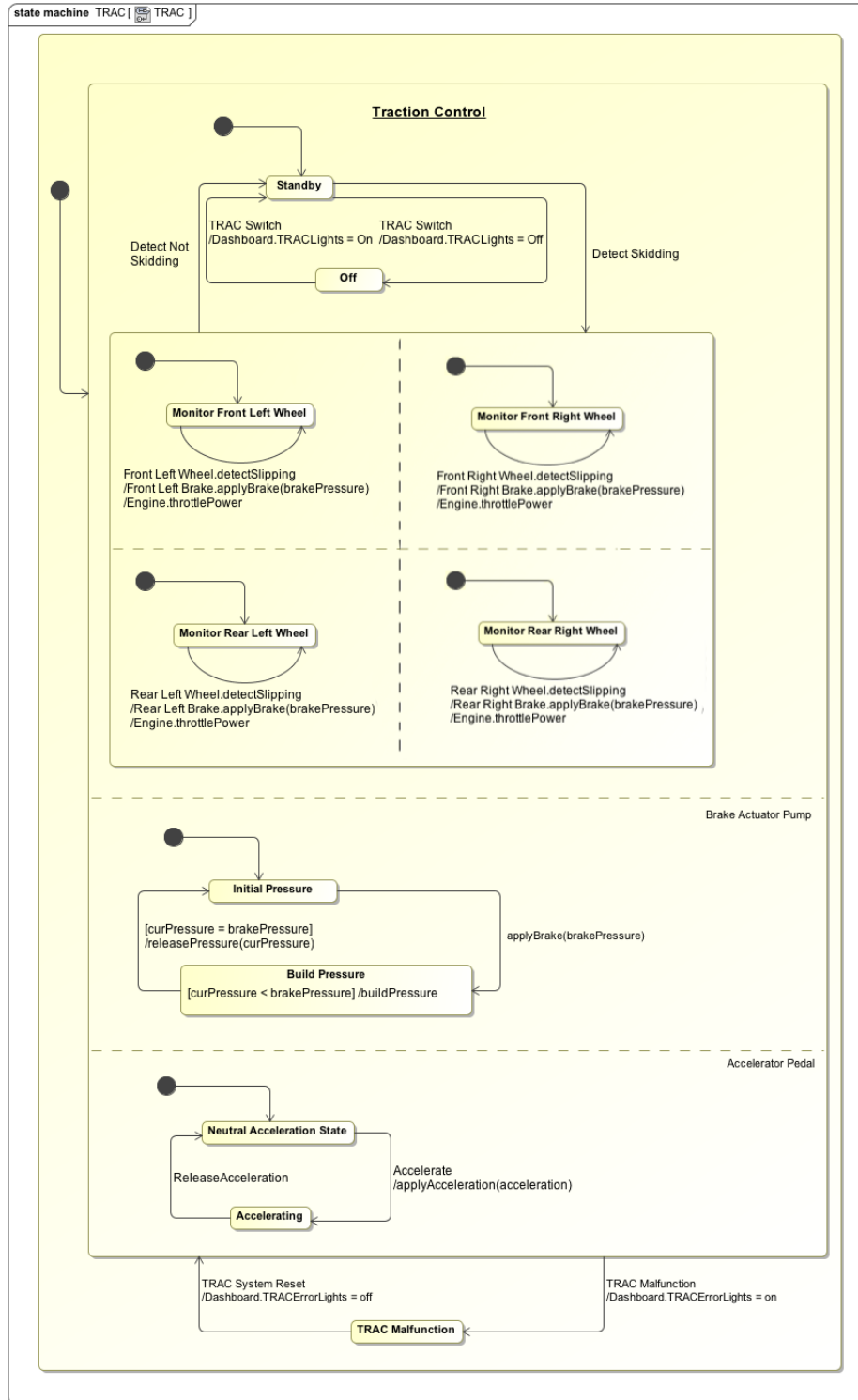
applyBrake(pressure): applies the brakes at pressure

releasePressure(pressure): releases the built up pressure of the actuator pump

buildPressure: build up the current pressure curPressure

Here's the TRAC state machine model that illustrates the different states/stages of a TRAC operation.

### Traction Control (TRAC)



**Variables:**

brakePressure: the pressure applied to the brake pedal

brakeThreshold: the threshold to determine if emergency braking is engaged, which is based on the acceleration and pressure on the pedal

curPressure: the current pressure built up in the actuator pump

acceleration: the pressure applied to the acceleration pedal

**Events:**

detectSlipping: triggers when a wheel(s) slips - determined by the rotation of the wheel relative to other wheels

TRAC Switch: driver toggles the TRAC switch

TRAC Malfunction: TRAC system is determined to be malfunctioning by the sensors

TRAC System Reset: TRAC system is diagnosed and reset

**Functions:**

applyBrake(pressure): applies the brakes at pressure

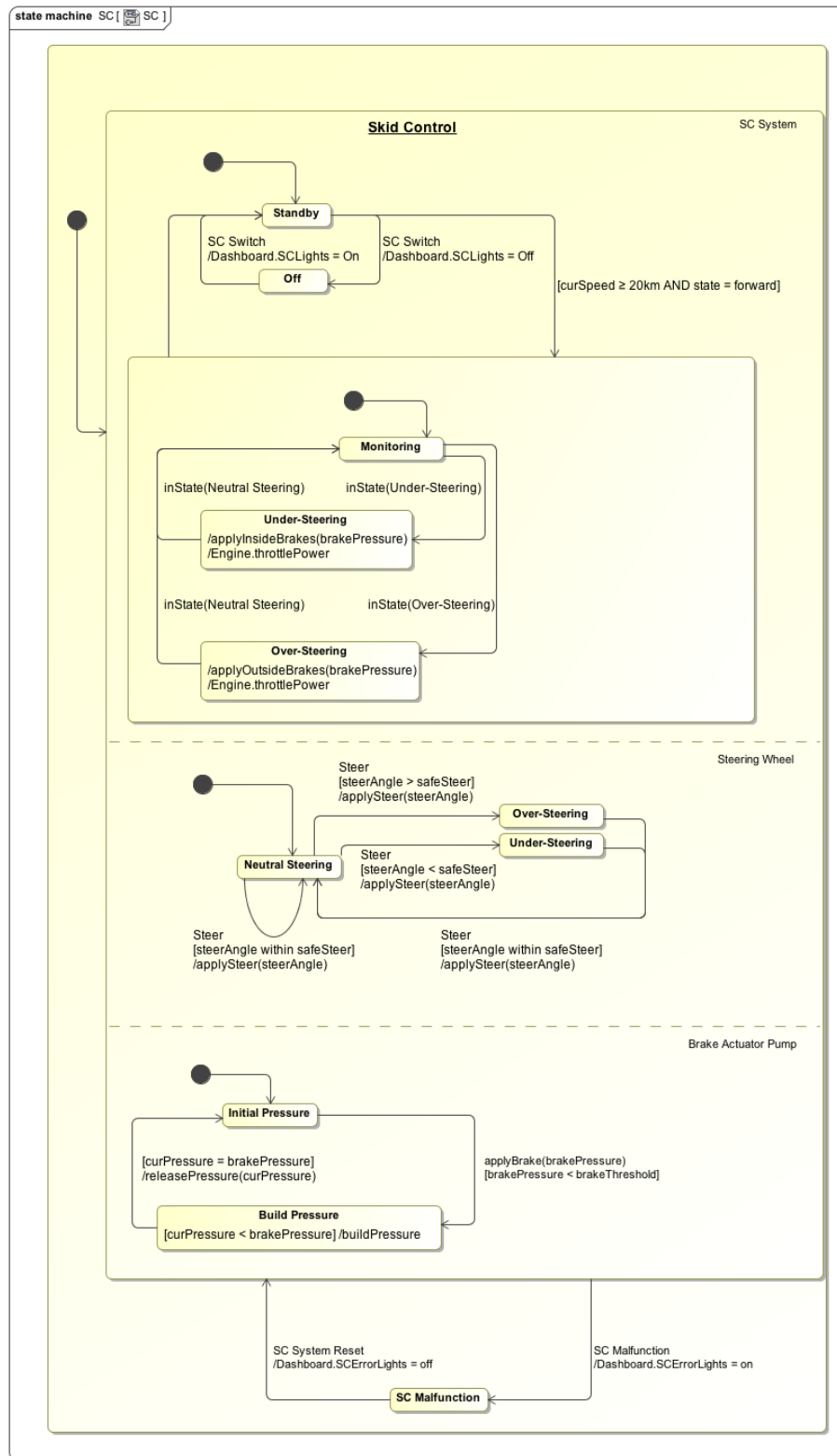
releasePressure(pressure): releases the built up pressure of the actuator pump

buildPressure: build up the current pressure curPressure

throttlePower: throttles the power of the engine

Here's the SC state machine model that illustrates the different states/stages of an SC operation.

### Skid Control (SC)



**Variables:**

steerAngle: the angle of the steering wheel

safeSteer: the range to determine if turning is safe or over/under, which is determined by sensors that checks the range of the angle for steering

brakePressure: the pressure applied to the brake pedal

brakeThreshold: the threshold to determine if emergency braking is engaged

curPressure: the current pressure built up in the actuator pump

curSpeed: the speed of the vehicle

SCLights: the indicator for the SC on/off

SCErrorLights: the error indicator of the SC

state: the state of the vehicle (forward, reverse, stationary)

**Events:**

Steer: driver steers by turning the steering wheel

SC Switch: driver toggles the SC switch

SC Malfunction: SC system is determined to be malfunctioning by the sensors SC System

Reset: SC system is diagnosed and reset

**Functions:**

applyInsideBrakes(pressure): applies the brakes at pressure to the inside wheels

applyOutsideBrakes(pressure): applies the brakes at pressure to the outside wheels

releasePressure(pressure): releases the built up pressure of the actuator pump

buildPressure: build up the current pressure curPressure

throttlePower: throttles the power of the engine

applySteer(angle): applies steering to the wheel based on steer angle

**Real-Time Constraints for ESC**

- The latency of anti-lock brakes must be at most 100 ms for the braking function to be effective.
- The car must be going above 20km/h for SC to be triggered.
- The yaw rate must be sufficiently large for SC to be triggered.

### 3.3 Performance Requirements

#### **Overall**

- Our Electronic Stability Control (ESC) system supports only one user at a time.
- All four features, ABS, BA, TRAC, SC, should run simultaneously.

#### **Anti-Lock Braking (ABS)**

- Anti-Lock Braking interacts with two informations, the speed of the wheels and the pressure on the brake.
- In normal workload conditions, near 100% of the transactions shall be processed in less than a few seconds.
- In peak workload conditions, almost 80% of the transactions should be processed in less than 10 seconds and the wheels should be in normal conditions.

#### **Brake Assist (BA)**

- Brake Assist interacts with the pressure on the brake.
- The pressure on the brake should be detected at a real time, and the necessary maximum pressures will be applied at the same time.

#### **Traction Control (TRAC)**

- Traction Control interacts with the speed of the wheels.
- The speed of the wheels should be detected at a real time, and the corrective actions shall be performed at the same time simultaneously.

#### **Skid Control (SC)**

- Skid Control interacts with the actual yaw rate of the car and the intended yaw rate of the car.
- Whenever the driver tries to make a turn, the actual yaw rate of the car and the intended yaw rate of the car are detected and calculated at a real time, and necessary actions should be performed simultaneously.

## 3.5 Quality Requirements

### **System Restart and Recover**

**Overview:** If any of the features malfunctions, or is not reporting the correct results, the system should restart and perform a recovery within a specified time period.

**Outstanding:** 5 s

**Target:** 10 s

**Minimum:** 30 s

### **System Start**

**Overview:** When the driver starts the engine, the ESC system should start at the same time and be ready to perform the safety features within a specified time period.

**Outstanding:** 1 s

**Target:** 5 s

**Minimum:** 10 s

### **System Shut Down**

**Overview:** When the driver turns off the engine, the ESC system should be turned off within a specified time period.

**Outstanding:** 1 s

**Target:** 5 s

**Minimum:** 10 s

### **Logging the Errors**

**Overview:** When the system detects a failure, it will log the errors.

**Outstanding:** < 1 s

**Target:** 1 s

**Minimum:** 2 s

## Appendix - Meeting Minutes

### Meeting Minutes - January 30th

Functions of each of the ESC features:

- ABS: Helps to prevent the wheels from locking when the driver brakes hard
- BA: Helps to reduce the time and distance needed to stop a car
- TRAC: Helps the wheels from slipping on wet or icy roads
- SC: Helps the wheels from skidding when stopping or turning too quickly

How does BA function?

- Uses hydraulic pumps to increase braking pressure
- Activated when the braking taps exceed the predetermined pressure
- Works with the ABS, but not the same system

How is brake assist (BA) different from normal braking?

- BA helps the driver to increase the brake pressure during emergency brakes
- Normal braking does not require BA to inject additional pressure to the brake pads via hydraulics

TRAC is ABS in reverse, only if excessive force on wheel and slippage happens

- Reduce power transferred to the wheel and apply the brake
- Braking must be almost instant, pressure must be continually maintained
- Actuator pump motor build constant pressure
- Actuator pump can be adaptive
- TRAC is not activated when the car is not on gas

Failure for sensors: each piece of equipment reports its status (loss of communication, abnormal signal levels)

- Self--diagnostic for certain hardware
- Connected to the lights on the dashboards
- Indicators come up when malfunction detected
- “Check engine” light
- Parallel software that turn off if not match with the correct range of data
- Restoring sensors: no back- up/mandatory, light remains lit continuously, the failed system will not be functioning
- The vehicle will continue to function even if all the ESC systems fails
- Sensors in an ESC system:
  - Yaw sensor (x--axis)
  - Speed sensor
  - Lateral sensos
  - Longitude sensor
  - Rotation of steering wheel

SC: determines which direction the driver is steering and where the car should go

- Lateral acceleration + yaw rate

- Over steering: activate outside brake
- Under steering: activate inside brake
- Intervene in engine (throttle), brake, gear box, are automatically controlled by the ESC
- Can be turned off by the driver if desired
- Only works when the car is traveling at 20km/h or more

Feature threshold: differential between speed of the wheels/calculated by engineers

- Different cars/makes/models have different initial constants, which are pre determined

Hand brake is completely separate from the ESC systems

Reactive action in car configurations: effects of different types of cars (AWD/4WD)

- Rear Wheel Drive, All Wheel Drive: always read sensor and adjust
- ABS: 4/3 sensors to activate wheel by wheel
  - (4 = 2 back+2 front, 3 = 2 front+1 back)
- Stability control is always on by default: AWD + off road = off (one exception)
- ABS: always on by default
- Traction control: stability good on curve, traction for acceleration but reduces stability control
- Brake assist triggers ABS, don't communicate with each other (independent)

TRAC: measure speed of wheels, individually, if one is faster than other wheels (relative slipping)

- Correction measures:
  - Reduce fuel supply to one or more cylinders
  - Brake force applied at one or more wheels
  - Reduce the power that goes to the wheels
  - Apply brakes to prevent the wheels from turning too fast
- Longitudinal slipping/latitudinal slipping
- Sensors write to a fault log when features fail
- No weather support
- If the car is suspended in mud or snow, TRAC should be turned off, it is not smart enough to detect weather conditions

Each sensor is independent and has own ECU

- If there's a problem, it shuts down and maintains the log.

ABS: de--acceleration threshold

-50 times per second

For some vehicles when a system is working the dashboard will blink indicator lights

None of the systems are mandatory by default

- Systems can be turned off by the user
- ABS is restarted when the car is restarted
- Skid Control is mandatory in states now for the new cars

-ESC is mandatory in Canada since September 1, 2011

If ABS fails:

- BA becomes dangerous and should be turned off
- Any safety feature that requires brake could become dangerous
- ABS is important for all other systems

Once ABS activated, will keep monitoring user actions

- Will stop once the driver releases the brake pedal

Stability control is always on and working

Manual transmission:

- ESC can not touch the gear box
- Only corrective action is reduce power, cut off gas

Messages are transmitted with BUS lanes by the sensors

For some cars brake takes precedence over accelerator

### **Meeting Minutes - February 6th**

General System Features

- 1 ECU with no redundancy (2 micro processors)
- Which system can be turned off?
  - ABS, TRAC and SC in certain situations
  - BA cannot be turned off
  - If only forward wheel drive, systems apply only to where the power is directed
  - Radar systems exist to sense proximity to other vehicles that will brake if driver does not within the time frame
  - Real time constraints: reaction time required for specific systems, assume there is time limit
  - Sensors check (ECU) if other systems are working and can turns off these systems if warranted
  - Assume certain conditions are detected and reported (pumps, sensors, ECU)
  - Other sensors to focus on: skid sensor, lateral/horizontal, yaw rate, brake sensors, speeds, wheel speeds, pressure of braking fluid sensors, throttle position sensor, steering angle sensor, master cylinder pressure sensor, brake fluid level warning switch, slip indicator light, system off indicators, system warning lights

Anti-lock Braking System

- Contains 4 sensors (one receives power, one is magnetic, ...)
- ABS will tell what is failing (sensor, pump, ECU, battery) with the diagnostic tool

Brake Assist

- Brake pedal sensor sensors on and off ONLY
- Other sensor measures acceleration on brake

#### Skid Control

- Skid control while braking (system must work in all conditions): SC must be actively monitoring the situation
- If braking hard, start to lose control, ABS take over but also SC will take corrective actions
- Understeering: selectively activate rear brake on the inside of the corner
- Oversteering, selectively activate front brake of outside corner

#### Traction Control

- Toyota vehicles contain normal TRAC (2WD) and active TRAC (4WD selectively apply brake to prevent slipping of individual wheels)
  - Limited slipping effect and must have even distribution of torque or divert to other wheels to compensate
- Does TRAC affect the gear box?
  - No, automatic transmission will adjust gears based on speed and pressure.

### **Meeting Minutes - March 12th**

#### General System Features

- Full diagnostics when car starts. Diagnostics is continuous
- All features are by default turned on
- Corrective action is done until problem is solved. For example, ABS will keep correcting until the wheel speed differential is non-existent
- You can turn SC or other controls off, but when you restart car, it turns on automatically

#### Brake Assist (BA)

- BA detects an emergency stop by seeing how fast the brake pedal goes down
- BA detects if your brake push is greater than the threshold, then adds more brake as required, this affects wheel speed and causes a differential which triggers ABS
- Corrective action for BA stops when you take foot off brake pedal, or when your foot eases off the pedal and there is no emergency detected anymore

#### Anti lock braking system (ABS)

- ABS checks speed differential among wheels
- ABS doesn't depend on whether you press brakes or not unlike BA

#### Traction Control (TRAC)

- For corrective action for TC: slow down speed aka break
- TRAC reduces the power of specific wheel if your car is sophisticated enough. So depends on your car configuration

#### Skid Control (SC)

SC enabled after you exceed 30km/h, ABS is enabled immediately car is started. ABS is always on

### **Meeting Minutes - March 26th**

- Must consult user manual, there is no training for drivers.
- The systems should be transparent, you aren't aware they are there and they only activate when they are required.
- Assume that the users can access input devices and press on the brake pedals and switches.
  
- Performance constraint: testing of the systems (warm up brakes, when reach certain speed and turn by a certain degree).
- Induce an error by plugging power supplies for the sensors. Within 2 minutes of reaching 48km per hour, the error lights must detect error. Then repeat the process with the power plugged in. Weight: 4536km
  
- The systems can fail but 95% of the time it works.
- ABS can fail but the normal brake has to work. When it comes to mission critical components these must always work (brakes etc), which is not the case for these assist systems.
- Beyond certain thresholds the system becomes useless.
- Must be able to react within a timeframe.
- Because most systems are optional, there is no minimum by law.
- Drift driving to circumvent these systems, the system will take make corrective actions regardless of intentions.
  
- Assumption: each system must exist in parallel.
- Component operating ranges (temperatures, humidity in Canada for Canadian cars in the right market)
- Are we concerned with the costs of the system? No.
- Sometimes have individual switches and lights, assume you will get signals, sometimes you get one switch. Details not necessary.
- What are the legal constraints for these systems. These systems are optional and not guaranteed for safety. Only if the systems do harm.
- In the US, ABS is mandatory. The technical standards are passed and establishes certification.
- For TRAC/SC there is a definition for satisfying identification as these systems.
- Nothing is established for Brake Assist.
- Sine with dwell test: driving straight, turn, then a period of straight. Signal post processing if values fall within a certain range (EMCSA 571.126 (ESC)).
- In Volkswagon and Audi, two components (one from Bosch and one from ITT) and have same parameters but differ in design they are used.