PROJECT REPORT

TRL Limited

PROJECT REPORT PR VE/069/07

TECHNICAL ASSISTANCE AND ECONOMIC ANALYSIS IN THE FIELD OF LEGISLATION PERTINENT TO THE ISSUE OF AUTOMOTIVE SAFETY: PROVISION FOR INFORMATION AND SERVICES ON THE SUBJECT OF BRAKE ASSIST SYSTEMS – FINAL REPORT

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Executive summary

The performance of the brake systems of passenger vehicles has improved substantially over the last ten to twenty years. However, research by TRL and many other organisations has shown that real drivers in emergency situations often fail to utilise fully the brake performance available to them. Typically, drivers fail to press the brake pedal sufficiently hard, particularly at the beginning of the brake stop. Brake Assist Systems (BAS) are vehicle braking systems which detect when a driver intends to make an emergency stop and act to try and increase the likelihood that full ABS braking is quickly achieved. Such systems are currently an unregulated optional fitment that is available on only some models. However, where fitted these systems can potentially decrease vehicle stopping distances and hence mitigate, or avoid, a collision.

TRL was commissioned by the EC to review the latest proposal for the technical requirements for BAS and to prepare a finalised technical proposal for inclusion in the appropriate regulations. The aim was to define a specification representative of 'best practice' with regard to systems currently voluntarily fitted to some production vehicles.

The work began with a consultation with industry to gather information on the type of BAS currently fitted to vehicles and their characteristics. This was followed by a programme of track tests designed to assess the latest technical proposals and propose modifications considered to improve the robustness of the technical requirements and/or test procedures. In parallel to this work a programme of simulator trials were carried out to compare the effect on driver performance between a force sensitive BAS, a speed sensitive BAS and a vehicle not equipped with BAS.

The track tests with a vehicle claimed by the manufacturer to be fitted with a force sensitive BAS showed no evidence of such a system being fitted to that vehicle. Despite this result TRL recommends that the basis of the test procedure remains as described by the existing technical proposals. The rationale for this recommendation is that the test procedure was proven to successfully identify a vehicle with a system not meeting requirements and analysis of the method has not revealed any obvious mechanisms by which it could fail to identify a system that did meet the requirements. TRL has proposed an upper boundary for the required decrease in the brake pedal force necessary to achieve full ABS deceleration. TRL has proposed a decrease of between 40% and 80%. The purpose of the upper boundary is to prevent a step boost to full ABS deceleration above the threshold force, F_T.

The presentation of the test procedure for the determination of F_{ABS} and a_{ABS} has been re-structured and is now fully contained within an Appendix. The test procedure and the requirements of the procedure remain unchanged.

TRL has recommended that manufacturers should declare the input variables influencing BAS activation and the mode of boost and the relationships between them as well as providing evidence to demonstrate how those variables and relationships can be demonstrated to be effective for ordinary drivers.

Ideally, a technology-neutral test procedure would be defined that only specified the fundamental performance enhancement that a Brake Assist system is expected to achieve. This may be possible but would still rely on the manufacturer defining the characteristic of brake input and is likely to be difficult to achieve in practice.

TRL acknowledges that the proposed test procedures adequately identifies the presence of speed sensitive BAS (category B or C) it cannot necessarily discriminate between the two and does not rigorously quantify the effectiveness of the systems.

The results of the simulator trials showed that both the force sensitive BAS and the speed sensitive BAS offered improved braking performance compared with a similar vehicle not fitted with BAS (i.e. the baseline configuration). It was estimated that, the time to reach 90% of peak deceleration was statistically the same for both the force sensitive BAS and the speed sensitive BAS, and that the mean deceleration of the speed sensitive system would only need to fall by 6% (from 8.87m/s² to 8.33m/s²) for it to be considered statistically indistinguishable from the force sensitive BAS.

Based on a study by ACEA using GIDAS data, Lawrence *et al* (2006) estimated that brake assist would reduce serious and fatal pedestrian injuries by approximately 5%. The results from the simulator trial in this project could not be directly compared to the ACEA study with scientific confidence but combining the results with those from a study by Page *et al* (2005) suggested that the benefits may be of broadly comparable magnitude to those estimated by Lawrence *et al* (2006).

1 Introduction

The performance of the brake systems of passenger vehicles has improved substantially over the last ten to twenty years. However, research by TRL and many other organisations has shown that real drivers in emergency situations often fail to utilise fully the brake performance available to them. Typically, drivers fail to press the brake pedal sufficiently hard, particularly at the beginning of the brake stop. Brake Assist Systems (BAS) are vehicle braking systems which detect when a driver intends to make an emergency stop and act to try and increase the likelihood that full ABS braking is quickly achieved. Such systems are currently an unregulated optional fitment that is available on only some models. However, where fitted these systems can potentially decrease vehicle stopping distances and hence mitigate, or avoid, a collision.

The EC has drafted a potential amendment to UNECE regulation 13H to provide technical requirements and test procedures for BAS to provide a minimum standard for the systems if fitted. This was based on an earlier technical proposal written by the European Automobile Manufacturers Association (ACEA). TRL was commissioned by the EC to review this latest proposal and to prepare a finalised technical proposal for inclusion in the appropriate regulations. The objective of this proposal was described as an intention to ensure that BAS fitted to vehicles in future conformed with a minimum standard representative of best practice for systems currently voluntarily fitted to production vehicles.

The work began with a consultation with industry to gather information on the type of BAS currently fitted to vehicles and their characteristics. This was followed by a programme of track tests designed to assess the latest technical proposals and propose modifications considered to improve the robustness of the technical requirements and/or test procedures. In parallel to this work a programme of simulator trials were carried out to compare the effect on driver performance between a force sensitive BAS, a speed sensitive BAS and a vehicle not equipped with BAS.

This report describes in full the methodology and the results obtained in relation to the objectives set out in the service request.

2 Background Information

2.1 Technical review of existing proposals

A proposal for a BAS test procedure written by ACEA defined two types of BAS:

- Pedal force sensitive BAS
- Pedal speed sensitive BAS

The requirements for each category of system prescribed that a force sensitive BAS proportionally boosted the braking once a certain force was exceeded such that the gradient of a graph plotting pedal force against deceleration was increased by a minimum amount at that point. The requirements for a speed sensitive BAS were that when the pedal was depressed according to a characteristic to be supplied by the manufacturer, at least 85% of full ABS braking must be achieved.

Research by Lawrence *et al* (2006) identified that in addition to the categories specified in the ACEA document, BAS was in existence that was sensitive to both pedal speed and pedal force and that, in theory at least, it would be possible for different systems to respond in different ways. For example, BAS sensitive to pedal speed could respond with proportional boost of braking rather than full ABS.

The proposal supplied to TRL by the EC at the start of this project acknowledged these findings and described two categories of BAS:

- Category A: Once an emergency situation has been detected the brake pressure is increased so as to trigger full ABS braking
- Category B: Once an emergency situation has been detected the ratio of brake pressure to applied pedal force is increased

The EC proposal also separately defined three different activation methods:

- Boost is activated when the pedal force is greater than a pre-defined value
- Boost is activated when the rate at which the brake pedal is applied is greater than a pre-defined value
- Boost is activated from a combination of the brake pedal force and speed requirements.

This meant that there were six possible types of systems that could potentially be defined as BAS. Therefore the example described above where a system activated based on the speed of the brake pedal application and, once triggered, proportionally increased the brake pressure would be included within the scope of the proposal (Category B). However, the test procedures for Category B systems in the EC proposal are to the same as those for force activated systems in the earlier ACEA proposal. Therefore, in theory a Category B system with activation based on the rate of application of the brake pedal would not necessarily qualify as a BAS in that test.

Table 1 shows that although there are potentially six different types of BAS systems, the requirements in the EC proposal mean that only two of these systems could qualify as BAS. Thus, as it stands the EC proposal restricts BAS to the same systems as the earlier ACEA proposal.

Table 1: Type of BAS system

Activation Method	Category	
	A	B
Force		X
Speed	X	
Both		

Key	
X	BAS
	Not BAS

Lawrence *et al* (2006) identified a further concern with the ACEA proposal for test procedures and technical requirements for BAS. This research suggested that minimum performance standards had been set in the proposal to govern the minimum amount that each type of system must boost braking once activated. For force sensitive systems a range of values at which the braking must start to be boosted was also specified and as such a minimum standard covering the activation of the system had also been specified. However, the ACEA proposal did not prescribe a threshold value for the pedal speed above which a pedal speed sensitive BAS must be activated. Instead the proposal stated that *"in order to activate BAS the brake pedal shall be applied as specified by the manufacturer"*.

Lawrence *et* al (2006) considered that this requirement meant that the procedure was considerably less robust than it could be because, theoretically at least, any pedal speed threshold could be specified by the manufacturer. This leaves the possibility that some BAS devices could trigger at very slow pedal speed, possibly resulting in a large number of false activations or, conversely, the manufacturer could specify a pedal speed so high that the BAS is never activated and does not provide any benefit.

2.2 BAS specifications

At the beginning of the project a meeting was held with members of the ACEA BAS task force to discuss the various modes of operation and technical specifications of typical BAS. The discussions confirmed the findings of Lawrence *et al* (2006) that there were three principle types of BAS:

- Systems that activated based on brake pedal force and acted to increase the ratio of brake pedal force to vehicle deceleration
- Systems that activated based on brake pedal speed and acted to increase the braking to full ABS
- Systems that activated based on a combination of brake pedal force and brake pedal speed and acted to increase braking to full ABS

However, it became apparent that the third system described above (pedal force and pedal speed activated) would more correctly be titled "multiple criteria" systems. This is because such systems tend to be fully electronic and typically change their characteristics in response to vehicle speed such that a three-dimensional contour map of performance characteristics is used to decide whether to activate the assistance. An example of such a three dimensional characteristic is shown in Figure 1, below.

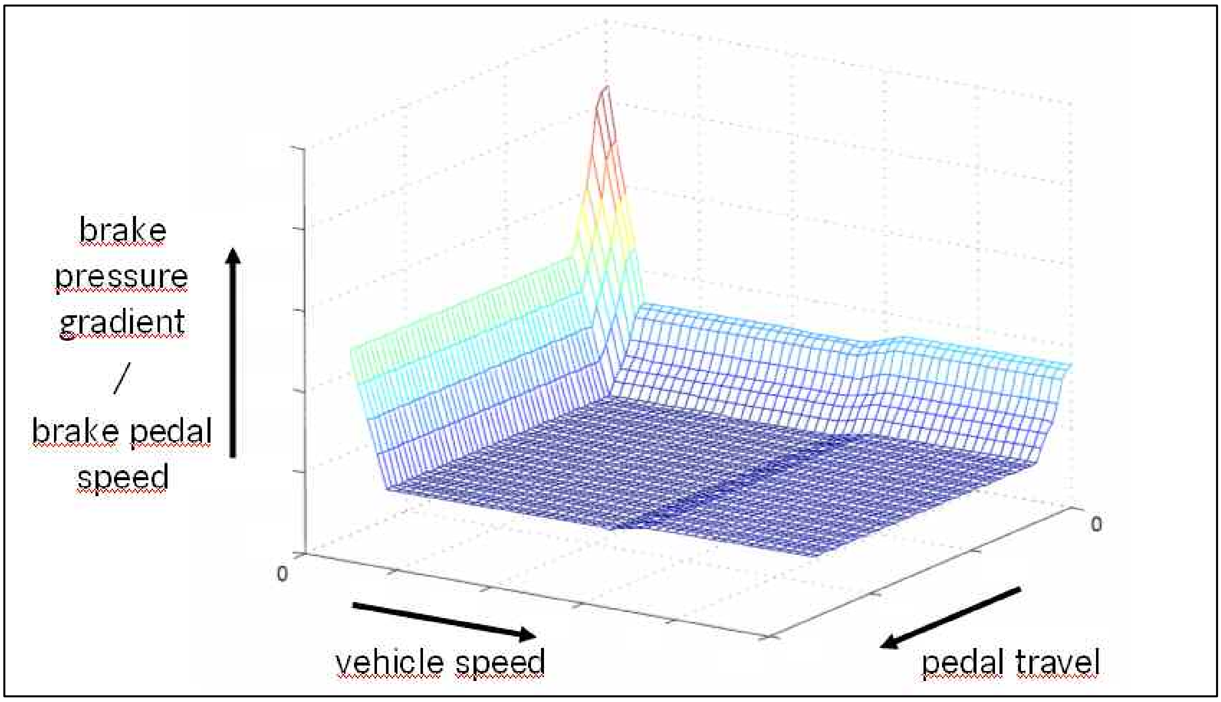


Figure 1. Example characteristic for a multiple criteria BAS

It can be seen that for this particular system there is a brake pedal speed threshold that remains constant over a wide range but that at very low vehicle speeds or low pedal travel (proportional to pedal force) then the pedal speed required to trigger BAS is much higher. It should also be noted that there is a slight increase in the pedal speed threshold at higher vehicle speeds. ACEA stated that the intention of such a characteristic was to provide BAS benefits when they were needed while minimising activation when not intended by the driver.

Subsequent to the meeting with representatives of the ACEA BAS task force, a letter was sent to all members of the group requesting more specific information relating to the type of BAS fitted to each model of vehicle they offered together with details of the activation criteria and thresholds. The aim was to identify vehicles suitable for use in the test programme and to identify typical characteristics with which to programme the driving simulator for the trials with ordinary drivers (to be reported separately). It was agreed that details of the data provided by manufacturers would remain confidential for commercial reasons. However, a short anonymous summary of the findings is included below.

Four car manufacturers responded to the request for information and provided data relating to 14 different BAS. The sample is, therefore, relatively small and cannot be considered fully representative. The mode of operation of systems was as follows:

- Two were pedal force activated
- Six were pedal speed activated
- Six were multi-criteria activated.

For the two force-activated systems the threshold pedal force was always expressed as a master cylinder pressure and was quoted as 45-50bar. For pedal speed activated systems the trigger thresholds quoted ranged from 90mm/s to 620mm/s, although it wasn’t always clear that this displacement rate was always recorded at the same point on the pedal. One further system expressed the threshold in terms of pressure gradient. The six multi-criteria systems all expressed the pedal speed threshold in terms of pressure gradient and these ranged between 600bar/s and 3,500bar/s. The minimum vehicle speed threshold ranged from 5km/h to 20km/h. Thresholds for pedal force, travel and “power” were also expressed but the relationships could be complex.

2.3 Initial ACEA views on existing proposals for test procedures.

ACEA were also given the opportunity to review the EC proposal for an amendment to UNECE regulation 13H. The ACEA response welcomed the fact that the proposal was based on the ACEA proposal but requested clarification for the rationale for some minor changes. The main objection to the EC draft was in relation to changes for systems activated using pedal speed.

Lawrence *et* al (2006) had highlighted a concern that the test procedure only assessed the action that BAS took to increase deceleration once it had been activated and did not prescribe what type of pedal application should activate the system. When the system should be activated remained entirely at the manufacturers discretion such that, in theory, a system that benefited only a small proportion of drivers, or one that regularly activated during normal driving for many drivers could gain approval to the standard. In response to this concern, the EC draft proposal specified a range of pedal speed thresholds that ensured a BAS with a very low or very high trigger threshold could not be approved but allowed the manufacturer to choose any threshold value in between.

ACEA could not support this proposal for two main reasons:

- The fundamental characteristics of the brake system in terms of pedal “feel” (relationship between pedal force, pedal travel and deceleration) has a significant influence on driver behaviour such that the pedal speed that characterises emergency braking in one car might be very different from the pedal speed applied in emergencies by the same drivers in different cars with different pedal "feel".

- Controlling the pedal speed correctly during the test would be very difficult.

It was stated that, for the reasons above, the ACEA expert group focussed on developing a standard assessing only the deceleration when triggered and that "*ergonomic and customer acceptance aspects*" were transferred to the manufacturer and considered as part of their "duty of care" obligations.

3 Methodology

3.1 Track trials

Using the information provided by industry TRL selected three vehicles to be used in the track trials; one with a force sensitive BAS, one with a speed sensitive BAS and one with a BAS sensitive to brake pedal force and speed.

The purpose of the track tests was to evaluate the brake performance characteristics of the three test vehicles and to assess whether the proposed test methods adequately identified the presence of Brake Assist in these vehicles, or whether an alternative test procedure would be more suitable.

3.1.1 Force sensitive BAS

Both the ACEA and EC proposals described a method to determine the brake pedal force at which full ABS deceleration is first achieved, F_{ABS}, and what value this deceleration is, a_{ABS}. The method for this test requires five tests where the brake pedal is applied slowly with a constant increase of deceleration until the ABS is activated. For these tests the full deceleration must be reached within a prescribed timeframe, as illustrated in Figure 2. To determine F_{ABS} and a_{ABS}, the five tests are averaged and compared to the ultimate deceleration achieved by the vehicle. TRL carried out a series of these tests to evaluate this test procedure and to determine the values of F_{ABS} and a_{ABS} for the test vehicle

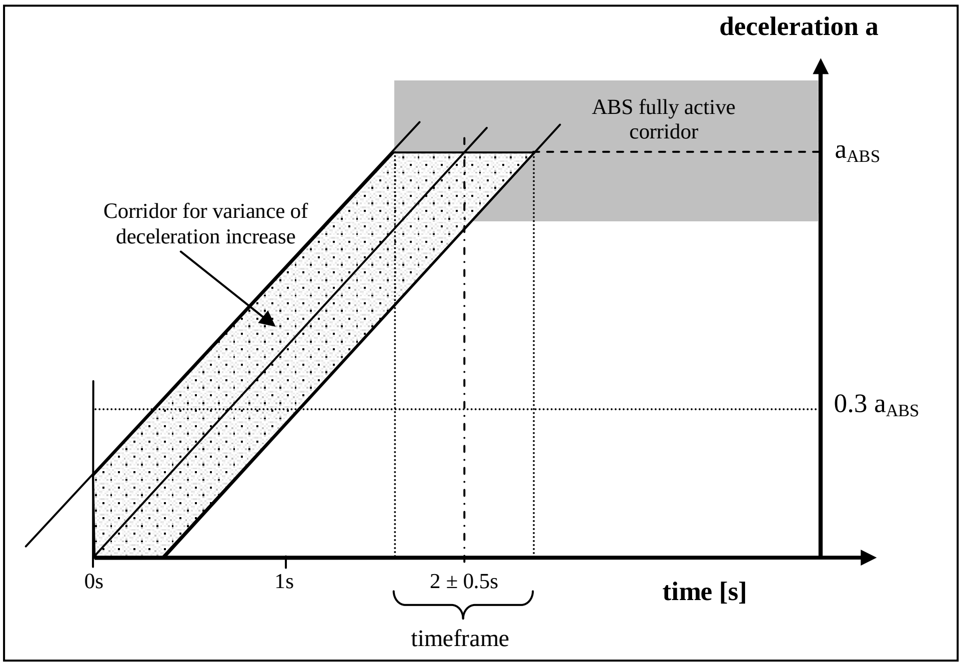


Figure 2: Test requirements for determination of F_{ABS} and a_{ABS}

In addition a series of straight line brake tests were carried out. For each test, the vehicle was driven at a constant speed before the brakes were quickly applied to a particular brake pedal force. This force was then maintained by the test driver for the duration of the stop and the resulting deceleration of the vehicle was measured. The brake pedal force was increased incrementally for each subsequent test so that the relationship between pedal force and deceleration could be evaluated by an alternative means to that described in the two BAS proposals.

3.1.2 Speed sensitive BAS

For this vehicle F_{ABS} and a_{ABS} were again determined using the procedure described in the BAS proposals.

To identify the threshold value of pedal speed a series of straight line tests were carried where a fixed pedal force was applied slowly and then held. For each subsequent test the speed at which this pedal force was reached was incrementally increased until the brake pedal was pressed as fast as possible.

The test method in the industry proposal identified the presence of a speed sensitive BAS based on how well the required deceleration is maintained even when the pedal force falls below F_{ABS} (Figure 3). To produce this condition, TRL carried out a series of tests where the brake pedal was quickly applied to a peak value and then the force was reduced and held at this lower value by the driver. TRL carried out some tests where the peak pedal force was greater than F_{ABS} and some tests where the peak force was lower than F_{ABS}.

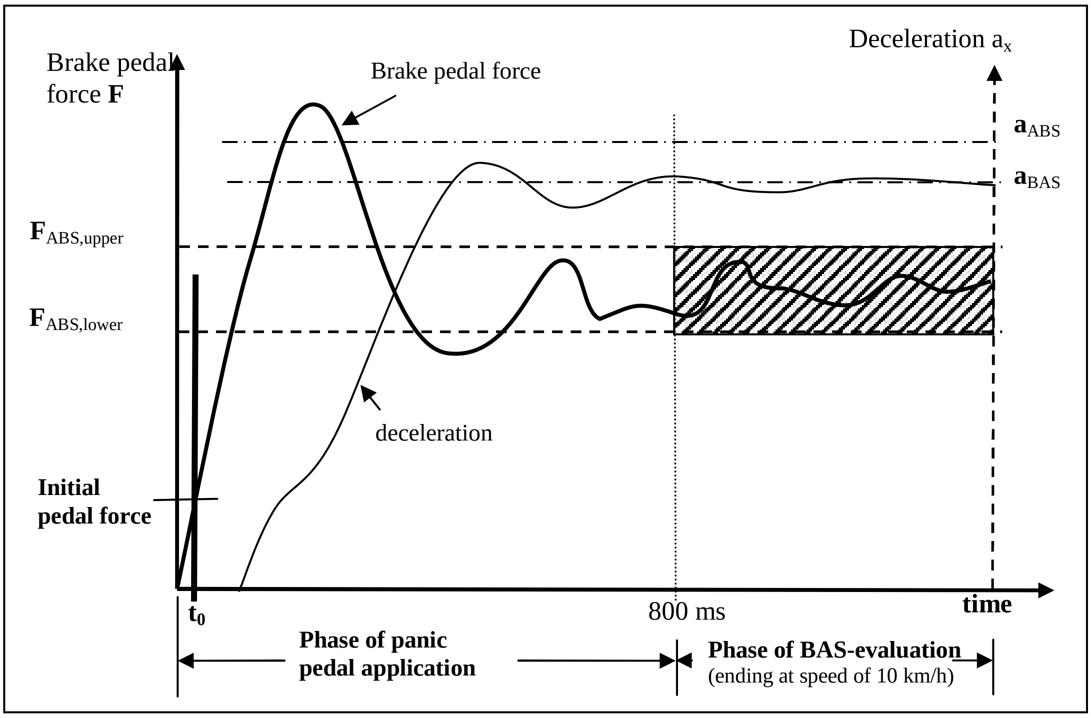


Figure 3: Proposed test condition for speed sensitive BAS

3.1.3 Force and speed sensitive BAS

F_{ABS} and a_{ABS} were again determined using the test procedure described in both existing proposals. The manufacturer of this vehicle reported that the BAS fitted was sensitive to both the rate at which the brake pedal was applied and the force applied to the pedal, therefore two types of tests were carried out for this vehicle. Firstly tests with a constant pedal speed and a pedal force that was incrementally increased for each test were carried out. These were followed by tests at a constant pedal force but with an incrementally increasing rate of application.

In addition to these tests the same test procedure as described for the speed sensitive BAS was again followed for this vehicle.

3.2 Simulator trials

3.2.1 TRL driving simulator

The TRL Driving Simulator (Figure 4), used for this study, consisted of a medium sized saloon car surrounded by 3 x 4 metre projection screens giving 210 degree front vision and 60 degree rear vision, enabling normal use of the vehicle mirrors.

Figure 4: The TRL Driving Simulator

The road images were generated by advanced Silicon Graphics computers and projected onto the screens. The realism was further enhanced through the provision of engine noise, external road noise and the sounds of passing traffic

As highlighted at the start of the project, the simulator used for this section of work had the advantage that the characteristics of the BAS could be relatively easily changed in the software, and that different emergency scenarios could be evaluated. Although the simulator is mounted on hydraulic rams that supply motion to simulate the heave, pitch and roll, the simulator is unable to provide feedback to the driver that simulates the feeling of deceleration

3.2.2 Trial configuration

Each participant completed three drives. One of the drives was a control drive with no BAS operational. The two subsequent drives had one of two standard BAS configurations (Force sensitive or pedal speed sensitive) as shown in Table 2.

Table 2: Vehicle configurations

N° of subjects	Vehicle configuration		
	Baseline (no BAS)	Force sensitive BAS	Speed sensitive BAS
36	✓	✓	✓

3.2.3 Participants

Thirty-six participants were chosen from TRL's database of volunteers to take part in the simulator trials. Of these, 34 completed all of the journeys; two participants did not complete the trial due to simulator sickness. Nineteen of the participants (53%) were male and 17 (47%) were female. The mean age of the sample was 40 years (range 26 to 55 years). Participants had held a driving licence for an average of 21 years (range 5 to 38 years). The average annual mileage driven by participants over the last 12 months was 10,164 miles (range 1,000 to 40,000 miles) and most (24 participants) reported driving every day, on average. Fewer participants reported having driven 4-6 days a week (10 participants).

At the start of each journey the participant was only instructed that they should drive normally with the aim of maintaining a changing target speed of around 80km/h. A tri-box speed indicator (Figure 5) was displayed on the in-car navigation screen positioned in the centre of the driving console.

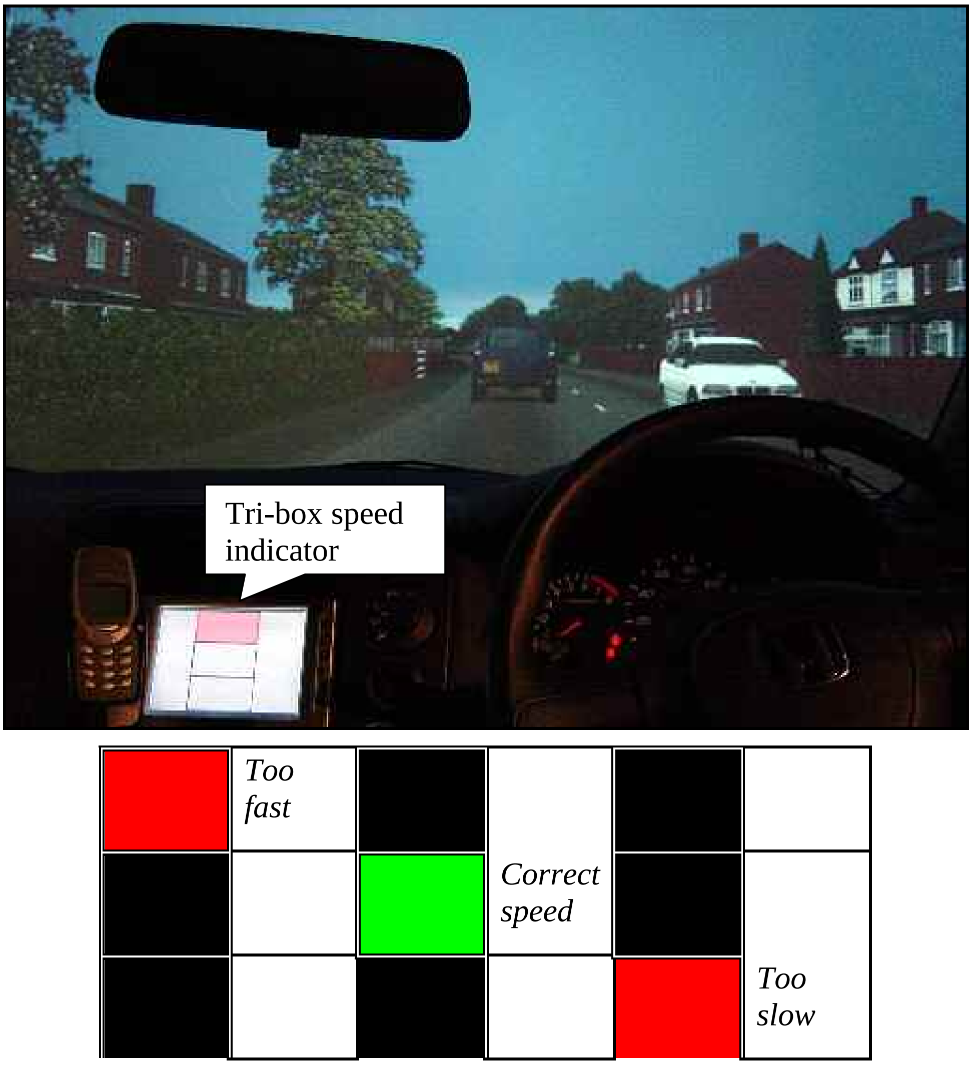


Figure 5: Tri-box speed indicator (Source: Ho *et al*, 2006)

The participants were told that when they were driving at the correct speed the bar would appear green in the middle box, if they were driving too fast the bar would appear red in the top box and they should slow down gently, and if they were driving too slowly, the bar would appear red in the bottom box and they should speed up.

The participants were also instructed to use the in-car tri-box display to keep to the target speed however, if they were to encounter any hazards, these had to take priority over keeping to the target speed. Finally participants were instructed not overtake any vehicle during the trial.

In addition to trying to make the initial speed at the braking events as consistent as possible, the purpose of using the tri-box display was to provide a secondary task for the drivers so they were not solely focused on the potential braking events ahead.

3.2.4 Route and braking events

One route was used for this trial and each participant drove this route three times. The route consisted of a rural road with a series of bend and junctions. Within each journey five events, requiring an emergency braking manoeuvre, were randomly distributed.

The five events were:

- A pedestrian crossing from the left side of the road
- A pedestrian crossing from the right side of the road
- A vehicle pulling out from the left side of the road
- A vehicle pulling out from the right side of the road
- A vehicle performing an emergency stop in front of the driven vehicle.

The order in which the participant experienced the three BAS configurations, and the order and location of the braking events were randomly distributed across the subjects, as described in Appendix A.

The movement of each of the vehicles pulling out from the side of the road, and the pedestrians crossing the road were triggered by the position of the simulator vehicle along the route. For the events where a vehicle pulled out from a side road, the movement of this vehicle was initiated when the simulator vehicle was slightly less than 200maway from the junction where the event was to take place. Movement of the pedestrian was initiated when the simulator vehicle was approximately 140m away from the event location. Using the tri-box speed indicator (Figure 5) the participant was asked to maintain a speed of 80km/h so that the participant would be approximately 50m away from the junction when the event vehicle/pedestrian started to encroach into the road (Figure 6). For the event where a vehicle braked in front of the simulator vehicle, the event vehicle was programmed to drive at a constant speed of 70km/h before performing the braking manoeuvre.

The reference time from which the reaction times of the participants were calculated was defined as either:

- The time when the event vehicle/pedestrian started to encroach into the road
- The time when the vehicle in front started its braking manoeuvre

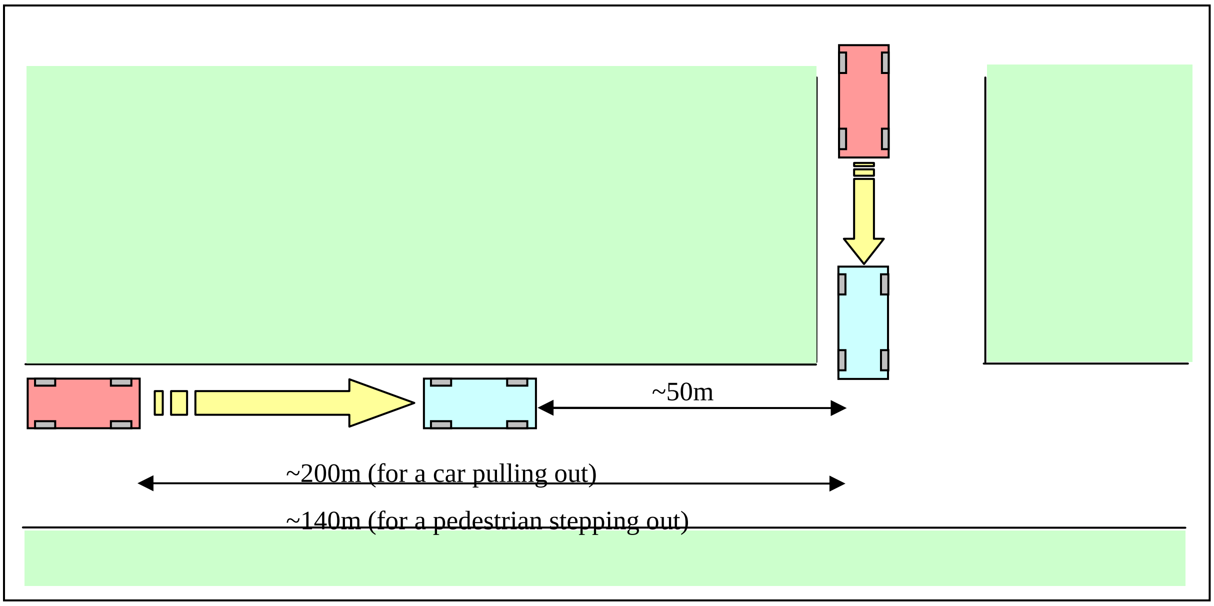


Figure 6: Movement of simulator event vehicles

3.2.5 Simulated Brake Assist Systems

3.2.5.1 Baseline system

The movement of the brake pedal in the simulator produces a voltage on a scale of 0-1v (where 0v is the pedal at its normal resting position, and 1v is when the pedal is fully depressed). This voltage is then fed into a complex dynamics model that calculates a resulting deceleration for the given pedal position (Figure 7)

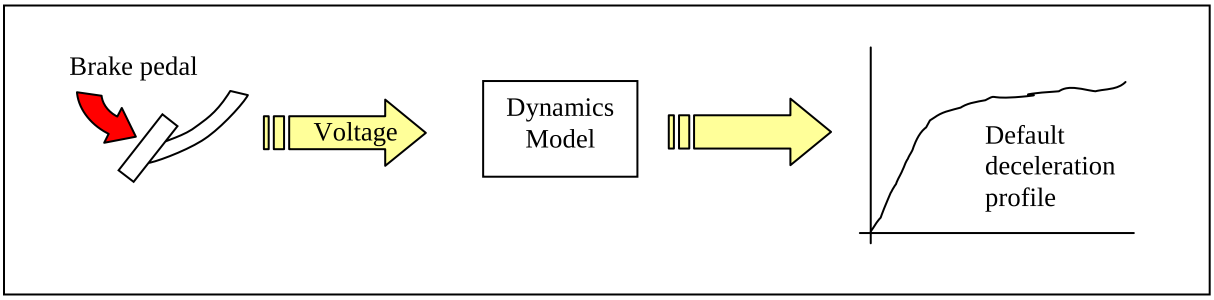


Figure 7: Default calculation of deceleration vs. pedal position profile

The default pedal position vs. deceleration characteristic for the TRL driving simulator showed a sharp increase in deceleration for a relatively small pedal movement. Full vehicle braking tests carried out by TRL as part of a separate project showed that cars typically have a brake pedal force versus deceleration characteristic (Figure 8) and a brake pedal position versus deceleration characteristic as shown in Figure 9. Based on the real vehicle results shown in these graphs, a target profile for the simulator was defined and is also shown by the black line in the Figures below.

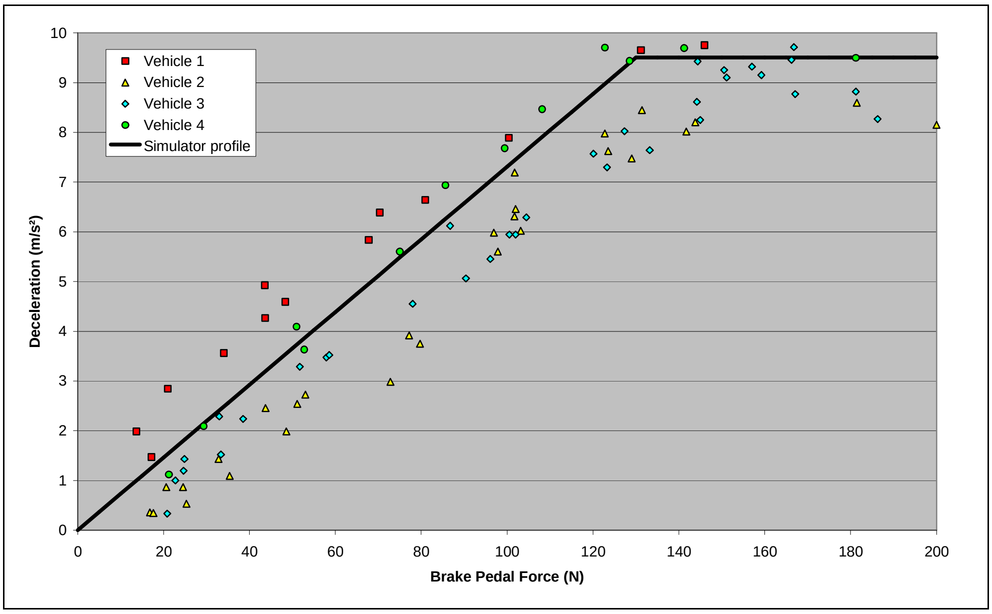


Figure 8: Brake pedal force vs. deceleration profiles

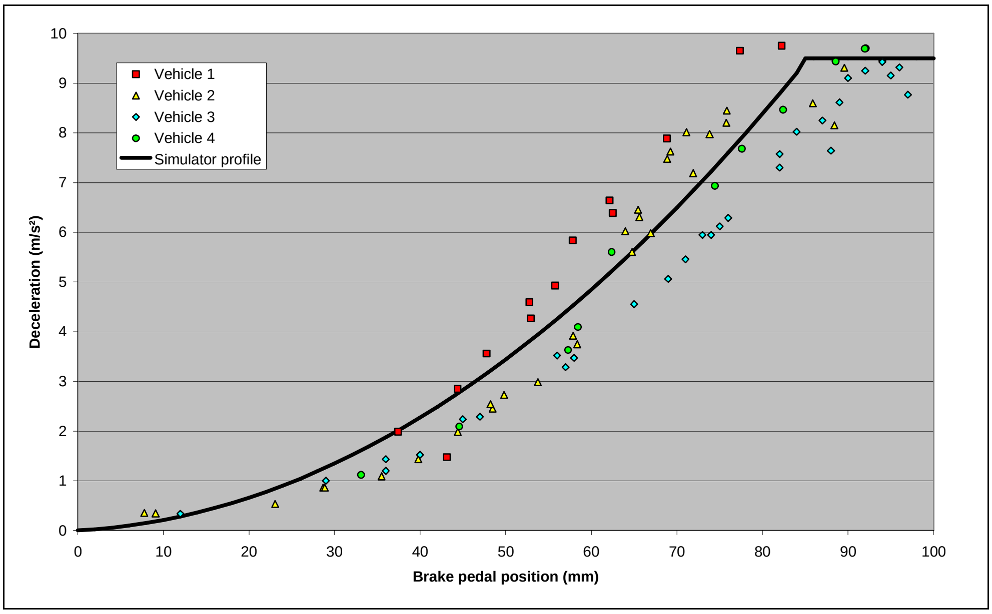


Figure 9: Brake pedal position vs. deceleration profiles

In order to achieve the characteristic shown above in the driving simulator, the output voltage from the brake pedal was modified before entering the dynamics model. Figure 10 shows a comparison between the modified profile that was programmed into the simulator (target pedal position/deceleration curve) and the actual data recorded during the pilot trial for this project. The data was recorded from a series of braking event and the scatter on the data occurs because of the different gear selection and (in some cases) the engagement of the clutch.

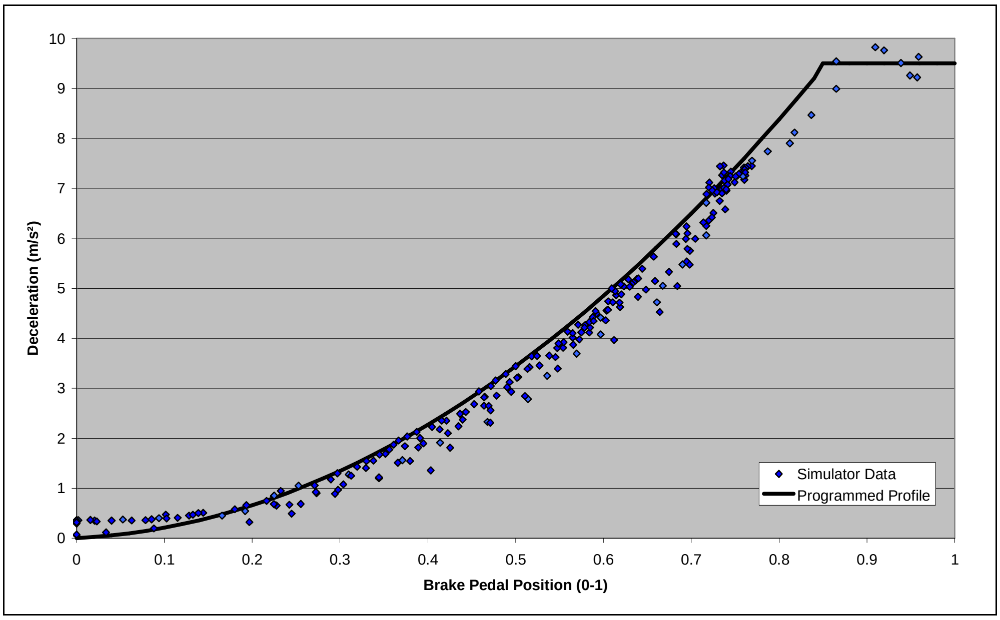


Figure 10: Comparison between programmed and actual deceleration profile in TRL Driving Simulator

3.2.5.2 Force sensitive BAS

For the purpose of this trial the simulator was configured with a force sensitive BAS equivalent to the minimum standard of the proposed technical requirements for BAS (i.e. a 40% reduction in the brake pedal force required to achieve a_{ABS}). Figure 11 shows that this was equivalent to reducing the brake pedal force from 130N to 100N at a_{ABS}.

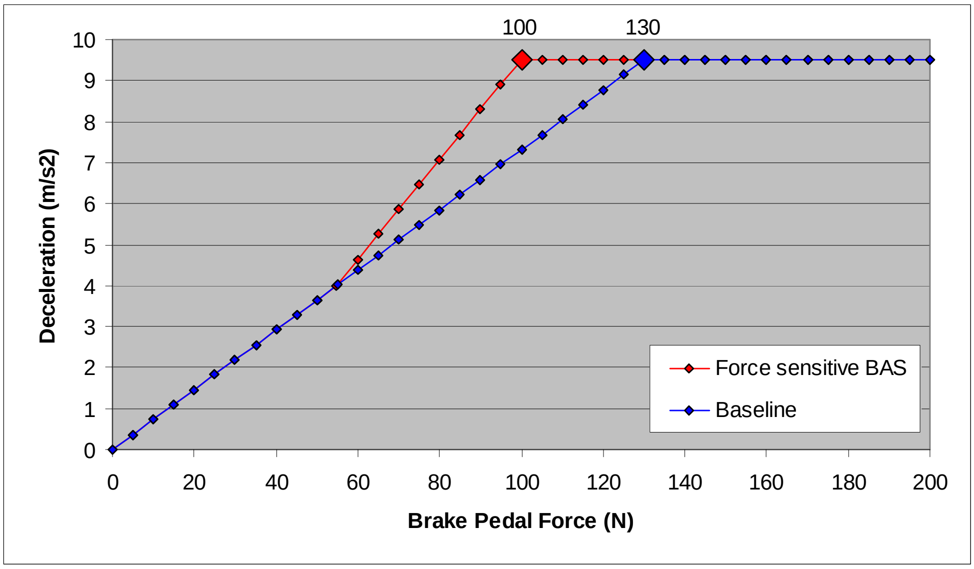


Figure 11: Typical relationship between brake pedal force and deceleration for a standard brake system and force sensitive BAS

A similar reduction in the required pedal position at a_{ABS} was also calculated as shown in Figure 12, this profile of pedal position vs. vehicle deceleration was then programmed into the simulator.

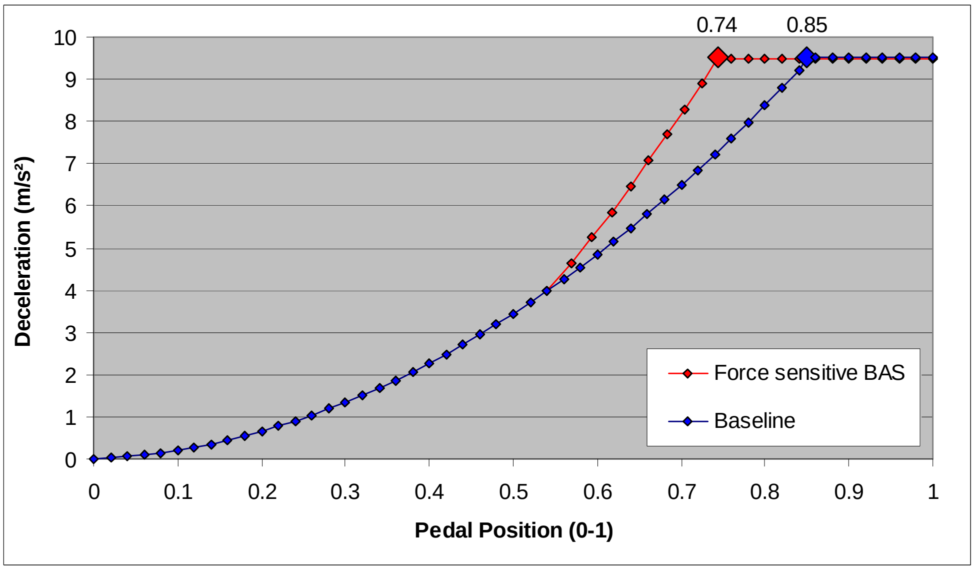


Figure 12: Simulator brake pedal characteristics for baseline and force sensitive BAS

3.2.5.3 Speed sensitive BAS

Hara *et al*. (1998) found that there was a significant difference in the initial pedal travel speed between ‘normal’ and ‘emergency’ situations and also that the initial pedal travel speed was the same for drivers who reached full pedal force and ABS braking and those who did not. This was supported by Perron *et al.* (2001), who produced the graph of driver behaviour shown in Figure 13 below.

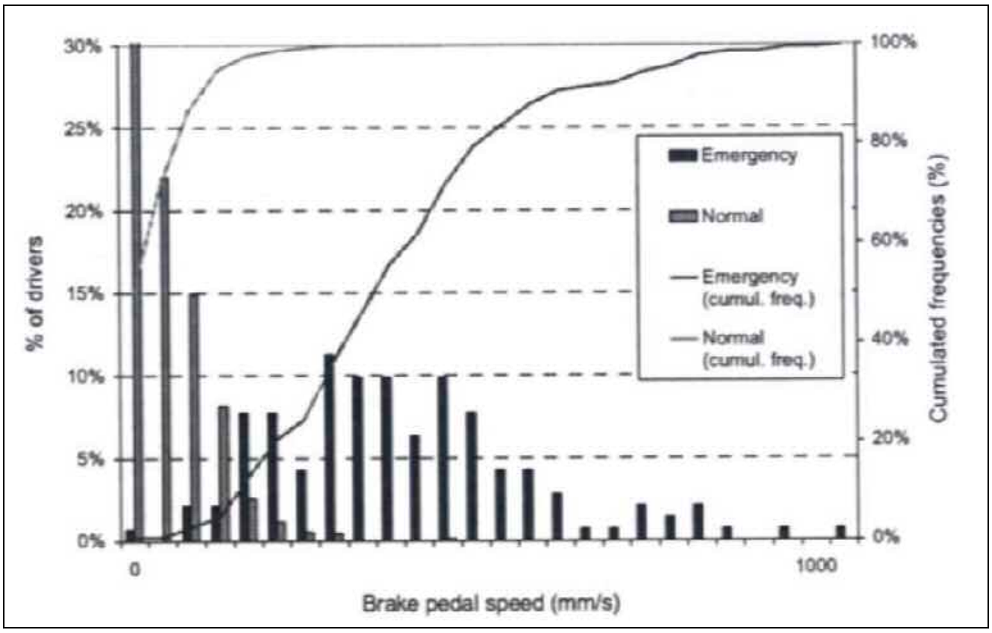
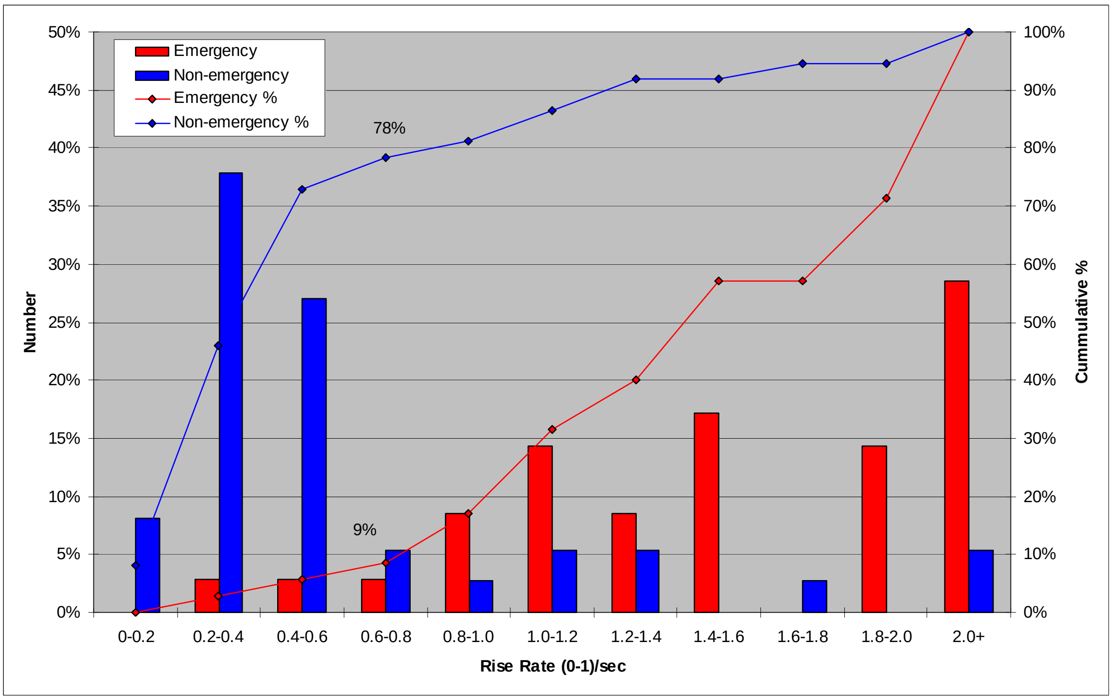


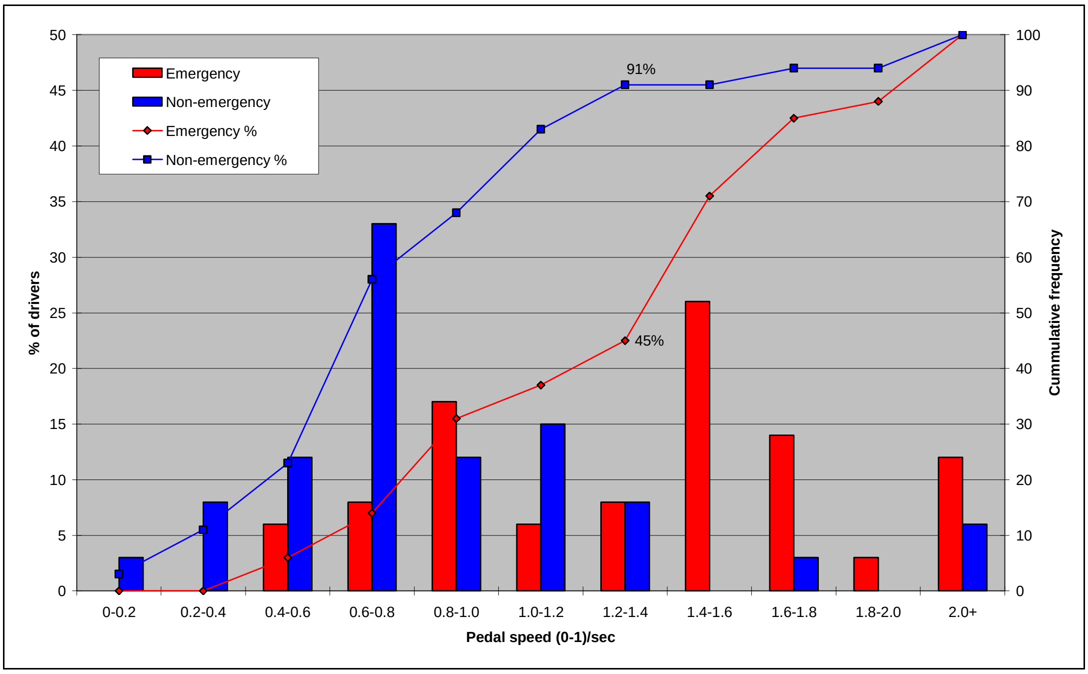
Figure 13: Driver braking reaction (Source: Perron *et al.*, 2001)

Figure 13 by Perron *et al*. (2001) showed a good separation between the emergency and non-emergency braking responses, and that for this particular vehicle the vast majority of emergency brake applications had a pedal speed greater than 300mm/s and the majority of non-emergency pedal applications had a pedal speed lower than this threshold.

Data from a previous simulator study carried out by TRL, where participants encountered both emergency and non-emergency situations was analysed to produce a graph similar to Figure 13 that was appropriate to the pedal characteristics of the driving simulator. During the course of this previous study, the TRL Driving Simulator was upgraded and the vehicle driven by the participants was also changed. Therefore data from two different simulator vehicles was available for comparison (as shown in Figure 14).



(a) Old simulator vehicle



(b) New simulator vehicle

Figure 14: Driver braking reaction times – TRL Driving Simulator

Figure 14a shows that the results using the old simulator vehicle had a clear separation between emergency and non-emergency braking events. Had this vehicle still been in use, a threshold value for the pedal speed would likely have been between 0.6/sec and 1.0/sec. In comparison, the data from the upgraded simulator vehicle (as used in this BAS study) showed a different characteristic and it could be seen that over 90% of non-emergency brake applications occurred below a threshold speed of 1.3/second, a substantially higher value than the old simulator vehicle. Therefore the simulator was programmed with the baseline profile such that when the pedal speed exceeded 1.3/second the deceleration of the vehicle would be boosted to maximum, where it would be maintained until the driver released the brake pedal.

4 Results

4.1 Track trials

4.1.1 Force sensitive BAS

The track tests carried out by TRL showed no evidence that the vehicle was equipped with any brake assist system.

Figure 15 shows a plot of mean deceleration and mean brake pedal force for a series of brake tests carried out with the above vehicle. The proposal states that the deceleration at the threshold force F_T, where the ratio of pedal force to vehicle deceleration changes, is required to be between 3.5m/s² and 5.0m/s² (as indicated by the red band). It was expected that a change in the relationship between brake pedal force and deceleration would be evident however the relationship was found to be approximately linear until maximum ABS controlled deceleration levels were reached.

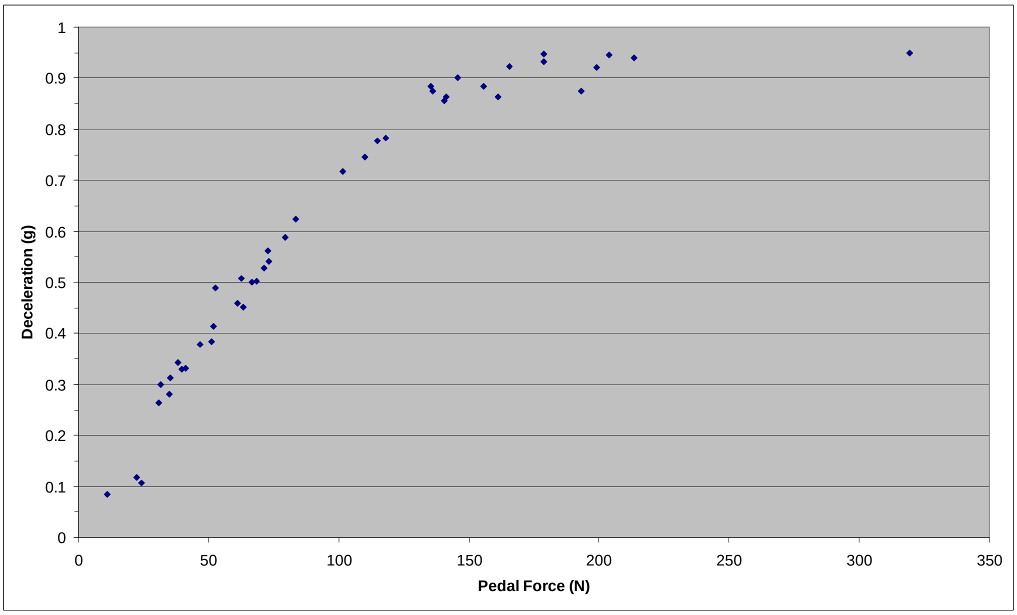


Figure 15: Pedal force characteristics – Force sensitive BAS – 100km/h

In determining F_{ABS} and a_{ABS}, five tests where the brake pedal is slowly and constantly applied are averaged. The plot of the average is referred to as the "maF curve". This graph was also analysed to see if there was any evidence of a change in the ratio between pedal force and vehicle deceleration.

Figure 16 shows a comparison between the maF curve produced for this vehicle and the minimum increase in the ratio of pedal force to vehicle deceleration required by the proposed technical standards (i.e. a decrease of at least 40% in the required brake pedal force). The exact threshold force was unknown for this vehicle; therefore a comparison was made at the upper and lower edges of the permitted range.

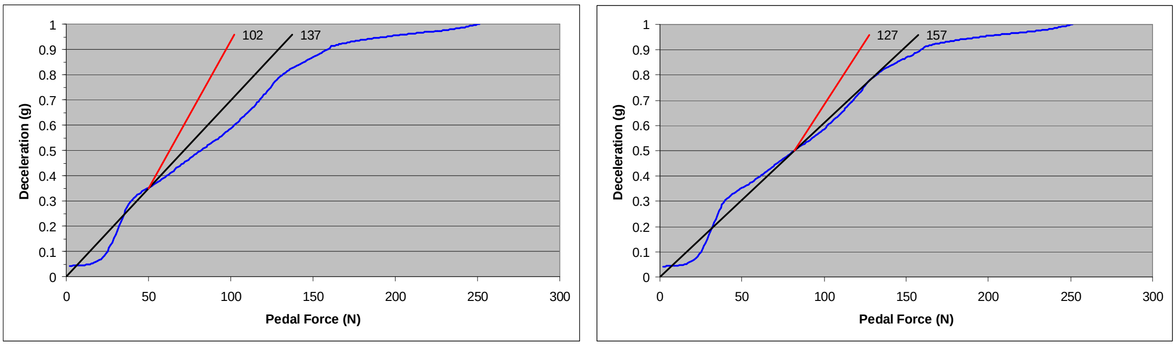


Figure 16: Comparison of 'maF curve' with requirement for force sensitive BAS

This result again supported the conclusion that this vehicle was not fitted with BAS. This matter has been discussed with the manufacturer but, to date, it has not been possible to conclusively identify why no brake assist action was found.

4.1.2 Speed sensitive BAS

Information provided by the manufacturer of the test vehicle suggested that this vehicle was fitted with a speed sensitive BAS. However, the test results appeared to show that it also depended upon the pedal force in order to activate the BAS and was in fact a multiple criteria system. This was supported by later discussion with the manufacturer. It seems likely that the reason for the misclassification was a confusion of terminology due to the fact that the ACEA proposal was intended, but not explicitly written, to treat multiple criteria systems as pedal speed sensitive.

F_{ABS} and a_{ABS} were determined to be 135N and 0.99g respectively for this test vehicle, as shown in Figure 17.

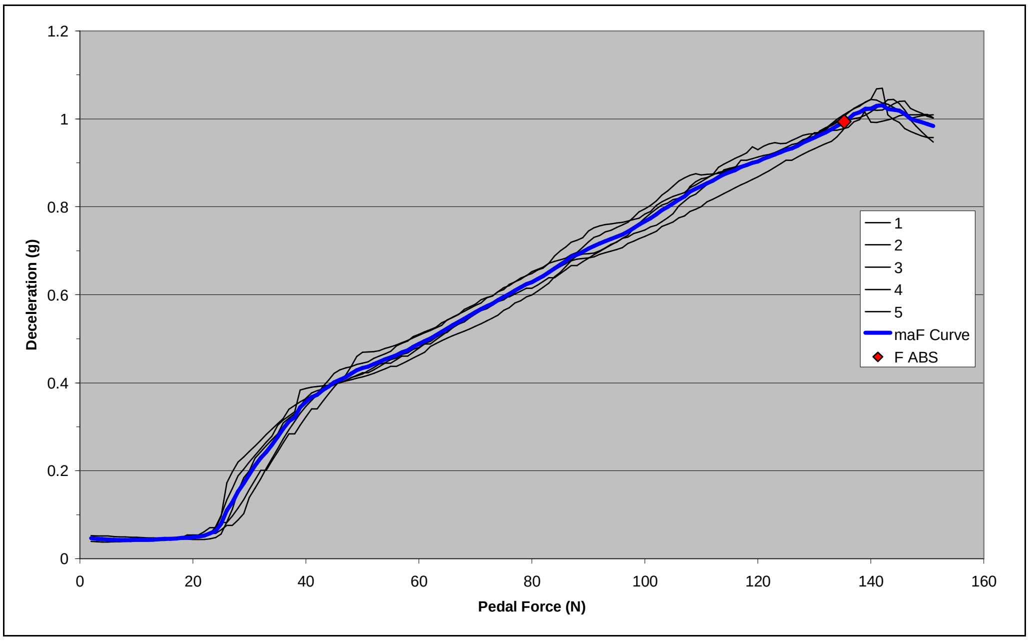
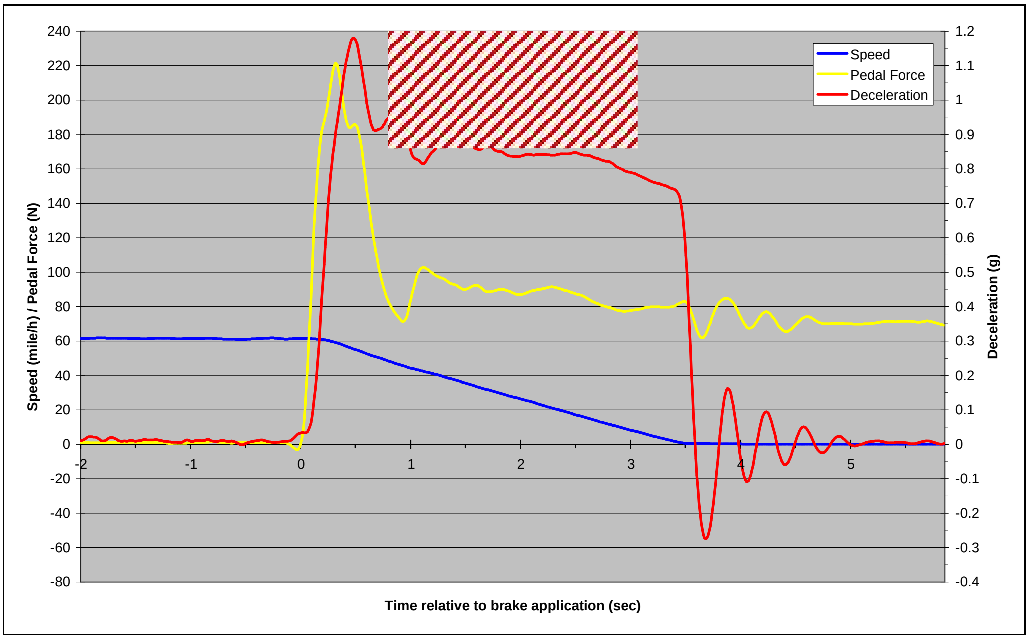


Figure 17: maF curve for test vehicle with speed sensitive BAS

The tests showed that when the pedal was pressed quickly and hard (to an initial force well above F_{ABS}) the BAS was activated. However, when the pedal was pressed just as quickly but to a lower pedal force, the BAS did not operate resulting in a lower deceleration. Figure 18 shows examples of these conditions in relation to the performance requirements of the proposed test procedure. The test requires that a pedal force is applied such that ABS and BAS are both activated. After a period of 0.8seconds, the driver is then required to maintain a pedal force between 50% and 70% of F_{ABS} until the vehicle slows to a speed of 10km/h. For BAS to be present the deceleration of the vehicle should be maintained above 85% of a_{ABS} during this time.



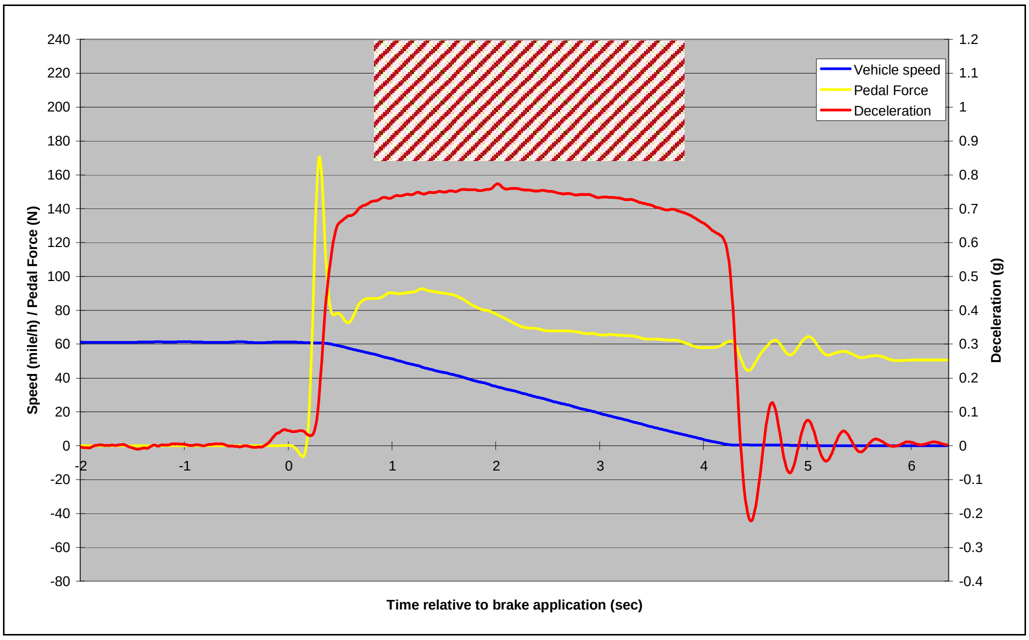


Figure 18: Comparison of tests with (top) and without (bottom) BAS activation.

It can be seen that although there is evidence of BAS activity, this particular BAS would have marginally failed the new requirements because it did not quite maintain the required $0.85a_{ABS}$ for the required duration.

In comparison, data from a completely separate project carried out by TRL was also analysed. The purpose of this other project was not to investigate BAS but as a result of the test conditions the BAS fitted to the test vehicle was activated in some tests. The test vehicle was fitted with a BAS dependant solely on the speed with which the brake pedal was applied. Figure 19 shows a graph of vehicle speed, pedal force and vehicle deceleration for a brake in a turn test. The pedal force applied was well below F_{ABS} (for this vehicle F_{ABS}=120N) and the resulting deceleration was relatively low.

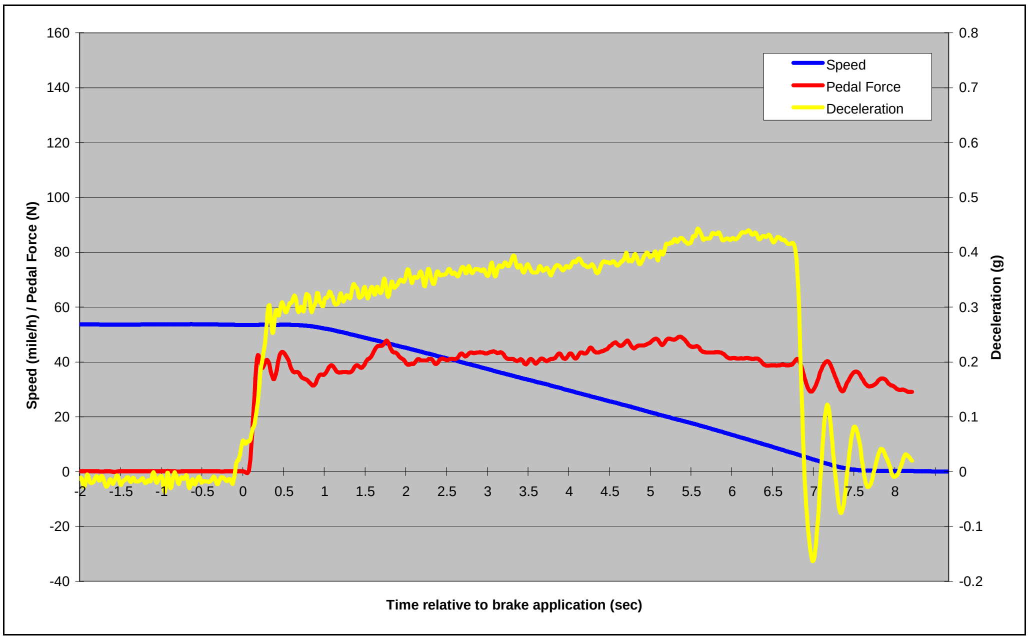


Figure 19: Brake in a turn test – without BAS intervention

In contrast, for a subsequent test with the same test conditions (Figure 20) the driver applied the brakes more quickly than in the first test and, even though the pedal force was still well below F_{ABS}, the brake assist was activated and a higher deceleration was seen. The reason that the duration of the brake application is shorter in the second test is because the driver aborted the test once it became apparent that the BAS had intervened, which in this other test programme invalidated the required conditions.

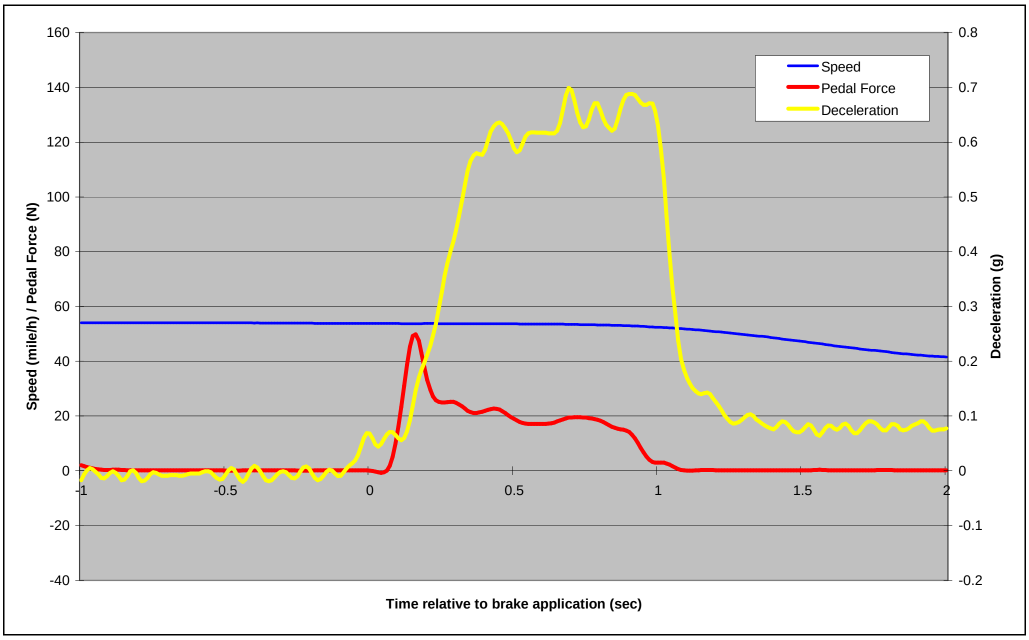


Figure 20: Brake in a turn test – with BAS intervention

It is highly likely that this speed sensitive BAS would have passed the requirements of the proposed test procedures.

4.1.3 Force and speed sensitive BAS

The third test vehicle used was, from the outset, declared by the manufacturer to be a “power” system sensitive to pedal speed, pedal force and vehicle speed. By applying the test method for speed sensitive BAS the test results showed clear evidence of BAS activity (Figure 21), even when the pedal force fell well below the required minimum.

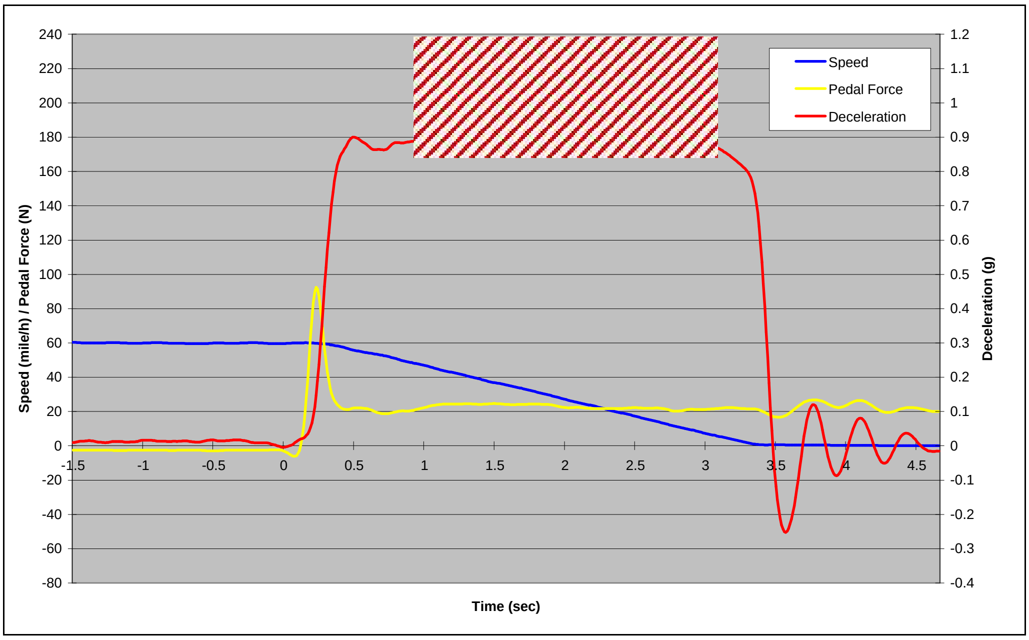


Figure 21: Evidence of BAS – Category ‘C’ BAS

Figure 22 shows a clear distinction between the tests where the BAS was activated (data points circled) and those where brake assist was not activated.

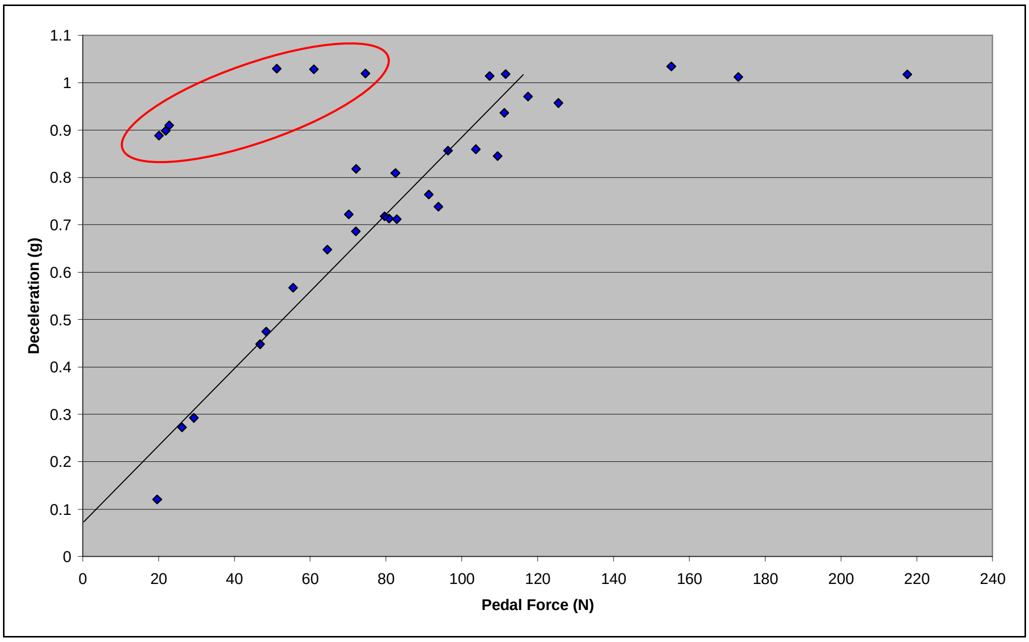


Figure 22: Pedal force characteristics – force and speed sensitive BAS – 100km/h

Additional tests were carried out with a range of pedal forces and pedal speeds and at a lower test speed (30mile/h) however, this remained insufficient to accurately map the performance of the system in three dimensions. The results, shown in Figure 23 show a strong similarity to the results at the initial test speed of 62mile/h and suggest that the pedal speed was the input variable that was most dominant in determining whether the BAS activated.

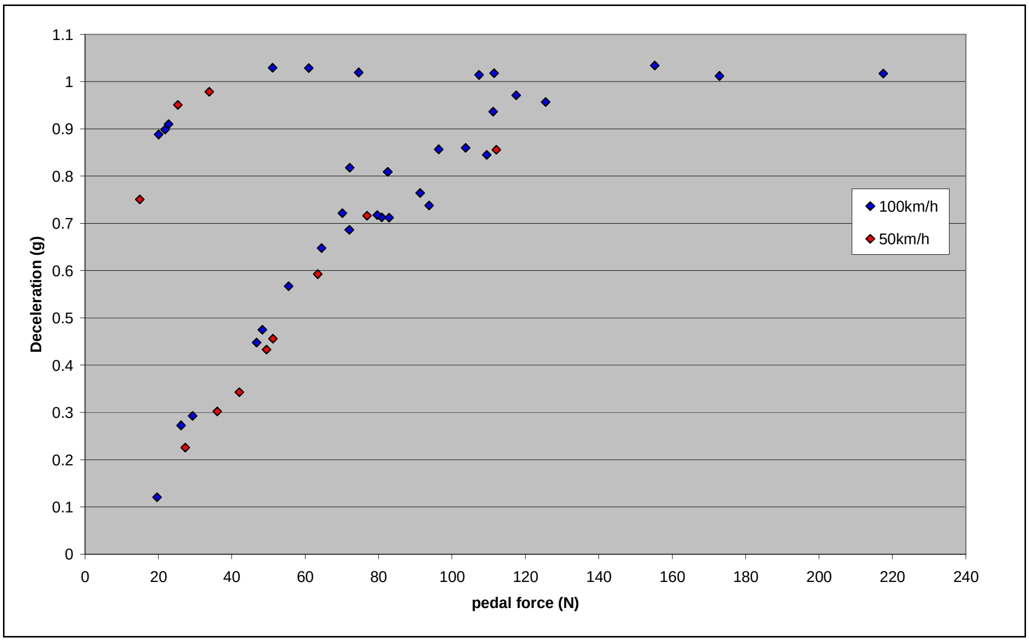


Figure 23: Pedal force characteristics at 100km/h and 50km/h

4.1.4 Additional information from industry

Following the completion of TRL's programme of track tests, a meeting was held with ACEA to discuss some of the findings. TRL presented the results that showed that the BAS initially thought to be solely dependant on pedal speed, did in fact also have a dependency on the pedal force applied by the driver and the manufacturer of that system confirmed that this was the case and also that they were aware that that particular system would require some modification to meet the proposed standard.

At this meeting ACEA presented an example of BAS which showed that, in some cases, activation would only be possible when the pedal force is above a prescribed threshold. Figure 24 shows that if the peak pedal speed was reached whilst the pedal force was still relatively low, this condition may not trigger BAS (point A on the graph). It also shows that the BAS would activate when the force reached its threshold level (point C) and if the pedal speed remained high (point B). This helps to explain why the speed sensitive BAS tested by TRL did not trigger at low pedal forces, even though the pedal speed was comparable to another test that did activate the brake assist.

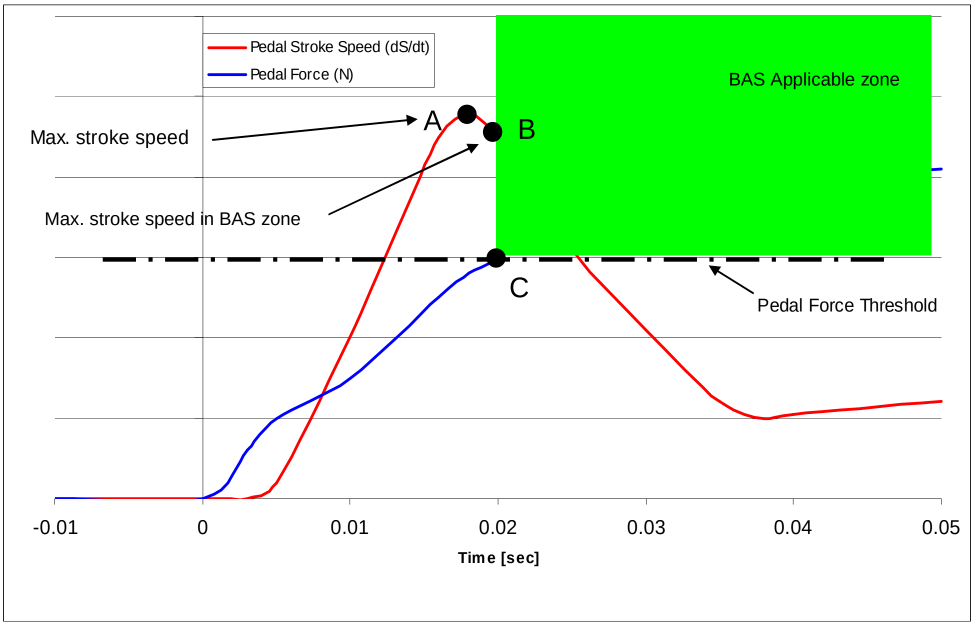


Figure 24: Activation of speed sensitive BAS (Source: ACEA)

From the start of the project ACEA held the view that it was not possible to prescribe limits on the pedal speed that should activate BAS. The reason given for this was that the speed and force with which a typical driver presses the pedal in an emergency is partly dependant on the characteristics and feel of the brake pedal.

At this second meeting, ACEA presented data which showed that two vehicles can have similar pedal force vs. deceleration characteristics (Figure 25 left) but differing pedal force vs. pedal stroke characteristics (Figure 25 right).

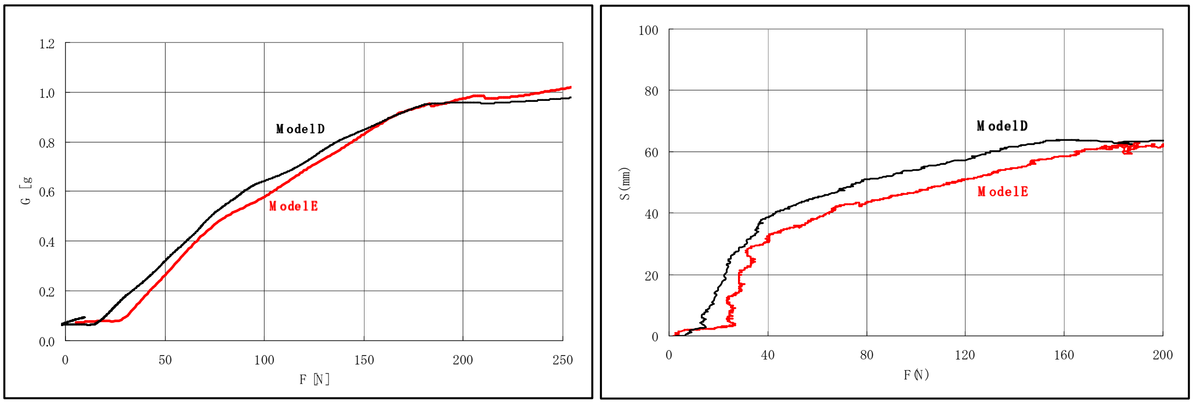


Figure 25: Pedal force vs. deceleration (left) and pedal force vs. pedal stroke (right) characteristics

As a consequence of these subtle differences the pedal speeds obtained during an emergency brake application would also be different because the greater stroke of 'model D' would lead to a greater pedal speed as shown in Figure 26. For vehicles with a much greater difference between the pedal force and pedal stroke characteristics, an even greater difference in pedal speed might be evident.

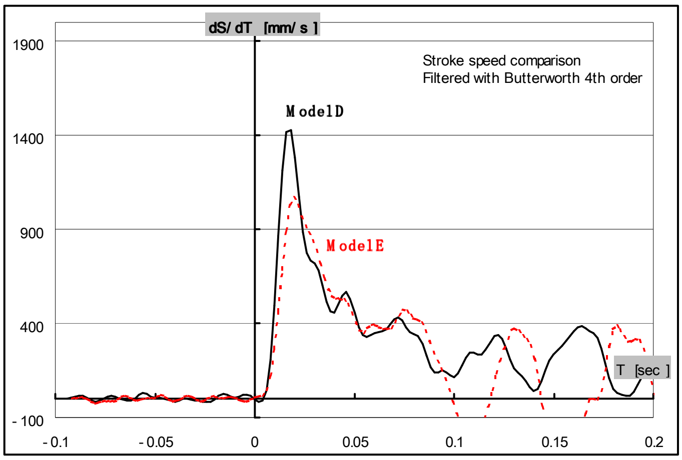


Figure 26: Example difference in pedal speed vs. time

ACEA, therefore, concluded that the appropriate threshold of pedal speed that should be used to ensure almost all drivers gain a benefit from BAS in an emergency situation while minimising intrusion on ordinary driving will vary substantially from car to car. This would mean that any limits on the thresholds may have adverse effects for some cars.

It was stated that manufacturers have dealt with this issue by correlating subjective rating of systems by skilled test drivers with the actual responses of ordinary drivers for a range of different vehicles with different characteristics. New vehicles are then developed and tuned based on the subjective ratings of the skilled test drivers.

4.2 Simulator trials

4.2.1 BAS deceleration profiles

The baseline deceleration profile, shown in Figure 12, was different to the default profile for the driving simulator as described in section 3.2.5. The default profile offered a much greater deceleration for a smaller brake pedal displacement and so it was changed to more accurately represent the deceleration profile typically seen on current passenger cars. An initial review of the data from the simulator trial revealed that for a number of subjects the deceleration profile had unexpectedly reverted back to the default profile and as a result some participants had achieved a higher deceleration than other participants.

This irregularity was investigated with the help of the company who designed and supply the software for the driving simulator however; the cause of the problem could not be established within the timescale of this project. Therefore the data from the test runs with the default deceleration profile were excluded from any further analysis.

4.2.2 Initial driving conditions

As explained in section 3.2.4, the initial driving conditions of the participants were controlled as best as possible by instructing them to maintain a speed of approximately 80km/h leading up to the braking events and by triggering the vehicle/pedestrian causing the emergency braking manoeuvre to start moving when the participants were a certain distance away from the location where the braking event was to take place.

Analysis of the initial driving conditions showed that in spite of these constraints there remained a substantial variation in the speed of the driven vehicle at the time when the event vehicle/participant first entered the road. Figure 27 shows that although the mean initial speed for each system was just below the target speed of 80km/h, overall the values ranged from 36km/h to 102km/h.

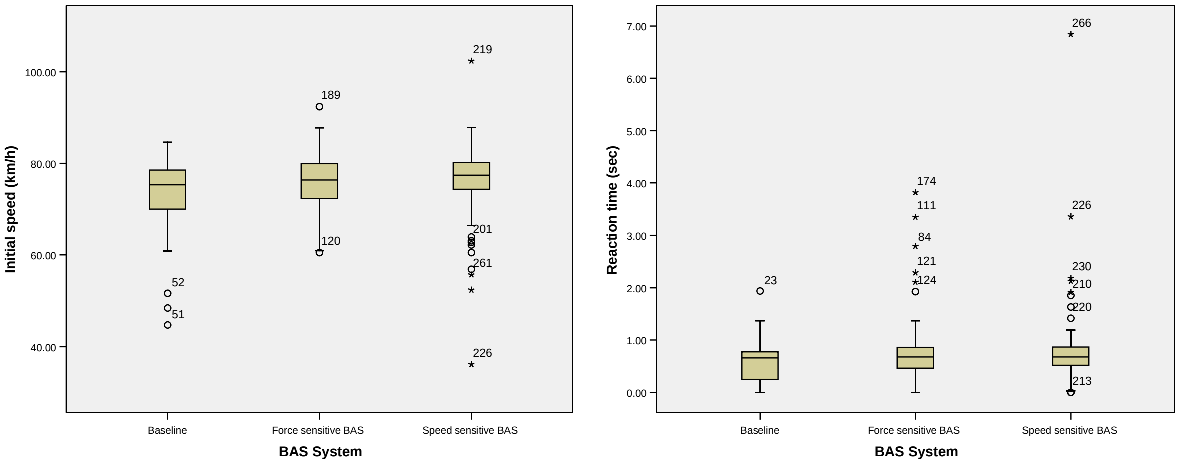


Figure 27: Range of results for initial driving speed and reaction time

Some of the variation was caused by the participants simply not adhering to the required target speed and in some cases the lower speed was caused by the participants pre-empting an event by braking before the event had even started. Figure 27 also shows the variation in the reaction times of the participants (i.e. the time taken from when the event vehicle/pedestrian first encroached into the road to the time the participant started to press the brake pedal).

To minimise this variation and to allow a statistical comparison between the baseline and two BAS systems the data was constrained by the initial driving conditions leading up to a braking event. For an initial speed of 80km/h the participant was expected to be 50m away from the location of the emergency braking event when either the vehicle/pedestrian causing the event first moved into the road. Therefore the data was restricted to consider only braking events where the participants were 50m±10m away from the location of the braking event at the time the vehicle/pedestrian first moved into the road.

Additionally it was apparent that in some cases the participants had pre-empted an emergency situation occurring and had started to apply the brakes before any vehicle had entered their lane. It was assumed that any participant making a genuine reaction to the emergency situation ahead would not start to apply the brakes any quicker than 0.5 seconds after the vehicle first entered the road. Also, if the participant were not to slow down then, from a distance of 50m and travelling at 80km/h, the participant would pass the location of the emergency braking event in approximately 2seconds. Therefore the second constraint applied to the data was to only consider braking events where the reaction time of the driver (i.e. the time taken to start to press the brake pedal) was between 0.5s and 2.0s. Figure 28 shows how the constraints reduced the scatter on the initial conditions.

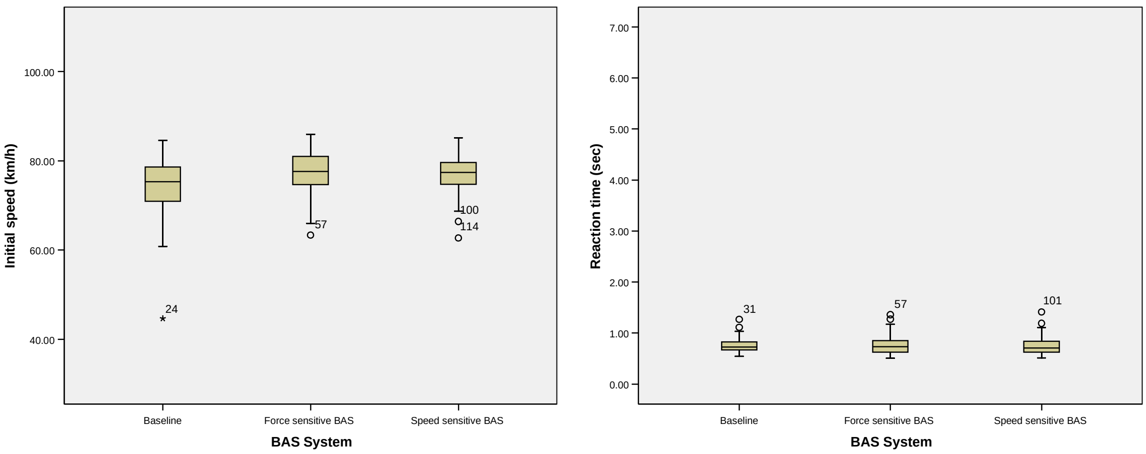


Figure 28: Range of results for initial driving speed and reaction time (constrained data)

4.2.3 *Braking events*

A brake assist system does not increase the maximum deceleration of a vehicle, but provides assistance to the driver by boosting the braking effort so full ABS deceleration is more easily achieved than for a normal driver in a car without brake assist. This has the effect of increasing the mean deceleration of the vehicle during a braking manoeuvre because a greater proportion of the manoeuvre is spent at a higher deceleration. Therefore, because the simulator vehicle had a consistent maximum deceleration, a comparison of the mean deceleration offered a good indication as to any potential benefit of the brake assist systems.

The average values for the mean deceleration are given in Table 3, for each of the three configurations.

Table 3: Mean deceleration statistics for constrained data

Configuration	Mean deceleration (m/s^2)	N° of data points	Standard Deviation
Baseline	7.541	33	0.777
Force sensitive BAS	7.886	54	0.677
Speed sensitive BAS	8.876	49	0.233
Total	**8.159**	**136**	**0.808**

An analysis of variance (ANOVA) was conducted on the data. Analysis of variance is used to test the null hypothesis that the different means and variances are equal and the samples are therefore from the same population. In this test the variance between the means of each sample (the three different configurations) was compared to the variance between individual results in the same sample. Variance is calculated by summing the squares of the difference between individual values and the mean. The degrees of freedom are related to the number of data points evaluated. The F-value is a statistical value that can be related to probability via published tables.

The ANOVA model included factors for the subject, the run number (i.e. whether it was the participants first, second or third journey) and the BAS configuration being assessed. The sums of squares were partitioned using the type IV approach which is appropriate for hierarchical models where there may be missing data at some levels. Even though the data were not balanced over subjects and BAS configurations, the statistical analysis software used calculated effect sizes taking this into account.

The factors were input in a hierarchical order, the first being the subject number. The effect of this was to control for subject differences – thereby largely eliminating individual driver differences.

The next factor fitted was the run number. This did not prove to be statistically significant (and so was removed from the analysis) however, had it been significant then it would have controlled for any learning effect. This suggests that there were no overall statistically significant learning effects. Finally, the BAS system factor was fitted.

The ANOVA analysis, Table 4, showed that there was a statistically significant effect ($p<0.001$)[1] due to different subjects and a stronger effect due to the BAS system ($p<0.001$), the ANOVA model explained more than 66% of the variation.

[1] p-value is the probability of obtaining a result at least as extreme as a given data point, assuming the data point was the result of chance alone.

Table 4: ANOVA table for: Mean deceleration

Source	Type IV Sum of Squares	Degrees of freedom	Mean Square	F-value	Significance
Corrected Model	66.20[a]	35	1.89	8.66	<0.001
Intercept	5982.27	1	5982.27	27376.55	<0.001
Subject Number	24.36	33	0.74	3.38	<0.001
BAS Configuration	27.47	2	13.74	62.86	<0.001

[a] R Squared = .752 (Adjusted R Squared = .665)

Although the ANOVA analysis identifies whether or not there is a difference it does not state which of the BAS configurations are different. To determine this, a post hoc analysis was carried out using Tukey's honestly significant difference (HSD) test.

The differences between the three configurations are evaluated in Table 5. It shows that the largest difference between raw (i.e. unadjusted) mean values was between the baseline system and speed sensitive BAS. The next largest was between the force sensitive BAS and the speed sensitive BAS ($p<0.001$) and that the difference between the baseline system and force sensitive BAS was also statistically significant different from zero ($p<0.01$).

Hence, it can be concluded that force sensitive BAS produced a statistically significant increase in mean deceleration as compared with the baseline system, as did the speed sensitive BAS. The speed sensitive BAS also produced a statistically significant increase in deceleration as compared with the force sensitive BAS.

Table 5: Multiple Comparisons - Mean deceleration (Tukey HSD)

Configuration		Mean Difference (I-J)	Std. Error	Significance	95% Confidence Interval	
(I)	(J)				Lower Bound	Upper Bound
Baseline	Force sensitive BAS	-0.345	0.103	<0.01	-0.591	-0.099
	Speed sensitive BAS	-1.335	0.105	<0.001	-1.586	-1.085
Force sensitive BAS	Baseline	0.345	0.103	<0.01	0.099	0.591
	Speed sensitive BAS	-0.99	0.092	<0.001	-1.21	-0.771
Speed sensitive BAS	Baseline	1.335	0.105	<0.001	1.085	1.586
	Force sensitive BAS	0.99	0.092	<0.001	0.771	1.21

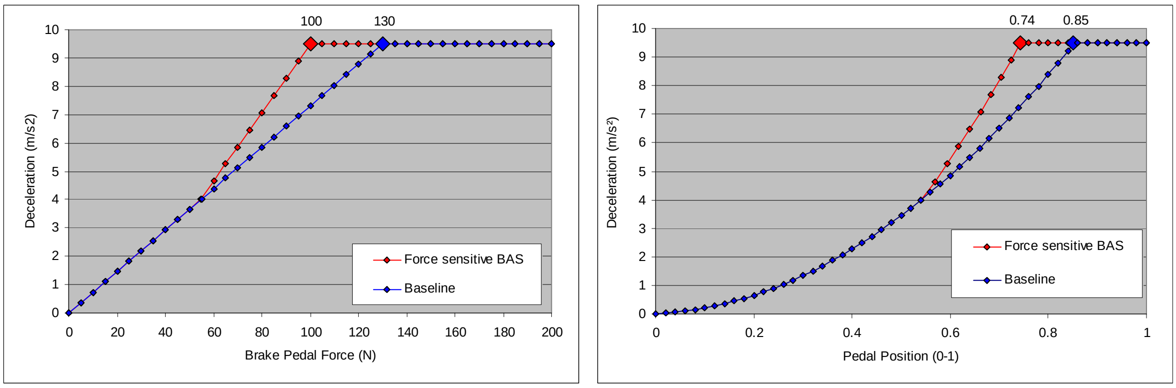
4.2.3.1 Brake pedal position

The deceleration profiles programmed into the Driving Simulator were designed such that the force sensitive BAS should give a 40% reduction the brake pedal force required to achieve full ABS braking compared to the baseline system. This was the minimum reduction proposed in the draft technical requirements (Appendix B). An analysis of the individual braking events revealed that although the deceleration profiles all had a similar shape (approximately quadratic) the gradient of the profiles varied from one braking event to another even within the same configuration. This variation did not affect the speed sensitive BAS because this system provided a step boost to maximum deceleration rather than provide a proportional increase in deceleration like the force sensitive BAS.

TRL's Driving Simulator works by taking a voltage reading from the brake pedal and feeding this into a complex dynamic model which calculates the output deceleration. When calculating the output deceleration, the dynamic model considers a large number of parameters including vehicle speed, tyre coefficients, brake temperature, the road surface condition and weather. This complexity combined with the different gear selections and (in some cases) engagement of the clutch meant there was a degree of variation in the deceleration profile from one braking event to another.

In order to quantify the difference between the individual braking events and to ensure that the desired reduction of 40% was met some measure was needed to describe the shape of the deceleration profile for each braking event. A number of options were considered including the area under the graph, and the gradient of the graph above the BAS trigger threshold of 4m/s². The parameter which appeared to best describe the shape of the graph was position of the brake pedal when the deceleration of the vehicle first reached 9m/s².

Figure 29 shows the expected brake pedal characteristics for the baseline and force sensitive BAS. It shows that a 40% reduction in brake pedal force corresponded to the force sensitive BAS reaching maximum deceleration when the brake pedal position was 0.74 (on a scale of 0-1) compared to 0.85 for the baseline system. For these profiles the pedal position when the deceleration reached 9m/s² was 0.73 and 0.83 for the force sensitive BAS and baseline respectively.



(a): Brake pedal force characteristics (b): Brake pedal position characteristics

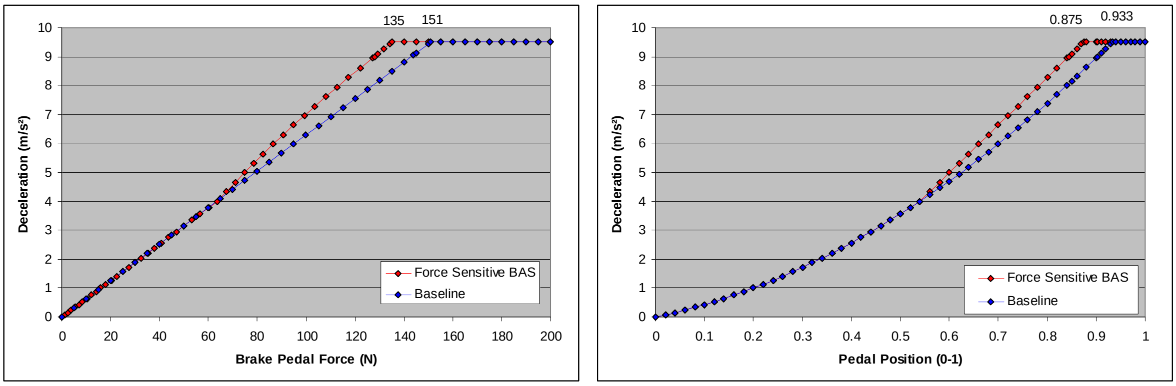
Figure 29: Expected simulator brake pedal characteristics for baseline and force sensitive BAS

Table 6 shows the mean values of the position of the brake pedal when the deceleration first reached 9m/s for the three configurations tested in the simulator. It shows that both the baseline and force sensitive systems reached a deceleration of 9m/s² at a higher pedal position than expected, and that the difference between the two systems was also smaller than anticipated.

Table 6: Average value of brake pedal position when deceleration reached 9m/s²

Configuration	Pedal Position
Baseline	0.90
Force sensitive BAS	0.84
Speed sensitive BAS	0.54

Figure 30 shows, based on the average values for each configuration, the actual brake pedal characteristics for the baseline and force sensitive BAS. It was calculated that the smaller than expected difference between the pedal position at 9m/s² for the baseline and force sensitive systems represented a reduction in the brake pedal force of only 18% compared to the 40% required by the proposed technical requirements. Therefore, had this vehicle been tested in accordance with the procedure in the proposed technical requirements, it would not have been considered to have BAS fitted. Despite this, the results described in section 4.2.3 did show that the mean deceleration of the simulator vehicle configured with a force sensitive BAS that only offered a 18% reduction in brake pedal force did give a statistically significant increase in mean deceleration compared to a similar vehicle not fitted with BAS.



(a): Brake pedal force characteristics (b): Brake pedal position characteristics

Figure 30: Actual simulator brake pedal characteristics for baseline and force sensitive BAS

4.2.3.2 Other measures of braking performance

Two other measures related to the performance of brake assist systems were also analysed. These were the pedal position when the vehicle first reached 90% of its peak deceleration, and the time taken from when the brakes were first applied to reach 90% of peak deceleration. The mean and standard deviations for these other measures are shown in Table 7.

Table 7: Mean and standard deviations for other braking performance measures

Configuration		90% of peak deceleration (m/s²)	Time to reach 90% peak deceleration (sec)
Baseline	Mean value	9.603	0.93
	Std. Deviation	0.555	0.321
Force sensitive BAS	Mean value	9.579	0.793
	Std. Deviation	0.355	0.271
Speed sensitive BAS	Mean value	9.628	0.596
	Std. Deviation	0.222	0.414
Total	Mean value	9.602	0.755
	Std. Deviation	0.375	0.362

An analysis of these measures was conducted following the same procedures that were used for the analysis of the mean deceleration. A summary of the results are shown in Table 8, where the probabilities that there is no difference between the mean values using different BAS systems are given.

Table 8: Probability that there is no difference between BAS systems – by measure

Measure	comparison between configurations		
	Baseline v force sensitive BAS	Baseline v speed sensitive BAS	Force sensitive BAS v speed sensitive BAS
90% of peak deceleration (m/s^2)	$p>0.10$	$p>0.10$	$p>0.10$
Time to reach 90% peak deceleration (sec)	$p<0.10$	$p<0.001$	$p<0.01$

It is evident from Table 7 and Table 8 that there was no difference between the three configurations when comparing the '90% of peak deceleration' measure, i.e. the probability was greater than 10% that the samples were the same. However the 'time to reach 90% of peak deceleration' measure was approaching statistical significance (at the usual 0.05 level) when comparing the baseline and force sensitive BAS, and was statistically significant when comparing the baseline and the speed sensitive BAS.

This again supports the view that using BAS does not increase the maximum deceleration of a vehicle, but it can help to reduce the time taken to reach the maximum deceleration and increase the mean deceleration during an emergency braking manoeuvre.

5 Discussion

5.1 Proposed technical requirements

Considering the information gathered from industry and the findings of the track trials carried out by TRL, a proposed revision to the technical requirements for BAS has been prepared by TRL. This proposal can be found in Appendix A to this document.

Some minor changes have been made to the wording of section A of the proposal, which identify the proposed modifications to UNECE Regulation 13H. A new paragraph has been inserted which requires that the service brake performance of the vehicle is maintained in the event of any failure of the brake assist system. The categories of BAS have also been renamed so that three categories of BAS are now defined. The third category was added after initial discussions with the ACEA BAS task force and the physical track tests confirmed that there were some systems that were sensitive to force alone, some that were sensitive to speed alone and some more complex electronic systems that used multiple activation criteria, typically brake demand pressure (approximating pedal force), brake demand pressure gradient (approximating pedal speed) and vehicle speed.

In both the ACEA and EC proposals the method for determining F_{ABS} and a_{ABS} was split, with part of the procedure described in the main document and part described in an Appendix. TRL has proposed moving all the requirements for this test method into Appendix 1 of the proposal to improve the clarity of the document. Additionally some modifications to the structure of the requirements have been proposed. In step 3 of the ACEA proposal a linear regression line must be drawn between *"all values on the maF curve below the pedal force F_{min} and above half the ABS deceleration value (0.7 * a_{ABS})"*. Mathematically, half of the ABS deceleration is equivalent to $0.5*a_{ABS}$, therefore, the EC's proposal to move the lower regression point to $0.5*a_{ABS}$ results in a mathematically correct requirement. Comparing the use of different regression points on the data from the test programme suggested that the use of $0.7a_{ABS}$ resulted in a better fit and a more accurate definition of F_{ABS} therefore TRL has proposed keeping the mathematically correct statement from the EC proposal but consider that returning to the ACEA value of $0.7a_{ABS}$ with the wording amended accordingly. It should be noted that it is not considered that the use of either value would make a large overall difference to the minimum performance of BAS.

Although the tests with a pedal force dependant BAS did not show any brake assist action, it is recommended that the basis of the test procedure remains as described by the existing technical proposals. The rationale for this recommendation is that the test procedure was proven to successfully identify a vehicle with a system not meeting requirements and analysis of the method has not revealed any obvious mechanisms by which it could fail to identify a system that did meet the requirements. However, the technical requirements contained in the ACEA and EC proposals only require a minimum reduction in the brake pedal force required to reach a_{ABS} (i.e. a decrease of at least 40% in the required brake pedal force). No upper limit for this reduction in required pedal force is required. This means that it would be theoretically possible, if unlikely, that a manufacturer could design a system that provides a step boost to full ABS deceleration above the threshold force. In such a case the driver would have graduated braking up to the threshold force and then, above this force, the brake pedal would effectively become a switch between the deceleration at the threshold force and full ABS deceleration. Such a system could have serious adverse safety effects.

It is likely that type approval authorities would interpret the regulations in such a way that a system as described above would not be considered to have "graduated braking" and would, therefore, not gain approval under existing braking regulations. However, for the avoidance of doubt, TRL has proposed including an upper limit to prevent the system simply providing a step boost to a_{ABS}, as illustrated in Figure 31. TRL has proposed that the maximum reduction in the brake pedal force is 80%. It should be noted that this value has not been derived experimentally and has been proposed in square brackets to indicate that the actual value used should be the subject of further analysis or negotiation.

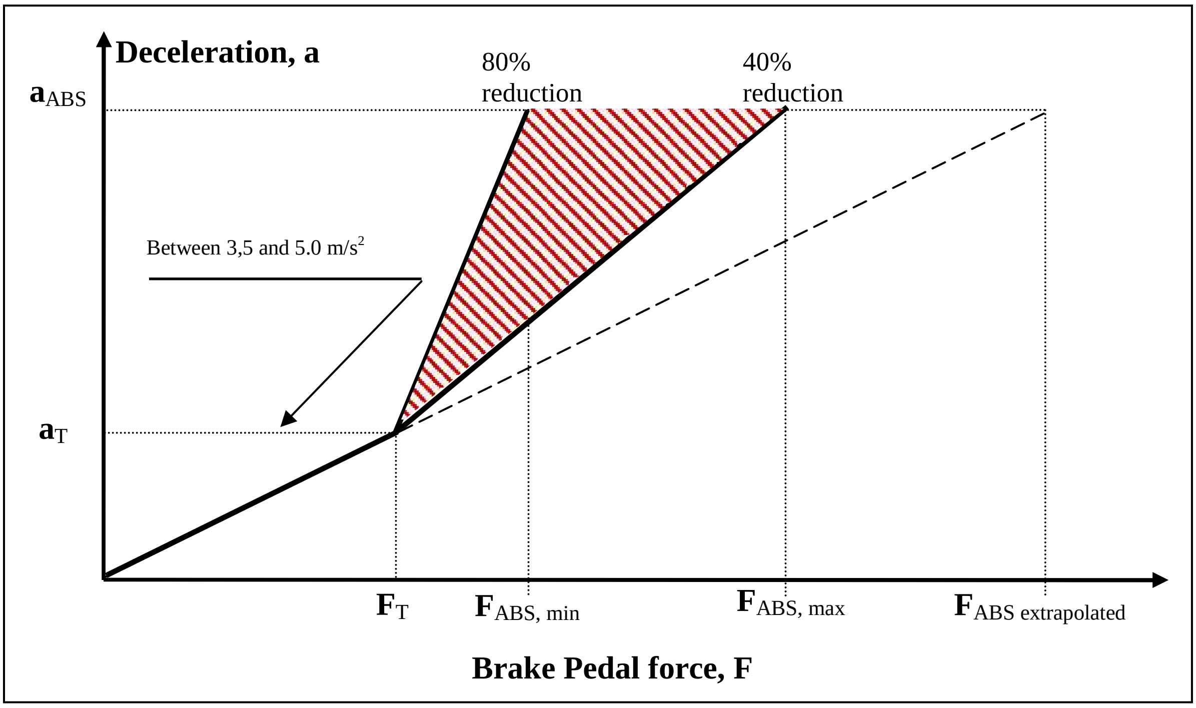


Figure 31: TRL's proposed requirements for force sensitive BAS

An explanation was sought both from the manufacturer of the test vehicle and the ACEA BAS task force as to why an initial pedal force in excess of F_{ABS} had to be applied at very high pedal speeds in order to activate the BAS originally classed as speed sensitive. The response of the vehicle used in this test programme that was thought to be fitted with a speed sensitive system was compared to data TRL obtained during the course of braking in a turn tests on another vehicle with solely speed dependent BAS as part of a separate project. For this earlier vehicle BAS activation was achieved wherever the pedal speed was high even with very low forces well below F_{ABS}.

The reasons given were two-fold. Firstly, simple speed sensitive devices had in some cases attracted complaints from drivers and passengers that the BAS activated when emergency braking was not intended. Thus, the force requirements and the relationships with vehicle speed were introduced to limit such intrusion on ordinary driving. The more complex systems tend to be electronic and are typically fitted to vehicles equipped with ESC. These systems rely on pressure transducers in the brake system to derive measures of brake pedal force and rate of application but there is an inherent lag and/or damping between the pedal and the brake pressure that means that a high speed at the pedal has to be maintained for a certain time before it is measured as a high pressure gradient. This inevitably means a higher force has to be reached. However, it was also claimed that the same lag and/or damping meant that typical drivers would actually do this in an emergency and then drop down to much lower levels of force almost immediately such that the BAS was still providing an advantage to drivers who pressed the pedal quickly but not sufficiently hard.

An example, presented by ACEA at a meeting with TRL showed that activation of BAS is, in some cases, only possible when the pedal force is above a prescribed threshold. Therefore, if the peak pedal speed is reached whilst the pedal force is still relatively low, this condition may not trigger BAS. This helps to explain why the “speed sensitive” BAS tested by TRL did not trigger at low pedal forces, even though the pedal speed was comparable to another test that did activate the brake assist.

Feedback from the TRL test driver appeared to confirm that the initial peaks in the pedal force, although recorded by the data logging equipment, would be barely noticeable to the driver and that they had been achieved in tests where the target was to achieve a low pedal force quickly. There is at least some evidence, therefore, that the explanation from industry is valid.

Initial discussion with the ACEA BAS task force suggested that the test they proposed for speed sensitive BAS was also intended to be applicable to multiple criteria (category C) system. The rationale appeared to be that category C systems were still “speed sensitive” even though they were also sensitive to other parameters. The results of the track tests did suggest that the pedal speed was the input variable that was most dominant in determining whether the BAS activated. It was, therefore, considered that the test procedure for speed sensitive category B systems was the most appropriate method for identifying category C systems as well unless a comprehensive matrix of tests and minimum performance criteria could be developed.

To ensure that it is perfectly clear to all involved that this is the case, additional paragraphs have been inserted into TRL’s proposal to specify that the test method for speed sensitive BAS should also be used for multiple criteria BAS. However it should be noted that although this system appears to be capable of identifying the presence of speed sensitive BAS (category B or C) it cannot necessarily discriminate between the two and does not rigorously quantify the effectiveness of the systems. For example, both speed sensitive systems tested as part of this research appeared to be category C systems but the second system was subjectively much easier to activate than the first and the objective measurements showed it could be activated with lower initial peaks of pedal force and that the difference between the BAS active and not active condition was greater. The speed sensitive category B system, tested as part of previous research, could be activated at even lower pedal forces. However, ACEA acknowledge that this type of system has, in some cases, attracted customer concern about activation in non-emergency situations. Which system is more effective at reducing accidents in the real world remains unknown although both systems would gain approval equally using this test procedure.

Lawrence *et al* (2006) suggested that the test procedure would be more robust of it was capable of setting boundaries for the BAS activation criteria as well as the amount by which deceleration was boosted. The intention was that it would then be impossible to approve extreme systems that could only be activated by drivers that already applied the pedal quickly and hard, thus offering little benefit, or systems that could be activated with slow gentle brake applications that would benefit the maximum number of drivers in emergency situations but potentially produce significant adverse effects for many drivers in non-emergency situations.

This has been possible for force dependant (category A) systems where the threshold force F_T must give a corresponding deceleration between 3.5m/s² and 5.0m/s², and where the upper and lower boundaries of the reduction in the brake pedal force required to reach a_{ABS} are defined. However TRL's work in this study has shown that it would be extremely difficult to prescribe such limits on the brake pedal speed that activates the BAS.

In order to investigate this further, the data from a previous TRL study into emergency braking behaviour (related to emergency brake light displays) in the driving simulator (Dodd et al, 2005) was re-analysed. In this study the simulator trials had been carried out either side of the simulator being upgraded to use a newer base car. Different brake pedal speeds in emergency and non-emergency situations were found. However, the speeds in emergency and non-emergency situations were also different in the new car compared with the old such that the pedal speed that appeared most appropriate to characterise emergency braking was different for the two different cars.

In addition to this, the information supplied to TRL by industry at the start of this project also revealed a large variance in the threshold values of pedal speed (90-620mm/sec) for the BAS vehicles they manufactured. It was found during the set up for the current simulator trial that if any of the pedal speed thresholds provided by industry had been used as the threshold for the simulator trials they could have been very inappropriate to the behaviour of typical drivers of the simulator. The evidence available to TRL does, therefore, support the view that it is not possible to specify ranges of appropriate pedal speeds. It is unlikely to be possible to define such limits without very extensive data from trials with subjects in a very wide range of conditions that would enable fundamental pedal characteristics to be positively linked with the speed and force with which drivers apply the pedal in emergencies and non-emergencies. Even if such research were to be carried out it would not necessarily be "future proof" because some new variable introduced on a new vehicle could change the relationships defined.

To impose a restriction on the range of speeds at which BAS must activate would, therefore, be expected to have at least one of the following effects:

- The range specified would be so wide that it would not actually exert any significant control on the design of such systems and would, therefore, be meaningless
- A narrower range of permitted activation speeds would have the effect of either:
    - Controlling the pedal "feel" characteristics so that only those pedal characteristics resulting in an emergency braking threshold within the permitted range of BAS activation speed were fitted to cars. In practice this could be difficult and costly to achieve because pedal "feel" is influenced by a wide range of design parameters that each have manufacturing tolerances that can affect it
    - BAS activation thresholds would be set within the range when the pedal characteristics result in an emergency braking threshold outside the range, thus guaranteeing reduced effectiveness of the system and allowing the possibility that entirely inappropriate systems could be approved.

The view of the ACEA BAS Task Force supported TRL's conclusion, saying that the speed and force with which a typical driver presses the pedal in an emergency is partly dependant on the characteristics and feel of the brake pedal. ACEA provided additional data based on the characteristics of other vehicles to further support this view.

For these reasons, the proposed test procedure has had to remain based on pedal application criteria to be defined by the manufacturer, which relies on the manufacturers' duty of care and product liability obligations to ensure that the systems are appropriate.

Discussion with manufacturers has suggested that manufacturers have coped with this difficulty by carrying out objective tests with subjects on a selection of cars with different characteristics and correlating the results with subjective assessments by highly skilled test drivers. The main work of developing BAS on new models is then carried out using the subjective assessments of skilled test drivers. This approach can be a suitable compromise but is ultimately subjective and requires careful handling and there is no guarantee that individual manufacturers use consistent and high quality approaches. This, combined with the fact that many facets of category three BAS remain untested, has led TRL to recommend requiring manufacturers to declare the input variables influencing BAS activation and the mode of boost and the relationships between them as well as providing evidence to demonstrate how those variables and relationships ensure that the system is effective for ordinary drivers.

Although this information led approach cannot guarantee minimum levels of effectiveness it will enable the implementation of BAS to be monitored by approval authorities to identify large inconsistencies between different systems and to identify if the nature of BAS gets changed substantially at any time. It may also give the Technical Authority the power to check that the completed system conforms to the design information if there is any reason for concern. It is likely that much of the information required would have to be presented anyway in order to enable the tests to be carried out and to satisfy Annex 8 (complex electronic control systems) but it should be noted that some BAS are purely or mostly mechanical and may not, therefore, fall within the scope of Annex 8. It is likely that the level of technical detail to be held by the Technical Service would have to be a matter of negotiation with industry to ensure a good balance between obtaining useful information and protecting any information that is commercially sensitive for the manufacturer.

Bearing in mind that there may be new categories of Brake Assist which may be developed by manufacturers in the future, which may also need to be included under the scope of the technical requirements, the ideal specification would be one that is technology-neutral and which specifies only the fundamental requirements that a Brake Assist system is expected to achieve. It is possible to conceive of a test whereby a specified brake pedal input, representative of a typical drivers' reaction, is applied and the stopping distance and/or mean deceleration of the vehicle is measured with Brake Assist inactive. The test could be repeated with an identical input with the BAS active and a minimum reduction in stopping distance or a minimum increase in deceleration could be prescribed. However, for all the reasons discussed above, such an approach would still have to rely on the manufacturer specifying the characteristic of brake input to be used because the pedal feel characteristics would still influence the speed and force with which a typical driver pressed the pedal in response to an emergency.

Such an approach also relies on being able to de-activate the Brake Assist. This may prove difficult for some of the simple force sensitive systems that may involve a two-stage piston which is permanently connected within the brake booster. Further work would be required to assess the benefits and limitations of this type of approach.

One further comment relates to the scope of application of the proposed standard. The proposal is based on one provided by the EC and is proposed as an amendment to UNECE regulation 13-H. It is understood that one of the main reasons for developing the requirement is to enable the introduction of BAS as a complementary measure in the pedestrian Directive for M1 passenger cars and the proposal would fulfil that requirement. However, regulation 13-H only applies to M1 passenger cars. BAS can be fitted to other vehicle types including light vans (N1), trucks (N2/3) and buses (M2/3). Although no specific tests or assessments of the effectiveness of the system or the test procedures have been carried for other vehicle types as part of this research there are no obvious reasons to suggest that the test procedures should be substantially different. It may, therefore, also be appropriate to propose the same or similar requirements be inserted into UNECE regulation 13 such that if BAS is fitted to other vehicle types it conforms to the same basic standards.

5.2 Relative performance of force sensitive BAS and speed sensitive BAS

The results of the simulator trials showed that both the force sensitive BAS and the speed sensitive BAS offered improved braking performance compared with a similar vehicle not fitted with BAS (i.e. the baseline configuration). The results showed that the speed sensitive system gave a higher mean deceleration and also reached 90% of its peak deceleration quicker than the force sensitive system. However, it is worth noting that the force sensitive BAS evaluated only achieved an 18% reduction in the brake pedal force at a_{ABS}, compared to the minimum requirement of a 40% reduction as prescribed in the proposed technical requirements. Had a reduction of 40% been achieved than it is reasonable to expect that the benefits of the force sensitive BAS would have been much closer to the speed sensitive BAS.

For example, the data from the simulator trials (Figure 32)showed that, for the baseline profile, a deceleration of 9m/s² was achieved with a the brake pedal position of 0.903 (this corresponds to a brake pedal force of 143N). The trials also showed that an 18% reduction in brake pedal force resulted in a pedal force of 128N (and a corresponding pedal position of 0.84). Using the same principle, if the required 40% reduction in brake pedal force had been achieved, then it can be estimated that the brake pedal force and brake pedal position at 9m/s² would have been 111N and 0.77 respectively.

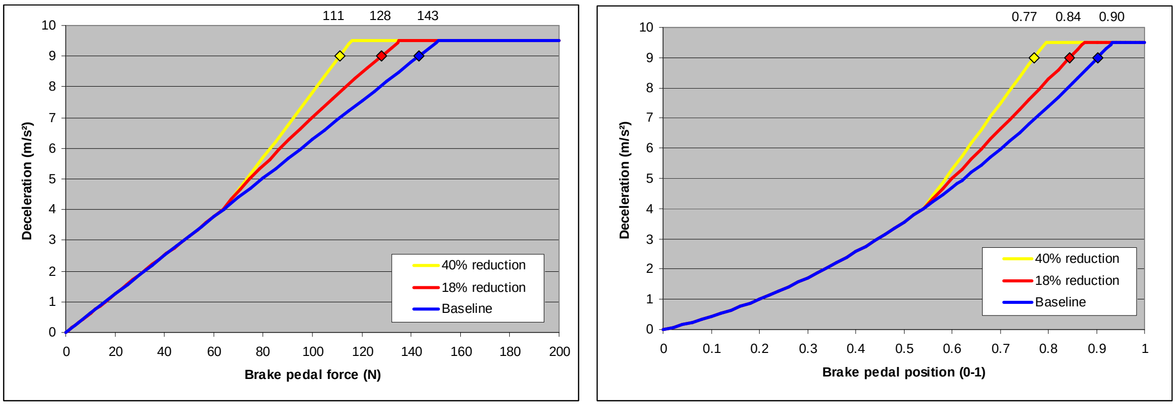


Figure 32: Brake pedal force and brake pedal position characteristics

By taking the pedal position at 9m/s² for the baseline, force sensitive BAS and speed sensitive BAS, and plotting them against the mean deceleration for each of the three configurations, an approximately linear relationship can be seen between the two variables (Figure 33).

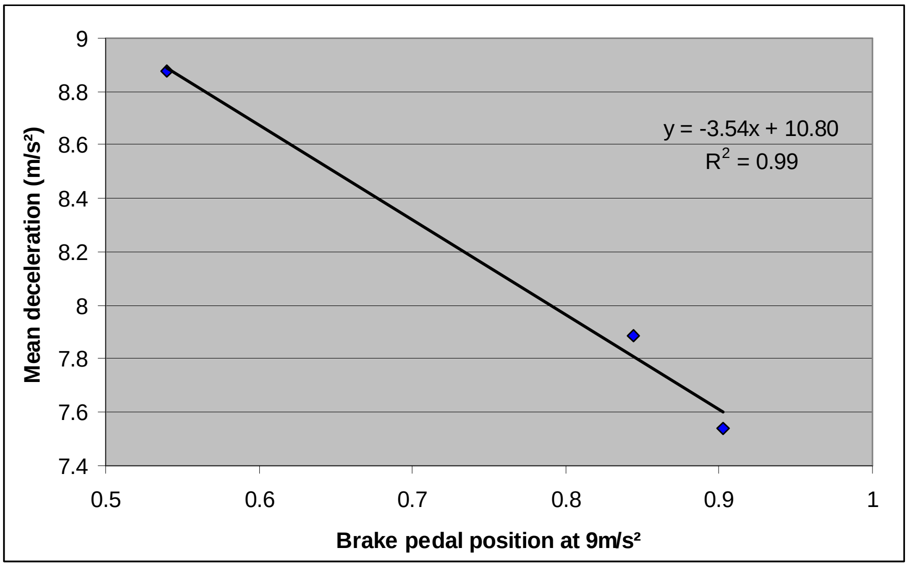


Figure 33: Brake pedal position at 9m/s^{2}and mean deceleration

By using this relationship it can be estimated that a 40% reduction in brake pedal force (giving a pedal position of 0.77) would result in a mean deceleration of 8.1m/s². This result still shows that the speed sensitive BAS offers a slightly higher mean deceleration than the force sensitive BAS but it would only require a 6% reduction in the mean deceleration of the speed sensitive system (from 8.87m/s² to 8.33m/s²) for the mean deceleration of the force sensitive system (8.1m/s²) to be considered statistically the same as the speed sensitive system.

Another important factor to consider when comparing the relative performance of the force sensitive BAS and the speed sensitive BAS is the activation criteria for the speed sensitive system. The simulator was programmed based on the assumption that the speed sensitive system was activated solely on the basis of how quickly the brake pedal moved, and independent of the force being applied to the pedal. However, the research has shown that many “speed sensitive” systems are actually multiple criteria systems that also have a dependency on the force being applied to the pedal such that they do not activate until the high pedal speed has been maintained for a certain time, which inevitably means a higher pedal force will be reached.

The speed sensitive system in the simulator did not require the pedal speed to be maintained for a certain period of time and so it is possible that, in some cases, the deceleration was boosted earlier in the braking manoeuvre than would have been the case for many current product systems. Therefore it is possible that the benefits of the speed sensitive BAS shown in the simulator trial represent a slight over-estimate of the actual benefits likely to be seen from current cars.

A similar comparison can be carried out when considering the time taken to reach 90% of the peak deceleration. Table 9 shows that both the force sensitive BAS and the speed sensitive BAS took less time than the baseline system to reach 90% of the peak deceleration.

Table 9: Time taken to reach 90% of peak deceleration

Configuration	Time to reach 90% peak deceleration (sec)
Baseline	0.93
Force sensitive BAS[1]	0.793
Speed sensitive BAS	0.596

[1]: With an 18% reduction in pedal force

To estimate the time to reach 90% of the peak deceleration for a force sensitive BAS (with a 40% reduction in brake pedal force), the times for the baseline system (i.e. 0% reduction in brake pedal force) and the force sensitive BAS (18% reduction) were linearly extrapolated as shown in Figure 34. This relationship estimated that the time to reach 90% of peak deceleration for a force sensitive BAS giving a 40% reduction in brake pedal force was 0.63seconds. Had this been achieved then a statistical analysis would have revealed no significant difference between time to reach 90% of peak deceleration for the force sensitive BAS and the speed sensitive BAS.

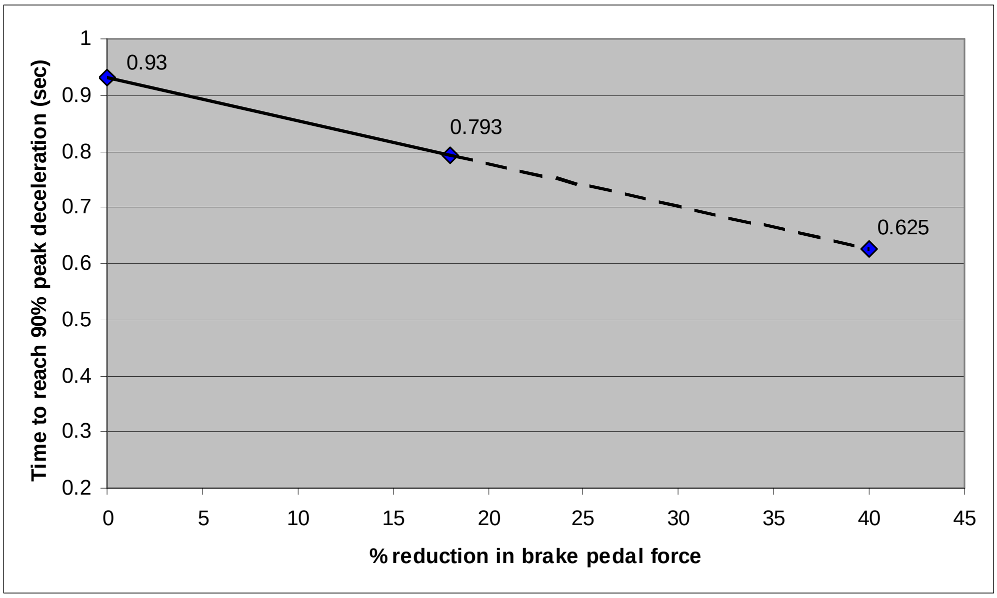


Figure 34: Extrapolation of time to reach 90% of peak deceleration

The estimated benefits in the report on the feasibility of measures relating to pedestrian protection (Lawrence *et al*, 2006) were based on a study from ACEA using GIDAS data. This study considered a sample of accidents and assumed that an incident where the mean deceleration was greater than 6m/s² was an emergency manoeuvre and would activate BAS. In these cases the benefits of BAS were estimated by assuming the deceleration of the vehicle was increased from whatever was actually recorded by the accident database to the maximum possible deceleration given the likely available friction, which was dependant on the type of surface. On this basis the study estimated that BAS would reduce the severity of approximately 5% of serious and fatal pedestrian casualties.

The assumption of simply increasing the mean deceleration is not directly comparable to BAS systems currently fitted to vehicles because these systems are generally triggered by brake pedal force or pedal speed, rather than the deceleration of the vehicle. It also assumes that the BAS would be potentially capable of boosting the mean deceleration from 6m/s² to up to 10m/s² (a maximum 66% increase assuming the incident occurred in an accident where the driver would only just have applied the pedal sufficiently to activate BAS and the road surface was dry concrete). The results from the simulator showed, on average, an increase from 7.5m/s² (for the baseline system) to a mean deceleration of 8.1 and 8.8m/s² (for the force sensitive and speed sensitive BAS respectively). However, these are values representing the mean of a group of drivers. No comparable means are available from the GIDAS analysis used in the study by Lawrence *et al* (2006) so it is not possible to state with confidence whether the results obtained in the simulator study would be expected to produce the level of benefits predicted by the analysis of GIDAS data.

The report by Lawrence et al (2006) also identified research (Page *et al*, 2005) which described a different analysis of the benefits of brake assist using both predictive and retrospective analysis methods. The predictive study assumed that Brake Assist would give a 50% reduction in the time taken to reach maximum deceleration (from 0.7seconds to 0.35seconds). Based on this, Page *et al* (2005) estimated that brake assist could reduce pedestrian fatalities by between 10% and 12%. The retrospective study also found that when the accident involvement of a small group of cars equipped with BAS was compared with a similar group of vehicles not equipped with BAS there was a reduction in all accidents of approximately 11% although this finding was not statistically significant.

The results of the simulator trials carried out for this study showed that the time taken to reach 90% of the peak deceleration was reduced by approximately 33% - 36%, a smaller reduction than that assumed by Page *et al* (2005). If a 50% reduction in the time to reach peak deceleration is assumed to be equivalent to a 10% - 12% reduction in pedestrian fatalities (as suggested by Page *et al*, 2005), then a 33% - 36% reduction in the time to reach peak deceleration might be estimated to represent a 6.6% - 8.6% reduction in pedestrian fatalities.

It is not possible to precisely quantify the results of the simulator study in terms of the ability of current generation BAS to guarantee that the casualty benefits predicted in the pedestrian protection report by Lawrence et al (2006) are actually achieved in practice. However, comparison of the simulator results with the research by Page *et al* (2005) suggests that the likely benefits may be broadly comparable to those used in the cost benefit analysis by Lawrence *et al* (2006).

6 Conclusions

1. TRL has proposed only minor modifications to the EC and ACEA proposed technical requirements for Brake Assist Systems (BAS).
2. TRL has redefined the categories of BAS to include a third category (Category C) which detects an emergency braking condition based on multiple criteria, one of which must be the speed with which the brake pedal is applied.
3. Although the track tests with a pedal force dependant BAS did not show any brake assist action, it is recommended that the basis of the test procedure remains as described by the existing technical proposals. The rationale for this recommendation is that the test procedure was proven to successfully identify a vehicle with a system not meeting requirements and analysis of the method has not revealed any obvious mechanisms by which it could fail to identify a system that did meet the requirements.
4. For the force dependant BAS, TRL has proposed an upper boundary for the required decrease in the brake pedal force necessary to achieve full ABS deceleration. TRL has proposed a decrease of between 40% and 80%. The purpose of the upper boundary is to prevent a step boost to full ABS deceleration above the threshold force, F_T, and thus guarantee graduated braking throughout the deceleration range as required by the spirit of existing braking regulations.
5. The presentation of the test procedure for the determination of F_{ABS} and a_{ABS} has been re-structured and is now fully contained within an Appendix.
6. TRL has recommended that manufacturers should declare the input variables influencing BAS activation and the mode of boost and the relationships between them as well as providing evidence to demonstrate how those variables and relationships will ensure that a system is effective for ordinary drivers.
7. The proposed test procedures adequately identify the presence of speed sensitive BAS (category B or C) but cannot necessarily discriminate between the two and does not rigorously quantify all aspects of the effectiveness of the systems. It is considered that it is not possible to fully control all aspects of the effectiveness of the system within the constraints of a typical type approval suite of tests.
8. Ideally, a technology-neutral test procedure would be defined that only specified the fundamental performance enhancement that a Brake Assist system is expected to achieve. This may be possible but would still rely on the manufacturer defining the characteristic of brake input and is likely to be difficult to achieve in practice.
9. The results of the simulator trials showed that both the force sensitive BAS and the speed sensitive BAS offered improved braking performance compared with a similar vehicle not fitted with BAS (i.e. the baseline configuration).
10. The force sensitive BAS evaluated in the simulator only achieved an 18% reduction in the brake pedal force at a_{ABS}, compared to the minimum requirement of a 40% reduction as prescribed in the proposed technical requirements. Had a reduction of 40% been achieved

than it is reasonable to expect that the benefits of the force sensitive BAS would have been much closer to the speed sensitive BAS.

11. It was estimated that, the time to reach 90% of peak deceleration was statistically the same for both the force sensitive BAS and the speed sensitive BAS, and that the mean deceleration of the speed sensitive system would only need to fall by 6% (from 8.87m/s² to 8.33m/s²) for it to be considered statistically indistinguishable from the force sensitive BAS.
12. Based on a study by ACEA using GIDAS data, Lawrence *et al* (2006) estimated that brake assist would reduce serious and fatal pedestrian injuries by approximately 5%. The results from the simulator trial in this project could not be directly compared to the ACEA study with scientific confidence but combining the results with those from a study by Page *et al* (2005) suggested that the benefits may be of broadly comparable magnitude to those estimated by Lawrence *et al* (2006).

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Appendix A. Simulator trials – event order and locations

(a): Order of events

Participant Number	Drive 1		Drive 2		Drive 3	
	System	Event order	System	Event order	System	Event order
1	A	X	B	Y	C	Z
2	A	X	C	Y	B	Z
3	B	X	A	Y	C	Z
4	B	X	C	Y	A	Z
5	C	X	A	Y	B	Z
6	C	X	B	Y	A	Z
7	A	X	B	Z	C	Y
8	A	X	C	Z	B	Y
9	B	X	A	Z	C	Y
10	B	X	C	Z	A	Y
11	C	X	A	Z	B	Y
12	C	X	B	Z	A	Y
13	A	Y	B	X	C	Z
14	A	Y	C	X	B	Z
15	B	Y	A	X	C	Z
16	B	Y	C	X	A	Z
17	C	Y	A	X	B	Z
18	C	Y	B	X	A	Z
19	A	Y	B	Z	C	X
20	A	Y	C	Z	B	X
21	B	Y	A	Z	C	X
22	B	Y	C	Z	A	X
23	C	Y	A	Z	B	X
24	C	Y	B	Z	A	X
25	A	Z	B	X	C	Y
26	A	Z	C	X	B	Y
27	B	Z	A	X	C	Y
28	B	Z	C	X	A	Y
29	C	Z	A	X	B	Y
30	C	Z	B	X	A	Y
31	A	Z	B	Y	C	X
32	A	Z	C	Y	B	X
33	B	Z	A	Y	C	X
34	B	Z	C	Y	A	X
35	C	Z	A	Y	B	X
36	C	Z	B	Y	A	X

(b): Location of braking events

Location ID	X Position	Event Order		
		1	2	3
28	27,000			
27	26,000			
26	25,000		LP	
25	24,000			B
24	23,000	RP		
23	22,000			RV
22	21,000			
21	20,000		RP	
20	19,000			
19	18,000		LV	
18	17,000	B		
17	16,000			LP
16	15,000	RV		
15	14,000			
14	13,000			
13	12,000			
12	11,000	LV		
11	10,000			RP
10	9,000		B	
9	8,000			
8	7,000			LV
7	6,000		RV	
6	5,000			
5	4,000	LP		
4	3,000			
3	2,000			
2	1,000			
1	0			

Legend	
LP	A pedestrian crossing from the left side of the road
RP	A pedestrian crossing from the right side of the road
LV	A vehicle pulling out from the left side of the road
RV	A vehicle pulling out from the left side of the road
B	A vehicle performing an emergency stop in front of the driven vehicle

Appendix B. TRL's draft proposal for technical requirements for BAS

Draft informal document to GRRF – Proposed amendments to ECE Regulation 13H to introduce requirements for Brake Assist Systems

A. Proposed Amendments to ECE Regulation 13H

Insert new item 5.2.10

5.2.10 In the event of failure in any part of the Brake Assist System (as defined in Annex 6) the prescribed service brake performance and brake distribution shall be guaranteed

After Paragraph 2.23 insert a new paragraph 2.24 as follows

'2.24**.** "Brake Assist System (BAS)" means a system which supports the driver in building up vehicle deceleration when the brake pedal is operated with an emergency characteristic. There are three categories of Brake Assist System:

2.24.1 "Category A Brake Assist System" means a system which detects an emergency braking condition based on the brake pedal force applied by the driver.

2.24.2 "Category B Brake Assist System" means a system which detects an emergency braking condition based on the rate at which the brake pedal is applied.

2.24.3 "Category C Brake Assist System" means a system which detects an emergency braking condition based on multiple criteria, one of which must be the rate at which the brake pedal is applied.'

Annex 1

Insert a new item 22 to read

'22. The vehicle is/is not fitted with a Brake Assist System meeting the requirements of Annex 10. 2/

22.1 category of Brake Assist System A/B/C 2/

22.1.1 for category A systems, define the force threshold at which the ratio between pedal force and brake pressure increases

22.1.2 for category B systems, define the brake pedal speed which must be achieved in order to activate the Brake Assist System (e.g. pedal speed during a given time interval)

22.1.3 For category C systems define the input variables affecting the decision to activate the Brake Assist System, the relationship between them and the pedal application required to activate the Brake Assist System for the tests described in Annex 9. 2/'

Items 22 to 31 (former), renumber as items 22 to 32.

Insert a new Annex 10 as follows:

‘Annex 10

SPECIAL REQUIREMENTS TO BE APPLIED TO BRAKE ASSIST SYSTEMS, WHERE FITTED

1. GENERAL

This Annex specifies test requirements for Brake Assist Systems, as defined in Paragraph 2.24 of this Regulation where fitted. [to a vehicle within the scope of this Regulation.]

In addition to the requirements of this Annex, Brake Assist Systems shall also be subject to any relevant requirements contained elsewhere within this Regulation.

2. GENERAL TEST REQUIREMENTS

2.1. VARIABLES

Whilst performing the tests described in this Annex, the following variables shall be measured:

2.1.1. brake pedal force, F_p, applied at the centre of the brake pedal plate following a tangential arc to the brake pedal pivot.

2.1.2. vehicle longitudinal velocity, v_x (ISO Standard 8855:1991).

2.1.3. vehicle longitudinal acceleration, a_x (ISO Standard 8855:1991)

2.1.4. brake temperature, T_d, measured on the braking path of the disc or drum of the front brakes.

2.1.5 brake pedal travel, [S_p], measured at the centre of the pedal plate or at a position on the pedal mechanism where the displacement is proportional to the displacement at the centre of the pedal plate allowing simple calibration of the measurement.

2.2. MEASURING EQUIPMENT

2.2.1. The variables listed in paragraph 2.1 of this Annex shall be measured by means of appropriate transducers. Accuracy, operating ranges, filtering techniques, data processing and other requirements are described in ISO Standard 15037-1:1998.

2.2.2. Accuracy of pedal force and disc temperature measurements shall be as follows:

Variable range system	Typical operating range of the transducers	Recommended maximum recording errors
Pedal force	0 to 2,000 N	± 10 N
Brake disc temperature	0 – 1,000°C	± 5°C

2.2.3. A sampling rate for data acquisition of at least 500Hz is required.

2.2.4 Further details on analogue and digital data processing of the BAS test procedures are described in Appendix 2 to this Annex.

2.3. TEST CONDITIONS

2.3.1. Test track: The requirements for test track and weather conditions are described in ISO Standard 15037-1:1998.The test track surface should have a nominal coefficient of friction of 0.8.

2.3.2. Test vehicle tyres: The specification of test tyres and their warm up are described in ISO Standard 15037-1:1998.

2.3.3. Test vehicle loading condition: The loading conditions of the vehicle are described in ISO Standard 15037-1:1998.

2.4. TEST METHOD

2.4.1. The tests as described in paragraphs 3 and 4 below shall be carried out from a test speed of 100 ± 2 km/h. The vehicle shall be driven at the test speed in a straight line.

2.4.2. The average temperature of the front brakes shall be measured, in accordance with paragraph 2.1.4., and recorded before each test and shall lie between 65°C and 100°C prior to any test.

2.4.3. The braking tests shall be performed on a dry asphalt test track in accordance with ISO Standard 15037-1:1998.

2.4.4. For the tests the reference time, t_0, is defined as the moment when the brake pedal force reaches 20N.

Note: For vehicles equipped with a vacuum booster the applied brake pedal force necessary depends on the vacuum level that exists in the vacuum brake booster. Therefore, a sufficient vacuum shall be ensured at the beginning of a braking test.

3. ASSESSMENT OF THE PRESENCE OF A CATEGORY 'A' BAS

A Category 'A' BAS shall meet the test requirements contained in paragraphs 3.1 and 3.2.

3.1. Test 1: Reference test to determine F_{ABS} and $a_{ABS.}$

3.1.1. The reference values F_{ABS} and a_{ABS} shall be determined in accordance with the procedure described in Appendix 1 to this Annex.

3.2. Test 2: For activation of BAS

3.2.1. Systems sensitive to pedal force shall show a significant increase in the ratio of brake pedal force to vehicle deceleration once an emergency braking condition has been detected.

3.2.2. The performance requirements for a Category 'A' BAS are met if a specific brake application characteristic can be defined that exhibits a decrease of between 40% and [80%] in required brake pedal force for ($F_{ABS\ extrapolated}$ - F_T) compared to (F_{ABS} - F_T).

3.2.3 F_T and a_T are threshold force and threshold deceleration as shown in Figure 1. The values of F_T and a_T shall be supplied to the Technical Service at the time of submission of the type-approval application. The value of a_T shall be between 3.5m/s² and 5.0m/s².

3.2.4 A straight line is drawn from the origin through the point F_T, a_T (as shown in Figure 1).The value of brake pedal force 'F', at the point of intersection between this line and a horizontal line defined by $a=a_{ABS}$, is defined as $F_{ABS,\ extrapolated}$:

$$F_{ABS,extrapolated} = \frac{F_T \times a_{ABS}}{a_T}$$

3.3. Data evaluation

The presence of a Category 'A' BAS is proven if

$$F_{ABS,min} \leq F_{ABS} \leq F_{ABS,max}$$

Where,

$$F_{ABS,max} - F_T \leq (F_{ABS,extrapolated} - F_T) \times 0.6$$

and

$$F_{ABS,min} - F_T \geq (F_{ABS,extrapolated} - F_T) \times [0.2]$$

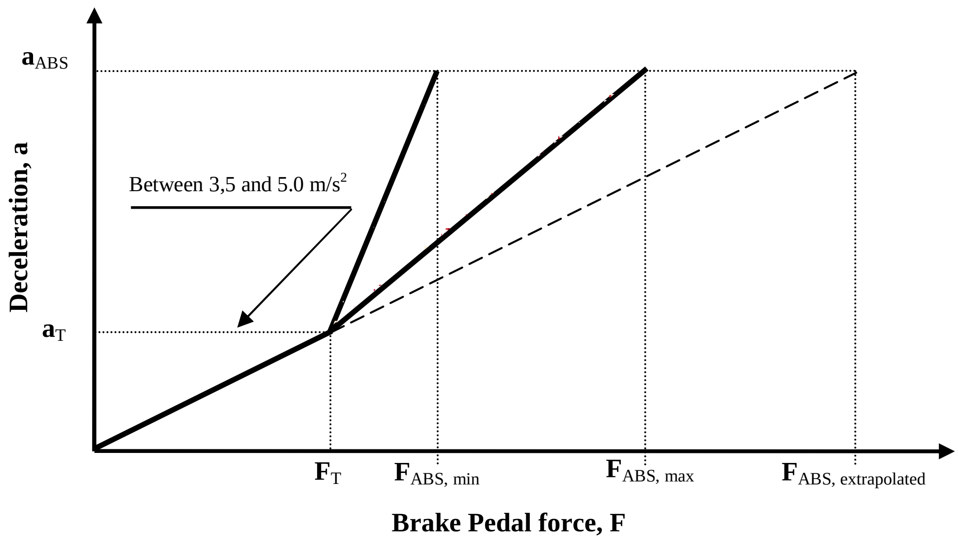

Figure 1: Pedal force characteristic needed in order to achieve maximum deceleration with Category 'A' BAS

4. ASSESSMENT OF THE PRESENCE OF A CATEGORY ‘B’ BAS

A Category 'B' BAS shall meet the test requirements contained within paragraphs 4.1 and 4.2 of this Annex.

4.1. <u>Test 1:</u> Reference test to determine F_{ABS} and $a_{ABS.}$

4.1.1. The reference values F_{ABS} and a_{ABS} shall be determined in accordance with the procedure described in Appendix 1 to this Annex.

4.2. <u>Test 2:</u> For activation of BAS

The vehicle shall be driven in a straight line at the test speed specified in 2.4 above. The driver shall apply the brake pedal quickly according to Figure 2, simulating emergency braking so that BAS is activated and ABS is fully cycling.

In order to activate BAS the brake pedal shall be applied as specified by the car manufacturer. The manufacturer shall notify the Technical Service of the required brake pedal input at the time of submission of the application for type-approval. After $t = t_0 + 0.8$ s and until the vehicle has slowed down to a speed of 10 km/h the brake pedal force shall be maintained in a corridor between $F_{ABS, upper}$ and $F_{ABS, lower}$. Where $F_{ABS, upper}$ is 0.7 F_{ABS} and $F_{ABS, lower}$ is 0.5 F_{ABS}.

The requirements also are considered to be met if, after $t = t_0 + 0.8$ s, the pedal force falls below $F_{ABS, lower}$ provided the requirement of paragraph 4.3 is fulfilled.

4.3. Data evaluation

The presence of BAS 'B' is proven if a mean deceleration of at least 0.85 x a_{ABS} is maintained from the time when $t = t_0 + 0.8$ s to the time when the vehicle speed has been reduced to 10 km/h.

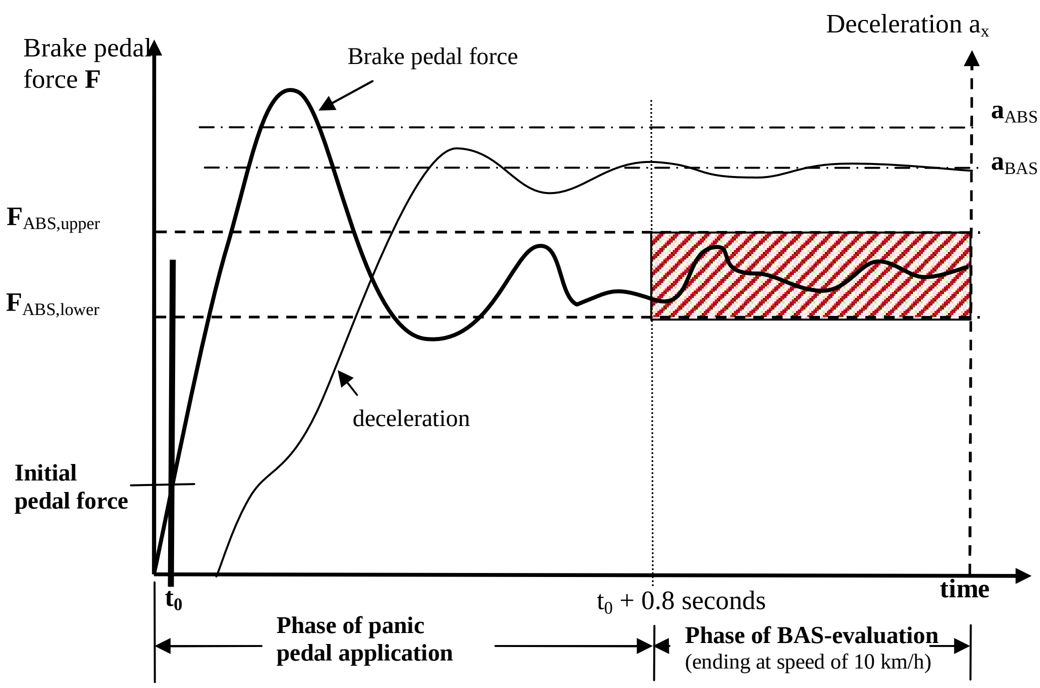

Figure 2: Test 2 of a Category 'B' BAS system.

5. ASSESSMENT OF THE PRESENCE OF A CATEGORY 'C' BAS

5.1 A Category 'C' BAS shall meet the test requirements of paragraphs 4.1 and 4.2 of this Annex.

5.2 Data evaluation

A Category 'C' BAS shall meet the requirements of paragraph 4.3 of this Annex.

Annex 10, Appendix 1

METHOD FOR DETERMINATION OF F_{ABS} and a_{ABS}

1.1 The brake pedal force F_{ABS} is the minimum pedal force that has to be applied for a given vehicle in order to achieve maximum deceleration which indicates that ABS is fully cycling. a_{ABS} is the deceleration for a given vehicle during ABS deceleration as defined in paragraph 1.7..

1.2 The brake pedal shall be applied slowly (without activating the Brake Assist System) providing a constant increase of deceleration until ABS is fully cycling (Figure 3). A brake pedal force of at least 600 N shall be achieved during the test.

1.3 The full deceleration must be reached within the timeframe of 2.0 ± 0.5 s. The deceleration curve, recorded against time, must be within a corridor of ±0.5 s around the centre line of the deceleration curve corridor. The example in Figure 3 has its origin at the time t_0 crossing the a_{ABS} line at 2 seconds. Once full deceleration has been achieved the pedal travel $[S_p]$ shall not be decreased for at least 1 s. The time of full activation of the ABS system is defined as the time when pedal force F_{ABS} is achieved. The measurement shall be within the corridor for variance of deceleration increase (see Figure 3).

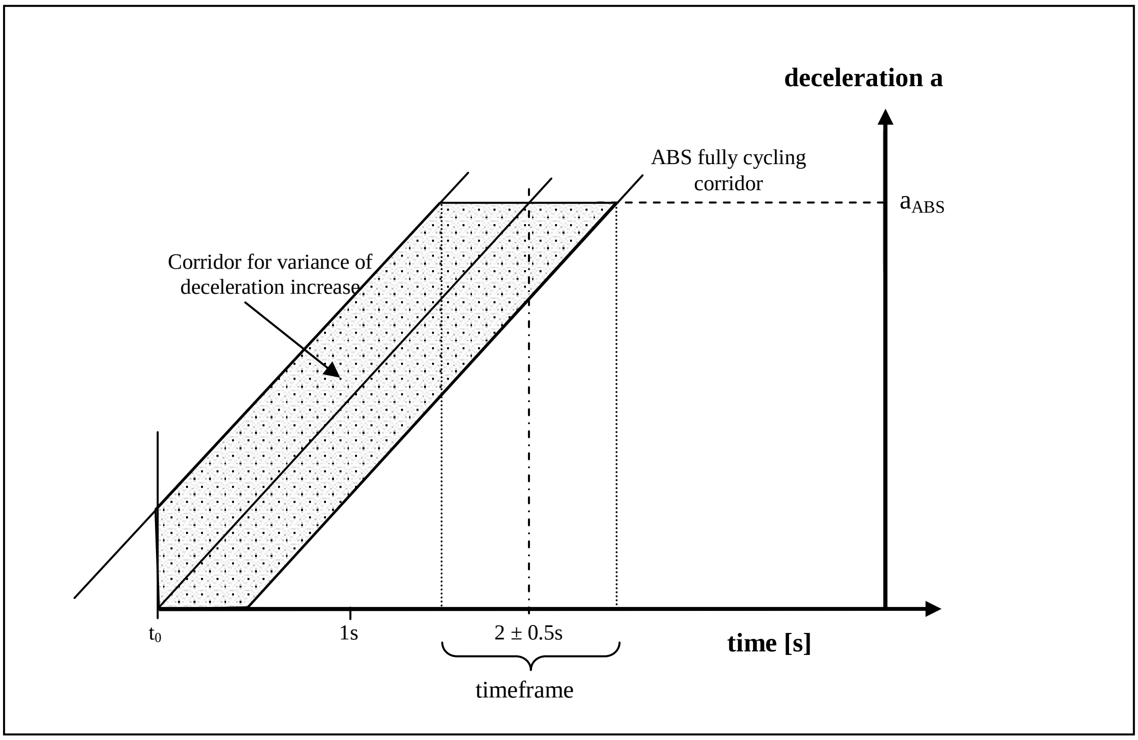

Figure 3: Deceleration corridor for determination of F_{ABS} and a_{ABS}

1.4 Five tests meeting the requirements of paragraph 1.3 shall be carried out. For each of these valid tests the vehicle deceleration shall be plotted as a function of the recorded brake pedal force.

1.5 The maximum individual value for the vehicle deceleration is determined from each of the five individual curves. The mean value (a_{max}) of these five maximum values represents the upper limit of the deceleration achieved.

1.6 The five individual 'deceleration versus brake pedal force' curves are averaged by calculating the mean deceleration of the five individual 'deceleration vs. brake pedal force" curves at increments of 1N pedal force. The result is the mean deceleration versus brake pedal force curve (Figure 4), which will be referred to as the "maF curve" in this Appendix.

1.7 The ABS deceleration (a_{ABS}) referred to in this appendix is the average value of the vehicle deceleration 'a' on the "maF" curve between the left and right hand border of Window I.

1.7.1 Window I on the "maF" is defined as follows:

- the upper border is a line where $a = a_{max}$.
- the lower border is a line where $a = 0.9 * a_{max}$.
- the left border is a line where F corresponds to $0.9 * a_{max}$ on the maF curve.

- the width of the window is 200N.

1.8 The minimum force on the pedal (F_{min}) sufficient to achieve the deceleration a_{ABS} calculated in 1.7 is defined as the value of F corresponding to a= a_{ABS} on the maF curve.

1.9 Using linear regression, a straight line is drawn through all maF curve values below the pedal force F_{min} and above the ABS deceleration value (0.7 * a_{ABS}). The value of the brake pedal force 'F' at the point of intersection between this line and the horizontal line where a= a_{ABS} is defined as F_{ABS} (diamond in figure 4).

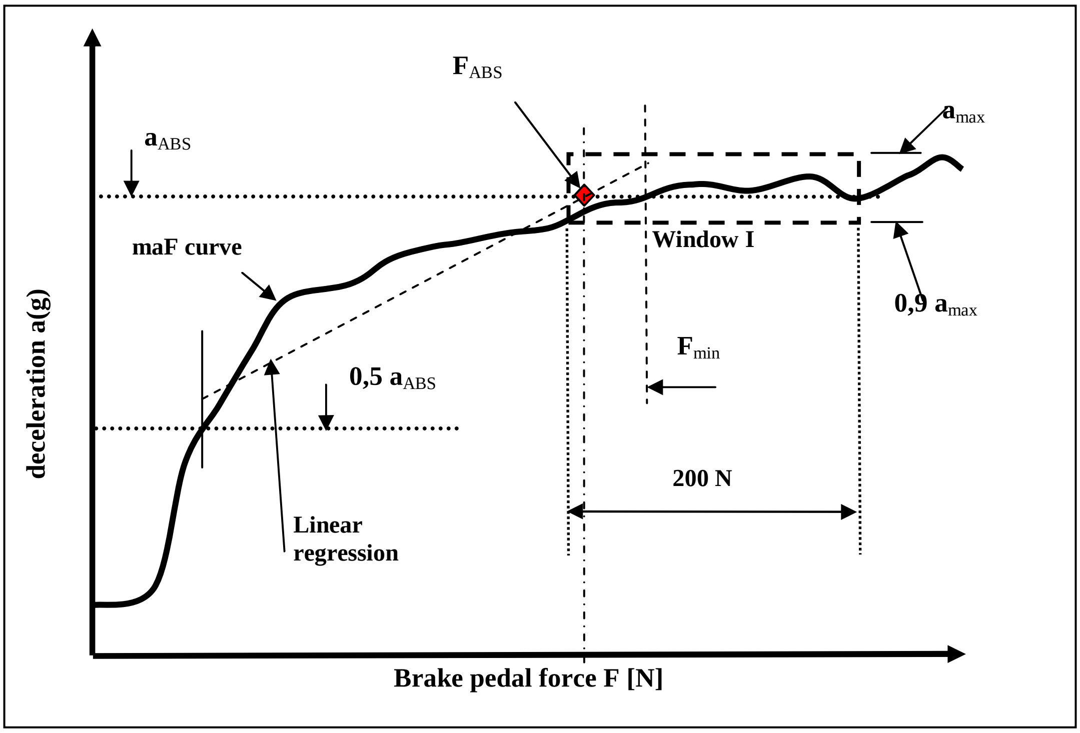

Figure 4: Determination of the value of F_{ABS}'

Annex 10, Appendix 2

DATA PROCESSING FOR THE BAS

1 ANALOGUE DATA PROCESSING

The bandwidth of the entire, combined transducer/recording system shall be no less than 30 Hz.

In order to execute the necessary filtering of signals, low-pass filters with order 4 or higher shall be employed. The width of the pass band (from 0 Hz to frequency f_0 at - 3 dB) shall not be less than 30 Hz. Amplitude errors shall be less than ± 0,5 % in the relevant frequency range of 0 Hz to 30 Hz. All analogue signals shall be processed with filters having sufficiently similar phase characteristics to ensure that time delay differences due to filtering lie within the required accuracy for time measurement.

NOTE: During analogue filtering of signals with different frequency contents, phase shifts can occur. Therefore, a data processing method, as described in paragraph 2 of this appendix, is preferable.

2 DIGITAL DATA PROCESSING

2.1 General consideration

Preparation of analogue signals includes consideration of filter amplitude attenuation and sampling rate to avoid aliasing errors, and filter phase lags and time delays. Sampling and digitising considerations include pre-sampling amplification of signals to minimize digitising errors; number of bits per sample; number of samples per cycle; sample and hold amplifiers; and time-wise spacing of samples. Considerations for additional phaseless digital filtering include selection of pass bands and stop bands and the attenuation and allowable ripple in each; and correction of filter phase lags. Each of these factors shall be considered in order to achieve a relative overall data acquisition accuracy of ± 0.5 %.

2.2 Aliasing errors

In order to avoid uncorrectable aliasing errors, the analogue signals shall be appropriately filtered before sampling and digitising. The order of the filters used and their pass band shall be chosen according to both the required flatness in the relevant frequency range and the sampling rate.

The minimum filter characteristics and sampling rate shall be such that

- within the relevant frequency range of 0 Hz to f_{max} = 30 Hz the attenuation is less than the resolution of the data acquisition system; and

- at one-half the sampling rate (i.e. the Nyquist or "folding" frequency) the magnitudes of all frequency components of signal and noise are reduced to less than the system resolution.

For 0.05 % resolution the filter attenuation shall be less than 0.05 % to 30 Hz, and the attenuation shall be greater than 99.95 % at all frequencies greater than one-half the sampling frequency.

NOTE: For a Butterworth filter the attenuation is given by:

$$A^2 = \frac{1}{1 + \left(f_{max} / f_0 \right)^{2n}} \quad \text{and} \quad A^2 = \frac{1}{1 + \left(f_N / f_0 \right)^{2n}}$$

where:

n is the order to filter;

f_{max} is the relevant frequency range (30 Hz);
f_o is the filter cut-off frequency;
f_N is the Nyquist or "folding" frequency.

For a fourth order filter

for A = 0.9995: $f_o = 2{,}37 * f_{max}$
for A = 0.0005: f_S, = 2 * (6.69 * f_o), where f_S, is the sampling frequency = 2 * fN.

2.3 Filter phase shifts and time delays for anti-aliasing filtering

Excessive analogue filtering shall be avoided, and all filters shall have sufficiently similar phase characteristics to ensure that time delay differences are within the required accuracy for the time measurement. Phase shifts are especially significant when measured variables are multiplied together to form new variables, because while amplitudes multiply, phase shifts and associated time delays add. Phase shifts and time delays are reduced by increasing f_o. Whenever equations describing the pre-sampling filters are known, it is practical to remove their phase shifts and time delays by simple algorithms performed in the frequency domain.

NOTE: In the frequency range in which the filter amplitude characteristics remain flat, the phase shift @ of a Butterworth filter can be approximated by

$\Phi = 81 \times (f/f_0)$ degrees for second order

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$\Phi = 81 \times (f/f_0)$ degrees for second order

The time delay for all filter orders is: $t = (\Phi/360) \times (1/f_0)$

2.4 Data sampling and digitising

At 30 Hz the signal amplitude changes by up to 18 % per millisecond. To limit dynamic errors caused by changing analogue inputs to 0.1 %, sampling or digitising time shall be less than 32 µs. All pairs or sets of data samples to be compared shall be taken simultaneously or over a sufficiently short time period.

2.5 System requirements

The data system shall have a resolution of 12 bits (± 0.05 %) or more and an accuracy of 2 LSB (± 0.1 %). Anti-aliasing filters shall be of order 4 or higher and the relevant data range f_{max} shall be 0 Hz to 30 Hz.

For fourth order filters the pass-band frequency f_o (from 0 Hz to frequency f_o) shall be greater than 2.37 * f_{max} if phase errors are subsequently adjusted in digital data processing, and greater than 5 * f_{max} otherwise. For fourth order filters the data sampling frequency f_s shall be greater than 13.4 * f_o.

B Justification

This document introduces provisions for brake-assist systems to enable manufacturers to declare, and for contracting parties to confirm, the presence of a brake assist system on a vehicle covered by this Regulation. It is not intended that this Regulation should mandate the installation of brake assist systems. However, it is envisaged that Contracting Parties wishing to encourage or mandate the use of such systems within their territories (for example, as part of a package of measures to improve the protection of pedestrians) could specify that vehicles are fitted with systems meeting the technical specifications proposed in this document.

The specifications contained within this document reflect systems that are currently available on the market. However, the tests and specifications cannot discriminate between a category B and a category C system. The tests also rely on a declaration from the manufacturer on how the pedal should be pressed to activate their particular BAS. It has, therefore, been requested that information regarding the brake pedal application required to activate BAS (all categories) and all of the input variables to category C systems and their relationships and threshold values be supplied to the Technical Service to monitor the way in which BAS is implemented and to help determine whether further requirements are necessary for these types of system. It is envisaged that in the future the requirements could be further developed to allow alternative methods of identifying emergency situations (for example, by using radar technology)