The reliability of electronically controlled systems on vehicles

by I Knight, A Eaton & D Whitehead

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THE RELIABILITY OF ELECTRONICALLY CONTROLLED SYSTEMS ON VEHICLES

by I Knight, A Eaton & D Whitehead (TRL Limited)

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EXECUTIVE SUMMARY

The aim of the project is to investigate the reliability of electronically controlled systems by collecting data from a variety of sources including breakdown organisations and leasing company fleets. At present there is little available data concerning how reliable these electronically controlled systems are or how they could be checked for correct function. This collaborative programme of research aims to address this issue by identifying current and near market systems and examining their performance, identifying if a need exists to carry out periodic inspections on the systems identified and developing test procedures for use in periodic and other inspections where necessary.

In order to do this effectively it is important to examine data on the in-service reliability of such systems. This enables research effort to be prioritised for those systems that are seen to be least reliable and provides a benchmark against which it is possible to measure the effectiveness of any periodic test procedures that might be introduced.

The systems identified as safety critical and most likely to benefit from periodic inspection at this stage are ABS and secondary safety restraints such as airbags. The level of detail available was not sufficient in most cases to enable component faults to be broken down to electronic, electrical / wiring or a mechanical component in the system.

The results of the research indicate that electronically controlled systems make up a small proportion of all the faults identified, especially when compared with service items such as tyres and exhausts. Where it has been possible to identify individual components of an electronically controlled system, the electronic components fail far less frequently than the mechanical components.

Data has been collected mostly from the UK with contributions also from Germany and Sweden.

- UK breakdown database – 1.7 million breakdowns per annum
- UK Lease company database – 2.4 million records

Whilst the proportion of electronic systems may be small there are significant numbers of faults. In many cases these were found in systems that could compromise the safety of the vehicle. Estimated safety critical failures includes:

- 225,000 airbag faults in the UK and 142,000 in Germany
- 288,000 ABS faults in the UK and 280,000 in Germany

Fault code memories have been used to monitor failures during vehicle service. The use of these systems is a valuable means of detecting system faults.

As the number of failures on European roads continues to rise and the number and complexity of electronic systems increases, it is important to provide annual checks to ensure the correct operation of these systems. Mechanical components such as brakes, lights and steering are already included in current tests so it is important that their electronic counterparts are also tested.

In the future electronic systems will control the operation of the vehicle; for example collision avoidance. These highly safety critical systems will require continuous checking as well as annual inspections.

THE RELIABILITY OF ELECTRONICALLY CONTROLLED SYSTEMS ON VEHICLES

ABSTRACT

Vehicle safety and environmental protection is increasingly dependent on the correct functioning of electronically controlled systems. At present there is insufficient data about the reliability of these systems and how this could be checked. This programme aims to address this issue by examining the performance of some current systems and developing test procedures for use in periodic and other inspections. In order to do this effectively it is important to examine data on the in-service reliability of such systems. This report looks at reliability data collected from a number of sources across Europe and aims to provide the basis for the development of test procedures for current electronically controlled systems. This enables research effort to be prioritised for those systems that are seen to be least reliable and provides a benchmark against which it is possible to measure the effectiveness of any periodic test procedures that might be introduced.

1 INTRODUCTION

Electronically controlled systems of increasing complexity are being fitted in growing numbers to new vehicles and vehicle safety and environmental protection is increasingly dependent on the correct function of these systems. At present there is little available data concerning how reliable these electronically controlled systems are or how they could be checked for correct function. This collaborative programme of research aims to address this issue by examining the performance of some current systems and developing test procedures for use in periodic and other inspections.

In order to do this effectively it is important to examine data on the in-service reliability of such systems. This enables research effort to be prioritised for those systems that are seen to be least reliable and provides a benchmark against which it is possible to measure the effectiveness of any periodic test procedures that might be introduced. This interim report includes a review of past, present and likely future electronic systems on vehicles. It then continues with an analysis of service records from a major UK lease company and call-out records from a roadside recovery service. The purpose of this analysis is to examine the frequency with which electronically controlled systems are found to fail in-service. The final report will include a cost-benefit analysis, which will be performed to assess the value of inspecting electronically controlled systems for roadworthiness on an annual basis.

Since the introduction of electronic systems in the 1960’s there has been a rapid growth in their use on vehicles. From the earliest examples such as cruise control and the replacement of dynamos with alternators, to the current anti-lock brake and engine management systems, the market has been overwhelmed with technological developments.

Safety critical systems, including those that play an active part in collision avoidance have become ever more sophisticated. Anti-lock brakes (ABS), for example, have become a required fit on larger heavy goods vehicles from 1992 and are increasingly common on cars of all sizes and types. The increasing sophistication and frequency of fitment could potentially lead to increasing problems with the reliability of these complex systems and this report aims to identify systems that would potentially benefit from inclusion in annual or periodic inspection.

2 INVENTORY OF SYSTEMS

Since the invention of the transistor in 1957 by Bardeen, Brattain and Shockley the electronics industry has grown at an unprecedented rate. Electronics in motor vehicles made their first appearance during the 1960's when they were fitted to radios. Later the alternator, made possible by the introduction of silicon rectifiers, replaced the rather large and inefficient dynamo. The middle 1970's saw the advent of the microprocessor, first used during 1974 in a trip mileage computer. A more advanced type of microprocessor was to be used later in electronic control units (ECUs), the brain of engine management and anti-lock braking systems.

The manufacturing cost of electronic components has reduced significantly since their conception in the 1950's making them a cost-effective alternative to mechanical or electrical systems. It is quite conceivable that modern electronic systems will utilise standard hardware blocks capable of providing a range of functions. Electronic systems are also very versatile enabling a single programmable device to be utilised for a number of different applications by altering the programming of the unit. A mechanical or electrical system would be required for each individual task increasing the cost to well above that of an electronic system. Tables 1 and 2 list some currently used electronic systems as well as some systems that TRL have identified as being near market and those considered likely to be seen in the future.

Table 1 - Current and near market vehicle electronic systems

Approximate Year of introduction	Electronic System
1960's	Solid state radio Alternator Cruise control
1970's	Electronic ignition Digital clock Trip mileage computer Fuel injection
1980's	Engine Management Sequential fuel injection
1990's	Anti-lock brakes Active suspension Powertrain control Distributorless ignition All wheel steering Global positioning and traffic systems Automatic cruise control
Near market	European on-board diagnostics Toll systems Seat cooling/heating system Electronic brake distribution/brake assist

Table 2 - Future systems

Time scale	Electronic system
Near future	Fully electronic braking (Brake by wire) Intelligent cruise control Electronic steering (Steer by wire)
Distant future	Adaptive safety systems Intelligent traction control Robotic drivers Intelligent suspension Intelligent braking systems Advanced driver assistance systems

2.1 ANTI-LOCK BRAKES

Current ABS systems employ wheel speed sensors that detect the rate at which the road wheel is decelerating. This information is then processed in an electronic control unit (ECU) which determines if there is a risk of wheel lock. If the wheel is locked or is about to lock, the system reduces the pressure to the brake of the locking wheel to prevent the wheel locking and the resulting loss of vehicle stability. This system is found on many vehicles including most new HGVs and coaches and is an effective electronically controlled safety system.

The ABS sensors, pump and modulator valves are also used by some traction control systems to apply the brakes of a spinning wheel and therefore control vehicle traction. Other systems use judicious application of the brakes of individual wheels to reduce the likelihood of loss of control in cornering manoeuvres. Further development of ABS technology has led to the development of electronic braking systems (EBS). EBS reduces the time taken for the brakes to react to application of the brake pedal by the use of electronic signals. These signals are passed to the brake at each wheel from the pedal rather than relying on the movement of brake fluid from the master cylinder to actuate the pistons in the brakes. Under emergency braking conditions, particularly with HGVs, this allows the anti-lock system to work more effectively by modulating the brakes individually and at a higher rate than ABS. Brake force distribution can also be improved through the use of EBS. Current braking systems rely on a mechanical valve with a preset brake distribution between the front and rear brakes, EBS allows dynamic weight measurements to be used in calculating the correct brake force distribution for individual wheels and thus improved stability and reduced stopping distances. EBS is currently most often found in vehicles equipped with air brakes where reaction time is more of an issue. In cars, electronic brake force distribution (EBD) is now often found on vehicles equipped with ABS. EBD works by constantly monitoring load on all four wheels of the vehicle under braking and applying brake pressure to the wheels in proportion to the grip available.

It is possible that future systems could also utilise the system to brake the vehicle when a dangerous situation is detected ahead, such as a pedestrian or animal which runs suddenly into the road. Such systems would utilise forward-looking sensors, capable of detecting obstacles ahead and discriminating between them and the prevailing environment, to decide whether the situation requires action. Research by TRL[1] has already shown the potential for their development. The system could also be used in conjunction with EBS to control the braking force if, for instance, the sensor in front of the vehicle has detected an object and the driver is not applying the brake sufficiently to stop before hitting the object. Another application could be to apply the brakes of an HGV if a pedestrian is crossing close to the front of the vehicle whilst it is stationary in traffic if the driver attempts to pull away without noticing their presence.

2.2 TRACTION CONTROL

Current traction control systems monitor wheel spin by comparing the speed of individual road wheels. The system uses either a reduction of engine power, the application of the brake of the spinning wheel or a combination of both in order to increase the vehicle's traction. Most modern systems are linked with the vehicles anti-lock brake system utilising the wheel speed sensors to detect wheel spin and the ABS pump and valves to apply the brake of the spinning wheel. One or more of the fuel injectors can also be switched off to prevent them from injecting fuel. This produces an engine misfire that achieves a reduction in engine power to help stop a wheel from spinning.

Similar systems are on the market in more expensive cars that use sensors to detect the onset of cornering instabilities. The ABS system is then used to apply braking to individual wheels to try to correct the instability or to limit the speed as a driver accelerates through a corner and approaches the limit of stability.

Future applications could utilise a forward-looking sensor that is capable of detecting a bend or hazard in the road before it is reached. The system could then reduce the engine power or apply the brakes to slow the vehicle if the driver did not take appropriate action. Measurements on the vehicle, such as yaw, acceleration, wheel load and vehicle position could also be used to predict a roll over situation and reduce the engine power or brake the vehicle to a safe speed. This would be of great benefit to HGV drivers. Similarly, if a stationary car was encountered mid-way around a bend or if the vehicle was about to slide on a change of road surface that was detected by the sensor then the vehicle could be brought under control without any action from the driver.

2.3 CRUISE CONTROL

Current systems allow the driver to select a speed that is then maintained until the system is either switched off or the brakes are applied. Road speed is sensed using road speed sensors (i.e. speedometer pulse) or by using the ABS sensors and the throttle is adjusted electro-mechanically or electronically, depending on the level of sophistication.

There are some current or near-market systems known as autonomous cruise control that are capable of maintaining a constant distance between one vehicle and a second vehicle ahead. These use sensors fitted to the front of the vehicle such as a laser or radar device to detect the presence and relative velocity of a vehicle ahead. The driver can, with this type of system, select a distance from the car in front that he or she wants to maintain. The system then calculates the distance from the vehicle in front by use of information

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[1] Unpublished TRL report number PR/SE/219/00, *Active Adaptive Secondary Safety Phase 3*

supplied by the forward-looking sensor. The vehicles speed is then increased or reduced with reference to the speed of the vehicle being followed using the throttle or brakes.

Other future applications are likely to include intelligent systems. Such systems could adjust the vehicle speed to suit the road conditions. For example vehicle speed could be reduced if adverse road surface or environmental conditions were detected. This type of system would greatly increase vehicle occupant, pedestrian and other road user safety. Research is currently being conducted to examine the feasibility of linking cruise control systems with Global Positioning Systems (GPS) or roadside transponders to prevent the driver from exceeding the speed limit set for that road. Given the growing use of both types of system at this time combined with the intention, in the UK at least, to reduce speed limits on some roads and to reduce drivers' speed in general, it seems likely that such intelligent speed limiters will eventually be brought to market.

2.4 SUPPLEMENTARY RESTRAINT SYSTEMS

Supplementary restraints that give extra protection to vehicle occupants that are wearing a seatbelt are now commonplace in new cars. Current systems use sensors that detect an impact during its early stages. The systems use accelerometers, usually two at the front of the vehicle and one in the centre of the passenger compartment, to sense the rate of vehicle deceleration. Information from those sensors is then sent to an ECU, which calculates whether the vehicle is crashing and if the impact is severe enough to warrant action. If the ECU detects an appropriate crash it fires pyrotechnic devices, which in turn inflate airbags and pre-tension seat belts. To avoid false activation of the restraints a signal representing an impact must be received from each sensor before the airbags are deployed.

The possibility of using sensor systems that detect an impact prior to it happening is currently being extensively researched both by TRL and others. These sensors will be able to detect whether the vehicle is about to collide with an object such as a car, tree, HGV, or pedestrian. This would allow more time to set up safety systems. In the case of a pedestrian or other unprotected road user, the deployment of airbags fitted to the front of the vehicle could reduce the risk of serious injury. Internal sensors can already detect the height, weight, position, and smart cards could also determine the sex and age of the vehicle occupants. This information can then be used to set up the restraint systems to best suit the occupant for the particular type of collision they are about to experience. The airbags in such systems could have dual pyrotechnic charges of different sizes, to give three deployment rates, using either one or both charges depending on the severity of the impact and to reduce the risk of injury to very small or out-of-position occupants. The driver and passenger seat could be moved backwards to reduce the risk of contact with the steering column or other objects intruding into the passenger compartment. Airbags could also be switched off if a child was detected sitting in the front passenger seat and could therefore reduce the possibility of injuries as a result of the deploying airbag.

2.5 ACTIVE SUSPENSION

Currently available active suspension systems typically monitor vehicle ride height and re-adjust it using a pump to increase/decrease pressure in suspension dampers, or bags. The height of the vehicle is monitored using sensors and adjustment is made by the ECU, or in some cases, by the driver. The type of adjustments that can be made typically involve increasing the ride height for vehicles when they are to be used off-road, stiffening the suspension to reduce body roll and improve vehicle handling, and softening the suspension to give the occupants a more comfortable ride. The damping rate can also be electronically adjusted to best match the suspension deflection and the undulations of the road surface and thus tuning the suspension for improved vehicle handling and stability.

In the future, forward-looking sensors could examine the road ahead and adjust the suspension in accordance with the road conditions. For example, the suspension could be stiffened just before the entrance to a bend to give good performance through the bend, and softened after exit to increase comfort to the occupants. Another possibility is that the suspension could be lowered when travelling at speed to reduce aerodynamic drag and hence, improve fuel consumption.

2.6 STEERING

Current steering systems use hydraulics, pneumatics or electric motors to reduce the effort needed by the driver to turn the steering wheel. In the case of hydraulics or pneumatics initial movement of the steering opens valves that operate rams assisting the driver to move the steering. Electrically assisted steering systems use electronic sensors to detect the driver's inputs and electric motors to assist the movement of the steering. When this type of system is fitted it becomes simple to incorporate features such as variable assistance to give very light steering when parking but heavier steering at normal road speeds to give a more solid feel to the driver. Fully electronic steering is commonly fitted to vehicles used by disabled people where the steering is controlled by a joystick. Early power steering systems tended to be hydraulically assisted but because of the reduction in size and cost of the electronic systems more manufacturers are now fitting electronically assisted systems. The use of fully electronic systems in normal road cars has been under development by manufacturers for some time. These systems will remove the direct mechanical link between the steering input device i.e. steering wheel or joystick and the conventional steering rack and associated components. Linking such systems to autonomous cruise control and EBS will lead the way towards fully automated driving. The major secondary safety advantage of a fully electronic steering system is the potential to remove the steering column from the vehicle and hence reduce the severity of driver injuries.

In the future, power steering systems could be utilised as part of collision avoidance systems where evasive manoeuvres are automatically performed to avoid a potential road accident ahead after it has been detected by sensors. It could also be used as part of a fully automated "robot" driver system.

2.7 DRIVE TRAIN

The modern motor vehicle usually incorporates an engine management system to increase fuel efficiency and reduce emissions. Although this is not an obvious safety critical system it does have significant influence on the environmental performance of the vehicle. In addition to this, a sudden loss of engine power or drive train whilst travelling at high speed on a motorway can have the potential to contribute to the cause of an accident. It must be remembered that accidents are rare events and are normally contributed to by multiple factors. It is often the case that removing just one of these contributory factors could have prevented the accident from occurring.

Engine management systems are controlled by an ECU that performs calculations based on signals received from various sensors around the engine. For example, the introduction of exhaust gas oxygen sensors enabled the system to monitor its performance using emission data and to re-adjust fuel settings based on a known engine map in order to optimise the emissions performance. The management system therefore constitutes a closed loop control system that will perform this, and a large number of other operations, many times a second.

Electronically controlled gearboxes and four wheel drive systems are also more commonly found on new vehicles than in the past. These work together with the engine management systems to optimise performance. The gear changes are matched more precisely to the engine load and speed, and road speed is also taken into account. Intelligent four-wheel drive systems can vary the torque transmitted to individual wheels, to enhance handling and off-road performance.

In the future, systems such as these could be incorporated into an automated driver system. The benefits of such a system with respect to the drive train could be to remove the imperfect acceleration and gear change behaviour of a human driver and to utilise the engine and gearbox control units to achieve a reduction in emissions and fuel consumption and to control speed.

3 ROADSIDE RECOVERY RECORDS

TRL has obtained a copy of a database recording all call-outs to roadside breakdowns by one of the major suppliers of roadside recovery services in the UK. Every time that one of the organisation's engineers attends a broken down vehicle they complete a report that contains information on the registration of the vehicle, the date of the call-out, and the specific fault(s) found. Each of these reports are subsequently coded onto a computer database that TRL have used for this analysis.

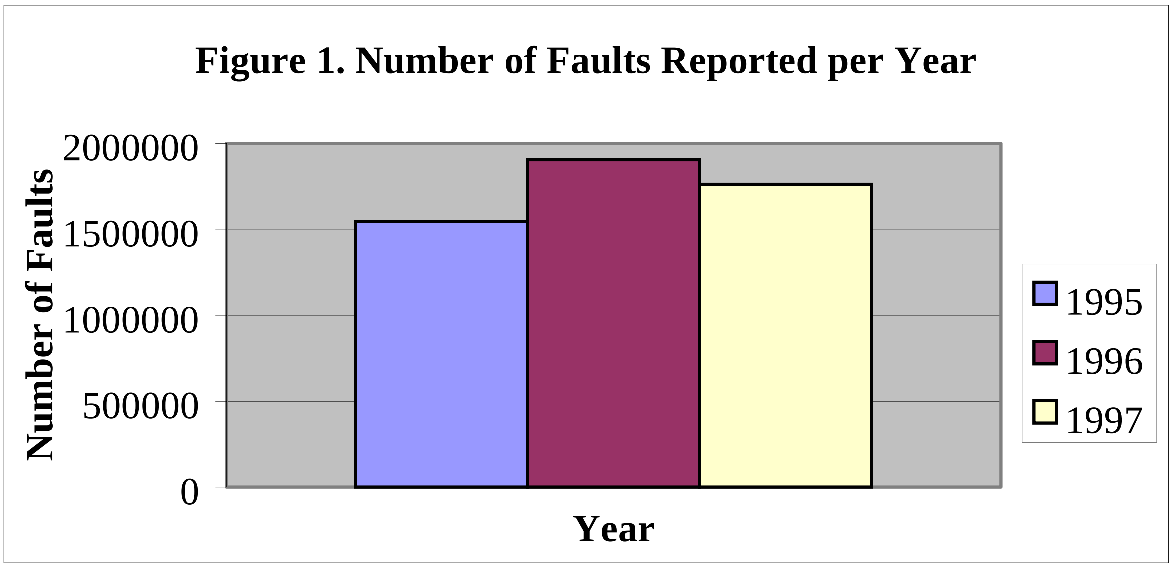
3.1 THE SAMPLE

The recovery organisation had approximately two million members during the period covered by the database. If it is assumed that they each had one vehicle then this represents approximately 10 percent of the UK vehicle fleet. The distribution of the age of vehicles across the organisation's membership is not known and neither is the average distance that each member travelled annually. However, it is known that membership of this organisation is taken by the full range of passenger car users from company fleets to individual private car owners. For this reason it is expected that the age of vehicle and average mileage would be reasonably representative of the UK car fleet.

It is to be expected that the majority of car owners in this sample, whether they are corporate or private owners, will have their car regularly serviced and will subject it to the obligatory annual inspection. It is highly likely that many of the faults and defects that occur within their vehicle will be detected and repaired at these times and will therefore not be recorded in this database. This database will only represent failures that have resulted in a vehicle breakdown either at the owners home or actually out on the road and from that point of view will not represent the overall reliability of cars in the UK. In particular, certain defects such as ABS or airbag warning lights may not always be considered sufficient cause to call out a breakdown company. This type of defect will be under-represented on the database.

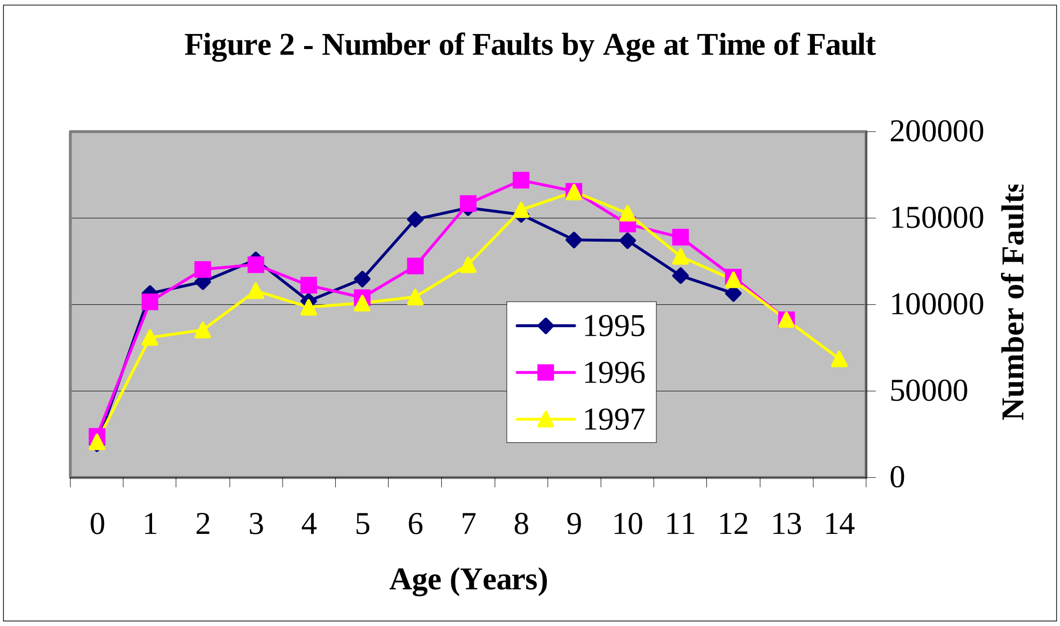
However, it is this type of failure, that has not been detected during routine servicing or annual inspection, that causes the most inconvenience and represents the biggest road safety risk. It is also likely to be the most expensive because no matter how small the defect, the repair will cost at least the same as if it had been detected during routine maintenance and some defects can cause further damage by reaching catastrophic failure while the car is in use. For example, if a timing belt fails in use it can cause extensive mechanical damage to the engine costing significantly more than simply replacing the belt during a service. Added to this is the cost of the call-out to the breakdown company, the cost to businesses through lost productivity because of delayed staff and the cost of accidents that occur because of defective vehicles.

The database contains information on call-outs to breakdowns during the years 1995, 1996 and 1997. Figure 1 shows the total number of call-outs during each year.



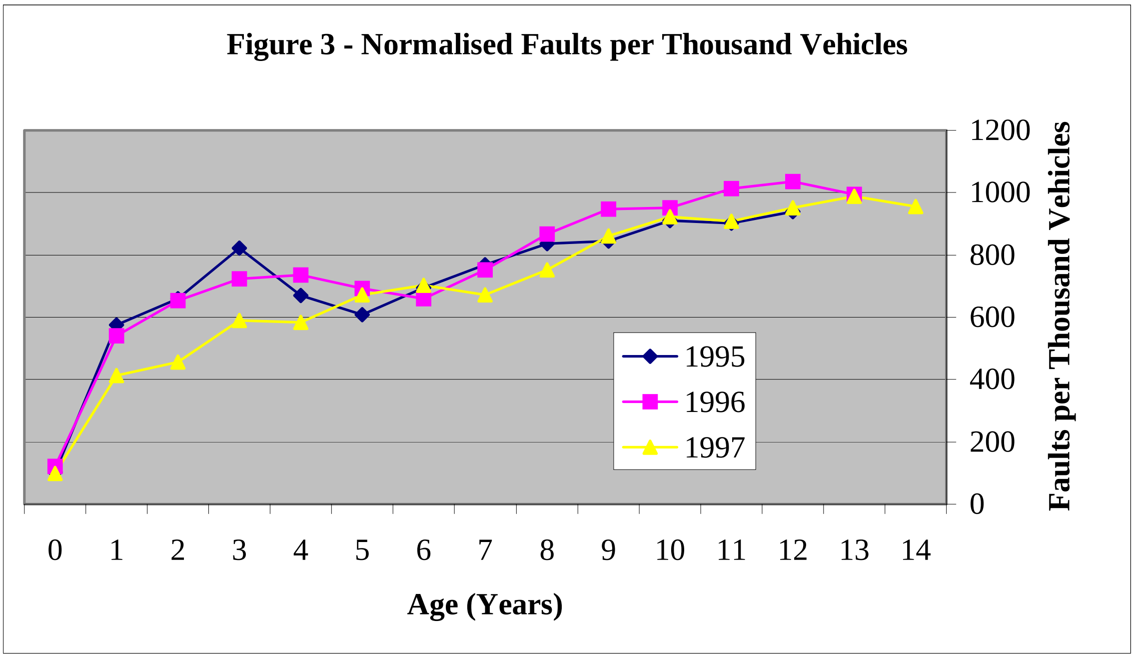
The number of reported faults found during callouts shows little change, averaging approximately 1,700,000 during the three years of this sample. However, since it is not known how membership of this organisation and the annual distance travelled by its members varied across the three years of the data, it is not possible to draw any conclusions from this on whether vehicles on the whole were getting more or less reliable.

Figure 2 shows the age of the vehicle at the time of the fault, broken down by the year of the sample in which the fault occurred.



When comparing the distribution of the age of the vehicle at the time of the fault with that of the whole UK fleet (Figure 44), there are few faults with vehicles less than 1 year old compared with the number of vehicles on the road that are less than one year old. For vehicles that are between 1 and 3 years old the number of faults increases noticeably while the number of vehicles of that age in the UK fleet is less than the number of vehicles of less than a year. The peak in faults at six to eight years old coincides with a peak in the number of vehicles registered in the UK vehicle fleet.

In order to remove the potential effect of the age profile of the sample on the comparisons of faults by age of vehicle, the data from the breakdown organisation has been normalised against the UK values detailed in Figure 44 for each year of data and each age of vehicle. This graph, Figure 3, is used when examining trends identified later in the analysis to determine whether the distribution of faults by age of the vehicle are as expected given the age profile of the UK fleet.



The number of vehicles covered by the breakdown service cannot be divided by age, because this information is not available. For this reason an assumption has been made that the number of vehicles in the breakdown fleet is representative of the UK fleet as a whole. The breakdown fleet represents approximately 10 percent of the UK fleet and the normalised calculation assumes that the age profile of the sample is identical to that of the whole UK fleet.

Figure 3 shows that there are an increasing number of faults with age of the vehicle, as would be expected. The trend seen in the 1995 data, and the following years, indicates that vehicles built around 1992 appear to have a higher failure rate than expected. The reasons for this are not known but may be a result of increased use of electronic components, in their early stages of series production, that are capable of causing the vehicle to suffer a roadside breakdown.

3.2 THE FAULT CODES

The motoring organisation that generated this sample of data used a specially designed coding system to classify vehicle faults. This is a three-character alphanumeric code that is intended to describe both the generic system the failure occurred in and the specific fault that occurred. The first character in the code is a number between 1 and 8 and this describes the generic system within which the failure occurred. Table 3 defines the codes at a generic system level.

Code	Title	Example components
1	Electrical system	Starter motor, wiring loom, ignition system, lighting.
2	Electronic system	Sensors, ECU, immobiliser,
3	Mechanical	Brakes steering and suspension components
4	Fuel system	Pump, carburettor, injectors etc
5	Body mechanics	Airbags, windows, sunroof, towbars, locks
6	Damage	Puncture, accident damage, vandalised, abandoned
7	Engine	Cambelt, crankshaft cooling system etc.
8	Driveline	Clutch, gearbox, CV joint, driveshaft

Table 3 - Description of system level codes

Prior to the start of the analysis it was decided that some of the "fault" codes did not sufficiently describe failures or reliability problems relating to this project. All such codes were excluded from the database. For example those relating to damage or routine service items. The codes excluded were: -

(1) All of those within system 6, relating to punctures and accident damage etc.

(2) Codes relating to flat batteries, for example if the lights are left on, other than those caused by a faulty battery.

(3) Codes relating to tyres.

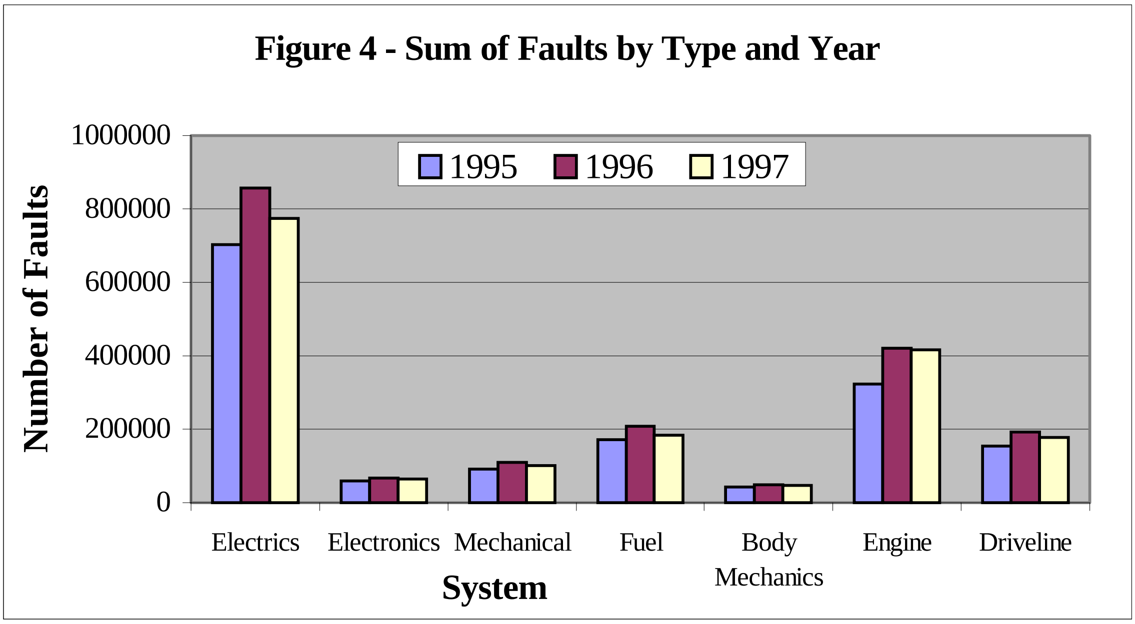
(4) Running out of fuel, contaminated fuel, or incorrect fuel

(5) Codes relating to Goods Vehicles.

(6) Engine oil

3.3 SYSTEM LEVEL FAILURES

Figure 4 shows the number of reported failures within each system group (as described in the preceding section) for the year in which the failure occurred. The total number of failures recorded in the database for these systems is given in Table 4.

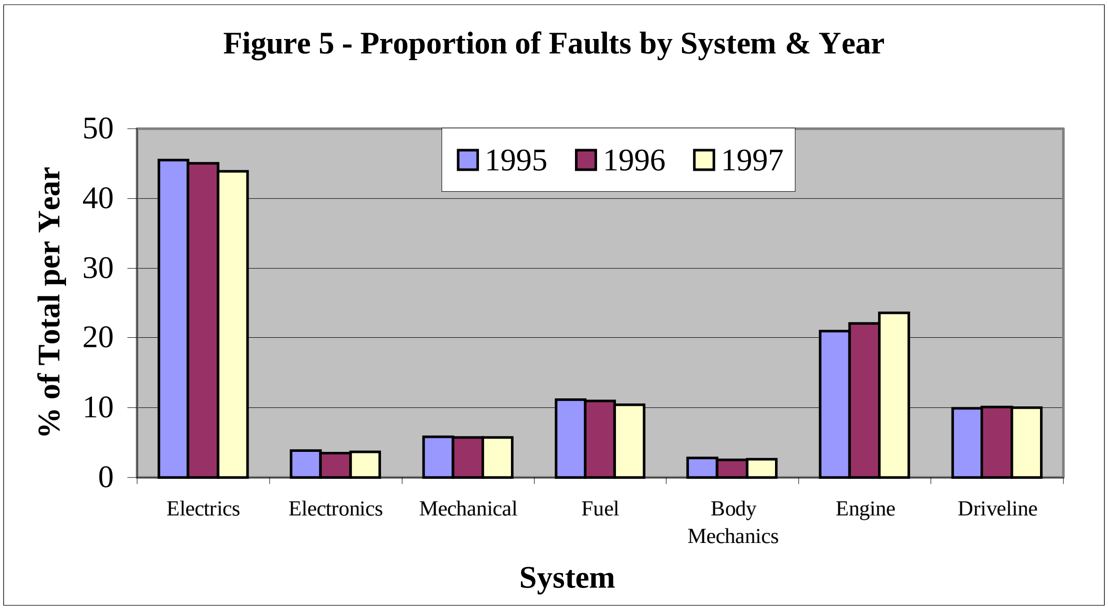


Code	Title	Number of failures
1	Electrical	2,334,527
2	Electronic	191,236
3	Mechanical	300,599
4	Fuel	563,723
5	Body Mechanics	137,181
7	Engine	1,160,013
8	Driveline	523,064
	Total	**5,210,343**

Table 4 - Total recorded faults analysed in database

Figure 4 shows that by far the greatest number of faults occurred in electrical components and that the electronics category represents the second lowest number of failures. The relative number of electrical, electronic and mechanical systems fitted to vehicles is not known. It is likely that the number of electronic systems and components in use is much lower than the number of mechanical systems and therefore points to a higher failure rate than that suggested by Figure 4. It is also worth noting that the number of electronic system failures is comparable to the number of mechanical failures and the mechanical category covers braking steering and suspension components, which constitute an important part of the current annual inspection schedule.

At first glance, Figure 4 does not show any particular trend over the three-year sample. However, this takes no account of the number of breakdowns attended each year, which may have been influenced by the number of members in each year. Figure 5 shows the same data expressed as a percentage of the total number of reported faults in each year of the sample.

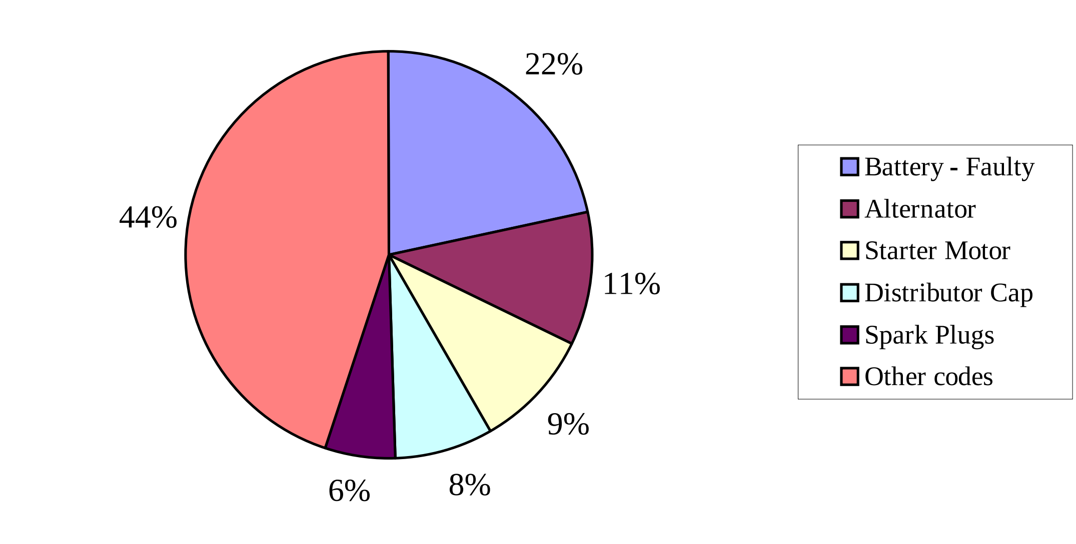


The data in Figure 5 suggest that the proportion of all call-outs that are due to a failure in an electrical system is falling slowly, whilst the proportion that are due to an engine failure are increasing and the other categories are staying approximately constant.

3.4 ELECTRICAL SYSTEM FAILURES

After the exclusions described in section 3.2, there are 67 separate fault codes that fall into the category of "electrical systems" covering a total of 2,334,527 faults or 44.8% of the total faults recorded. Figure 6 shows the five most common electrical faults as a proportion of all electrical faults.

Figure 6 - The 5 most common electrical faults



It can be seen that more than one in five of all electrical faults is actually a faulty battery. At this point it must be remembered that eight other codes relating to flat batteries and low electrolyte have been excluded from this data before the analysis above. None of the top five faults is related to the electronic systems of interest to this project.

The only components classified in the electrical category that were related to electronically controlled systems were the wiring loom for the ignition system (60,689 failures, 2.6% of total electrical faults), the ignition module/amplifier (2.6%), electronic ignition (2.1%) and the wiring loom for the engine management system (0.5%). These are ranked 10^{th}, 11^{th}, 13^{th} and 33^{rd} respectively. The components classified as 'other codes' include all types of lighting, ignition and instrumentation faults not covered by this analysis.

Figures 7 to 10 show the numbers of failures for these components by age of the vehicle at the time of the callout for each year of the sample, expressed as a percentage of total faults for all systems for the year.

Figure 7 - Wiring Loom, Ignition

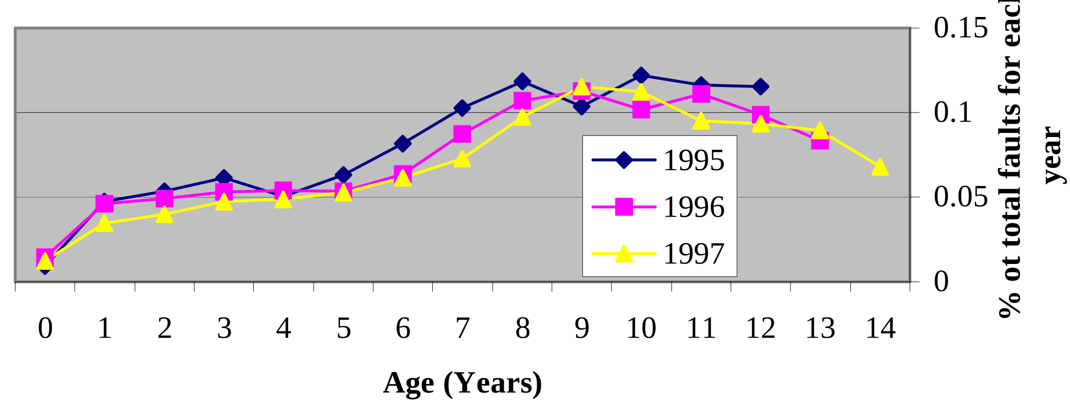
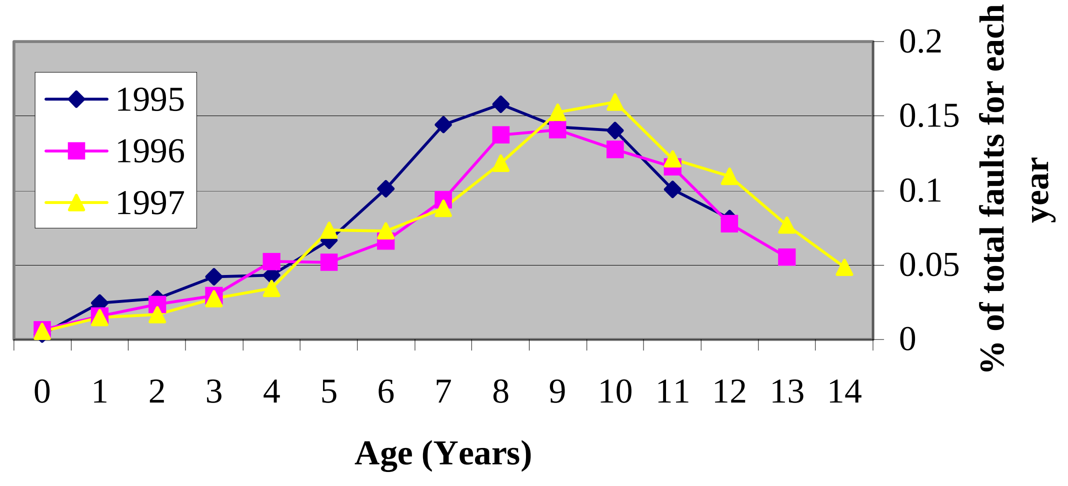


Figure 8 - Ignition module/amplifier



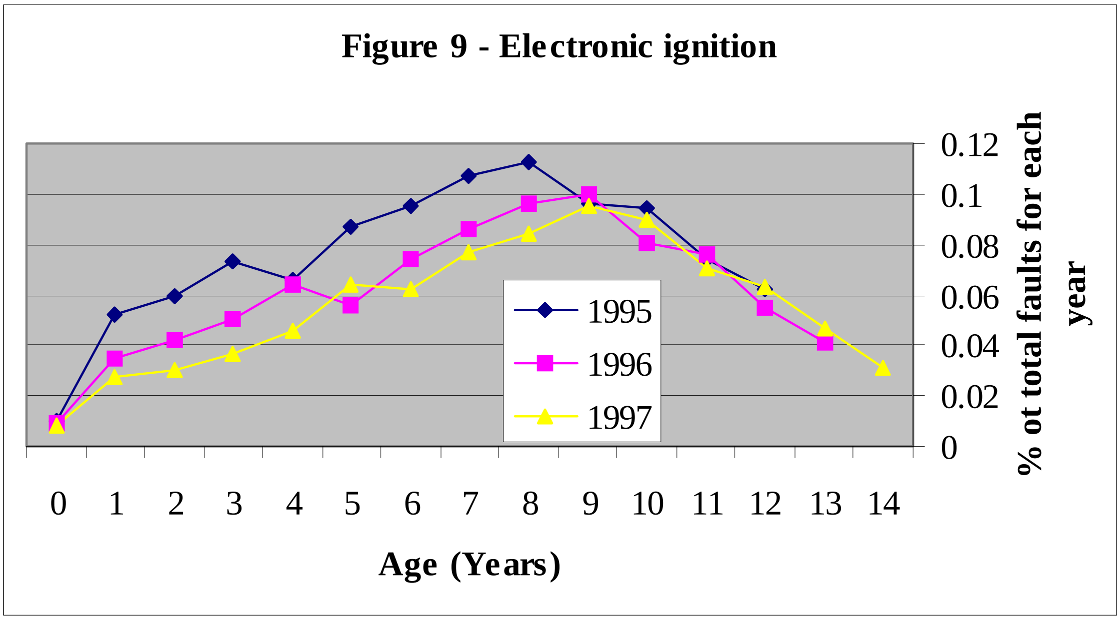


Figure 9 - Electronic ignition
0.12
0.1
0.08
0.06
0.04
0.02
0
% ot total faults for each year
1995
1996
1997
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
Age (Years)

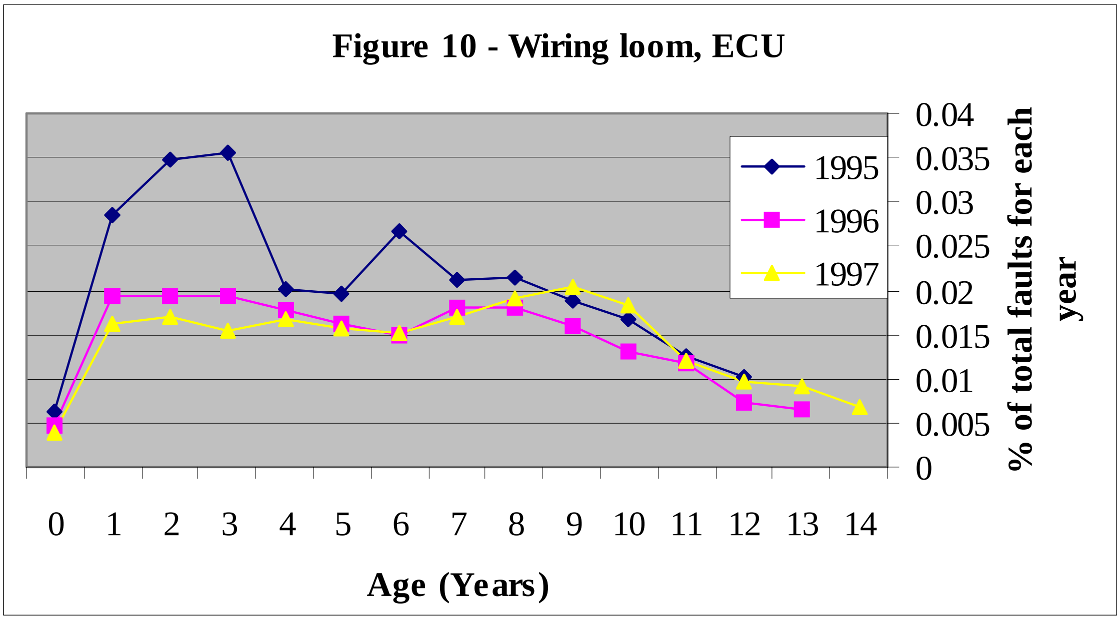


Figure 10 - Wiring loom, ECU
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
% of total faults for each year
1995
1996
1997
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
Age (Years)

Figures 7 to 9 show very similar trends both with the age of the vehicle and over the three years of data. As expected, an upward trend is detected as the vehicle gets older, with each year of data showing that the age at which faults develop is increasing. The profile of the curves follows that shown in Figure 2 to an acceptable level. Figure 10 shows a different trend. The number of faults remains at a similar level throughout the first ten years; this is most likely due to vehicles built prior to 1990 having an extremely low probability of being equipped with an ECU. The greatest number of faults in 1995 would appear to occur much earlier in the vehicle's life, typically in the first three years. This may be due to the rapid increase in the number of vehicles fitted with ECUs and may represent early problems with their design.

These trends do relate to very small values, particularly for the ECU wiring loom and conclusions are limited by not knowing how many of the vehicles in the UK fleet are fitted with ECUs or electronic ignition for the period covered by the breakdown data. As ECUs become more and more common it is likely that the number of failures shown in Figures 7 to 10 will increase markedly.

3.5 ELECTRONIC SYSTEM FAILURES

This category contains information on many of the systems of interest to this project. Table 5 shows a complete list of the number of failures of each component in this category. There were a total of 191,236 failures, which represents 3.7% of the total faults recorded. Also included in Table 5 is an estimation of the number of faults likely to be present in the whole UK fleet and the estimated UK failures per billion vehicle kilometres for the electronic systems listed.

Code	Description	Number of failures	Percentage of all electronic	Estimated UK failures per year	Estimated UK failures per billion vehicle km
282	Immobiliser – Electronic Key	24034	12.6	80,113	222
254	ECU - Engine Management (Combined)	22379	11.7	74,597	207
273	Relay - Fuel Pump	21762	11.4	72,540	201
256	ECU – Ignition	20710	10.8	69,033	191
255	ECU – Fuel	19004	9.9	63,347	175
234	Sensors - Crank/Flywheel	18741	9.8	62,470	173
233	Sensors - Coolant Temperature	9469	5.0	31,563	87.4
283	Immobiliser – Mechanical Key	5419	2.8	18,063	50.0
279	Relay – Starter	4379	2.3	14,597	40.4
232	Sensors – Coolant	4303	2.3	14,343	39.7
236	Sensors - Oil Pressure	4192	2.2	13,973	38.7
281	Alarm Switch	4144	2.2	13,813	38.2
284	Alarm - Key Fob (Electrical)	4056	2.1	13,520	37.4
271	Relay – Coldstart	4047	2.1	13,490	37.4
231	Sensors - Air Flow	3860	2.0	12,867	35.6
238	Sensors – Throttle	3249	1.7	10,830	30.0
278	Relay – Other	2999	1.6	9,997	27.7
286	Alarm/Immobiliser Key Fob Battery Flat	2959	1.5	9,863	27.3
275	Relay – Lights	2500	1.3	8,333	23.1
274	Relay – Ignition	2282	1.2	7,607	21.1
272	Relay - Cooling Fan	1750	0.9	5,833	16.2
235	Sensors – Manifold Pressure	876	0.5	2,920	8.09

Code	Description	Number of failures	Percentage of all electronic	Estimated UK failures per year [2]	Estimated UK failures per billion vehicle km [3]
237	Sensors - Oxygen/Lambda	836	0.4	2,786	7.71
252	ECU - Air Conditioning	705	0.4	2,350	6.51
257	ECU – Suspension	603	0.3	2,010	5.57
276	Relay – Main	570	0.3	1,900	5.26
285	Alarm – Mechanical Key	500	0.3	1,667	4.62
253	ECU - Auto Gearbox	330	0.2	1,100	3.05
251	ECU – ABS	295	0.2	983	2.72
277	Relay - Oil Pressure	283	0.1	943	2.61
	TOTAL	191236	100	637,451	1,770

Table 5 - Number of failures of all components classified as "electronic"

The Estimated UK failures per year is derived as follows: (X/3)*10

Where X equals the number of failures for the three years of data in the database. This is then multiplied by ten as the breakdown database covers approximately ten percent of the whole UK fleet.

Estimated UK failures per billion vehicle km is derived as follows: (Y/361,133,000,000)*1,000,000,000

Where Y equals the estimated UK failures per year, and 361,133 million is the average UK traffic volume over three years.

[2] Values for estimated UK failures per year given to nearest whole number.
[3] Values for estimated UK failures per billion vehicle kilometres given to three significant figures.

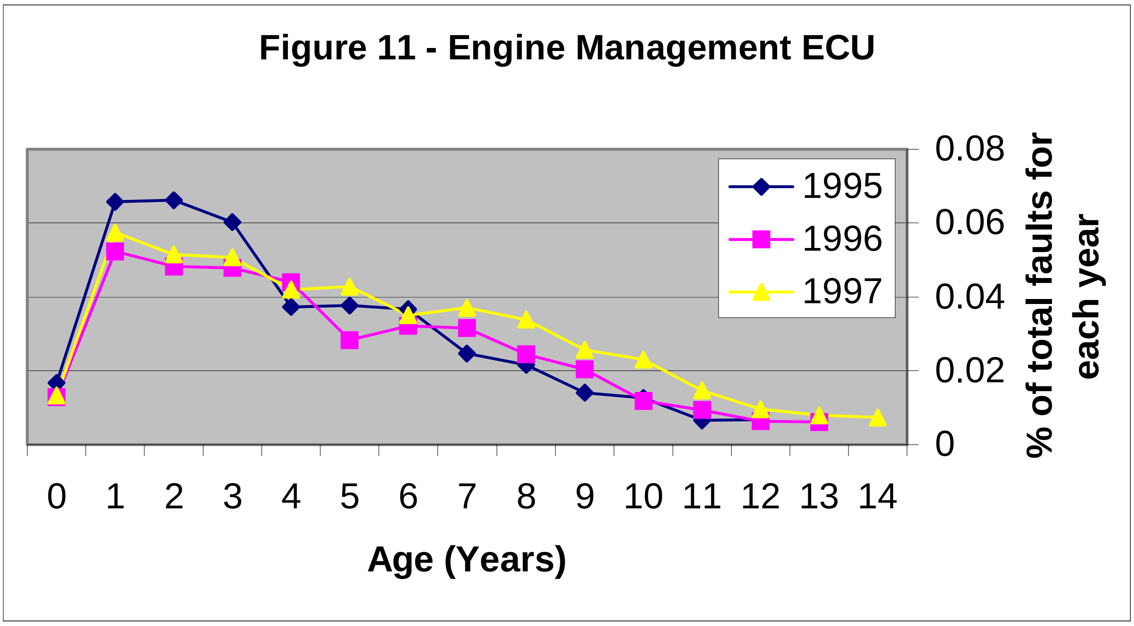
An estimate of 1,770 faults per billion vehicle kilometres with the electronic systems listed may not seem significant. Comparison with the accident rates in the UK helps give this value more significance. The casualty rate per billion vehicle kilometres given in the 1998 edition of Road Accidents Great Britain is 70. When comparing these figures it would appear that the electronic system faults are extremely relevant, and represent a significant number of faults, many of which will have an influence on the safety of the vehicle. The number of accidents caused or contributed to by a fault in an electronic system is not known, as this information is not recorded. It is likely that if the in-service reliability of these systems can be improved then there will be a positive benefit to road safety.

It can be seen that after the seven most common faults, those remaining have a very low incidence of failure even within the electronic system category, which itself is a small category when analysed as a proportion of all faults in the sample. If the faults for the various different types of ECU are added together there are a total of 64,026 (33.5% of all electronic system failures) ECU failures. Comparing this with the number of faults within wiring looms for ECUs (73,215 or 38.3% if wiring loom - ignition is included) suggests that the wiring and connectors to the electronically controlled systems are only slightly more likely to suffer a fault than the electronic components themselves. Electronic devices should be extremely reliable due to the manufacturing processes used, so the number of failures would appear to be extremely high considering the low failure rates usually found for individual components. This is disappointing and most likely due to factors such as the design of the surrounding equipment and the environment in which these components are installed. Where wiring looms join the ECU itself there is a much higher risk that a fault can develop due to continued temperature cycling causing premature failure of wiring, shielding and vibration related problems. Since the introduction of ECUs into the automotive environment, the development process has been extremely fast-paced and should result in a better understanding of the requirements when siting and designing ECUs and thus a reduced number of failures. However this reduction may not be sufficient to offset an increasing number of ECU faults due to the much larger number of vehicles using them.

It is worth noting that there are relatively few component failures listed in Table 5 that could be considered to be directly safety critical. This may be due to the low population of safety critical systems and also the high build standards employed. The faults in the engine management system could have an influence on safety if they were to result in a sudden and unexpected total loss of power. However, it is more likely that they would result in the engine running inefficiently. Throttle sensors could potentially cause problems if they are part of an electronic throttle system, which could result in the throttle "sticking" open. However, these sensors are more often used simply to give the engine management system information on which to base fuel requirements.

The only components that are obviously safety critical are the ECUs for the suspension and ABS and these have both sustained very small numbers of failures relative to other electronic components. It is likely that there were considerably fewer vehicles on the road between 1995 and 1997 that were fitted with active electronic suspension control than there were vehicles fitted with ABS, although there is no evidence available to support this. However, ECU's for ABS systems had less than half of the reported failures of those for suspension systems.

Figures 11 to 13 overleaf show the numbers of failures for engine, ABS and suspension ECUs by age of the vehicle at the time of the callout for each year of the sample. The figures for ABS and suspension ECUs have not been expressed as a percentage of the total call outs for the year as the numbers are so small, less then 0.5% of total electronic system faults for combined ABS and suspension ECU failures.



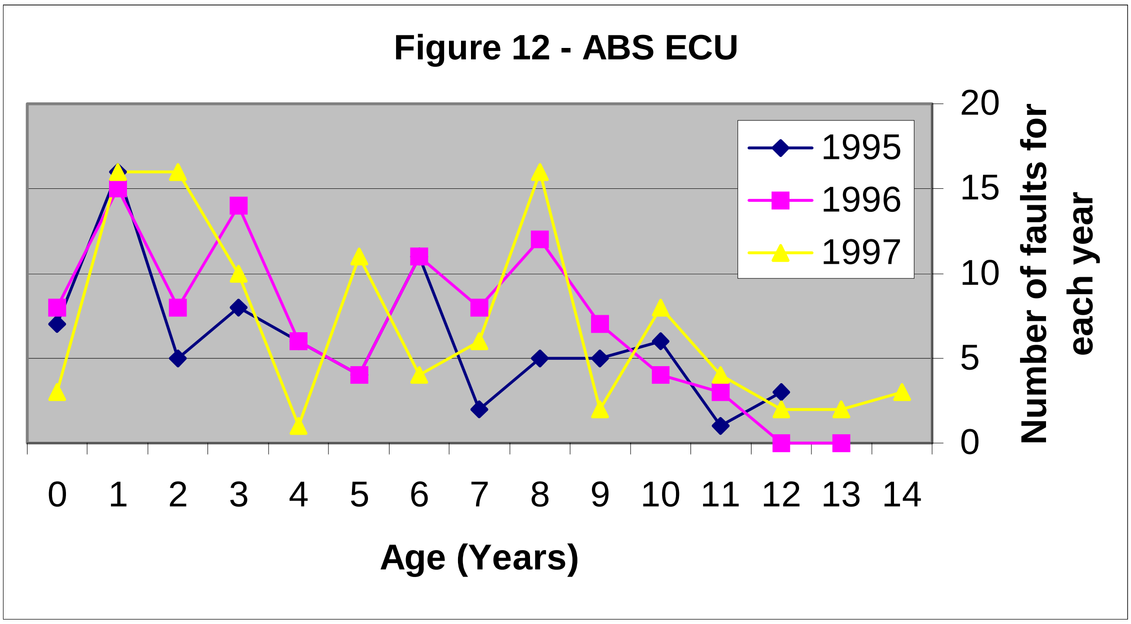
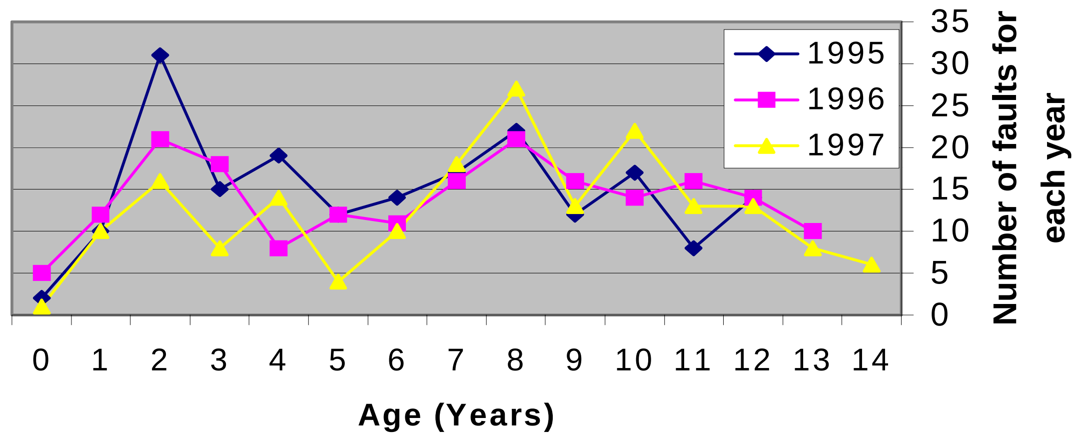


Figure 13 - Suspension ECU

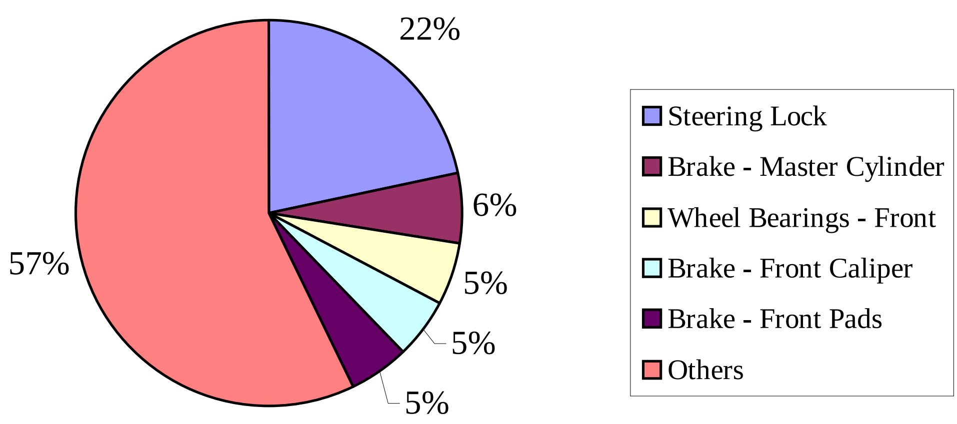


Engine management ECUs show a relatively high number of failures in the first year, with slight reductions in the second and third year. From that point onwards the number of failures reduces steadily. This trend, as explained in the previous section looking at electrical system failures, is likely to be due to the low number of ECUs in use on earlier vehicles. ABS ECU failures are very rare within the breakdown service database, with a peak number of failures of 16 for a given age of vehicle per year. There is no identifiable trend due to the small numbers involved. A likely reason for this is that ABS ECU failures rarely lead to the vehicle being undriveable, thus any fault will be reported to a garage for rectification and will not involve a breakdown callout. Suspension ECU faults are more common than ABS ECU faults in the database. This is surprising due to the small number of vehicles with electronically controlled suspension in the market place, particularly when the number of vehicles fitted with electronically controlled suspension built prior to 1990 is taken into consideration. The higher incidence of reported faults to the breakdown service might be due to the effect a failure has on the vehicle's behaviour.

3.6 MECHANICAL SYSTEM FAILURES

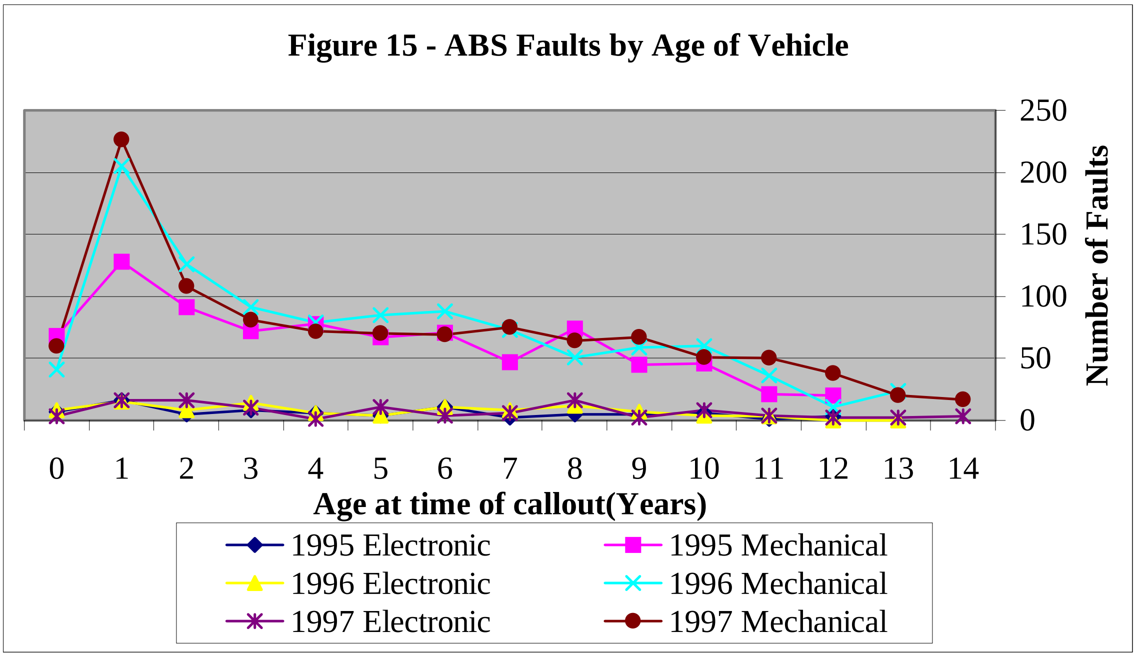
There are a total of 50 failure codes and a total of 300,599 recorded faults in the "mechanical" category covering brakes, steering and suspension components. This category accounts for 5.8% of the total faults recorded. The five most common faults found during call-outs are shown in Figure 14.

Figure 14 - Five most common mechanical faults



It can be seen that problems with the mechanical steering lock fitted to the majority of cars are by far the most common mechanical problem. The 57% of faults shown as “others” above are distributed among the remaining 45 fault codes such that none of the components outside the top five make up a large proportion of mechanical failures. Examples of faults covered in the “others” category includes problems with rear brake shoes and handbrakes, sixth and seventh respectively. Also covered are problems with hydraulic suspension systems, these faults are ranked 12th with a total of 8,422 faults. The remaining categories mainly cover components of the braking system, steering and suspension systems.

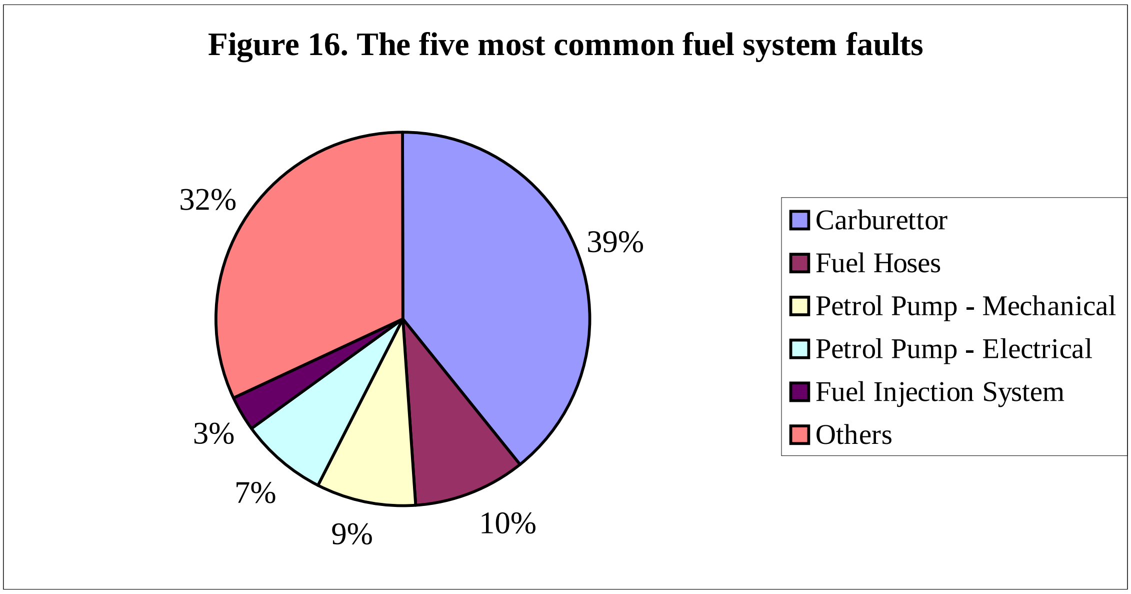
There is only one fault code in this category that is of direct relevance to this work and that is titled “brakes - ABS”. It is likely that this code is intended to represent mechanical problems with the ABS system but there is no information available to allow further detailed examination. There were a total of 3,053 recorded faults classified as mechanical-brakes-ABS, which is equivalent to 1% of all mechanical faults and a ranking position of 24th most common mechanical failure. If this figure is compared to that from the previous section regarding faults within the ECU for the ABS then it appears that a mechanical failure within the ABS is ten times more common than a failure within the relevant Electronic Control Unit. However, it should be noted that mechanical failures in the ABS are likely to have a stronger influence on vehicle behaviour than electronic ones and are therefore more likely to lead to a call-out. It is possible that electronic ABS failures are left until such time as the driver can take the car to a garage. Figure 15 shows a comparison of mechanical and electronic failures within ABS systems divided by age of vehicle at the time of the fault and the year in which the fault occurred.



It can be seen that the number of mechanical failures within ABS systems is much greater than electronic ones, as discussed previously. It also appears that the number of such failures is increasing slightly for each year of the sample. This is to be expected because ABS systems are becoming more common as standard equipment on new vehicles. However, further data on the proportion of cars fitted with ABS for each of the above years would be required before conclusions could be drawn on whether the increase in failures is in direct proportion to the increase in vehicles equipped with ABS. This increase is not readily apparent with electronic failures but this may be simply due to the low numbers of such failures in the database. The distribution of ABS faults by age of vehicle is entirely consistent with the distribution of all mechanical system faults with age. However, in Figure 2 (section 3.1) the distribution of all faults by age of vehicle was considerably different with the peak number of failures seen at around seven or eight years old. This would suggest that mechanical systems suffer an unusually high number of failures in the first two years of their life and become relatively more reliable as they age. It is possible that these early failures in mechanical components are due to the nature of the manufacturing processes that can allow imperfect components that may fail early to reach the market. Unlike electronic components that are likely to fail when first switched on or last several years, mechanical components could last substantially longer before a manufacturing fault becomes evident. It is not possible to determine the cause from the data available.

3.7 FUEL SYSTEM FAILURES

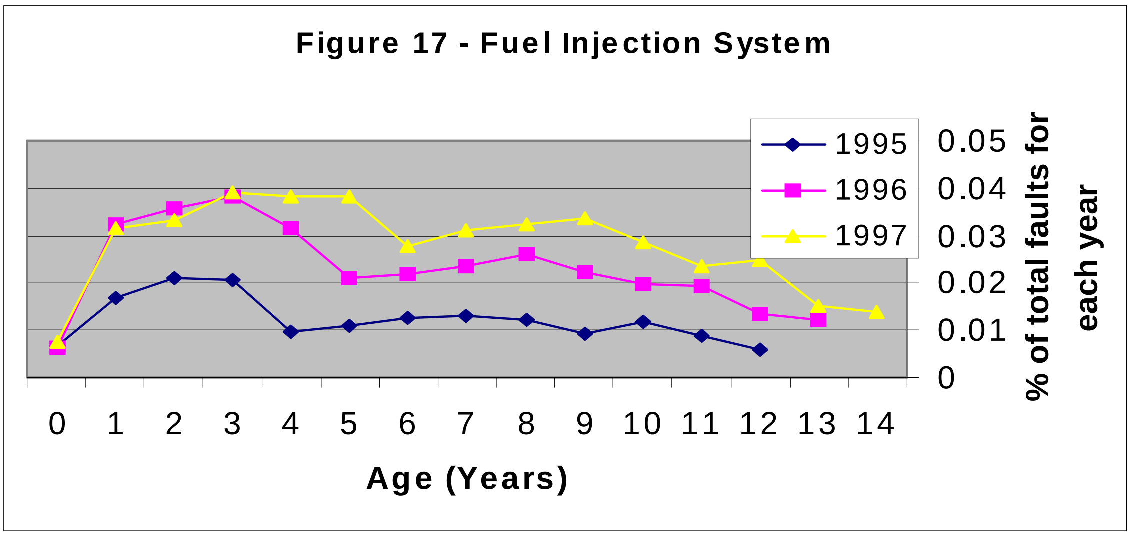
There were a total of 563,723 fuel system failures recorded on the database, distributed between 25 different failure codes, accounting for 10.8% of all reported faults. Figure 16 shows the five most common faults.



It can be seen that despite the current dominance of fuel injection systems over the traditional carburettor in modern cars, carburettors are by far the most common fuel system to have suffered failure in this sample. This suggests that fuel injection systems are considerably more reliable than the carburettor systems that they have replaced, although it is not possible to draw firm conclusions without further data on the number of vehicles in this sample fitted with each system.

There are no obviously safety critical electronically controlled systems in this fault category although, as previously discussed, systems affecting engine power could potentially pose a risk if all power was suddenly lost as a result of a failure.

Figure 17 shows a breakdown of fuel injection system faults by age of the vehicle at the time of the callout for each year of the sample.

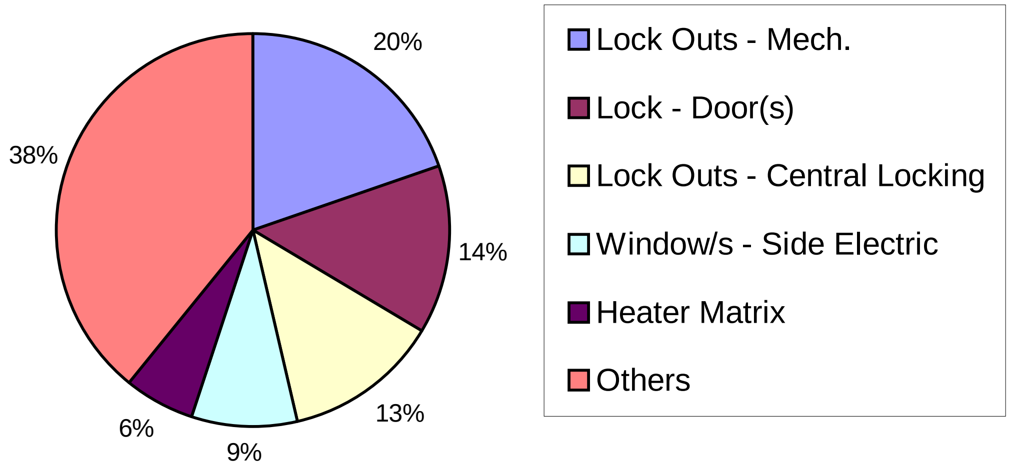


The trend in Figure 17 shows an increasing number of fuel injection system related faults for each year of data. At first inspection it appears there is also a tendency for the largest number of faults to appear early in the vehicle's life. Closer examination shows a phase lag over each year of data that suggests a change in vehicle design between 1991 and 1992 whereby the number of vehicles fitted with fuel injection systems has increased sharply, most likely due to the impending introduction of new emissions regulations in the UK. As stated previously it is not possible to draw firm conclusions with the data currently available, however it is likely that fuel injection faults will continue to increase with a corresponding reduction in carburettor faults, which currently cause the most faults in this system.

3.8 FAULTS WITH BODY MECHANICS

The database contains information on 137,181 faults with components deemed to be body mechanics, accounting for 2.6% of all reported faults. These faults are distributed between 41 different failure codes. Figure 18 shows the five most common faults in this category.

Figure 18 - The five most common body mechanics faults



It can be seen that all of the most common faults are to do with failures of locks/loss of keys, windows and heaters, which are of little relevance to this project. However, this defect category contains one very important safety critical component, namely the airbag, ranked 23rd in this category. The reliability of airbags is of particular importance because not only do you lose the positive benefits of the feature if a failure occurs, but there is also the potential for a false inflation, which has the potential to actually cause serious accidents and injuries on its own. This is unlike ABS systems that are designed to have no influence on the ordinary braking performance of a car when they fail.

There are 723 recorded instances of a call-out where an airbag fault was found. Although this is relatively low in the context of the total number of call-outs recorded in the database it is still a significant number of defects not detected during servicing and annual inspection considering the potentially very serious consequences of catastrophic failure.

Airbag faults are reported to the driver of the vehicle via a warning light on the dashboard and the reaction of the driver to this event is unknown. It may be that he immediately stops and calls for breakdown recovery or he may elect to drive to a garage for later repair. The number of call outs for an airbag fault could be unrepresentative due to the fact that the fault does not prevent the vehicle from being driven, thus hiding further faults where the vehicle is driven to a garage for repair.

Figure 19 shows a breakdown of airbag faults by age of the vehicle at the time of the callout for each year of the sample.

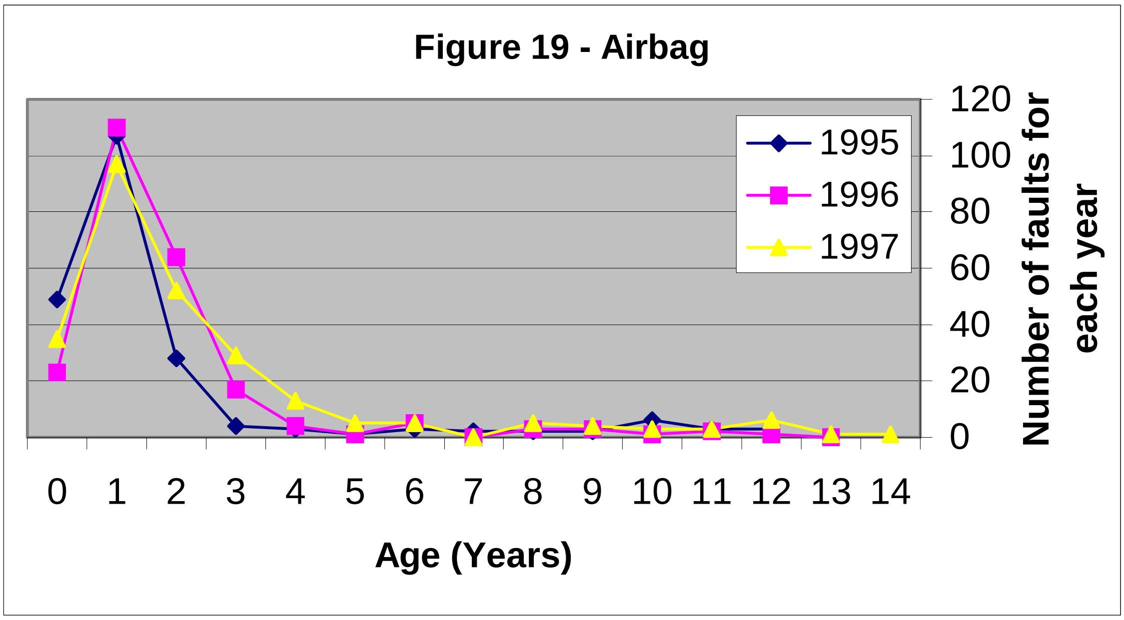
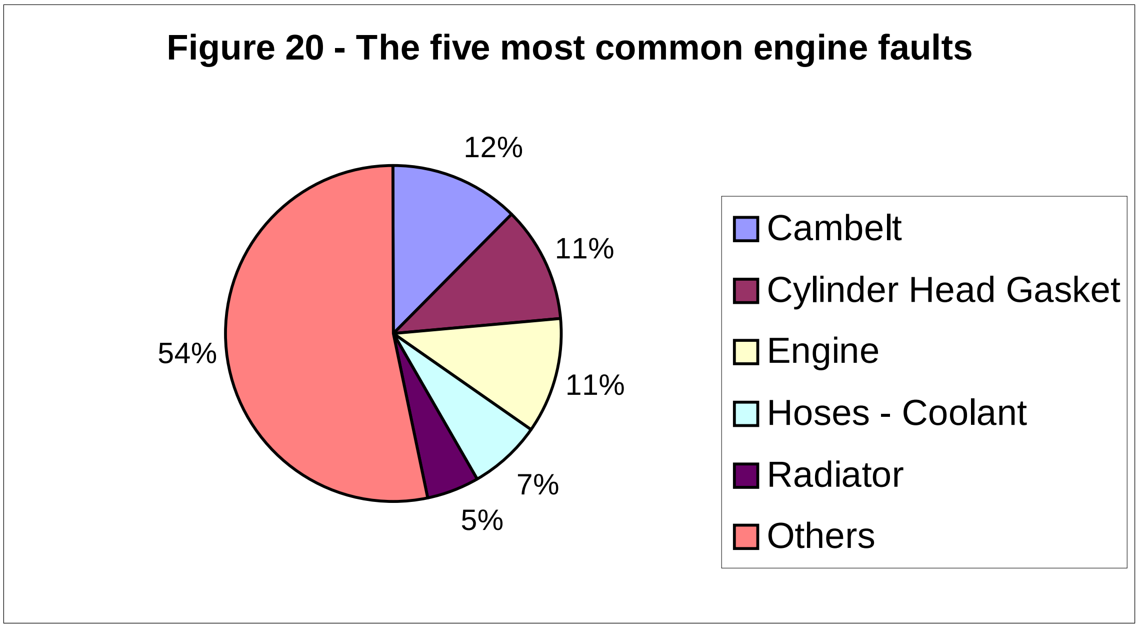


Figure 19 shows a strong trend towards faults in the first two to three years of the vehicles life for each of the three survey years. The number of vehicles fitted with airbags is unknown but it is safe to say that the numbers will only have become significant in more recent years. At present it appears that older vehicles have no particular problems with their airbag systems; in fact it is most likely that this is due to the low number of older vehicles equipped with airbags. It is likely that as more airbag equipped cars are found over five years old, the age distribution will more closely reflect that of the UK fleet as a whole.

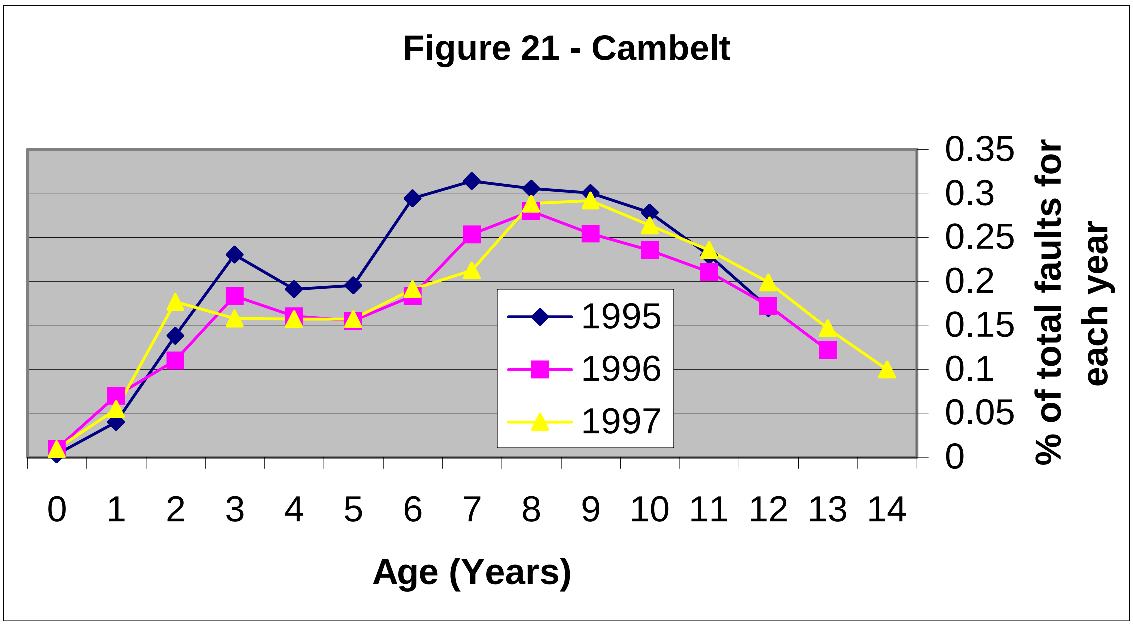
3.9 ENGINE FAILURES

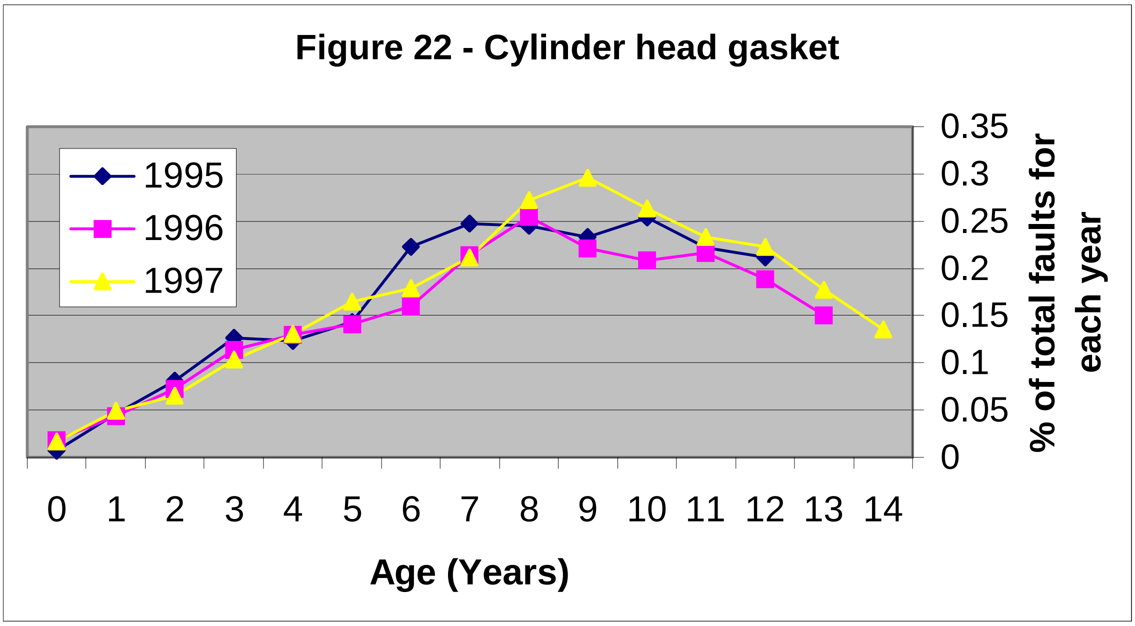
The database contains information on 1,160,013 faults with components deemed to be part of the engine, which represents 22.3% of all reported faults. These faults are distributed between 73 different failure codes. Figure 20 shows the five most common faults in this category.



The most common cause of breakdown in the 'engine' category is as a result of cambelt failure, closely followed by cylinder head gasket failures. The third ranked fault 'engine' does not give sufficient detail to be able to determine which particular component has caused a failure to occur.

There are no obviously safety critical electronically controlled systems in this fault category. These faults fall into the category where regular and correct servicing should prevent the majority of potential faults developing into breakdowns. As with the fuel system failures, any failure in the engine that results in a sudden loss of power has the potential to be safety critical. Figures 21 and 22 detail cambelt and cylinder head gasket failures by age of the vehicle.



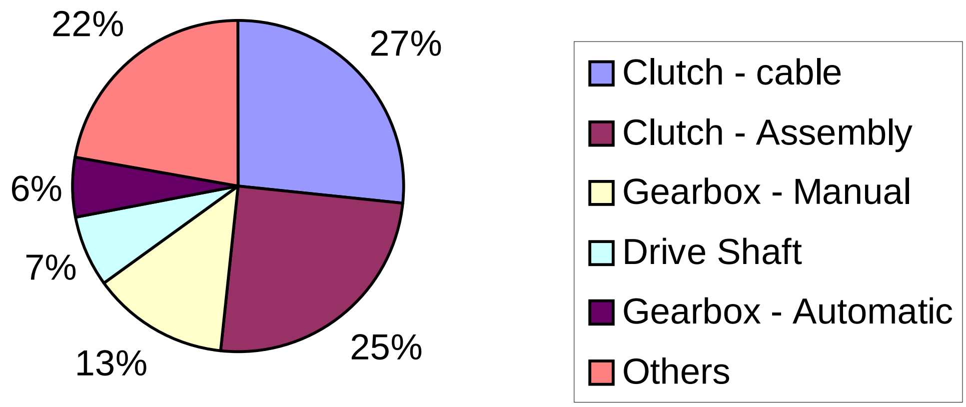


Cambelt failures follow the age distribution for the database with two distinct peaks at approximately two and eight years old. Although cambelt failures account for 12.4% of all engine faults it is not possible to determine whether these faults are as a result of genuine failures of components or use beyond service life. Cylinder head gaskets account for 11.1% of engine faults.

3.10 DRIVELINE FAILURES

The database contains information on 523,064 faults with components deemed to be part of the driveline, which represents 10.0% of all reported faults. These faults are distributed between 30 different failure codes. Figure 23 shows the five most common faults in this category.

Figure 23 - The five most common driveline faults



As would be expected for driveline components the clutch cable proved to be the weakest link in terms of causing roadside breakdown, closely followed by the clutch assembly itself. Any clutch failure could potentially lead to an accident, especially in slow moving traffic where the driver is unable to react quickly enough to prevent a collision. However this type of failure does not fall within the scope of this project so no further analysis has been carried out.

4 ANALYSIS OF LEASE COMPANY SERVICE RECORDS

TRL have also obtained a copy of a database provided by one of the UK's largest vehicle leasing organisations. A record is entered onto this database for every individual repair to every vehicle in their fleet and includes all repairs from routine servicing to major overhauls and will include garage repairs after a roadside breakdown. This database differs from that provided by the breakdown organisation in that it does not solely cover incidents where a vehicle has broken down at the side of the road. The leasing company carries out repair work due to breakdowns, but mainly carries out routine servicing and rectification of faults found during service. It is also likely that faults, which a driver considers to be non-urgent, could be left until a service is due.

4.1 THE SAMPLE

Table 6 shows the approximate number of vehicles in the lease company fleet during each year for which we have maintenance data. These numbers are approximate because they refer to one specific date within each year and vehicles are being bought and sold throughout the course of each year.

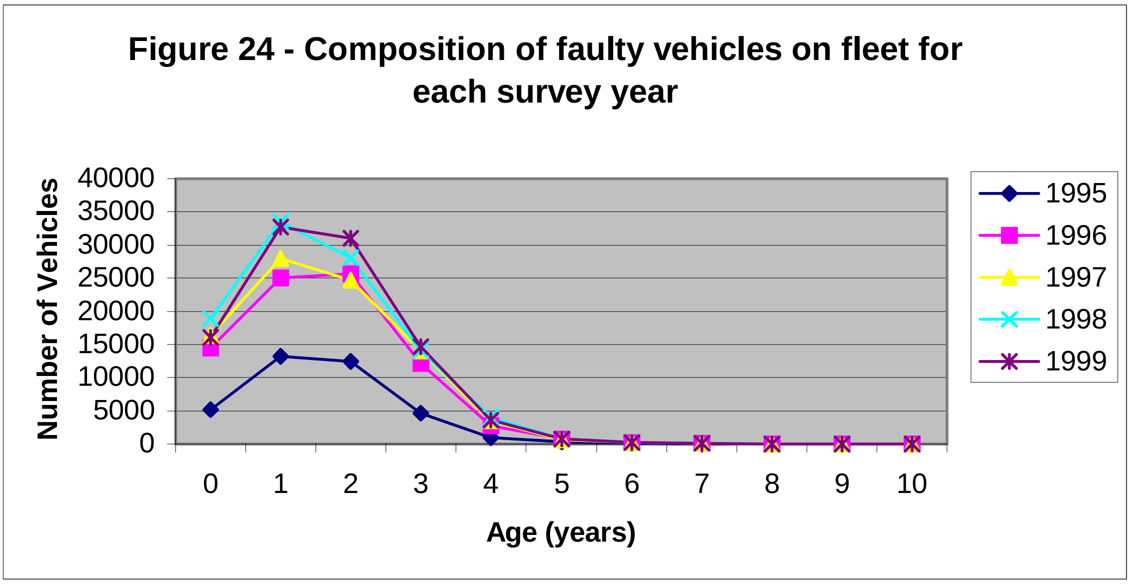
Survey Year	Number of Vehicles
1995	Unavailable
1996	56,790
1997	71,053
1998	79,110
1999	82,877

Table 6 – Vehicles in lease fleet

The above figures are taken from the leasing company's fleet management database and not from the sub-set of maintenance records that are in TRL's possession. It is possible that some of these vehicles may be excluded from the maintenance database where only routine maintenance has been carried out. This is because certain service related faults have been excluded from the maintenance database due to a lack of relevance to this project, and if a vehicle suffered no other faults during those years there will be no record of it. When looking at Figure 24, the number of cars under one year old appears low. This could be due to the reliability of these vehicles and hence they do not appear in the database until they are over one year old.

The maintenance database contains information on 140,000 unique vehicles. This number is not equivalent to the sum of the yearly totals in Table 6 because most vehicles are present in more than one year of data. The reason that there are more than 82,877 vehicles on the database is that most of the vehicles present in 1996, and many of those from 1997, will have been sold and replaced by 1999. Likewise vehicles that were four years old in 1996 are likely to have been replaced in 1997.

The leasing company fleet covers a broad cross section of manufacturers and vehicle types including light vans, car-derived vans and cars. Most vehicles are less than four years old and only a handful are older than ten years old. Figure 24 shows the distribution of the age of each faulty vehicle for each survey year.



The leasing company fleet covers an average of 43,091 kilometres per year, which is higher than the average for most privately owned vehicles of a similar age. This higher than average mileage should allow trends in failure rates to be identified earlier in a vehicle's life than would normally be the case. It should also be noted that the number of vehicles is actually the number of vehicles with a fault, therefore those vehicles with no faults during the first year of their life will not appear in the database. Some faults may also be repaired under a manufacturers warranty and hence not feature in the database.

Figure 25 shows that the number of faults has generally been increasing over the last five years. However the database is not complete for the first and last years, 1995 and 1999. The first year of data collected by the leasing company was 1995 and as such carried a high proportion of errors that have since been cleansed from their database prior to analysis. The final year of data includes all entries up to the beginning of November 1999 and as such represents over 80% of the calendar year. When looking at trends over years, 1999 data will be underrepresented. It is likely that the faults recorded in 1999 will be around 80 to 85% of the actual total faults in that year. This is in line with the 83% of the year for which we have data. After looking at the trends shown for data from 1995, and after consultation with the database supplier, the decision has been taken to exclude this data from our more detailed analysis by systems shown in sections 4.4 to 4.13 due to the cleansed nature of the database.

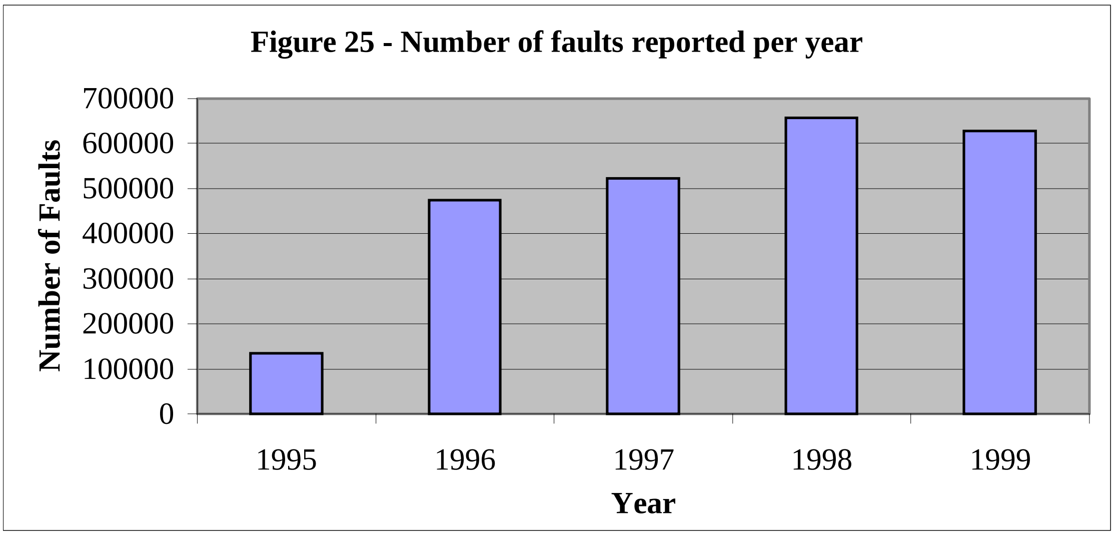
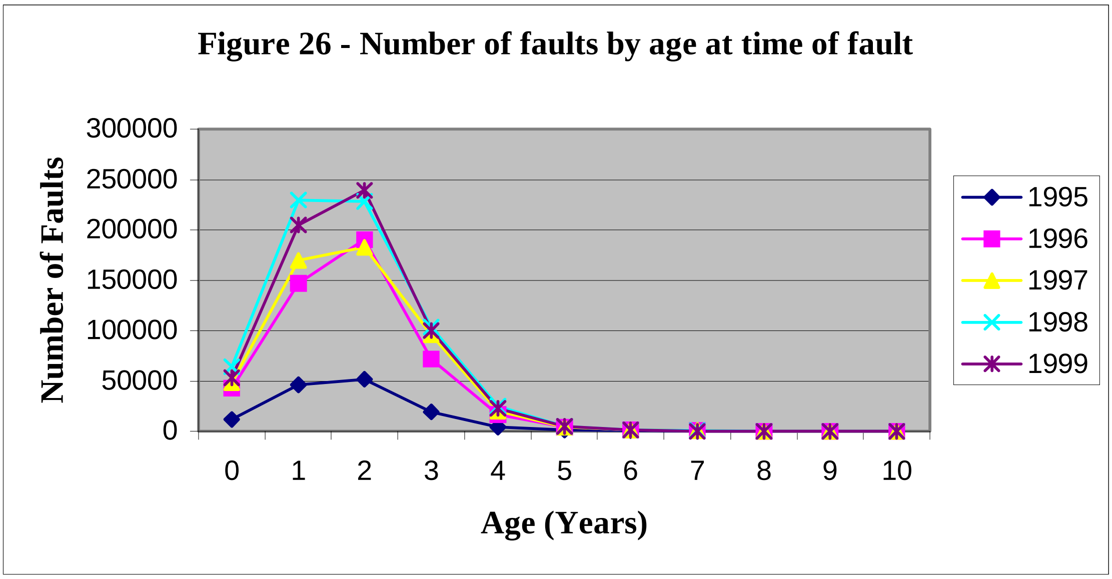


Figure 26 shows the age of the vehicle at the time of repair disaggregated by the year of the sample in which the repair occurred. A total of 43 repairs relate to vehicles that are over ten years old and these have been excluded due to the extremely low numbers involved.



The age distribution of the number of faults developing with age of the vehicle reflects the fact that vehicles of less than one year of age suffer very few faults and that there are very few vehicles that are more than three years old on the database. As mentioned earlier it is likely that the 1999 curve would be slightly higher than the previous year, if the full year's data were available. When comparing Figure 24 to Figure 26 it can be seen that when the vehicle is less than one year old relatively few faults are reported. Looking at the figures for two and three year old vehicles shows that the number of faults is increasing while the number of vehicles suffering those faults is decreasing. In other words the vehicles are becoming more prone to suffering faults as they get older, this is particularly clear for those years of data where the sample size is large enough to allow firm conclusions to be drawn.

4.2 THE FAULT CODES

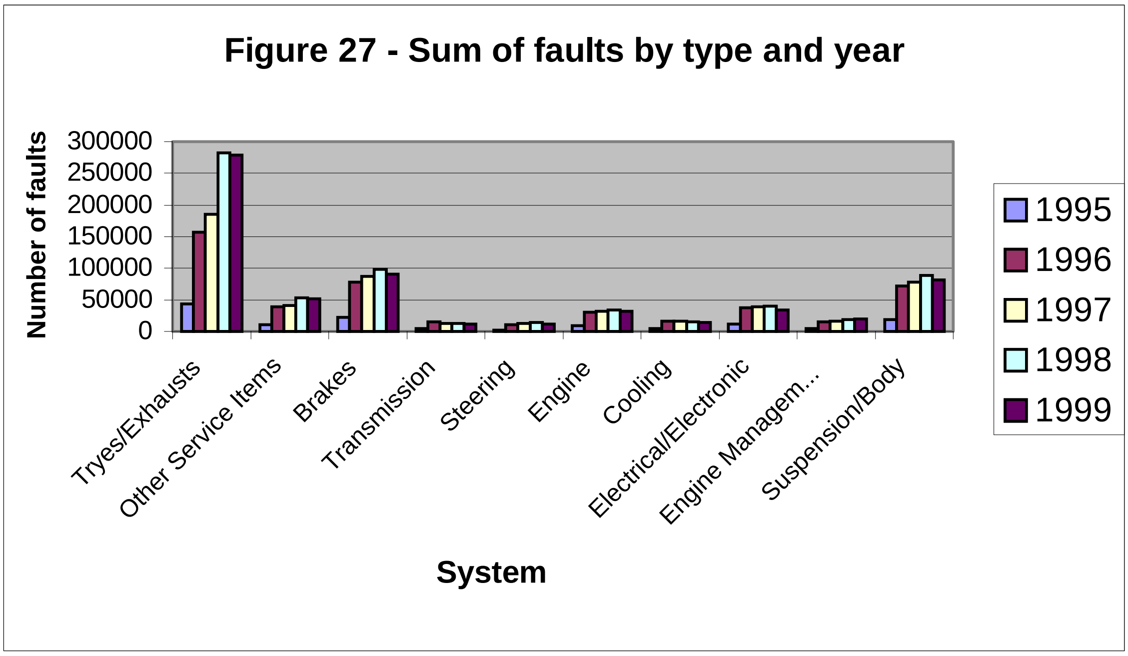
The leasing company uses a broadly similar coding system to the breakdown organisation in order to classify vehicle faults. The code is a three character alphanumeric reference that describes both the generic system that the fault has occurred in and a more specific level to determine the particular component and whether it has required a repair, replacement, adjustment or cleaning. The first character, as for the breakdown data, is a number between 0 and 9. Table 7 defines the generic system codes.

Code	Title	Example Components	No. of failures
0	Tyres/Exhausts	Wheels, tyres, balancing, exhaust sections etc.	948,682
1	Other Service Items	Wiper blades, windscreen washers, MOTs etc.	197,736
2	Brakes	Disc/Drum, linings, cylinders, ABS sensors and control units	377,494
3	Transmission	Clutch, driveshaft, differential	57,655
4	Steering	Wheel bearings, steering rack, hubs, airbags	53,354
5	Engine	Cylinder head, drivebelts etc	137,035
6	Cooling	Radiator, water pump, air conditioning	68,333
7	Electrical/Electronic	Wiring loom, motors, instruments, airbag sensor	162,028
8	Engine Management/Fuelling	Carburettor, injectors, ignition etc.	75,263
9	Suspension/Body	Locks, brake pipes, engine mounts, dampers etc.	338,332
		Total	**2,415,912**

Table 7 – Generic system codes for lease fleet

4.3 SYSTEM LEVEL FAILURES

Figure 27 shows the number of reported failures within each system group, as shown in Table 7, for each year in which the fault occurred.



The leasing company data includes repairs as a result of faults identified at the time of servicing, including those due to normal wear and tear. Figure 27 shows a much higher proportion of faults relating to service items such as tyres, exhausts and brakes than that found in the breakdown data. This is especially true when considering the average mileage covered by the fleet.

Figure 28 shows the same data expressed as a percentage of the total number of faults in each sample year.

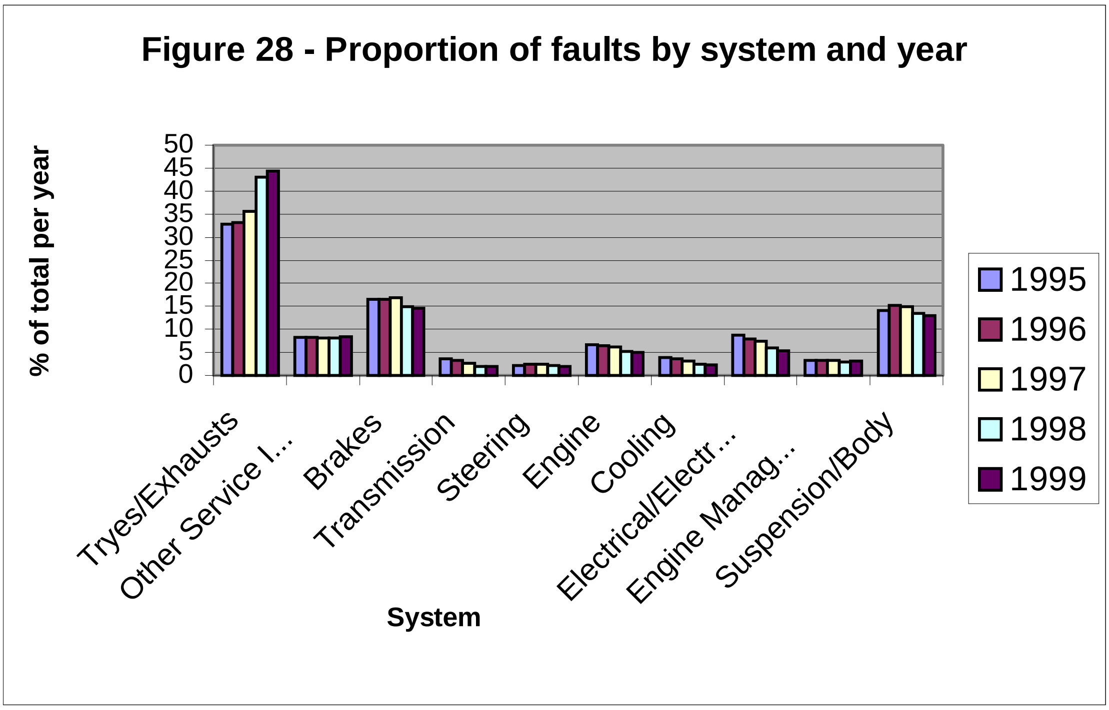


Figure 28 shows an upward trend in faults due to tyres/exhausts, with other service items remaining approximately constant. Braking and suspension/body faults show an increase over the first two years before decreasing over the remaining years. All other systems have remained broadly similar or have decreased over time.

Prior to the start of the analysis it was decided that some of the "fault" codes did not really describe failures or reliability problems which were applicable to the work in this project. Records relating to these codes were excluded from the database to give a more useful figure for the number of actual faults under each generic system code. For example, those relating to damage or routine service items. The codes excluded were: -

(1) Codes relating to fitting of tyres, but not tyre renewal/repair.

(2) All servicing/MOTs and valeting etc.

(3) All codes relating to investigating and reporting on an undefined fault under each system.

Table 8 overleaf gives the total number of faults analysed in the database by system after the fault codes listed above have been excluded.

Code	Title	Example Components	No. of failures
0	Tyres/Exhausts	Wheels, tyres, balancing, exhaust sections etc.	3,816
1	Other Service Items	Wiper blades, windscreen washers, MOTs etc.	24,907
2	Brakes	Disc/Drum, linings, cylinders, ABS sensors and control units	377,494
3	Transmission	Clutch, driveshaft, differential	57,655
4	Steering	Wheel bearings, steering rack, hubs, airbags	53,354
5	Engine	Cylinder head, drivebelts etc	136,404
6	Cooling	Radiator, water pump, air conditioning	68,333
7	Electrical/Electronic	Wiring loom, motors, instruments, airbag sensor	118,589
8	Engine Management/Fuelling	Carburettor, injectors, ignition etc.	57,024
9	Suspension/Body	Locks, brake pipes, engine mounts, dampers etc.	138,767
		Total	**1,036,343**

Table 8 - Total recorded faults analysed in database

Table 8 shows that the vast majority of repairs under system 0 and 1 were service items of no relevance to this project. However, for the following analyses the full database of faults has been used to enable the reader to put the faults of interest into perspective with the overall reliability of vehicles on the database.

Many of the codes found within the lease fleet database relate to potential service items. The majority of system codes 0 and 1 relate to items requiring regular replacement such as tyres, exhausts, wiper blades and air conditioning units. A number of other service items appear throughout the database, most notably the replacement of instruments, bulbs etc. Figures 28 and 29 show the breakdown of faults by system when these service items are removed from the database as identified earlier in Table 8.

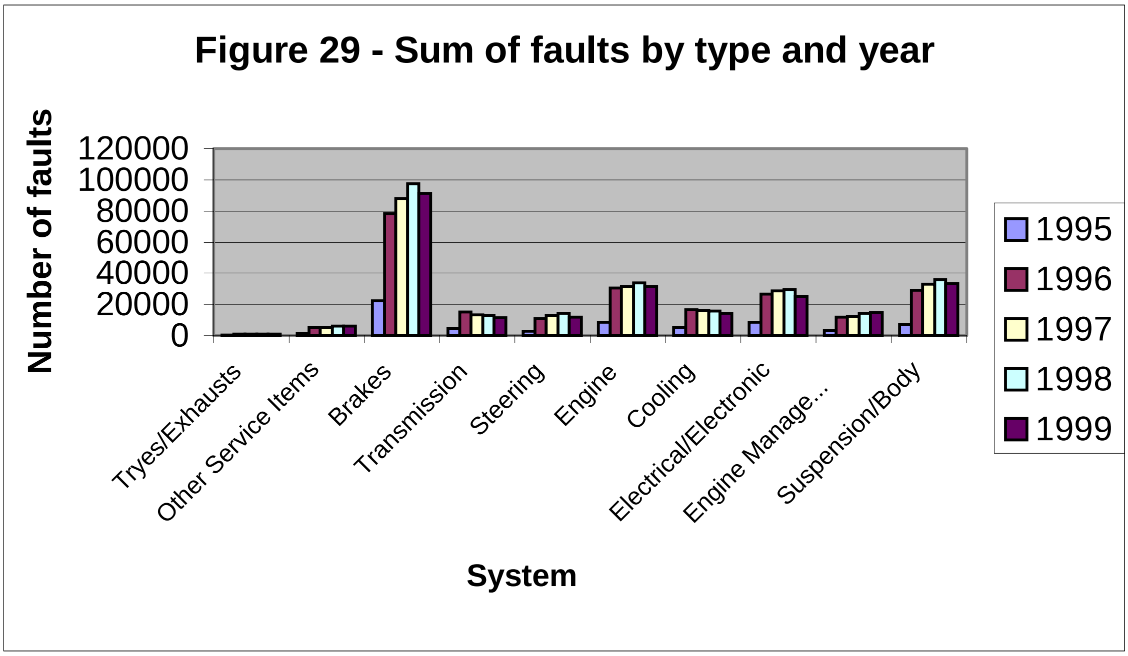
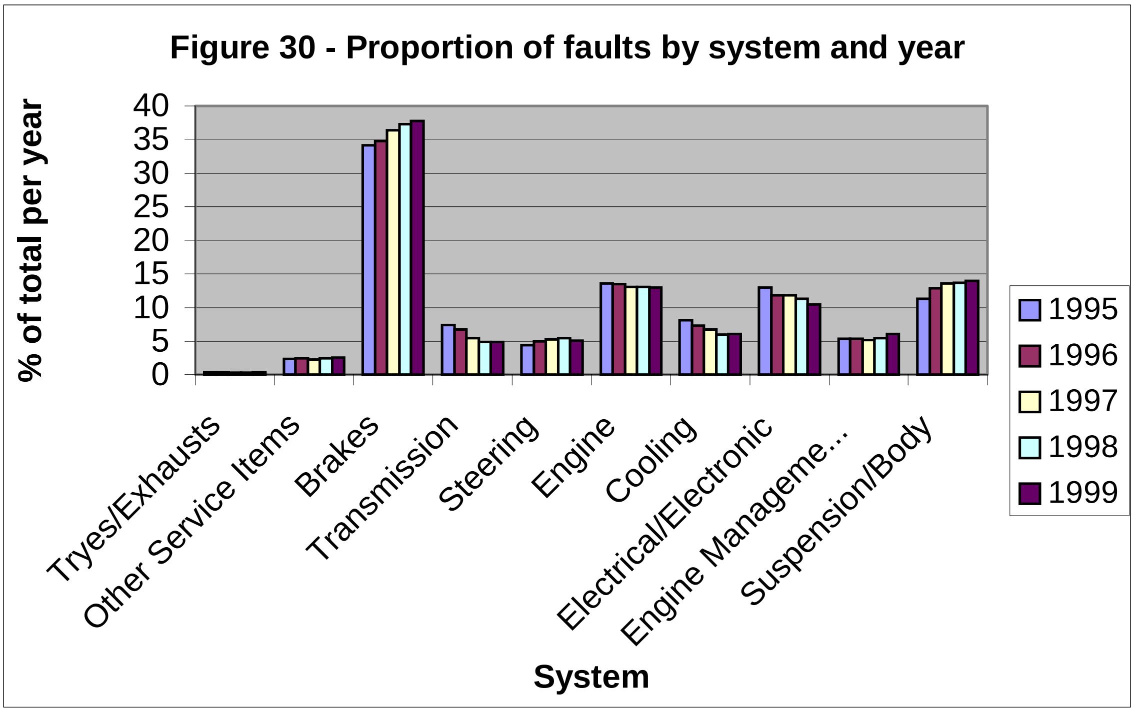


Figure 29 now shows that the greatest number of repairs occurs in the braking system. This is at least partly due to the fact that it is not possible to separate replacement before it affects performance and replacement as a result of faulty components or use beyond service limits. Figure 30 shows the same data represented as a percentage of the total faults within each system.

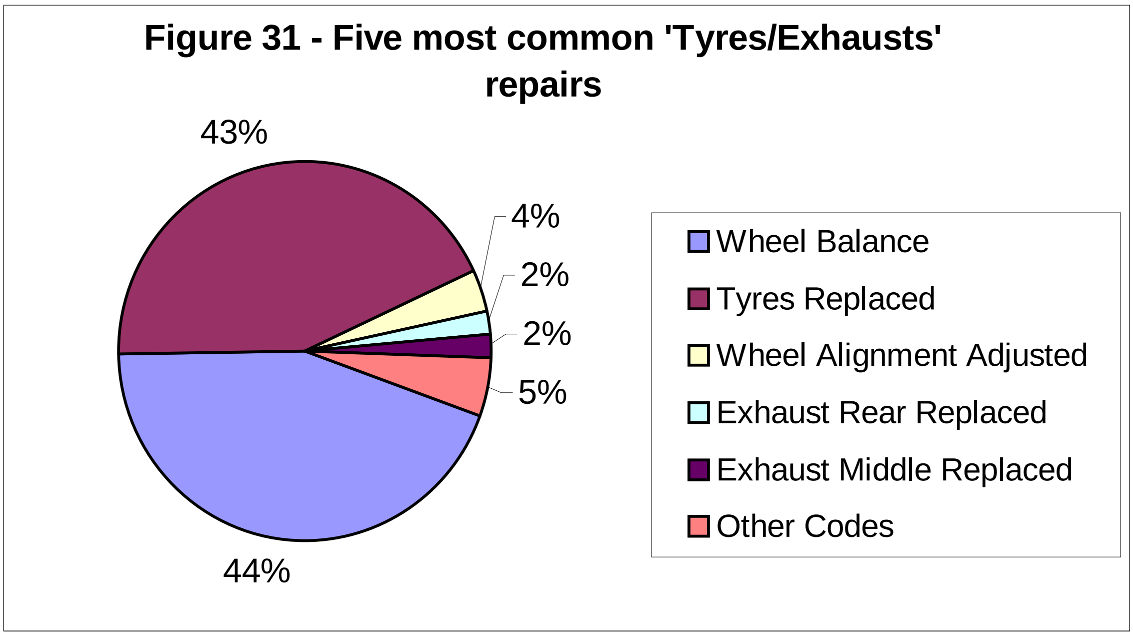


The trends over time have also altered slightly since the removal of some of the wear and tear related codes. As a percentage of each year's faults, brakes now represent an increasing proportion of repairs, however it must be stressed that it is likely that the majority will be service items, which cannot be separated from genuine failures of components or use beyond service life. Engine management faults are increasing slightly but are still at a lower level than the majority of mechanical systems.

The following sections 4.4 to 4.13 show a more detailed analysis of the top five repairs carried out under each system code. The figures given are based on the whole database available for analysis as explained in section 4.2.

4.4 TYRES/EXHAUSTS SYSTEM FAILURES

There are 29 separate fault codes, representing a total of 948,682 repairs, within the tyre/exhaust system referring mainly to exhaust section replacements and repairs. The top five repairs as a proportion of the total tyre/exhaust system repairs is shown in Figure 31.



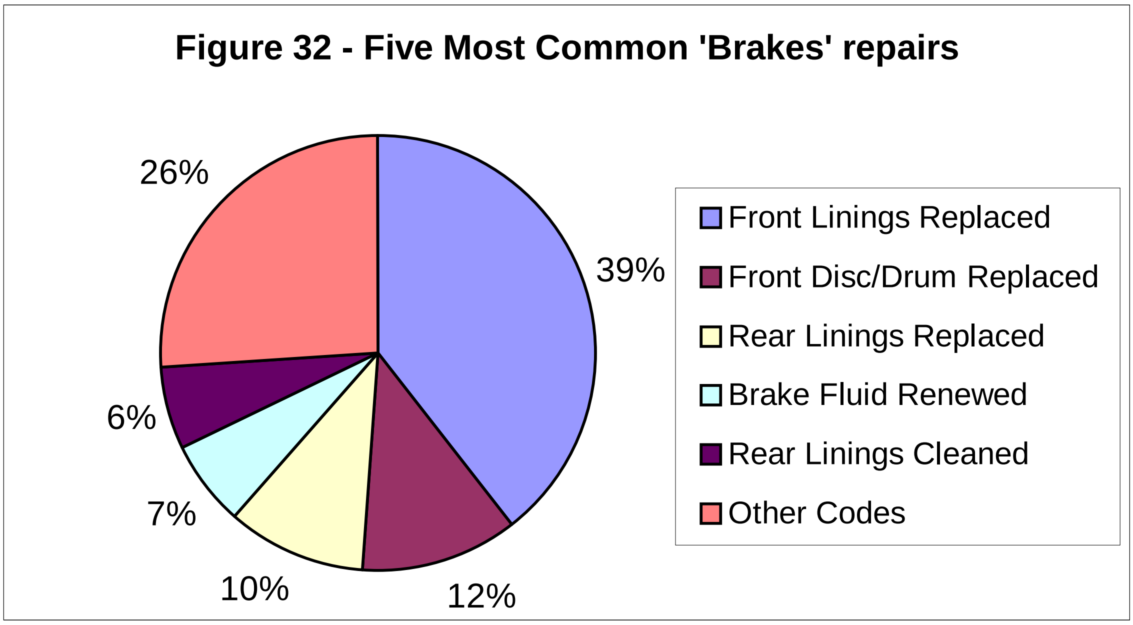
It was found that there were no faults in this section of the data that were considered directly relevant to the project, as a result no further analysis of this data was undertaken. The figure is shown for comparison only.

4.5 OTHER SERVICE ITEMS

As shown in Table 7 and Table 8 this code relates purely to service items such as oil changes and as such is of no interest, therefore no analysis has been carried out.

4.6 BRAKE SYSTEM FAILURES

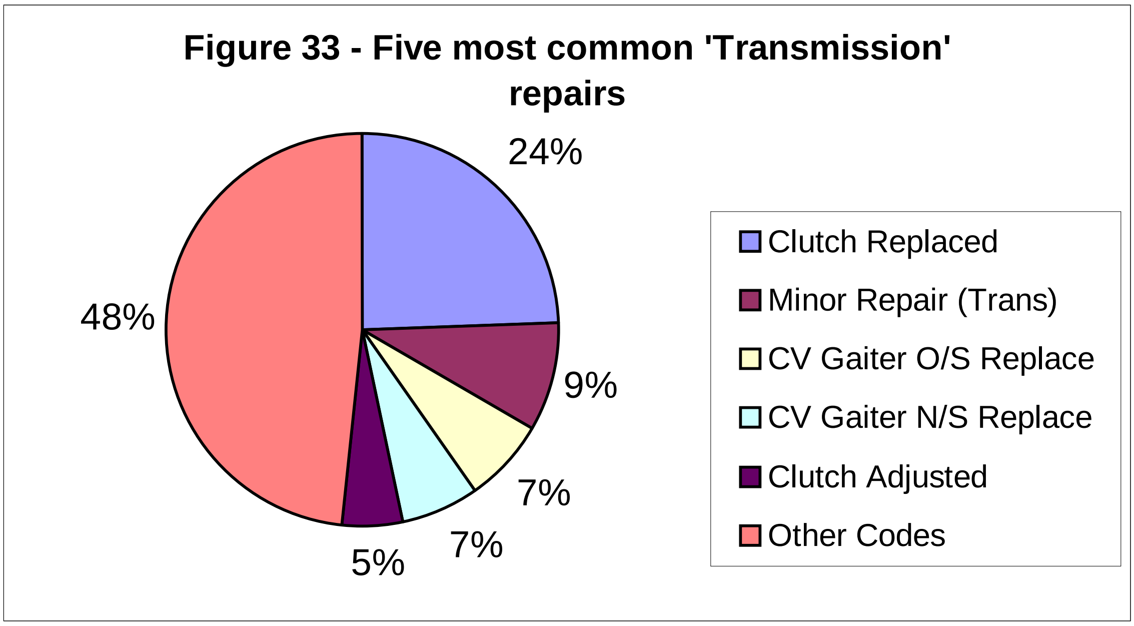
These data contained 67 separate codes, most of which concerned the mechanical components of the braking system. The five most common faults in this section as a proportion of all brake system faults are shown in Figure 32.



There were eight fault categories, which were directly related to the anti-lock braking system electronics, including the renewal and repair of the control unit and sensors. Out of a total of 377,494 brake system repairs, 2146 (0.6%), were related to ABS faults. The age distribution of these faults was broadly similar to the distribution of all faults in the sample with most faults occurring in vehicles that were two and three years old. This age distribution simply reflects the number of vehicles of that age within the sample. This contrasts with that found in the breakdown data where the mechanical ABS faults were found to peak early in the vehicle's life.

4.7 TRANSMISSION FAILURES

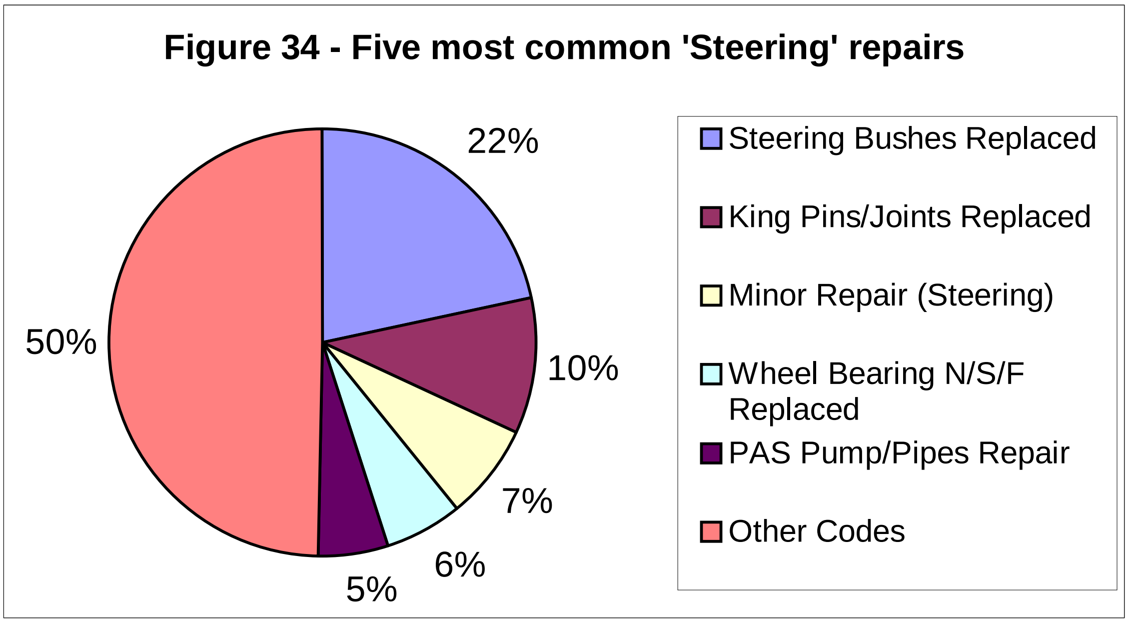
This data sample had 62 separate fault codes, representing a total of 57,655 repairs, and consisted mainly of mechanical repairs to the system. The top five faults identified with the transmission are shown in Figure 33.



There were no specific codes relating to electronic components, thus in depth analysis of the data was not carried out.

4.8 STEERING SYSTEM FAILURES

Figure 34 shows the 5 most common faults identified with the steering system. There are a total of 66 fault codes, covering a total of 53,354 repairs.

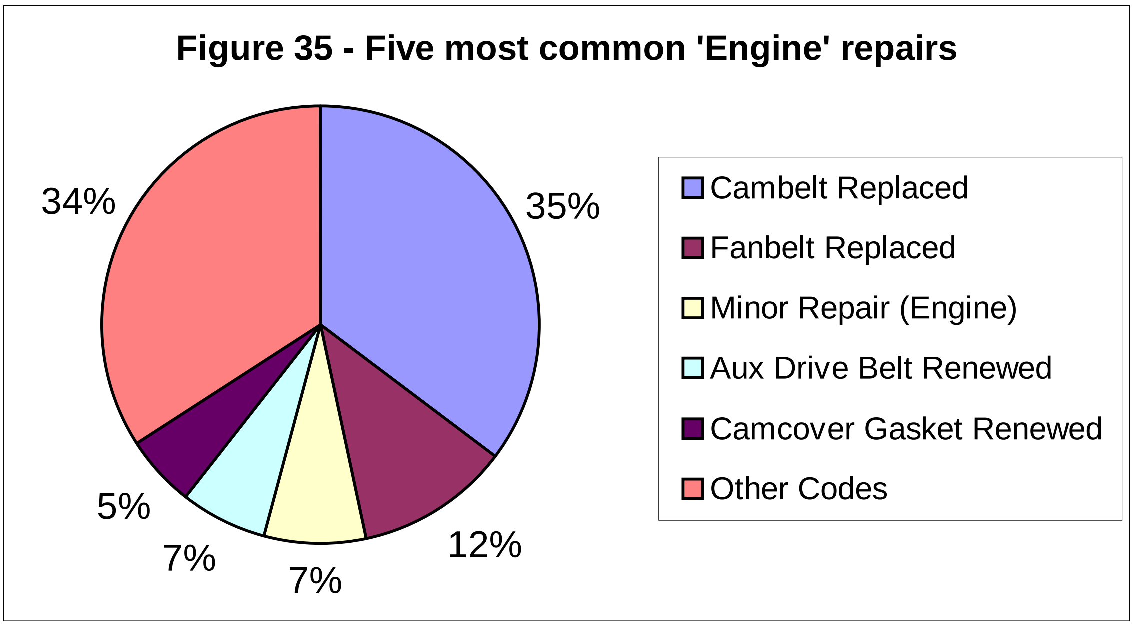


There were no categories in this section that specifically referred to electronic systems. However, airbag repairs were listed in this section and there was a total of 1,138 faults recorded. These faults follow the typical age profile identified in Figure 26. If these data are combined with data on the airbag sensor repairs, covered under section 4.11 and accounting for 489 repairs or 0.3% of the total electrical and electronic system repairs, the total number of faults increases to 1,627. This is equivalent to 1.2% of all vehicles on the maintenance database being affected by such airbag faults during the period the vehicle is part of the fleet.

Seatbelts and airbags are directly comparable systems because they are both intended to restrain occupants in frontal collisions. Seatbelts are more important when it comes to that primary function and will have a more severe effect if they fail to operate correctly in a frontal collision. However, airbags have far more potential to cause accidents and injuries because they could potentially suffer an unintended inflation. It is considered an important part of the periodic inspection to examine seatbelts and it can be seen from the data that the number of seatbelt repairs totalled 2,988. The number of airbag repairs (1,627) was lower than the number for seatbelts but the number of airbags in service is probably still considerably lower than the number of seatbelts. However, that number is continuing to rise with very few cars not fitted with at least a drivers airbag and the trend is likely to swing further towards more airbag related faults as passenger and side impact airbags become ever more popular. These figures therefore suggest that if there is justification for inspecting seatbelts there is a similar justification for including airbags in the periodic inspection regime, and that justification is likely to increase markedly.

4.9 ENGINE FAILURES

Figure 35 shows the five most common engine faults. A total of 137,035 repairs are split between 68 fault codes.

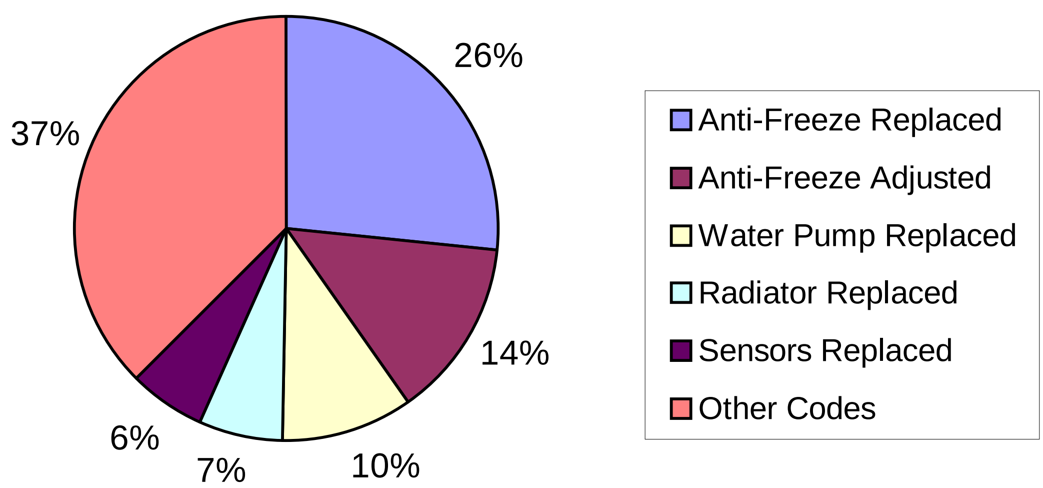


The engine data was primarily involved with the mechanical repair and overhaul of specific engine systems such as cylinder heads and replacement of camshafts and drive belts. For this reason only the most common faults have been highlighted. The electronic control of the engine is listed in a later section.

4.10 COOLING SYSTEM FAILURES

This section in the database contained 46 separate fault codes, totalling 68,333 repairs, which again contained mostly mechanical faults. Figure 36 shows the five most common faults identified.

Figure 36 - Five most common 'Cooling' repairs

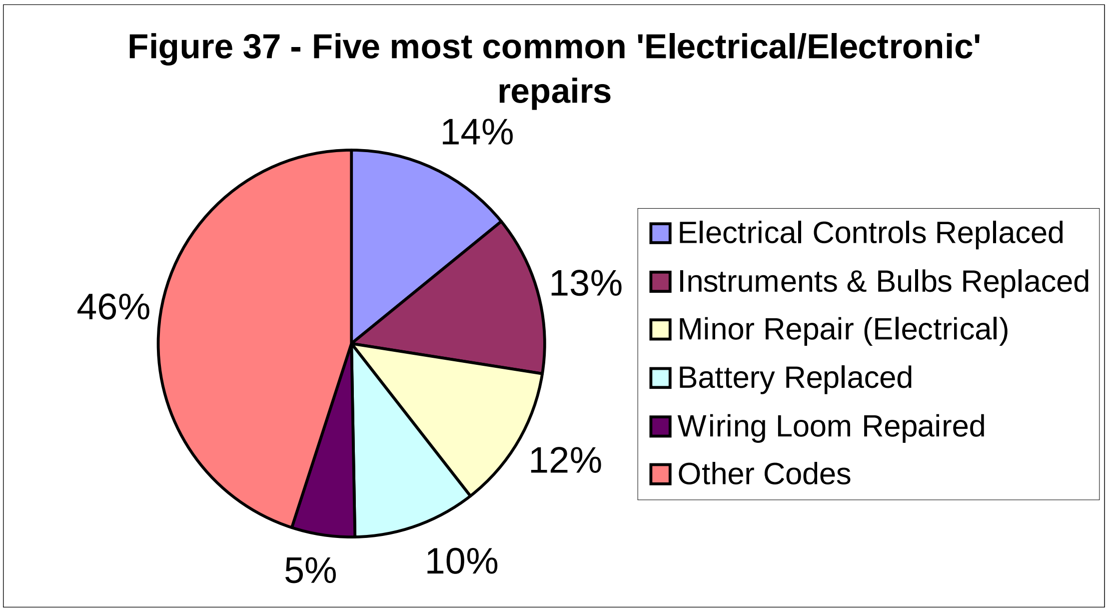


There were four fault codes in this category that related to sensors. The database did not make it exactly clear what these sensors were, but it is thought that they related to the operation of air conditioning systems. The following data concerning these sensors are included for completeness.

There were 4,066 faults in the data set concerning the sensors. Again this was distributed similarly to the age profile seen in the database with the largest proportion of faults occurring around the two and three year old vehicles.

4.11 ELECTRICAL AND ELECTRONIC SYSTEM FAILURES

There was a total of 162,028 faults in the category divided between 56 fault codes. Figure 37 shows the five most common faults in this section as a proportion of the total electrical/electronic faults.

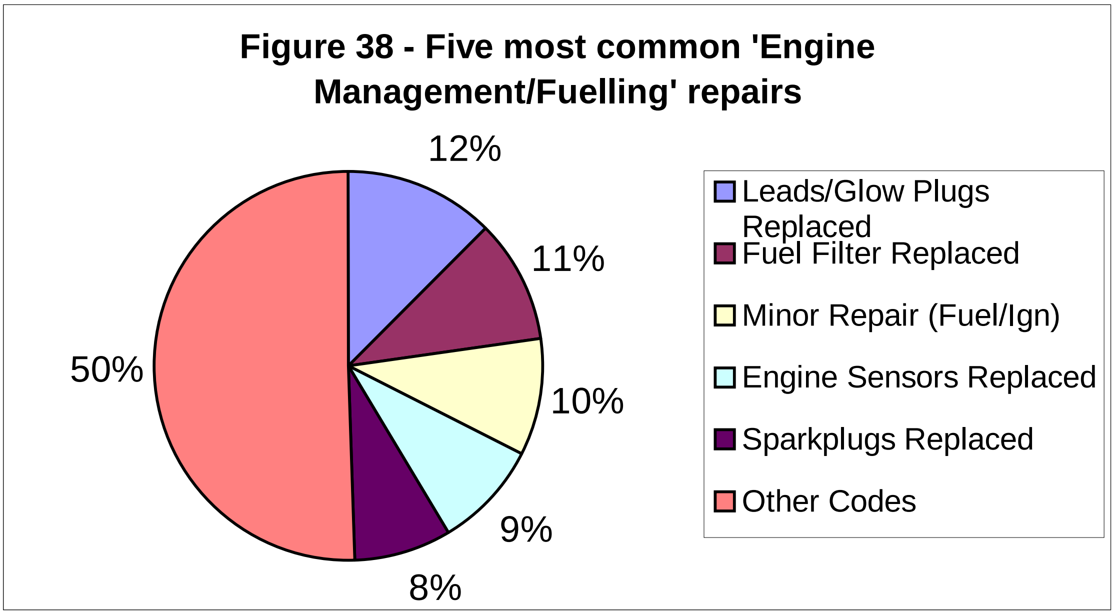


A large proportion of the data in this category concerned batteries, alternators, and bulb replacement. A total of 10,395 (6.4%) repairs were associated with wiring, although it has not been possible to be more specific as to which system component these relate to. There was however, some data on alarm and immobiliser repairs and replacements. Although alarms and immobilisers may not be perceived as safety critical systems there is a theoretical chance that a defective application of the immobiliser could result in the engine cutting out at speed, which could potentially result in an accident. The data set contained 7,455 alarm faults and 275 immobiliser faults. The faults were distributed in line with the overall age distribution within the fleet. Alarm faults affected 5.3% [4] of the vehicles in the fleet. Immobilisers had a similar distribution with the majority of faults occurring in years two and three but with only 0.2% of the vehicles in the fleet affected.

4.12 ENGINE MANAGEMENT AND FUELLING SYSTEM FAILURES

This category covers components dealing with the fuelling of the vehicle, either carburettor, petrol fuel injection or diesel injection pump. Some components controlling the engine are also included such as ECU/coil, engine sensors, fuel relays, air flow meter and throttle potentiometer. The ECU/coil category is a general grouping of faults covering both systems incorporating a typical spark ignition system and those more advanced systems where the ignition system is replaced by an ECU. The total number of faults for this category was 75,263 spread over 67 fault codes. Figure 38 shows the five most common repairs to the engine management / fuel system.

[4] Assuming 140,000 unique vehicles and one fault per vehicle



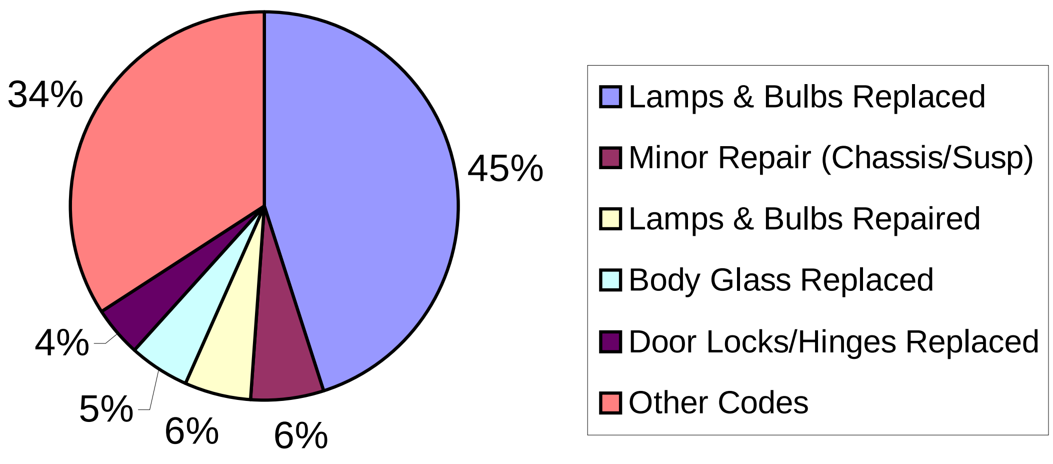
Some of these components are electronically controlled; however, none can be identified as safety critical beyond the possibility of causing the engine to cut out at speed as per the previously described engine faults. Those items likely to have such a potential are limited to the ECU/coil, engine sensors and throttle potentiometer. The data set contained 2,846 ECU/coil faults, 7,394 engine sensor faults and 2,672 throttle potentiometer faults and together they constitute 17% of all engine management / fuelling faults. The age profile follows that seen in the whole database with the largest proportion of faults occurring in the two and three year old vehicles. The percentage of the whole vehicle fleet (140,000 vehicles) affected is as follows: 2.0% for ECU / coil, 5.3% for engine sensors and 1.9% throttle potentiometer faults. Fuel tanks, covered under current periodic inspection regimes, account for 2,523 faults or 1.8% of the whole vehicle fleet.

A comparison of the number of failures of engine sensors (not part of current inspection regime) and fuel tanks (currently inspected) shows that in this particular instance the electronic system is failing more frequently than the mechanical system. These two systems are not directly comparable, they fulfil different functions and have different safety implications, but this does demonstrate that although electronic failures are relatively rare, so are failures of mechanical systems that are already part of the annual inspection programme.

4.13 SUSPENSION AND BODY SYSTEM FAILURES

The top five faults identified within the category of suspension and body mechanics are shown in Figure 39. This component category covers items as diverse as brake pipes and engine mounts to sunroofs and window regulators. As such it covers those items that do not fit into the other system categories. This data sample had 72 separate fault codes, accounting for 138,767 repairs, and consisted mainly of mechanical repairs to suspension and body components.

Figure 39 - Five most common 'Suspension/Body' repairs



There were no specific codes relating to electronic components, thus in depth analysis of the data was not carried out and the figure is shown for comparison.

5 EUROPEAN DATA

In order to ensure that the UK data analysed here is broadly representative of the situation across Europe, data has been collected by a number of European project partners. The results of these investigations are discussed and compared to the findings in the UK.

5.1 SWEDEN

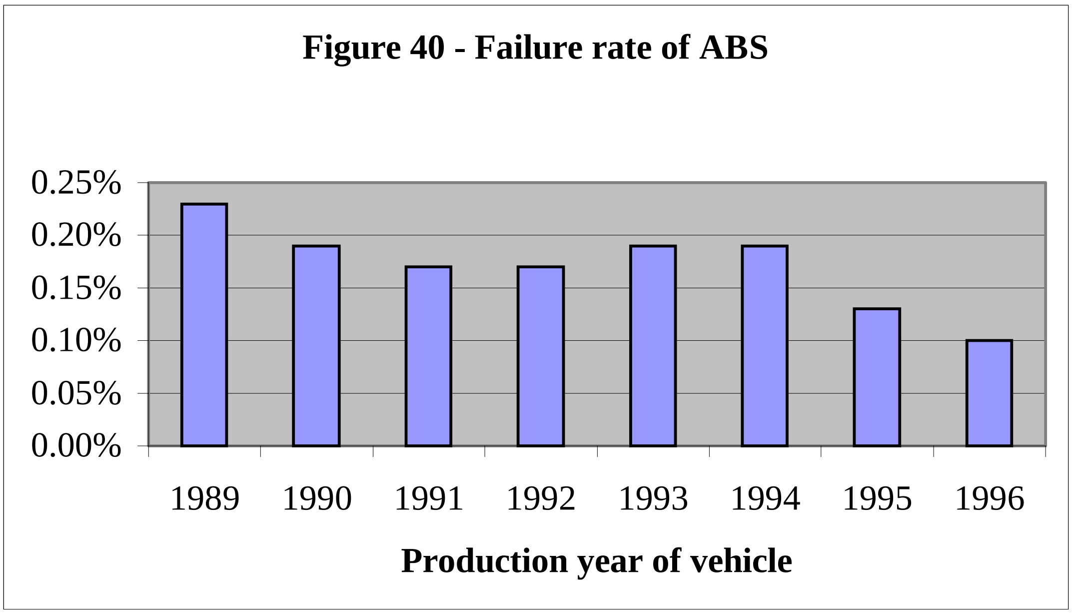
Bilprovningen, the Swedish vehicle inspection organisation, have been working to supply data to compare with that of the UK. To date this has involved surveys carried out at annual inspections during 1999 into the functionality of the ABS and engine control warning lamps.

Table 9 gives the total number of inspections performed during 1999 by the year of manufacture of the vehicle.

Year of Manufacture	Number of Vehicles Inspected
1989	168,289
1990	204,418
1991	109,335
1992	128,676
1993	75,407
1994	86,791
1995	83,108
1996	73,519
Total	**929,543**

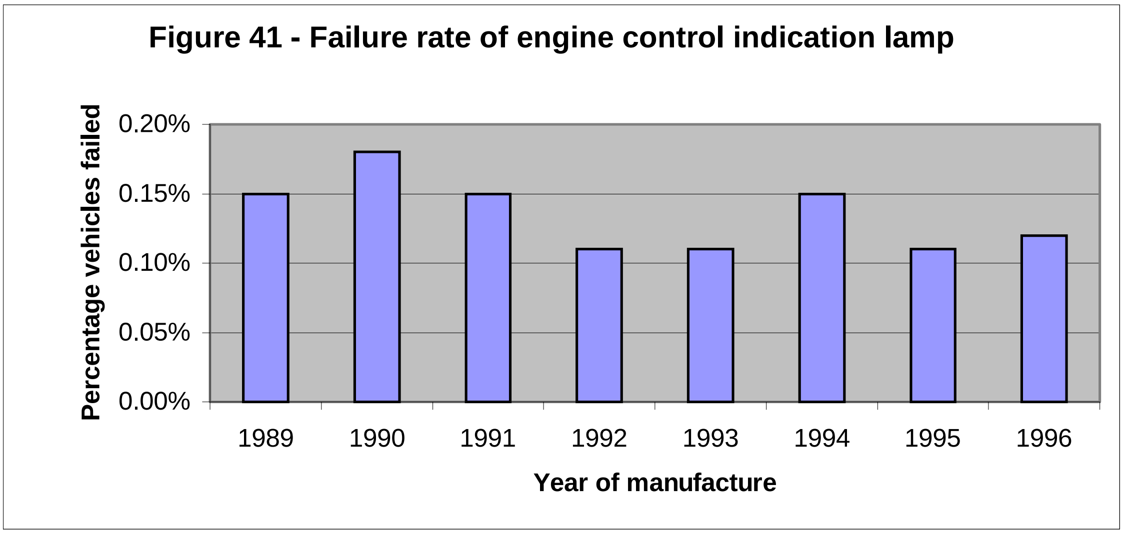
Table 9 – Number of inspections carried out in 1999

The total number of vehicles in Sweden that are over three years old is less than one million so the sample size is small compared to the UK. The failure of the ABS system, as indicated by a warning lamp, has been checked at the annual inspections and the total percentage for each year of manufacture is given. Note that the values given in Figure 40 are for all cars manufactured in each year, independent of whether ABS is fitted.



The graph shows an upward trend with age as would be expected. However the number of vehicles likely to have been manufactured with ABS in 1989 is very small whereas in 1996 it is quite large therefore the fact that a higher percentage of 1989 vehicles have defective ABS compared to 1996 vehicles could indicate a serious problem with ageing ABS systems.

Bilprovningen have also provided data regarding the functionality of engine check warning lights at annual inspection. The data collected was based on annual inspection observations of the engine control warning lamp and an emission control check. No checks of the emission control system are made beyond the normal emission test, nor is the warning lamp system inspected except to confirm the light is not on. The following Figures 41 and 42 show the percentage of vehicles in Table 9 that failed the inspections.



No clear trend can be identified from the data available in Figure 41, however the numbers of faults involved are very small.

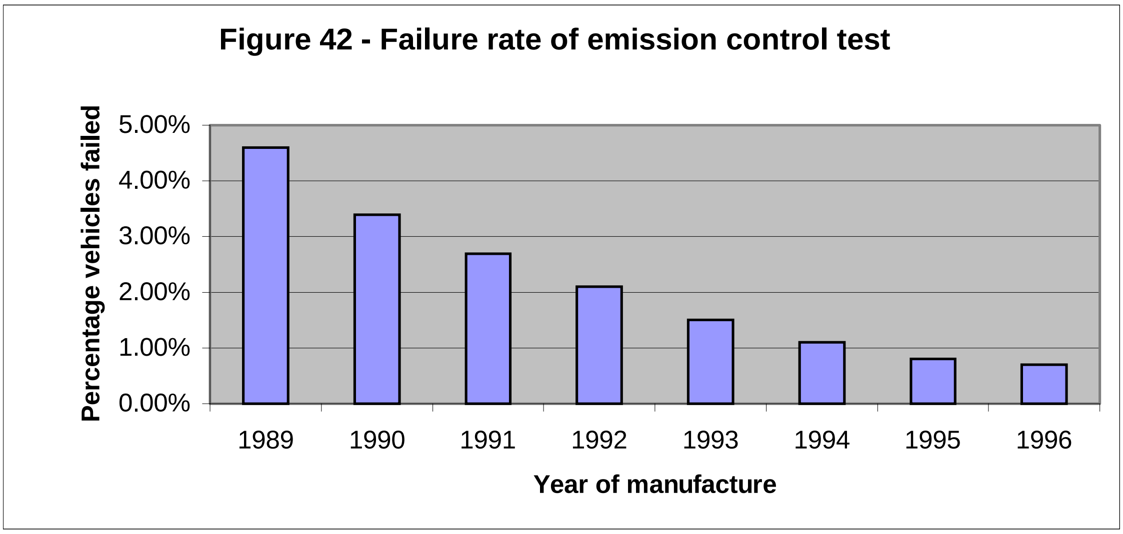
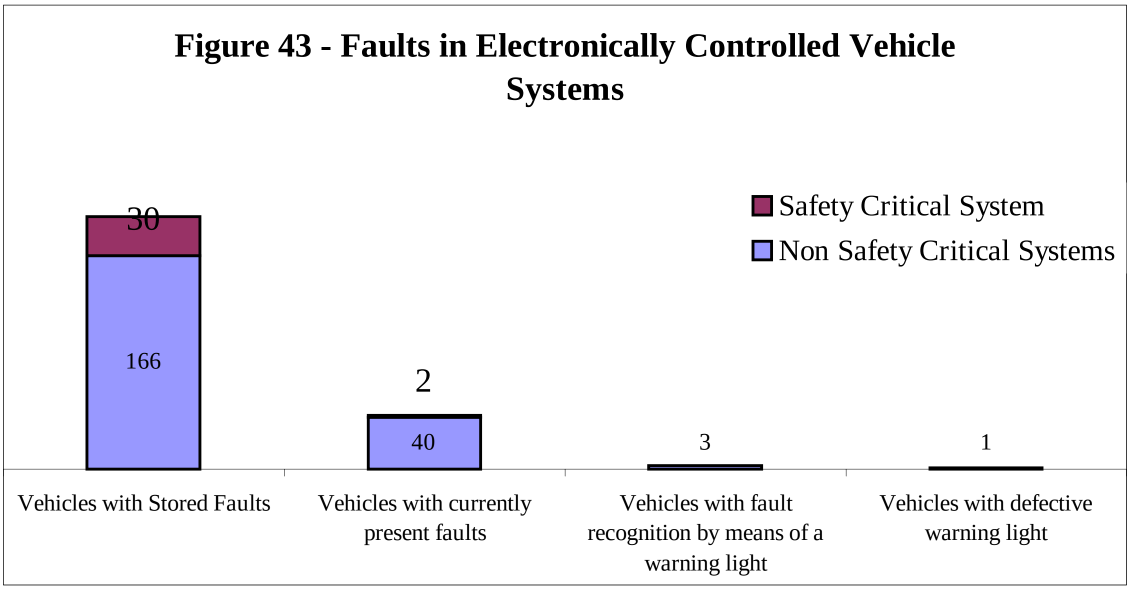


Figure 42 shows a clear downward trend in failures by year of manufacture. This is most likely a combination of factors relating to the increasing fitment of modern emission control equipment and the ageing systems proving to be less reliable than the newer systems available.

5.2 GERMANY

A potential method of checking faults within safety critical systems has been identified through the availability of fault code memories within certain systems. These are primarily intended to allow fault diagnosis under servicing conditions by garages where a warning light has alerted the vehicle driver to a potential fault. There is good reason therefore to interrogate these fault-identifying systems at periodic inspection as they offer an improved safety check compared to checking the operation of the warning lamp for systems such as ABS, airbags, engine management etc. Work carried out in Germany by TUV and Aachen University for this programme has dealt with a number of issues relating to the ageing of electronic systems such as airbags. These are covered by a separate report and are not included here; the research carried out on fault code stores is included below.

Aachen University carried out a survey in 1996 of fault code stores. Recent work (spring 1999) by a major manufacturer looking at fault code memories, in the same way as Aachen University, on a number of their own vehicles has shown the potential to utilise them for periodic inspection purposes. Their research looked at a total of 418 vehicles, of which 304 were considered suitable. Figure 43 shows a breakdown of fault code memory results found during testing. Of 196 vehicles a total of 30 (15.3%) had faults in safety critical systems such as airbag, ABS or active/dynamic stability control. Of these 30 faults only two were present at the time of checking, meaning that without the fault code memory no fault would have been obvious when inspected. Of these 42 faults, three (7.1%) should be apparent from a warning light but one vehicle had a defective warning light resulting in only one percent of faults recorded actually resulting in a warning light operating at the time of inspection. As more vehicles in the manufacturers' range are due to have integrated electronic control systems installed, there is likely to be an updated report in the spring of next year covering a larger number of vehicles.



The age range of vehicles examined corresponded with that of the Aachen survey. However due to the small numbers of vehicles examined no correlation could be identified between the age of the vehicle and the number of recorded fault codes.

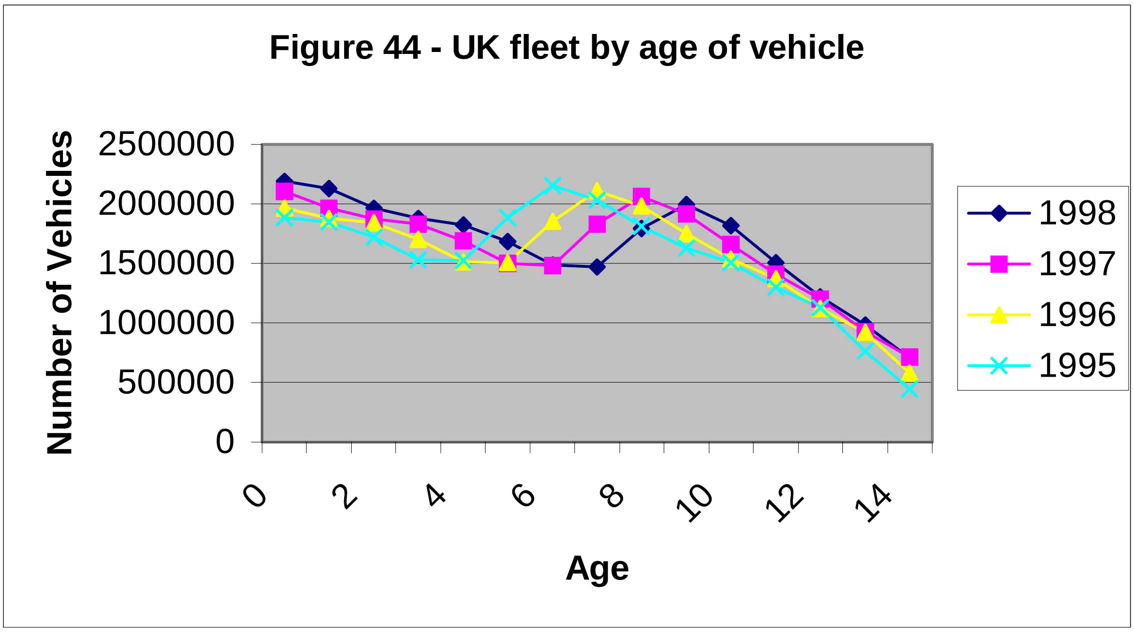
TUV have also carried out analysis of the German recall system to identify how many safety critical systems are subject to recalls. This information has been obtained through analysis of published information from motoring magazines. It shows that in the period 1997 to August 2000 approximately two million vehicles were the subject of a manufacturer recall for a component of the airbag system. Of these, around 80% actually responded and presented their vehicle for an inspection. To include a check of recall notifications against chassis numbers and relevant paperwork for an individual vehicle at annual inspections would lead to a much improved response rate to recalls and hence less vehicles on the public road with identified, and uncorrected, design faults.

Further data regarding the reliability of vehicles has been identified through Allgemeiner Deutscher Automobil-Club (ADAC). The organisation carries out vehicle recovery operations and a sample of fault codes seen would indicate that the codes operate on much the same lines as the breakdown database analysed in the UK. To add valuable comparison with the work carried out in the UK, and to support our estimates of European failure rates, this database could be analysed to give typical failure rates for safety critical systems in Germany but this will involve significant further analysis, beyond this current study.

6 NATIONAL FLEET DATA

6.1 EUROPEAN VEHICLE POPULATION

The Society of Motor Manufacturers and Traders has supplied details of all vehicles in use in the UK by year of registration. Figure 44 shows this data for the years covered by the breakdown and leasing fleet data. This survey is carried out annually hence a separate line represents each year of the survey, however figures for 1999 are as yet unavailable.



The lease vehicle fleet surveyed represents approximately 0.25% of the total United Kingdom vehicle fleet. The breakdown data supplied cannot be analysed to show how many vehicles each member owns for each year, because there is no way to uniquely identify vehicles in the database. However, the number of members of the breakdown service analysed is known for each of the survey years and averages two million members for each year, or approximately 10% of the total UK vehicle fleet, if it is assumed that each member has one vehicle.

Table 10 shows a breakdown of the number of passenger vehicles in use for some Western European Member States.

Country	Year	Total Passenger Vehicles (million)	Traffic Volume Passenger Cars (million vehicle kilometres)	Average Annual Distance (km per year)
Belgium	1995	4.24	91,158	14,662
	1996	4.31	92,416	14,627
	1997	4.37	94,033	14,676
France	1995	25.10	351,000	14,0007
	1996	25.50	364,000	14,000
	1997	25.90	370,000	14,000
Germany	1995	40.40	514,900 (e)	12,700
	1996	40.99	519,100 (e)	12,400
	1997	41.37	524,800 (e)	12,600
Italy	1995	30.00	187,056	10,467
	1996	30.60	190,926	10,539
	1997	31.00	48,770	10,594
Netherlands	1995	5.58	89094	16,560
	1996	5.66	89973	16,270
	1997	5.81	89661	16,550
Sweden	1995	3.63	56279	15,501
	1996	3.65	56571	15,478
	1997	3.70	56596	15,285
Spain	1995	14.21	107994	10,000
	1996	14.75	112895	10,000
	1997	15.30	149412	10,000
Switzerland	1995	3.23	43,794 (e)	13,562
	1996	3.27	44,000	13,463
	1997	3.32	44,500 (e)	13,390
UK	1995	20.51	353,200	15,000
	1996	21.17	362,400	14,400
	1997	21.88	367,800	---

Table 10 – Number of passenger vehicles in use

The UK represents the fourth highest number of vehicles in use for Western Europe with Germany, Italy and France respectively occupying the higher rankings. The UK also represents the third highest average annual distance covered.

6.2 VEHICLE USEAGE

The average distances covered for both fault data sets can be estimated from available information. The lease vehicle fleet covered an average annual distance of 43,091 kilometres for the four years of data analysed. Details of distance covered by members of the breakdown service is not known, however since 10% of the whole UK vehicle fleet is covered by the service an estimate can be made based on that covered by the whole fleet.

Table 10, on the previous page, also shows the total distance covered by the vehicle population and the average annual distance covered by each vehicle. The UK average is 14,700 kilometres per year and can be assumed to be representative of the typical distance covered by members of the breakdown service. The lease vehicle fleet therefore represents almost three times the average annual distance covered.

6.3 ESTIMATED UK FAILURE RATES

This section looks again at the component systems already identified as relevant, or used for comparison with an electronically controlled system. Failure rates per billion vehicle kilometres, derived from the lease database, can be used in combination with the total distance covered in the UK to give an estimate of the number of faults in the UK fleet. This assumes that the lease company fleet is representative of the whole UK fleet, when in fact it is likely to be much younger as most of their vehicles are under four years old, although they travel higher than average annual distances. Therefore, an estimate based upon this method will fairly represent faults that are related to the distance travelled, but substantially under represent faults that are related to age.

A second estimate of UK failures can be derived from the proportion of all vehicles on the lease database that are affected by a particular fault. This proportion can then be applied directly to the number of vehicles registered in the UK to derive an estimate of the number of UK faults. As stated above the lease fleet is younger than the UK average but travels higher distances. This means that for this estimating method faults related to distance travelled will be over represented and faults related to age will be under represented. It is not known whether electronic faults are more common on old low mileage vehicles or young high mileage vehicles so it is not possible to determine which estimating method is most accurate. However, it is likely that the true answer will lie somewhere between the two estimates.

Table 11 shows the total estimated number of faults in the UK for a range of components, using both estimating methods described above.

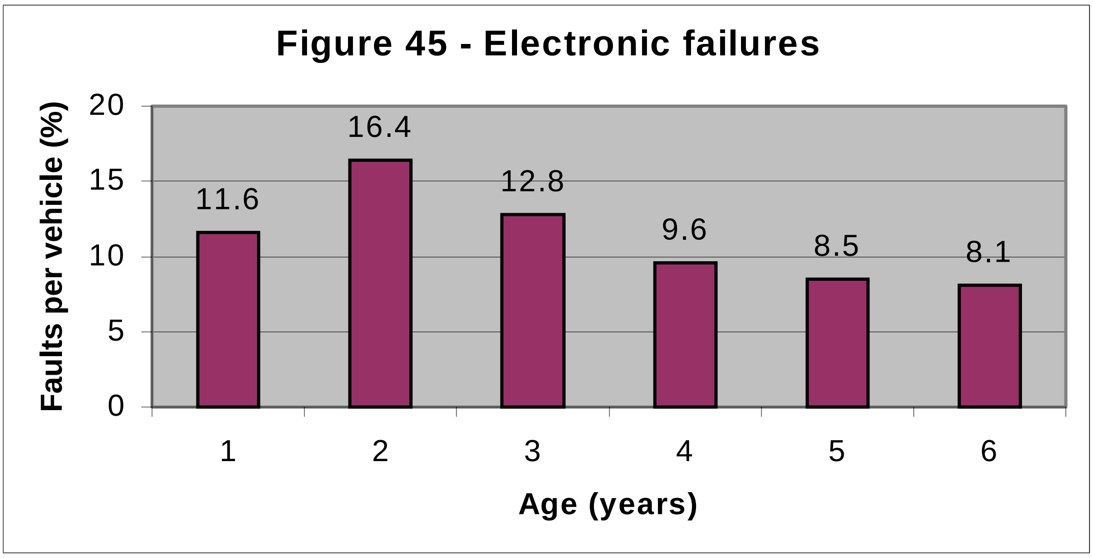
Component	**Annual UK faults (based on faults per vehicle km travelled)**	**Annual UK faults (based on faults per vehicle)**
ABS control unit and sensors	99,955	288,000
Airbag	79,601	225,000
Seatbelt	146,187	413,215

Table 11 – Estimated safety critical faults in the UK

Although the number of likely faults with electronically controlled systems is currently lower than with those components already covered under the periodic inspection, the future trend is likely to be upward based on the assumption that such components will become increasingly common.

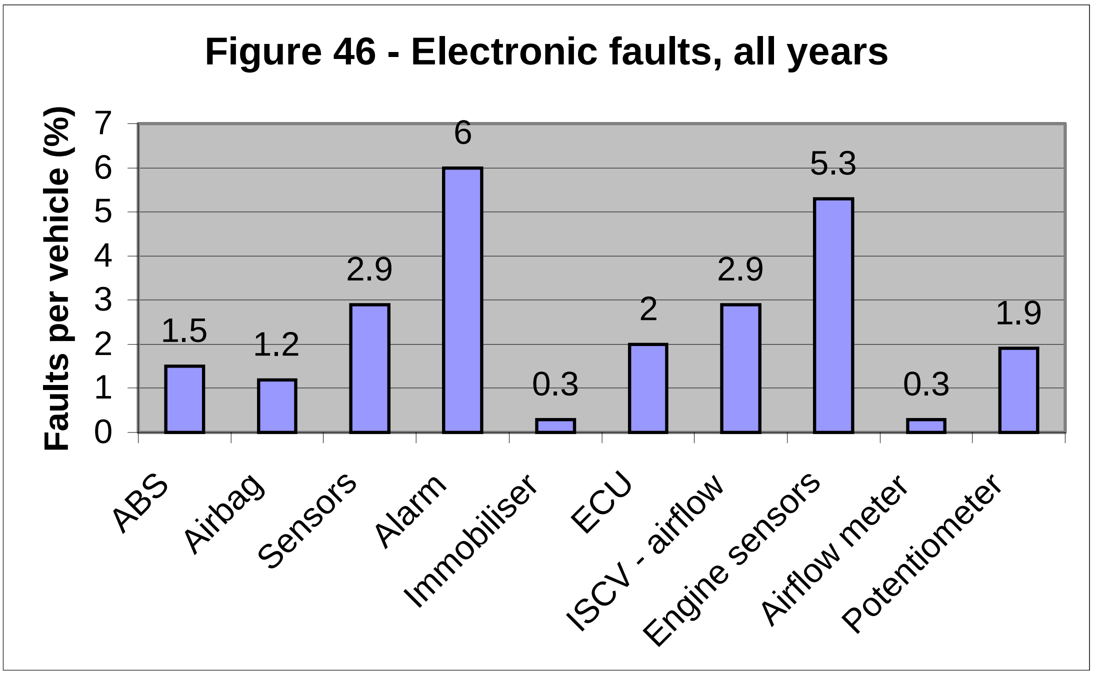
7 SUMMARY ANALYSIS

The following summary analysis examines the relationship between failure rates and age of vehicle. In addition, some data has been included for German vehicles. The data provided by the vehicle leasing company can be analysed for all types of electronic system failure. Figure 45 shows the percentage faults per vehicle plotted against the vehicle age at the time the fault occurred. In this example, we have shown the age of the vehicle up to 6 years old.



The graph shows that 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.

This data can be analysed in more detail by splitting the data into different categories such as sensors, ABS and ECU. Figure 46 shows the number of failures per vehicle plotted against fault category over the full period of the study, 1995 to 1999.



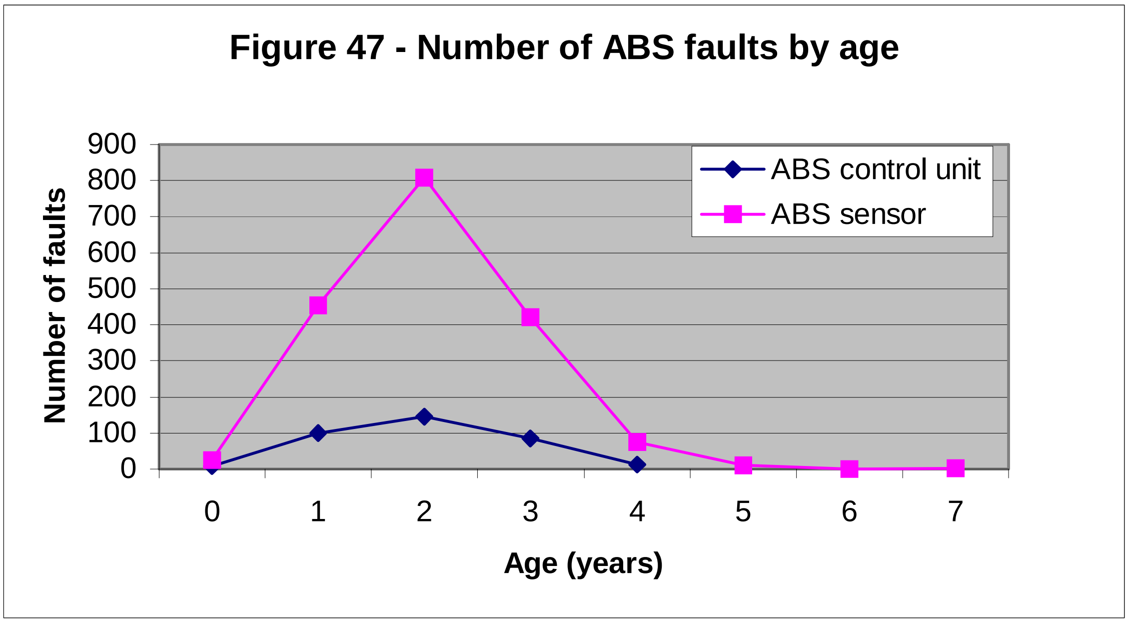
The graph shows that 6% of vehicles experienced alarm system faults and 5.3% experienced engine sensor faults. Airbags and ABS also contributed significantly with 1.2% of vehicles experiencing airbag faults and 1.5% experiencing ABS faults.

The major contributor to the total number of faults was the alarm system, which produced 24.7% of the total. This was followed by engine sensors, which contributed 21.7%, and other sensors that contributed 11.9%. The total numbers of faults for airbags and ABS were 2,146 and 1,627 respectively.

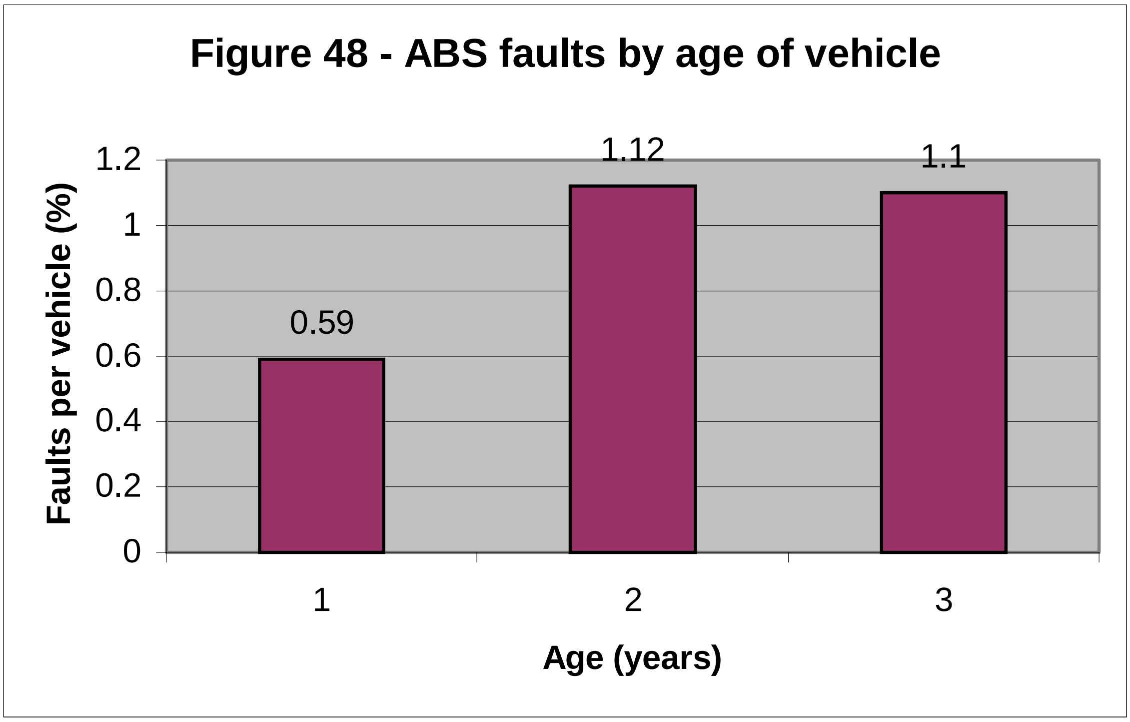
The systems considered to be safety critical, either because they influence the performance of the vehicle during an impact or their failure to operate correctly could indirectly result in an accident occurring, have been described in several different previous sections in this report. The main systems of interest identified in the data are ABS and airbags. These are considered to have the greatest potential for investigation at annual test. The following sections will draw together information regarding these systems, from each of the preceding sections in which they can be found. This will include information from both the breakdown company and leasing company databases.

7.1 ANTI-LOCK BRAKES

As covered in section 4.6, ABS faults account for 0.6% of all brake faults and affect 1.5% of all vehicles in the lease database. Figure 47 shows the breakdown of ABS faults between sensors and control units, broken down by the age at which the fault occurred.



It is clear that ABS sensors are between five and six times more likely to develop a fault than ABS control units at their highest incidence at two years old. ABS sensor faults can be mechanical such as clogged toothed wheels or incorrect gap between the sensor and toothed wheel. Of all braking faults covered by the lease database, ABS sensor renewals appears 21st out of 67 fault codes. Failure rates have been calculated for the ABS control unit and ABS sensor showing typical repairs per billion vehicle kilometres (BVK) as follows: ABS control unit 44.98 per BVK, ABS sensor 231.80 per BVK. Figure 48 shows the percentage faults per vehicle plotted against the age of the vehicle.



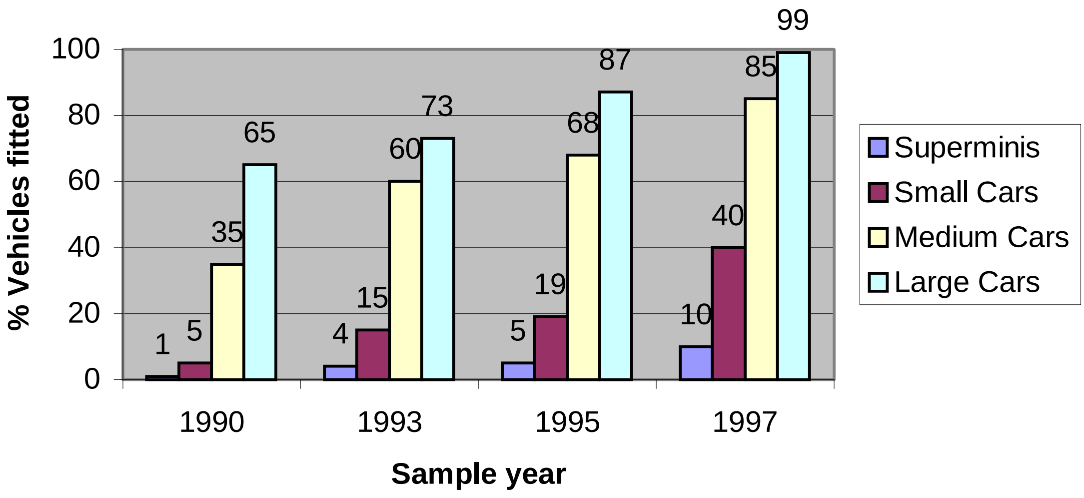
The graph shows a significant rise in the number of faults per vehicle between years 1 and 2 whilst 3 year old vehicles appear to have a similar number of faults to 2 year old vehicles.

Both databases show similar trends with regard to age distribution and type of fault. This in itself warrants investigation at annual inspection since a faulty sensor has the potential to greatly influence the behaviour of the vehicle. Depending on the type of ABS system fitted, the most likely result of the loss of a sensor is simply that the ABS will become inoperative and the wheels will lock during emergency braking, which in turn results in a loss of steering control, instability and can mean a longer stopping distance. However, there is a small chance that for some systems it could result in loss of servo assistance and if the ABS replaces a pressure limiting / reduction valve for the rear brakes, an increased risk of instability due to locking the rear wheels under moderate to harsh braking.

The number of vehicles fitted with ABS is known to have increased significantly in recent years as fitment has been widened to lower specification models. The number of vehicles over four years old fitted with ABS is still likely to be small in comparison with those up to three years old due to the age distribution of the lease fleet. The shape of the curve in Figure 47 is unlikely to change drastically in the next few years for the lease fleet, however the number of faults will increase substantially.

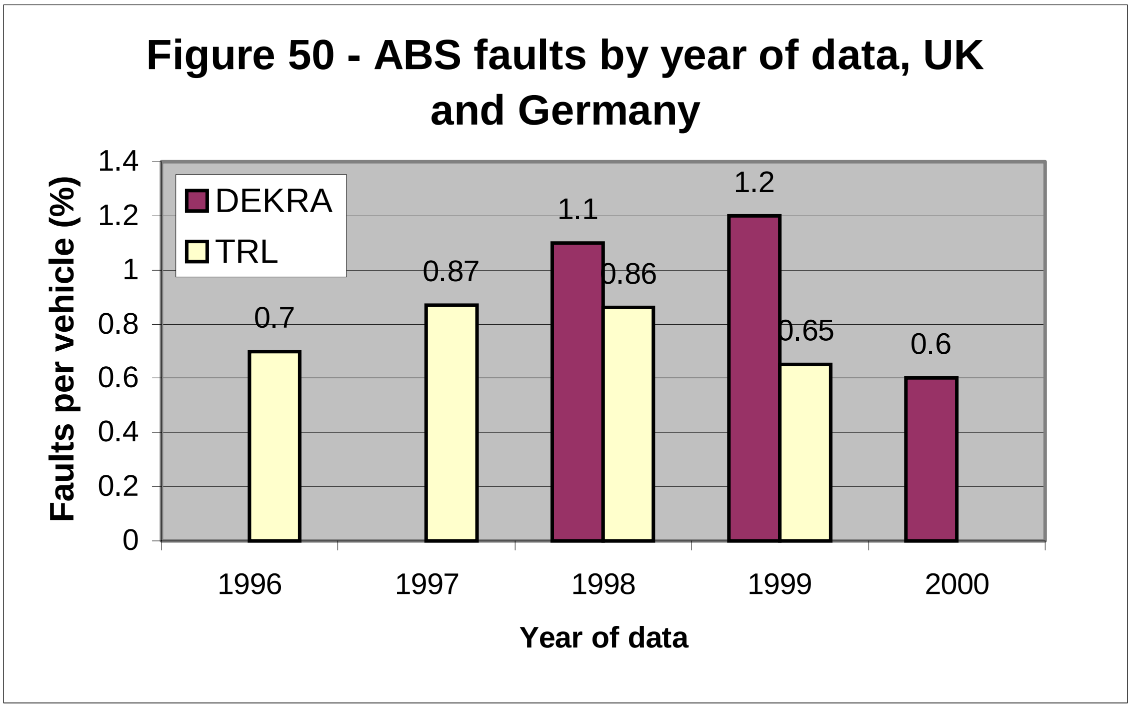
Fitment rates for ABS in the UK are unknown, however in Germany data has been collected that supports the view that ABS is becoming increasingly common across the vehicle fleet in all but the smallest of cars. The following Figure 49 shows the percentage of new vehicles in Germany, by size, fitted with ABS.

Figure 49 - ABS fitment rate - Germany



Large cars are now, almost without exception, fitted with ABS as standard. The rate of increase in the fitment of ABS amongst the medium and small cars will eventually lead to as many cars in these groups having ABS as the large cars. Only in the supermini class are cars still lacking from widespread fitting of ABS.

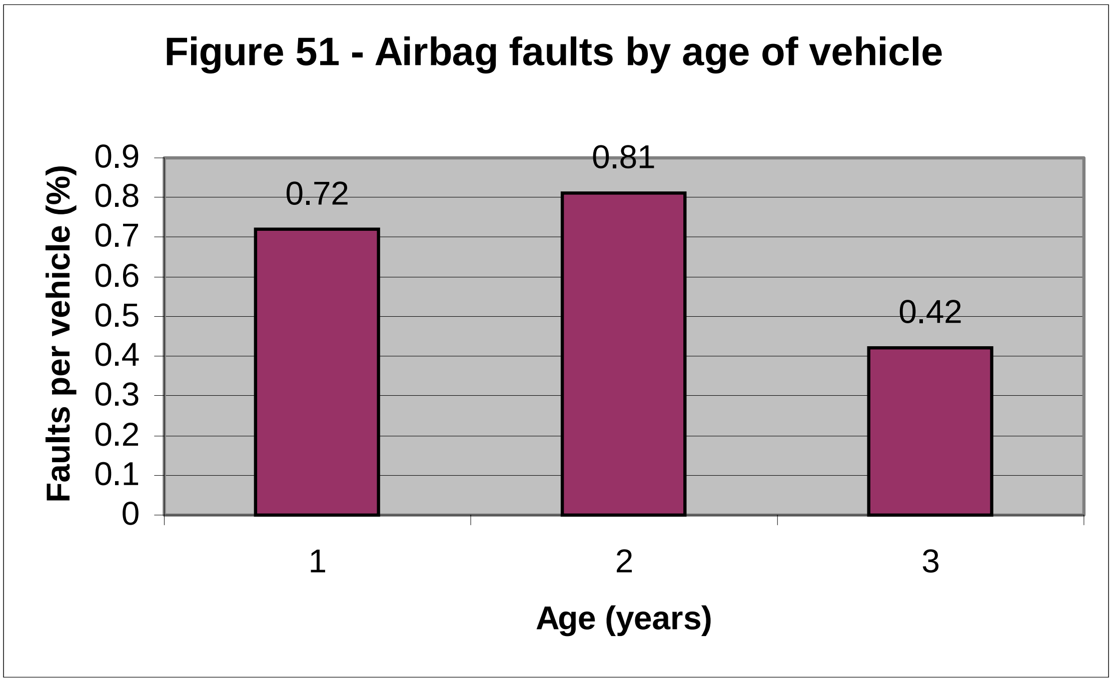
It is also possible to plot the faults per vehicle for ABS against the year of the data for both the UK and German results. Figure 50 shows the pattern of faults over the period 1996 to 2000.



The UK data shows a slight increase in the faults per vehicle between 1996 and 1997. There is little change in 1998 and a small drop in the number of faults in 1999. For comparison, the German data follows a similar pattern but one year out of phase. This may be due to the different fitment rates between the UK and Germany for ABS. In general terms, the numbers of faults found in UK vehicles was higher than those found in Germany. This may be due to differences in the data. As an example, the total expected number of ABS faults in 1999 for the UK was between 99,955 and 288,000 (depending on estimating method) whilst in Germany there were about 280,000 (based on 539 faults per BVK).

7.2 AIRBAGS

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. Figure 51 shows the percentage number of faults per vehicle plotted against vehicle age which varied from 1 to 3 years.



The results show that 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.

The breakdown database contains information on 723 airbag faults. This means that approximately 0.04% of members cars were affected by airbag problems. In contrast, 1.2% of the vehicles in the lease company fleet were affected by airbag faults. The reason for this major difference is likely to be twofold. Firstly there is a possibility that when the airbag warning light appears in a person's car they do not consider it serious enough to warrant stopping the car and calling the breakdown service and simply take the car to a garage instead. Secondly, the vehicle population in the breakdown data is on average considerably older than that of the lease data. It is highly likely that this means that a much smaller proportion of the vehicles in the breakdown data is fitted with airbags. Although firm conclusions cannot be drawn without further data on the number of vehicles fitted with airbags in each population, these figures would tend to add weight to the argument that the reliability of airbags is a growing problem.

The lease database does not detail what kind of repair was required so functionality of the airbag system at the time of repair is unknown. Both the breakdown data and the lease data show a trend towards early faults with airbag systems. However, as previously stated, the number of vehicles fitted with airbags in each database is unknown, and the likely trend towards more advanced safety systems will lead to the number of faults increasing with age as the systems become more common in older vehicles.

As covered in section 4.8, airbag faults account for 1,627 repairs. Figure 52 shows repairs and replacements to the airbag system.

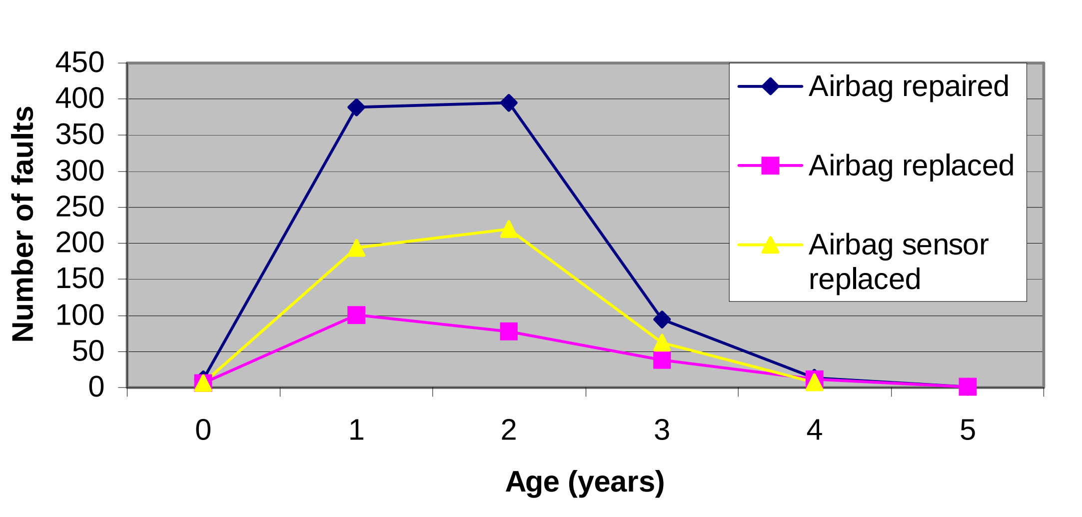
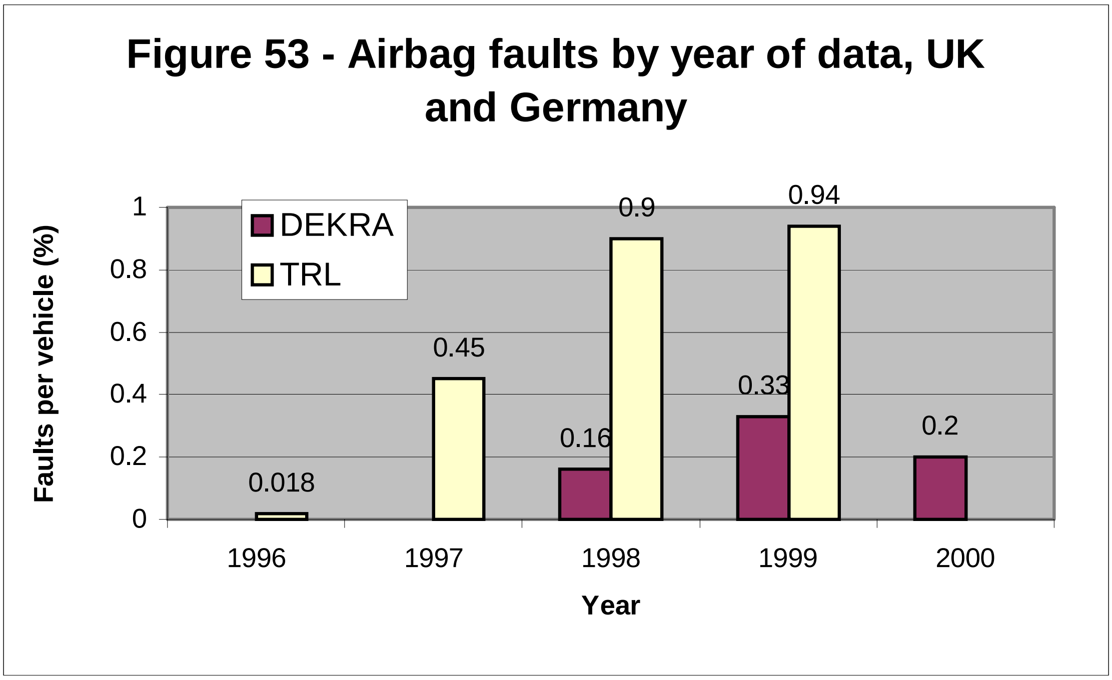


Figure 52 - Number of airbag faults by age

Significant numbers of faults were found during the first two years that gives rise to concern over the reliability of airbags. The faults included airbags and sensors being completely replaced. The exact cause of the faults is not available from the data and a more detailed study of airbag system failures would be worth carrying out.

For the lease company data, an airbag failure rate of 220 per BVK has been calculated. This compares to 405 per BVK for seatbelts. Although the exact functionality of the airbag as a result of each fault is not known, it is likely that a defect sufficient to operate the airbag warning light is likely to result in a failure to operate the airbag in the event of an accident. This would have a serious adverse effect on the injury outcome for the occupant and there is also the possibility that false impact detection could cause an injury where no accident would otherwise have occurred. In addition to this, it is possible, if not likely, that if a defect does not result in the operation of the warning light it will remain undetected. Considering the current failure rate of airbag systems in the context of a comparison with seatbelts, the problems described above and a rapidly expanding number of systems in use suggest that the reliability of airbags is an increasingly important issue. It is likely that a test of its function at periodic inspection will have a positive safety benefit, if an effective test can be created.

As well as the data from the UK leasing company, DEKRA in Germany has also produced some data on electronic system failure rates. Figure 53 shows the percentage number of faults per vehicle plotted against the year of the data for both sets of data.



The UK data shows an increasing number of faults with year beginning to flatten during 1998 and 1999. There is no clear trend for the German data over the period 1998 to 2000. It is interesting that the UK data shows considerably more faults than the German data but this may be due to the German sample being different. However, the total numbers of failures are high when the populations of vehicles in use are considered. If 0.94% of the vehicles in the UK experienced airbag faults during 1999 this would represent a total of about 225,000 faults. Similarly, the total number of faults in Germany for the same year would represent about 142,000 faults. As before, we need to obtain more data over a longer time period and from more countries in order to identify any significant trends. Several attempts were made to predict trends in the data but none of these produced a statistically sound result.

7.3 SYSTEM FAILURES

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 de 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. As examples, we have seen the development of ABS from relatively simple systems to complex multi-wheel systems including traction control. In the next few years, braking systems will 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.

Traffic growth is expected to rise by about 5% 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.

In the near future current systems will be further developed and will become more sophisticated. For example, airbag systems will develop into complex arrays of bags for both front and side protection using sophisticated algorithms to optimise the deployment of the systems. 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 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.

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 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. This suggests that approximately 24% of the entire UK sample will have experienced electronic faults.

A similar analysis for airbag faults showed that a total of 1,627 faults were recorded. Approximately 1.2% of the UK sample experienced airbag faults. 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. Approximately 1.5% of the UK sample experienced ABS faults. It should also be remembered that the fitment rate of ABS was also increasing during the period of this study.

If the failure rates per vehicle for airbags and ABS were applicable for the entire national vehicle fleet then using the 1999-year as an example there would have been the following numbers of faults:

- 225,000 airbag faults in the UK and 142,000 in Germany
- 288,000 ABS faults in the UK and 280,000 in Germany

8 IMPLICATIONS FOR PERIODIC TESTING

The use, and increasing complexity of, electronically controlled systems on vehicles means there is an ever increasing need to ensure that those systems which influence the vehicle's behaviour both under normal driving conditions and in the event of an accident are functioning correctly. With the wide range of systems available to control systems such as ABS, supplementary restraints and drive train components there is an issue concerning the compatibility of manufacturers' systems. Either periodic inspection centres will be required to purchase and maintain a range of interrogation systems or some form of standardisation will be needed to keep the likely cost of carrying out functional tests to an acceptable level.

Standardisation is already a well-recognised issue in terms of vehicle electronics from a telematics point of view. Increasingly manufacturers are likely to integrate vehicle systems into a small number of control units covering several control systems for the vehicle. This could present an opportunity to allow systems to be analysed through a central CAN-bus that would hold an up to date record of system status.

Without standardisation the cost implications of testing a number of safety critical systems through the use of individual pieces of equipment for each suppliers' systems may make the corresponding increase in the cost of carrying out an annual inspection too high in the long term. Short term, the affects are less likely to be a problem from the evidence so far fault code memories offer an important function for annual inspection.

The availability of fault code memories may enable simple test procedures to be developed to allow the interrogation of safety critical system components. The results from the cost-benefit analysis will assist in deciding what method will be most suitable.

Safety critical systems are a special case and merit the inclusion in annual testing from a safety point of view alone. It may be necessary to link the level of safety criticality to the test requirements. This can be derived by referring to IEC 61508 (I E C, 1999). This document specifies methods for determining the safety critical nature of systems.

The availability of fault code memories is an important input to annual testing. Most vehicle system manufacturers include some form of diagnostic capability into their systems and it would be relatively simple to provide information for the annual testing procedure.

It is important to consider the cost versus benefits of adding to the current test procedure. However, it is important that safety critical systems should be given a high priority.

9 RECOMMENDATIONS

The work carried out to date has identified a number of recommendations for further work.

1. A long term study of electronic system reliability would be worthwhile. Data needs to be collected annually over at least the next five years.

2. Attempts should be made to find more detailed data particularly relating to specific failure modes.

3. Further studies should include data from a wider range of sources including several European countries.

4. A more detailed analysis of ABS failures will provide a clearer picture of the actual failure modes and possibly provide a means of predicting trends.

5. A more detailed analysis of airbag failures will provide a clearer picture of the actual failure modes and possibly provide a means of predicting trends.

10 CONCLUSIONS

1. The failure of electronically controlled systems makes up a small proportion of all faults identified when compared to service items such as tyres, exhausts and batteries.

2. Of the electronically controlled systems investigated, safety critical components are again a small proportion of the total number of faults.

3. Electronic components tend to fail far less frequently than mechanical components in the same system; for example ABS control unit's compared with ABS pumps/valves etc. However, the failure rate of certain electronically controlled systems is comparable to some mechanical systems considered important enough to be part of the annual inspection regime.

4. The failure of safety critical electronically controlled systems is shown to be when compared with all component failures. However, it is important to put this into context. The failure of electronically controlled safety critical systems is 25 times more frequent (per BVK) than the incidence of injury in a road accident.

5. It is clear from the statistics that it is very rare for such a failure to cause an injury accident but it is also clear that they have the potential to do so. Where a defect does cause an accident the consequences can be very severe.

6. Electronically controlled systems are becoming increasingly relevant to the periodic inspection due to their increasing popularity when compared with the electrical and mechanical systems currently inspected.

7. When considering safety critical systems it can be argued that where a vehicle depends on electronics to provide occupants with increased protection through the use of airbags, pretensioners and ABS for example, then their inclusion in annual inspections is important.

8. It is estimated that between 99,955 and 288,000 vehicles in the UK suffer from ABS faults each year and that between 79,601 and 225,000 vehicles suffer from airbag faults. These estimates are based on the number of repairs carried out per vehicle and the number of repairs per vehicle km travelled. It is likely that before it is repaired the vehicle will be driven some distance on the road.

9. Fault code memories are a useful method of interrogating vehicle systems for faults at periodic inspections. The cost benefit analysis to be carried out will determine the value of this information set against the likely increased cost in carrying out the inspection.

10. The interrogation of fault code memories by Aachen University and others suggests that there are many faults that could remain undetected by the self-diagnostic routine. Such undetected faults will not be included in the above estimates and may be driven substantial distances in this condition.

11. Vehicle electronic systems should be tested as part of the periodic inspection. It is important that all safety critical systems such as ABS and airbag systems should be tested regularly.