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**EUROPEAN/AUSTRALIAN EXPERIENCE WITH
ANTILOCK BRAKING SYSTEMS IN FLEET
SERVICE**

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16. Abstract The objective of this report is to document the experience, that is, performance, reliability, maintainability, etc., that European and Australian owners/operators of commercial vehicles have had with antilock braking systems (ABS's) of European design in actual revenue service. This report provides estimates of the level of usage of ABSs on heavy vehicles, stratified by vehicle type. In addition, NHTSA's program to assess the practicality and reliability of these types of systems has been supported directly by observations on failure rates, service requirements, failure modes, etc.			
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EUROPEAN/AUSTRALIAN EXPERIENCE WITH ANTILOCK BRAKING SYSTEMS IN FLEET SERVICE

Introduction

This document reports on a task (with the above title) contained in contract number DTNH22-85-D-07259 between the National Highway Traffic Safety Administration (NHTSA) and The University of Michigan Transportation Research Institute (UMTRI). The title of the primary contract is "Heavy Truck Braking and Dynamic Stability Support."

The objective of this report is to document the experience, that is, performance, reliability, maintainability, etc., that European and Australian owners/operators of commercial vehicles have had with antilock braking systems (ABS's) of European design in actual revenue service. The report provides estimates of the level of usage of ABS's on heavy vehicles, stratified by vehicle type. In addition, NHTSA's program to assess the practicality and reliability of these types of systems has been supported directly by observations on failure rates, service requirements, failure modes, etc.

An iterative approach has been used by UMTRI to obtain the information sought by NHTSA. This approach is based on the idea that initial estimates of antilock usage and performance can be improved by asking knowledgeable people to (1) comment on a set of initial estimates and (2) provide quantitative data indicating actual fleet experience.

The resulting usage estimates presented here are approximations derived from piecing together various bits of information from several sources. The size of the heavy vehicle fleet and the distribution of ABS's has been ascertained primarily from discussions with manufacturers of ABS's in Europe. In most cases the numbers presented have been confirmed to a reasonable approximation by at least two separate sources. In that sense, the results represent a composite of the informed views of people intimately involved with the production, sales, and use of ABS's.

Data on fleet experiences with ABS's come from two types of sources: one being visits and interviews with several fleets, and the other being large surveys conducted by ABS and vehicle manufacturers. Given the approach used and the lack of a sampling scheme, the accuracy and generality of the results cannot be estimated. Nevertheless, the information obtained provides evidence supporting a reliability estimate on the order of approximately 1 or 2 ABS component failures in 1000 vehicles in one month (where wiring is counted as a component), that is, around 2 to 5 component failures in a fleet of 200 vehicles in a year.

Five consultant/reporters were hired to facilitate the process of gathering information in Europe and Australia. In Germany, the U.K., and France, the consultants served as contact persons and arranged for visits to fleets by a person (the author of this report) from

UMTRI . In Australia and Sweden, the consultants made the fleet contacts alone. Given the differences in languages, laws, culture, and customs regarding heavy vehicles, the consultants' interpretations of the information received were very important in developing an understanding of the "European experience." In all five cases, the consultants provided letter reports (in English) describing their activities and the situations in their countries. Copies of these letter reports have been appended to this report, thereby providing alternative descriptions of the findings obtained.

The main body of this report is comprised of three sections. The first two of these sections present information on (1) the level of usage of ABS systems and (2) the reliability, maintainability, and performance of ABS systems, respectively. A summarizing and concluding section extrapolates the implications of the information gathered to a hypothetical fleet of 200 vehicles equipped with ABS in the USA.

The Level of Usage of ABS

Commercial Vehicles in Service

The potential for installing ABS is of course limited by the number of vehicles in service. One might think that counts of the numbers of air-braked heavy trucks would be readily available in government records or public surveys of some kind, but that is not the case in Europe. As a result, private organizations make estimates of the number of vehicles that are available (or, possibly, registered) for service. The information presented on the total numbers of various classes of vehicle units in service (see Table 1 and Figures 1 and 2) is based primarily upon the estimates of the manufacturers of ABS systems. The estimates indicate that in Western Europe there are approximately 1.5 million heavy trucks (including those designed to tow full trailers) and tractors and 1 million semi- and full trailers in service.

To put these numbers in perspective, in 1982 there were approximately 900,000 truck tractors and 740,000 single-unit heavy trucks in use in the USA. [1]. It is estimated there are approximately 2.5 million trailers in use in the USA. Hence, truck usage in Western Europe is somewhat smaller, but roughly comparable in number to that in the USA.

The number of vehicles in the European countries selected for emphasis in this study (France, Sweden, U.K., and W. Germany) is more than half of the total number of vehicle units existing in Western Europe. Figures 1 and 2 indicate the differences among the emphasized European countries plus Australia. Clearly, Germany, France, and the U.K. dominate the comparison shown with roughly 250,000 trucks and truck tractors and 150,000 trailers in each of these countries.

Table 1. Antilock Braking Systems (ABS) in Service on Air-Braked Trucks (GVWR or GCW \geq 26,400 lbs (12,000 Kg) - Entries in thousands.

Regional Estimates

	Single-Unit Trucks*	Total Trucks & Tractors	Truck Tractors	Semitrailers	Total Trailers	Full Trailers
<i>W. Europe</i>						
Total Number	1110.0	1490.0	380.0	623.0	935.0	312.0
Units with ABS	27.0	67.5	40.5	43.5	52.5	9.0
Expected ABS growth in 1988	13.0	26.0	13.0	15.0	21.0	6.0
<i>Australia</i>						
Total Number	52.0	92.0	40.0	60.0	80.0	20.0
Units with ABS	0.09	1.19	1.1	0.01	0.02	0.01
Expected ABS growth in 1988	0.05	0.55	0.5	0.01	0.02	0.01

Breakdown Comparing Selected Countries in Western Europe

<i>France</i>						
Total Number	203.0	273.0	70.0	94.0	143.0	49.0
Units with ABS	0.1	0.4	0.3	0.5	0.7	0.2
Expected ABS growth in 1988	0.1	0.3	0.2	0.2	0.3	0.1
<i>Sweden</i>						
Total Number	42.0	50.0	8.0	8.0	28.0	20.0
Units with ABS	1.5	2.0	0.5	0.0	0.0	0.0
Expected ABS growth in 1988	0.4	0.6	0.2	0.0	0.0	0.0
<i>United Kingdom</i>						
Total Number	155.0	235.0	80.0	160.0	175.0	15.0
Units with ABS	3.2	23.2	20.0	38.0	39.0	1.0
Expected ABS growth in 1988	0.7	4.1	3.4	11.0	12.4	1.4
<i>W. Germany</i>						
Total Number	270.0	330.0	60.0	60.0	180.0	120.0
Units with ABS	20.0	35.0	15.0	4.0	10.0	6.0
Expected ABS growth in 1988	9.0	16.0	7.0	3.0	7.0	4.0

*Does not include medium trucks with GVW \leq 26,400 lbs (12,000 Kg.) Includes trucks designed to tow full trailers. In the USA, such vehicles generally have hydraulically actuated brakes. We wish to consider vehicles with pneumatically actuated brakes in this column.

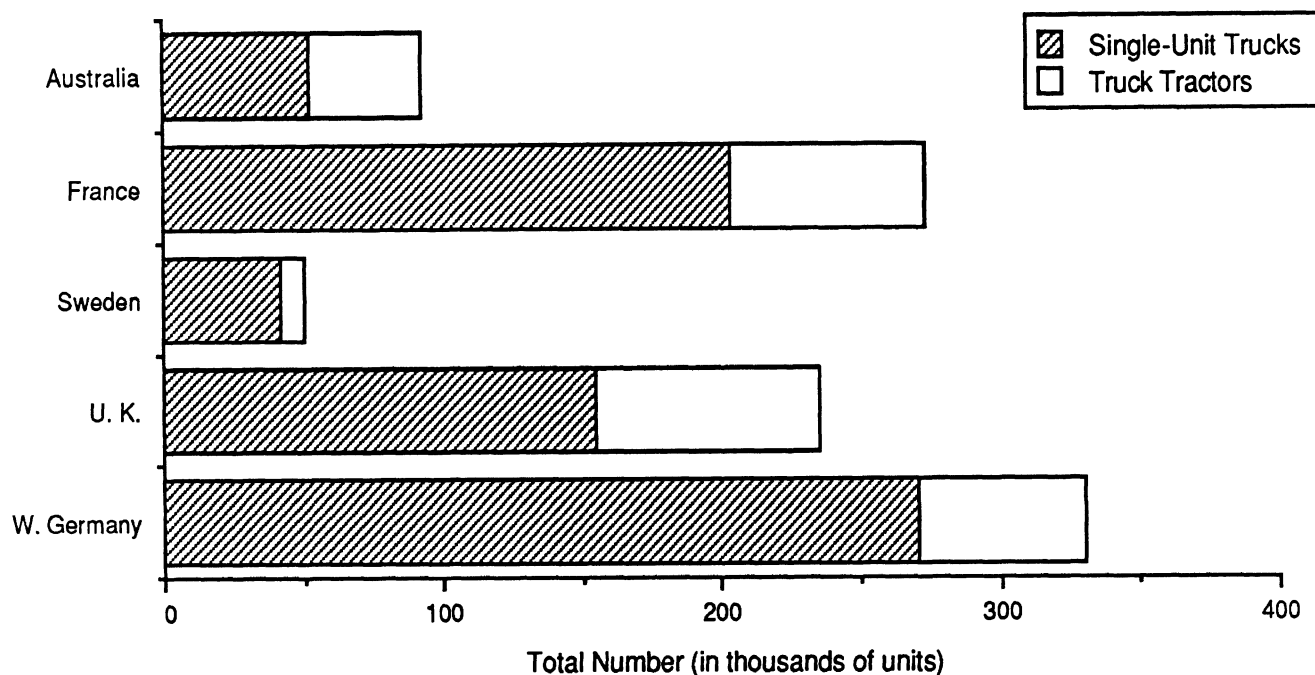
Table 1. (Continued)

Breakdown Comparing Selected Countries with the Remainder of Western Europe

	Single-Unit Trucks*	Total Trucks & Tractors	Truck Tractors	Semitrailers	Total Trailers	Full Trailers
<i>Total for France, Sweden, United Kingdom and West Germany</i>						
Total Number	670.0	890.0	220.0	324.0	528.0	204.0
Units with ABS	24.8	60.6	35.8	42.5	49.7	7.2
Expected ABS growth in 1988	10.2	21.0	10.8	14.2	19.7	5.5
<i>Total for all other European countries **</i>						
Total Number	440.0	600.0	160.0	299.0	407.0	108.0
Units with ABS	2.2	6.9	4.7	1.0	2.8	1.8
Expected ABS growth in 1988	2.8	5.0	2.2	0.8	1.3	0.5

**Other countries include Italy, Austria, Switzerland, Netherlands, Spain, Portugal, Belgium, Finland, Norway, and Denmark.

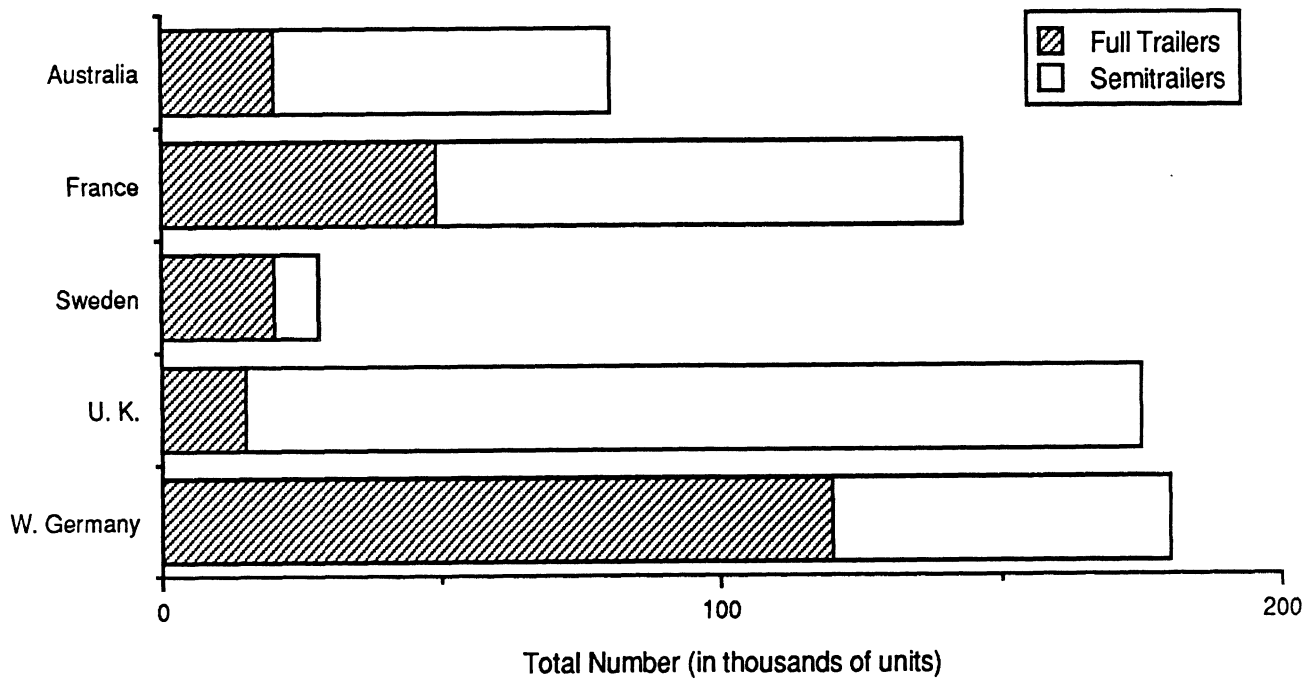
Total Number of Trucks and Tractors in Service in 1987.
GVWR \geq 26,400 lb (12,000 Kg).



Estimates from discussions with ABS manufacturers

Figure 1. Total number of trucks and tractors in service in 1987.
GVWR \geq 26,400 lb (12,000 Kg).

Total Number of Trailers in Service in 1987.
GVWR \geq 26,400 lb (12,000 Kg).



Estimates from discussions with ABS manufacturers

Figure 2. Total number of trailers in service in 1987.
GVWR \geq 26,400 lb (12,000 Kg).

The vehicles used in Europe differ from those used in the U.S.A. and the distribution of trailer types also differs from country to country in Europe. Heavy trucks in Europe consist mainly of three types: straight trucks, straight trucks that have been type-approved to pull full trailers, and tractor semitrailer units. In Europe one does not simply attach a pintle hitch to a truck in order to pull a trailer — type approval is necessary. Furthermore, vehicle combinations are routinely limited to no more than 5 axles and only to 2 load carrying compartments. Tractor semitrailers usually consist of 2 axle tractors pulling 3 axle semitrailers, although units like the American 3-S2 (3 axle tractor with a tandem axle semitrailer) are not uncommon. The truck full trailer combinations seem to be fairly evenly divided between combinations with 2 or 3 axle full trailers, although the Europeans appear to favor 2 axle tractors because they do not like the cost and weight of an extra drive axle. Lift axles are frequently used and axles are lifted when loading permits it.

The major differences among European countries are in their preferences for truck full trailers or semitrailers. Figure 2 illustrates the extent to which truckers in the U.K., France, and Australia prefer semitrailers over full trailers. In Germany and Sweden the preferences are reversed with a predominance of full trailers in those countries.

The situation in Australia is slightly different from that in Europe. They generally allow 6 axle combinations, with 3 axle tractors pulling 3 axle semitrailers being a fairly common configuration. Also, they are starting to permit B-trains (tractor-semitrailer-semitrailer combinations).

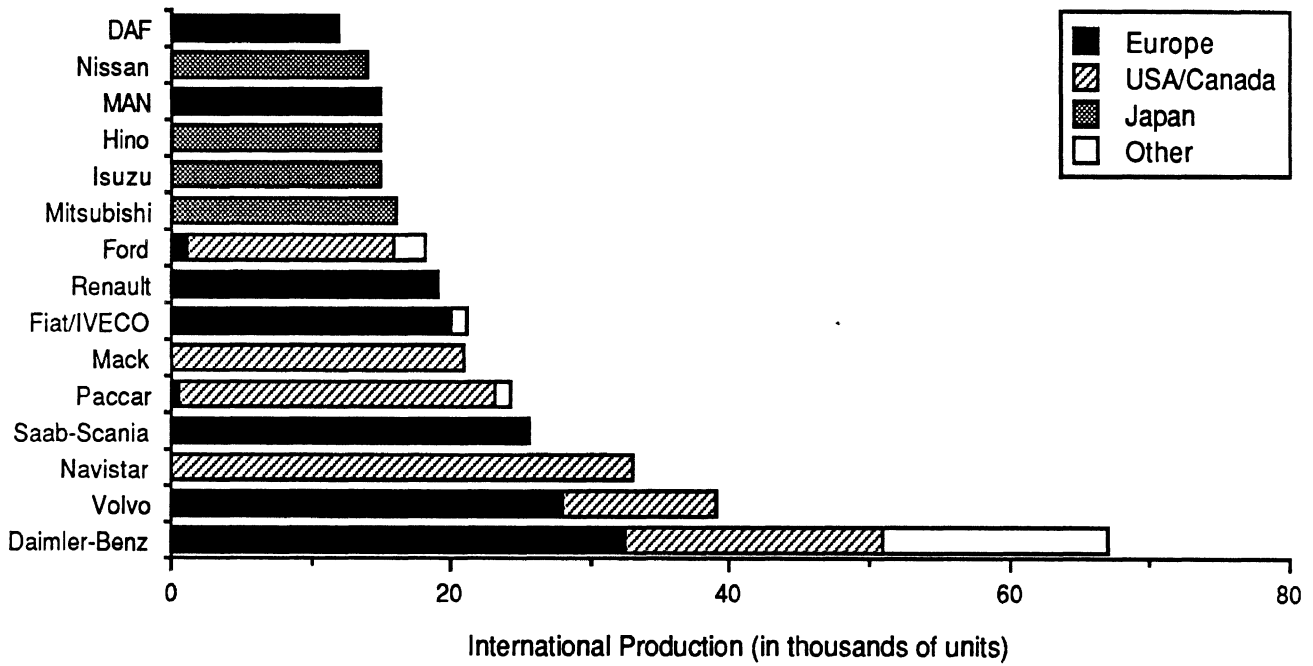
Vehicle Production

The material above views every vehicle as a potential candidate for an ABS system, which is fine from a usage perspective. However, from a market prospective in which retrofits are considered uneconomical, it is vehicle production that defines the market. In times of rapidly increasing use of ABS (such as now in Europe), production numbers indicate the immediate potential for ABS installations without including the irrelevant vehicles included in estimate of the number of vehicles in service.

Production numbers also provide interesting insights into the "European situation" in relation to the rest of the world (see Figure 3). For heavy trucks of more than 15 metric tons (that would be, more than 33,000 lbs or class 8 trucks in the USA), Figure 3 shows that there are many comparably sized truck manufacturing companies in the world. However, Daimler-Benz is by far the largest when Freightliner in the USA and the facilities in Brazil and elsewhere are included. Similarly, Volvo is the second largest when Volvo-GM Heavy Truck Corp. in the USA is included.

The information presented in Figure 3 has been used to construct a comparison among production totals for USA/Canada, Europe, and Japan (see Figure 4). As shown, Europe has the largest production of class 8 heavy trucks; however, approximately 40 to 50 percent

International Production of Major Manufacturers (1986)
Trucks of 15 Tonnes and more Gross Vehicle Weight

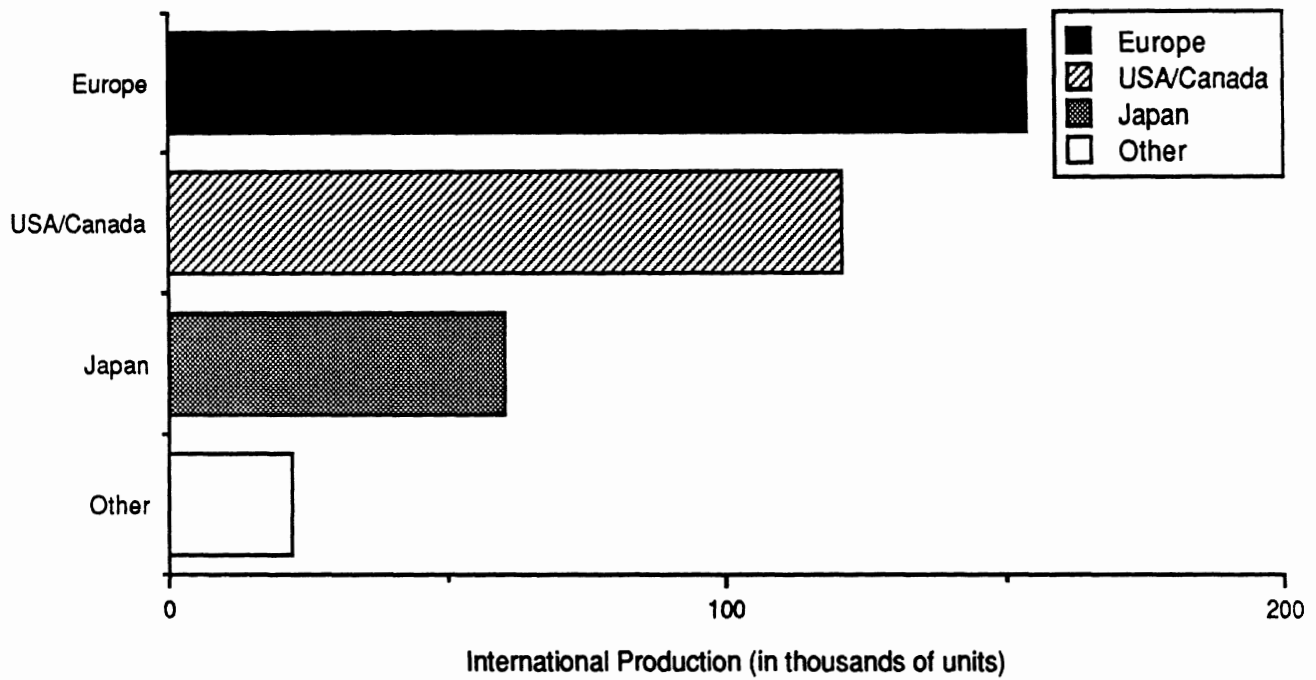


Source : Daimler-Benz

Note : Estimates shown for U.S. production are somewhat higher than those available from U.S. information sources.

Figure 3. International production of major manufacturers (1986).
Trucks of 15 tonnes or more gross vehicle weight.

International Production of Major Regions (1986)
Trucks of 15 Tonnes and more Gross Vehicle Weight



Source : Daimler-Benz
See note on Figure 3.

Figure 4. International production of major regions (1986).
Trucks of 15 tonnes or more gross vehicle weight.

of that production is exported outside of Europe. This makes production numbers from European vehicle manufacturers difficult to interpret with regard to the internal situation in Europe. Furthermore, Volvo and Scania export nearly 92 percent of the heavy trucks that they produce in Sweden to customers outside of Sweden. Nevertheless, the production figures are another indication that the heavy truck population in Western Europe is comparable to that in the USA.

NHTSA is also interested in the use of ABS on other vehicles over 10,000 lbs GVW. Figures 5 and 6 present production information on vehicles from 6 to 15 tonnes (13,200 lbs to 33,000 lbs). That range of GVW was used because those data were available for this study. There does not seem to be any consistency in load ranges used in presenting information from country to country or manufacturer to manufacturer. The range of loaded weight from 12 to 15 tonnes generally corresponds to vehicles in Class 7 in the USA. In the USA essentially all heavy truck tractors and most Class 7 and 8 single-unit trucks have pneumatically actuated brakes. Smaller trucks tend to have hydraulically actuated brakes. This is not necessarily the case in Europe. For example, almost all vehicles over 6 tonnes and produced by Daimler-Benz in Europe have air actuated brakes.

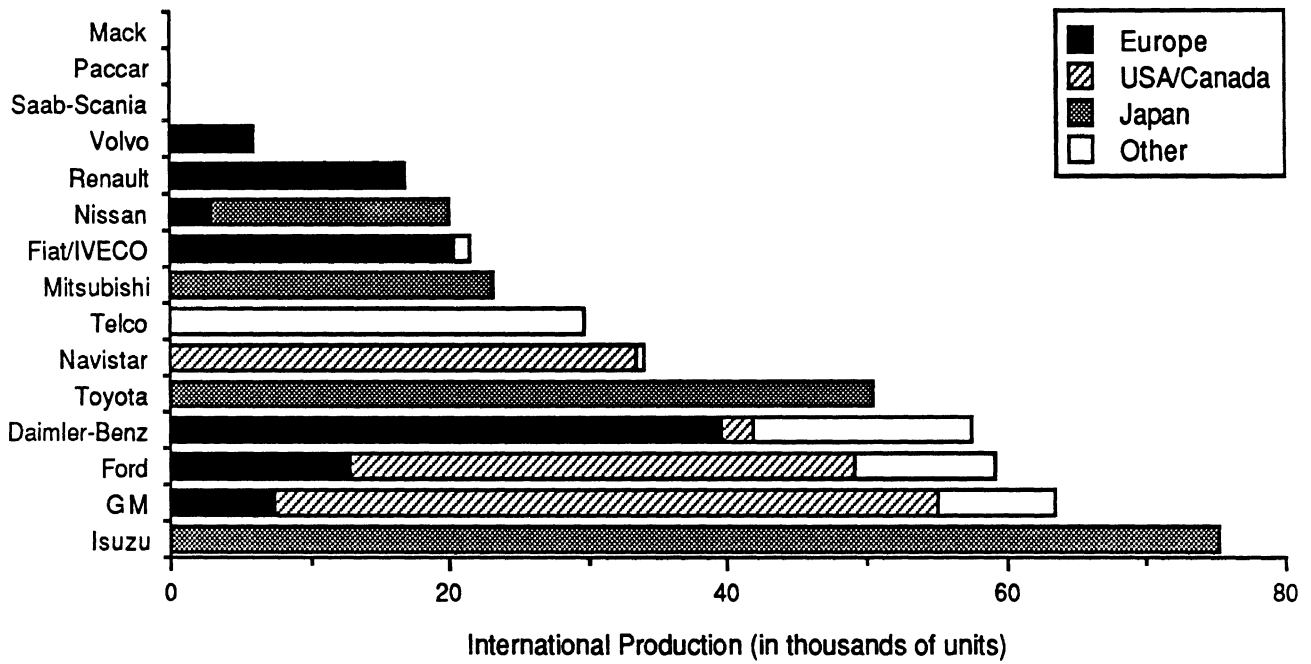
As shown in Figure 6, the Japanese manufacturers lead in the numbers of lighter trucks produced in the world. If the total production of vehicles over 6 tonnes were to be examined, which is equivalent to combining the bar graphs from Figures 4 and 6, one would find that commercial vehicle production is nearly equal in the USA/Canada, Europe, and Japan and in a year each area produces approximately 300,000 trucks over 6 tons.

Although lighter trucks are a potential market for ABS, that market has not been served. Currently, the European approach is to concentrate on the heavier vehicles with GVW's over 9 tonnes. Legislative initiatives are directed at the heavier trucks and buses. According to ABS manufacturers and personnel at Daimler-Benz, there are almost no ABS systems on the lighter trucks in Europe.

Furthermore, there are likely to be considerable differences in ABS for the lighter vehicles because of the differences in the types of braking systems used by various manufacturers. In Japan, the manufacturers use air over hydraulic systems. In Europe, Daimler-Benz uses full air but RVI (Renault Industrial Vehicles), Volvo, and IVECO use air over hydraulic or hydraulic systems. In contrast, vehicles in this general weight range in the USA have hydraulic brakes.

Given the lack of ABS installations on the lighter vehicles, the differences in their types of braking systems, and the projection that heavy trucks are going to be emphasized in the next 2 or 3 years, the remainder of this report will address ABS on vehicles over 12 tons, that is, vehicles comparable in weight to class 7 and 8 vehicles in the USA.

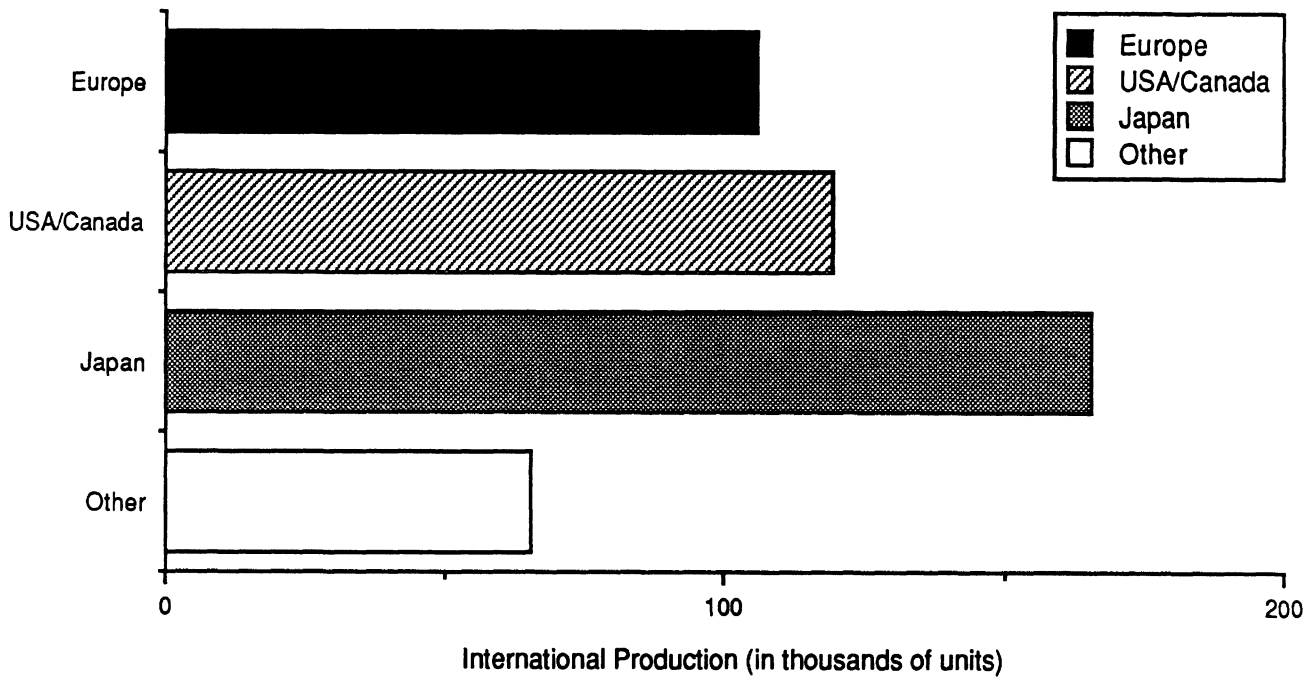
International Production of Major Manufacturers (1986)
Trucks of 6 to 15 Tonnes of Gross Vehicle Weight



Source : Daimler-Benz
See note on Figure 3.

Figure 5. International production of major manufacturers (1986).
Trucks of 6 to 15 tonnes of gross vehicle weight.

International Production of Major Regions (1986)
Trucks of 6 to 15 Tonnes of Gross Vehicle Weight



Source : Daimler-Benz

See note on Figure 3.

Figure 6. International production of major regions (1986).
Trucks of 6 to 15 tonnes of gross vehicle weight.

ABS Installations

Table 1 contains estimates of the number of ABS systems installed on heavy trucks in various parts of Europe and Australia. Examinations of these numbers show that the largest numbers of ABS installations are in the United Kingdom and West Germany. Even as a percentage of the total number of vehicles in service, ABS usage is much greater in Germany and the UK than in the remainder of Europe or Australia.

The information contained in Table 1 on ABS installations for Australia, France, Sweden, UK, and W. Germany is presented in bar graphs in Figures 7 and 8. These figures illustrate a predominance of the number of semitrailer installations in the UK and the comparatively large numbers of installations in trucks and truck tractors in W. Germany and the UK. Although France has approximately the same number of trucks as either Germany or the UK, there are very few ABS installations in France. Australia and Sweden have small truck fleets relative to those of the other countries, but they have more ABS installations on trucks and truck tractors than France does. France appears to be representative of the other countries in Europe which have very few ABS systems compared to the UK and West Germany.

When the estimates of ABS installations are ratioed to the number of vehicles in service in each country, one finds that almost 25 percent of the tractors in West Germany and 25 percent of the tractors and semitrailers in the UK are equipped with ABS (see Figure 9). In the countries considered, less than 10 percent of the various vehicle combinations are equipped with ABS. It is believed that uncertainties in gathering these estimates may have led to a certain amount of overestimating because ABS-equipped vehicles might have been exported even though the systems were installed in a European country. Also, the division between (a) single-unit trucks and tractors and (b) semitrailers and full trailers was not always clear, since this information was combined in much of the information available. Nevertheless, it is reasonable to conclude that the percentages obtained indicate a substantial usage of ABS systems on heavy duty tractors and semitrailers only in Germany and the UK as of the end of 1987.

ABS Population by Manufacturer

There are four companies that have manufactured the ABS's reported here. The numbers of installations in various types of vehicle units appear as entries in Table 2 and these results are illustrated by bar graphs in Figures 10 and 11. WABCO and Grau-Girling are first and second in the numbers of installations with WABCO having more than 60,000 installations and Grau-Girling having more than 50,000 installations.

Inspection of Figure 10 indicates that the ABS manufacturers tend to install their systems in different proportions among the various types of heavy vehicle units. Each

Antilock Braking Systems (ABS) in Service in 1987.
Trucks and Tractors with GVWR \geq 26,400 lb (12,000 Kg).

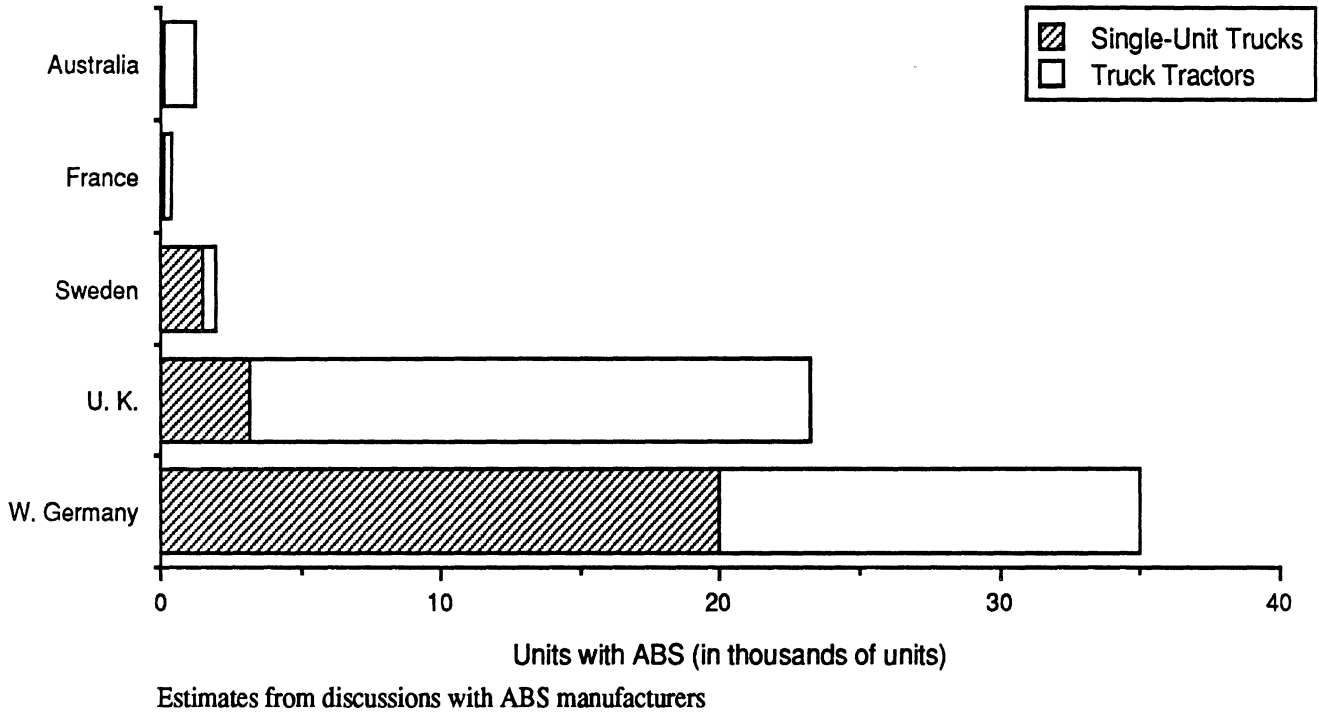
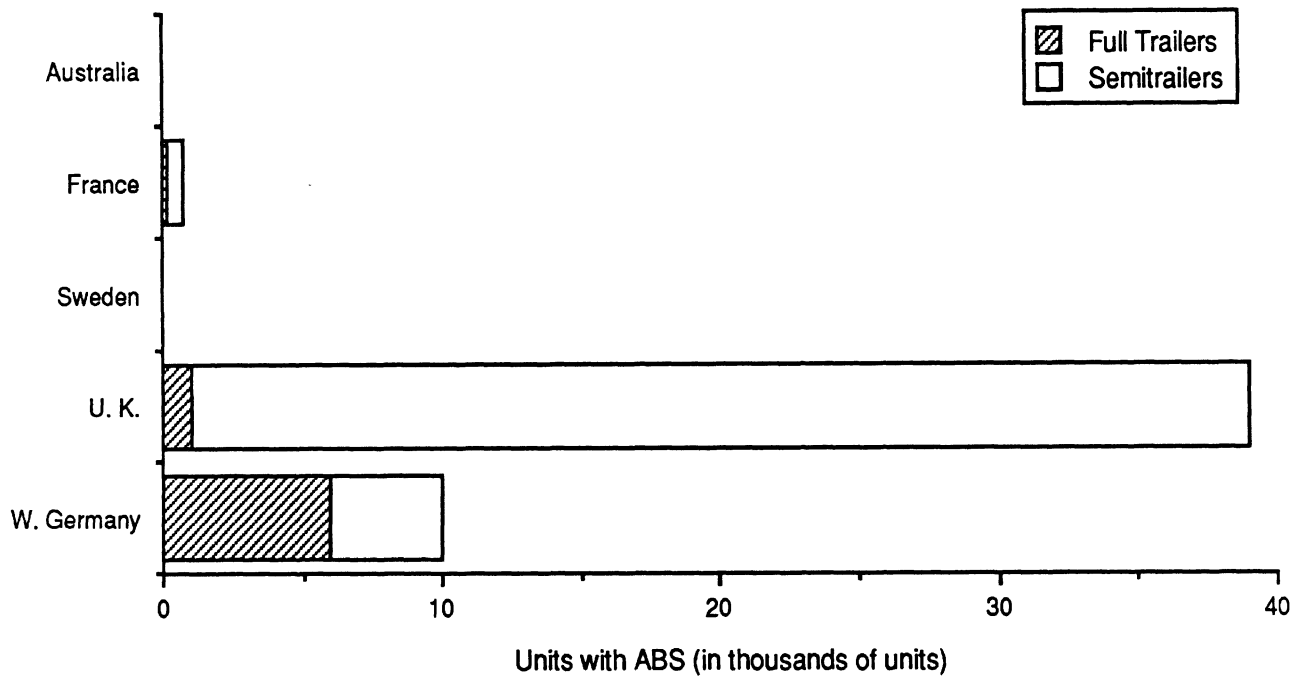


Figure 7. Antilock braking systems (ABS) in service in 1987.
Trucks and Tractors with GVWR \geq 26,400 lb (12,000 Kg).

Antilock Braking Systems (ABS) in Service in 1987
Trailers with GVWR \geq 26,400 lb (12,000 Kg).

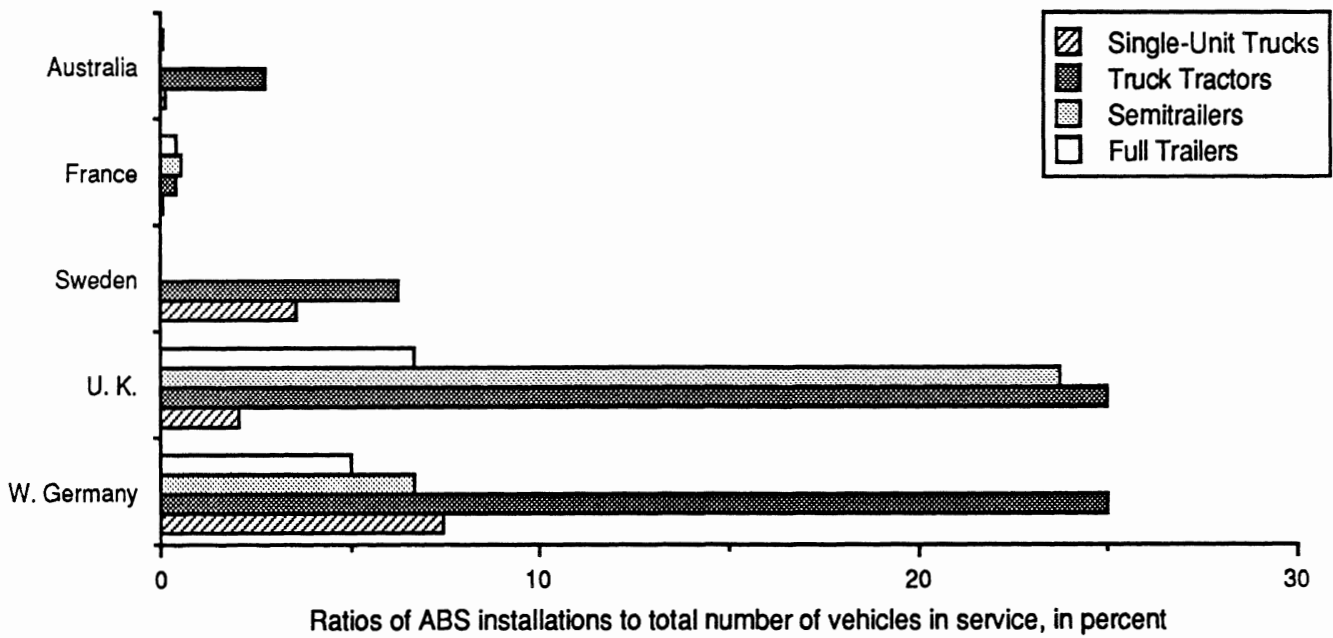


Estimates from discussions with ABS manufacturers

Figure 8. Antilock braking systems (ABS) in service in 1987.
Trailers with GVWR \geq 26,400 lb (12,000 Kg).

Ratios of ABS installations to total number of vehicles in service - by Country

GVWR \geq 26,400 lb (12,000 Kg).



Estimates from discussions with ABS manufacturers

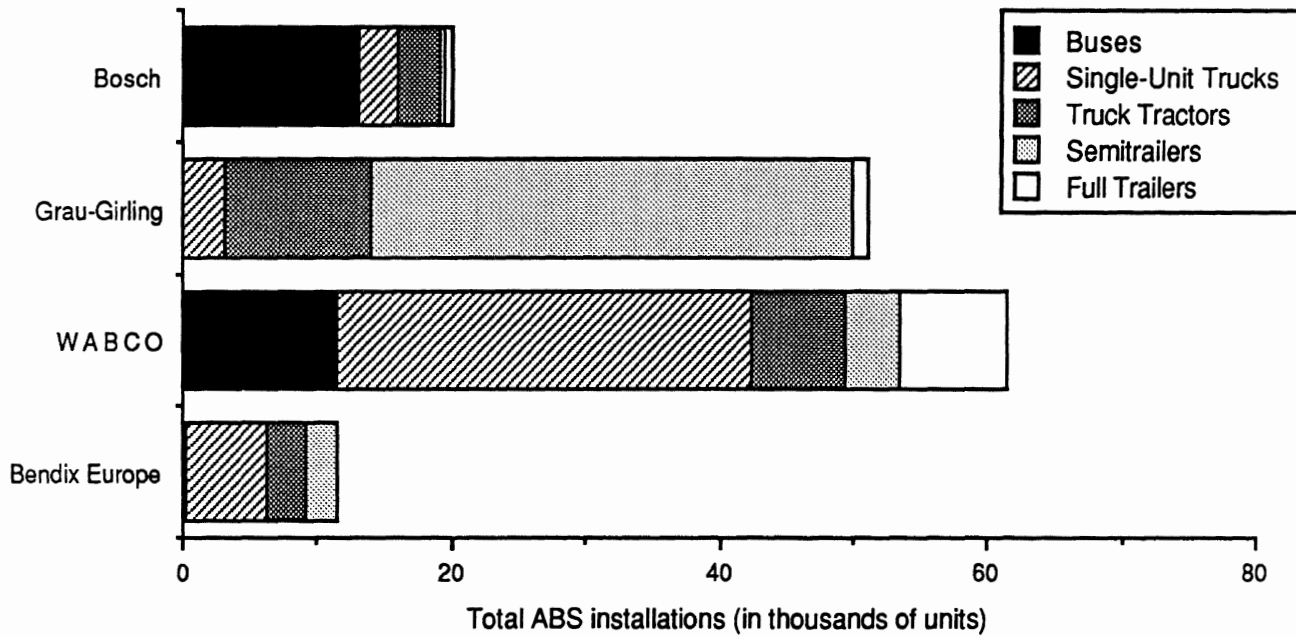
Figure 9. Ratios of ABS installations to total number of vehicles in service - by Country
GVWR \geq 26,400 lb (12,000 Kg).

Table 2. Further Stratification of ABS Installations
(Entries in thousands)

Antilock Mfgs. Systems Installed in Europe

	Buses	Single- Unit Trucks	Total Trucks & Tractors	Truck Tractors	Semitrailers	Total Trailers	Full Trailers
<i>Bosch</i>							
Total ABS installations	13.0	3.0	6.0	3.0	0.5	1.0	0.5
Expected in '88	4.5	1.5	3.0	1.5	0.25	0.5	0.25
<i>Grau-Girling (Lucas Girling)</i>							
Total ABS installations	0.0	3.1	14.1	11.0	36.0	37.0	1.0
Expected in '88	0.0	0.7	3.2	2.5	9.5	9.9	0.4
<i>WABCO</i>							
Total ABS installations	11.5	31.0	38.0	7.0	4.0	12.0	8.0
Expected in '88	5.0	14.7	18.0	3.3	3.0	9.0	6.0
<i>Bendix Europe</i>							
Total ABS installations	0.2	6.0	9.0	3.0	2.3	2.3	0.0
Expected in '88	0.0	0.7	1.0	0.3	1.5	1.5	0.0

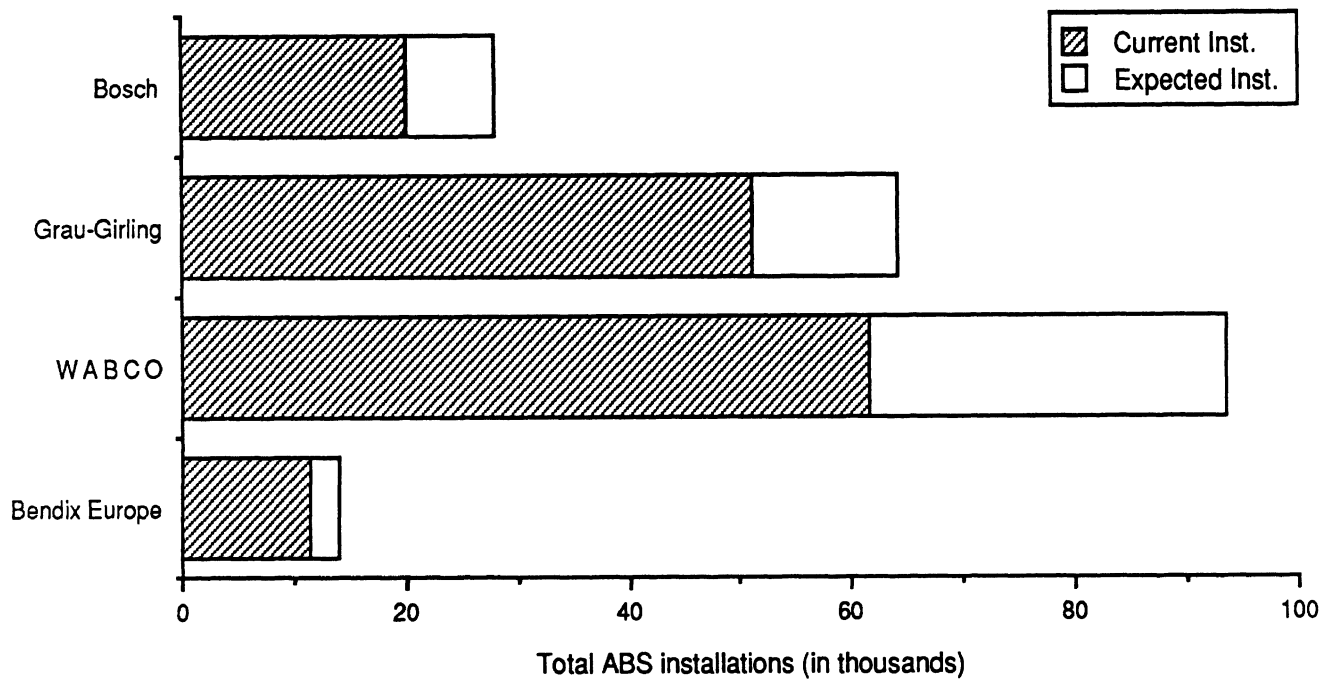
Antilock Braking Systems (ABS) in Service in Europe (1987) - by Manufacturer
 GVWR \geq 26,400 lb (12,000 Kg).



Estimates from discussions with ABS manufacturers

Figure 10. Antilock braking systems (ABS) in service in Europe (1987) - by manufacturer
 GVWR \geq 26,400 lb (12,000 Kg).

Current (1987) and Expected (1988) ABS Installations - by Manufacturer
 GVWR \geq 26,400 lb (12,000 Kg).



Estimates from discussions with ABS manufacturers

Figure 11. Current (1987) and expected (1988) ABS installations - by manufacturer.
 GVWR \geq 26,400 lb (12,000 Kg).

manufacturer has a different history of experience explaining the differences in size and distribution of ABS installations.

Bendix Europe is a recent organizational move to combine activities that include Maxaret systems, Bendix France (Renix), and Bendix in the UK. Some of the ABS systems included in Figure 10 are Maxaret systems which were installed on vehicles many years ago in the UK. Since Renault in France (RVI) has only installed ABS on a few vehicles, the newer ABS's sold by Bendix France have not been installed on many vehicles. In general, Bendix Europe has been slowly getting into the market up to now.

Bosch has been in cooperation with MAN in developing antilock systems. Many of their installations have been on buses sold by MAN. Bosch personnel point out that Bosch is a parts supplier — not a systems supplier. They supply modules, sensors, valves, etc. but not entire systems. Nevertheless, the Bosch ABS is similar to the WABCO ABS and it seems that some vehicle manufacturers may approve either type of system for their trucks and buses in the future.

Grau-Girling includes the part of the ABS market previously associated with Lucas Girling. They have been the major suppliers of ABS to semitrailer manufacturers in the UK. They now have 80 to 90 percent of that market. These ABS systems have used analog technology in the electronic control modules. These systems have been an outgrowth of the Kelsey Hayes ABS introduced in the USA in the mid 1970's. Currently Grau-Girling is introducing a new ABS based on digital rather than analog technology. In this sense, the new Grau Girling ABS will be similar to those of WABCO, Bosch, and Bendix; however, each manufacturer would claim important features for the logic and function of their ABS.

WABCO has been installing ABS since 1981. They have teamed with Daimler-Benz in developing their ABS. Through this association, the WABCO ABS has been installed on approximately the same number of buses as the Bosch ABS. The largest use of the WABCO systems is on straight trucks but many of them have been applied to tractors and full trailers as well. Many of these installations are on vehicles used in Germany. In addition, most of the ABS use in Australia has been on Daimler-Benz vehicles equipped with WABCO ABS.

Prognosis for Future Usage of ABS

Figure 11 indicates the expected number of ABS installations predicted for 1988. (The raw data for these predictions are tabulated in Table 2.) These predictions are of course subject to the possibility of large differences from future experience. For example, if the demand for semitrailers in the UK increases dramatically (as some think it might) then Grau-Girling may provide many more ABS than that predicted here. Even acknowledging uncertainties, the bar graphs in Figure 11 indicate a rapidly expanding market. This

expansion might be characterized by noting that WABCO is predicted to provide over 30,000 ABS in '88, although they have provided approximately 60,000 ABS from '81 through '87.

Discussions with personnel at Daimler-Benz provided further insight into future trends. They say that as of 1987, 98 percent of their coaches, 87 percent of their city buses, and 18 percent of their commercial vehicles over 6.5 tonnes were being equipped with ABS. They predict that the coaches and buses are headed for 100 percent and that the trucks over 6.5 tonnes are headed for 50 percent in the next few years.

The 50 percent estimate for trucks over 6.5 tonnes appears to overestimate the situation. If it is assumed that most of the ABS installations on Daimler-Benz trucks will be on the heavier vehicles (those over 15 tonnes) and that the heavier vehicles constitute 50 percent of the Daimler-Benz production in Europe, then about 100 percent of their heavy truck (Class 8) production in Europe would have to be equipped with ABS in order to meet the 50 percent estimate. Given the legislative initiatives that are starting to take place to require ABS on heavy trucks in Europe [2], a more conservative estimate would be that something over 70 percent of the trucks over 15 tonnes will be equipped with ABS by sometime in the early 1990's.

In the future other vehicle manufacturers besides Daimler-Benz, MAN, Volvo, and Scania are expected to increase their installations of ABS. IVECO has been offering ABS for only a year and for over a year RVI (Renault) has been expected to come out with a new truck design that may include ABS. Clearly, when new legislation goes into effect, vehicle manufacturers will need to be able to supply ABS.

The history of ABS development has been strongly shaped by governmental influences. The situation in Europe is currently being driven by EEC directives [2]. These directives define categories of ABS performance and the types of vehicle units requiring various categories of ABS. In 1985 there was a considerable lack of harmony within Europe as to the definitions of the categories of ABS and the application requirements. The UK and German views differed considerably. Nevertheless, these differences have been resolved now and the EEC directives are being followed up in the sense that individual countries are preparing legislation supporting the EEC directives.

The type of legislation that is being prepared requires ABS on straight trucks that are type approved for pulling full trailers and on tractors for pulling semitrailers. Straight trucks that are not approved for pulling trailers will not be required to have ABS. Full trailers and semitrailers will be required to have some category of ABS.

The EEC directives are to be applied to all type approval actions after October of 1989 and to all new vehicles as of October 1991. Clearly, these directives provide strong incentives for equipping heavy vehicles with ABS.

An example of an ordinance expected to apply in the summer of 1988 in Germany is included in the letter report from Germany. This ordinance states that trucks and tractors of a gross vehicle weight exceeding 9 tonnes and a maximum speed of more than 60 km/h as well as full trailers of a gross weight exceeding 9 tonnes must be equipped with ABS. This also applies to semitrailers if their gross weight minus the fifth wheel load exceeds 9 tonnes.

The German government also presents some interesting projections concerning the advantages of ABS. They cite a 7.1 percent reduction in accidents based on predictions made in a study of 182 accidents [3]; an insurance rebate of 10 percent; a tax advantage in terms of annual depreciation; a reduction in tire wear, possibly 28 percent; and an increase in resale value. Whether all of these benefits will be achieved was questioned by the fleet representatives that we visited, but these items represent potential incentives for considering the use of ABS.

If the projections of ABS installations presented in Table 1 are combined with predicted installations as of the end of 1987, one obtains rather startling predictions of the percentages of truck tractors in Germany and truck tractors and semitrailers in the UK as of the end of 1988 (see Figure 12). According to these estimates, approximately 37 percent of the truck tractors in Germany and 30 percent of the truck tractors and semitrailers in the UK would be equipped with ABS by the end of 1988. Even with allowances for some amount of overestimation, there will undoubtedly be a substantial increase during 1988 in the number of heavy vehicles with ABS operating in the UK and Germany.

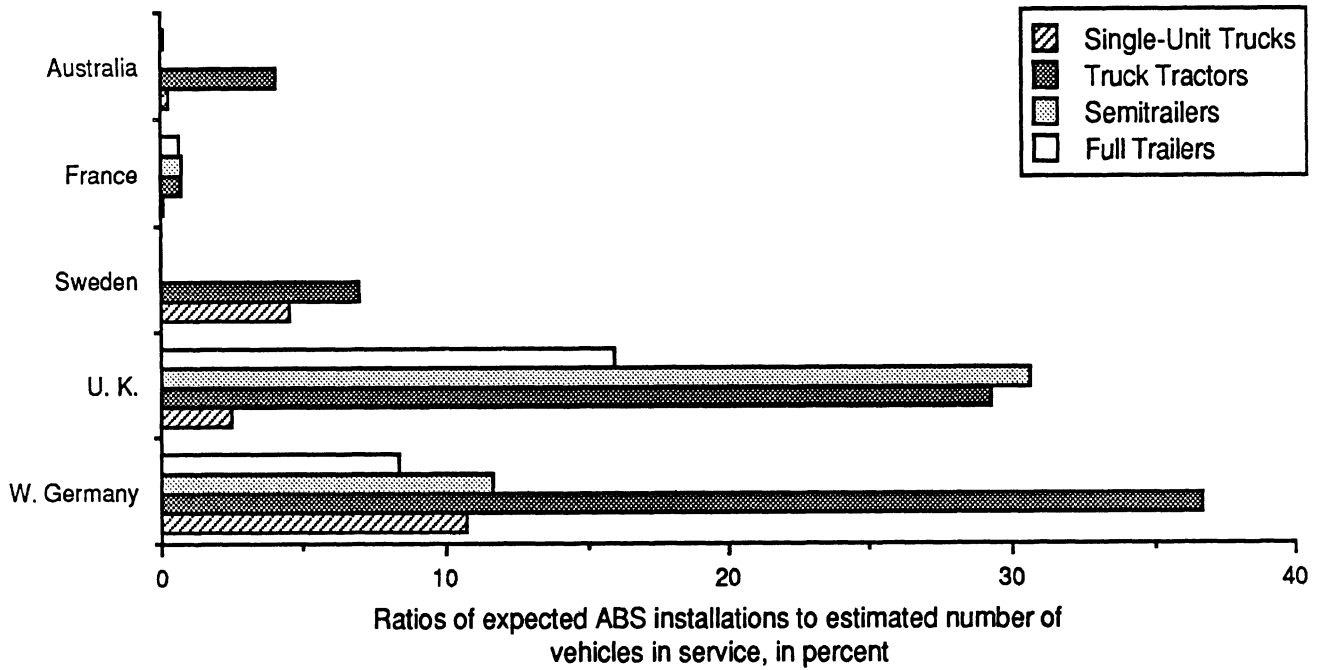
Reliability, Maintainability, and Performance of ABS

Background Discussion concerning Truck Braking Systems in Europe

The previous results on the distribution of ABS usage indicate that Germany and the UK are where experience exists. The other countries in Europe have little overall usage although individual fleets may have substantial experience with ABS. Even though Germany and the UK operate under EEC and ECE requirements, and thereby have European style braking systems, the circumstances that have led to the use of ABS in Germany are different from those pertaining to the UK. In essence, there have been German experiences and there have been UK experiences, and they have not been the same.

In the UK, antilock usage received a big impetus when ABS's on semitrailer axles were allowed in place of the load sensing proportioning valves that had been required previously. The load sensing valves had developed a poor reputation for reliability and were a source of difficulties in passing the annual brake inspections that all trucks are

Ratios of expected ABS installations (1988) to estimated number of vehicles in service - by Country
 GVWR \geq 26,400 lb (12,000 Kg).



Estimates from discussions with ABS manufacturers

Figure 12. Ratios of expected ABS installations (1988) to estimated number of vehicles in service - by Country.
 GVWR \geq 26,400 lb (12,000 Kg).

required to pass. At present many organizations prefer ABS to load sensing proportioning, for example, ABS is standard equipment on Crane Freuhauf trailers in the UK.

Possibly, because of the European emphasis on the physics of vehicle performance in emergency braking, the fleet engineers in the UK tend to think in terms of preventing accidents involving trailer swing, jackknifing, or loss of steering control during braking. In this regard ABS has been introduced first on trailer axles to stop trailer swing, then on tractor axles to prevent jackknifing, and in some cases just recently on front axles to provide additional potential for steering control. The introduction of ABS has been a gradual one in the UK — from axle to axle one might say.

(Concern for directional stability has always been an important feature of European braking regulations, even to the extent that they aim to have brakes on front axles lock before brakes on rear axles. In a sense, they have preferred "aggressive" front brakes.)

The ABS's introduced on trailer axles in the UK have been of the "select low" type. That is, the "worst wheel" (the one closest to lockup) controls both brakes on an axle or sometimes all brakes on a suspension. As mentioned earlier, this type of control scheme was developed in the USA during the "121 era." The newer digital systems are starting to be introduced in the UK now.

In contrast, the ABS systems introduced in the last 6 years in Germany have been digital systems that use individual wheel control (however, sometimes with slave controls to other wheels on the same side of the vehicle) . Only on the front axle is there any semblance of an axle control system. The recent EEC directives require these types of systems on towing units. The categories assigned to ABSs by the EEC involve definitions of ABS performance and the hardware required to meet that performance. In this regard, braking on a "split- μ " surface has become a very important maneuver. The new category 1 systems are expected to provide good stopping performance, directional stability, and satisfactory directional control even if one side of the vehicle is on ice and the other is on dry pavement. All of these considerations are part of an outlook that says that we need definitions of what constitutes an ABS. The categories of ABS given in the EEC directives provide European definitions of various levels of ABS performance. Daimler-Benz now provides Category 1 systems as standard equipment on their heavy trucks.

Brake inspections for heavy vehicles are frequent in Germany. Some heavy trucks have inspections every 6 months. (Our consultant for Germany, TUV Rheinland, has been an agency for performing these inspections.) Truckers are used to having their brakes thoroughly inspected for condition and performance.

The situations portrayed for Germany and the UK are much different from that in the USA. The Europeans have developed proportioning schemes to promote stable, controllable braking for various states of loading of heavy trucks. European regulations

also emphasize emergency stopping performance. The EEC rules and regulations seem to be driven by inputs from the vehicle manufacturers [4]. Many of the fleets are small and they are not organized to advance the fleet point of view. Given the requirements for frequent inspections, brake maintenance is expensive, but trucking firms have no choice except to accept the expense of keeping their brakes prepared for emergency stops.

The new antilock systems differ from the 121 systems tried in the USA. The new digital systems have many checks and redundancies to ensure that the ABS is operating correctly. Furthermore, European users are convinced that the basic European braking arrangement, which they refer to as "classical," is excellent. Their feeling is that, if the ABS warning light indicates a malfunction, they still have the braking system that has served them well in the past. Thus, they need not be overly concerned if the warning light comes on. In talking with fleet engineers in Europe, one gets the impression that they believe that they have a great confidence in the performance of their basic braking system and that ABS further enforces that performance.

The Basic Information Gathered During Fleet Visits

The following set of questions was prepared to serve as a guide in conducting discussions with fleets. These questions are divided into the following subject areas: (1) reliability, (2) maintainability (durability, serviceability), (3) trucking environment, and (4) performance.

Reliability of ABS Systems

- 1a. How often is service or repair (other than routine maintenance) required?
- 1b. What is the mean time or distance between malfunctions? (How often do malfunctions occur?)
2. Which parts of the system require the most service?
3. What kind of maintenance schedule is used to provide reliable operations?
4. Are deliveries delayed because of factors that are related to the antilock system?
5. What does the driver do when a malfunction is indicated? How often do drivers delay deliveries to wait for service?
6. Any problems with electromagnetic or radio frequency interference (EMI/RFI)?

Maintainability (Durability, Serviceability)

1. Is the readiness of the antilock system easily checked by the driver?
2. What checks for proper operations of the system do your maintenance and service personnel make? Are these checks easy to make?
3. What service does the vehicle or antilock manufacturer provide during a warranty period?

4. What is the life of an antilock system in service?
5. Which parts have you replaced and how often (time or miles)?
6. Which parts wear out? Are these parts easy to replace?
7. Which parts of the system do you service?
8. Are they easy to get at for service?
9. Which parts require frequent adjustment? Are the adjustments easy to make? How often are adjustments made?
10. How often do you adjust wheel speed sensors?

Trucking Environment

1. What types of vehicles do you operate? How many? How many of your vehicles are equipped with antilock systems?
2. What goods do you deliver?
3. What is the amount of load in a typical delivery? What percentages of vehicle miles are empty, partially laden, or fully laden?
4. How many miles do your ABS-equipped vehicles accumulate each year? Your non-ABS vehicles?
5. What is a typical delivery like? What kinds of roads are involved? Approximately how many routine stops are involved? Approximately how many downhill descents are involved? Do traffic conflicts require high deceleration stops? Do you operate when the road is slippery? Wet? Snowy? Icy?

Performance

1. Do your drivers like or complain about the antilock systems installed on their vehicles?
2. Do your drivers observe improved braking performance? Do they know of "accidents which didn't happen" because of ABS?
3. How many of these near misses have they had?
4. Do drivers drive ABS vehicles differently than those without? If so, how?
5. Have there been any complaints about "loss of brakes?"
6. Is the accident record of your ABS vehicles different from your non-ABS vehicles?
7. Have other aspects of your operation improved, changed, or degraded, e.g., tire wear, brake relinings, brake repairs, etc.?

The consultants/reporters were provided copies of these questions to use in preparing for fleet visits. Nevertheless, the questions were not used rigorously, rather they served as

guidelines for selecting the subjects to pursue in discussions with fleets. For example, it was found that discussing the trucking environment was a convenient place to start and that the questions in the maintenance category were covered for the most part in discussions on the other categories.

The information gathered with regard to several of these questions was universally the same. The following items pertain to those areas in which our discussions provided firm overall impressions of the nature of the fleet experience with ABS in Europe and Australia. These items are based on discussions with 3 fleets in England, 6 fleets in Germany, 2 fleets in France, plus the consultants discussions with 2 fleets in Sweden, 3 fleets in Norway, and 5 fleets in Australia. (Details concerning the fleets in the UK, Germany, and France are presented later in this section. The letter reports from the consultants for Australia and Sweden describe the fleets in those countries and Norway.)

In general, it was found that:

- Maintenance is done when the malfunction warning light indicates that it is needed. ("If it is not broken, do not fix it.")
- Deliveries are not delayed if the malfunction light comes on. The driver simply checks to insure that the basic braking system is performing properly and then proceeds with the delivery if the brakes are working normally.
- ABSs receive no routine attention aside from checks performed when preparing for required brake inspections.
- This study uncovered no reports of interference problems from radios or external sources. (There have been some wiring errors in buses and interactions with door controls, etc.)
- Vehicle and ABS manufacturers provide warranties of 1 year or 100,000 kilometers on the ABS.
- The life of the ABS (with proper maintenance) is equal to the life of the vehicle.
- Carriers report that drivers like to drive with the ABS operating.
- Only one of the fleets observed any change (good or bad) in tire wear, brake relinings, or brake repairs, etc. since they have installed ABS. (See the addendum to the letter report from the UK for a case in which tire savings were reported.)

Of these items, the first two concerning the warning light and what to do if it is on were the most surprising. Clearly, the questions posed could have been structured differently and the search for extensive records of ABS maintenance could have been avoided if it were known that problems were rare. The results of the fleet discussions presented here

appear to indicate the confidence and acceptance generated by having faith in the basic braking system (even if the ABS is malfunctioning).

The three fleets visited in the UK all use the older style of ABS with analog hardware. Nevertheless, these systems were viewed by their users as quite reliable and any routine checking or adjusting could easily be handled in connection with activities associated with brake inspections (see Table 3 for a summary of the information recorded).

Although complete information on failures and problems was not available from these fleets, many typical difficulties were mentioned, the most prevalent of these being wiring and connector failures. Wetness was a problem causing the warning lights to come on — often to be cured when the sensors dried out. As heard later at other fleets, high pressure washing can lead to malfunctions or, at least, temporary warnings of malfunctions. Some of the control valves had been known to freeze in cold weather. The use of air dryers and careful attention to maintaining clean air systems has solved this problem. One of the fleets has gone to putting wires in conduits as required for vehicles carrying hazardous materials. This was reported to help considerably.

One of the fleet engineers had information prepared on accidents. This turned out to be an unusual circumstance, presumably because accidents represent events that are hard for fleet engineers to explain without implicating their fleets in responsibility for the accidents. In this case, the fleet engineer had observed an elimination of accidents involving trailer swing. However, he also had observed a near elimination of rollovers in the same time period with the same vehicles. It is possible that the greater directional stability provided by ABS contributed to safer driving performance. Even though credit for improvements in safety is in general difficult to assign, this evidence supports the view that ABS reduces the risk of trailer swing accidents. This fleet engineer felt that the demonstrated improvement provided by ABS in directional stability during braking reduces the risk involved in successfully performing vehicle maneuvers involving heavy braking.

The discussions in the UK led to adding new points to be emphasized in the discussions with fleets in Germany. Two new questions were: (1) how often does the warning light come on? and (2) why ABS?

The question, "why ABS?" was a reaction to finding no evidence of economic benefits in tire or brake savings and the realization that any safety benefits that do result would be hard to prove to those that sought proof of an economic reward. The answer to this question seems to be that (1) theory and proving grounds demonstrations have convinced people that safety will be improved and (2) the fear of a major accident that might have been prevented with ABS is enough justification for purchasing the systems. The fleets visited also advocated load sensing proportioning, automatic slack adjustment, and ASR (that is, automatic slip control to prevent wheel spinning on slippery surfaces). One might say they

Table 3: Summaries of Fleet Visits in the UK

Fleet #1	
Type of Trucking	Derbyshire Fire brigade
Fleet Size	72 heavy vehicles (fire fighting equipment)
Vehicles with ABS	69 with ABS
Time period with ABS	6 1/2 years (gradually equipping all vehicles)
Estimated annual travel	6,000 to 10,000 miles per vehicle
Delivery characteristics	Longest run to a fire is about 30 miles. Heavy braking is a frequent occurrence
Maintenance activities	ABS checked when the brakes are checked every 6 months
Failures identified	2 air valve kits 1 computer cable
Problems observed	- wiring and wetness - sensor adjustment - air valve
Accident indications	Not available
Driver perceptions	"Drivers wouldn't allow ABS to be removed because it is a safety device"
Comments:	

Table 3 (Continued)

Fleet #2	
Type of Trucking	Brewery in the UK (Kegs and Bottles of Beer)
Fleet Size	<ul style="list-style-type: none"> - 103 heavy duty, 2 axle tractors 417 triaxle semitrailers. These vehicles operate on trunk lines. - about 2100 smaller and/or rigid vehicles.
Vehicles with ABS	<ul style="list-style-type: none"> - All trunk-line vehicles have ABS on the tractor and trailer. - starting to install ABS on small "retail" trailers.
Time period with ABS	>5 years on heavy vehicles
Estimated annual travel	<ul style="list-style-type: none"> - heavy tractors 120,000 km/vehicle - heavy trailers 30,000 km/vehicle (vehicles empty nearly 1/2 the time)
Delivery characteristics	<ul style="list-style-type: none"> - roughly 240 stops in a trip with 90% of these less than 2.5 bar (36 psi) - return trips are empty (unladen 1/2 of the time)
Maintenance activities	<ul style="list-style-type: none"> - trailer brakes are checked 4 times/year - 26 roving maintenance inspectors making "random" checks - 3 months prior to annual inspections all drums come off, all sensors are reset, exciter ring is reset
Malfunction light on (number of times)	Unknown
Failures identified	<ul style="list-style-type: none"> - broken warning lights on trailer head board (put lights in the cab) - wiring in winter of 83/84 (now put wires in a conduit) - early system had too much time lag in the fail safe
Problems observed	<ul style="list-style-type: none"> - ABS too critical of level of voltage supplied to the trailer - washing vehicles can cause problems with warning lights
Accident indications	<ul style="list-style-type: none"> - no trailer swing accidents in the last 4 years (there used to be 2 per year) - doesn't know why but there used to be 2 rollovers per year but since ABS there has been 1 in the last 5 years.
Driver perceptions	<ul style="list-style-type: none"> - drivers convinced of safety by proving ground experience and demonstrations
Comments:	Their approach is to put ABS on trailer axles first to prevent trailer swing, then drive axles to prevent jackknife, and then on steering axles to insure driver control

Table 3 (Continued)

Fleet #3	
Type of Trucking	Lubricating Oil and petroleum products; even so these are mainly non-hazardous materials in this case
Fleet Size	2 types of vehicles: <ul style="list-style-type: none"> - 24 ton single-unit tankers - 4 x 2 tractors pulling 3 axle semitrailers (all the tractors and semitrailers have ABS)
Vehicles with ABS	<ul style="list-style-type: none"> - no ABS on single-unit tankers - 40 to 50 tractors with ABS (no steering axle antilocks) - 80 to 100 semitrailers with ABS
Time period with ABS	Started to bring in ABS on new vehicles about 10 years ago
Estimated annual travel	40,000 miles per vehicle
Delivery characteristics	<ul style="list-style-type: none"> - Company drivers only - Many empty trips, approaching 1/2 the time - The ABS equipped vehicles make deliveries to major terminals in UK
Maintenance activities	<ul style="list-style-type: none"> - Sensors are adjusted whenever the hubs come off. - Brake system serviced and inspected every 5000 miles, involving a basic check of the ABS and brake adjustment
Malfunction light on (number of times)	Unknown
Failures identified	Wiring, corrosion of control unit boxes
Problems observed	RFI ten years ago but none now
Accident indications	<ul style="list-style-type: none"> - ABS vehicles have fewer accidents than non-ABS vehicles (no quantification) - With regard to braking, they have had a relay valve failure and a service line failure that contributed to accidents in the last 10 to 15 years
Driver perceptions	<ul style="list-style-type: none"> - Although they have load sensing proportioning, the drivers do not like to drive with the ABS malfunction light on.
Comment:	They put ABS on tractor rear axles first to prevent jackknife. Then, they installed ABS on trailer axles to prevent trailer swing. Now, they are ready to install ABS on front axles (Many other UK carriers have chosen to buy ABS equipped trailers first.)

were interested in the best technology available for controlling wheel slip and they were willing to accept the price.

The question about the warning light was prompted by a realization that the warning light was not only the main communication to the driver but it was an integral part of the maintenance procedure. As it turned out, the warning light was even more crucial to maintenance practices in Germany than to those in the UK. (The summaries of the fleet surveys for Germany, see Table 4, have a new item entitled "Malfunction light on.") The answers to this question indicate that the malfunction light may come on rather frequently in service, particularly in bus service. Surprisingly, many of these warnings are either false or temporary because turning the ignition off and on again seems to "cure" most of them.

Examination of the summaries in Table 4 shows that sensor failures and problems are noted more often than other types of malfunctions. Sometimes malfunction warnings are cured by drying the sensors. Wires to the sensors are damaged frequently enough to be worth mentioning as a basic, possibly universal problem.

The drivers of these vehicles are reported to like ABS systems. They believe that they can stop more quickly. The drivers feel safer with ABS. Many of them have had training for operating trucks with ABS. In one fleet the drivers feel unsafe with a tractor with ABS and a trailer without ABS. (Proving grounds experiments performed by Daimler-Benz show that drivers can operate reasonably well with combinations in which towing units with ABS are pulling trailers without ABS — certainly much better than without any ABS on either unit. In this situation the driver needs to use the mirror to be aware of the path of the trailer.) In another fleet they schedule units to avoid mixes of units with ABS in combination with units without ABS. In summary these drivers would prefer to have ABS on all wheels.

The information obtained from fleet visits in France (see Table 5) indicates many of the same types of observations as those noted in Germany and the UK. In particular, problems with cables and connectors appear again. Designers of wiring systems for heavy trucks apparently underestimate the rigors of that environment. Even though lighting systems have always been troublesome to maintenance people, simple, economical solutions for wiring problems have not been found. Clearly, the advanced electronic logic used in ABS identifies these problems and prevents them from becoming disastrous failures of the braking system, but strong, protected, water-invincible wires and connectors would have gone a long way towards reducing ABS service requirements to an even smaller number of events than that reported here. (This is not to say that significant improvements in wiring have not taken place, just that wiring problems remain and they need attention.)

Further discussions of the information gathered from contacts with fleets are given in the letter reports. All of these reports provide items that could be of importance in

Table 4: Summaries of Fleet Visits in W. Germany

Fleet #4	
Type of Trucking	Hannover Bus System
Fleet Size	220 buses in total
Vehicles with ABS	<ul style="list-style-type: none"> - 60 articulated buses with ABS - 20 2-axle buses with ABS - 3 new 2-axle buses with ABS (but 30 other new buses don't have ABS because the city council rejected the additional cost)
Time period with ABS	5 years (since 1982)
Estimated annual travel	60,000 km/per vehicle
Delivery characteristics	<ul style="list-style-type: none"> - no hills - stops are 500 to 700 meters apart in the city - travel in all kinds of weather. They have retarders that are controlled by the ABS
Maintenance activities	<ul style="list-style-type: none"> - No routine maintenance because ABS is self checking - They use the check unit (test box) supplied by the ABS manufacturer. If they do anything to the brakes, they test the ABS. They look at and adjust sensors about once a year for sure.
Malfunction light on (number of times)	It could happen once a week but it is not a fault that lasts. (Switching ignition on and off almost always cures it.)
Failures identified	<ul style="list-style-type: none"> - 3 electronic control units (2 because the boxes filled with water when washing buses) - In 5 years, they have changed about 20 sensors due to corrosion or "short" wires to the front axles
Problems observed	<ul style="list-style-type: none"> - some electrical problems with "interface" with electrically controlled devices such as doors, etc. on buses.
Accident indications	No statistics available
Driver perceptions	<ul style="list-style-type: none"> - Drivers prefer ABS because they feel safer. - The drivers "observe" improved braking performance
Comments:	Theory and tests are used to convince people that safety will be improved.

Table 4 Continued

Fleet #5	
Type of Trucking	Wuppertal Bus System
Fleet Size	300 buses of which 101 are articulated
Vehicles with ABS	<ul style="list-style-type: none"> - In the whole fleet, 156 buses have ABS 68 of the 101 articulated buses have ABS - "category 1" on every wheel - 46 have ASR
Time period with ABS	<ul style="list-style-type: none"> - started acquiring buses with ABS in 1979 - started ASR in 1982
Estimated annual travel	50,000 km per bus
Delivery characteristics	<ul style="list-style-type: none"> - 90% city; 10% country roads - very hilly and rainy region
Maintenance activities	<ul style="list-style-type: none"> - Buses checked every day. Service is not interrupted because of ABS failure but the bus will not go out with an ABS malfunction unless there are not enough buses available. - ABS sensors are only adjusted when a malfunction is indicated. - Every 3 months the buses are inspected; they check ABS then.
Malfunction light on (number of times)	<ul style="list-style-type: none"> - 80 times on 156 buses in 1987. (These malfunction indications came from 36 of the buses.)
Failures identified	<ul style="list-style-type: none"> - 20 sensor (with cable) units changed in 1987 - 60 times they adjusted sensors (some of these might not have been necessary)
Problems observed	<ul style="list-style-type: none"> - fatigue failures of cables, mechanical failures of connections (but cables and connectors are better now) - no RFI problems
Accident indications	<ul style="list-style-type: none"> - They don't differentiate between vehicles with and without ABS but they may have 500 "great and small" accidents in a year. They would have to analyze every accident to see if ABS were relevant. See the Comments
Driver perceptions	<ul style="list-style-type: none"> - ABS seldom used because passengers become very unhappy with high deceleration stops. (Bus drivers drive conservatively to maintain passenger comfort.)
Comments:	<p>Mr. Sac, director of the Wuppertal Bus fleet, prepared an SAE presentation for the 1985 International Congress. In it, he gives answers to "Why ABS?" and some braking and accident samples. In 22 months in a sample of 4 buses, they measured 8.5 brakings per mile or 540,000 brakings in which the ABS reacted 12,600 times, 4,250 times for longer than 2 seconds. This means that once in 127 brakings the ABS prevented wheel lock. In two particularly bad winter months of 1985*, the fleet had about 100 accidents but only 4 accidents for vehicles equipped with ABS. Of these 4, the bus drivers attempted physical impossibilities in 2 cases and other vehicles ran into the buses in 2 cases. At that time the fleet consisted of 179 buses without ABS and 51 buses with ABS.</p>

*1985 was an exceptionally cold winter with much snow and ice plus a new law prohibiting the use of salt on the roads.

Table 4 (Continued)

Fleet #6	
Type of Trucking	<ul style="list-style-type: none"> - Tanker vehicles - gases and liquified gases; oxygen, nitrogen argon, hydrogen, etc. - hazardous materials
Fleet Size	19 tractors, 25 trailers, 5 large single unit trucks, 12 small trucks
Vehicles with ABS	<ul style="list-style-type: none"> - 16 tractors with ABS - 2 trailers with ABS - 1 heavy single-unit truck
Time period with ABS	- 1 year
Estimated annual travel	<ul style="list-style-type: none"> - liquid 150,000 km/vehicle - gas 80,000 km/vehicle
Delivery characteristics	<ul style="list-style-type: none"> - 70% motorways - some 6 & 7% grades - vehicles are empty 1/2 time and some gases weigh almost nothing.
Maintenance activities	<ul style="list-style-type: none"> - none on ABS - Brakes inspected by TUV or Dekkra every six months.
Malfunction light on (number of times)	Unknown
Failures identified	- no repairs in first year
Problems observed	- knows of one time the malfunction light came on but all service is done by vehicle manufacturer (either Daimler-Benz or MAN.)
Accident indications	<ul style="list-style-type: none"> - No accidents with ABS - one minor trailer swing accident for a non-ABS trailer in the past year
Driver perceptions	<ul style="list-style-type: none"> - Drivers like to drive with ABS. - "The main thing is that you can steer." - Subjectively drivers say they have shorter stopping distance capabilities. <p>(On the other hand, the fleet engineer felt that drivers routinely stop quicker with ABS. He is concerned that drivers may be taking slightly greater risks.)</p>
Comments:	Drivers of vehicles carrying hazardous materials are specially trained. They have few accidents. Receive special schooling twice a year. Must pass an examination every year

Table 4 (Continued)

Fleet #7	
Type of Trucking	<ul style="list-style-type: none"> - Powders, granulated plastics, some liquids - 70% hazardous materials such as coal dust. - vehicles have pressurized containers to prevent explosions.
Fleet Size	<p>80 tractors 100 semitrailers</p>
Vehicles with ABS	<p>15 tractors 15 semitrailers</p>
Time period with ABS	<ul style="list-style-type: none"> - 2 vehicles with ABS for 4 or 5 years - the others with ABS for 2 years
Estimated annual travel	<ul style="list-style-type: none"> - 200,000 to 300,000 km per vehicle (trucks operate 24 hours/day with 2 drivers - each driver operates for 12 hours)
Delivery characteristics	<ul style="list-style-type: none"> - 60% laden, 40% empty (about 40 tonnes laden) - 85% on motor ways, 15% country roads and in town - deliveries are not delayed if the ABS light is on.
Maintenance activities	<ul style="list-style-type: none"> - maintenance done by the vehicle manufacturers (Daimler-Benz, IVECO, or Scania) - no routine maintenance, they depend upon the malfunction light
Malfunction light on (number of times)	<ul style="list-style-type: none"> - They had one truck with the lamp on and an engineer from WABCO was coming to identify the problem.
Failures identified	<ul style="list-style-type: none"> - One broken sensor cable. This cable was broken while repairing the brake system in the shop.
Problems observed	<ul style="list-style-type: none"> - They are not happy with tractors with ABS pulling semitrailers without ABS. They worry about trailer swing.
Accident indications	<p>Last year they had 2 jackknives with vehicles without ABS, none with vehicles with ABS.</p>
Driver perceptions	<ul style="list-style-type: none"> - Drivers speak about shorter distances in braking with ABS on wet roads. - In one case, a driver has gone out of his way to emphasize that he avoided an accident on a wet road because of ABS. - "Drivers feel unsafe with a tractor with ABS and a semi trailer without ABS."
Comments:	<p>They use ABS because of the great danger of a major accident/explosion in their business. The economics of ABS use is not influential in their decision to use ABS. New vehicles are being ordered with ABS and ASR from now on. They have ordered 33 new tractors with ABS and they will retrofit 33 semitrailers with ABS to go with these tractors</p>

Table 4 (Continued)

Fleet #8	
Type of Trucking	Köln fire department
Fleet Size	- 67 heavy trucks
Vehicles with ABS	- 11 with ABS
Time period with ABS	- 2 years
Estimated annual travel	- 7,000 km/vehicle (even less for special vehicles for particular types of fires)
Delivery characteristics	- Always fully laden - They operate at high speed on city streets in all types of weather - They use ASR in place of chains for operating in snow
Maintenance activities	- No routine maintenance on ABS - They do simple checks if malfunction light comes on - Repairs done by the vehicle manufacturer
Malfunction light on (number of times)	- 10 times in '87 (in 8 of these cases, the problem went away by switching the system off and on.)
Failures identified	- 2 times they went to the manufacturers (Daimler Benz and MAN) (not clear as to the repair)
Problems observed	- no RFI problems - wiring errors between information displays (many information displays on fire trucks) - When they clean the trucks, the malfunction lamps come on, but drying the sensors with compressed air fixes the problem.
Accident indications	- 150 accidents in '86 and '87.
Driver perceptions	- Drivers like ABS
Comments:	

Table 4 (Continued)

Fleet #9	
Type of Trucking	<ul style="list-style-type: none"> - General Freight, for hire trucking - only 6 tankers for chemicals, only a few hazardous items
Fleet Size	<ul style="list-style-type: none"> - 69 trucks, 36 tractors - 86 full trailers, 50 semitrailers
Vehicles with ABS	<ul style="list-style-type: none"> - 41 trucks, 13 tractors - 27 full trailers, 10 semitrailers
Time period with ABS	2 years
Estimated annual travel	150,000 km/vehicle
Delivery characteristics	<ul style="list-style-type: none"> - mostly fully laden (goods taken both ways) - 80 to 90% on motor ways - all weather and throughout Germany and outside also
Maintenance activities	<ul style="list-style-type: none"> - They use WABCO test equipment to do maintenance themselves. - They only test or check the system when a fault is indicated. - Nearly no repairs for ABS compared to the multitude of repairs in general
Malfunction light on (number of times)	- 5 times in 1987
Failures identified	- Sensor cables broken 3 or 4 times
Problems observed	<ul style="list-style-type: none"> - they try to avoid mixes of ABS and non-ABS units. - no RFI problems
Accident indications	<ul style="list-style-type: none"> - in the last 18 months they have had fewer accidents, maybe it is ABS and the other systems - no major accidents (>10,000 Deutsch marks) in '87, one in '86.
Driver perceptions	<ul style="list-style-type: none"> - Drivers feel safer - Every driver goes to Daimler Benz once a year for training. - If they buy a new truck, a driver goes to the manufacturer for training on that vehicle
Comments:	<p>They try to schedule so that both units have ABS. They succeed 95% of the time. Possibly the whole fleet will have ABS by '95. Trailers will take longer because they are not replaced as often and they do not plan to retrofit trailers.</p> <p>They believe that the combination of ABS, load sensing proportioning, automatic slack adjusters, and ASR makes for much better and safer vehicles.</p>

Table 5: Summaries of Fleet Visits in France

Fleet #10	
Type of Trucking	Bus fleet operating between Paris and its airports
Fleet Size	51 heavy buses
Vehicles with ABS	39 buses with ABS
Time period with ABS	<ul style="list-style-type: none"> - 2 years for 27 of the ABS vehicles) - 12 ABS equipped buses are only 3 months old
Estimated annual travel	- 100,000 km/vehicle
Delivery characteristics	<ul style="list-style-type: none"> - maximum trip is 40 km - 2/3 on motorway with dense traffic and speeds less than 100 km/hr. - lots of stop and go situations and dense traffic both on and off the motorway
Maintenance activities	<ul style="list-style-type: none"> - no scheduled maintenance on ABS - one of the newer ABS systems gives diagnostics without requiring a separate test box
Malfunction light on (number of times)	- Unknown
Failures identified	- Changed 2 or 3 sensors in the last two years (that is, in about 4,300,000 km)
Problems observed	- Last week, for example, a sensor lead was broken because a clip had broken and allowed the wire to rub.
Accident indications	<ul style="list-style-type: none"> - 2 major accidents with non-antiskid vehicles in last 2 years but no braking accidents with ABS vehicles - Slippery areas under bridges have caused many accidents, but none of these incidents with ABS equipped vehicles
Driver perceptions	<ul style="list-style-type: none"> - drivers complain if ABS is not working - drivers were willing to accept ABS as a compensation for manual transmission on new buses
Comments:	They are uncertain about improvements in accident rates. They now have automatic slack adjustment plus ABS. In the past accidents were found to be caused by misadjustment. The weather may have contributed. If a shower follows a dry period, they have problems with slippery areas under bridges. In the past, they were lucky to get through one of those days without an accident. None of the ABS vehicles have been involved in one of these types of accidents.

Table 5 (Continued)

Fleet #11	
Type of Trucking	General freight (like a "Federal Express" operation for France)
Fleet Size	- 800 vehicles including 300 heavy duty vehicles
Vehicles with ABS	- over 200 big vehicles with ABS
Time period with ABS	- oldest system installed in 1979 - had select low systems - now individual wheel control
Estimated annual travel	120,000 km/vehicle for freight vehicles operating between terminals
Delivery characteristics	- All over France and into neighboring countries - They have terminals like UPS and other American companies.
Malfunction light on (number of times)	- not available, but we happened to look at 4 vehicles in the repair yard and the light came on in 2 of them. They needed new fuses and then ABS worked properly.
Failures identified	- connectors, cables, and fuses (amounts not quantified)
Problems observed	- cables and fuses are problems. In some vehicles, they install circuit breakers in place of the fuses. - no problems with computers.
Accident indications	- without ABS, they have problems in braking in a turn on small roads - with ABS, no jackknives or trailer swings, no braking accidents (quantification not available)
Driver perceptions	- The carrier expressed fear that drivers will be reassured and go too fast - In the carrier's opinion, stopping distance is not as important as the ability to steer
Maintenance activities	- 150,000 km between maintenance checks, vehicles must be very reliable - ABS is not a maintenance problem
Comments:	This carrier is very safety conscious and they try to prevent accidents by responding to risks. Their insurance is only 20% of the list price. They are also quite driver oriented and have suggestions for improving the systems. These include (1) only one cable for connecting tractor and trailer (current systems require 2 cables and the drivers forget one sometimes), (2) the initial start-up check of the ABS should be when the driver wants it, not when the vehicle happens to pass through 7 km/hour (the driver could be busy getting out of the yard then).

particular situations. They provide a good idea of what has been happening in Australia and Scandinavia as well as in the countries just discussed.

Reliability

In addition to fleet visits, discussions were held with personnel from each of the major ABS producers in Europe, and the discussion with WABCO included a trip to Daimler-Benz to aid in gathering information on the reliability of ABS. There were two opportunities to view production facilities — one in the UK and the other in Germany. The production operations can be characterized as (1) being efficient, (2) having concern for the cleanliness and dryness of the parts produced, and (3) testing of partial as well as fully assembled sets of the hardware. Electronic control units were operated for a "burn in" period to reduce the risk of early failures of electronic components in the field.

Although the fleet visits provided instances of reliability related problems, they did not appear to provide a satisfactory basis for extrapolating to other situations and for making overall estimates of reliability. Material gathered on the visits to ABS manufacturers and material referenced by them has been used here to discuss and to quantify reliability.

In order to discuss reliability, it is convenient to list the components of ABSs and the things that are known to have gone wrong with these components. The following list is an extension of material obtained from Daimler-Benz. (There is going to be an SAE special publication, scheduled for completion in April or May 1988, that will contain material presented by Mr. Gohring of Daimler-Benz at the SAE Truck and Bus meeting in November 1987.)

ABS Component Failure Modes

- Rotors
 - mechanical damage
 - foreign matter (Australian dust, for example)
 - looseness
 - wheel bearing adjustment
 - unanticipated wheel rotations (for example, lifted wheels on lift axles may rotate thereby yielding a false ABS failure)
- Sensors
 - mechanical damage
 - positioning error
 - cable defect
 - plug defect
 - sensor attachment problem
 - electronic fault

- Electronic Control Units (Modules) or (ECUs)
 - component defect
 - internal jumper defect
 - corrosion
 - humidity
 - temperature
 - damaged cable
 - damaged plug
- Solenoid Control Valve
 - pollution of pressure medium
 - electrical error
 - membrane defect
 - cable defect
 - plug connection defect
- Display and Warning Equipment
 - wiring errors
 - plug connection defect
 - cable defect
 - shorted or burned out lights
 - relay failures
- Other Wiring and Connections between ABS components and Vehicle Units
 - cable defects
 - connector defects

Service, environmental, and operating conditions that are known to have contributed to these reliability problems are:

- temperature
- humidity
- corrosive media
- vibration
- impulsive disturbance
- electromagnetic interference
- wetness (fording rivers, washing vehicles)
- foreign matter (dust)
- wheel bearing looseness

- failure to connect both trailer cables
- electric arc welding on the vehicle

The above lists provide a fairly comprehensive indication of the various types of things that have gone wrong. In presenting and summarizing counts of failures, it is convenient to put them into categories that correspond to "natural" divisions of the ABS. Based upon the type of information available (and judgement), these divisions are designated here as "wiring," "sensor," "module," "valve," and "other," where the meanings of these terms are extended to cover a range of the problems listed above. In particular, "wiring" includes cabling and connector defects plus installation problems. Also, "sensor" includes both sensor and rotor difficulties plus some of the problems in the cables and connectors attached to the sensor. (That is, the part, called a "sensor," comes with several feet of cable and a connector. In order to repair problems with this wiring people often order a new sensor.) And, "other" involves failures that defy classification (even allowing for some uncertainty in selecting the proper category) and it includes cases in which service visits were made but no problems were found.

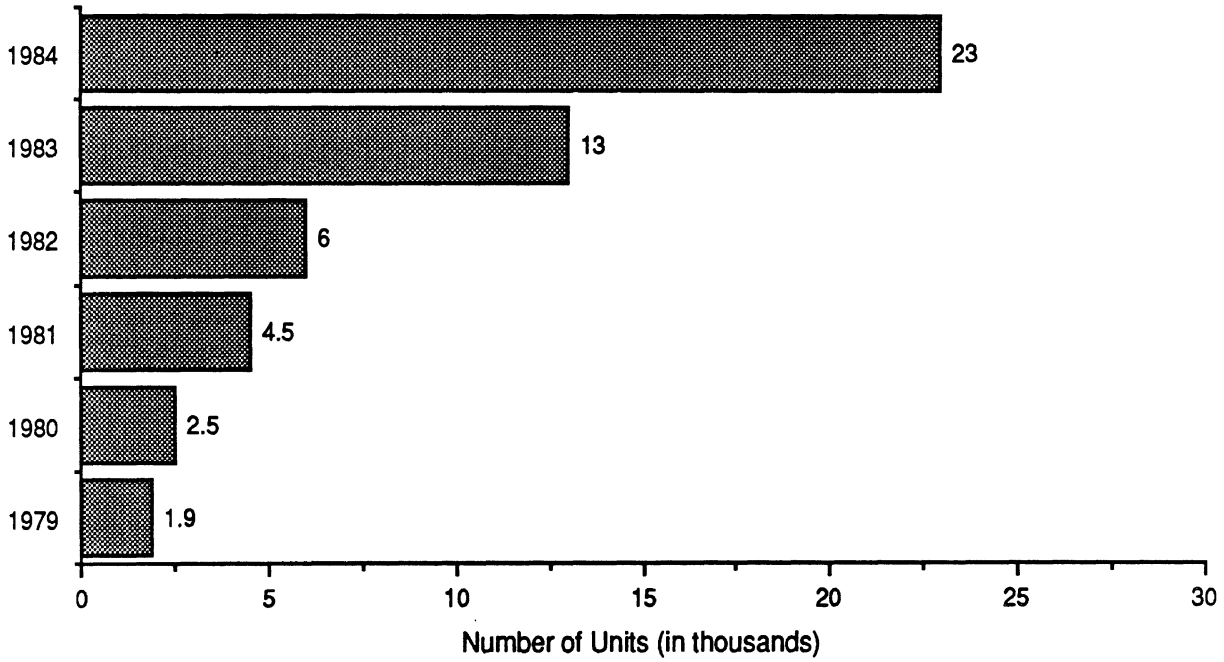
In 1985, Lucas Girling made a survey of their service visits for the period from January 1983 to May 1984 [5]. As illustrated in Figure 13, that was a period of rapid increase in the population of ABS systems in use. During that period the number of service calls ranged from 5 to 30 per month on from 6000 vehicles at the beginning of the period to approximately 18,000 vehicles in May 1984. If the results for these months are combined and separated into individual categories, wiring is seen to be the most common problem with "other" being second most prevalent (see Figure 14).

The results show that valve problems and failures happened the least (7.4%), module problems were twice as frequent as valve problems (14.5%), sensor problems were three times as prevalent as valve problems (21%), and wiring and installation problems happened more than 4 times as often as valve problems (31.4%).

If all of these problems illustrated in Figure 13 are combined to give an overall reliability numeric, the average service call rate is estimated to be 0.0015 service visits per month per vehicle in use. That is, these figures indicate that approximately 1.7 percent of the vehicles in use had a problem difficult enough to merit a service call in a year.

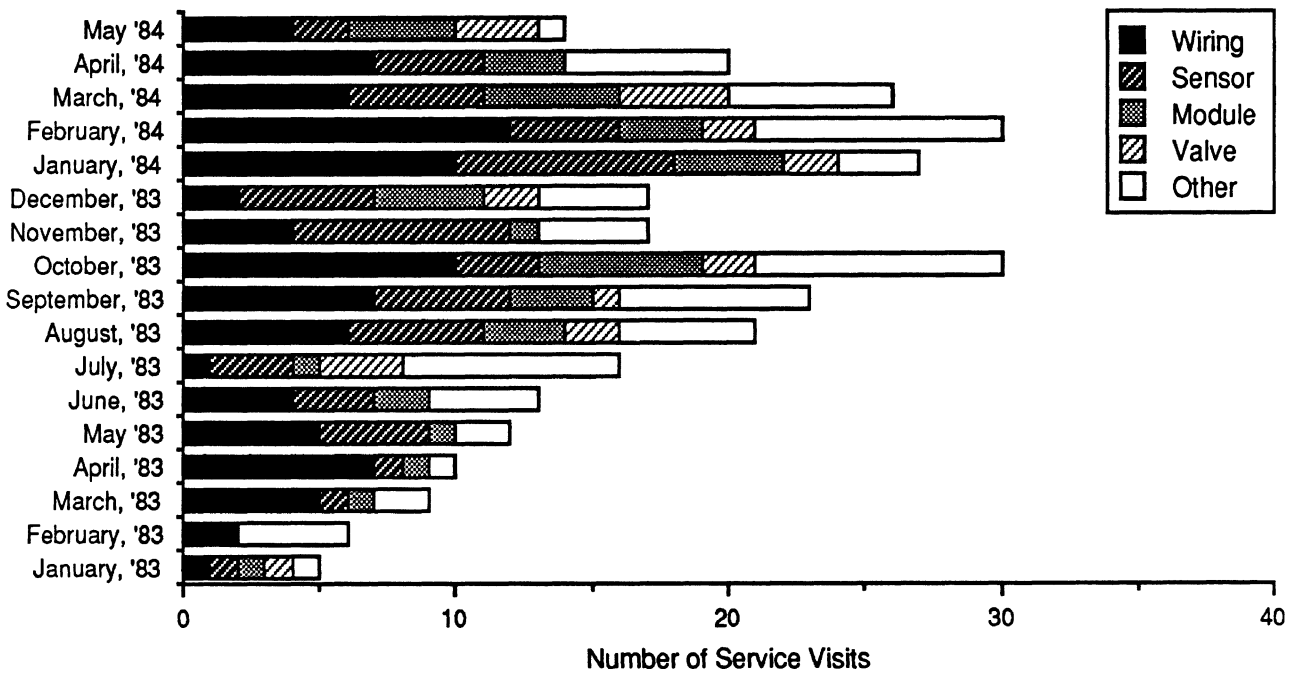
These results from the analog systems in the UK are 3 years old. Other information has been recently published [6]. Part of this information is from a survey of 14,860 warranty claims Crane Fruehauf experienced in the last 5 years. Of that number, 835 claims (5.7 percent) were for ABS-related problems. A study of a sample of 293 of these 835 claims shows that 93 were module failures (31.4%), 147 were sensor failures (50%), 10 were sensor adjustment (3.4%), 33 were valve failures (11.4%), and 10 were fuses (3.4%).

Population of Lucas-Girling Antilock Braking Systems in the field



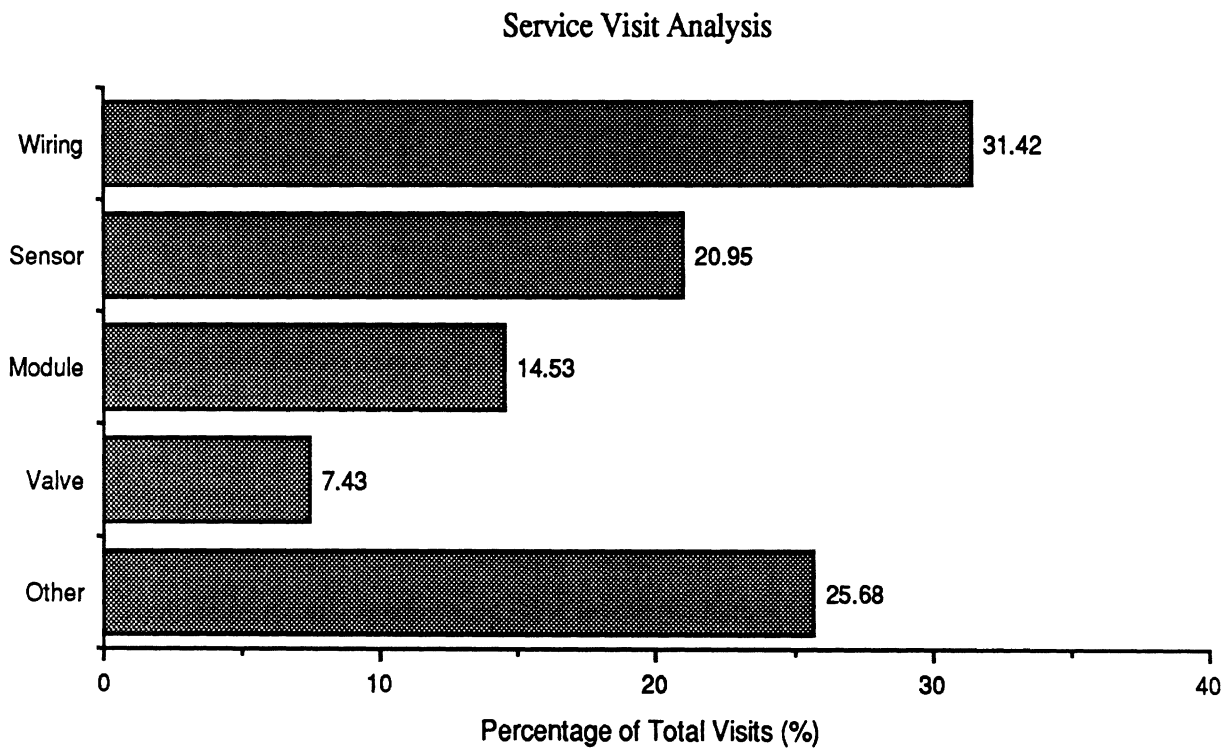
Data Source : Lucas-Girling { I. Mech. E paper [5] }

Service Visit Analysis



Data Source : Lucas-Girling { I. Mech. E paper [5] }

Figure 13. Service visits and the population of ABS.



Data Source : Lucas-Girling {I. Mech. E paper [5]}

Figure 14. Service visit analysis by component.

The percentages for valves, modules, and sensors are in approximately the same proportions relative to each other as they were in the earlier Girling survey of service calls.

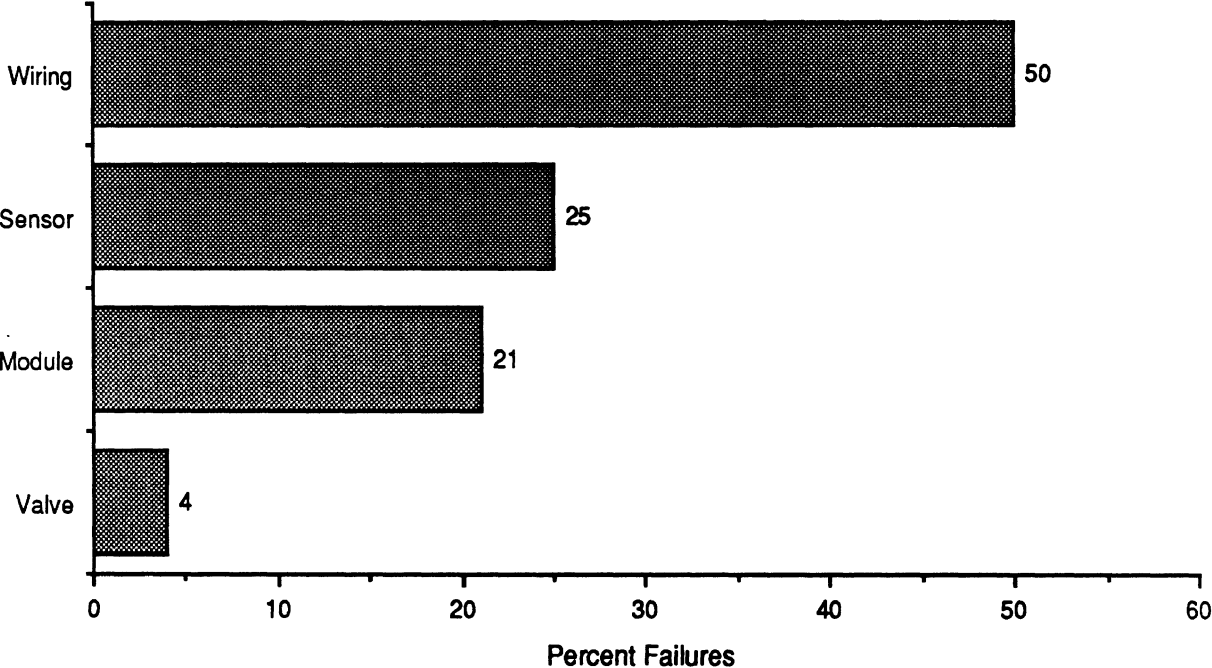
An ABS manufacturer in Germany gave information that indicates the reliability with which ABS components can be produced. These results are not indicative of all the problems in the field, of course, but they do indicate approximately the chance that a component with manufacturing defects will get out into service. Out of approximately 250,000 sensors in use 21 have been found to have defects. Similarly for approximately 250,000 solenoid valves 55 have been found to have defects created during production. Out of approximately 60,000 electronic control units 55 have been found to have production defects. In the last 4 years the percentages of ECUs returned from service (many of which do not have production defects) have been 0.25, 1.0, 0.35, and 0.15 percent (for example, out of 23,000 units produced last year 35 were returned).

Information on the field experience of the newer digital systems was obtained from surveys conducted by Daimler-Benz. (This information should appear soon in an SAE special publication.) By our estimates this information is based on approximately 40,000 heavy vehicles sold with ABS installed since 1982. The causes of failure are divided among components as follows: sensors 25%, cables and connectors 50%, ECUs 21%, and solenoid valves 4% (see Figure 15).

The percentages of ABS equipment failures in the vehicles produced by Daimler-Benz are illustrated in Figure 16. These data are influenced by both continual improvements made in the ABS and increasing numbers of failures of a long-term nature. The figure shows that by 1987 improvements in the design and construction of the ABS more than compensated for the longer term failures. Specifically, it is predicted that failures reported in 1987 will total slightly over 2% of the number of vehicles sold with ABS in 1987. As we understand the situation, Daimler-Benz states that the expected failure rate for vehicles produced in future years will be 1%. That is, 1 percent of new vehicles might be predicted to have a component failure.

Reliability information was sent to us from Australia. Records of component failures show the experience of 1801 heavy vehicles equipped with ABS. These vehicles were built by Daimler-Benz and they are equipped with WABCO ABS. Vehicles with ABS were introduced starting in mid 1983 and the population has been increasing since then, reaching 1801 by mid 1987. Out of 615 buses there have been 30 failures of ECUs (4.9%), 4 sensor failures (0.6%), and 3 failures of solenoid valves (0.5%). Out of 1186 tractors there have been 22 failures of ECUs (1.8%), 2 sensor failures (0.2%), and 4 failures of valves (0.3%). A number of the ECU failures were caused by welding (approximately 12 on the buses and 2 on the tractors). There were 28 failures for tractors in 4 years in which the population went from 0 to 1186, that is 2.4 percent of the vehicle population experience a failure.

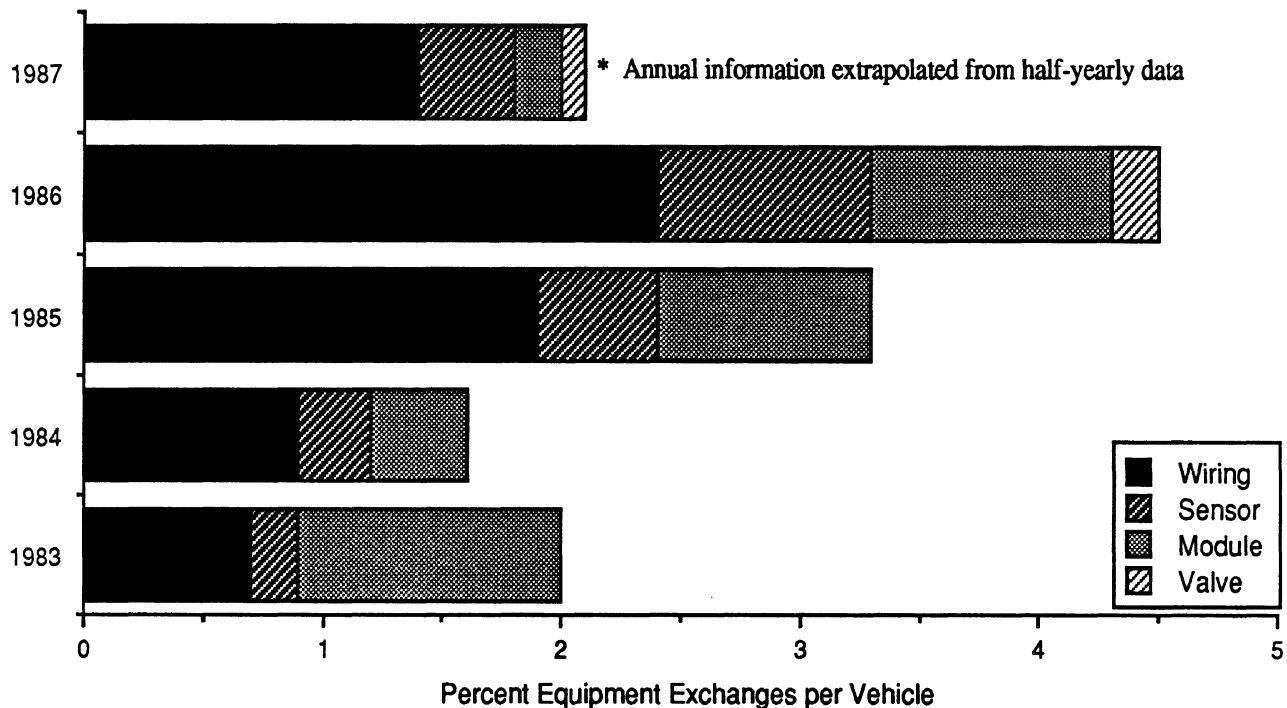
Percentage of ABS Failures by Component



Data Source : Daimler-Benz

Figure 15. Percentage of ABS failures by component.

Percent Equipment Exchanges per Vehicle



Data Source : Daimler-Benz

Note : Percent Equipment Exchanges per Vehicle is interpreted to reflect the number of failures reported each year divided by the number of ABS units sold that year.

Figure 16. Percentage of ABS failures by year and component.

Maintainability (Durability, Serviceability)

Very little maintenance is performed on the new systems unless the warning light comes on. There are many false alarms with regard to the warning light and it appears that the users develop strategies to deal with these occurrences. Some of the fleets have test gear for the systems but many of these test set ups have no provision for evaluating the ECU. If nothing else fails its check-out and the malfunction light is still on, then it is determined by the process of elimination that the ECU is bad. Users feel that some positive indication that the ECU is bad should be provided by the test gear. The users realize that they can not fix the ECU, but their trouble-shooting would be more straightforward if they could tell when it had failed. Given the intermittent warning indications, stored diagnostics would be helpful. We understand that some of the new ABS designs might include a feature in which the ECU stores the reason it turned on the warning light and by pushing a button the user can get a coded signal that identifies the type of failure.

If the ABS is serviced, much of it involves the sensors. Sensors are easy to adjust by pushing them gently against the rotors. Eccentricity in the wheel provides the desired clearance after a few wheel revolutions. Since the sensor is one of the few things that users can adjust to try to fix problems, they may get more attention than needed. On the other hand, sensor drying and adjustment seems to be the solution to some of the random warnings that occur.

The lack of maintenance requirements and lack of knowledge of the life of components makes it difficult for fleets to plan and to know when they will need replacement components and the funds to buy those components [6]. Service by the vehicle manufacturer can result in the vehicle being out of service for one or two days. Operating with the ABS off (the malfunction warning light on) can be used as a means for attempting to avoid the loss of the use of the vehicle.

Most of the evidence gathered indicates that the parts of the ABS are quite durable. Valves are reported to last 4 or 5 years like relay valves; however, Crane Fruehauf is reported as recommending changing valves once a year [6]. The wiring is subject to all of the problems experienced by any wires on a truck. Sheathing can and has been added to protect wires. In Australia, the indications are that fleets fix ABS wire and connector problems themselves whereas in Europe the fleets tend to rely on manufacturers to do this.

Performance

What does one mean by performance? There is no standard answer. Here performance is judged on whether the ABS does what it is expected to do from four perspectives: (1) an accident avoidance point of view, (2) the driver's point of view, (3) a cost savings perspective, and (4) fail safe requirements. Reliability issues have already been addressed.

There is limited information on accidents prevented by ABS. Indirect evidence of the belief in accident reduction is provided by the insurance rebates given in Germany. However, this seems to be based largely on a paper in which accident reductions were predicted using the measured performance of vehicles equipped with ABS [3].

Since the development of the EEC directives, performance of ABS has taken on new implications. The categories of ABS are defined in terms of performance. The identification of risks that are reduced and sometimes practically eliminated are now accepted. The risks reduced are those associated with trailer swing, jackknifing, and loss of steering control due to wheel lock. With ABS, stopping distance with the vehicle under directional control can be demonstrated on the proving grounds in obstacle avoidance and braking-in-a-turn maneuvers on slippery surfaces. Even on split- μ surfaces, safe and efficient stopping maneuvers can be demonstrated with the ABS functioning. In Europe the performance of the ABS as a safety device is demonstrated by these proving grounds tests and proven by analyses.

The driver is informed of proper ABS functioning by warning lights. The way these lights function has not been standardized among the systems, however. Depending on the system, lights tell the driver if the towing unit's ABS is malfunctioning, if the trailer's ABS is malfunctioning, if the trailer has an ABS, and if the driver has connected both cables to the trailer. At start up, the warning lights come on and go off at some prescribed sequence. Mr. Prost in France suggests that this sequence should be controlled by the driver. The lights should flash to indicate they are working. Then the driver should tap the brakes once to see that the systems are working properly and to hear the air system respond. He believes that the drivers may be too busy getting out of the yard to observe what the lights do the first time the vehicle's speed exceeds 7 kph or 5 mph. In this sense the performance of some of the ABS systems could be improved to make it easier for the driver to know that the ABS is functioning properly.

Also Mr. Prost recommends that only one cable be used to carry signals to trailers. This way drivers would not forget them and the extra warning signal would not be needed. This is an important issue given the numbers of cabling problems. It interacts with the suggestions that only ISO connectors be allowed. One ABS manufacturer suggested that existing US standards be modified to allow the ISO cable specifications. In any event, there are those in Europe that see the need to improve both the reliability and convenience of the cabling between units.

As indicated earlier, drivers are reported to like driving with the ABS operating. They believe that they can brake better and more safely on slippery surfaces. The ABS provides an indication of slippery road conditions by cycling the air pressure. If the driver can hear this and feel it in the brake valve, the system provides valuable safety information to the driver.

From a cost savings point of view, the ABS is not seen as being particularly beneficial. However, insurance rebates and tax advantages are being offered in Germany. Although accidents are very rare events, the avoidance of one property damage accident could pay for the ABS. Also, the avoidance of two wheel lock ups on dry surfaces could pay for the ABS in terms of tire wear, but wheel lockups are also very rare on dry surfaces. The ABS provides much of the hardware needed for ASR (wheel spin control). There are those that believe that the introduction of ASR will make ABS more attractive from a financial view point.

One of the basic premises of ABS is that the units will fail-safe. In February 1988, an article in *Transport Engineer* [6] describes a survey of 2270 heavy vehicles fitted with ABS in the UK. This survey found 17 cases in which the "fail safe" features of the ABS did not operate and the brakes did not work. Six of these were on a group of tractors that required a recall of the new digital systems produced in Germany. Of the 11 failures on trailers 5 of them were related to failures of Maxaret systems. Of these, 4 involved air dumping and no trailer brakes. These problems were corrected before further incidents could occur. Nevertheless, the presence of these problems indicate a potential problem and the need for drivers to check their brakes if the warning light comes on.

The new digital ABS has a diagonal feature in which only one diagonal at a time is shut down because of a malfunction. The other diagonal continues with normal ABS function which provides a substantial margin of directional control and stability compared to the vehicle without ABS.

Summarizing Example and Concluding Remarks

What might happen if 200 vehicles with ABS were placed in fleet service in the US? The previous information has been used here to make informed predictions.

Based on the data reported herein, one could anticipate between 1 and 5 malfunctions per 100 vehicles requiring repair actions in a year. Thus, 2 to 10 malfunctions might be expected in the fleet of 200 test vehicles that NHTSA anticipates studying. Half of these would be cabling or connector problems, i.e., 1 to 5; about 1/3 would be ECU's, i.e., 1 to 3; about 1/4 would be sensors, i.e., 1 to 2 probably.

A rash of problems might be caused by welding on vehicles if the control units become part of the "ground" of the circuit for welding.

A number of sensor malfunctions might be indicated if the fleet uses water under pressure in washing their vehicles. The experiences of some fleets indicate that more sensor problems may occur in areas with extremely wet or snowy weather. Sensor difficulties might easily be substantially more than that predicted above if all the vehicles are subjected to very severe service.

The warning lights might come on once in half of the vehicles in a year, that is, there could be as many as 100 times that the warning lights indicated a malfunction. (There also could be as few as 10 times.) If there were 100 warning signals, possibly half of them would go away by simply turning the ignition off and on. Sensor adjustment, cleaning, or drying might correct many of the intermittent or false alarms. This could be as high as an 80 percent correction rate in those cases not cured by turning the ignition off and on.

Vehicles without air dryers might have trouble in cold weather and suffer lack of braking in some cases. Vehicles using ABS with pneumatic logic may be more susceptible to this problem. Otherwise, very few control valve failures would be anticipated--maybe none. Vehicles with poor voltage regulation could have trouble with many false malfunction signals. Vehicles with poor wheel bearing adjustment will have improper sensor signals and malfunction warnings.

If the drivers have to connect an additional cable for the trailer's ABS, they will fail to do so on a few occasions. (One cable would be preferable.)

Drivers may complain of lack of braking if they can not hear the ABS operating. Also driver training could help the drivers to develop a "feel" for how the new systems work and to recognize previous situations in which they locked wheels to check for proper operation of the braking system. Drivers need to know that the ABS does not change normal braking and that once cycling starts they cannot get wheels to lock by pushing harder on the brake valve.

There seems to be a likelihood of many blown fuses. Circuit breakers might be used in place of the fuses if the frustration becomes too large.

A great deal of care in installing wiring and protecting connectors can go a long way to prevent troubles. If the vehicle manufacturer has not provided enough protection, wiring may need to be put in conduits or to be specially padded.

Sensor and excitor mounting can be a problem. Avoiding spray, exhaust fumes, dirt, and high stress locations on the axle will help to avoid difficulties.

Based on US accident rates, these 200 vehicles may have approximately 40 police-reported accidents in a year if they didn't have ABS. About 3 out of 200 tractor-semitrailers might have a trailer swing or jackknifing accident. If the German accident predictions apply, i.e., a 7% reduction, then the vehicles might have about 37 accidents instead of 40, but it would be impossible to ascertain statistically if the ABS made any difference. Possibly the lack of trailer swings or jackknives could be observed.

The driver may make 250 brake applications in a day's operation, based on average brake usage in Germany. About 2 of these might be severe enough to cause the ABS to operate. If this were the case, there would be approximately 40,000 ABS operations (200

vehicles x 200 days of operation x 2 ABS operations/day) out of 5 million brake applications for 200 vehicles in a year. Depending upon the type of fleet service, one might estimate that the number of braking events in the USA would be less than of that given above.

These predictions for 200 vehicles are much more optimistic than one would project from the previous 121 experiences in the USA. Even if these predictions are true, the author is not clear as to what is good enough. Those types of value judgements appear to have been avoided in Europe. They are just proceeding to try to provide better braking performance as reliably as possible. ABS manufacturers in Europe indicated to us that they were proud of the reliability that they have been able to achieve so far and they expect it to improve.

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APPENDIX

Letter Reports

From

Australia
France
Sweden
U.K., and
W. Germany

**HEAVY VEHICLE ANTILOCK BRAKING SYSTEMS
IN AUSTRALIA**

**J.R. Jarvis
Senior Research Scientist**

**DN 1579
Australian Road Research Board
March 1988**

INTRODUCTION

This report is the result of a contract from the University of Michigan Transportation Research Institute to the Australian Road Research Board. Its aim is to provide information on Australian experience which could support the National Highways and Transportation Safety Administration program to assess the practicality and reliability of anti-lock braking systems (ABSs).

The objective of the task is to document the experience of users with ABS fleets in actual revenue service. In addition, there is an indication of the level of usage of ABS systems in Australia including distribution by vehicle types.

ABS USAGE IN AUSTRALIA

Notification of the provision of ABS is not a requirement when vehicles are submitted for certification through the national Australian Design Rule system (although ABS may be reported and/or noted), nor does ABS form part of the registration particulars required by the various States. It is not possible, therefore, to obtain centralised data which give overall ABS usage throughout Australia.

The main anti-lock braking systems in use in Australia are the Wabco System, fitted to a variety of vehicles and used as standard in the Mercedes heavy vehicle range, together with the Bosch electronic/Knorr pneumatic system, used on M.A.N. vehicles for example.

Since information had already been obtained on Mercedes-Benz vehicles, further information was sought from the Australian distributors of Wabco, M.A.N. Automotive, and Bosch direct. The following are the known and proposed registration totals as at the end of 1987:

WABCO

Mercedes-Benz	Prime movers	1097
	Rigid truck	89
	Rigid city bus	350
	Art. city bus	65
	Long haul coach	200
M.A.N.	* Rigid city bus	50
	* Art. city bus	7
Other +	'B-doubles'	16
	Prime movers (inc. trailer)	12
	Trailers (semi and dog)	10
	Coaches	8

BOSCH/KNORR

M.A.N.	Art. city bus	40
	* Rigid city bus	100
	* Long haul coach	20

* Under contract, delivery imminent

+ Estimates only

Both Mercedes and M.A.N. report that all recent contracts for Australian city-buses have included ABS specifications.

THE USAGE SURVEY

Five companies known to operate vehicles with ABS were contacted and interviewed regarding their experiences with the system. Three interviews took place in Melbourne, Victoria and two in Adelaide, South Australia. The companies contacted were:

- . a medium size general haulier with several areas of specialised haulage
- . a distribution centre for a large petroleum company
- . a large city-bus operator
- . a large tourist coach line.
- . a large carrier with a number of dedicated contract fleets

The information was considered in four areas:

fleet operation
 reliability of ABS system
 maintenance of ABS system
 driver perceptions and other factors

The format of the remainder of the report will be to consider the responses from each operator separately.

MEDIUM SIZE GENERAL HAULIER

Contacts - Director, fleet operations
 Chief maintenance mechanic

Fleet operation

The fleet operation was general haulage; however, there was some specialisation into line haul, bulk commodity transport, particularly grain on drop frame trailers, local container and whole load deliveries.

The total fleet of 72 comprised 70 Mercedes-Benz, 1 Isuzu, and 1 International. The ABS vehicles figured as the major prime movers used for front-line operations:

M-B Model	Configuration	ABS	Fleet Total
2238	6 x 4	2) line	2
2228	6 x 4	4) haul	8
1625	6 x 2	6	6
1422	4 X 2	8	20

Six prime-movers (Model 1625) were fitted with lazy axles. In this configuration the ABS was removed from the driven axle and put on the lazy axle. The rationale was that without drive and with load transfer forward to the driven axle under heavy braking, the lazy axle was the most likely to lock up.

The company operated an average of 2.7 trailers per prime mover, but did not have ABS fitted to any trailer. The main trailer used, built by Freighters was not thought to lend itself to ABS installation, and it was felt that in any event the main consideration for Australian conditions was stability of the prime mover. Given the number of trailers involved, and the level of tractor-trailer mixing in operation despite the areas of specialised business, it would be difficult to match a limited number of ABS fitted trailers to suitable prime movers. Even if the whole trailer fleet were converted there would still be a high proportion of non-ABS prime movers pulling ABS trailers. While the cost of a trailer ABS conversion was not seen as prohibitive per se, costs for a whole fleet were large and even a part fleet conversion was not seen as really cost effective.

The six line haul vehicles cover approximately 300,000 kms per year and those on more local delivery (dependent on age of vehicle) approximately 60,000 kms/year. Most ABS vehicles are less than 3 years old, although one has already been sold out of the fleet after covering 1 million kms. The line haul load would be about 35 tonnes gross with virtually continuous full load running. Local delivery loads would usually be up to 29 tonnes gross and 30 per cent of the time (or distance) would be empty running. There is no difference between the operational requirements for ABS and non ABS vehicles.

All travel would be on sealed roads. Line haul vehicles would obviously operate at higher speeds and with fewer stops than for load delivery. Virtually no operation would be under snow or ice, the climate being temperate with moderate rainfall.

Reliability

Given a short time to settle into fleet operations there has been virtually no requirement for specific ABS repairs. One vehicle had electronic control problems from the time of delivery which were dealt with by Mercedes during the first few weeks of operation. Two vehicles also suffered interference between the CB radios fitted and the ABS operating system. This was rectified by changes to the ABS system by Mercedes.

Once these initial problems were solved, these, and all other ABS vehicles have been trouble free for a considerable kilometreage. Faults are so infrequent an accurate estimate of time of distance between malfunctions cannot be considered meaningful. The only reported faults have been on two model 1425s where intermittent false failure warnings have been given during wet weather. There appears to be no loss of ABS operation and the problem clears when the weather becomes dry. Moisture in the wheel sensors has been suspected. There have been no reported ABS faults in the last 6 months.

There is no special maintenance schedule associated with the ABS, nor is it formally checked as operable. The operation of the system is readily checked by the driver, either by a dash warning light or a trial heavy brake application with characteristic air release sequence. Any failure warning is reported on the next visit to the depot (nightly for local vehicles, every 3 days or so for line haul operations). The driver is instructed that if the ABS warning is signalled he is to confirm normal operation of his brakes and continue his trip. No delay to vehicles or goods has been experienced.

Maintability

Provided no dash warning light is given, no check for ABS operation is routinely made. No parts have been serviced or adjusted and none have been found to wear out. As to the life of ABS components, most ABS vehicles are less than 3 years old, but one vehicle has already been sold after 1 million ABS trouble free kilometres.

An initial introduction to ABS was given to the fleet mechanics and some in-house knowledge has built-up, but this has not been of a detailed nature due to the lack of problems. It is assumed by the mechanics that any major malfunction would be referred to Mercedes. No test kits were mentioned. The only apparent maintenance concession to ABS appears to be awareness of the need for care and disconnection and/or removal of electronic control gears before any electric welding is carried out on the truck. Standard brake linings have been fitted throughout the fleet and there is no difference in wear rates between ABS and non ABS vehicles.

Driver perception

The drivers interviewed, who drive ABS vehicles infrequently, found little or no difference in the braking behaviour of ABS and non ABS vehicles in normal service. Their general driving strategy was to reduce the need for heavy braking and neither thought they could recall having occasion to use ABS when driving equipped vehicles. One effect noted was when driving an ABS prime mover without trailer. A heavy stop had resulted in a 'pedal to the floor' situation in which full braking did not appear to be occurring, even though the vehicle stopped without incident or accident. The driver commented that there was a more immediate 'feel' to the braking with the same prime mover when the trailer was connected. Drivers tended to be dedicated to one vehicle or operation type and line haul or other more regular drivers of ABS vehicles had not been available for interview.

The fleet had suffered no major accidents in recent years, and monitoring of minor accidents had not suggested a significant difference in accident types for ABS or non ABS vehicles.

DISTRIBUTION FOR A LARGE PETROLEUM COMPANY

Contact Chief Mechanic

Fleet operation

The fleet comprised 17 petroleum tankers:

Prime mover	trailer	with ABS	without ABS
Mack 350 H.P. 6 x 4	triaxle	-	12
"	B-double	2	1
Volvo rigid	-	-	1
International	triaxle	-	1

ABS is only fitted to the 'B-double' combinations and was specified to maximise the safety of B-doubles when they were first being introduced into South Australia. The fleet had an established history of Mack prime movers, thus Mack were commissioned to fit Wabco ABS to the B-double configuration as part of the initial construction of the vehicles. The axles fitted with ABS were:

- . steer and both drive axles of prime movers
- . leading and rear axles of triaxle semi trailer
- . both axles of the rear trailer bogie.

The operation of B-double type vehicles is via a permit to travel on approved routes and in this case is usually line haul with bulk delivery to other distribution centres. There is some local delivery, however, to large capacity service stations sited on approved routes. Due to the nature of the load, approximately 50 per cent of running is empty.

One unit is a little over a year old, the other almost 2 years with each having an annual kilometrage of approximately 250,000. Similar kilometres are covered by other line haul vehicles, both the other B-double and triaxle trailers. Older vehicles, often relegated to local deliveries can average as low as 20,000 kms a year.

B-double gross weights are approximately 56 tons and the permit for operation covers only one combination of vehicles, thus trailers cannot be interchanged. Indeed, drive-in, drive out facilities at most delivery points mean that the units are rarely separated. The type of operation is generally over flat terrain, the climate generally being hot and dry with little operation under slippery conditions. An exception is during and immediately after rain which follows a period of dry weather.

Reliability

Once the vehicles had been settled into service there were no major faults requiring repair. No spares are kept for the system and none have been needed until recently when sets of connecting plugs were ordered. The parts requiring most attention were the plugs carrying the ABS signals between the various units of the B-double. The system was separately wired using dedicated plugs and these were sometimes crushed through mishandling by drivers or at depots, or water entered the plugs and caused shorting out. Water was a particular problem when the vehicles were run through high pressure washes, a frequent procedure under company policy. To date, crushed plugs etc. have been repaired in-house, but one set, although operating, now requires replacement. A spare set have been ordered but the matter is complicated by the fact that the Wabco system installed is 12V to match the Mack electrics and the plugs are therefore different to the normal 24V type stocked by Mercedes Agents and must be obtained from Wabco direct. The only faults reported have been false warnings invariably associated with the plug problem.

No special maintenance schedule is adopted for the ABS system. The driver reports a warning light of ABS malfunction on his next return to the depot and the matter is investigated. Wabco provided a full system testing kit and demonstrated its use, but to date this has not had to be used since all faults have been the result of obvious mechanic damage or the effect of water, usually involving the plugs.

Deliveries have never been delayed as a result of an ABS warning or failure, and although both vehicles are fitted with CB radios there has been no report of interference.

Maintainability

The anti-lock braking system is not viewed as a maintenance item. It is exceptionally dealt with if a fault is reported by the driver via a warning light. If no fault is reported the system is assumed to be operating correctly. There is no formal checking, either by driver or maintenance staff as to whether the ABS system is actually operational. No parts are routinely adjusted or serviced, no parts have been noted to wear and the plugs already mentioned are the only parts to date that were required replacement, due to damage in service.

The major change to maintenance procedure as a result of ABS has concerned brakedrum replacement. For other Macks in the fleet, replacement drums are held in stock and simply changed during a brake reline etc. With the ABS sensor ring fitted to the drums, changeover drums are not held. The drums are removed, sent for resurfacing and returned during one maintenance shift, with the cooperation of the local brake service shop. Thus maintenance is still carried out within the normal maintenance period, but it does require a little organisation and cooperation with the local brake agent. The ABS equipment has not provided any other problems during brake relining procedures.

Driver perceptions

An early problem with apparent ABS failure was a driver concern that normal braking was also affected. This misconception was soon overcome by educating the drivers in the operation of ABS.

A positive benefit noted by drivers concerned the bogie of the rear trailer. Since up to 50 per cent of operation was empty, it was found to be very easy to lock the rear bogie of the second trailer even in dry conditions. This has been removed by the use of ABS but is the only major difference noted, there being no difference in braking characteristics under normal stopping conditions.

STATE TRANSPORT AUTHORITY

Contacts

Chief Mechanical Engineer
 Technical Supervisor (bus maintenance)
 Electrical Services Supervisor (buses)
 Bus Services Superintendent (drivers)

Fleet operation

This State Transport Authority operates a total fleet of some 750 buses, the main elements of which are:

Bus type	ABS	Non ABS
Volvo rigid	-	280
Volvo articulated	-	120
Mercedes rigid	41	-
Mercedes articulated	51	-
M.A.N. articulated	40	-

The Authority currently operates 12 kms of bus guided expressway (O-bahn) with a further 12 kms to be opened in 1988. The Mercedes buses are dedicated to O-bahn use, the O-bahn section representing some 20 per cent of the overall route length for these buses. Buses fitted with ABS were an integral part of the O-bahn installation to ensure that under any necessary heavy braking speeds of up to 100 km/hr there would be no loss of control of the rear of the bus. Any sideways movement would allow the bus to collide with the guide rails of the expressway which are necessarily in close proximity to either side of the bus.

ABS has been specified for the M.A.N. buses to keep open the option of using them on the O-bahn at some later date if required. M.A.N. vehicles have been in service for approximately 6 months. As already pointed out in the introduction, Mercedes buses use the Wabco ABS while M.A.N., for the SG280 in service, use the Bosch/Knorr system. From a maintenance and repair point of view, the Authority engineers had no problems dealing with the two systems since in control and operation they were almost identical.

The Mercedes buses have been in service for two years. The average life of buses is 13 to 15 years, and they generally cover about 50,000 kms per year. The climate is hot and dry and terrain generally flat although some services have to negotiate an extremely long steep and winding grade on the outskirts of the city. Interestingly, the buses used in these cases are articulated, but non-ABS Volvos. Apparently, heavy use is made of the retarders in the automatic gearbox to reduce the braking required during a descent. The general use of retarders is thought to increase the brake life of a bus threefold or more, and were a very popular feature with the engineers.

Reliability

Both Mercedes and M.A.N. vehicles had problems when ABS was initially introduced into service. Some M.A.N. vehicles were supplied with poorly fitted wheel bearings which allowed axial movement in the wheel, particularly during cornering, which in turn resulted in a false warning due to excess sensor/ring clearance. Once located the problem was readily cured and apart from a few sensor retaining clip breakages, the ABS system fitted to the M.A.N. vehicles has operated largely without problem since.

Similarly, early Mercedes buses gave a number of false warnings. When a full check was run on the system nothing was found to be amiss. It was found that if the ABS was switched off for 30 secs or so and then restarted, this resetting of the control module would remove the false warning. The problem appeared to be worse during hot weather and a high temperature problem with the control units was suspected but could not be confirmed. The control units are mounted at the front of the bus in as cool a place as possible, but there are a large number of such modules, for a variety of functions, all vying for space and ideal siting is not always possible. Some difficulty was experienced with alternator output and it was known that voltage could be unreliable. Other modules, such as gearbox controls had had problems, so this was also suspected as a possible cause for the false ABS warnings. The problem has now largely disappeared, but maintenance staff feel that drivers may be resetting the false warnings as a matter of course to some extent and not reporting the fact.

Actual defects with the 92 Mercedes buses which have been in service for nearly two years have been remarkably few. Ten control units have been changed, only half of which were definitely faulty. Similarly, possibly 20 wheel sensors have been replaced, but half of these were as a precaution after a minor fault.

To date, valving has not caused a problem in either type of vehicle, but for longevity of the system, the need for clean, dry air in the system was stressed, with the use of a proprietary heater.

No specific maintenance schedule for ABS has been necessary, action only being taken on the report of a warning light from a driver, firstly over the radio phone to the depot and then on his service sheet on return.

All vehicles are fitted with radio phones but no interference has been experienced with ABS. In recent times, due to the variety and complexity of the electronic systems, all cable specifications have included full sheathing. In the early days of electric control gearboxes a phone call to base has been known to change gear from second to top (not with present ABS buses)!

Maintainability

Very little in the way of routine ABS servicing is carried out on either bus type. Examination of recent fault reports indicated that there had been no ABS faults reported on any of the 132 buses in the previous 4 months, representing something over 2 million veh/kms.

Testing kits are available and have been used when necessary. Both companies sent representatives to the Authority to introduce their buses, but the point was made that with the intimate contact the maintenance staff have with the vehicles, they soon build a wealth of knowledge about the buses and can often contribute to the manufacturers understanding of their operation. None of the initial ABS problems were referred to the suppliers for solution, all were dealt with in house. Regarding ease of service, no drive axle sensors were easy to access, but the rear axle of the M.A.N. was particularly difficult since the brake chambers had to be removed.

With the present age of the ABS fleet it is difficult to comment on the life of an anti-lock system. The systems do not exhibit wear in any of their components, it may be general wear in the bus which affects ABS operation. However, it was pointed out that wheel bearings, for example, rarely need replacement, and normal maintenance tolerances will meet the requirements of ABS.

A policy of holding minimum spares levels results in a total of 3 control units together with a sensor for each vehicle type at each of the two depots from which ABS vehicles operate. It was a complaint that neither type of control box could be tested for faults. If a fault was signalled and could not be corrected, all other components were checked and, if operational, then the control unit was changed. Although easily replaced in the vehicle they are expensive and it was felt that some form of testing procedure for control units should be possible.

Those interviewed with responsibility for controlling the servicing of the bus fleet had 40 years and 23 years experience. They pointed out that in the last 15 years bus technology has advanced at an extremely fast rate. There is far greater complexity of operation with electric gear boxes, hydraulic anti-jackknifing equipment, articulated drive trains, etc. Servicing techniques have changed to meet these needs, and ABS is just one other set of components, and a set that appears to give very little problems.

Driver perceptions

Driver reaction to ABS appears to be quite different at the two depots which operate ABS buses.

The first depot is one dedicated to Mercedes buses having ABS. These are the buses which run on the O-bahn bus expressway. Training for expressway driving was comprehensive, including 'hands off' running and protection of the protruding guide wheels during normal running. A significant part of the training was a complete

familiarisation with ABS including demonstrations, lectures and video presentations. There had been considerable driver concern regarding safety should heavy braking be necessary within the confines of the expressway, and ABS was promoted as a solution to the problem. Consequently there is high driver awareness of ABS at the depot. All drivers use ABS equipped buses all the time, and a number of incidents have been reported where drivers consider that ABS has prevented an accident or near miss under normal driving conditions. At least two heavy brakings have been necessary on the expressway and each was completed safely.

At the second depot the 40 ABS equipped M.A.N. buses form part of a 200+ fleet of 5 bus types used by over 400 drivers. The ABS system was included as part of the introduction to the buses when they were brought into service, but not given undue emphasis. There is random bus/driver rostering so any one driver is likely to drive a M.A.N. vehicle only infrequently. It was the opinion of the maintenance staff that there was little awareness of ABS amongst these drivers and few would have experienced ABS in operation.

The Authority has an accident monitoring system which routinely checks for changes, trends, etc. in reported accidents. Although never specifically addressed, there appears to be no evidence of a different accident pattern between ABS and non-ABS buses.

LARGE TOURIST COACH LINE

Contact

Fleet Operations Manager

Fleet operation

Tourist operation means daylight travel only, frequent stops for meals, sight seeing etc. and results in a relatively low average of 80,000 kms travelled per year. A wide variety of road conditions are experienced, however, with a considerable amount of travel on unmade gravel roads into the more inaccessible parts of the Australian outback. Although daily distances covered do not compare with inter-city express type operations, where conditions permit the road speeds maintained are similar to line haul operations. Conditions are generally dry and hot, however unmade roads result in loose and often slippery surfaces.

The coach fleet comprises:

Coach type	ABS	non ABS
48 seats	33	29
50 seats	18	-

Most coaches are built on a Mercedes Benz 0303 chassis although some older models are of Denning construction. For the ABS coaches the system is fitted to the steer and drive axle. In addition there is a single wheel trailing axle which operates under reduced pressure and is linked into the drive axle ABS system. Thus if the drive axle is protected from locking by ABS, so is the lazy axle. There could be occasions, however, when the trailing axle might lock without the drive axle and consequently

without the protection of the ABS system.

Vehicles are kept in the fleet for approximately 5 years. The first ABS vehicles were introduced in mid-1985 and are approaching 800,000 kms.

Reliability

Early problems were in part due to inexperience with the system, not helped by the inability of Mercedes to supply an ABS test kit for some months after the delivery of the first vehicles. Kits were eventually made available and are now held at depots in Melbourne and Sydney, out of which most of the ABS vehicles operate.

The initial problem was the entry of dust into the brake shoe area through a hole in the back plate. Much of the operation being on unmade roads, conditions were often very dusty. Although not normally a problem with conventional brakes, the dust coated the sensor ring and rendered the anti-lock system inoperative.

Once the hole was plugged, and dust excluded, the anti-lock systems have been very reliable in service with very few reported faults.

Two control modules were replaced under warranty and perhaps 6 sensors or the associated looms have been replaced. The arduous unmade road conditions, suspension movement, vibration, etc. appears to have resulted in mechanical failure of several sensor looms. There have been few, if any, reports of ABS failure in the last 6 months.

Drivers are instructed to check conventional braking if a warning is signalled and report the fault at the earliest opportunity. No coaches have been delayed as a result of an ABS failure.

CB radios are not fitted, there has been no known interference between the ABS system and the public address system used in the coach.

Maintainability

All the company mechanics were sent to the Mercedes training centre to familiarise themselves with ABS. All maintenance is carried out in house, including brake drum machining and relining. No special maintenance procedures have been adopted for ABS. High standards of maintenance are considered important, but it was felt that the tolerances required for normal servicing were sufficient for ABS operation. Only parts which have a steady turnover are stocked, none of these being ABS parts. Emphasis was placed on the high level of engineering on Mercedes vehicles and doubt expressed as to the serviceability of heavy vehicles of less sophisticated manufacture. Good service life was obtained from brakes and there appeared to be no difference between ABS and non-ABS vehicles. Emphasis was placed on the need for a clean air system to prevent contamination and damage to valves. The ABS valves have proved trouble free, but contamination may be more important as the vehicle gets older.

Driver perceptions

It is an understandable part of company policy to accentuate the need for safe operations. The ABS feature of the coaches is used in company advertising. It is company policy to make drivers aware of all the benefits provided by the vehicles they have to drive. Drivers are shown a video of ABS in action, given an explanation of system mechanics and shown the hardware in the workshop.

Drivers are generally given the same coach for a season, perhaps more, and those with ABS vehicles are conscious of the fact and appear to have more confidence. There was nothing to suggest, however, that drivers changed their braking behaviour if they did have to move between ABS and non-ABS vehicles. Drivers are encouraged to report all driving 'incidents' as well as accidents and those drivers that have experienced ABS in action are generally good supporters of the system. A number of incidents have been reported where potential accidents have been avoided by the use of ABS. Some drivers reported that on heavy braking their impression was that they were not going to stop even with maximum pedal pressure but that the vehicle had indeed stopped quickly and without drama.

Accident records were not to hand, but the impression was that minor front-end accidents had been reduced, and the company certainly felt that ABS had repaid its initial cost. The point was made, however, that this was for a large fleet with a variety and changing set of employed drivers. Benefits might be more 'invisible' to a small fleet where ABS incidents were few and far between.

LARGE CARRIER OF DEDICATED CONTRACT FLEETS

Contacts

Divisional Fleet Manager
Assistant Service Engineer

Fleet operations

The company had a total of approximately 650 vehicles of a variety of types and manufacture. The more recent acquisitions had tended to be Scania or Mercedes Benz. Of the 120 Mercedes in operation, 50 were fitted with ABS, 25 prime movers and 25 rigid vehicles. All ABS vehicles are two years old or less. None of the trailers used with the prime movers, mainly Maxicube or Freighters, had ABS fitted. Average kilometreage is of the order 100,000 per year, mainly intra state and metropolitan delivery. Vehicles and drivers are generally dedicated to contract fleets for individual customer companies. Usual loadings are 38 tonnes for prime-mover/semi-trailers which run approximately 35 per cent empty - and 12 tonnes for rigid vehicles which run 40 per cent empty.

Reliability

With a total fleet of 650+ vehicles, and a relatively small mechanical workshop of less than 15 which concentrates on major repairs, much of the routine servicing and minor repair work is carried out under contract, usually by the manufacturer of the truck or their agents. However, the fault reporting process is through a defect report sheet which is processed by the company service centre, through to the servicing agents if necessary. Since the introduction of ABS into the fleet, less than 5 vehicles have had to be returned to Mercedes for work on the system, and none for a major fault. These returns were usually arranged to include a routine service, resulting in little or no lost time associated with ABS.

A number of the vehicles have two-way radio installed, and there have been no reported cases of interference between radios and ABS systems.

Maintainability

Due to the contract nature of much of the servicing, ABS is largely 'invisible' to the company with regard to maintenance procedures. No testing equipment is held and no spare parts stocked. There is no intention to change this policy in the foreseeable

future. All aspects of ABS maintenance or repair would be referred to the service agents.

Driver perceptions

The introduction of ABS into the fleet appears to have been largely by default as the system became available as standard on Mercedes vehicles. Drivers are made aware that the vehicle has ABS and that any warning of faults should be reported, but generally there is little emphasis placed on the system. There is transfer of drivers between vehicles, but this is usually within any given contract fleet, and the ABS vehicles are largely confined to two such fleets. These fleets were at dispersed centres and it was not possible to interview drivers direct. The company opinion appeared to be that while drivers may be aware any given vehicle had ABS it was unlikely that this would affect their braking behaviour, and there had been no specific reports of ABS braking incidents.

CONCLUSIONS

A varied range of heavy vehicle fleets was examined containing a total of some 250 ABS equipped units. Fleet size varied between 17 and 750 vehicles and the ABS content within these fleets was from 2 vehicles to 140. There was a variety of vehicle configurations, from B-double combinations through articulated buses to 12 tonne rigid trucks. Two applications of ABS were specifically introduced to overcome possible braking difficulties - the introduction of B-double operation and buses running under guided expressway conditions. There appear to be few trailers fitted with antilock braking equipment; either by default or choice most operators rely on the ABS of the prime-mover to provide improvement in drive axle control under heaving braking, to reduce the likelihood of jackknifing for example. Most Australian ABS vehicles are three years old or less and few have covered the distances required to test the ultimate life of an ABS system. One vehicle has already been sold from its original fleet, however, with 1 million ABS trouble free kilometres to its credit.

In-service experience has been very much the same for all fleets. After a variety of initial 'teething' problems, the systems have settled down to virtually trouble free operation. Early problems were associated with faulty vehicle adjustments on delivery, the ingress of dust, mechanical damage to connector plugs and sensor looms, and control module replacement. Once the systems had settled down, plug damage remained a problem, and sensors were the parts, if any, that required attention. None of the fleets experienced any delays to their operations as a result of ABS faults.

All fleets hold either the minimum of spares or none at all, and repairs are carried out on a demand basis, based on reports of a malfunction warning from the driver. Apart from 2 associated instances in early installations, there have been no reports of interference between radios or other electrical equipment and the ABS system.

There were no formal maintenance schedules associated with ABS in any of the fleets interviewed. The system was assumed to be operating unless a warning light was displayed and there were no routine checks made to establish whether this was the case. One company made special arrangements for a quick drum reconditioning turn-round, but this was the only concession made to ABS during routine maintenance by any operator. To ensure the long life of ABS systems, an emphasis was placed upon high initial engineering standards from the manufacturer, adherence to maintenance tolerances and the need for a dry, uncontaminated air system.

It was clear from discussions with maintenance personnel, often with many years of experience, that truck, and particularly bus technology had become more complex over recent years to an extent that ABS was considered just one more system, and a relatively trouble free one at that.

Driver awareness of ABS seemed to be linked directly to the company's commitment and their own exposure to the system. Where drivers regularly used ABS equipped vehicles and the company actively promoted the system, drivers appeared to respond and perhaps gain confidence from a knowledge of the equipment and its benefit. In contrast, where drivers only infrequently drove ABS vehicles and the company did not place any emphasis on the system, drivers did not seem aware of the benefits of ABS or indeed aware of the system itself.

Although available accident records were neither detailed nor extensive, little difference was reported between the accident record of ABS and non-ABS vehicles, although one operator commented on a perceived reduction in front end damage for ABS vehicles.

Two aspects of ABS braking were particularly mentioned by several drivers. There was an apparent lack of braking under heavy application where no additional braking effort seemed forthcoming as pedal pressure was increased. This perception was held despite an admitted efficient and uneventful stop. ABS was also reported to eliminate the lockup of the remote rear axle on B-doubles and articulated buses under lightly loaded or empty conditions which was experienced by similar non-ABS vehicles, even in the dry.

Despite its recent introduction into the Australian heavy vehicle fleet and some early 'teething' problems, those operators interviewed consider ABS as virtually a 'fit and forget' system and just another of the many new technologies introduced into the industry over recent years.

USER EXPERIENCE WITH ABS
IN HEAVY VEHICLES IN FRANCE

INTRODUCTION

As part of the overall effort to obtain information on user experience with ABS in Europe, meetings were arranged in France for Mr. Fancher with two of the major users of ABS, Air France and Prost Transport. A meeting was also arranged with Bendix France, a supplier of ABS for trucks and buses through Renault VI (Industrial Vehicles).

Because of the limited experience with ABS in France, attempts to arrange meetings with other fleets were unsuccessful. One trucking company, Geraud Transport, Paris, for example, declined to be interviewed because--as the President of the firm said--the company's experience with ABS was so limited that it would be impossible to provide any significant data on performance and reliability.

The effort in France also involved making all the arrangements for Mr. Fancher's visit, including setting up the meetings with ABS users suggested by experts in France, Switzerland and England,

ensuring that the language barrier would not be a problem, making hotel reservations for Mr. Fancher, arranging for the trip to Rennes and helping Mr. Fancher understand the very real differences between the trucking industry in France and those of other countries, particularly the United States.

OVERVIEW OF ABS IN FRANCE

It is generally known that the French experience todate with ABS is limited.

Less than 3% of the heavy-duty vehicles in the country are equipped with some form of anti-lock braking and of those the majority are buses and coaches.

According to figures supplied by Bendix France, less than 1% of the total heavy-duty truck PARC is equipped with these devices. Bendix itself has only about 70 ABS truck ABS units operating in France, which is a relatively small number compared to the units it has sold in Britain, for example.

In addition, the vast majority of the limited number of ABS-equipped trucks have been operating for no more than two years.

These figures will change in the near future with the introduction of mandatory anti-lock braking regulations announced by the European Economic Commission, but at this point France is among a group of "southern" European nations, which includes Spain and Italy, where ABS is a relatively new device for trucks.

AIR FRANCE

Air France operates a shuttle bus service between Paris' two major airports and the downtown area. The trips take the buses along high-speed highways and city streets, but the vast majority of time is spent in slow-moving, stop-and-go traffic. Company officials also pointed out that these buses operate frequently in adverse weather conditions, i.e. rainy weather.

The company uses 51 buses to shuttle passengers to and from the airports and 39 of these buses are equipped with ABS. There are 15 Wabco systems that are more than two years old and over the past two years Air France has purchased an additional 24 Wabco and Bendix units. (It should be noted that Air France does not make the decision on which type of ABS will be installed on a particular bus. Renault VI, which builds the FRI bus Air France uses, makes that decision. The cost, however, remains the same: 17,000 FF, or approximately \$3,000 at current exchange rates.)

The total fleet of ABS-equipped buses has recorded some 4,300,000 kilometers, according to Air France officials, with "only two or three problems" and no accidents. They said the problems they have experienced were related to sensor components and "the leads to the sensors".

The three fleet managers interviewed for the study said they knew of no instances when the warning light for the ABS

had malfunctioned. When asked how they could be sure, they explained that the company has a complaint book for drivers and they are required to note any malfunctions. None have done so regarding the ABS warning lights, they said.

In terms of maintenance, Air France is following the advice of the ABS manufacturers, which is to not touch the system unless there is a problem. "The less you touch it," one official said, "the less chance of problems."

When the few problems that have occurred arose, Air France did the repairs itself using a trouble-shooting information sheet provided by the ABS manufacturers.

They said they have observed no improvement in tire wear and that it is difficult to tell if ABS is extending the life of brake linings.

The officials also did not claim that the ABS system was the major factor in the record of no accidents by ABS-equipped vehicles in the fleet, which they nonetheless believe is statistically important. The new FRI buses, which have been equipped with ABS, have a very good braking system, the officials pointed out, and this is probably a major reason for the good safety record of these buses.

When asked if ABS is cost effective, one official responded: "Jamais!" ("Never!"). Still, he quickly added that he would only purchase buses equipped with ABS.

PROST TRANSPORT

Prost is a general freight haulier in Rennes, France, that offers overnight package delivery, as well as other more traditional trucking services in France and Belgium.

The company places great value on safety and, indeed, has a reputation throughout Europe as a safety-conscious company.

Michel Prost, chief operating officer for the company, embodies the company's concern with safety. He agreed to be interviewed for the study and also submitted a lengthy reply to Mr. Fancher's questionnaire that was sent out before his trip to Europe.

The Prost fleet includes more than 300 heavy-duty tractors (very large by French standards), of which more than 200 are equipped with ABS. The total fleet of vehicles, which includes small local delivery vans, logged about 31 million kilometers last year, or about 19 million miles.

Prost has both Wabco and Grau Girling ABS units and said he had had no serious problems with either. He prefers the Grau-Girling system, however, because of the testing sequence

used to check the ABS at the beginning of a trip. With the Grau-Girlinging system, a light flashes on the ABS warning panel in the cab when the key is turned for the first time. It flashes again when the brake is touched for the first time. If the lights both come on in response to these actions, then the system is operating properly. With the Wabco system, the light comes on when the key is turned and then again when the vehicle reaches a speed of 15 kilometers. According to Mr. Prost, however, the driver has better things to do when he reaches that speed than to check on the ABS warning light. He also prefers the Grau-Girlinging system because it is more "active". The driver is more involved and is sure the system is operating properly before he begins to move.

"This is a very important aspect of the system and I would like to see it standardized," Mr. Prost said.

(In a demonstration after the interview, however, two of four systems in randomly selected vehicles failed to operate properly during the start-up test. One failure was never explained. For the other, according to Mr. Prost, it was a blown fuse that caused the light to not come on when the driver turned the ignition key. Mr. Prost said that the company has started replacing all its fuses with heavy-duty types to prevent this kind of problem.)

According to Mr. Prost, the company has vehicles equipped with ABS that have been operating for more than two years without incident. In fact, he said, he has not had any serious ABS-related

malfunction in any of his vehicles.

Mr. Prost also follows the manufacturer's advice on maintenance practices. He does not touch the ABS components unless there is a serious problem indicated by the warning lights. He said, however, that a visual inspection is made during routine preventive maintenance for other components. In addition, twice yearly government inspections are required in France, which include braking tests.

Mr. Prost said that the company was so pleased with the performance of ABS that it plans to incorporate acceleration anti-skid devices as part of its specifications for new trucks starting this year. Later, he said, the company also plans to buy mini-cam video cameras, which will be installed on the rear of trailers to give drivers a better view behind them both in parking and city traffic situations.

Mr. Prost said that he did not believe ABS is cost effective in terms of savings to other components such as brake linings and tire wear. But he too said he would not want a truck not equipped with ABS.

CONCLUSIONS

The experience in France with ABS is so limited in terms of both the number of trucks equipped with these devices and the time period that they have been operating, that it is hard to draw

hard statistical conclusions. The evidence is at best anecdotal. The systems, according to those interviewed, seem to be working without flaw, despite the fact that during the one impromptu demonstration, two out of four start up tests ended with the system malfunctioning.

It's fair to say that the feeling the owners of ABS in France have is that the systems work and are reliable and don't require any? maintenance. That, with a few minor exceptions, is what we were told in France.

THE USE OF ANTILOCK BRAKING SYSTEMS (ABS) ON HEAVY TRUCKS AND TRAILERS. AN INTERVIEW INVESTIGATION

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INTRODUCTION

The information concerning ABS reported here has been gathered by means of telephone interviews with technical managers and owners of trucking companies in Sweden and Norway selected at random from lists delivered by the Swedish truck manufacturer Volvo and the ABS-dealers WABCO, Hova, FOMA, Ängelholm and the Norwegian vehicle accessory dealer MoRek A/S, Oslo.

SCOPE

Gathering of information concerning the reliability, maintainability, trucking environment and performance of ABS equipped heavy trucks and trailers from two or more fleets including one that uses Bosch ABS.

METHOD

- 1) Gathering names of trucking companies with ABS-equipped vehicles from truck manufacturers and ABS-dealers
- 2) Sending questionnaires to selected trucking companies
- 3) Telephone interviews with technical representatives of these companies.

RESULTS

0 TRUCKING COMPANIES

- A Kinnarps AB, Falköping Sweden
- B Termotransport AB Kristianstad Sweden
- C Majortrans A/S Oslo Norway
- D Troms Innland Rutebil, Finnsnes, Norway
- E Tor Fossberg Transport, Rasta, Norway

1 VEHICLE FLEETS

COMPANY A : Kinnarps AB, Falköping, Sweden

Vehicle fleet:

1	two axle Volvo F10 tractor	WABCO 4 channel ABS	1983	240 000	km
2	two axle Volvo F10 tractor	WABCO 4 channel ABS	1984	180 000	km
5	two axle Volvo F10 tractor	WABCO 4 channel ABS	1985	120 000	km
5	two axle Volvo F10 tractor	WABCO 4 channel ABS	1987	20 000	km
1	two axle Scania tractor	WABCO 4 channel ABS	1987	20 000	k

19 one axle van body semitrailers WABCO 2 channel ABS 40 000 km/year
5 one axle dollies with WABCO 2 channel ABS 50000 km/year
All vehicles are equipped with VBG 14 pin trailer connector
— common for lighting and ABS.

Total amount of driven km for the ABS trucks 1020 000 km

Total amount of km for the semitrailers about 1000 000 km

Total amount of km for the dollies about 500 000 km

COMPANY B : TERMOTRANSPORT AB Kristianstad, Sweden

8 three axle Scania 140 van body trucks, Bosch 4 channel ABS,
ISO electric trailer ABS connector, GWW 24 000 kg
total mileage 1900 000 km, time period 1985-1988

Individual milages: 440, 420, 300, 250, 200, 180, 100 and 8 thousand km

8 four axle BRIAB van body full trailers, Bosch 4 channel ABS,
GWW 32 000 kg, total mileage 1900 000 km, time period 1985-1988

As the trailers always run together with the same truck the
individual milages are the same.

The van bodies of all vehicles are refrigerated.

COMPANY C : TROMS INNLAND RUTEBIL, Finnsnes Norge

1 three axle Mercedes Benz MB 1938 van body truck, WABCO 4
channel ABS GWW 23500 kg, Mileage 650 000 km 1982-1988

2 three axle DAF 3300, van body truck, WABCO 4 channel ABS
ISO ABS trailer connector, GWW 23500 kg,
Mileage 480 000 km 1984-1988

1 three axle DAF 3600, van body truck, WABCO 4 channel ABS
ISO ABS trailer connector, GWW 235000 kg, mileage 350 000 km
1985-1988.

4 two axle DAMM van body full trailers, WABCO 4 channel ABS
GWW 20 000 kg, Mileage : 300 000 km, 250 000 km, 31 000 km
and 30 000 km.

2 three axle DAMM van body full trailers, WABCO 4 channel ABS
GWW 26 000 kg, mileage 380 000 km and 3500 km

COMPANY D : Majortrans A/S, Oslo, Norge

3 three-axle DAF 3600 van body trucks, WABCO 4 channel ABS,
GWW 23500 kg, ISO ABS trailer connector,
mileage 10 000 km each, time period 1987-88

4 two-axle DAMM van body full trailers, WABCO 4 channel ABS,
GWW 20 000 kg, mileage 10000 km each, time period 1987-88

COMPANY E : Tor Fossberg Transport, Rasta, Norge

1 two axle Mercedes Benz MB 1320 ,garbage container truck,
WABCO 4 channel ABS, GWW 17000 kg, milage 60 000 km 1987-88

1 three axle Mercedes Benz MB 2235, sided body truck, WABCO
4 channel ABS, GWW 23500 kg, milage 30 000 km 1987-8

2. RELIABILITY OF ABS SYSTEMS

The general impression from the interviews with the technical managers of the companies is that the reliability of the ABS-systems is satisfactory to excellent .

The part of the system that requires most attention is the ABS-connector that is subject to corrosion though not worse than the ordinary lighting connector.

Company A uses a common connector for ABS and lighting type V86 with 14 pins. Initially there were severe corrosion problems which were drastically reduced after reducing the originally two separate ABS and lighting power supply pins to one common pin with 6 square mm cross area with zero voltage except when the truck engine is running. Company A runs so called double combinations with in all 5 connectors in each combination. The trailer ABS malfunction signal in the tractor cab in the early combinations turned out to be unreliable due to connector pin crosstalk. The system was then changed so that each semitrailer and dolly had its own warning indicator in the shape of side lamps visible to the driver through the rear view mirror and this arrangement has worked successfully.

The companies B and C that use the separate ISO - connector report that corrosion problems exist but not severe . Connectors are changed at most once a year. Company C has only operated one year and did not report any connector or other ABS-problems. Company E which also had operated ABS only one year had no problems to report and also no trailer connectors .

No special maintenance schedule specially for ABS was used by any of the companies except for company C that had special test equipment to check the ABS . This was done once a year together with wheel drum disassembly for general brake inspection.

No delays because of factors that were related to ABS were reported except for a single case in company A where one of the dolly brakes became inactive because of a permanent false controller signal to the regulating valve.

When malfunction is indicated, the drivers of all companies continue their journey if it occurs while driving. If trailer malfunction is indicated after connecting the trailer , the trailer connector is inspected and recoupled.

No problems with electromagnetic or radio frequency interference were reported by any of the companies.

3. MAINTAINABILITY (DURABILITY, SERVICEABILITY)

All companies claim that the readiness of the system is easily checked by observing the ABS warning lights. No other checks are made by the drivers.

Only one company (C) makes regular checks by means of special instruments provided by the ABS - manufacturer. This is done once a year. Company D has a service contract that includes the ABS-systems.

The ABS -manufacturers provide a one year warranty including new parts and labour .

None of the companies found it possible to give an answer to the question of the life of an antilock system in service. All systems were still in operation although some parts had been replaced.

Company A had replaced one tractor sensor due to defective wire caused by mechanical damage due to bad installation, two tractor controllers and one semitrailer controller. Two of these were changed after only two months of operation and one (on a tractor) after 4 years of service. After initial troubles mentioned earlier the VBG connectors these are changed less than once a year .

Company B has changed 2 sensor exit rings , one sensor due to cable damage and a warning indicator relay.

Company C has changed between 10-20 sensors, about 10 controllers and 10-15 ABS-connectors from 1982 to 1988

Company D and E did not report any repairs

The trailer connectors wear out due to corrosion, and are easy to replace. No other parts were reported to wear out .

No parts of the system were reported to be serviced regularly

No parts were reported to need frequent adjustment. Adjustment was only reported in connection with replacement of sensors.

4. TRUCKING ENVIRONMENT

Type of goods:

-
- Company A delivers furniture, primarily office furniture.
- Company B delivers food
- Company C delivers food and general cargo
- Company D delivers general cargo
- Company E delivers garbage and general cargo

Amount of load in a typical delivery:

Company A : 7000 kg/semitrailer. Of the vehicle mileage it is estimated that 70% is fully laden and 30% empty.

Company B: 25000-27000 kg on a truck-full trailer combination.
Of the vehicle mileage it is estimated that about 80 % is fully laden and 40 % is with partial load.

Company C: 24000 kg on a truck full trailer combination
Of the mileage it is estimated that about 50 % is fully laden and 50 % is with partial load.

Company D: 25000 kg on a truck full trailer combination. It was not possible to get an estimate of the proportion fully laden, partial load and empty mileage.

Company E: No figures could be obtained.

Difficulties during introduction of ABS in the operations:

None of the companies reported any difficulties.

Driving conditions:

All companies except E had primarily long distance driving on asphalt roads with some city distribution. All were operating under all season conditions which includes slippery roads due to snow and ice in the winter period from October to April. Wet roads are also quite frequent but not regarded as especially slippery. Severe downhill descents were encountered by the Norwegian companies C and D though any specific number could not be given. High deceleration stops due to traffic conflicts had not been reported by the drivers in any of the companies.

5. PERFORMANCE

All companies reported that the drivers were very enthusiastic about driving ABS vehicles.

The main advantage reported by the drivers of all companies was the ability to brake on snow and ice without losing steerability and stability especially without getting trailer swing or front axle breakaway.

None of the companies could report on specific near accidents avoided by ABS

In general none of the companies had observed any obvious change in driving behaviour though company A and C expressed a feeling that the drivers drove somewhat faster under severe road conditions due to the higher confidence in being able to brake more efficiently without skidding.

None of the companies reported complaints about loss of brakes except for one case in company A on one dolly wheel due to malfunction in a controller unit. This was observed during a coupling operation under an almost stationary condition.

None of the companies had any accidents to report for vehicles with or without ABS nor could they report on any improvement or change in tyre wear, brake relinings, brake repairs or other circumstances.

USER EXPERIENCE WITH ANTILOCK SYSTEMS ON LARGE TRUCKS IN THE UNITED KINGDOM

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The report summarizing the UK experience with antilock follows. Please bear in mind that the report is not based on any extensive survey of purchasers, but instead on contacts with a few fleets and with suppliers, as well as on a survey of some of the recent literature. There is naturally something of a tendency to focus on the negative aspects, i.e. the problems experienced by the users, as opposed to the positive aspects, i.e. the general satisfaction with the systems. It should be emphasized that no fleet expressed any intention of abandoning antilock.

The contacts from which much of this material is drawn were arranged by Grau Girling, which dominates the UK market for antilock systems. The assistance of Grau Girling is gratefully acknowledged, as is that of the fleet personnel who were willing to spend considerable time describing their experience with ABS.

BACKGROUND

As of the beginning of 1988, there are some 40,000 or more semitrailers and 18,000-20,000 power units equipped with antilock brake systems (ABS) operating in the UK. ABS on trailers has become relatively popular as a result of regulatory changes in 1981 which permitted the fitting of antilock instead of load sensing valves as a means of controlling the balance of braking between tractor and trailer. Antilock use on power units is expected to increase dramatically because of impending EEC regulations that will require antilock on vehicles presented for new type approval on or after October 1, 1989 and on new registrations on or after October 1, 1991. One large trailer manufacturer, Crane Fruehauf, offers antilock as standard. Most of the ABS units in operation have a single controller per set of axles, with sensing on the front axle of two-axle trailers and the middle axle of three-axle trailers, but there is some move toward systems with sensors on all wheels. Equally, many of the early systems were powered by the brake-light circuit on the tractor and were thus not under continuous power or continuous self-monitoring. Many operators have now switched to dedicated power through the auxiliary seven-pin connectors.

SAFETY BENEFITS

None of the fleets were able to provide any definitive safety data, but all expressed confidence that antilock did have a safety benefit. One user reported that his employees would be upset if the system were removed. A large fleet informed us that their "trunking" (over-the-road) vehicles used to have two trailerswings and two rollovers a year, but with antilock the same group of vehicles has only had no trailerswings and only

one rollover on five years. This fleet had intentionally timed the brakes on the trailers so that they were applied fractionally before the tractor brakes: thus the vehicle "stretched" in braking and there was no load transfer forward. An earlier survey by Lucas Girling (now Grau Girling) of their customer experience indicated that driver confidence was above average in over half the cases, and was reduced in only a fraction of cases (Broome 1985).

INSTALLATION PROBLEMS

According to Grau Girling, a substantial proportion of service calls, particularly in the early years, have occurred as a result of faulty installation or faulty wiring on the trailers. This was confirmed in discussions with the fleets. Most of these installation problems seem to have been cured, partly as a result of the manufacturer doing more pre-assembly and partly as a result of more experience by the trailer or body builder.

MAINTENANCE REQUIREMENTS

All the fleets emphasized the need for regular maintenance. Grau Girling recommend an annual service on the air valves. The sensor-exciter gap needs to be reset and the exciter ring checked when the drums are serviced, usually once a year. Some fire brigades do this maintenance every six months, because of the demanding environment in which their vehicles are used. All parties emphasize the need for properly trained maintenance personnel. "It is essential of course to apply high standards of maintenance," is a typical remark. Andrew Davis (Transport Engineer, January 1988) quotes another fleet as reporting: "Anti-lock requires planned maintenance. It's not a fit and forget item." Maintenance personnel have to be trained (this is often done at courses conducted by the manufacturers) and expensive diagnostic equipment is required to check controllers. This diagnostic equipment has changed with each new generation of ABS, but there is now a promise from the manufacturers that the current diagnostic units will work on future generations of ABS.

There is some complaint about shortages of spare parts, with one fleet describing the situation as "atrocious." Grau Girling acknowledges that this has been a problem in the past, partly as a result of moving production facilities, but says that the situation is now under control.

RELIABILITY

As indicated above, many of the problems experienced were due to faulty installation, rather than faulty equipment. There was also much more dissatisfaction expressed with older equipment than with newer generations. Some of the older equipment was not in fact fail-safe, i.e. it did not on failure restore normal foundation braking. In general there were three areas of complaint:

1. Failures of the electronic control module. Many of these failed after the end of the warranty period. In the early period many such failures were attributable to water ingress and there was also a problem with long delays on reverting to normal brakes on failure. Both the moisture problem and the delays in reverting to normal seem to have been cured, but there are still a worrying number of random module failures. It should be noted that these units cannot be serviced but must be exchanged for new ones at substantial expense.

2. Failures in wheel sensors and exciter rings. Here the problems are almost invariably the result of poor initial installation or inadequate maintenance. The sensor must be pushed back into close contact with the exciter ring when the brakes are overhauled (the exact gap is self-adjusting); if this is not done, the sensor will not detect wheel motion. Difficulties can also occur as a result of too much play in the wheel bearings, leading to a sensor gap that is too large.
3. Air valve failures. One fleet reported that this was the item that required most attention, while a survey found that moisture could cause relay valves and booster valves to freeze (Davis 1988). The remedy is to fit air driers, but the manufacturers have apparently issued no warnings of this problem.

Other problems are more minor: external warning bulbs on trailers blowing as a result of washing or some incompatibility problems because earlier units were too critical on voltage requirements. But overall, the image of unreliability should not be exaggerated. One somewhat critical user sums up: "From [the listing of] faults it can be seen that the system is not without problems but not withstanding the above the system has proved to be reliable." (Newbolt 1988) The need for good preventative maintenance is universally emphasized.

CONCLUSIONS

Reliability remains an area of concern. It is clear that ABS is not at all maintenance free, that parts replacement can be expensive, and that properly trained mechanics are required. Even a simple operation like a brake overhaul must be performed with care. But there is no pressure from the fleets to abandon ABS. Almost all users are satisfied that the systems have a safety benefit and would continue to specify them irrespective of regulatory requirements. There is also some hope that the new, digital generation of ABS will prove more reliable than the existing analog systems.

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Addendum March 28, 1988

Here is my note on my meeting with a fleet on Friday. The contact person was quite helpful, but was not able to provide any quantitative data on failures or service calls, except for claims made under warranty. Out-of-warranty repairs are not recorded on the company's computer, but the contact person said that almost all the failures occur while the equipment is still under warranty.

The fleet is the second company mentioned in Andrew Davis' February article in *Transport Engineer*, and much of what was said expanded on the information the contact person provided to Davis.

The fleet currently consists of 280 tractors and 40 straight trucks. The latter are being phased out. The tractors are 6x2s. Approximately half of them are 32 tonne vehicles, pulling 1-axle trailers; the other half are 38 tonne, pulling 2-axle trailers. The units are effectively permanently coupled, so they do not have any problems with compatibility or with coupling and uncoupling.

They first installed antilock in 1969, because of problems with jackknifing. Initially they had the Dunlop Maxaret system. At that time they had a fleet of 2000 tractors. Prior to antilock they had 6-8 jackknifings (some of them with rollover) a year; since the fitting of antilock to the drive axle of the tractors, they have had virtually none.

In the early 80s they decided to fit antilock (Skidchek) on their trailers as well. They had both safety and cost reasons for this. The cost reasons is to save on tire wear, which he reports is now under 3p per mile, as well as on linings, drums, brake bearings, etc. They are now fitting antilock on tractor steering axles.

Their articulated vehicles are fitted with Jake brakes, with a retarder inhibitor module so that do not fight the antilock. The tractors are fitted with predominance valves for proportioning. They have air dry equipment, and therefore have no freezing problems. There are automatic slack adjusters on each wheel. They use their own 12-core connectors, with 2 pins used to power the trailer antilock. They have begun to retrofit their trailers, with one sensor operating diagonally on twin-axle trailers. Now, to meet EEC requirements, they will have to sense the front axle of the trailer separately, and the front axle will have to apply first. The contact person was unhappy with this arrangement. This year they are ordering 34 tractors, of which 1 or 2 will have DGX systems. The extra cost of DGX is about 600-800 pounds, but the contact person expects that it will pay for itself in reduced tire wear, because of the sensing on all wheels. He is also pleased about the relatively cheap diagnostic units for DGX: each unit will cost 80 pounds, which will permit him to distribute the units widely. He does not consider antilock a major expense.

On failures he indicated that he is not particularly bothered about their rate or about any consequent safety problems. The systems fail safe (i.e. they revert to normal braking), and, since his vehicles have load sensing, they can operate legally without antilock. Most of the failures occur during the warranty period: all the ones mentioned in

the article were failures covered by warranty. The eccentric exciter ring was an installation problem. He considers the equipment to be generally reliable. The modules have had most problems, but many of these are installation related (mounting two modules back-to-back on one bracket is not a good idea). He estimates that half the module problems are manufacturing related and half are installation related. He is looking forward to in-cab modules and to exciter rings integrated into the hub, since the current ones are rather flimsy. To put the 20 failures in perspective, they occurred over 12 million miles of usage by the relevant vehicles. The average annual mileage for the fleet is 50,000; the 38 tonners average 80,000 miles a year and sometimes do as much as 100,000 miles.

Maintenance: they do not necessarily pull the hubs every 50,000 miles, but rather use their judgment as to when to do maintenance. But on average brake relinings probably occur at 50,000 mile intervals. Some of the problems occur as a result of relining, particularly with exciter rings being bent. He considers the sensors to be almost "fit and forget."

Life expectancy: the life of the truck. They currently keep their vehicles for six years, but are switching to three years, under a manufacturer's (ERF) buyback scheme.

The load carried is 25 and a 1/2 tonnes of motor spirit. The load is dropped off as they go. The main safety problem was with the return trip home when empty, when drivers might go 60 mph. They operate in all weather conditions. He thinks that the drivers "must" driver harder with ABS, since they have more confidence in the vehicle. There has been only the one incident of loss of brakes. Other than the observed reduction in jackknifings and rollovers, he is not aware of any accidents specifically avoided because of ABS.

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Summary Report

ABS Systems in Trucks in the FRG

1. Task Definition

The trucks, tractors, full trailers and semi trailers are to be classified in the categories up to 3 t, 3 t to 6 t, 6 t to 9 t and more than 9 t of gross vehicle weight.

Legal requirements and reasons for ABS introduction in the FRG. Estimated decline in accidents through use of ABS systems.

Company interviews

Phone information from 50 companies.

Impressions of the information from the companies that were visited by Mr. Fancher and the TÜV Rheinland (Rhineland Technical Inspection Agency).

Why are ABS vehicles bought in the Federal Republic.

TÜV comment on the reliability of the ABS systems.

Legal Requirements

Amending Ordinance (effective as from: presumably summer 1988)

Trucks and tractors of a gross vehicle weight exceeding 9 t and a design-dependent maximum speed of more than 60 km/h as well as full trailers of a gross vehicle

Vehicle type	Gross vehicle weight			
	up to 3 t	3 t to 6 t	6 t to 9 t	more than 9 t up to 9 t
Trucks	609369 N	214255 N	191597 N	189350 N
	2157 S	5268 S	15001 S	67777 S
	<u>611526</u>	<u>219523</u>	<u>206598</u>	<u>257127</u>
Tractors	37	569	2265	63602
Full trailers	2551 N	5837 N	22096 N	96956 N
	533 S	1262 S	2452 S	34586 S
	<u>3084</u>	<u>7099</u>	<u>24548</u>	<u>131542</u>
Semi trailers	117 N	270 N	1067 N	48531 N
	85 S	65 S	80 S	28423 S
	<u>202</u>	<u>335</u>	<u>1147</u>	<u>76954</u>

No single-axle full trailers included

N: standard body

S: special body

As of: July 1, 1986

Table: Trucks, tractors, full trailers as well as semi trailers
registered in the FRG



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weight exceeding 9 t must be equipped with ABS. This applies to semi trailers only in case the gross vehicle weight reduced by the fifth-wheel load exceeds 9 t.

Vehicles are only allowed to be equipped with an ABS of category 1.

On full trailers with ABS, at least one wheel on each side must be controlled with - semi trailers excepted - at least one front and one rear wheel (diagonally opposite each other) being directly controlled by independent actuators.

Full trailers with ABS but without automatic load-sensitive brake system are only allowed to be connected with vehicles that ensure the ABS function in the trailer.

Having made a detailed analysis of 182 traffic accidents involving commercial vehicles, a team of researchers of the Hanover Traffic Accident Research Institute, the Hanover Medical School and the Berlin Technical University came to the conclusion that with ABS it would have been possible to completely avoid 7.1 % of the accidents. In addition, there would have been the following decrease in consequences of the accidents (property damage and personal injury) both for commercial vehicles and partners in the accident:

13.9 % of the property damage related to the commercial vehicle,

17.4 % of the personal injury related to the commercial vehicle,

11.1 % of the property damage related to the partner in the accident, and

10.8 % of the personal injury related to the partner in the accident.



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In this analysis, only accidents involving personal injury were considered. If the lighter collisions involving only property damage were included, the number of accidents avoidable through ABS would still be higher.

The analysis showed that with ABS the injuries to the commercial vehicle occupants could have been completely avoided by 8.7 %.

In 4 accidents involving most severe personal injury, the severity of the injuries to the partners in the collision could have been considerably reduced, and in one case in which a person was killed the accident could even have been completely avoided.

This shows that by using an ABS in commercial vehicles accidents can be avoided and the consequences of accidents considerably reduced.

This benefit can be contributed to the fact that an ABS allows the directional control to be maintained and the braking distance to be shortened with these two factors having almost the same effect.

Frequently, it is only one characteristic that contributes to the avoidance of accidents and the reduction of the seriousness of accidents. It could only be noticed to a small extent that both characteristics are required at the same time.

Concerning the analyzed accidents, the use of an ABS would also have implied a reduction or avoidability of the property damage and personal injury in the secondary collisions.



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Of the 182 vehicles, 18 had a secondary collision in addition to the primary collision. Here the property damage could have been reduced through ABS in 5.9 % of the cases. The damage to property could have been reduced by 33.3 %. The injuries suffered by the vehicle occupants in the secondary collision could have been avoided in 33.3 % of the accidents and this suffered by the partners in the collision in 16.7 % of the accidents.

In addition, a cost-benefit analysis was made by a manufacturer in which the ABS purchase cost was allocated to a service life of 5 years and compared with annual savings. These annual savings are made up of:

- insurance rebate (10 % on the net full coverage insurance premium),
- increase in the resale value resulting from additional price of ABS at the end of the service life,
- reduction in tire wear (experience figure from practice approx. 28 %),
- tax advantage (annual depreciation).

Incidental expenses, if any, are not yet considered in this calculation. The cost-benefit analysis showed that the introduction of ABS systems not only yields increased safety but also a higher benefit for the income statement.



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Company Interviews

50 haulage contractors of the about 200 - 250 companies receiving TÜV support were interviewed by phone concerning the use of ABS systems. These 50 companies have together 566 trucks and tractors of which only 38 are equipped with ABS. 6 of these ABS vehicles were only registered in 1988. The remaining 32 ABS vehicles are distributed among 7 enterprises, thus one company having a maximum average of 5 vehicles equipped with ABS. Due to the small portion of vehicles equipped with ABS and the fact that the maximum age of these ABS vehicles is 2 years, these enterprises found themselves not in a position to give specific information about their experience with ABS vehicles. Obviously, so far all ABS vehicles have not attracted any attention. All companies that were interviewed by phone will order only vehicles with ABS system in future.

Five other enterprises, among them Wuppertal City Transportation and the Fire Department of the City of Cologne, were visited.

The other three companies are forwarding companies having together 345 trucks and tractors and approx. 280 full trailers and semi trailers of which already 149 trucks and tractors and approx. 90 full trailers and semi trailers are equipped with ABS.

All 3 forwarding companies expressed the intention to order only road trains equipped with ABS in future. In addition to ABS, all vehicles mentioned above are provided with

- ALA (Automatic Load Adjusting)
- DSC (Drive Slip Control)



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and automatically adjustable brakes. Also most of the vehicles not yet equipped with ABS are provided with ALA and an automatically adjustable brake system. This is possibly the reason why in the above mentioned companies the advantage of the ABS vehicles in comparison with the rest of the vehicle fleet is not clearly revealed by the accident trend. For the same reason, a reduction in tire wear of 28 %, as mentioned in the Amending Ordinance, cannot be confirmed by any of the companies interviewed. Also on vehicles not yet equipped with ABS, tire wear caused by wheel lockup has been rarely found. Problems with the ABS system indicated by a warning lamp have only occurred in a very few cases.

Of the 67 trucks of the Fire Department of the City of Cologne, only 11 are equipped with ABS. The ABS vehicles were bought only 2 years ago, and the mileage of these vehicles amounts to max. 10,000 km/year. So far no information on the sensitiveness of the system has been possible.

Their service as such causes the fire-fighting vehicles to be frequently involved in accidents. A detailed analysis of the accidents in which ABS vehicles were involved showed, however, that these accidents would have happened in the same way with conventionally braked vehicles, for example, another vehicle crashing into the side of the fire-fighting vehicle or similar accident situations.

Of the 300 buses of Wuppertal City Transportation, 156 are equipped with ABS. Whereas there have been no or only very few troubles with the trucks equipped with ABS, Wuppertal City Transportation have recorded on 36 ABS buses a total of 80 problem cases in the course of 1987. Among other things, the sensors and the cable



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connections were replaced or the sensors adjusted again. All of these troubles were remedied by the Wuppertal City Transportation personnel, whereas the trucks having problems with the ABS system were almost all repaired in the specialized workshop.

All interviewed companies said that they will order only vehicles with ABS systems in future to guarantee their drivers an optimum of safety in every traffic situation and under any possible weather conditions. The visited companies are of the opinion that the ABS system rounds off the high level of safety already reached by introducing ALA, DSC and automatically adjustable brakes.

At present, the TÜV Rheinland (Rhineland Technical Inspection Agency) is testing the efficiency of ABS systems in passenger cars by means of a four-wheel test bench especially developed for this purpose. After completion of this large-scale test, the results will be published. At the moment, the TÜV Rheinland (Rhineland Technical Inspection Agency) does not yet have any information on the reliability of ABS systems in trucks.

