CHALMERS

Post impact braking verification in motion platform simulator

Master's Thesis in the Systems control and Mechatronics (MPSYS)

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CHALMERS UNIVERSITY OF TECHNOLOGY
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VTI Simulator which was used in this project.

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ABSTRACT

The goal of this thesis is to develop a test method and to apply it on a new safety function named Post Impact Braking (PIB) on different vehicle simulator platforms. The aim of this function is to avoid multiple events accident, so that the car starts braking as fast as possible to avoid a subsequent collision after a first impact.

The PIB function is tested with different types of accidents on the Chalmers simulator S2 with motion in order to understand and quantify how a driver can react during and after the impact, and also how efficient this function can be. The main advantage of the simulator is that there is no need of any driver model.

It is found out that the PIB function is beneficial in most of the situations combined with an ABS intervention.

Key words: Post Impact Braking, simulator, multiple events accident, safety, post crash

Verifiering i simulator med rörelseplattform av automatisk bromsning efter kollision
Examensarbete inom Styrning och mekatronik

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SAMMANFATTNING

Målet med detta examenarbete är att utveckla en testmetod och tillämpa den på en ny säkerhetsfunktion som heter Post Impact Braking (PIB) och att göra detta på olika fordonssimulatorplattformar.

Målet med funktionen är att undvika fler skadliga händelser efter den första krocken i en olycka. Funktionen innebär att bilen börjar bromsa så snabbt som möjligt för att undvika efterföljande kollisioner.

PIB-funktionen testades i flera typer av olyckor i Chalmers simulator S2 för att förstå och kvantifiera hur en förare kan reagera under och efter första krocken, och också hur effektiv denna funktion kan vara. Simulators huvudsakliga fördel är att man inte behöver någon simuleringsmodell av föraren.

Slutsatsen är att PIB funktionen är fördelaktig i de flesta av situationerna, kombinerad med ABS-ingrepp.

Nyckelord: PIB, Chalmers simulator s2, multipla krockar, säkerhet

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Preface

This study was carried out for the Division of Vehicle Dynamics at Chalmers University of Technology and the Brake & Vehicle Dynamics Functions' department at Volvo Car Corporation by two students from the Master program "Systems, Control and Mechatronics" during spring and summer 2012.

The theoretical parts and the model development parts were carried out in the Vehicle dynamics division in the Applied mechanics department while the experiments and the upgrades on the simulator were done in the Vehicle dynamics lab.

The present work is based on previous studies made by our supervisor Derong Yang from Chalmers University at the Applied Mechanics department which we would like to thank for her precious help.

We also would like to thank our supervisor Bengt Jacobson for his endless help and his priceless advices which guided us throughout this thesis.

The thesis work was also supervised and guided by our two coordinators at Volvo Car Corp. Karin Meinhardt Hallgren and Maria Stranne which were really helpful throughout this project by providing precious resources from Volvo Car Corp.

Special thanks to Bruno Augusto and Josef Nilsson which were able to unlock us in many situations and to find smart solutions to tricky problems.

1 Introduction

This chapter describes the environment in which the project was carried out, the literature study done before and also the resources used.

1.1 Background

According to different statistical studies (CCIS, GIDAS, NASS-CDS…) about 30% of the passenger car accidents are multiple event accidents (which involve more than one impact, called MEA).

Two types of systems are defined in order to avoid or reduce the effects of car accidents. Active safety systems aim at avoiding accident (ABS, ESC…) while passive safety systems aim at reducing the severity of the accident (Airbags…) usually after a first collision.

The Post Impact Braking function is a passive safety system which aims to reduce the severity of an occurring accident by stopping the car after the detection of a first impact or at least by reducing the car's speed even if the driver became unable to react.

1.2 Master thesis goal

The thesis work aims at developing methods to evaluate a version of the PIB functions, but it also aims at applying these methods on the function to evaluate its efficiency. It is a pre-requisite that a Motion Platform Simulator should be used in this thesis. A simulator allows us to avoid a driver model which wouldn't be as reliable as a real driver, and a motion platform simulator offers much more realistic effects during impacts. In this way drivers' reactions can be understood. A set of different experiments will be derived in order to evaluate this function in different emergency situations. Accurate methods will then be derived to analyse this set of experiments in order to evaluate the efficiency of the PIB function.

1.3 Literature Review

1.3.1 Vehicle Stability Control for Roadside Departure Incidents by Steering Wheel Torque Superposition (Benito & Nilsson, 2006)

This master thesis project was made in Chalmers at 2006. The aim was to investigate the suitability of a system based on active superposition of torque on the steering wheel using the electric power steering in order to help the driver to keep control of the car during traffic accidents. Part of the project was to develop the model compatible with Chalmers University of Technology driving simulator, which is used in our thesis.

1.3.2 Methods for Verification of Post-Impact Control including Driver Interaction (Beltran & Song, 2011)

This thesis project was focused on choosing the method of verification a safety function called Post-Impact Control. The main destabilization mechanisms were studied and graded, with analytical and numerical methods. Verification of PIC using motion platform simulator was suggested at the end of the thesis.

1.3.3 Post-Impact Vehicle Path Control in Multiple Event Accidents (Yang, 2011)

The main target of this project was to develop Vehicle Post-Impact Control strategies in order to reduce the possibility of secondary events. To make a deep analysis of the car accident, a database was investigated and different post-impact control strategies were suggested.

1.3.4 Post impact braking functions on the market

General material found, without confirmed availability on series produced car:

Secondary Collision Mitigation by Bosch (23 of February 2012):

http://www.youtube.com/watch?v=nmt0Zq0ZqxQ

Volkswagen multi-collision brake (14 of February 2012):

http://www.youtube.com/watch?v=xwmzZovjSLg

1.4 Simulator

The overall architecture of the simulator is shown in Figure 1.1. The motion platform is controlled by four computers. A computer called the “Kernel” is responsible for running a “scenario” and takes care of all the communications and interactions. The car model (developed in Simulink) is sent to a real time computer (NI XPI 1042Q) which runs it and sends information about the car states to the Kernel (car’s positions, speeds, accelerations…). After reception, the Kernel sends the car speeds and engine speed to another computer responsible for the graphical environment and sound. It also sends commands to the motion platform in order to simulate the car’s accelerations. Another computer is used for backups and internet connections.

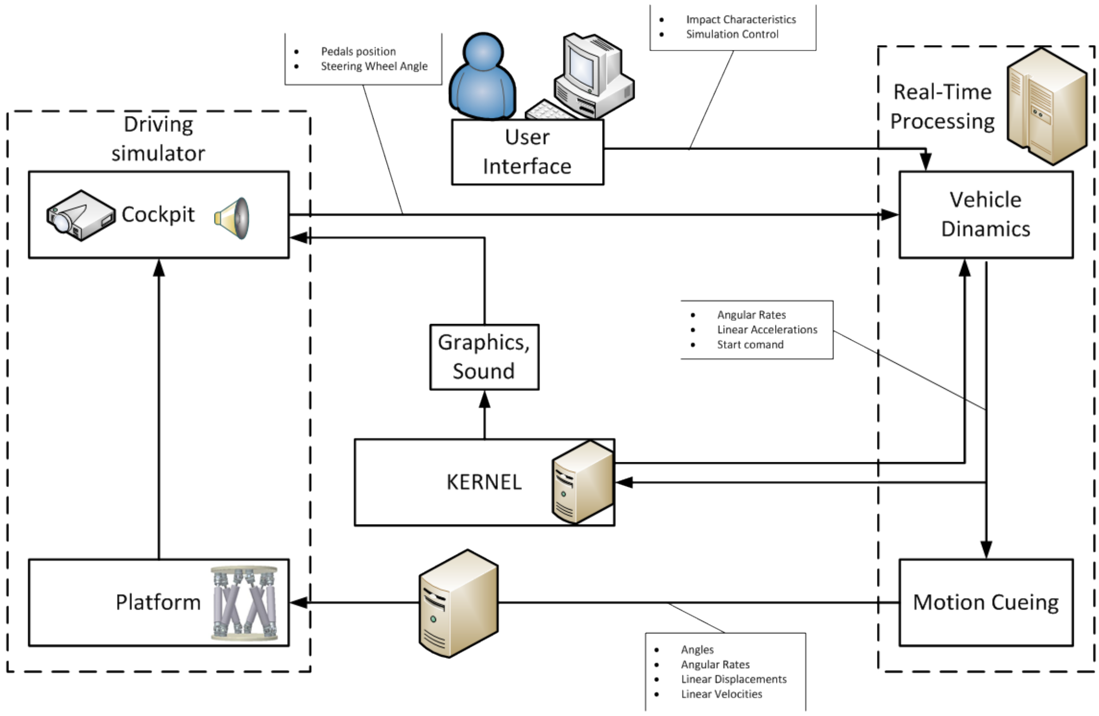

Figure 1.1 Simulator architecture

Detailed description of the driving simulator can be found in Chapter 3.

Figure 1.2Chalmers S2 Simulator

2 Vehicle Model

2.1 Description of the SUV car model and its limits

The model used in this thesis is the SUV car model derived and verified in (Benito & Nilsson, 2006) with veDYNA. It is implemented in Matlab/Simulink and exists in two variations – online and offline. Online model can be connected to the simulator and run in real-time. Offline model is made for research and study purposes and can be used on any computer. Nevertheless the inputs to the model have different sources (for online this is real signals from driver through steering wheel and pedals and for offline model these inputs are simulated), the model dynamics are the same.

The SUV car model is made of six sub-blocks, which model the steering dynamics, the bakes, the powertrain, the wheels, the suspension and the chassis. There is also additional block that basically defines which active systems (ABS, ESC, PIB, etc.) will be used during the simulation.

The most important and complex sub-block is the tyre model which is based on a widely used model called TMEasy. This model is using the magic formula to describe the contact between the road and tires.

The ABS system is a simple PID that controls the longitudinal slip around a desired reference value. Its efficiency was verified and it appears to be enough here. In this thesis the PID coefficients were tuned in order to match as much as possible to some existing cases.

2.2 Implementation of an impact in the model

Some calculation channels in the chassis sub-model had been enhanced to describe an impact in the car:

- The pitch calculation part
- The roll calculation part
- The yaw calculation part
- Velocity calculation part

An impact is defined by its amplitude in kN, angle from the longitudinal axis and its positions in the car body coordinates. As you can see in Figure 2.1 impact position is set with respect to the center of gravity, s.t. x positive is towards the front part of the car and y positive is a left hand side. Positive z is in upward direction.

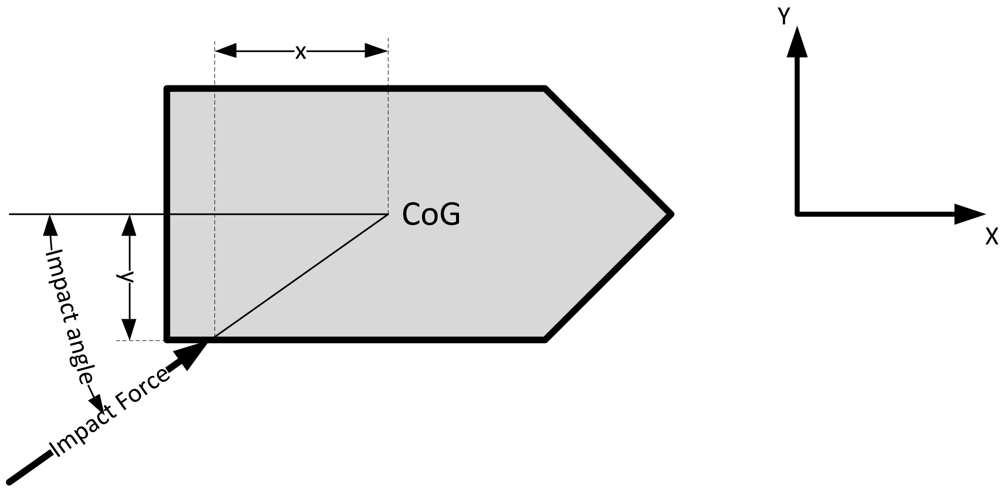

Figure 2.1 Impact definition

All the parameters, such as the position, angle and amplitude of the impact are tunable in real-time through the UI – NI VeriStand Workspace.

2.3 Description of the PIB function (PUBLIC)

After a collision which induces an acceleration higher than a certain threshold, the PIB function is triggered and decelerates the car to zero speed state and holds it stationary.

This function is supposed to brake the car after detecting an impact and forbid the driver to accelerate. The characteristic of this function are listed below:

- Performs a braking with a certain deceleration
- Can be overridden if the driver is pressing very hard the acceleration pedal only. Then the car would stop braking, but accelerating is forbidden.

The aim of such requirements is to have a system which is able to brake and stop the car when the driver is not able to do so. Concerning the steering, the driver is of course able to steer to avoid any obstacle.

2.4 Description of the PIB function (CONFIDENTIAL)

2.5 Implementation of the PIB function (PUBLIC)

The PIB block is located in Vehicle Control sub-block. It intersects the *Acceleration* and *Braking pedal* signals and operates with them in order to reach the desired functionality.

The PIB function block has 7 inputs:

- V_x the longitudinal speed of the vehicle in the body frame
- V_y the lateral speed of the vehicle in the body frame
- A_x the longitudinal acceleration in the body frame
- The *Accelerator pedal* position [0 – 1]
- *Brake pedal* position [0 – 1]
- The *Impact force* in [N]
- A Boolean value which decide whether or not to allow PIB function

The two outputs of this block are the *Brake* and *Accelerator positions*.

Appendix A.1 shows the Simulink model of the PIB block.

2.5.1 Impact detection sub-function

First of all, an impact has to be detected in order to trigger the function, but also the type of impact has to be identified, namely lateral, side or front impact types.

Two ways of detection were developed in this project. The first mode is based on the variation of speed of the car during a certain amount of time: ΔV [kph] over Δt [ms]. The second impact detection mode is simply based on the impact force input – basically the simulation of the Boolean command from Airbag system that impact occurred.

The second method was chosen.

The type of impact identification in this case, is based on the angle of the impact.

2.5.2 Decision sub-block

Even if an impact is detected, a decision about whether or not the PIB function has to be triggered must be made.

The decision depends on many parameters like the car's speed or the non-overriding case in which the decision of triggering will be negative.

So the PIB decision will be positive only when all four statements are true:

- PIB function is allowed (only used for testing in our thesis)
- Impact happened
- $V_x \neq 0$ for more than a certain time
- It is not overridden

The Simulink block of this part can be found in appendix A.2.

2.5.3 PIB sub-block

This block controls the *Acceleration* and *Braking pedal* positions based on the Decision block and Overriding block.

The PIB function should be able to decelerate the car with certain acceleration.

When the decision of triggering the PIB function is made, the PIB sub-block brakes the car using the *Brake pedal*.

The accelerator pedal is disabled until the car is totally stopped during a certain amount of time.

2.6 Implementation of the PIB function (CONFIDENTIAL)

3 Motion platform control and motion cueing

3.1 Hexapod and cockpit

The platform is an electrically powered six degree of freedom hexapod. It is a self-contained motion system with power system, servo controls, safety system and so on.

Motion mechanics is shown in Figure 3.1. The motion is accomplished using six identical electro-mechanic actuators. Controlling the actuators, six degrees of motion can be got:

- Pitch – rotation forward and aft (around Y axes). Positive is nose up.
- Roll – rotation left and right (around X axes). Positive when left side up.
- Yaw – rotation clockwise and counterclockwise (around Z axes). Positive is clockwise if viewed from top.
- Heave – vertical displacement. Positive is down.
- Surge – longitudinal displacement. Positive is forward.
- Lateral – lateral displacement. Positive is right.

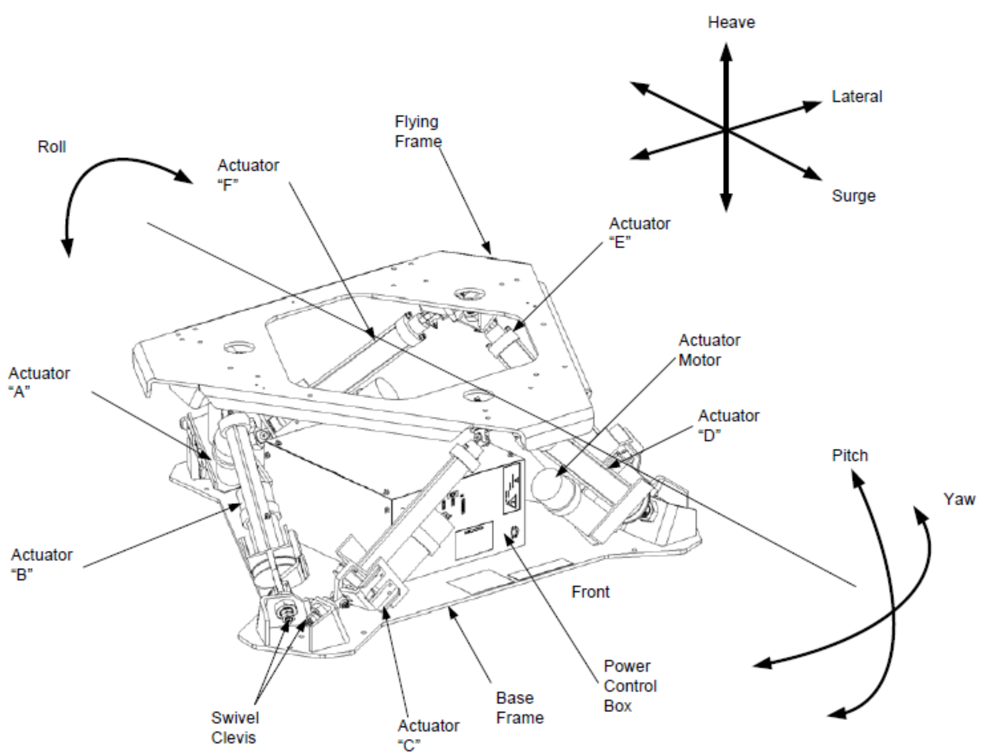

Figure 3.1 Simulator motion system.

The cockpit is an aluminum frame with the part of Volvo V40 car body (approximately the quarter of the car with driver sit, control panel and necessary electronics), projector screen and sound system. It is mounted on the flying platform frame. Since the graphic is provided by the projector, whole cockpit is covered in order to protect it from light.

3.2 Motion cueing

The platform is controlled by an algorithm which converts the output of the car model (car's linear accelerations and rotational speeds) into commands (linear and angular displacements) to the motion platform. The control strategy used is an MPC or model predictive control based on a simplified linear version of the real vehicle model called bicycle model which is a car model with one front and one rear wheel. The choice of this control strategy was made to overcome the fact that there are multiple ways to simulate any acceleration, like the gravity or the centrifugal force. Thus, for each acceleration to be simulated all the possibilities are taken into account and the optimal one is selected, i.e. the one which will let more freedom afterward.

In order to be able to simulate all the driving conditions with motion on the platform a dynamic factor controls the output of the motion cueing. In other words, during driving in normal condition without impact, the car model gives accelerations which will be converted to commands to the motion platforms. Since the dynamic of the car is not very aggressive in those cases, the commands sent to the platform will be far below the safety limits. But when an input is triggered, huge accelerations are generated by the car model and converted into huge signal commands to the motion platform. Those signals can easily be out of the hardware safety limits and seriously damage the hardware.

The chosen solution to cope with this issue was to use a dynamic scaling factor right on the output of the motion cueing block, in order to saturate any out-bounded command and also to scale the commands to keep a linear behavior during all the situations. The scaling in this part of the project is very important since during a relatively strong impact some of the motion cueing variables will reach the safety limits and if only the saturation will be implemented there will be a loss of important information. Thus this scaling factor will be high (=1) during normal driving condition to make the driver "feel the road", but as soon as a high amplitude impact is triggered, the commands to platform are out of limits and automatically scaled down to avoid saturation. Detailed description can be found on chapter 3.3.2.

This trade-off makes possible to simulate both high amplitude impacts and realistic driving sensations, keeping the platform safe.

3.3 Simulator upgrades

Some general upgrades were made to the Chalmers S2 simulator during this project like an additional safety system controlling all the inputs to the motion platform and a dynamic torque added to the steering wheel. Additional upgrades related to the impact and PIB function parts of this project were made in order to make the experiments more realistic to the test driver.

3.3.1 Safety systems

As seen in the previous chapter, an algorithm was made in order to keep all the commands to the motion platform at most 70% below the hardware safety limits. A safety block was added at the output of the motion cueing insuring that all the limits are respected and redundancies were made for each variable, for their first time derivative and second time derivative.

An additional safety measure was added in the scenario while controlling all the commands going to the motion platform. If any command reaches a safety limit, the scenario is automatically stopped and the platform goes safely to its parking position.

3.3.2 Scaling

Along with safety system, some functional improvements were made. The purpose of the platform is to reproduce the motion of the real car during normal driving or the car crashes. Obviously these two driving conditions have different scales of accelerations, forces and so on, and obviously the simulator cannot mimic any of these regimes to give the same feelings as it would be in real life situation. So certain parameters should be scaled down.

In order to have a smooth driving feeling, the outputs of the car model are scaled by a factor of 0.3 all the time. This factor makes sure that the platform generates smooth accelerations and avoids any jerks and out bounded accelerations during normal driving condition.

However, during the impact some of the parameters (even though they are scaled down with 0.3) might exceed the simulator's capabilities. Usual saturation of these parameters would cause information loss, so an additional scaling mechanism which is activated during the impact was added. During the usual behavior this scaling factor is equal to 1 (same one for all of the parameters), so the signals are not changed. However, as soon as the value of any of the parameter approaches its boundary, the scaling factor starts gradually decreasing, scaling down all the other parameters at the same time. Since all of the parameters are scaled down in the same time, the general behavior remains the same. Slow change of the scaling factor was made in order to avoid infinitely fast change of any of the parameter, which might damage the hardware if the simulator tries to follow such change. The rate of change of the scaling factor is determined by the rate of change of the value which caused the scaling. If multiple parameters reaches their limits, for each of them the scaling factor is calculated and the smallest one is been chosen. The example of such behavior is shown in Figure 3.2.

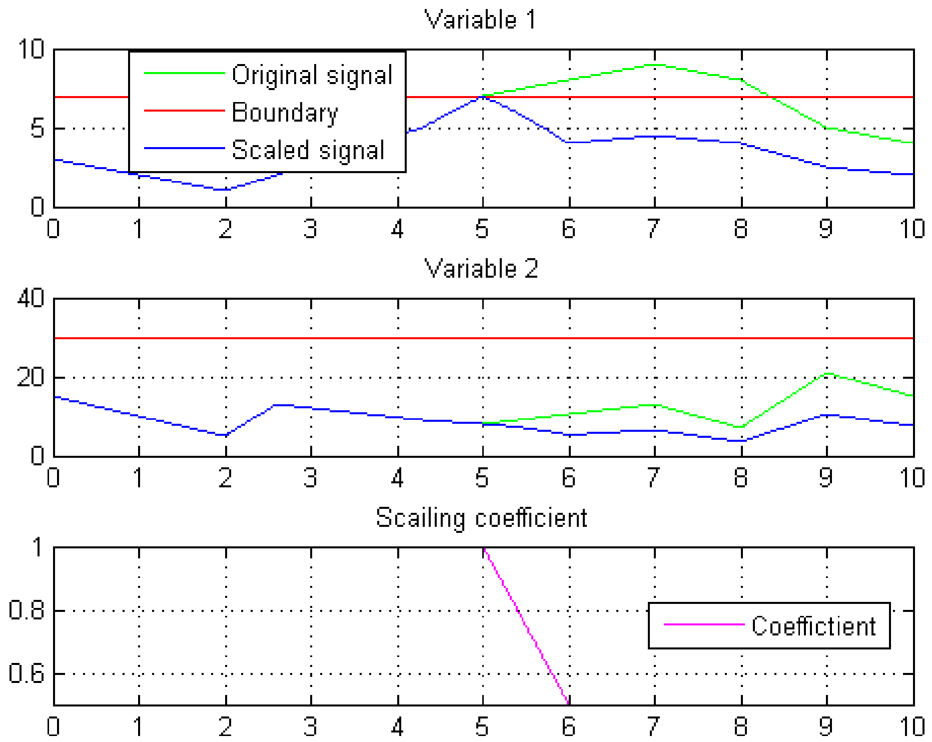

Figure 3.2 Example of motion cueing scaling mechanism. When on 5 seconds mark Variable 1 (which is any of variables) reaches the limit, coefficient value decreases, so all the variables (here only 2 are shown, but there might be any number of them) scales down as well.

3.3.3 Sound improvements

Extra sounds were added in order to represent front, rear and side collisions during the experiments. A sound was also added when the PIB function is acting on the systems. This sound has been removed during experiments in order to not inform the test driver if the PIB function is acting or not. However this sound was quite useful to verify that the function is acting at the good moment and ends at the proper time.

3.3.4 Steering torque control strategy

The torque in the steering wheel is generated by a servo controlled by a device generating a voltage between -5 and +5V. A voltage of -5V will generate a torque enough strong to turn the steering wheel counter clockwise and of course a voltage of +5V will create a torque that will turn the steering wheel clockwise. When 0V or no voltage is applied on the servo, no torques are generated thus the steering wheel will not rotate. However, the servo will try to keep the current position making any manual rotation of the steering wheel very difficult.

In order to cope with this issue a controller was added in the car model reading the variation of angle of the steering wheel (taking new position as a new reference command) and generating a torque helping the test driver to turn the steering wheel. This steering wheel controller called steering assist is implemented directly in the car model and reads the variation of the steering wheel angle to guess the driver's wishes. If the steering wheel is turning clockwise, then the steering assist will generate a clockwise torque in order to help the test driver to turn. This controller could be seen as unstable from a control point of view, but the frictions make it actually stable. Frictions between the steering wheel and the rest of the dash board generate a torque that increases with the rotational speed.

The SUV car model used in this thesis already has a self-aligning torque sub modeled and ready to be used. This last torque is added to the steering assist torque and converted with empiric coefficients into a voltage before being sent to the servo.

In this project, the self-aligning torque is very important especially at high speed and when the car has a high yaw rate after an impact. Indeed, in these situations very high torques are generated and affects the driver response.

4 Test cases and clinics

For this set of experiments four cases were chosen from GIDAS database. These impact cases are of the most common cases according to GIDAS database. Moreover they induce a temporary loss of control of the car. Each of them will be tested with different safety system combinations and with different driver behaviours.

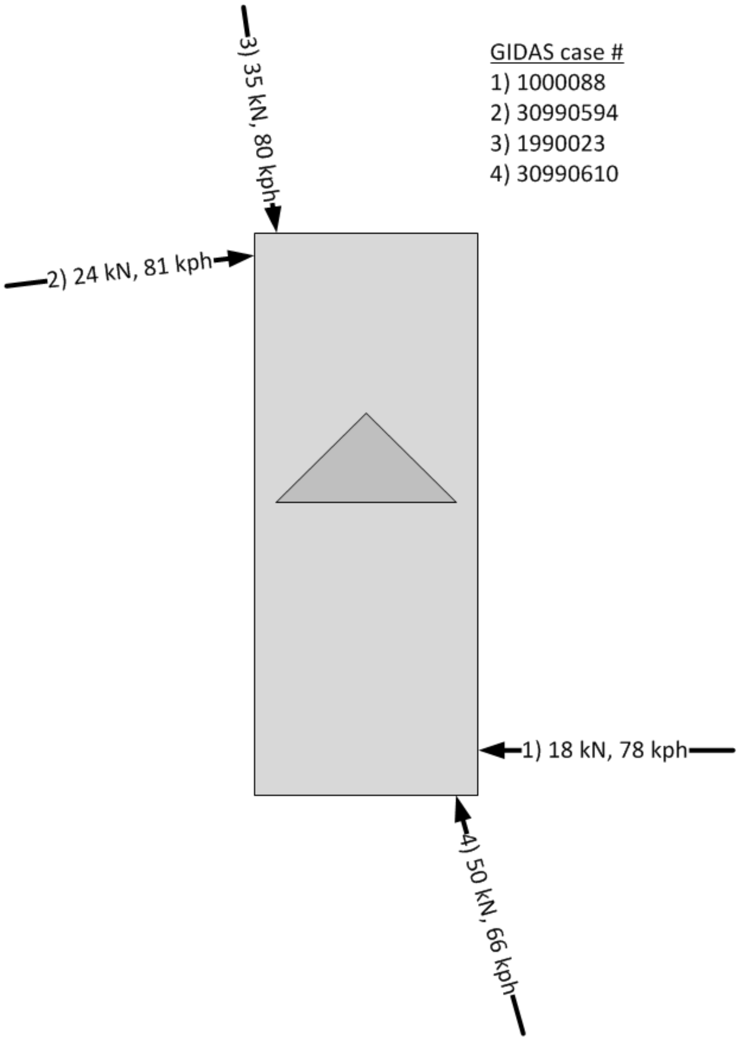

Figure 4.1 Impact cases used in this study.

4.1 Methods to evaluate PIB efficiency

4.1.1 Unprepared driver test:

These tests are performed on people that are supposed to drive a car in a highway in normal driving condition until a sudden impact is triggered at a certain speed. The impact characteristics will be defined according to existing cases.

The test driver is unaware of the impact before it occurs in the experiment. Three experiments will be performed for each test driver: the first PIB on, the second with PIB off and the third one with PIB on. First two impacts are identical, but the third will be a “mirror reflection” (regarding impact angle) of the first one. It will give the data set which is comparable with the first impact, but the driver will have completely different impression, comparatively with first two cases. In this set of experiments the ABS is always active.

The real reason for this is to be able to observe the efficiency of the PIB function in an objective way. Indeed, during the first impact the driver is surprised by an unintended impact and takes time to react. His reaction time after the first impact would be logically longer than in the next experiment in which he or she will be expecting an impact and will be ready to react quickly. Thus it wouldn’t be honest to test the PIB function off and then on only.

The aim of the on/off/on configuration is to first show that the PIB function reacts faster than a forewarned driver to brake (two first cases). The second point of this configuration is to observe the differences between two cases where the driver is forewarned but one would be without PIB and the other with PIB function (two last cases).

4.1.2 Passive driver test:

The previous impact cases are taken and tested with PIB & ABS, PIB only, ABS only and no safety function. When the impact occurs the driver does not react in order to simulate the behavior of a passive driver.

This test is made in order to evaluate the efficiency of the PIB function when the driver collapsed because of the impact.

4.1.3 Prepared driver test:

One impact case is taken and tested with PIB & ABS, PIB only, ABS only and without safety function. The test driver has to stabilize the car, try to keep it on the road as much as possible and then stop it safely for each of the previous condition (PIB & ABS, ABS…). The driver is allowed to retry each condition as many times as he/she wants in order to reach his/her “optimal” driving reaction.

4.2 Parameters to evaluate PIB efficiency

The following parameters are taken in order to evaluate the efficiency of the PIB function and to measure the improvements/drawbacks brought by the function.

- Post impact longitudinal distance: distance the car traveled after the impact until it stops. This distance is taken parallel to the road.
- Post impact lateral distance: lateral distance the car traveled after the impact until it stops. This distance is perpendicular to the road.
- Perpendicular lane crossing speed: speed at which the car leaves the road after the impact. This speed is perpendicular to the road.
- Absolute lane crossing speed: absolute speed at which the car leaves the road after the impact.
- Post impact maximum yaw angle: maximum yaw angle the car did after the impact.

5 Results (PUBLIC)

In this section, the benefits of the PIB function (with and without ABS) are calculated in the three types of tests: unprepared driver test, prepared driver test and passive driver test.

Here the efficiency of the PIB function is expressed in terms of “benefits” by comparing a measure (e.g. for the post-impact braking distance) with PIB ON versus PIB OFF. A benefit is calculated as the difference of a result (when PIB is ON and when PIB is OFF) in percentage:

$$Benefit\ [\%] = \frac{Measure_{PIB\,OFF} - Measure_{PIB\,ON}}{Measure_{PIB\,OFF}} * 100$$

A set of parameters are chosen to describe these benefits:

- The lateral/longitudinal displacements of the car after the impact and until stabilization (zero speed).
- The speeds at which the car leaves the road (perpendicular and absolute).
    - o The perpendicular speed is a projection of the car’s speed expressed in a frame which is perpendicular to the road.
    - o The absolute speed is the true speed of the car.
- The maximum variation of yaw angle of the car after the impact and until stabilization.

This set of parameters was chosen as the most important from the passenger safety point of view. Higher displacement increases the possibility of secondary events (especially lateral), like collision with another cars or trees. The crossing speeds are crucial when the car leaves the road and has a high chance to collide with a barrier or another car. A high yaw angle makes the passenger vulnerable to a secondary impact.

Since the reaction of the unprepared drivers in our experiments represent the most common behavior, their data is taken as reference values, with which we compared ‘extremes’, like prepared (or professionals, whose reaction can be considered as optimal) and passive drivers (people who do not react because of the shock or loss of consciousness).

Before starting calculating benefits of the function in all the situation, let’s first understand how people react when an impact occurs.

5.1 Driver’s reaction analysis

Through the unprepared and prepared driver tests, the driver’s reaction will be analyzed when PIB is OFF. Different parameters will be considered:

- Driver's first reaction after the impact (steering, braking, releasing/pressing the accelerator pedal)

- Reaction time to steer after the impact

- Reaction time to brake after impact

- Reaction time to release/press the accelerator pedal after the impact

5.1.1 Unprepared driver's reaction

For this type of test, only the second ride without PIB will be considered. An impact case is experienced by three drivers. Thus, for each impact case, each reaction time will be averaged over the three drivers.

After analysis, it can easily be noticed that driver's first reaction after the impact consists on steering and/or releasing the accelerator pedal first and then braking one or two seconds later.

5.1.2 Prepared driver's reaction

In the prepared driver test, one driver is considered for each impact case: the professional driver Ulf for impact case 2 and 4, Mikael for impact case 1 and 3. Only rides without PIB will be considered here.

The same result is found here, driver's first reaction after the impact consists on steering and/or releasing the accelerator pedal first and then braking later.

5.2 Unprepared driver test:

Twelve kind people performed this test. Each of them did three rides: the first with PIB and ABS functions active, the second with ABS only and the third with active PIB and ABS again. Only the first and second ride will be compared here, since the idea behind the third ride was to "confirm" the first one.

In *Figure 5.1* you can see the example of the cars' paths for the first two rides. The picture shows the part of the trajectory from the impact moment to the final, stabilized state.

The three magenta lines show the boundaries of the road-lanes on one carriageway.

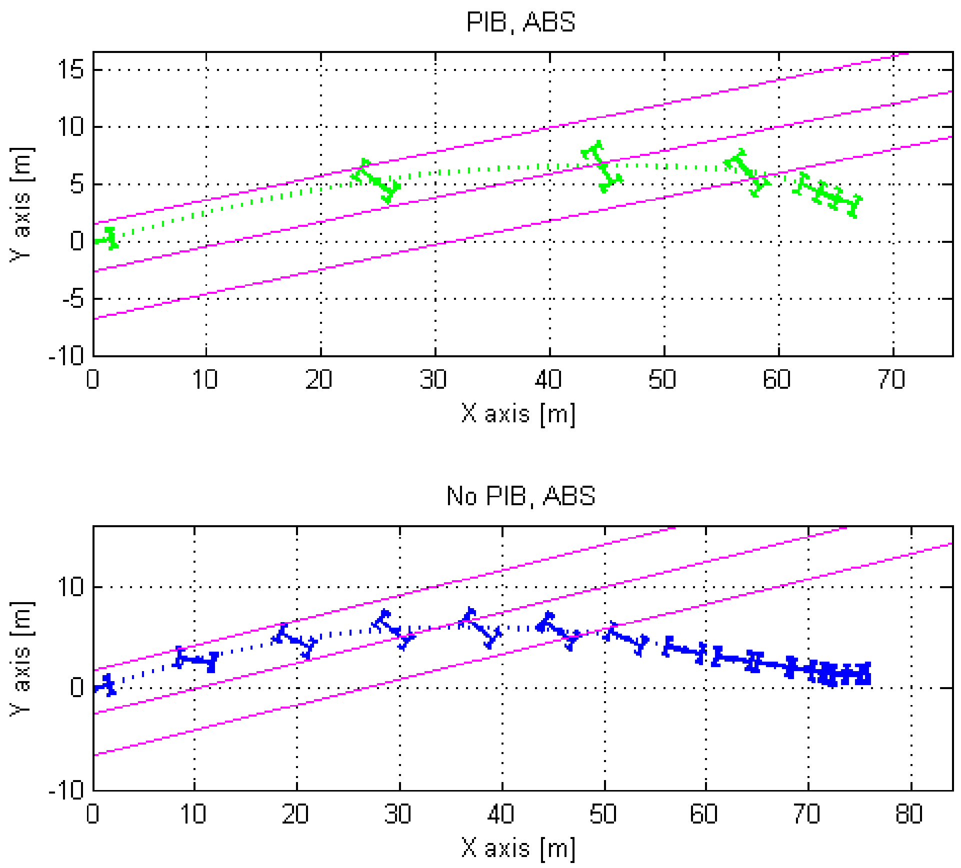

Figure 5.1 Example of the path (Impact case #1)

In this set of comparisons we are going to compare the influence of the PIB for unprepared drivers.

In the figures below, each green rectangle represents the average value of all the unprepared driver results over the four impact cases, for different safety systems combination. The red circles represent the average value of the prepared driver results over the four impact cases, while the blue crosses are the average value for the passive driver results.

5.2.1 The post-impact longitudinal distance

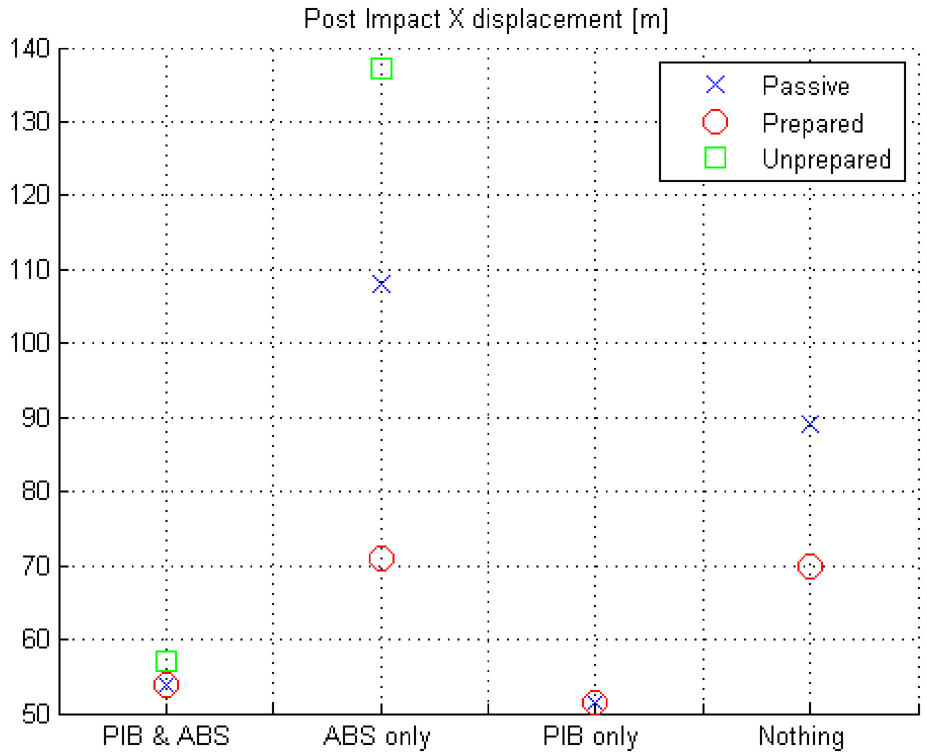

Figure 5.2 Comparison plot for X displacement for the impact case 1

As it can be seen in the figure above for the impact case 1, the longitudinal displacement is significantly reduced.

Over the four impact cases the longitudinal displacement is reduced when the PIB function is ON and ABS active.

This reduction is the result of the automatic braking applied by the PIB. This difference is emphasized by the fact that the unprepared driver's first reaction after the impact is to steer and then brake, which delay any braking intervention when the PIB is OFF.

5.2.2 The post-impact lateral distance

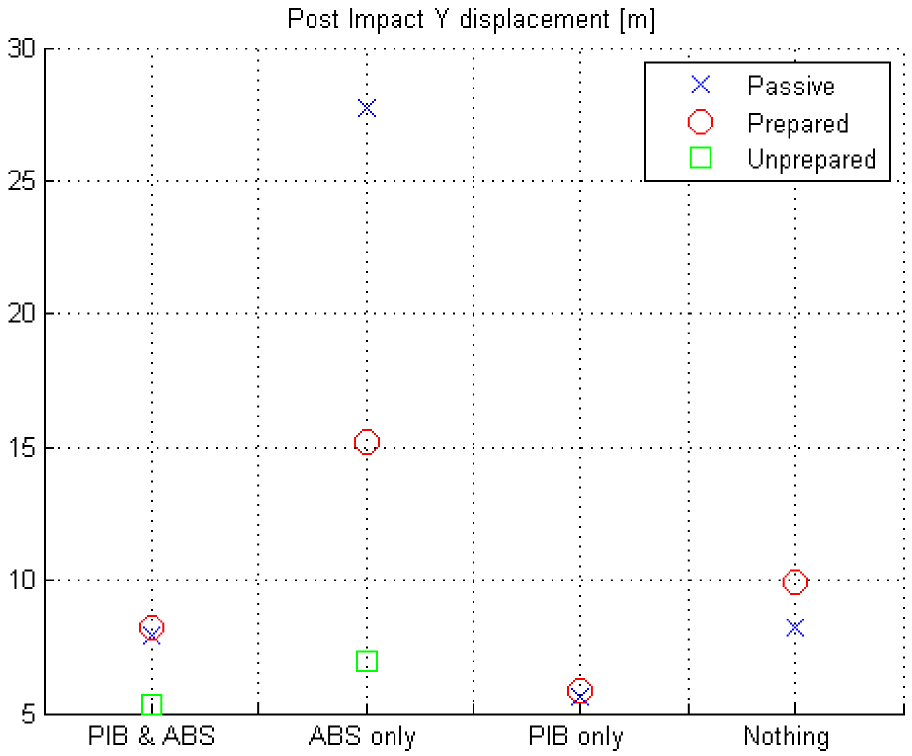

Figure 5.3 Comparison plot for Y displacement for the impact case 1

As seen above, the PIB function reduces the lateral displacement.

Over the four impact cases, the PIB function reduced the lateral displacement with ABS active. The reason is the same as before, the automatic braking reacts faster than an unprepared driver, and since after the impact the car is moving out of the road, this braking reduces the post-impact lateral displacement.

5.2.3 The perpendicular and absolute crossing speeds

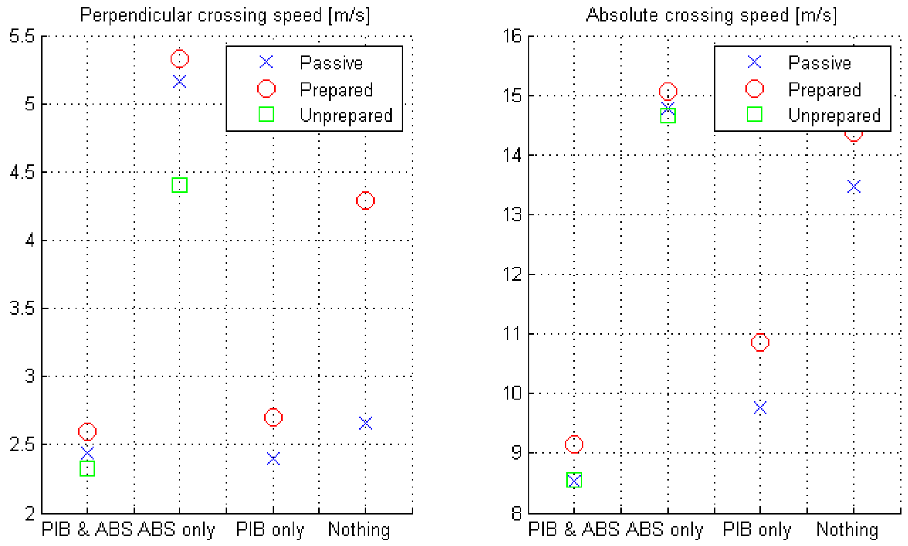

Figure 5.4 comparison plot for crossing speeds for the impact case 1

As seen above the PIB function reduces the perpendicular and absolute crossing speeds.

Over the four cases of impact, the PIB function reduced the perpendicular crossing speed and the absolute crossing speed when ABS is active.

This speed reduction can be explained by the fact that the automatic braking generated by the PIB function is faster to react or brake than an unprepared driver without PIB.

5.2.4 The post-impact yaw angle

As it can be seen on the plot below, the PIB function highly increases the yaw angle after the impact, when ABS is active.

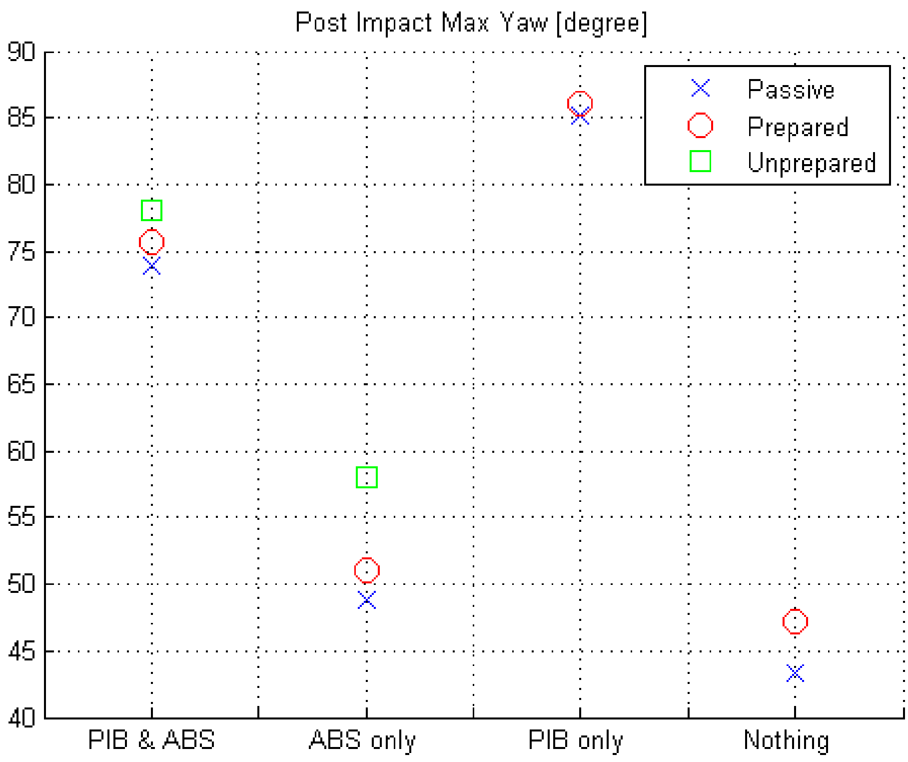

Figure 5.5 Comparison plot for the yaw angle for the impact case 1

As it can be seen on the plot above, the PIB function significantly increases the post-impact maximum yaw angle for the impact case 1. The same result is found for the other type of impact.

According to the results of this experiment, the PIB function increases the maximum yaw angle after the impact.

This effect is induced by the car's loss of grip with the road after the impact. The contact with the road is not recovered fast enough because of the PIB braking intervention. This loss of grip limits the steering and thus also the counter steering a driver would perform.

5.2.5 Results analysis

On the overall, it can easily be noticed that the PIB function reduces the post-impact longitudinal and lateral displacements the car traveled after the impact, and also the speeds at which the car leaves the road. However, the post-impact yaw angle is increased by the PIB's intervention.

5.3 Passive driver test:

During this set of experiments the driver does not react after the impact, simulating a driver that faints because of the accident. The results obtained here are compared with the unprepared driver test (our reference).

Two analyses are made here, since after the impact the ABS can be deactivated if any sensor is damaged. The first analysis is done with ABS active by comparing columns “PIB & ABS” with “ABS only” to see what benefit PIB can provide. The second analysis is made with ABS inactive and thus by comparing columns “PIB only” with “Nothing” (no safety systems at all).

5.3.1 Comparison of the post-impact longitudinal distance between the passive and the unprepared driver tests

As expected, the benefits on the post-impact longitudinal distance are increased by the PIB function in this test.

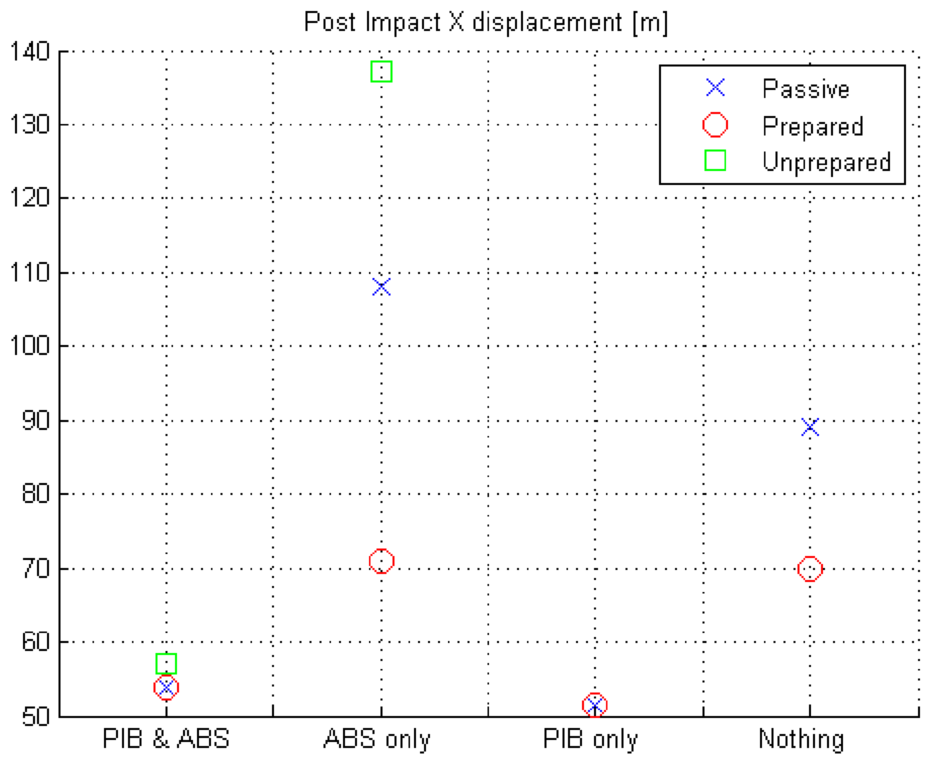

Figure 5.6 Comparison plot for X displacement for the impact case 1

First analysis: influence of PIB when ABS is active

As it can be seen on the plot above, the PIB function is more beneficial when the driver is passive.

This result is also true over the four impact cases.

When the driver is passive, the post-impact longitudinal displacement is very high without the PIB intervention, while this displacement will be quit short when the PIB is ON. This difference explains why the PIB function in such case is really beneficial.

Second analysis: influence of PIB when ABS is inactive

The PIB function is still beneficial even when ABS is deactivated since it reduces the post-impact longitudinal displacement over the four cases.

5.3.2 Comparison of the post-impact lateral distance between the passive and the unprepared driver tests

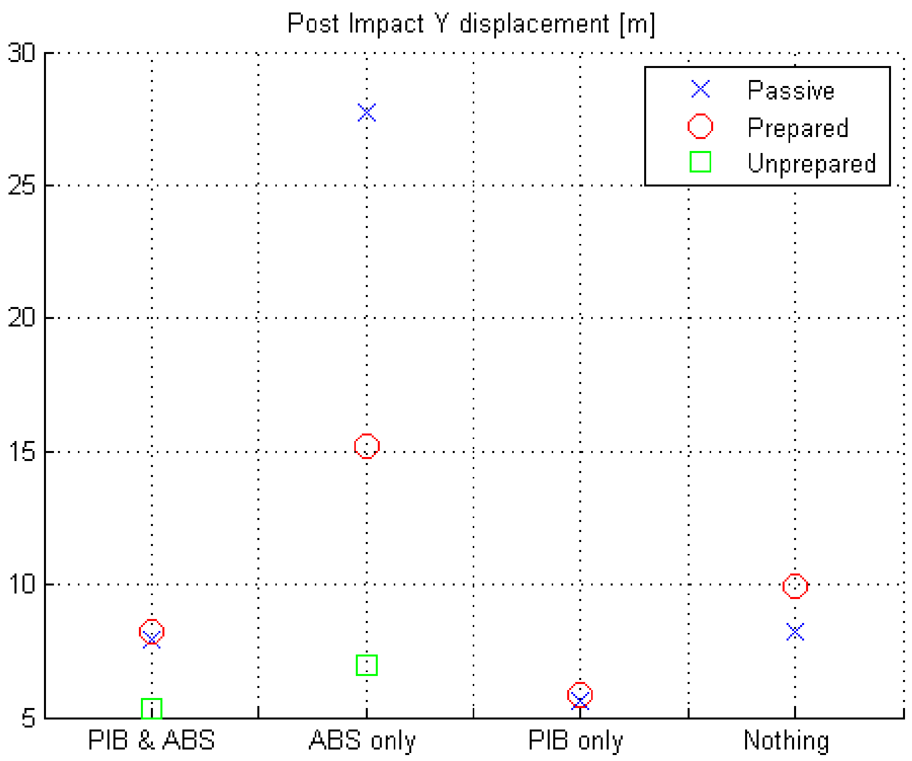

Figure 5.7 Comparison plot for the Y displacement for the impact case 1

First analysis: influence of PIB when ABS is active

According to *Figure 5.7*, the PIB shows more benefits for reducing the lateral displacement when the driver is passive than when the driver is unprepared.

And the previous statement is valid over the four impact cases, which is also due to the absence of braking for the passive driver.

Second analysis: influence of PIB when ABS is inactive

In this experiment the influence of ABS is also noticeable when we compare the column "PIB only" with "Nothing" (no safety systems). The PIB function without ABS gives a high benefit on the lateral displacement over the four impact cases.

With the PIB and without ABS the car loses the grip after the impact and the contact with the road is not easily recovered due to the full braking applied by the PIB. It results in a very high yaw rate and a small post-impact lateral displacement.

5.3.3 Comparison of the road leaving speeds between the passive and the unprepared driver tests

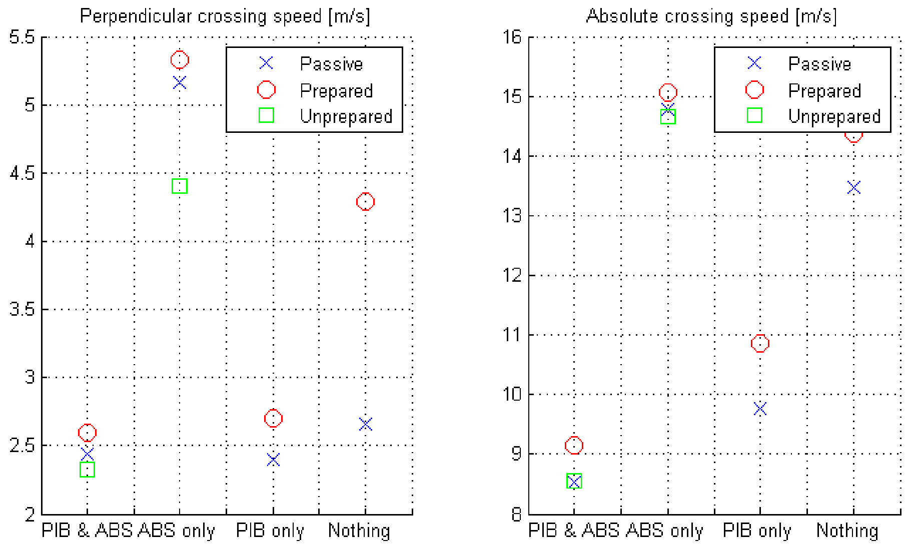

Figure 5.8 Comparison plot for the Crossing speeds for the impact case 1

First analysis: influence of PIB when ABS is active

On the plot above, it can be seen that the variation between the passive driver and the unprepared one is not significant regarding both crossing speeds.

By taking the average between the four types of impact we can see that the benefits given by the PIB function does not vary between a passive driver and an unprepared one regarding the lane crossing speeds.

Second analysis: influence of PIB when ABS is inactive

As seen before, the car's lateral displacement is smaller when the PIB function is ON and the ABS is inactive which makes the car leave the road later and thus with a lower speed than with no safety systems.

5.3.4 Comparison of the maximum yaw angle between the passive and the unprepared driver tests

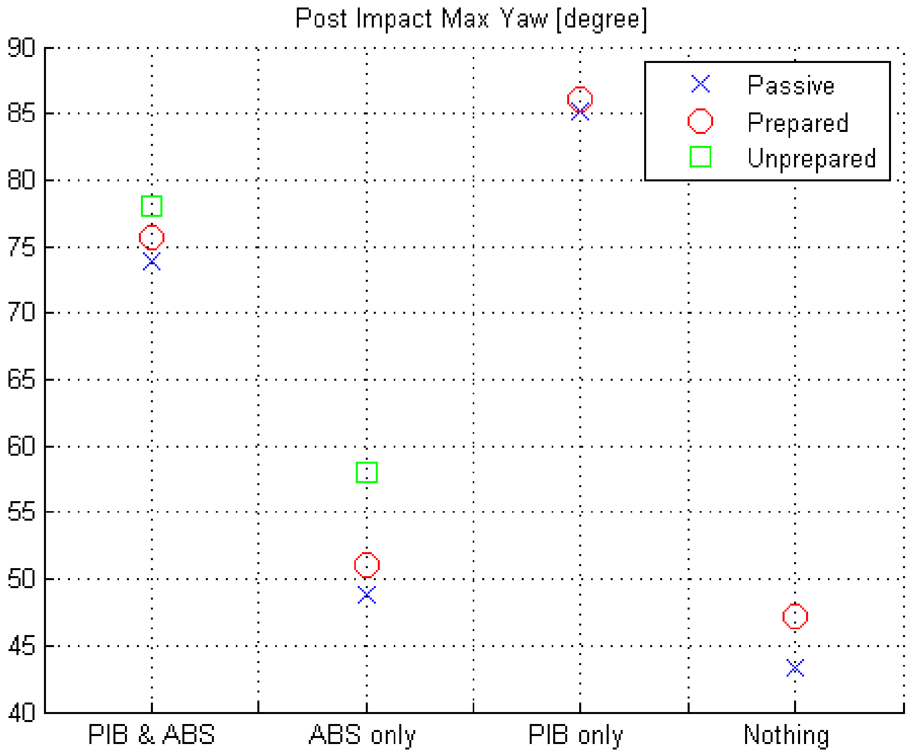

Figure 5.9 Comparison plot for the yaw angle for the impact case 1

First analysis: influence of PIB when ABS is active

As seen on the plot above, the PIB function is more disadvantageous for a passive driver than for a prepared one regarding the post-impact yaw angle in the case 1.

Since the passive driver does not control the car after the impact, the post-impact yaw cannot be reduced by counter steering which makes doesn't make the PIB more advantageous for a passive driver regarding yaw angle over the four impact cases.

Second analysis: influence of PIB when ABS is inactive

The PIB function in this case also significantly increases the post-impact yaw angle.

5.3.5 Results analysis:

The PIB function is much more beneficial when the driver is passive than when the driver is active (or unprepared) for reducing the post-impact longitudinal and lateral displacements.

However, we can see that the PIB function is equally efficient in reducing the crossing lane speeds for passive and active driver, which means that the driver’s steering response or possibilities are limited.

5.4 Prepared driver test:

During this test, the driver is aware of the impact, and knows when and how the impact is going to occur. The driver is supposed to stabilize the car, try to keep it on the road as much as possible and then stop it safely. The results obtained here are compared to the unprepared driver test.

In most of the cases, the prepared drivers tried to steer first to stabilize the car and then brake.

For this test professional test drivers from Volvo Car Corporation were invited. We would like to thank Ulf Lång and Mikael Riikonen for their participation in this experiment.

Here also two analyses are made. The first one is done with ABS active by comparing columns “PIB & ABS” with “ABS only” to see what benefit PIB can provide. The second is made with ABS inactive and thus by comparing columns “PIB only” with “Nothing” (no safety systems at all).

5.4.1 Comparison of the post-impact longitudinal distance between the prepared and the unprepared driver tests

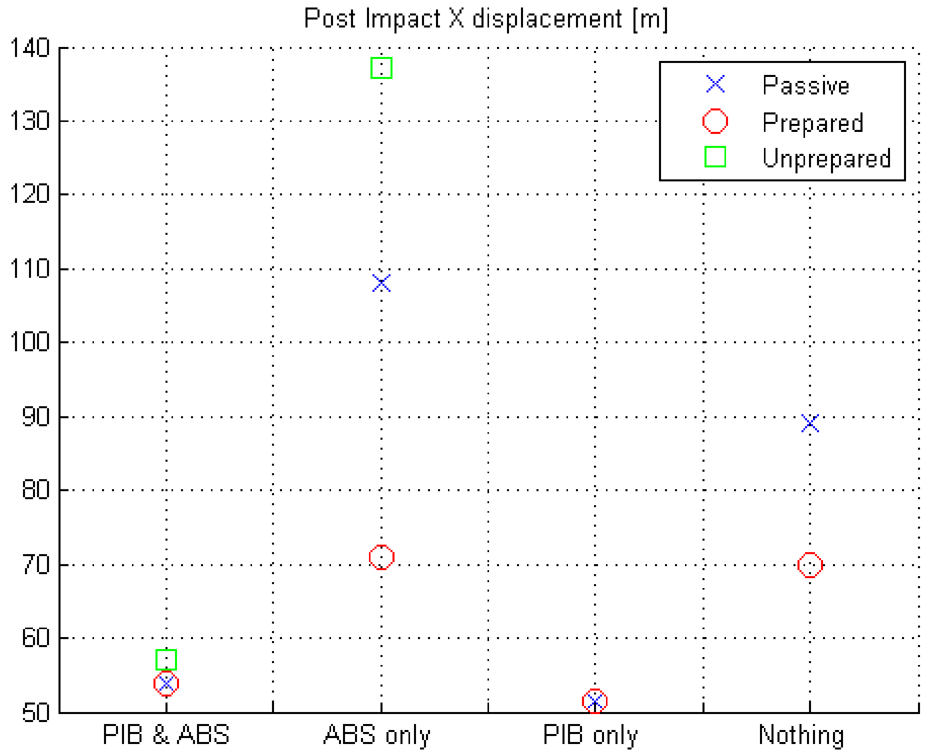

Figure 5.10 Comparison plot for X displacement for the impact case 1

First analysis: influence of PIB when ABS is active

According to the obtained results in *Figure 5.10*, the PIB function is more beneficial for an unprepared driver than for a prepared driver regarding the post-impact longitudinal displacement.

Taking the average over the four impact cases, the result remains the same.

Second analysis: influence of PIB when ABS is inactive

The PIB function even without ABS appears to be efficient by reducing the post-impact longitudinal displacement over the four cases.

5.4.2 Comparison of the post-impact lateral distance between the prepared and the unprepared driver tests

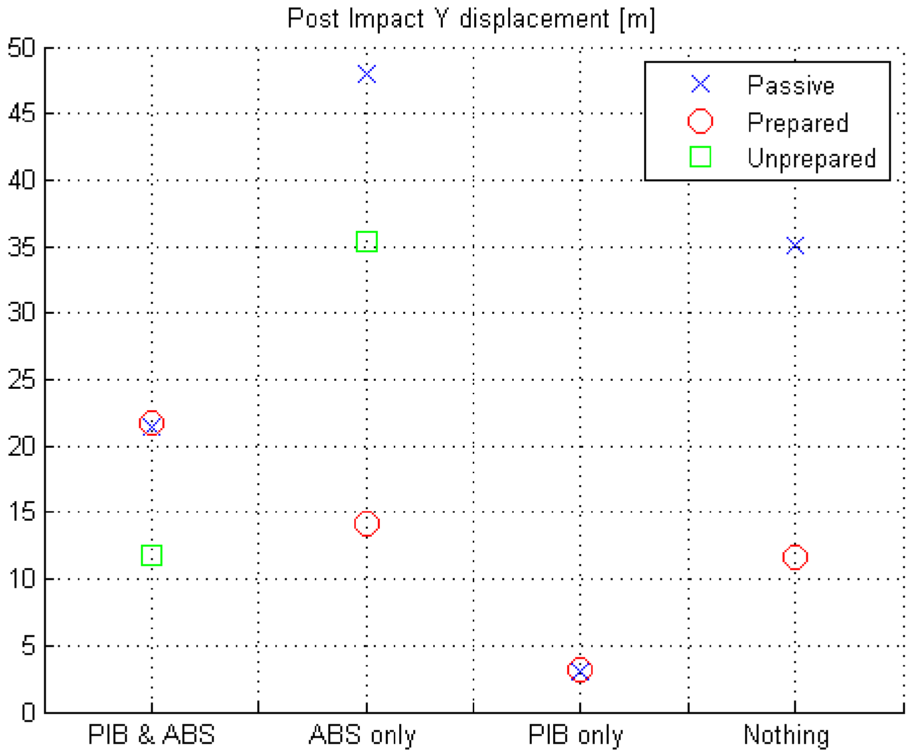

Figure 5.11 Comparison plot for Y displacement for the impact case 2

First analysis: influence of PIB when ABS is active

This experiment shows an interesting result: the PIB function for the prepared driver is disadvantageous while the unprepared driver gives benefits.

Over the four impact cases, the result is verified since the PIB function for the prepared driver not advantageous while for the unprepared driver it gives benefits.

By analyzing the plots for the steering wheel angle and the plots of the different paths we drew the following conclusion: the highest priority for the prepared (professional) drivers was to stay on the road and thus to reduce the lateral displacement. Which was quite successful without PIB, while with PIB the result was worse, and as a result the benefit is not positive. On the other hand, the unprepared drivers have different priorities regarding the safety criteria, which cause a smoother steering and a braking in the same time. On its turn this behavior causes a large difference in displacements between the case with and without PIB.

Second analysis: influence of PIB when ABS is inactive

ABS makes an important difference as well in this case. As mentioned before, the car with PIB and without ABS after the impact has worse grip with the road and starts sliding forward with a small lateral displacement.

5.4.3 Comparison of the road leaving speed between the prepared and the unprepared driver tests

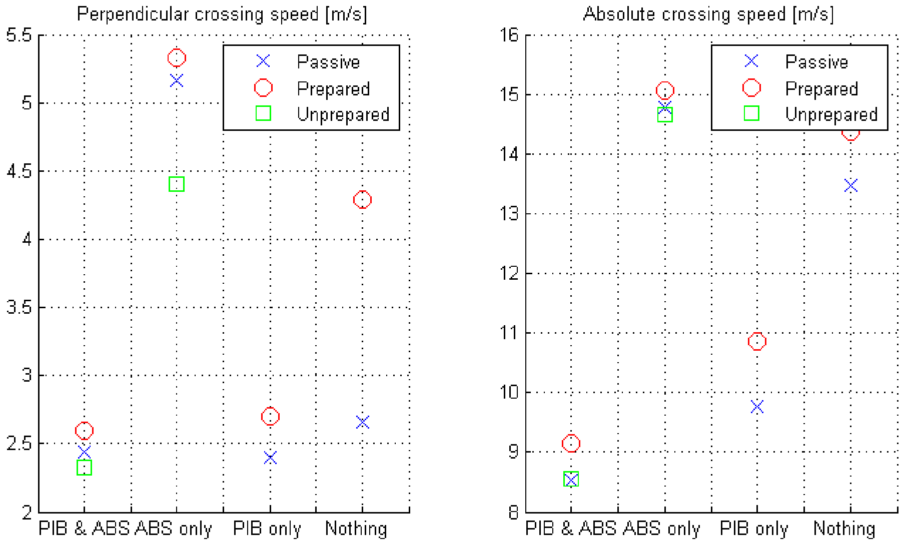

Figure 5.12 Comparison plot for the Crossing speeds for the impact case 1

First analysis: influence of PIB when ABS is active

As seen in figure above, the unprepared drivers feel more benefit from the PIB function than the prepared drivers regarding reducing lane crossing speeds.

This result is found over the four cases. This can easily be explained by the fact that the unprepared driver is surprised by the impact and takes more time to react.

Second analysis: influence of PIB when ABS is inactive

It can also be noticed in this case, that the PIB function without ABS is much more beneficial than without safety functions regarding reducing lane crossing speeds. The reason for this is the low lateral displacement (see Subchapter 5.3.2) when ABS is inactive which postpone the lane departure.

5.4.4 Comparison of the maximum yaw between the prepared and the unprepared driver tests

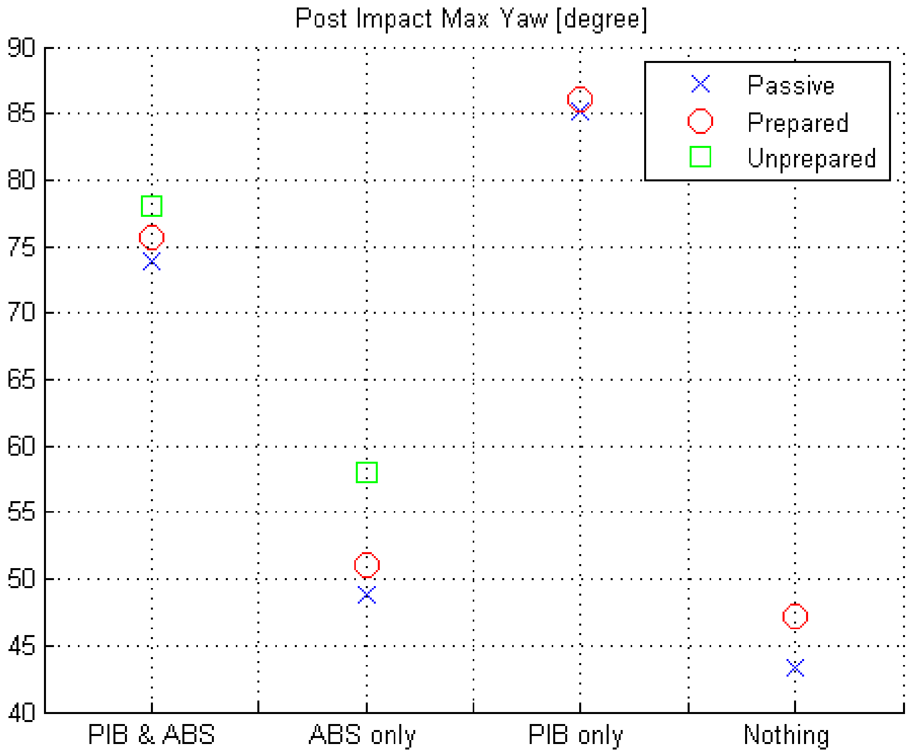

Figure 5.13 Comparison plot for the yaw angle for the impact case 1

First analysis: influence of PIB when ABS is active

The results plotted above show that the PIB function is not advantageous at all for a prepared driver when ABS is active regarding the post-impact yaw angle, meaning that without PIB the prepared driver is able to have a lower post-impact yaw angle.

Over the four impact cases, the results remain the same.

Second analysis: influence of PIB when ABS is inactive

By analyzing the efficiency of the PIB function here, we clearly see a that the PIB function increases the post-impact yaw angle due to worse grip with the road.

5.4.5 Results analysis:

By comparing the benefits of the PIB function between unprepared and prepared drivers we can see that unprepared drivers get more benefits from the PIB function.

The prepared or professional driver can control the car without PIB in a quite good way, while the unprepared driver can get lost because of the surprise (or shock in a real car crash) or just make mistakes due to a lack of skills. However, we should remember that in a real situation the driver is unprepared to react to an impact or is even passive. From this we can conclude that for most of the driver types the PIB function will be highly beneficial and desirable safety function.

6 Results (CONFIDENTIAL)

7 Conclusion (PUBLIC)

The Post-Impact Braking function appears to be efficient for reducing the longitudinal and lateral distances the car traveled after the impact, and also the speed at which the car is leaving the road when the driver is not prepared for an impact. The PIB function is even more efficient for these parameters when the driver is passive (simulating a driver that faints due to the impact).

When the driver is active and ready to react after the impact (prepared driver), the PIB function is still beneficial since it reduces the longitudinal displacement and the speed at which the car leaves the road.

Moreover, the PIB function in all the cases may cause a higher yaw rate and thus a higher post-impact yaw angle.

8 Conclusion (CONFIDENTIAL)

9 Evaluation of the PIB with a cost function and improvements proposition (CONFIDENTIAL)

10 Simulator comparison

The prepared driver test was performed in the VTI simulator with 8 different people and the results were compared with the prepared driver test done in Chalmers S2 simulator.

According to test drivers' comments the main difference between the two simulators is in the steering wheel. They noticed that the Chalmers simulator has a stiffer steering wheel and also a higher steering wheel feedback.

By comparing the two simulators for the road leaving speed (figure below), we can see that in VTI simulator these speeds are lower.

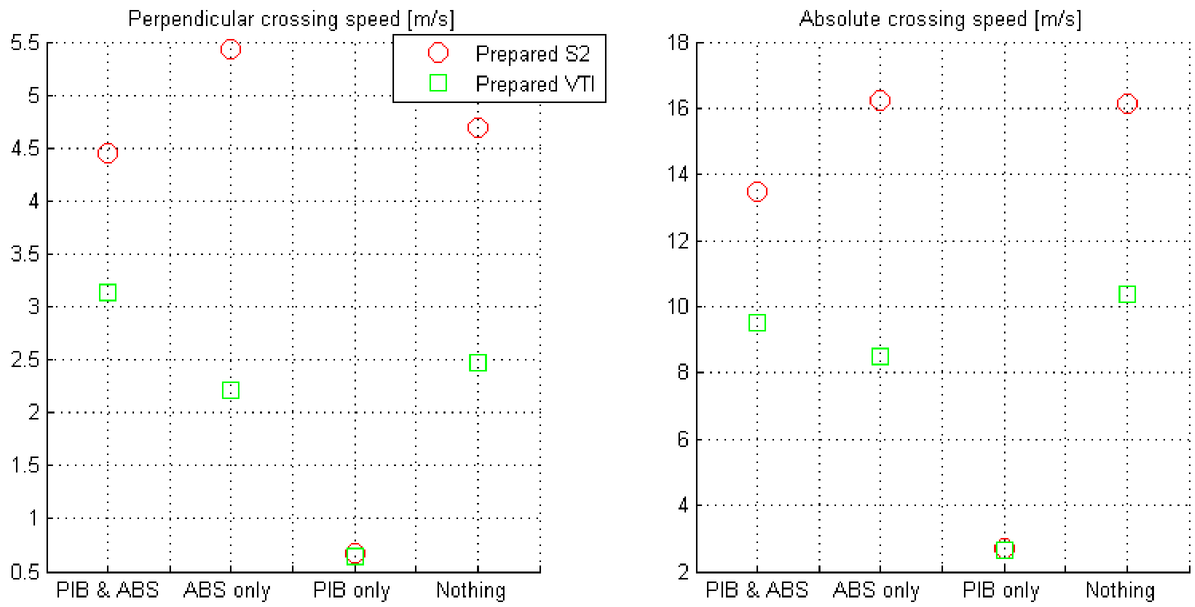

Figure 10.1 Road leaving speeds for VTI and S2 simulators

This difference is caused by the stiffness of the Chalmers S2 simulator's steering wheel which does not allow the driver to counter steer as much as in the VTI simulator. It can also be noticed that the behavior of the car concerning road leaving speeds when PIB function is ON and without ABS (column "PIB only" in *Figure 10.1*) does not depend on the steering reaction since these speeds are equal in both simulator.

As it can be seen in figure below, the post-impact lateral displacement in the VTI simulator is much smaller than in the S2 simulator which confirms again the effect of the steering wheel stiffness. We can also notice that in the case where PIB function is ON without ABS (column "PIB only") the lateral displacement is not influenced at all by the steering.

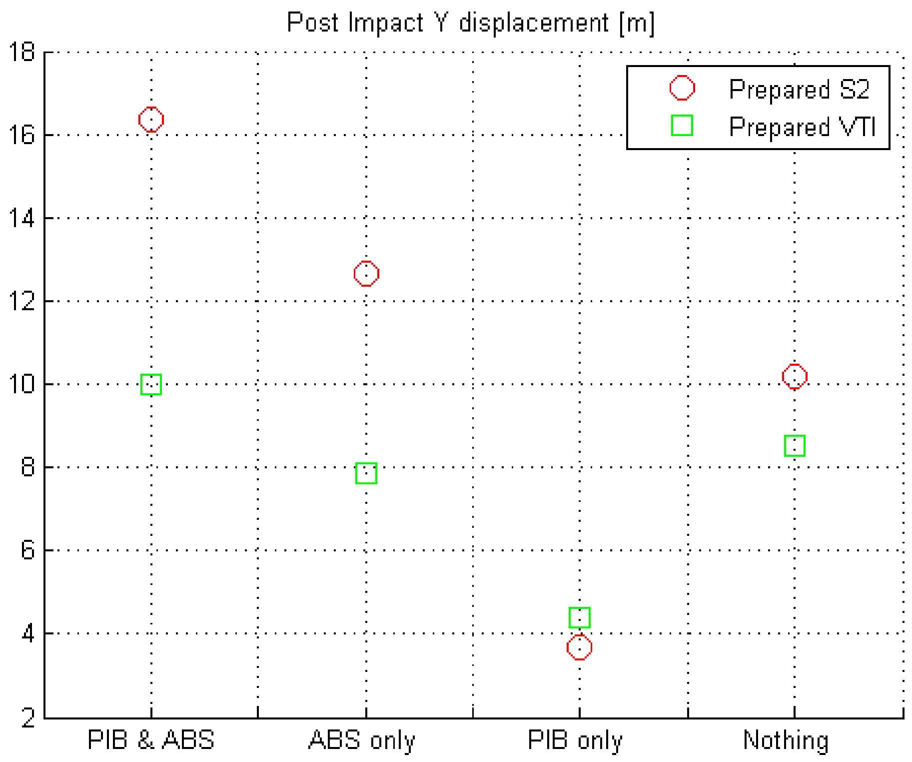

Figure 10.2 Post-impact lateral displacement for VTI and S2 simulators

Concerning the X displacement between the two simulators we can see that they are really close again in the case “PIB only”.

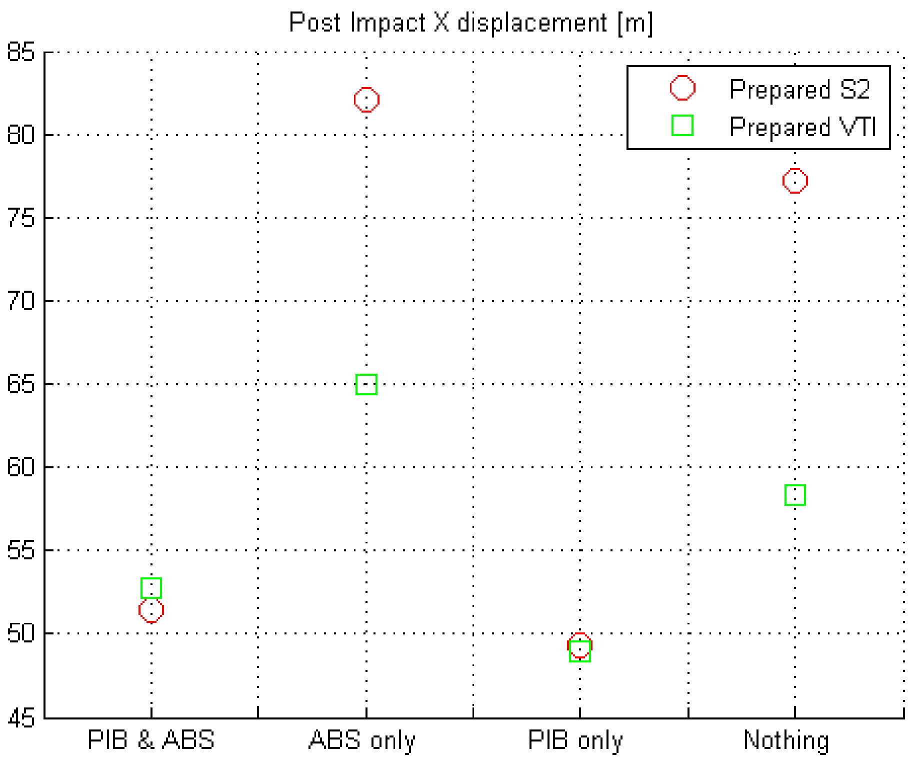

Figure 10.3 Post-impact longitudinal displacement for VTI and S2 simulators

In figure above, it can be seen that the VTI simulator the post-impact yaw angle is higher when ABS is deactivated probably due to the steering which is more “easy” to turn.

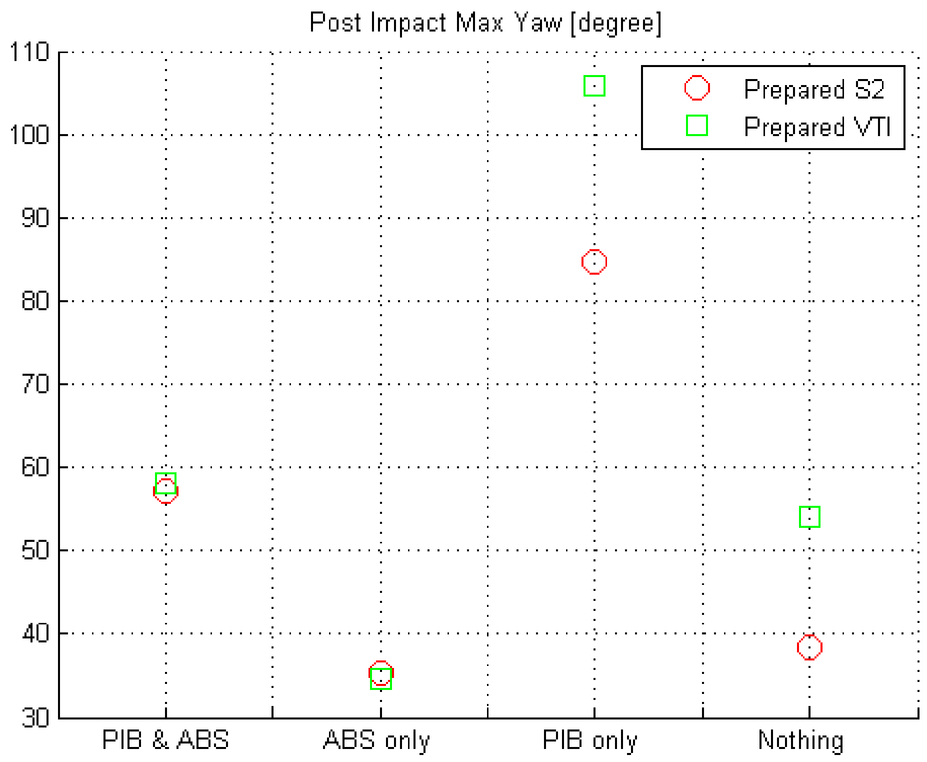

Figure 10.4 Post-impact yaw angle for VTI and S2 simulators

11 Summary and future work

11.1 Summary

Methods to evaluate the PIB functions have been developed based on a Motion Platform Simulator. Among these one can mention:

- Vehicle Model including PIB function used in the Motion platform simulator.
- Proposal of 1st impact types based on existing and recurrent cases.
- Proposal of clinics with unprepared, prepared and passive drivers.
- Proposal of methods to analyze results from clinics with unprepared, prepared and passive drivers.
- Five benefit measures were proposed: Post Impact Longitudinal Distance, Post Impact Lateral Distance, Post Impact Perpendicular Speed and Absolute speed and Post Impact Maximum Yaw Angle.
- The method enables test with same model in different 3 environments: off-line simulation, Chalmers S2 simulator and VTI IV simulator.

The most important results provided by these methods are listed below:

- When the driver is passive:
  - PIB function is totally efficient and relevant in all the cases with and without ABS.
- When the driver is unprepared or prepared face to an impact:
  - PIB function appears to be relevant for most of the evaluated parameters, in all the tested situations when ABS is active.

11.2 Summary (CONFIDENTIAL)

11.3 Future work

Possible improvements that can be done or should be done are listed below:

- Improve the motion cueing on the Chalmers S2 simulator (drifting problem)

  The drifting problem is a small uncertainty in motion cueing algorithm. This problem occurs when many strong impacts are triggered during a simulation, and the platform start to tilt without any reason, of course the simulation has to be aborted. But since in our project we do not need to trigger many impacts in a row, this problem can be considerate as not crucial.

- Steering feedback can be modeled and verified

  In our project the steering feedback is tuned to have realistic feeling, but certain coefficients are chosen empirically. In order to have better representation of car behavior a model for steering feedback can be developed.

- ABS function can be improved

  As mentioned before, ABS is a PID-control of longitudinal slip. Another approach might be used or existing control parameters can be adjusted.

- Slip calculations and tire forces on speed close to zero may be reconsidered (if necessary).

- The projector in the simulator should be replaced, since it gives a poor quality image.

- The sound program (C coded) can be improved and react on the car’s slip.

12 References

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13 Appendix A.1: PIB function (CONFIDENTIAL)

14 Appendix A.2: PIB decision block (CONFIDENTIAL)

Appendix A.3: Reaction times

Table 3.Reaction times of the prepared drivers

	Reaction time before first steering after the impact [s]	Reaction time before first braking after the impact [s]	Reaction time before releasing/pressing the accelerator [s]
Impact case 1	0.255; 0.2010	2.8310; 3.0730	0.1370; 0.3850
Impact case 2	0.154; 0.1750	4.0820; 3.8520	-1; -1
Impact case 3	0.1580; 0.1930	8.2230; 6.9860	-1; 0.5450
Impact case 4	0.1760; 0.1590	0.3740; 0.4190	0.4550; 0.4670

Table 4. Reaction times of the unprepared drivers

	Reaction time before first steering after the impact [s]	Reaction time before first braking after the impact [s]	Reaction time before releasing/pressing the accelerator [s]
Impact case 1	0.3570; 0.0990; 0.1340	1.4480; 0.6750;-1	0.6950; 0.1630; 0.1340
Impact case 2	0.3840; 2.4950; 1.0520	1.15; 10.6140; 0.7430	0.3840; 0.7080; -1
Impact case 3	0.2090; 0.4060; 0.68	0.7070; 0.6040; 2.2080	0.5; 0.0110; 0.2040
Impact case 4	0.7440; 0.2750; 0.3360	-1; -1; 2.7370	0.4660; 0.49; 0.5760

Appendix A.4: Vehicle states during unprepared driver test: impact case 1 done by Åse

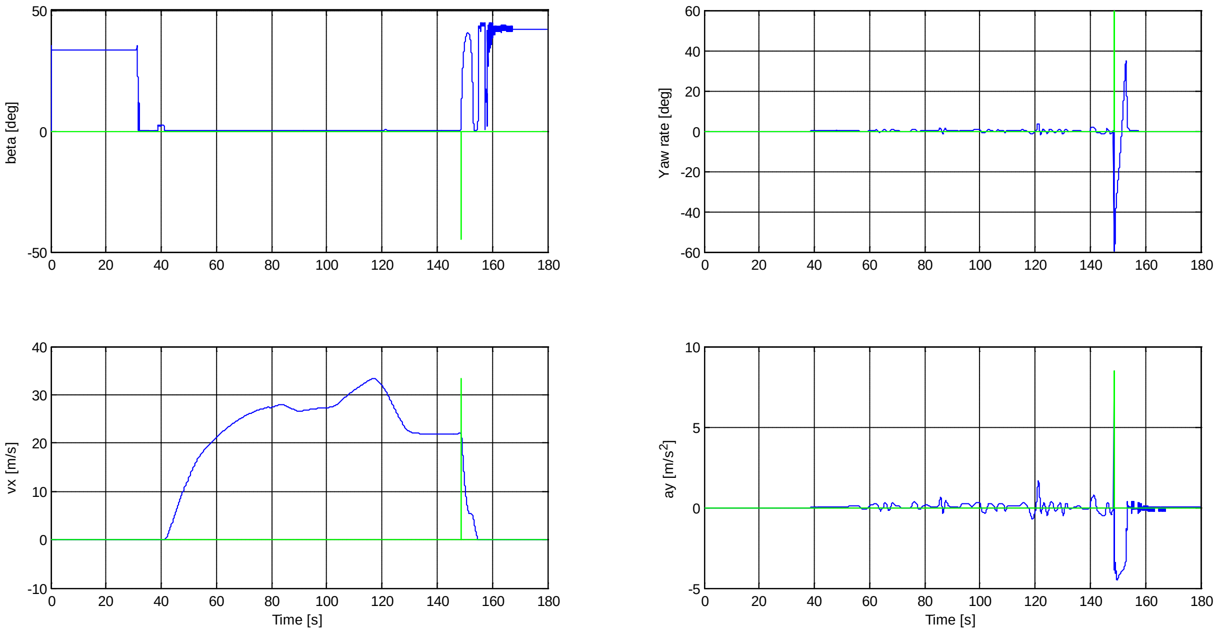

Figure 5. Vehicle states for impact case 1 (Åse), ride 1 with PIB

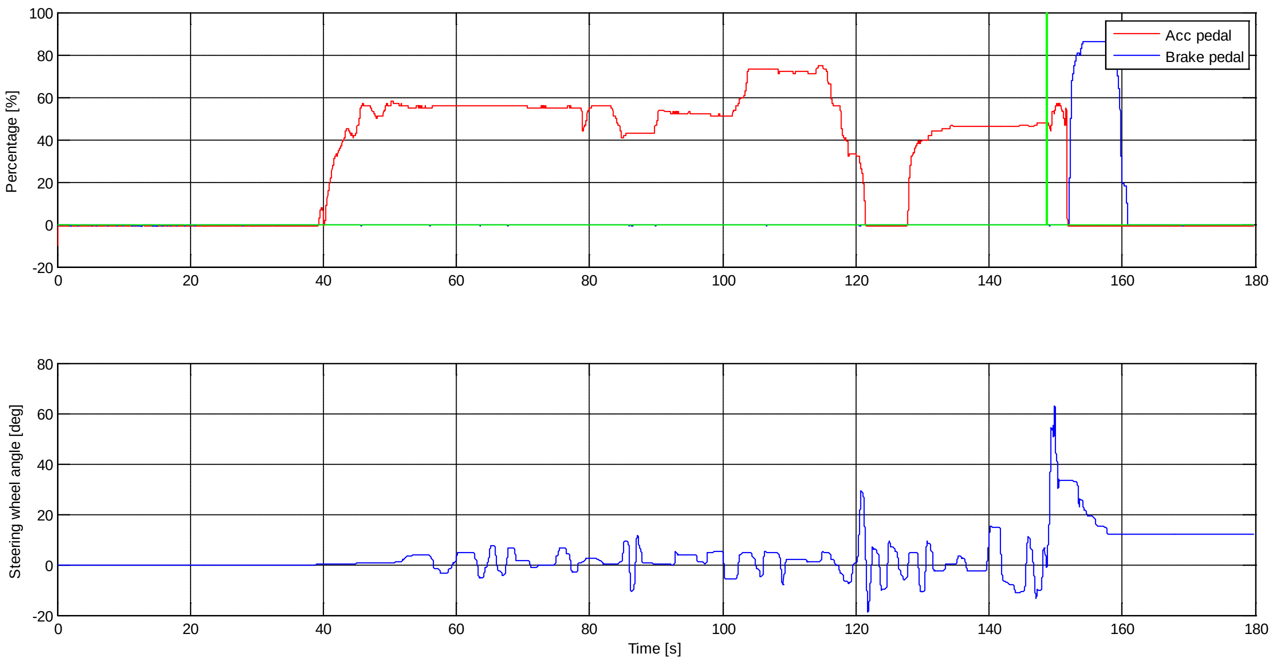

Figure 6. Unprepared driver's response for impact case 1 (Åse), ride 1 with PIB

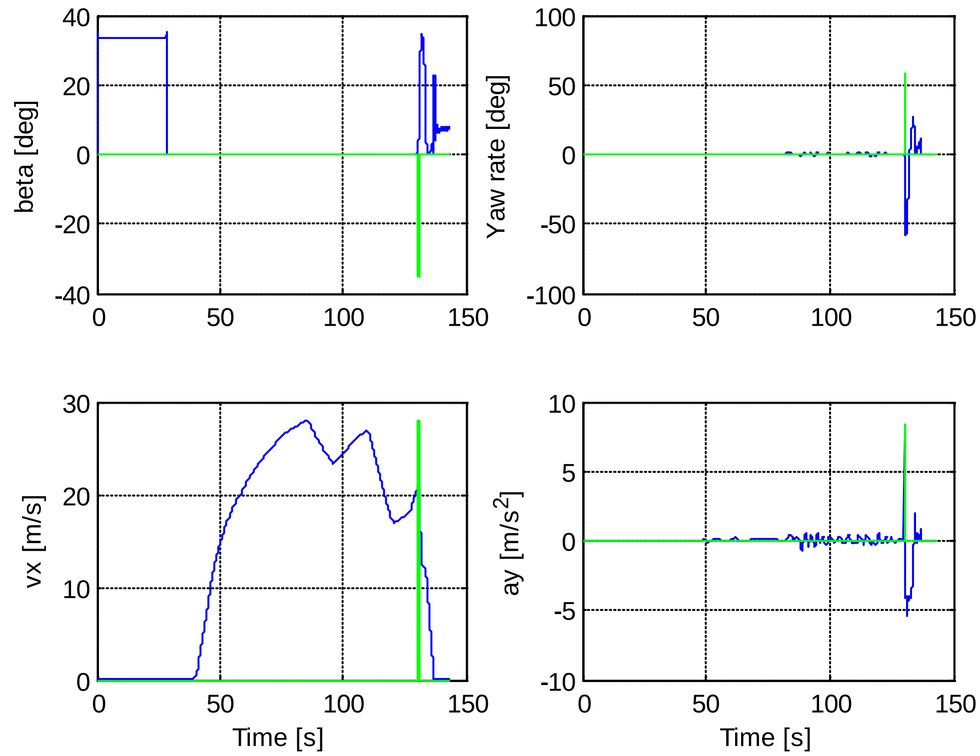

Figure 7. Vehicle states for impact case 1 (Åse), ride 2 without PIB

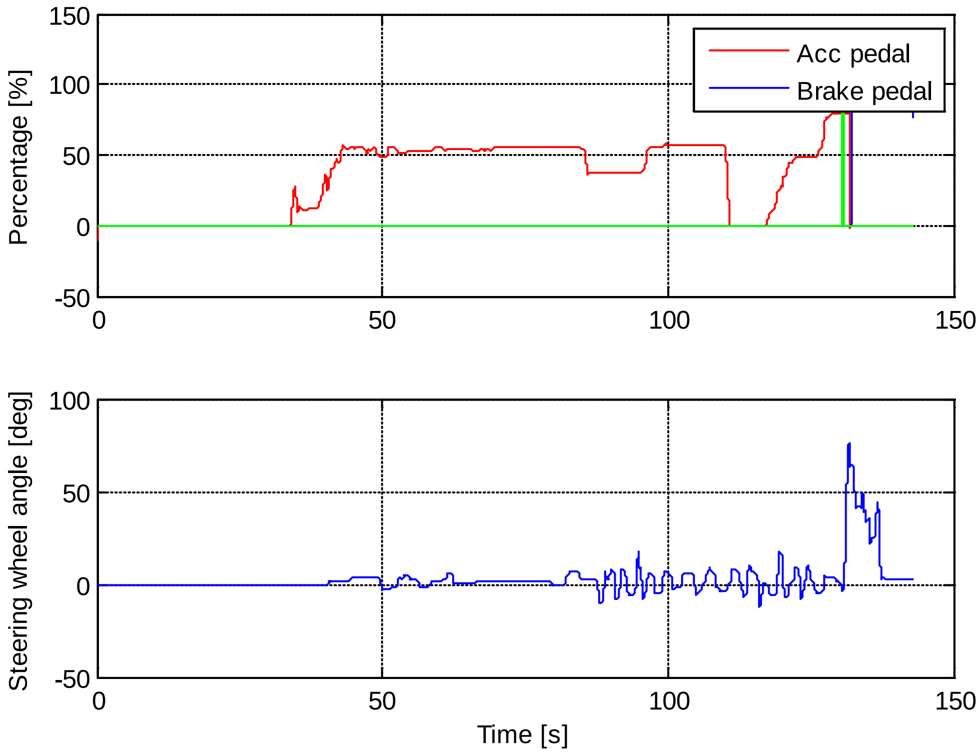

Figure 8. Unprepared driver's response for impact case 1 (Åse), ride 2 without PIB

Appendix A.5: Vehicle states during prepared driver test in impact case 1

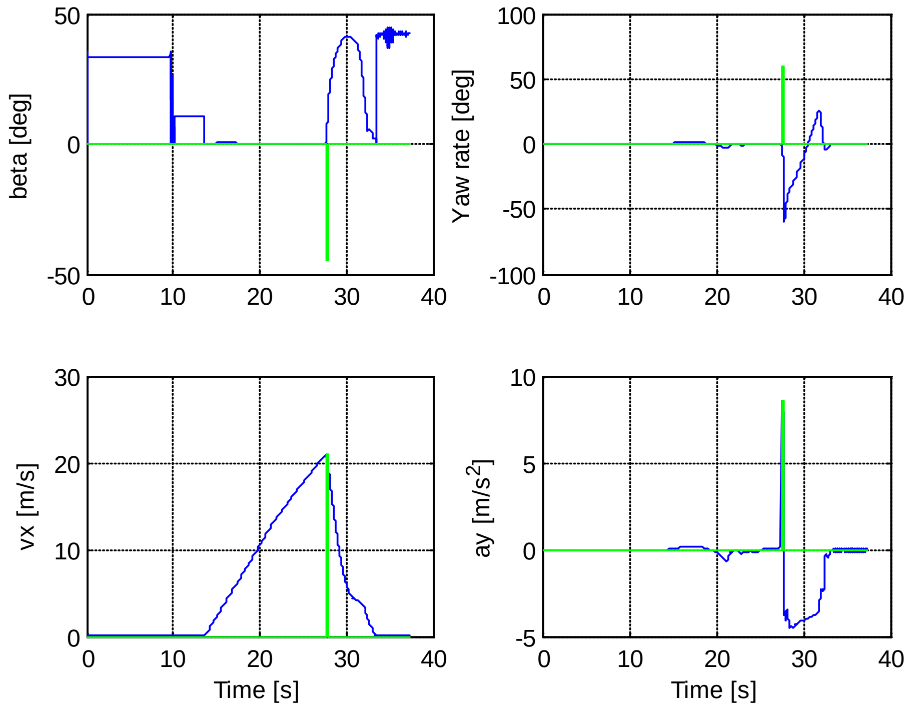

Figure 9. Vehicle states for the prepared driver in impact case 1, ride 1 with PIB

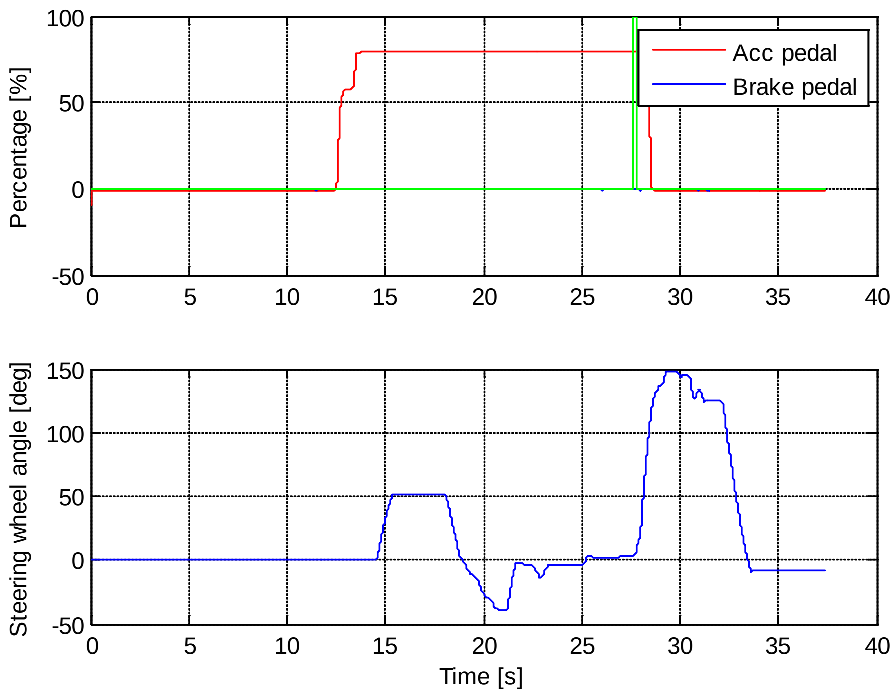

Figure 10. Prepared driver's response in impact case 1, ride 1 with PIB

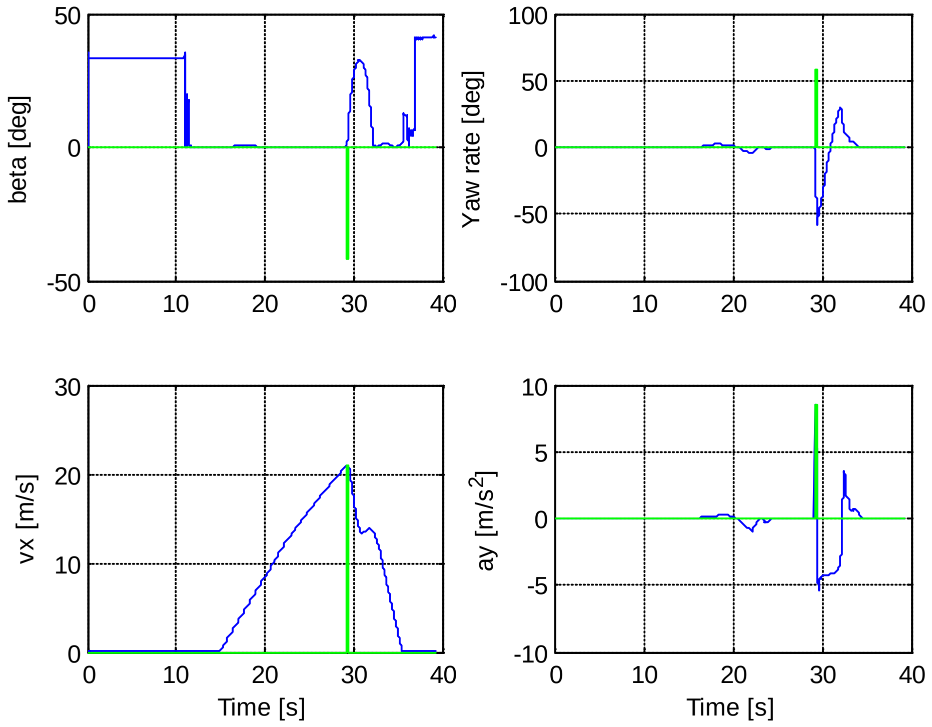

Figure 11. Vehicle states for the prepared driver in impact case 1, ride 2 without PIB

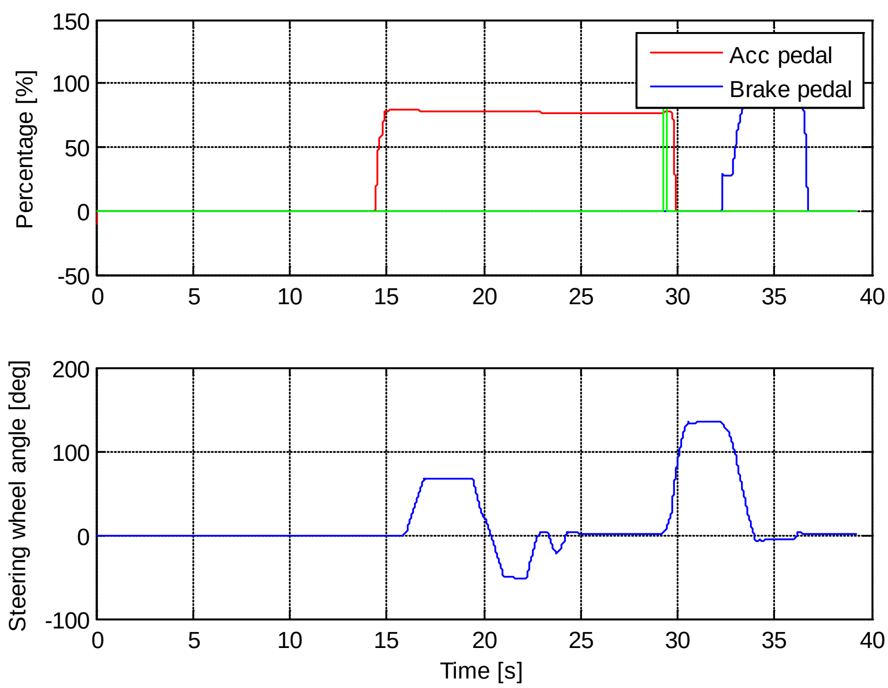

Figure 12. Prepared driver's response in impact case 1, ride 2 without PIB