Periodical Inspection of Electronically Controlled Systems on Vehicles

Programme Summary Report

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Brussels, 31st March 2002

funded by

European Commission, DG TREN, Brussels

and

DEKRA, Stuttgart
EGEA, Brussels
Svensk Bilprovning, Stockholm
VdTÜV, Berlin

CITA/ECS-RSP/SR/Final

Preface

Electronically controlled systems will increasingly be the decisive determining factor in the safety and environmental performance of vehicles. But currently inspection of these systems is, for all practical purposes, not part of mandatory periodical technical inspection of vehicles. In 1997 CITA set up a specific working group, called Working Group VII: Testing of electronically controlled systems, to consider this issue. This group examined available reliability data and failure rates of electronically controlled systems and possible test procedures that had already been proposed. Based on this evaluation, CITA WG VII formulated a research programme to advance the state of knowledge and discussed it with the European Commission DG TREN. The EU Commission decided to provide 50% funding for the proposed programme, for which CITA would like to express their thanks. The remaining 50 % was provided by contributions from several CITA members and the European Garage Equipment Association, to whom thanks also go. In addition, all the other organizations that participated in meetings of CITA WGVII contributed through the salary and travel costs of their representatives.

Under the guidance of CITA WG VII five studies were completed by the following organizations:

(1) (a) The reliability of electronically controlled systems on vehicles; and (b) Cost/benefit analysis

TRL, Crowthorne, Berkshire ((a) and (b)); Svensk Bilprovning, Stockholm ((a) only)

(2) A test procedure for airbags

Institut für Kraftfahrwesen, RWTH Aachen; TÜV Nord, Hannover; Svensk Bilprovning, Stockholm

(3) Testing of existing antilock braking systems

Institut für Verkehrssicherheit, TÜV Rheinland/Berlin-Brandenburg

(4) A test procedure for vehicle dynamic controllers

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A full list of the titles and authors of the studies is given in annex 1.

This report summarizes the most important findings and results of the 5 studies and sets out the overall conclusion of CITA WG VII, namely that periodical motor vehicle inspection should be developed to include inspection of electronically controlled systems to ensure optimum traffic safety.

Members of CITA WG VII

The following organizations were represented in the CITA Working Group on Testing of electronically controlled systems which oversaw this programme:-

CITA	Klaus Rompe, Prof. Dr., Chairman of WG VII Julian David, CITA Technical Adviser
DEKRA	Hans-Jürgen Mäurer Reiner Sauer
EGEA	Frank Leimbach Carsten Sante Rainer Heinzmann John Nelson Timothy Snelgar
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1. Aim of the project

Electronically controlled systems of increasing complexity are being fitted in growing numbers to new vehicles. Vehicle safety and environmental protection is increasingly dependent on the proper functioning of these systems. At present there is insufficient data about the reliability of electronically controlled systems and little information about how they could be checked during periodical and other inspections in the event that this was found necessary. This programme aimed to address these deficiencies by collecting reliability data about current systems and by examining their performance in order to develop possible test procedures for use in periodical and other inspections. The cost benefit case for such tests has also been examined. The programme had 4 work packages and a co-ordinating group.

The programme of studies aimed to:-

1. Collect reliable and statistically significant data on failure rates and modes for electronically controlled systems on vehicles currently in use. As well as helping to establish whether there is a need for the introduction of tests on electronic systems into periodical inspection, this work also aimed to provide information on the priority order for the detailed investigations into particular systems and to provide information that might be used to estimate the reliability of future electronically controlled systems.

2. For a number of systems that are already in use or are currently coming onto the market –

   (a) investigate how they perform in a variety of situations and, where appropriate, examine the performance of components that have been in service for some time; and
   (b) either develop, or make recommendations for further work to develop, test procedures and, if necessary, test equipment that would enable critical functions to be checked during periodical and other inspections of vehicles in use.

The work was divided into four work packages as follows –

1. Inventory of current systems, collection of reliability data and cost-benefit case for inspections

2. Airbags

3. Existing anti-lock braking systems

4. Vehicle dynamic controllers

2. State of the art

For a variety of reasons, very few results of individual investigations into the actual failure rate of electronically controlled systems performed in different countries are currently available and the answer to the question about the significance of such failures in causing accidents is the same as it is for all technical defects: they are not systematically recorded as causes of accidents.

New electronic systems in vehicles have a failure rate of about one failure per million operating hours. Taking into account the fact that 10 or more such installations will be installed in future vehicles – and this includes private cars as well as commercial vehicles – and that there are more than 180 million motor vehicles on the roads of the EU, even this failure rate is not insignificant. It has been found that the electronics themselves are not subject to time or distance dependent wear or ageing. Failures cannot therefore be predicted and prevented. Self diagnosis, complemented by periodical inspection, is necessary to achieve optimal safety.

Since 1990, TÜV and DEKRA in Germany have performed various investigations into the question of defects on electronically controlled systems. These include reader questionnaires, assessments as part of specific accident investigations and error analyses during repair work in the workshops.

Although these investigations have still not produced any information on the actual frequency of errors in electronically controlled systems compared to other systems, the findings make it evident that there are errors in all important electronically controlled systems.

Random Check of the Contents of the Fault Code Store

The German Transport Ministry requested Aachen University to undertake a random survey of fault code stores in order to obtain an impression of the extent of the fault recordings in electronically controlled systems. The results, which are based on investigations made in 1996, were published in 1999[1].

Overall, the readings of the fault code store revealed recordings in surprisingly many vehicles, i.e. there was a much higher level of (recordable) malfunctions in the electronics of vehicles than previously presumed. For example, out of 152 cars from a range of manufacturers and ages, 17 % were found to have recorded faults with the ABS. At the time of the readings, only 2 of the vehicles actually had a malfunction as indicated by the warning lamp. The survey also demonstrated that the number of recordable malfunctions and faults rose with the vehicle's age and complexity of electronic systems, **Figure 1**. It was concluded from the results of the survey that in the interests of improved vehicle safety, a regular monitoring of electronic systems would be both sensible and desirable.

[1] Kohlstruck, R.; Wallentowitz, H.: Überprüfung elektronischer Systeme in Kraftfahrzeugen. Berichte der Bundesanstalt für Straßenwesen: Fahrzeugtechnik Heft F 28, Bergisch Gladbach 6/1999

Indications in the ABS fault store of 148 cars

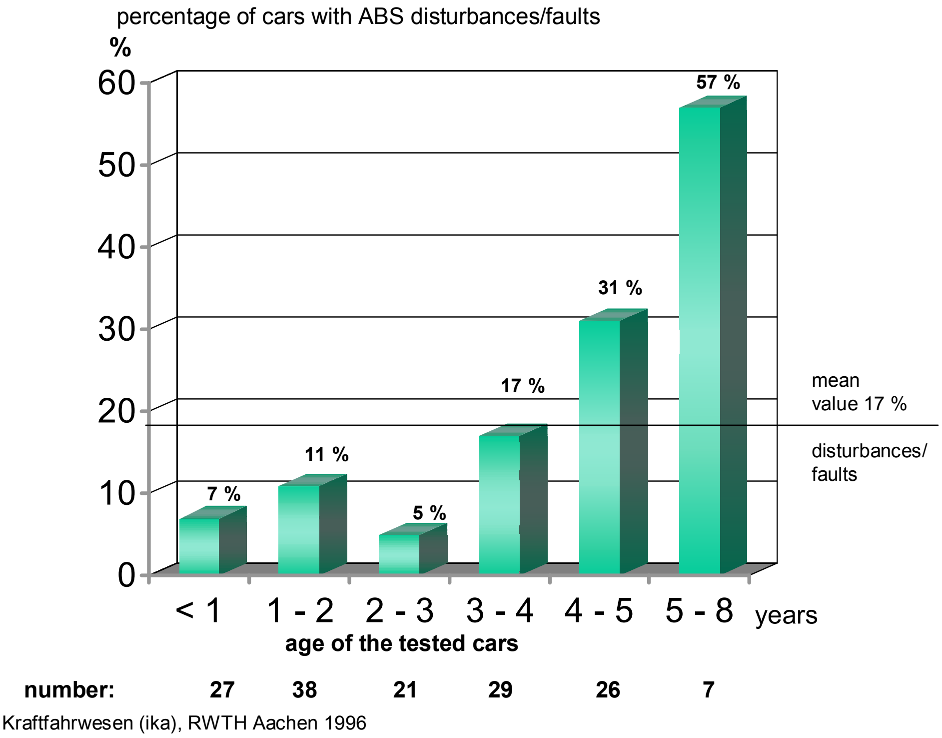


Figure 1

To verify Aachen's results, BMW carried out their own survey in 1999. The fault code store was read on 304 BMWs brought to a BMW workshop for periodical inspection[2]. Fault recordings relating to ABS or Airbags were found on 20 (7 %) vehicles. Two thirds of these concerned ABS, which is switched off as soon as the malfunction is recorded and this condition continues till the next time the car is started. At the time of inspection, actual malfunctioning of ABS was found in only 2 vehicles. This was apparent from the warning lamp indicator. In one additional vehicle, the warning lamp indicator had failed. The age range of the BMW vehicles corresponded to that of Aachen's survey, but it did not really confirm that fault recording depended upon the age of the vehicle.

Airbag Activation Errors

The Institut für Fahrzeugsicherheit beim Gesamtverband der Deutschen Versicherungswirtschaft e.V. (Institute of Vehicle Safety of the National Association of the German Insurance Business) analysed activation errors in airbags. During the last years, 23 incidents were reported to the Institute: 11 unintentional activations in stationary vehicles, 7 unintentional activations in moving vehicles and 5 non-activations in vehicles involved in serious accidents, **figure 2**. Further data collection[3] has found significant increases in the numbers of unintended release during driving and no release in severe accidents. The number of problems that have come to light is very small compared with the high percentage of vehicles in Germany equipped with airbags – in 2000 about 55 % of all cars had a driver-side airbag and 45 % a front passenger side airbag – and it does not affect the effectiveness

[2] BMW Abt. VS-20: Feldtest zur Prüfung elektronisch geregelter Systeme an BMW-Fahrzeugen anläßlich der HU/§ 29-Untersuchung, München 6/1999

[3] Rau, H.; Ahlgrimm, J.; Rohm, M.: Hat der Airbag versagt?; Verkehrsunfall und Fahrzeugtechnik, December 2001, Heft 12

of this protection system. But it is absolutely necessary to reduce the number of problematic incidents even further e.g. through adequate mandatory periodical technical inspection of vehicles, especially since the number of vehicles furnished with airbags is steadily increasing, as is the average age of these vehicles.

Airbag release failures

23 fully documented problem cases

11	**unintended release at stand still**
	1 short circuit because of cable interruption, 6 others
7	**unintended release during driving**
	4 push against the floor of the car, 3 failures in the control unit
5	**no release in a severe accident**

Total number collected: 335 fully documented airbag accidents

Institut für Fahrzeugsicherheit
Gesamtverband der Deutschen Versicherungswirtschaft e.V.
May, 2001

Figure 2

Changes on Vehicles and Repair Behaviour of the Car Users

In addition to unwanted failures of electronically controlled systems, there are other changes which have been accepted or consciously tolerated. Nowadays, this includes unregistered chip tuning – which can achieve up to 30 % more power with a commensurate increase in harmful emissions. Additional risks can also occur due to errors caused by the transfer of pirated software. In the same way that there are now simple means for making changes to the inspection displays of electronic tachographs, tomorrow it will probably be possible to alter the self-diagnosis display on older vehicles, if replacing the control unit would account for a considerable proportion of the value of a vehicle. Even now, it is possible to obtain a control unit from a scrap yard and no-one knows whether the software used matches the vehicle to be repaired. This should all be considered in conjunction with the fact that the older the vehicle, the more likely it is to be the subject of do-it-yourself maintenance and repair: in 2000, this applied to 23 % of vehicles aged 8 years and older in Germany.

There is yet another factor in favour of meaningful tests of electronically controlled systems during compulsory regular motor vehicle inspections. After an accident for instance, it is not generally easy to identify whether a failure in an electronically controlled system may have contributed to the accident. It is particularly difficult for drivers to provide evidence of whether the imperfect operation of the ABS caused the breaking distance to be longer than is usual or whether the airbag was activated before the accident. This problem may intensify with the use of driver assistance systems such as automatic distance control. This means that it is all the more important to use mandatory technical inspection as a tool to ensure the efficiency of these systems throughout the lifetime of a vehicle, for both the safety of the driver and the future acceptance of new electronically controlled systems.

Recall Campaigns by Car Manufacturers

Although no EU country officially registers recall actions by car manufacturers, a large proportion of these can be obtained from the press. **Figure 3** is a summary of such publications in Germany, which relate to electronically controlled systems for 1997 – 2001. Practically every large car manufacturer carried out a recall action during this period. Approximately 2 million vehicles were recalled to workshops for checks or replacements in respect of airbag systems. Only around 80 % of all vehicles recalled responded to the recall action and received an inspection. A system check within the framework of periodical technical inspection could lead to a significant increase in this figure, bringing benefits to the driver, car manufacturer and to traffic safety.

Recall actions for electronically controlled systems (ECS) 1997 – 2001

Manufacturer	Type	Design Year	ECS	Number	Region	Year
Audi	80, A4, A6, A8	95,96	Airbag	790.000	World	1997
BMW	M3	from 97	Side Airbag	17.000	US-Version	2000
Daimler/Chrysler	Dodge, Ram	95-98	Airbag	328.500	World	1999
Fiat	Punto		Belt Pretensioner			1997
	Escort, Mondeo, Scorpio		Passenger Airbag	124.000	Germany	1998
Ford	Mondeo	00	Airbag-Module	2.500	Europe	2001
	Focus		Engine Control	100.000	Great Britain	2000
	Focus	99/00	Engine Control		Germany	2000
	Focus	99	Airbag	9.000	Germany	2000
	All		Brake Assist	176.000	World	1997
Mercedes	E Class		Side Head Airbag	4.160	World	1998
	All	95/96	Driver Airbag	150.000	Europe	2001
Opel	Vectra		Side Airbag	1.300	Germany	1997
	Sintra		Airbag	72.000		1997
Porsche	911	96	Driver Airbag	6.376	World	1999
	Twingo, Clio, Laguna		Airbag	160.000		1997
Renault	Twingo	98/99	Front-Airbag	138.426	World	2000
	Kangoo	98-00	Airbag, Belt Pretensioner	264.000	World	2000
	Range	94,95	ABS	12.900		
Rover	Range, Land	95 - 98	Airbag	6.498		1998
	Type 75	99	Crankshaft Sensor	22.000	World	2000
Land Rover	Discovery	99	ABS	2.150	World	1999
Volkswagen	Golf III		Airbag, Control Unit	50.000	Europe	1999
Volvo	440, 460, 480		Airbag	20.000		
	S70, V70, C70	97,98	Passenger-Airbag	235.000	World	1999

Figure 3

Discussions in the European Union as the Law-making Authority

Having undertaken extensive discussions, the German Transport Ministry made a proposal to the EU in April 1997 for an annex XV to the Type-approval systems. Stated here for the first time was the requirement to be able to test such systems within the framework of periodical technical inspections. In conjunction with this initiative, corresponding proposals were also made to the ECE.

In the Emissions Directive 98/69/EEC published in October 1998, Article 4 requires the EU Commission to produce a report on extending On-Board-Diagnosis to other electronic components that have an influence on active and passive safety. This report is to be made available to the European Parliament and Council by 30th June, 2002.

Finally, it has been proposed that ECE-Regulations 13 (Brakes) and 79 (Steering) have new identical annexes (annexes 19 and 6 respectively) added with specific requirements for the safety of electronically controlled systems. Among other things, these annexes will have a requirement to provide documentation on how the systems can be checked during periodical inspection. Because, as yet, these annexes are of a general nature, more thorough and extensive requirements are being developed, e.g. that malfunctioning of a system should be identifiable in an inspection. However, such requirements are currently part of controversial discussions.

Benefit of Warning Lights

One common argument against the introduction of differentiated procedures during the periodical technical inspection is the low failure probability of the electronics and the self-monitoring systems. Obviously, it is true that electronically controlled systems consist of both electronic control and computer units, plus additional sensors for signal acquisition and mechanical and/or pneumatic actuators and controls, including the power supply. The electronics are, therefore, in the truest sense of the word only a small part of the total electronically controlled system.

This also makes clear what electronic self-diagnosis or on-board-diagnosis can and cannot do. Electronic diagnosis is able to check the control program, the incoming sensor signals and outgoing control pulses for plausibility. However, diagnosis is not able to determine whether a solenoid valve actually opens or closes sufficiently to achieve the desired pressure increase or whether the desired braking force is actually exerted on the wheel. This is only possible by means of more extensive tests. But nevertheless on-board-diagnosis will in future be a useful supplement to periodical technical inspection.

3. Study 1 (a) - Reliability of Electronically Controlled Systems On Vehicles

During 1999, vehicle reliability data from a roadside call-out company and a major vehicle leasing company in the UK was examined. **Figure 4** compares the characteristics of the two data sources. Additional data was also included from Germany and Sweden.

Characteristics of the data sources

	Call-out	Leasing
Years covered	1995-1997	1995-1999
Number of vehicles	2,000,000[*]	140,000
Average annual distance covered	14,700[**]	43,091
Total number of faults recorded	5,210,343	2,415,912
Electrical system failures	2,334,527	
Electronic system failures	191,236	165,801[***]
Electric/electronic failures as % of total	48%	7%
ABS failure	3,348	2,146
Airbag failure	723	1,627

[*] Assumes one member has one vehicle
[**] Assumes call-out fleet represents UK fleet
[***] Lease data is categorised differently and electrical/electronic is one category

Figure 4

The roadside call-out data was provided by a major UK motoring organisation that had about 2 million members during the period of this study, which represents almost 10% of the current UK vehicle fleet. The data provided covered the years 1995 to 1997 and related to vehicles that had broken down either at the driver's home or on the road. However, it is this type of failure that causes the most inconvenience and represents the biggest road safety risk. It is also likely to be the most expensive type of failure and may involve damage to other components, cost of recovery and loss of productivity. During the period of this part of the study, an average of approximately 1,735,000 call-outs was recorded each year. The type of fault recorded was itemised into categories ranging from body mechanics to electronic systems. For the analysis some faults were excluded because they related to damage or routine service items, for example flat batteries, punctures and running out of fuel.

The greatest number of faults occurred in electrical systems, averaging about 700,000 per year. The average number of faults for engine system failures averaged over 300,000 per year. Electronic system failures averaged over 60,000 per year which is still a very large number and is comparable to the failure rate of mechanical systems such as braking, steering and suspension components which are an important part of the current periodical technical inspection according to directive 96/96/EC. The number of faults by age of vehicle for each year of data is shown in **Figure 5.**

Number of Faults by Age at Time of Fault

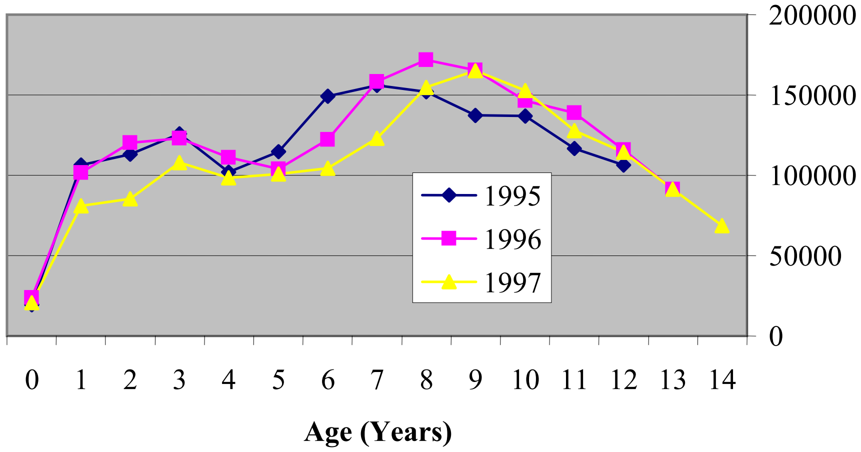


Figure 5

The lease company data was provided by a major UK vehicle leasing company and contains data on all the repair and maintenance carried out during the period 1995 to 1999. The routine maintenance records have been removed from this analysis which covers the system failures and not routine servicing. The leasing company had an average fleet size of about 72,000 vehicles during the period of this study, such that the 5-year database contained information on approximately 140,000 unique vehicles. The vehicle fleet covers a cross section of manufacturers and vehicle types including light vans, car-derived vans and cars.

As with the data from the roadside call-out company, the data was itemised into different system types. The largest number of faults was due to tyres and exhausts, accounting for over 280,000 faults over the last two years of the sample period. This level of faults has risen sharply over the period of the study. Electrical and electronic systems averaged about 40,000 per year between 1996 and 1999 with no apparent trend over the time period. Approximately 6 per cent of all the electronic/electrical system faults were actually due to wiring problems.

Electronic failures

The data for the full period 1995-99 provided by the vehicle leasing company can be analysed for all types of electronic system failure. The highest number of faults occurred when the vehicles were 2 years old with a steady drop off until about 5 years old when the percentage number of failures appeared to level out, **Figure 6**.

This data can be analysed in more detail by splitting the data into different categories such as sensors, ABS and ECU. 5.3 per cent of vehicles experienced engine sensor faults and an additional 5.2% suffered other sensor faults. Airbags and ABS also contributed significantly with 1.2 per cent of vehicles experiencing airbag faults and 1.5 per cent experiencing ABS faults. The total numbers of faults for airbags and ABS were 1,627 and 2,146 respectively.

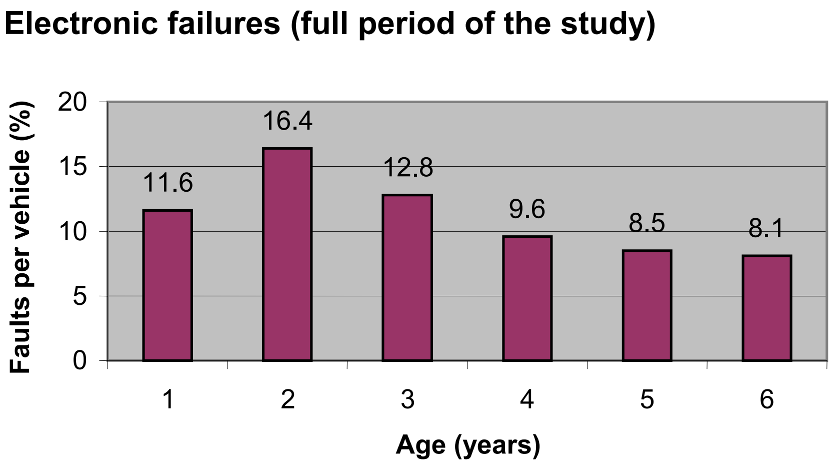


Figure 6

Airbag Failures

The data from the UK vehicle leasing company can be used to examine the faults from airbag systems by age of vehicle. This is useful in determining the effect of vehicle age on the failure rate. Vehicles of 1 and 2 years of age developed more faults than 3 year old vehicles. It is difficult to identify any trend with the limited data available and it would be necessary to collect data over a much longer time span in order to make any meaningful predictions.

As well as the data from the UK leasing company, DEKRA in Germany has also produced some data on electronic system failure rates.

The total numbers of failures are high when the populations of vehicles in use are considered. It has been estimated that the number of failures in the UK is between 79,601 and 225,000 faults, depending whether the estimate is based on the proportion of vehicles affected or the failure rate per vehicle km driven. Similarly, the total number of faults in Germany for the same year would represent about 142,000 faults based on the proportion of vehicles affected. As before, we need to obtain more data over a longer time period in order to identify any trends. However, it is interesting that the single estimate for the German data lies approximately half way between the two estimates for the UK.

ABS failures

A similar analysis has been performed on the data for ABS failures. There was a significant rise in the number of faults per vehicle between years 1 and 2, whilst 3 year old vehicles appear to have a similar number of faults to 2 year old vehicles.

The UK data showed a slight increase in the faults per vehicle between 1996 and 1997, little change in 1998 and a small drop in the number of faults in 1999. For comparison, the German data followed a similar pattern but 1 year out of phase. This may be due to the different fitment rates between the UK and Germany for ABS. As an example, the total expected number of ABS faults in 1999 for the UK was between 99,955 and 288,000 whilst in Germany there were about 280,000. It is interesting to note that the German estimate lies close to the upper end of the estimated range for the UK. This contrasts with the equivalent estimates for airbags where the German number was in the middle of the UK range.

Discussion

The data provided by the roadside call-out company is believed to underestimate the total number of faults for vehicles in the UK. This is because the data only covers incidents where the vehicle has broken down resulting in the driver seeking help from the call-out company. It is also believed that the data from the leasing company may also underestimate the total number of faults because the vehicles owned by the company are mostly less than four years old. Hence faults occurring in older vehicles will not be included.

It is not possible to make accurate predictions about the future numbers of system failures as no clear trends were shown in the data. This may be due to a number of reasons. It is not unreasonable to expect that system failure rates will have a cyclic nature with a high number of faults during the early years of introduction and a lower number of faults as the system matures. Each time a system is upgraded or a completely new system introduced then a new cycle would begin. To determine whether this cyclic pattern is true we would need to collect more data over a much longer time span. In the next few years, braking systems will change ABS into ESP and evolve into fully electronic systems, EBS. Similarly, airbag technology will develop using more bags, improved deployment rates and more complex control algorithms capable of detecting the characteristics of the occupants and the type of impact.

Hence, we would expect the failure rate to increase simply because the number of devices is increasing. The added complexity of the systems for both hardware and software is also likely to cause an increase in the numbers of failures.

In the future, electronic systems will be used to provide full control of the steering, collision avoidance, pedestrian protection and automatic route guidance. These types of system are highly safety critical and any failures in these systems could have serious consequences. It will be essential to ensure that these systems are operating correctly and are regularly inspected.

Traffic growth is expected to rise by about 5 per cent per year for the UK and it is not unreasonable to expect similar growth in other European countries. We would, therefore, expect that the failure rates for electronic systems fitted to vehicles to increase in proportion with this increase in the number of vehicles in use.

The number of electronic system faults is significant and is likely to increase in the future as the number of systems fitted to vehicles increases and their complexity grows. Current data for the UK suggests that about 7% of all faults are likely to be electronic system failures. Of these electronic faults 6% were due to wiring problems. The UK currently has 26 million vehicles in use (year 2000). The numbers of faults described above will result in 24 per cent of vehicles experiencing electronic system failures.

Electronic faults, all years

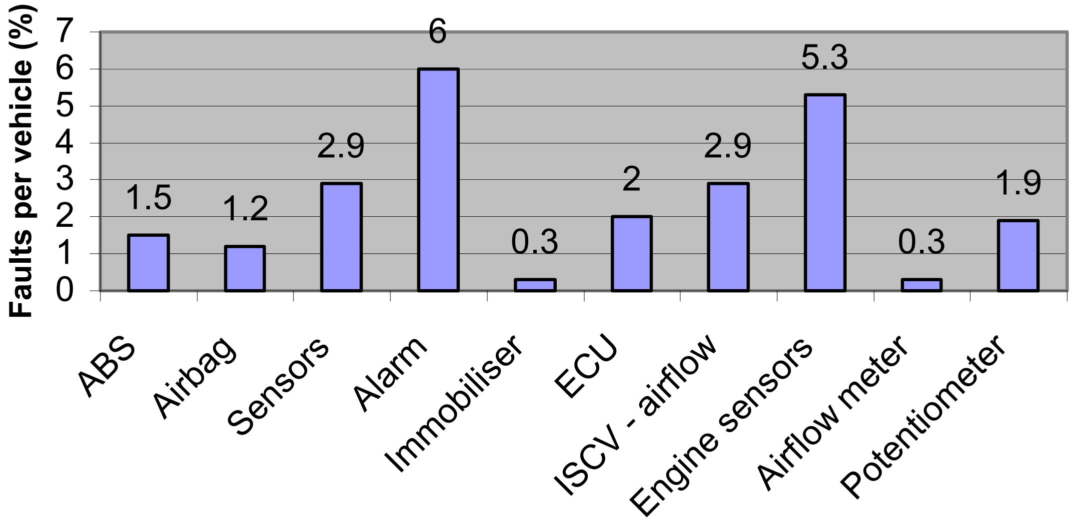


Figure 7

Data from the leasing company showed that 34,154 electronic system faults occurred during the period 1995 to 1999, **figure 7**. A similar analysis for airbag faults showed that a total of 1,627 faults were recorded. It should be remembered that during the period of this study the airbag fitment rate was increasing rapidly. In the case of ABS, 2,146 faults were recorded over the period of the study. It should also be remembered that the fitment rate of ABS was also increasing during the period of this study.

Specific tests for vehicle electronic systems do not form part of periodical technical inspection. As failure rates are comparable to other systems already included in periodical inspection, there is a strong case to include specific tests for electronic systems. The case for the inclusion of specific tests in periodical technical inspection is further supported by the use of electronics in complex safety critical systems in the near future. Examples include steer-by-wire, pedestrian protection and collision avoidance systems.

Research in Germany has shown that the use of warning lamps to indicate system failures is inadequate and significant numbers of faults have been identified using fault code memories: these faults were not indicated by the system warning lamp. Hence, fault code memories should be interrogated as part of annual inspections.

4. Study 1 (b) - Cost/benefit Considerations

Using the information from the study reported in the previous section, a cost benefit analysis was carried out using information gained about reliability issues affecting vehicle electronic equipment and the effect of introducing specific testing of ABS and airbag systems as part of periodical inspections required by directive 96/96/EC. The actual reliability of the electronic systems will not be affected by changes in periodical technical inspection as the reliability is dependent upon the electronic design, build and installation. However, introducing specific tests could significantly reduce the consequences of the number of failures. These will be found in terms of reducing the number of breakdowns and the potential reduction in accident costs, for example reducing the severity of injuries from fatal to serious.

The reliability study provided failure rates of electronic systems from a roadside call-out organisation and detailed system failure data from a major leasing company in the UK. Additional data was provided by Germany and Sweden. The cost benefit analysis used the more detailed UK data as the basis of the calculations. The costs of breakdowns and accidents were estimated from available data.

Two key assumptions were made in the analysis:

- The potential reduced number of accidents and breakdowns as a result of introducing a test.
- The probability of reducing the level of severity of an accident as a result of introducing a test.

The calculations were performed using an EXCEL spreadsheet from which minimum, maximum and typical costs were derived. It was found that, for the UK, the total typical benefit from the potential reduction in the cost of breakdowns and repairs and the potential benefit from avoiding accidents relating to airbag faults was €76,200,000, whilst the total potential benefit for ABS was €67,600,000, **figure 8**. It is estimated that the benefit of introducing testing for airbags and ABS in the UK would be typically 6 Euros per vehicle assuming that the test is able to reduce the consequences of failure by 50 per cent. The analysis also considered the potential benefits across the European Union. However, the level of traffic, inspection frequency, number of vehicles, fitment rate of equipment and the number of fatal accidents varies between the different EC countries. Where fitment rates are higher and inspection frequencies lower, the benefits are likely to be higher.

Estimates of potential benefits from introducing tests for airbags and ABS

Level of benefit	Airbag benefit M€	ABS benefit M€	Total benefit M€
Minimum	56.3	55.8	101.9
Typical	76.2	67.6	143.8
Maximum	170.2	77.1	247.8

Figure 8

5. Study 2 - Airbags

Airbags are a standard feature in most new vehicles today. A large number of vehicles already have more than one airbag. All of these systems use a number of acceleration sensors located at different positions on the vehicle. The deceleration occurring after an impact is detected by the systems, evaluated and if necessary the decision taken to trigger the individual airbags. A self-diagnosis system monitors the integrity of the systems before and during journeys. If malfunctions are recognized the system is deactivated, a message saved in the fault memory and the driver notified by an indicator light which comes on.

In this study the operation of older airbag systems was investigated.

In order to be able to make a statement about the condition of the airbag systems, the electronic components of the systems were subjected to closer scrutiny. For this purpose, the sensor mechanism, the cable harness and the ECU were mounted onto a test sledge of a crash test facility. Experiments at different impact velocities as well as variable decelerations were carried out and the test results were analysed individually as well as in comparison with each other. Furthermore, the airbag modules of the individual systems were triggered and checked to see that they inflated correctly.

Figure 9 shows by model year of the systems the measured signal duration, the release time period, the delay until ignition of the passenger airbag (if applicable) and the average inflation duration of the airbag (if applicable).

Model year, signal duration, triggering period, time delay for ignition of passenger airbag and inflation duration of airbag (ika measured values)

	Model Year	Signal Duration [ms]	Triggering Period [ms]	Time Delay for Ingnition of Passenger Bag [ms]	Inflation Duration of Airbag [ms]
Mercedes-Benz 300E	'86	46 - 67	37 - 70	-	-
Mercedes-Benz S-Klasse	'84 / '84	62 - 100	18 - 73	-	20 / 20
Opel Vectra	'94 / '94 / '95 / '95	5 - 12 / 67 - 105	13 - 33	-	38 / 27 / 31 / 27
Ford Mondeo	'94	3 - 5	18 - 66	-	25
Ford Escort	'94 / '94 / '95	3 - 6	22 - 73	-	27 / 24 / 25
Ford Ka	'96	3	16 - 47	13	-
VW Lupo 3L TDI	'99	50	14 - 39	0	-
Fiat Multipla	'99	49	17 - 60	10	-

Figure 9

Even in this survey significant differences can be seen between the various systems. While the Ford Ka only emits a signal for 3 ms, the signal duration in the VW Lupo is 50 ms. While some systems simultaneously ignite the driver and passenger airbags (e.g. VW Lupo), with other systems there is a time lapse between the two ignitions of 13 ms (Ford Ka). However, in all systems studied the time lag between the two ignitions was constant. The investigation clearly showed differences in the time period before release. No unambiguous relationship could be discerned between the time periods and vehicle parameters, such as empty weight or year of manufacture. It was concluded that the values used do not appear to have been specifically adapted to the car in which the airbag is used. It would seem that there is the potential for optimization.

For the analysis of the test results, presenting "changes in velocity" versus the "time" on the one hand and versus the "displacement" up to the airbag system's moment of ignition on the other proved to be the most meaningful in order to be able to follow the airbag system's release strategy. In the first case, the release thresholds could be approximated very well with exponential functions in all of the systems. In the second case a linear relationship became evident between the change in velocity and the displacement so that it was possible to decide on the basis of this characteristic line whether malfunction was present or not in an airbag system.

Apparently the Opel and Ford systems, in order to release at a given point in time, need a greater change in velocity than do the Mercedes-Benz systems. The Opel Vectra system is the only system that does not react adaptively to the severity of the accident but rather monitors a velocity change threshold value of about 10 km/h. If the change in velocity traverses this limit, the airbag is ignited. Additionally, the threshold value must be attained within 13 ms to 33 ms if the ECU is to classify the deceleration process or the accident as serious and to consider airbag ignition to be necessary.

Similar processes emerge for the velocity change - displacement diagramme, **figure 10**. The airbag release can be depicted for all systems as a linear function of velocity change over the displacement. This approximation was significantly better for all vehicles.

Velocity change versus displacement for all systems

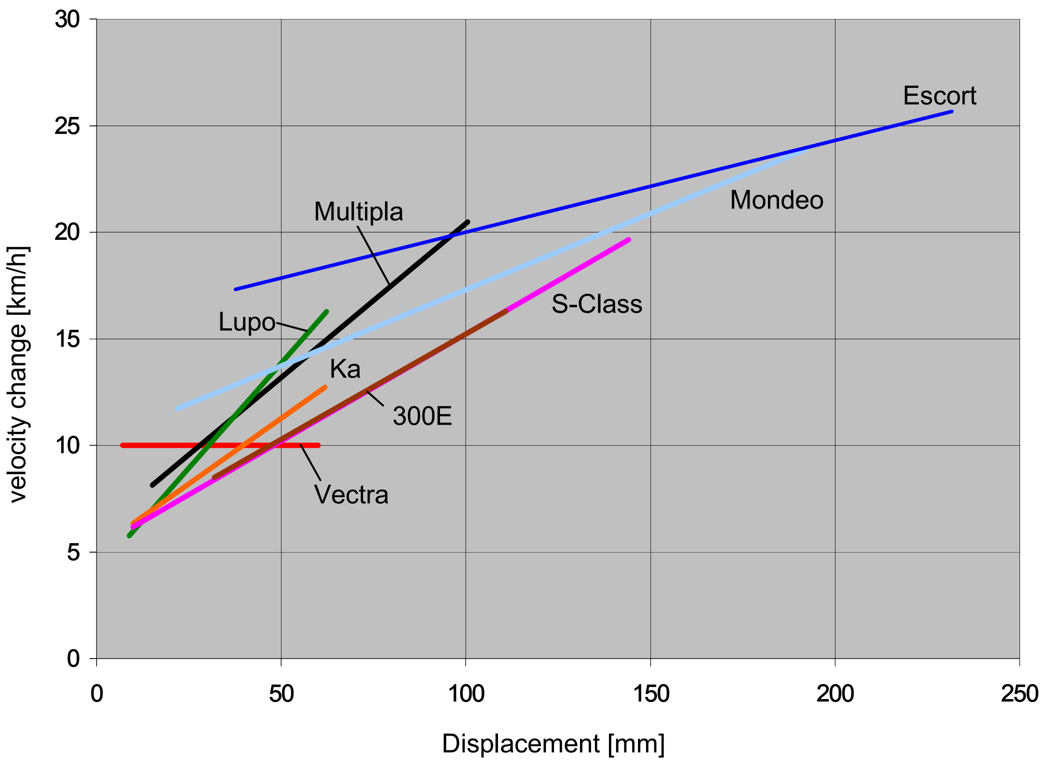


Figure 10

The trend lines of the two Mercedes-Benz cars diverge only slightly from each other. Complicated adjustment to each of the front body section structures could not be detected.

In summary, the experimental work showed:

1. The release threshold with all airbags was recognised reliably by the ECU's. In addition, it was found that all airbag modules ignited without flaw. Any influence of ageing of airbag ECU's and modules caused by environmental conditions could not be found in the experiments carried out.

2. Contrary to the statements of vehicle manufacturers, the airbag ECU is able to emit an ignition impulse several times, even with the MIL (Malfunction Indication Lamp) turned on.

3. The release thresholds are mathematically quite simple trend lines. Even with two different vehicle types from one manufacturer, the trend lines diverge only slightly from each other. Complicated adjustment to each of the front body section structures could not be detected.

Although all airbag releases or decisions not to release were carried out correctly, it still makes sense to reflect on a test procedure for airbags since the number of systems studied was much too small to arrive at any statistically significant statements about realiability. Reports about improper release of airbags, recall actions precisely in regard to the airbag and the general issue of electronic system ageing underscore this necessity. With any type of test procedure one must be able to connect with the airbag electronic system via a diagnostic interface and here a standard diagnostic interface for all types of vehicle would be something to aim at.

The first step is to check that all system components are present and of the correct type. It is possible that after an accident not all airbags are renewed or components may be used which are not compatible with the original airbag system. A system check made at the very beginning of testing will detect such failure.

The next step in evaluating an airbag system should be the read out of the fault memory. It indicates to what extent the system itself has already recognised a malfunctioning or a disturbance.

The diagnosis routines are not only checking the components of the airbag-system permanently, but also the proper functioning of the ECU itself. This function is usually called "Watch-dog". The performance will be checked by a functionality test. **Figure 11** shows a procedure which was derived from the experiments that have been carried out.

Functionality test of airbag electronics

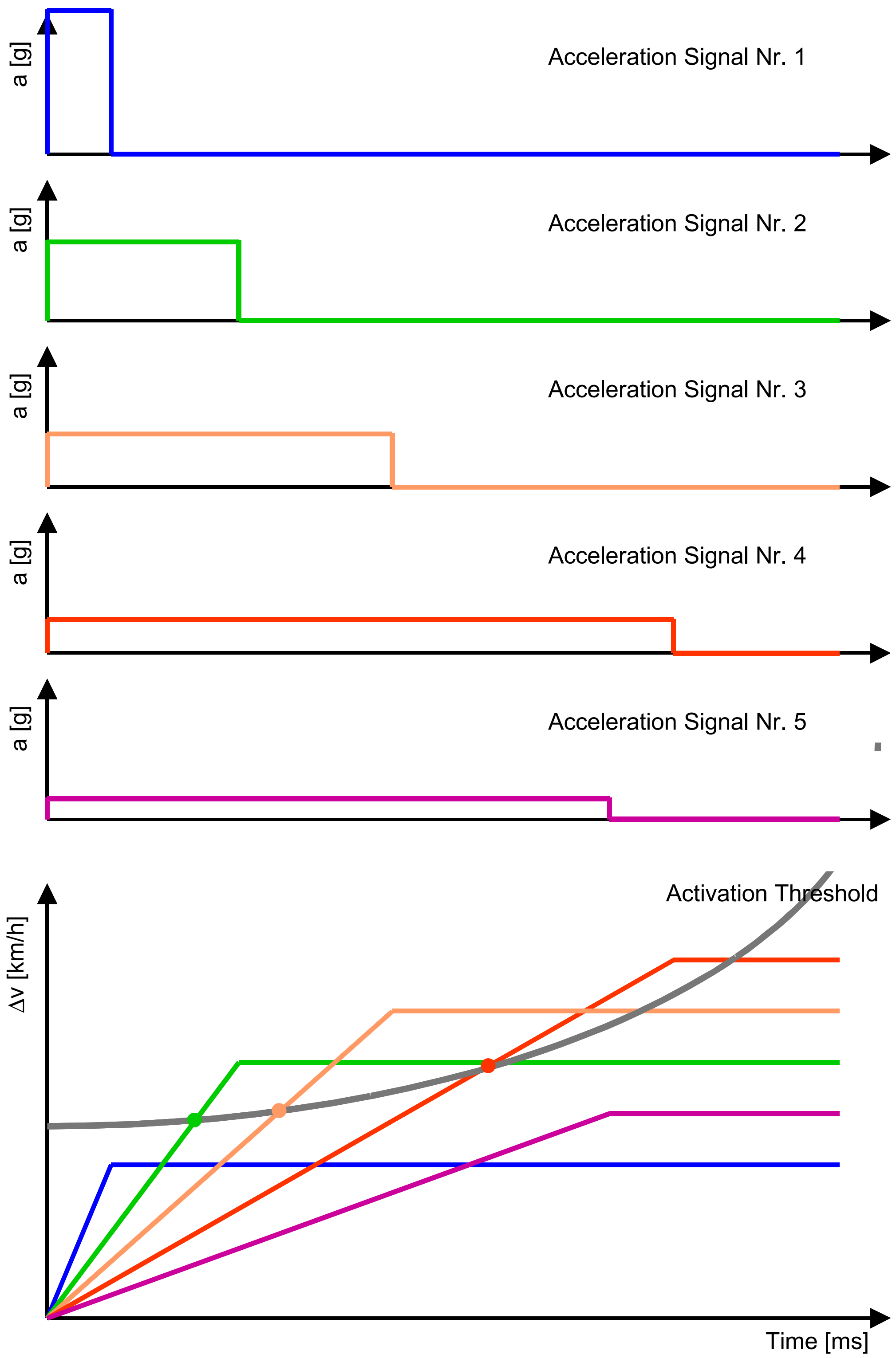


Figure 11

In order to be able to carry out a real functionality test of airbag electronic systems, acceleration signals would have to be fed to the evaluation unit which correspond to those of a real-life crash situation. In principle, acceleration graphs in the form of rectangular signals of varying size and duration would suffice. These rectangular signals would be integrated up by the airbag electronic system to straight lines of change in velocity. Depending on whether the changes in velocity thus calculated are large enough or not, the ECU will determine whether or not to emit an ignition impulse (**figure 11**). Signals No. 2, 3 and 4 will make the airbag fire, signal No. 1 is too short, and the level of signal No. 5 is too low.

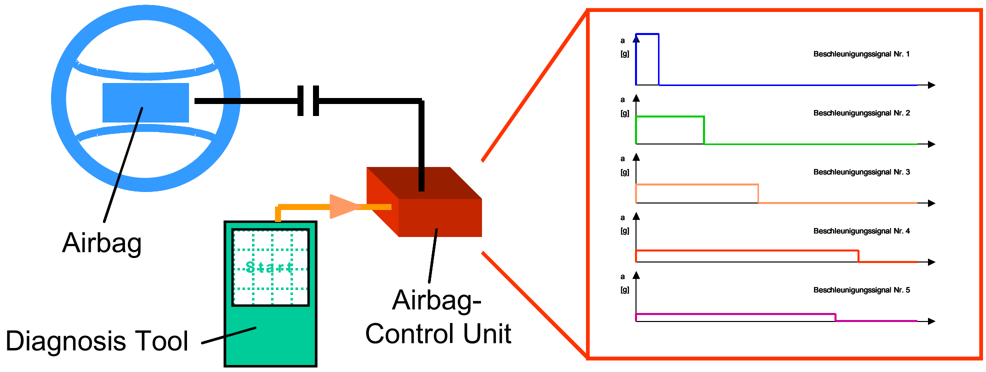
From the deceleration graphs which produce an ignition impulse, the characteristic release graph of the airbag electronic system can be reconstructed very simply. If the measured release threshold diverges very much from a basic shape, then the airbag is clearly malfunctioning. The test signals should be directly produced in the ECU to ensure that the airbag electronic system always uses appropriate signals. In addition, it will be certain that all relevant functions are actually tested. Moreover, manufacturers would not be forced to provide access to feed in the signals but may form the test signals in accordance with the characteristices of their systems. The ignition impulse must be picked up and evaluated. For this, access to the 'safeing' sensor would appear to be the most feasible option as this prevents inadvertent ignition of the airbag in the conditions of the test. As this procedure covers the complete signal path from entry of the deceleration signal up through emission of the ignition impulse, it constitutes a clear extension of the self diagnosis routines.

Figure 12 gives an overview of the principles of the function test. The diagnostic tool only takes care of the communication. All the required signals and the evaluation software are directly installed into the airbag-ECU.

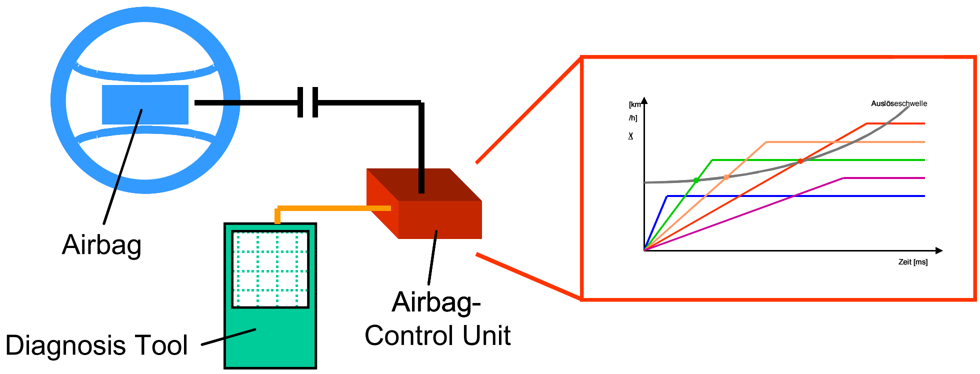
This procedure will also support future airbag systems. They will be fitted out with a whole series of so-called “smart” features meant, on the one hand to improve determination of the right ignition moment and, on the other to release the appropriate airbag to protect the passengers. The features could include, for instance, extended recognition of seat occupancy with an estimate of passenger weight as well as of the passenger’s sex, “out-of-position” recognition to minimise passenger injuries by the airbag as well as a multistage ignition of the actual airbags. All of these “smart” features can be integrated in the test procedure relatively easily. Thus, as an example, the tester can change his seat position during testing. The system would have to recognise correctly the weight and sex of the passenger or, if the sitting position is too close to the airbag. In the latter case, the airbag would have to be deactivated. Likewise, different acceleration signals can be combined so that the airbag system is fooled into recognising various accident situations. Depending on the accident situation, ignition signals should be emitted only to the front or only to the side airbags.

Schematic Function Test

1. Call test Signals



2. Function and Action Test Execution



3. Output Results on Diagnosis Tool

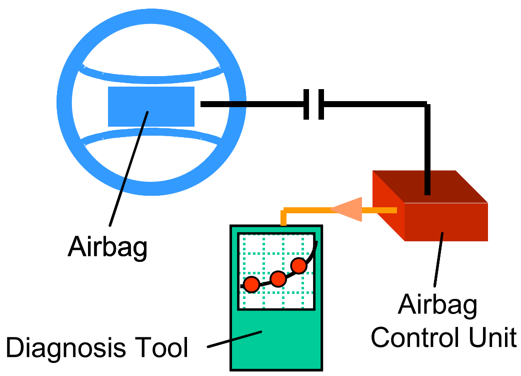


Figure 12

In summary, the recommended airbag test procedure can be described as follows:

I. System check
II. Read out of the fault memory
III. Check of the “Watch-dog”
IV. Functionality test
V. Testing of the “smart” features

6. Study 3 - Existing Anti-lock Braking Systems

Modern vehicle drive systems are characterised by a multitude of complex control and regulating systems optimize the drive characteristics to the prevailing driving conditions. One existing systems with high fitment rates is electronic devices for regulating the brake system to obtain increased safety by means of automatic slip regulation when braking (ABS, ESP etc.) or accelerating. The information about the availability and reliability of these systems is insufficient. Therefore, in this study the functional behaviour of a large number of cars (>250) fitted with older ABS systems was examined using a four wheel ABS Test Bench. The functional behaviour was analysed and compared with the fault memory content before and after the efficiency test on the test bench.

ABS Tests

Figure 13 shows the general principle of the 4-Wheel ABS Test Bench. The rear rollers can be used for conventional measurement of the brake forces with a test velocity of approx. 5 km/h. These rollers are deactivated during the ABS-Tests. The central roller serves as supporting roller for the vehicle wheel and is equipped with a revolution indicator for measuring the wheel circumferential velocity; the front roller is directly coupled with an asynchronous motor designed for ABS simulation with a test velocity of approx. 50 km/h and is used for simulating an icy road. A hydraulic system is used for automatic wheelbase adaptation.

4-WHEEL ABS TEST BENCH

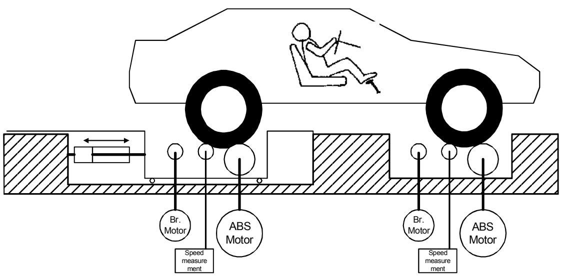


Figure 13

The test sequence was made up of 3 phases:

Period 1:	0 s	-	8 s	:	$\mu \approx 0.2$	"SNOW" phase
Period 2:	8 s	-	9.5 s	:	$\mu \approx 0.1$	"ICE" phase
Period 3:	9.5 s	-	13 s	:	$\mu \approx 0.2$	"SNOW" phase

During this time, the driver has to initiate and continue full braking. A “failure” is recorded if a wheel locks for more than 1 second. This definition of failure matches the requirements of ECE-Regulation 13, which allows "short wheel locking". Once a wheel has locked for more than 1 second, the motors of the test bench are switched off to avoid tyre damage.

The implementation of tests and data collection was done between August 2000 and August 2001. The number of tests was increased by inviting owners of the selected car types from the TÜV customer database by mail. At the end of the test phase, 262 tests had been done.

The first analysis step was the identification of valid datafiles. Datafiles were considered invalid if

- There was no braking;
- Braking was too late;
- Vehicle had no ABS;
- There were any measurement problems.

The result was the identification of 234 valid datasets, which were analysed further. For a subgroup of 144 cars, both the efficiency test and an additional scan of the fault memory were done. The test procedure included fault memory scans before and after the efficiency test on the test bench. **Figure 14** shows the number of tested cars for each car type (Σ 234).

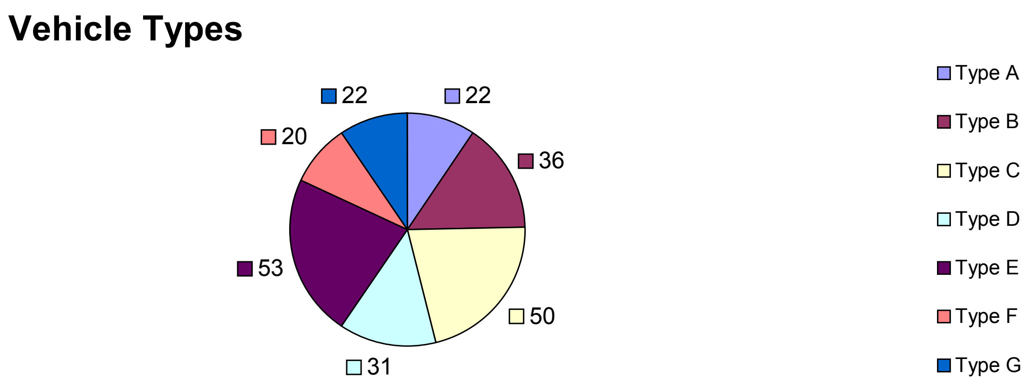


Figure 14

After the analysis of the collected data, the following main failure types were selected:

- Locking of one or more wheels during the test procedure, divided into locking in the "snow" phase and locking in the "ice" phase.
- Significant variation between the measurement results of an individual car and the collective results of the same vehicles after statistical analysis. These failures are described in the final test report and not included in this summary.

Evaluation of the collected data

Except from type B, the failure rate in the snow phase ranged between 6.0 % (type C) and 18.2 % (type G). In the ice phase, between 4.5 % (type A and G) and 9.7 % (type D) locked during the tests. The total failure rate was 8.1 % for failures in the snow phase and only 4.3% for failures in the ice phase. The reason of this difference could be that most of the ABS-failures will lead to locking in the snow phase (which already puts high stress on the ABS-system) so that these cars did not reach the ice phase. Only 4.3% of the cars had failures, which did not lead to locking in the snow phase but caused locking in the ice phase, which puts the severest stress on the ABS-System ($\mu \approx 0,1$). **Figure 15.**

Failure analysis by type: relative

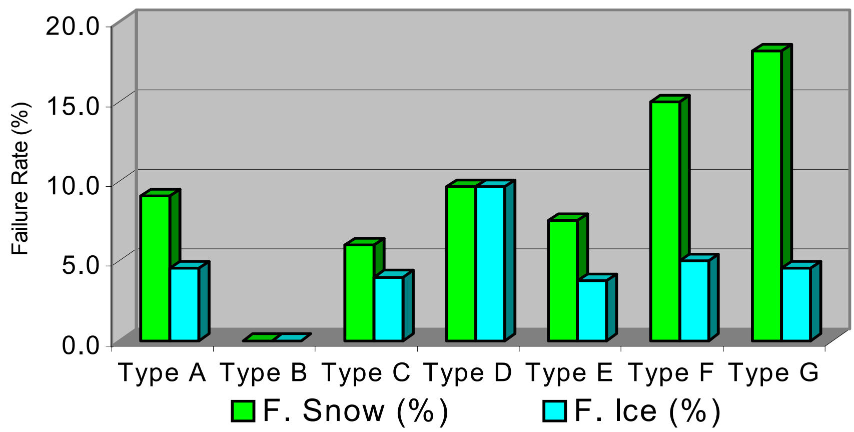


Figure 15

The age of a car, and with it the age of the ABS, has an influence on the reliability of the system and the availability of the correct system functions. A higher failure rate is likely to occur in older systems. To show if this trend existed in the collected data of this study, the total failure rate (snow + ice) was analysed by the year of construction of the car. Only a small number of cars built in 1989 and 1991 were tested and the results are not statistically significant. **Figure 16** shows the failure rate increases with the age of the car. For cars with an age between 3 years (year of construction 1998) and 7 years (year of construction 1994), the failure rate increased with a high gradient. For older cars, the gradient is less.

Failure Rates by Age of the Car

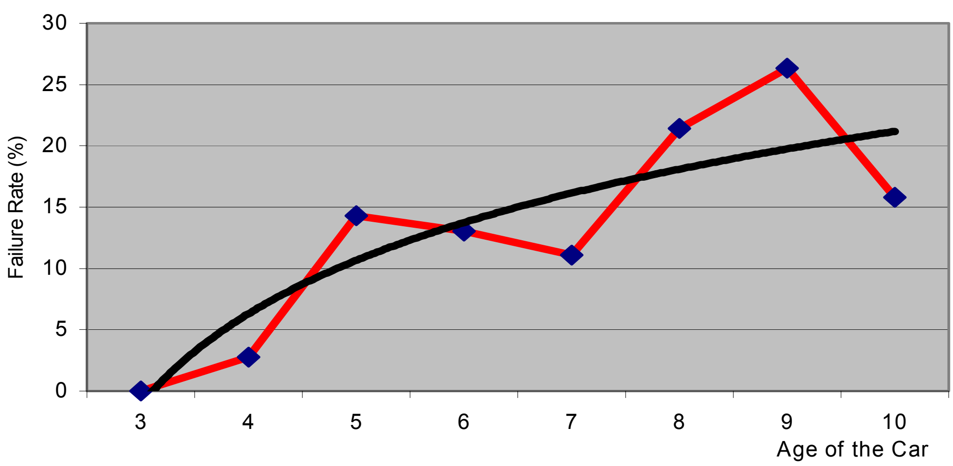


Figure 16

Another important factor for the availability and reliability of electronic and mechanical systems is the odometer reading of the car. The failure rate increased with the odometer reading of the between 0 and 175 thousand kilometres, **figure 17.** For more than 175 thousand kilometres, only a small number of cars (13 between 175 tkm and 200 tkm and 9 with more than 200 tkm) were tested, therefore no relevant analysis could be done for this odometer reading.

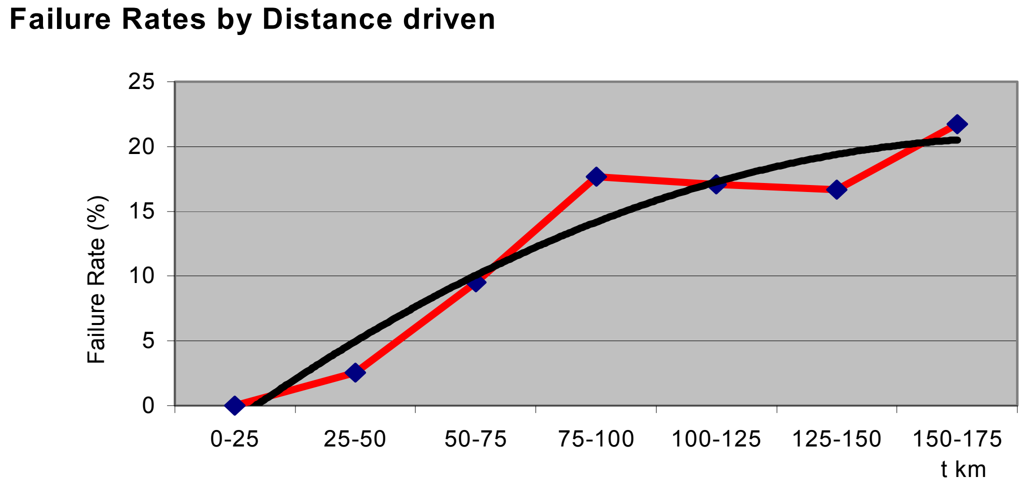


Figure 17

From the tests with valid datasets (234), a subgroup of 144 tests included both an efficiency test on test bench and a scan of the fault memory before and after the efficiency test. From these 144 cars, the fault memory was readable in 95 cases and not readable in 49 cases for various reasons, which are described in the main report.

Figure 18 shows the relative fault entry rates. It is remarkable, that up to 30% of the cars of one type have fault memory entries before test on test bench (type D: 30%, type C and G: 20%, type E: 16,7%). After the deletion of the fault memory entries and the efficiency test on the test bench, for type F and G up to 30% of fault entries recur after test on test bench. More than 20% of type A cars have failure entries after the test on the test bench.

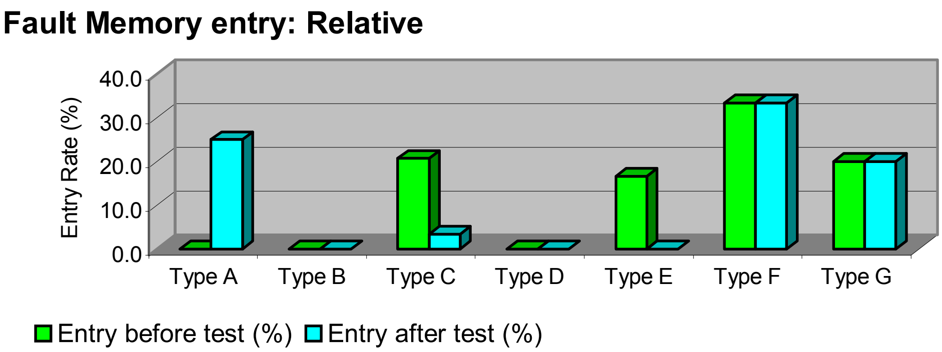


Figure 18

In addition to the fault memory scans, the function of the ABS warning lamp was checked. For the cars with failures in the snow phase (n=19), the warning lamp was alight before the efficiency test on only one car. In two cars, the warning lamp was switched on during the failed test (wheel locking) and remained alight until further brake applications on the road. In two cars, the warning lamp was only alight while the wheels locked. None of the failures during the ice phase (n=10) were signalled by the warning lamp.

Most of the fault entries of the cars coming to the ABS tests were faults in *one or more wheel speed signals*. 9 cars had such fault entries. This could be caused from temporary problems with one or more wheel speed sensors in the past, or from current failures. If it was a failure entry because of a temporary problem in the past, the fault would not recur during the subsequent test on the test bench. For 3 of the 9 cars with sensor-related faults, there was no fault memory entry after the test and so were of the "historical" type. The remaining 6 vehicles must have had current faults in the ABS-system, because there was a new fault memory entry after the efficiency test on the test bench.

To check this, the correlation between the results of the fault memory scans and the efficiency test on the test bench was analysed. The aim was to check the effectiveness of the test via fault memory scan and the efficiency test on the test bench. The tests on test bench with failures were related to the fault memory entries belonging to these tests as follows:-

- **12** cars locked on snow
  - **8** had readable fault memories
  - Results of fault memory scan:
    - **5** failure entries before test
    - **5** failure entries after test

      (the same 5 cars)

Fault memory entries:
3 x WHEEL SPEED SIGNAL(S)
1 x PLAUSIBILITY PRESSURE/ BRAKE LIGHT SWITCH
1 x CONTROL UNIT DEFECT

At least 3 cars with failed test on test bench, but without fault memory entry!

- **3** locked on ice
  - **1** had a readable fault memory
  - Results of fault memory scan:
    - **0** failure entries before test
    - **0** failure entries after test

At least 1 car with failed test on test bench, but without fault memory entry!

One aim of this study was to examine the integration of the efficiency test into the normal periodical inspection. Therefore, the test bench was modified for an automated test sequence, so that the test could be executed by the normal test centre staff after an instruction.

From this work, the study came to the following conclusions:

- The ABS-test bench has shown its ability to detect failures with a test procedure that only takes a short time to perform.
- The automated test sequence allows the integration of the test into periodical inspection.
- Fault memory scans would be of advantage at periodic inspection, as more faults are detected than by looking at the warning lamp alone, but there are still some communication difficulties with current equipment.

Using an ABS test bench, ABS tests were done and a huge database (more than 250 tested cars) was created. The test procedure used simulated a complex and demanding, but realistic, task for the ABS (emergency braking on ice and snow). The measurement system and the evaluation possibilities allow detection of deviations from the normal system behaviour and of complete failures (locking in the snow phase or in the ice phase). For these very strict failures, a statistical analysis was done leading to following conclusions:

- There is a significant failure rate (average value 12.4 %) for ABS.
- The failure rate increases with the odometer reading of the car. It starts with 0 % for cars with 0-25.000 km and increases to 21.7 % for cars with 150.000 - 175.000 km.
- The failure rate increases with year of construction of the car. It starts with 0 % for cars from 1998 (age at the time of the test: 3 years) and increases to ca. 20 % for cars built before 1992 (age > 9 years at the time of the test).

From 234 total tests on test bench with valid datasets, a subgroup of 144 tests includes both an efficiency test on test bench and a scan of the fault memory before and after the efficiency test. From these 144 cars, the fault memory was readable in 95 tests (66%) and not readable in 49 tests (34%) because of various reasons.

A significant number of failures was not detected by the self diagnosis routine and was not documented in the fault memory. From 9 cars with readable fault memory and locking in the snow phase (failed efficiency test), the failure was not detected and documented in the fault memory for 4 cars.

This requires efficiency tests combined with fault memory scans to cover most of the failures of the ABS-Systems.

7. Study 4 - Vehicle Dynamic Controllers

In vehicle dynamic controllers, the driving condition of the vehicle is monitored by sensors and the vehicle is stabilised in critical driving situations by powerful interventions into the throttle and individually to each wheel by the brake.

As there is a "grey area" between the functioning of all components within normal parameters (green) and the recognition of an error by self-diagnosis (red) in **figure 19** a test procedure was developed to identify system deterioration or wear during periodical technical inspection or in workshop tests. In the "grey area", the self-diagnosis system is unable to identify problems, even though they influence the quality of the control system itself. This has been confirmed both by tests on real systems, for instance when electrical resistances were increased, as well as through simulation results.

Coherence between intensity of the failure and the identification possibilities

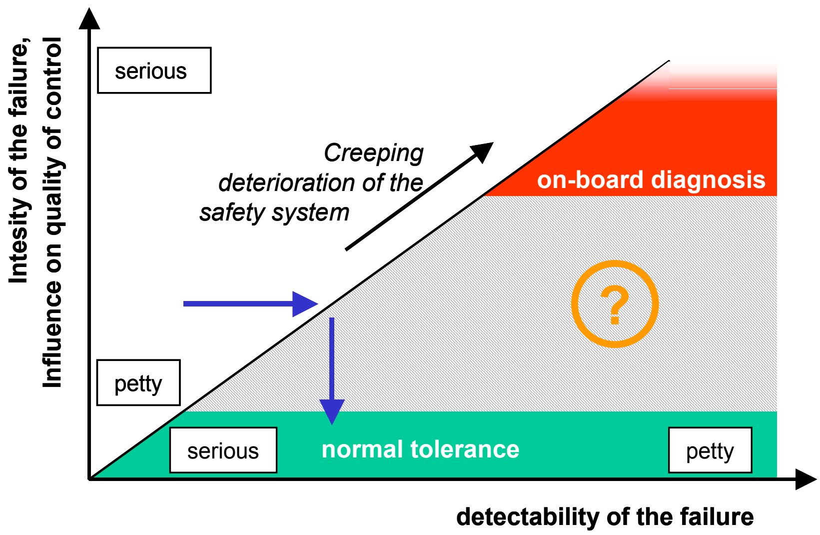


Figure 19

For a vehicle test to be useful to the vehicle owner, it should address both of the following aspects:

1) There are limited options for self-diagnosis.
2) Creeping system deterioration is only recognized late in the day.

Therefore a test procedure for vehicle dynamics controllers was developed by use of simulation models. During the driving tests of Mercedes-Benz A-Class and BMW 330xi the purely passive handling performance of the vehicles, as well as the performance with the intervention of the driving dynamics controller were measured. From the results of the test rig tests, it was possible to create vehicle models as multi-body systems (SIMPACK). A driving dynamics controller model was created with MATLAB/Simulink and linked to the vehicle models. The close agreement between test and simulation model ensured the validity of the investigations that followed.

The present situation using only the Malfunction Indication Lamp (MIL) is an unsatisfactory solution for the future. The same is valid for the pure communication with the electronic control unit through a standardized interface (like today's emission-OBD), although this would be a significant improvement on the present situation, because it would allow checks on whether the built-in electronic components are present and work together properly and it would allow the system's error memory and the readiness code to be read. But as it would still not be possible to make any judgement to the efficiency of the system, real functionality and performance tests should be carried out.

For the inspection option, test signals would be stored directly in the control unit. A simple diagnostic tool with the necessary interface (i.e. the current emission-OBD) would be capable of retrieving these test signals. The responses of the electronically controlled system would then be measured and compared with standard responses using available dynamic test facilities such as roller brake testing rigs. The advantage of this approach is that physical tests are carried out. This form of testing is very safe, since the electronics always receive the appropriate signals and all relevant functions can be properly tested. Furthermore, vehicle manufacturers are not obliged to provide an access point for test signals but can design the test signals themselves according to the requirements of their own systems.

These requirements are not met when the test signals are provided externally. This approach is expensive and prone to errors. This option only has benefits if the system responses are measured and evaluated directly and serve as the basis for calculating of the next default values. These kinds of “hardware in the loop” test rigs have become established for the development of electronically controlled systems. They are, however, too expensive for tests in the context of periodical technical inspections.

Figure 20 summarises the pros and cons of the discussed approaches.

Communication in conjunction with the storage of test signals in the particular control units, was therefore, considered the most reasonable way to check electronically controlled systems, since real-life functionality and operational testing can be carried out at acceptable cost.

Electronically controlled systems consist basically of sensors, cable harness, Electronic Control Unit (ECU) and actuators. The main source or problems with electronically controlled systems are the sensors, the wiring and mechanical components, such as valves, pumps, etc. However, a test of a vehicle's electronics should not be confined just to individual components like the sensors. All components should be checked.

Sensor-signals that have only slight noise or drift, or have a small offset are not yet classified as faulty. Such signals have considerable influence on the quality of the control system and can be symptomatic of the onset of problems. A judgment on the signal quality of all sensors should therefore be covered by the test procedure.

Concepts of tests during periodical vehicle inspection

Warning device check	Communication with electronics via OBD-interface	Internal function test with mechanical influence	External function test with mechanical influence
Defined Faults are indicated by a warning device.	Defined Faults are indicated by a warning device. Additionally there is communication with the electronics.	Supplementary to the communication, test signals stored in the control unit are activated.	Supplementary to the communication, optional test signals are passed on to the control unit via a new interface.
Advantage: • Inexpensive method.	**Advantage:** • Inexpensive method, as interface exists in OBD. • Information about installed systems available (tamperproof).	**Advantage:** • High quality of Information. • Fast testing. • System safety, as no outside intervention occurs. • Information about installed systems available (tamperproof).	**Advantage:** • High quality of Information. • High test variability • Information about installed systems available (tamperproof).
Disadvantage: • No reliable information about the function of the systems. • No information about installed systems (less tamperproof).	**Disadvantage:** • No reliable information about the function of the systems.	**Disadvantage:** • More expensive than a mere fault read out.	**Disadvantage:** • More expensive, as technical modifications are necessary. • Enhanced risk due to possible access to hardware and software (intentional and involuntary).

Figure 20

The actuators, on the other hand, are not adequately monitored by the vehicle's own electronics. Thus any test procedure should certainly include the mechanical components of the electronically controlled systems.

As the self-diagnostic system provides already a lot of important checks, during periodical inspection it is preferable to test how effectively the system is working, in order to diagnose system deterioration before the self-diagnostic systems are able to do so. As the sensors and the wiring must be included in the test, the following testing strategy is suggested:

Vehicle dynamics controllers must be tested for functionality. Performance must be checked on a roller brake test rig, during which test signals, stored in the control unit, are added to the sensor signals.

The test signals are to be added as supplementary signals to the signals provided by the vehicle's own sensors. Noise or drifting or an offset of a sensor signal are then still included in the test signal. This ensures that the signal quality of the vehicle's own sensor signals is taken into account in the test.

The complete test procedure involves a mixture of data and sensor value readings, as well as the activation of the test signals. A diagnostic tool is needed here, which is able to communicate via a standard diagnostic interface with the vehicle electronics. When this tool is initially connected to the electronics, it identifies the vehicle.

The total test consists out of four stages:

1) Hardware and software recognition

   First a check is done to see if all system components are actually available, are suitable for the system under test and have correctly "identified themselves" to the control unit. Additionally, the version numbers of the software are checked so that out of date software can be replaced, if possible, with an upgrade.

2) Reading the error memory and the readiness codes

   The error memory of the system is read out. The test is not passed, if self-tests have not been performed, shown by the readiness code (as today’s emission-OBD).

3) Testing the master sensor (steering wheel angle sensor)

   The value of the steering wheel angle sensor is read out with the steering wheel in its centre position and at the two extremes. Furthermore, the quality of this sensor signal (noise, drift, etc. ...) is measured with the steering wheel in its centre position.

4) Effectiveness and function test with test signals

   At the start, the vehicle is positioned with the front wheels on a conventional roller brake test rig, such as the one used in regular periodical technical inspection. Using the diagnostic tool, the stored test signals for the brake intervention of the front axle are retrieved and the braking responses of the system measured.

Total test signal with resulting brake forces

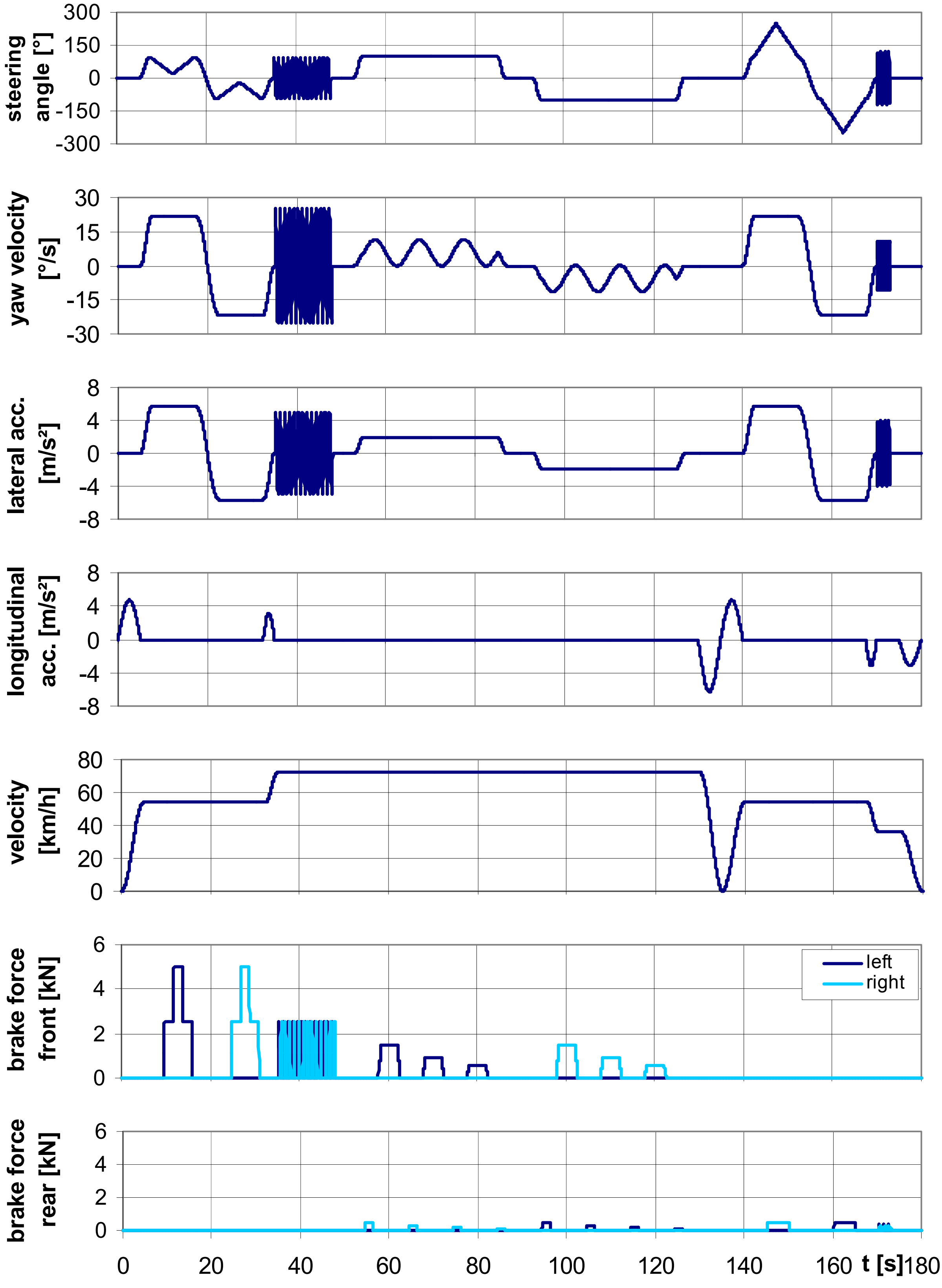


Figure 21

Then the vehicle is driven so that the rear wheels are on the roller brake test rig. The signals are started, to cause the VDC for braking interventions on the rear axle. An automated evaluation of measured braking force allows a reliable judgment to be made of the complete system.

The simulation results in this study have shown that minimum signal deteriorations can be detected by comparing the actual brake forces to a master scan. In order to check the whole system, the driving tests used to derive the test signals should cover all possible interventions of the vehicle dynamic controller.

Figure 21 shows, in conclusion, the complete test signals with the resultant braking forces. The aim of the test signals is to recognize system deteriorations that have already occurred and to reliably recognize potential system problems long before the self-diagnostics are able to do so. To do this, the test signals are added to the sensor values.

Influence of minimum defects on quality of control – random of 0.002rad on the velocity sensor – oversteer - behaviour in right bends

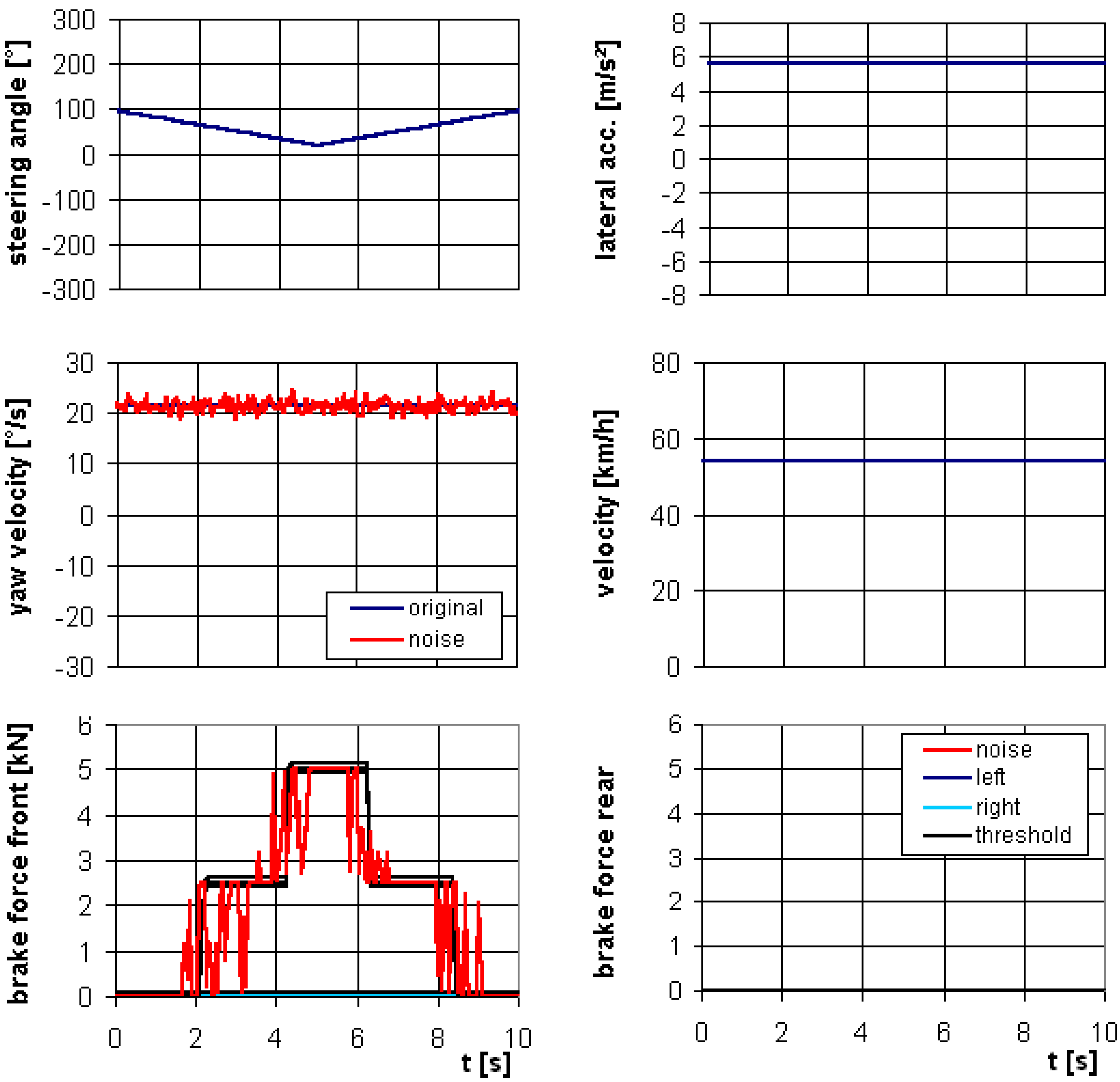


Figure 22

How, for example, the noise of the yaw velocity sensor with a variance of only 0.002 rad can affect the braking force, can be seen in **figure 22**. A variance of this magnitude cannot be recognized by a self-diagnosis based on signal plausibility.

It is relatively simple to define a control criterion that will show whether the system is still working perfectly, or whether it is already suffering from major problems. Under this criterion, all braking forces that deviate by less than 100 Nm from the standard curve are judged to be OK. If the braking power deviates more than 100 Nm from the standard curve, the relationship of the duration of the deviation to the duration of the entire standard curve is stated.

The correlation to the standard braking power curve becomes one, minus this relationship.

$$\text{Correlation} = \left(1 - \frac{\text{duration of the deviation}}{\text{duration of the entire standard curve}}\right) \cdot 100\%$$

The correlation is 100% if the measured braking power remains within the tolerance band around the standard braking power curve at all times. If there is no braking at all at the wheel in question, the measured braking forces are outside the tolerance band for the complete duration of the standard braking period and the correlation is therefore 0%. For the braking forces at the rear axle, the tolerance band is restricted by the braking force distribution factor, since absolute braking moments are considerably less at the rear.

Figure 23 shows the correlations at the individual wheels for the driving dynamic controller models during the complete test signals. In this case errors have occurred, which will not actuate the self-diagnosis systems. However, if the criterion states that there must be a correlation of at least 95% at all wheels, it can be seen that the slight deterioration in signal quality is occurring in nearly every instance.

With this method, it is possible to test the driving dynamic controller as a complete system, since the actual sensor values also influence the measured braking responses. A meaningful analysis of the system will be possible, long before the problems are such that the system's self-diagnostics will have to completely or partially deactivate the system. Communication is possible using interfaces already fitted to today's vehicles. Available testing technology can be used to measure the braking responses, which means that investment in new equipment can be kept within limits. The test procedure is quick and can be integrated into periodical technical inspection of vehicles without any problem. The shown procedure in **figure 21** can be developed for every car.

Influence of minimum defects on quality of control

				Correlation [%]			
				front left	front right	rear left	rear right
steering angle	offset	0.05	rad	96.10	91.61	95.81	95.81
	offset	-0.05	rad	95.74	96.1	95.81	95.81
	noise	0.05	rad	73.59	76.54	83.96	86.24
	drift	0.05	rad	96.83	95.56	100.00	100.00
yaw velocity	offset	0.002	rad/s	87.87	88.64	97.45	100.00
	offset	-0.002	rad/s	88.64	87.87	100.00	97.45
	noise	0.002	rad/s	58.20	63.36	67.73	73.47
	drift	0.002	rad/s	99.07	98.48	100.00	100.00
lateral acc.	offset	0.05	m/s²	86.58	86.76	100.00	100.00
	offset	-0.05	m/s²	86.76	86.58	100.00	100.00
	noise	0.05	m/s²	94.74	95.28	100.00	100.00
	drift	0.05	m/s²	98.82	99.03	100.00	100.00
long. acc.	offset	0.4	m/s²	100.00	100.00	100.00	100.00
	offset	-0.4	m/s²	100.00	100.00	100.00	100.00
	noise	0.4	m/s²	100.00	100.00	100.00	100.00
	drift	0.4	m/s²	100.00	100.00	100.00	100.00
wheel speed front left	offset	3	rad/s	100.00	100.00	100.00	100.00
	offset	-3	rad/s	95.24	90.59	100.00	100.00
	noise	3	rad/s	30.22	99.03	100.00	100.00
	drift	3	rad/s	98.25	98.25	100.00	100.00
wheel speed rear left	offset	3	rad/s	90.41	86.35	100.00	100.00
	offset	-3	rad/s	95.24	90.59	100.00	100.00
	noise	3	rad/s	97.66	96.92	18.05	100.00
	drift	3	rad/s	87.44	89.75	100.00	100.00
actuator front left	failure			0.00	100.00	100.00	100.00
	delay	0.10	s	78.19	100.00	100.00	100.00
	delay	0.25	s	64.14	100.00	100.00	100.00
actuator rear left	failure			100.00	100.00	0.00	100.00
	delay	0.10	s	100.00	100.00	75.39	100.00
	delay	0.25	s	100.00	100.00	69.92	100.00

Figure 23

8. Conclusions

The number of electronic system faults is significant and is likely to increase in the future as the number of systems fitted to vehicles increases and their complexity grows. The TRL analysis of the roadside call-out data provided by a major UK motoring organisation and of the data of a major UK vehicle leasing company suggests that 7% of all faults are in electronic systems (6.6% without failures caused by wiring problems) and that about 24% of vehicles are likely to experience electronic system failures: the UK currently has 26 million vehicles in use (year 2000).

Data from the leasing company showed that 34,154 electronic system faults occurred during the period 1995 to 1999. A similar analysis for airbag faults showed that a total of 1,627 faults were recorded (1.2% of the vehicles). It should be remembered that during the period of this study the airbag fitment rate was increasing rapidly. In the case of ABS, 2,146 faults were recorded over the period of the study (1.5% of the vehicles). It should also be remembered that the fitment rate of ABS was also increasing during the period of this study

Specific tests for vehicle electronic systems do not form part of mandatory periodical technical inspection. As failure rates are comparable to other systems already included in periodical technical inspection, there is a strong case to include specific tests for electronic systems. The case for the inclusion of specific tests is further supported by the use of electronics in complex safety critical systems in the near future. Examples include steer-by-wire, pedestrian protection and collision avoidance systems.

The total benefits of testing airbags and ABS, assuming that 50 per cent of the consequences of failure were removed, would lie in the range 4 to 10 Euros per car. A typical value would be 6 Euros per car. These figures are based upon data from the UK where the fitment rate of electronic systems is known to be lower than Germany, for example. Also the frequency of testing is higher in the UK so that these results may be in the lower range and potential benefits in other countries may be higher.

Airbags have become practically a standard feature in modern cars. As there are several recalls and malfunctions within these systems, Institut für Kraftfahrwesen of RWTH Aachen developed a test procedure for examining whether airbag systems function as designed. Several older and some modern systems are tested at a crash test facility. Differences in designs have been found. There is no defined time relationship between airbag system and any vehicle characteristic. Signal duration for triggering (3 to 105 ms), triggering period (13 to 73 ms) and time delay (immediately to 13 ms) as well as inflation duration (20 to 38 ms) vary considerably.

The identification of the system performance can be done by correlation of velocity change with ignition timing or velocity change with sensor displacement. Each airbag system produces a typical characteristic for the decision to ignite or not to ignite. Using these results, a testing procedure has been defined. Artificial input signals, which can be installed in the airbag-ECU, must be used. A diagnosis tester starts the procedure and the resulting characteristic curve for "just ignited" is displayed on the tester. Even malfunctions can be evaluated. The signal for ignition will be measured at the 'safeing' sensor, which is the mechanical switch in front of the explosive material.

This procedure is also suitable for advanced airbag systems, when additional sensors must be checked. Out of position or passenger weight-measurement can be easily done.

With the TÜV Rheinland ABS test bench, ABS tests were done and a large database (more than 250 tested cars) was created. Statistical analysis lead to following conclusions:

- There is a significant failure rate (average value 12.4 %) for ABS.
- The failure rate increases with distance driven, up to 21.7 % for cars with 150.000 - 175.000 km.
- The failure rate increases with the age of the car, up to ca. 20 % for cars > 9 years at the time of the test.

For a subgroup of 95 cars, the fault memory was successfully examined. A significant number of failures was not detected by the self-diagnosis routine and was not documented in the fault memory. In 4 of 9 cars with readable fault memory and which also locked wheels during the efficiency test, the failure was not detected and documented in the fault memory.

Efficiency tests combined with fault memory scans will be required to identify most of the failures of the ABS-Systems.

In vehicle dynamic controllers, low electrical noise levels in the yaw velocity sensor signal with a variance of only 0.002 rad, which cannot be recognized by a self-diagnosis based on signal plausibility can affect the braking force to a magnitude. Therefore IKA developed a testing procedure:

Vehicle dynamics controllers must be tested for functionality. Performance must be checked on a brake test rig, during which test signals, stored in the control unit, are added to the sensor signals.

The test signals are to be added as supplementary signals to the signals provided by the vehicle's own sensors. Electrical noise or drifting or an offset of a sensor signal is still included in the test signal. This ensures that the signal quality of the vehicle's own sensor signals is taken into account in the test. The complete test procedure involves a mixture of data and sensor value readings, as well as the activation of the test signals. With a diagnostic tool and communication through the diagnostic interface, all relevant data are available during the braking test. The test procedure is quick (about 180 sec) and can be integrated into the regular vehicle test inspection without any problem. A correlation coefficient shows the performance of the system. The suggested procedure can be developed for every type car.

9. Vision

Electronically controlled systems on vehicles have failure rates comparable to other mechanical systems considered important enough to be included in periodical inspection.

Accidents and injuries, caused by faults in electronically controlled systems, reduce road safety. This reduction of benefit as a consequence of electronic faults can be quantified.

Procedures have been suggested and shown to be practicable to check electronically controlled systems and detect faults during periodical inspection.

Legislative authorities should now implement periodical inspection requirements to regain as many as possible of the benefits of electronically controlled systems lost because of faults.

Cars currently under development show rapid increases in the number of electronic systems fitted. The inspection that is demanded will also help guarantee the increased traffic safety resulting from these additional systems.

ANNEX 1

List of Reports and Authors

Study 1

(a) The reliability of electronically controlled systems on vehicles – I.Knight, A.Eaton and D.Whitehead;

(b) The reliability of ABS and airbag systems with respect to periodic testing: a cost benefit analysis – R.S.Bartlett, I.C.P.Simmons and Miss T.L.Smith.

Study 2

A test procedure for airbags – M.Sagefka and S.Olders

Study 3

Testing of antilock braking systems – T.Frese and Dr. G.Heuser

Study 4

A test procedure for vehicle dynamic controllers – M.Sagefka