February 1983
NHTSA Technical Report

DOT HS-806-359

U.S. Department
of Transportation
**National Highway
Traffic Safety
Administration**

A Preliminary Evaluation of Two Braking Improvements for Passenger Cars

Dual Master Cylinders and Front Disc Brakes

Plans and Programs
Office of Program Evaluation

This document is available to the U.S. public through the National Technical Information
Service, Springfield, Virginia 22161

Technical Report Documentation Page

1. Report No. DOT HS-806 359	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle A PRELIMINARY EVALUATION OF TWO BRAKING IMPROVEMENTS FOR PASSENGER CARS Dual Master Cylinders and Front Disc Brakes		5. Report Date February 1983
		6. Performing Organization Code NPP-10
7. Author(s) Charles Jesse Kahane, Ph.D.		8. Performing Organization Report No.
9. Performing Organization Name and Address Office of Program Evaluation National Highway Traffic Safety Administration 400 7th St., S.W. Washington, D.C. 20590		10. Work Unit No. (TRAIS)
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address U.S. Department of Transportation National Highway Traffic Safety Administration Washington, D.C. 20590		13. Type of Report and Period Covered NHTSA Technical Report
		14. Sponsoring Agency Code

15. Supplementary Notes
An Agency staff review of an existing Federal regulation performed in response to Executive Order 12291.

16. Abstract Dual master cylinders were installed in passenger cars in order to provide a dual braking system, which is a requirement of Federal Motor Vehicle Safety Standard 105. Front disc brakes were installed to improve a car's handling capability during braking and to enhance resistance to braking losses due to fade or water exposure: they meet the Standard 105 requirements on fade and water resistance more readily than drum brakes. The objective of this Agency staff evaluation is to determine how many fatalities, injuries and damages are prevented by dual master cylinders and front disc brakes and to measure the actual cost of the devices. The evaluation is based on statistical analyses of North Carolina, Texas and Fatal Accident Reporting System data, a review of Indiana in-depth accident analyses, and manufacturing and repair cost analyses for production brake assemblies. It was found that:

o Dual master cylinders annually prevent 40,000 accidents that would have resulted in 260 fatalities, 24,000 injuries and $132 million in property damage. They add $17 to the lifetime cost of owning and operating a car (in 1982 dollars).

o Front disc brakes annually prevent 10,000 accidents that would have resulted in 64 fatalities, 5,700 injuries and $32 million in property damage. They add $21 to the lifetime cost of a car.

17. Key Words braking; master cylinder; disc brakes; brake defects; defective brakes; Federal Motor Vehicle Safety Standard 105; accident analysis; evaluation; statistical analysis; cost-effectiveness		18. Distribution Statement Document is available to the public through the National Technical Information Service, Springfield, Virginia 22161	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 105	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

TABLE OF CONTENTS

Contents | Page

Contents | Page

*Unpublished computer printouts

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

CY	Calendar Year
df	degrees of freedom
EFU	Equivalent Fatality Unit
FARS	Fatal Accident Reporting System
MM	Make/Model
MY	Model Year
NASS	National Accident Sampling System
NHTSA	National Highway Traffic Safety Administration
SAE	Society of Automotive Engineers
SAS	Statistical Analysis System
STD	Standard

SUMMARY

Two of the most notable changes in the braking systems of domestic passenger cars during the 1960's and 1970's were the installation of dual master cylinders and the replacement of front drum brakes by disc brakes. Dual master cylinders are the chief component of a split or dual braking system. Without dual brakes, a failure in the hydraulic system can lead to catastrophic loss of braking power. With dual brakes, should one of the systems fail, the driver can still stop with the other. Disc brakes give the driver a better "feel" of the car's braking power because they have a more linear relationship between brake pedal pressure and vehicle deceleration than do drum brakes. In addition to improving a car's handling capabilities, they have potential safety benefits such as alleviating side-to-side brake imbalance due to improper maintenance, enhancing resistance to temporary braking power losses due to fade or exposure to water, and helping to prevent premature lockup of the front wheels during heavy brake applications.

Federal Motor Vehicle Safety Standard 105 regulates the hydraulic brake systems of passenger cars (and certain other vehicles). There were two versions of Standard 105: 105-68, which became effective on January 1, 1968 and 105-75 which was effective on January 1, 1976. Both versions consist primarily of a series of stopping tests simulating normal, adverse and emergency braking conditions. They also specify that cars shall have a dual braking system.

Executive Order 12291 (February 1981) requires agencies to evaluate their existing major regulations, including any rule whose annual effect on the economy is $100 million or more. The objectives of an evaluation are to determine the actual benefits - lives saved, injuries prevented, damages avoided - and costs of safety equipment installed in production vehicles in response to a standard and to assess cost-effectiveness.

This preliminary evaluation of passenger car braking improvements does not cover all aspects of Standard 105 but is limited to dual master cylinders and front disc brakes. Dual master cylinders are clearly a safety device. They satisfy Standard 105's requirement for a dual braking system and were installed at least one year before its effective date. Disc brakes, on the other hand, are not required by Standard 105 and were not necessarily installed for safety reasons alone. On the other hand, disc brakes were the most noticeable braking change of the late 1960's and early 1970's and made it considerably easier for cars to pass some of the specific stopping tests (fade and water recovery) of Standard 105-75.

The accident reduction benefits for dual master cylinders and disc brakes were initially surveyed by reviewing in-depth accident analyses form the Indiana Tri-Level Study of the Causes of Accidents. Then, effectiveness estimates were obtained by statistically analyzing accident data from the North Carolina and Texas State files and the Fatal Accident Reporting System. Costs were estimated by analyzing braking system components of a representative sample of cars and by obtaining data on repair frequencies and costs.

The most important conclusions of this preliminary evaluation are that dual master cylinders are a cost-effective safety device, saving 200-300 lives each year, preventing thousands of injuries and significantly reducing property damage in crashes. The conclusions on dual master cylinders can be drawn firmly because of the high level of consistency between the statistical analyses of three accident data files, the in-depth accident analyses and engineering intuition. Disc brakes, as stated above, are not required by Standard 105 and are not exclusively a safety device. Nevertheless, the evaluation indicates that disc brakes have significant safety benefits, although these are only about one-fourth as large as the benefits for dual master cylinders. The specific estimate of disc brake effectiveness is made with less certainty than for dual master cylinders, but at least it can be said that disc brakes are not harmful and in all likelihood beneficial, on the one hand, and do not have very large safety benefits, on the other.

The principal findings and conclusions of the study are the following:

Principal Findings

Effectiveness of dual master cylinders

o The fleetwide installation of dual master cylinders eliminated 40,000 reported accidents per year, which is 0.7 percent of all accidents involving passenger cars (confidence bounds: 0.58 - 0.82 percent). The accidents eliminated were those in which brake defects had been a contributing factor to the crash.

o Effectiveness was approximately the same in property damage, injury and fatal crashes.

Effectiveness of front disc brakes

o The fleetwide introduction of front disc brakes eliminated 10,000 reported accidents per year, which is 0.17 percent of all accidents involving passenger cars (confidence bounds: 0.10 - 0.24 percent). The accidents eliminated were those in which brake defects had been a contributing factor to the crash.

o Effectiveness was approximately the same in property damage, injury and fatal crashes.

o Effectiveness was just as great on dry roads in flat regions as on wet roads (possible water exposure conditions) or in hilly regions (possible fade conditions).

o In two-car front-to-rear collisions, disc brakes were not found to have any effect on the likelihood that a car is the striking vehicle. In other words, disc brakes did not lead to a reduction of these types of accidents.

Cost of braking improvements

o The costs per car (in 1982 dollars) for dual master cylinders and front disc brakes are the following:

	Dual Master Cylinders	Front Disc Brakes
Initial purchase price increase	$9.50	$ 2.90
Lifetime fuel consumption due to weight increase	2.25	5.21
Lifetime repair cost increase	5.20	12.97
TOTAL COST PER CAR	$16.95	$21.08

o The annual costs of the improvements in the United States (based on 10 million cars sold) are $170 million for dual master cylinders and $210 million for front disc brakes.

Benefits of braking improvements

o The annual benefits, when all cars on the road in the United States have dual master cylinders and front disc brakes, will be:

	Dual Master Cylinders		Front Disc Brakes	
Reduction of	Best Estimate	Confidence Bounds	Best Estimate	Confidence Bounds
Fatalities	260	220-310	64	38-90
Nonfatal hospitalizations	2,500	2,100-3,000	610	360-860
Injuries (any type)	24,000	19,000-28,000	5,700	3,400-8,100
Police-reported accidents	40,000	33,000-47,000	9,800	5,800-13,800
Property damage	$132M	$110-155M	$32M	$19-45M

Cost-effectiveness

o An "Equivalent Fatality Unit" corresponds to 1 fatality or 16.9 nonfatal hospitalizations. Dual master cylinders eliminate 2.4 Equivalent Fatality Units per million dollars of cost (confidence bounds: 2.0 - 2.9).

o Front disc brakes eliminate 0.5 Equivalent Fatality Units per million dollars of cost (confidence bounds: 0.3 - 0.7).

Conclusions

Dual master cylinders

o Dual master cylinders have accomplished their objective of significantly reducing accidents due to brake failure.

o Dual master cylinders are a cost-effective safety device.

Disc brakes

o Front disc brakes appear to have been effective in reducing accidents due to brake failure.

o Front disc brakes do not significantly reduce the numbers of accidents due to brake fade or exposure to water, relative to drum brakes of the late 1960's and early 1970's.

o Disc brakes do not appear to have had a significant effect in accidents that did not involve brake defects. The better "feel" and handling qualities of disc brakes did not result in a measurable safety payoff.

o It is tentatively concluded that the primary benefit of disc brakes is a reduction in accidents due to severe side-to-side brake imbalance.

o Disc brakes increase the cost of owning and operating a car primarily because their repair and maintenance costs are higher than for drum brakes.

CHAPTER 1

INTRODUCTION AND BACKGROUND

1.1 Evaluation of Federal Motor Vehicle Safety Standards

Executive Order 12291, dated February 17, 1981, requires Federal agencies to perform evaluations of their existing regulations, including those rules which result in an annual effect on the economy of $100 million or more [7]. The evaluation shall determine the actual costs and actual benefits of the existing rule.

The National Highway Traffic Safety Administration began to evaluate its existing Federal Motor Vehicle Safety Standards in 1975. Its goals have been to monitor the actual benefits and costs of safety equipment installed in production vehicles in response to standards and, more generally, to assess whether a standard has met the specifications of the National Traffic and Motor Vehicle Safety Act of 1966 [14]: practicability, meet the need for motor vehicle safety, protect against "unreasonable" risk of accidents, deaths or injuries, provide objective criteria. The Agency has published 6 comprehensive evaluations to date.

1.2 Evaluation of Standard 105

Federal Motor Vehicle Safety Standard 105 regulates hydraulic brake systems for passenger cars, school buses and light trucks. This evaluation is limited to passenger cars, however. Standard 105 took effect for passenger cars on January 1, 1968 [6] and, to a large extent, incorporated SAE recommended practices that dated back to 1966. The standard was extensively rewritten in the mid-1970's and the new rule, originally called Standard 105-75, took effect on January 1, 1976 [5].

Standard 105 consists, to a large extent, of a series of stopping tests simulating normal and emergency braking, brake fade, exposure to water, and partially disabled brakes. The performance requirements are expressed in terms of stopping distance (especially on the original Standard 105) or deceleration rates (especially on 105-75). The performance requirements apply only to new cars. In addition, the standard requires a dual or split braking system, warning lights and it regulates the parking brake.

Standard 105 is the first "100 series" - crash avoidance - standard to be evaluated. In many ways, the crash avoidance standards are more difficult to evaluate than the crashworthiness standards:

o The performance specifications in the crash avoidance standards in many cases cannot be related to specific hardware modifications. For example, a stopping distance requirement could be achieved by any one of several changes in a brake system.

o The specific types of accidents which are eliminated as a result of a crash avoidance standard (or one of its requirements) often cannot be identified in accident data because the data are insufficiently detailed. For example, it is hard to identify specifically those accidents that would be eliminated by a 10 percent reduction in stopping distance, because the data do not contain that detailed a record of pre-crash movements.

o The overall crash avoidance due to one of those standards is often too small to be easily identifiable in statistical accident analyses.

o The performance requirements apply to new cars. It is not clear to what extent the improved performance levels persist over the life of the car. By contrast, most crashworthiness standards have resulted in the installation of hardware items that are unlikely to deteriorate over the life of the car.

o Crash avoidance equipment generally does not function automatically but requires appropriate actions by the driver. The causal chain from the safety improvement to the eventual benefits is less direct than with injury avoidance equipment.

For these reasons it is difficult to define what constitutes a "comprehensive evaluation of the actual costs and benefits of Standard 105," and even harder to perform it. An additional difficulty is that brake designs have been frequently modified during the past 20 years for reasons not necessarily related to Standard 105: changes in car size, customer preferences, development of superior materials or designs.

It is also hard to distinguish what braking improvements should be attributed to Standard 105-75, 105-68, or the earlier SAE requirements.

It is best, then, to begin the evaluation of braking improvements by singling out a few aspects of the problem that are more readily amenable to analysis. For example, in an earlier report on this subject, the Agency concentrated on the issue of deterioration of vehicles in use. Used 1973 and 1978 model cars were run through the performance tests of Standard 105-75 [10].

This report concentrates on finding the costs and, by statistical analysis of accident data, the safety benefits of two of the most notable and universal changes in braking systems of the past 20 years: dual master cylinders and front disc brakes. To what extent were those changes made "in response to" Standard 105? The standard explicitly requires a dual or split braking system--a need that is met by dual master cylinders which had been installed by manufacturers beginning at least one year before the effective date. Disc brakes are not strictly needed, in theory or practice, for compliance with either Standard 105-68 or 105-75, but they do make it easier to pass some of the performance tests--thus, the standard is likely to have accelerated the industry-wide shift to disc brakes. Therefore, while this report is not an evaluation of Standard 105 in the strict sense, it is one in a larger sense.

The remainder of the report is devoted exclusively to the costs and benefits of dual and disc brakes. Before proceeding though, it is worthwhile to mention some of the other brake modifications that may have been made to ensure compliance with Standard 105 or 105-75 on some makes and models:

o Upsizing the brakes relative to the car (not necessarily done for the purpose of standard compliance and certainly not done "across the board").

o Increased installation of power brakes and upgrading of existing power brakes (again, may be more a result of customer preferences than of Standard 105).

o Rebalancing the brakes so that substantially higher effort is applied at the front wheels than at rear wheels (this is the modification that is most directly attributable to Standard 105-75).

o More effective lining materials and fluids (brake suppliers are always looking for ways to improve these).

It is evident that these modifications would be difficult to evaluate by statistical analysis of accident data.

1.3 Dual master cylinders

Both versions of Standard 105 require a split or dual braking system. Without dual brakes, a failure in the hydraulic system can lead to catastrophic loss of braking power. With dual brakes, should one of the systems fail, the driver can still stop the car with the other. Also, a warning light on the dashboard notifies the driver of a hydraulic failure.

Compliance with the split brake requirement was obtained by using a dual or tandem master cylinder. In most cars with rear wheel drive, one chamber serves the front brakes and the other, the rear brakes. More recently, front-wheel drive cars have typically had a diagonally split system. A pressure imbalance between the two chambers actuates the warning light.

Although Standard 105 did not take effect until January 1, 1968, all domestic passenger cars had dual master cylinders by the 1967 model year, some as early as 1962. Table 1-1 shows the percentage of domestic passenger cars with dual master cylinders, by model year. It is based on Chilton's auto repair manuals. The percentage for 1966 could not be readily determined. Essentially, relatively few cars had them up to 1965 and all had them starting in 1967.

The main potential benefit of dual master cylinders is a reduction of accidents due to catastrophic brake failure, specifically, failure of the hydraulic system. If accidents are classified by investigators as to the presence or absence of "brake defects as a contributing factor," the percentage of accident-involved vehicles with brake defects should be significantly lower for model year 1967 (and later) than for model year 1965 (and earlier).

1.4 Front disc brakes

Disc brakes were initially available only on imported cars but began to appear on deluxe domestic cars in the 1965 model year. Subsequently, front disc brakes became universal, reaching 100 percent market penetration in 1977. As Table 1-1 shows, the greatest shift from

TABLE 1-1

PERCENT OF DOMESTIC CARS WITH DUAL MASTER CYLINDERS, FRONT DISC BRAKES AND POWER BRAKES, BY MODEL YEAR

Model Year	Percent of Cars: Dual[1]	Disc[2]	Power[2]
1960	0	0	26
1961	0	0	24
1962	9	0	26
1963	9	0	27
1964	7	0	29
1965	7	2	32
1966	unknown	3	35
1967	100	6	41
1968	100	13	42
1969	100	28	49
1970	100	41	51
1971	100	63	57
1972	100	74	68
1973	100	86	76
1974	100	84	67
1975	100	93	76
1976	100	99	81
1977	100	100	87
1978	100	100	85
1979	100	100	83
1980	100	100	82
1981	100	100	85

[1]Source: Chilton's Repair Manuals [2]

[2]Source: Ward's Almanacs [24]

drum to disc took place during 1969-73, i.e., several years after the installation of dual master cylinders and several years before the effective date of Standard 105-75.

Front disc brakes were installed for reasons of safety, product quality and customer preference. The safety benefits of disc brakes, relative to drum brakes, are [21]:

o water resistance: immersion of the brake assembly (e.g., by driving through deep water) can lead to temporary reduction or loss of friction capability. But disc brakes, by design, shed water more easily than drums.

o fade resistance: overheating of drums or rotors (due to heavy, repeated use of brakes) can lead to reduced friction capability. The design of disc brakes makes it easier for them to dissipate heat. Furthermore, overheating might cause drums to expand to the point where the brake shoes fail to contact them, resulting in catastrophic braking loss; by contrast, an expanding disc would come closer to the brake pads.

o directional control: imbalance of the braking power in the left and right wheels, possibly as a result of undermaintenance, may cause the car to pull to one side during braking. Disc brakes have an excellent self-adjustment mechanism that alleviates the imbalance problem. Drum brakes, because of their self-energizing capability (positive feedback) aggravate the problem.

o linear pedal feel: with disc brakes, the friction between the pads and rotor is more or less proportional to the pressure that the driver applies to the brake pedal. That makes it relatively easy for the driver to modulate pedal pressure, stopping in a desired distance without completely locking up the wheels. Drum brake power increases more rapidly than pedal pressure (self-energizing capability), making it somewhat more difficult for the driver to prevent lockup and achieve the desired stopping distance.

On the other hand, disc brakes are not intrinsically capable of stopping a car in a shorter distance than drum brakes. On the contrary, the self-energizing feature of drum brakes gives them more stopping power for a given amount of pedal pressure. On larger cars, it is usually necessary to provide power assist for disc brakes, in order to avoid excessive pedal pressures.

Furthermore, certain designs of drum brakes could and did meet strict water and fade resistance requirements, such as those of Standard 105 and 105-75. There have been important advances in heat dissipation and self adjustment for drum brakes. Nevertheless, disc brakes make it easier to meet the requirements of Standard 105-75. Thus, Standard 105 did not, by itself, cause the industry-wide shift to disc brakes in the early 1970's although it was probably a contributing factor. For example, Ford mentioned disc brakes first among the modifications it used for meeting Standard 105-75 [1]. On the other hand, customer preferences for disc brakes--based on perceptions of superior handling, stability and technology as described in the trade and hobby literature--also must have played a major role in the industry-wide shift.

What types of accidents might be avoided as a consequence of disc brakes? A reduction of brake imbalance problems could lead to fewer accidents resulting from catastrophic loss of control while braking--i.e., a reduction in the percentage of accidents in which brake defects are a contributing factor.

An improvement in water resistance capability could lead to a reduction of accidents resulting from loss of braking after traveling through water--more generally, a reduction in the percentage of brake defect accidents on wet roadways.

An improvement in fade resistance could lead to a reduction of accidents in which braking power is lost after repeated, prolonged brake applications--e.g., on hilly roads, there should be a reduction in the percentage of accidents with brake defects.

An improvement in "pedal feel" could help drivers judge stopping distances better and avoid a collision due to misjudging the appropriate pedal pressure or locking the wheels. Such collisions, however, would not ordinarily be labeled as "due to defective brakes." In two-car front-to-rear collisions, the car with disc brakes, all other things being equal, might less likely be the striking car. That is because a misjudgment of pedal pressure by the driver of the striking car could be a causative factor in the accident, whereas the struck car's driver has no comparable task.

1.5 Evaluation objectives and limitations

This preliminary evaluation is limited to a study of the costs and accident avoidance benefits of dual master cylinders and front disc brakes. Costs are calculated by disassembling and analyzing brake components in production vehicles and by estimating lifetime maintenance expenses.

Accident avoidance benefits are calculated by statistically analyzing large accident data files, supplemented by some information from in-depth accident studies. The statistical analyses are limited to 3 files for which many years of accident data are available: North Carolina, Texas and the Fatal Accident Reporting System. Multiple years are needed because the accident phenomena under consideration (presence of brake defect, striking vs. struck vehicle) are sensitive to vehicle age as well as type of brake equipment. A statistical procedure--multiple regression--is needed to isolate the effect of brake improvements from the age effect. Multiple years of accident data are needed to obtain meaningful regression results. (For more details, see pp. 143-147, 161-166 and 174-179 of the evaluation of side door beams [12].)

Specifically, the analyses are:

o Regressions of the percentage of accident-involved vehicles in which defective brakes were a contributing factor, by model year, calendar year and, sometimes make/model, as a function of percentage of fleet with dual master cylinders, percent with disc brakes and vehicle age (plus some additional control variables). The objective is to find the reduction, attributable to dual master cylinders and disc brakes, of brake malfunction accidents. (In Sections 1.3 and 1.4, such reductions were hypothesized.)

o The regressions are repeated for injury accidents alone and fatal accidents alone, to check if the reductions are consistent across severity levels.

o The regressions are repeated for accidents on wet roadways, alone, to see if disc brakes' water resistance makes them even more effective in eliminating brake malfunction accidents on wet roads than dry roads.

o The regressions were repeated for accidents in the hilly portion of North Carolina to see if disc brakes' fade resistance provides incremental benefits there.

o Regressions of the probabilities, given a 2-car front-to-rear collision, that a car of a given model year, calendar year and make/model will be the striking vehicle--as a function of disc brake installation and vehicle age. The objective is to find the reduction, attributable to disc brakes, in the likelihood of being the striking vehicle--as was hypothesized in Section 1.4.

The classification of whether or not "defective brakes were a contributing factor" is, throughout the analyses, based on whether that item was checked on the police report. A review of North Carolina police report narratives showed that over 90 percent did not contain any explanation of why the brakes were defective or how they contributed to the accident [18]. Thus, the police-reported accident data used in this evaluation cannot be further subdivided into categories such as hydraulic failure, imbalance, fade, etc. Section 2.1 does, however, review detailed causes of brake failure in multidisciplinary investigations and the findings appear to be consistent with the reductions of brake failure accidents observed in the regression analyses.

CHAPTER 2

ANALYSES OF ACCIDENTS INVOLVING BRAKE DEFECTS

The percentages of accident-involved vehicles in which police officers judged brake defects to be a contributing factor are analyzed in this chapter. The objective, as formulated in Section 1.5, is to isolate by statistical means the reductions in those percentages which can be attributed to dual master cylinders and front disc brakes. Analyses are performed on North Carolina, Texas and Fatal Accident Reporting System data. The statistical approach is weighted regression using the General Linear Model procedure of the Statistical Analysis System (SAS) [16].

Dual master cylinders are shown to clearly reduce the incidence of brake defect accidents and, thereby, have eliminated approximately 0.7 percent of all crashes involving passenger cars. Disc brakes also appear to be effective in reducing brake defect accidents, with a benefit about one fourth as large as the one for dual master cylinders.

2.1 Review of brake defects found in multidisciplinary accident investigation

The Tri-Level Study of the Causes of Traffic Accidents, conducted by the University of Indiana during 1972-77, provides detailed information on vehicular defects, failures or malfunctions that contributed to accidents [23]. There were 2258 accident-involved vehicles that were investigated at the scene a team of technicians (Level B) and 420 vehicles that received a full-scale multidisciplinary accident investigation (Level C).

Brake system performance was found to be a certain or probable causal factor in 2.6 percent of the Level B investigations and 4.8 percent of the Level C investigations.

Close to two thirds of these cases involved gross failure of the brakes: 1.7 percent of the Level B and 2.6 percent of the Level C cases. Detailed descriptions of the Level C gross failures indicate that most of them involved a leak or failure somewhere in the hydraulic system, due to inadequate or improper maintenence of hoses, wheel cylinders, etc. They happened in cars with single master cylinders, rendering the brakes entirely inoperable. It was Indiana's judgment that a large proportion of these accidents would have been avoided by a dual master cylinder, which would have left the driver with a backup system and a warning that partial hydraulic failure had occurred. In other words, the Indiana data suggest that 1 percent or even up to 2 percent of accidents can be avoided by installing dual master cylinders.

None of the gross failures or other brake defect accidents appear to have been attributed to brake fade or loss of friction as a consequence of contact with water. Thus, the relatively small Indiana sample appears to suggest that the potential accident reduction benefits of disc brakes in preventing fade or water-induced failure are limited.

Brake imbalance (pulling to one side), grabbing or premature locking were identified as certain or probable causal factors in 0.4 percent of the Level B investigations and 1.9 percent of Level C. To what extent could these problems have been avoided by front disc brakes? The detailed descriptions of the Level C cases indicate that close to half of them involved a problem with the rear brakes and, of course, could not have been avoided by front disc brakes. Another third of the cases involved contamination of the friction surfaces with brake fluid or extreme wear of the linings on both sides- again, disc brakes would probably not have made a difference. The remaining 1/6 of the cases appeared to be due to maladjustment at one wheel (too much clearance between drums and shoes) or excessive wear on one side. Here, the problem was a combination of inadequate maintenance and the inherent maintenance problems of drum brakes (see Section 1.4). Perhaps, disc brakes could have made a difference. In other words, the accident avoidence potential for disc brakes, in preventing imbalance or grabbing, would appear to be well under 0.5 percent.

A "driver's ineffective evasive steer due to locked front wheels" was a certain or probable causal factor in 4.3 percent of Level B cases and 4.8 percent of Level C. If front disc brakes give the driver a better feel of the car's braking power and permit the driver to modulate pedal pressure more effectively, perhaps some portion of those accidents could be eliminated. In other words, there might be a reduction of involvements as the striking vehicle in front-to-rear collisions. Undoubtedly, though, many of those cases involved panic braking, where even disc brakes will not prevent locking of the wheels.

2.2 North Carolina accidents

Automated North Carolina accident files were available (as of November 1982) for every year from 1971 to 1981. Dr. J. R. Stewart of the Highway Safety Research Center, under contract to NHTSA, performed regressions on the proportion of accident involvements in which defective brakes were a contributing factor [19], [20]. His results are reported here, essentially without modification.

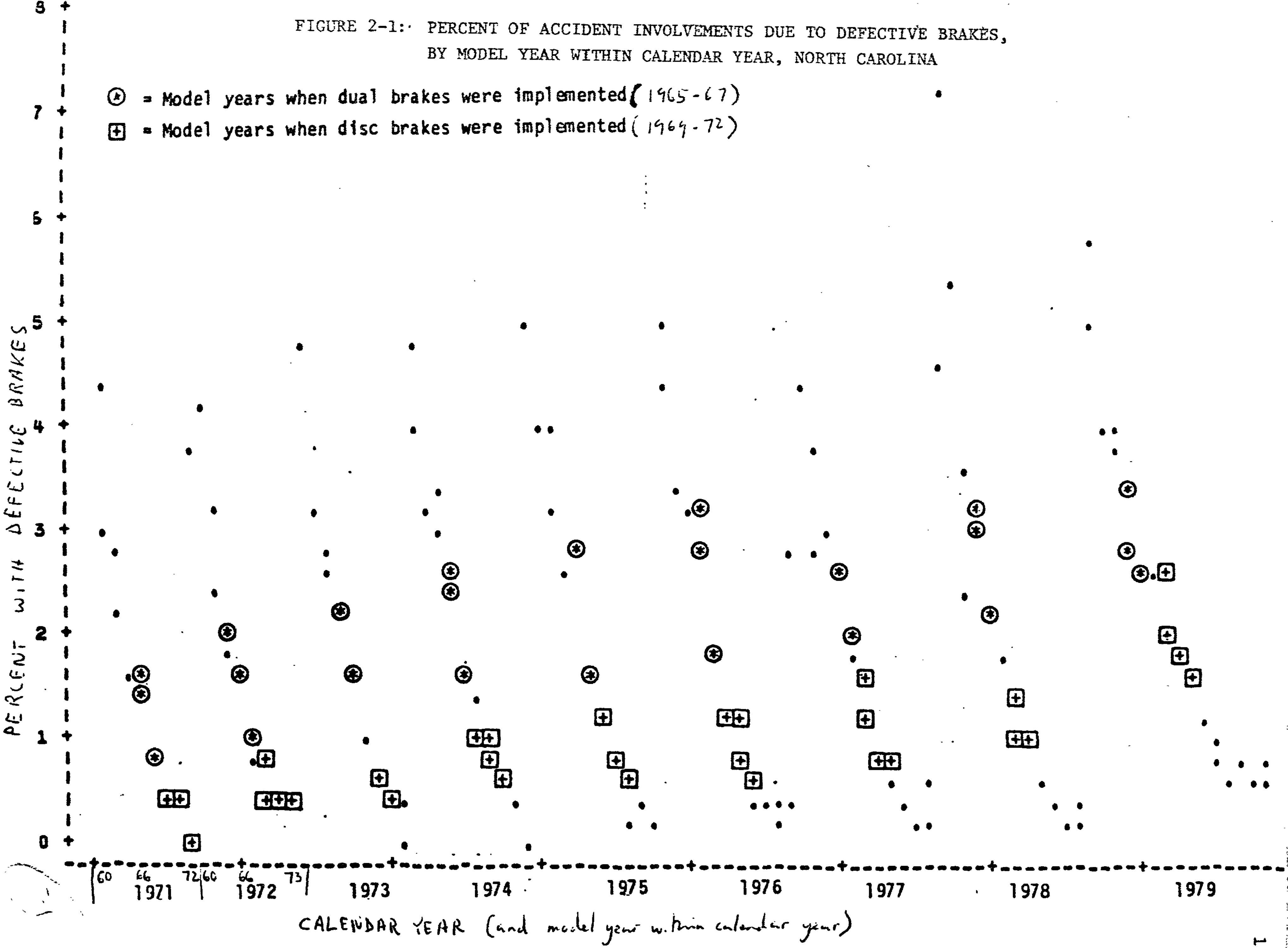
2.2.1 Overall incidence of defective brakes

Figure 2-1 is a plot of the percentages of domestic passenger cars involved in accidents for which brake defects were a contributing factor, by calendar year and model year. The vertical axis indicates the percent of accident-involved cars in which defective brakes contributed to the accident. The horizontal axis indicates calendar year (1971-79) and, within calendar year, the model year (from 1960 up to that calendar year plus 1 - e.g., 1960-72 in 1971). For example, the left-most point on the figure means that approximately 4.3 percent of the 1960-model cars involved in accidents during 1971 had defective brakes as a contributing factor. The lowest and rightmost point in the 1971 group means that the 1972 - model cars involved in accidents during 1971 did not have any defective brakes.

In each calendar year, the points for model years 1965-67 are represented by asterisks within circles. Those were the model years in which dual master cylinders were implemented: 7 percent of 1965-model cars had them and 100 percent of 1967 models. The points for model years 1969-72 are represented by pluses within squares. Those were the years in which the transition from drum to front disc brakes was most noticeable: 28 percent of 1969 models had disc brakes, vs. 74 percent of 1972 models.

The following trends can be discerned in Figure 2-1:

FIGURE 2-1: PERCENT OF ACCIDENT INVOLVEMENTS DUE TO DEFECTIVE BRAKES, BY MODEL YEAR WITHIN CALENDAR YEAR, NORTH CAROLINA



NOTE: 19 OBS HIDDEN

o The percent of cars with accident-contributory brake defects increases steeply as vehicle age increases. Moreover, the rate of increase gets larger as vehicle age increases. The trend is consistent with the hypothesis that most accident-causing brake defects are, at least in part, a consequence of improper or inadequate maintenance of aging components (See Section 2.1).

o The downward trend in brake defect accidents during model years 1965-67 (circled asterisks) is, in nearly all the calendar years, quite noticeably steeper than in the surrounding model years. It is evident from looking at Figure 2-1 that installation of dual master cylinders significantly reduced accidents.

o The downward trend in brake defect accidents during model years 1969-72 (squared pluses) is generally larger than the trend in subsequent model years. It is not necessarily larger than the trend in earlier years. Thus, from simple inspection of Figure 2-1, it is possible but not certain that disc brakes accelerated the trend toward fewer brake defect accidents.

o There does not appear to be any substantial reduction in brake defect accidents after model year 1973. In part, that may be due to the fact that, even by 1979, the cars were not old enough to have developed maintenance-related defects that may cause accidents.

The data points in Figure 2-1 are subjected to regression analysis in order to isolate the effects of dual and disc brakes on defective brake accidents from the effects of vehicle age and other factors ([20], pp. 6-8).

For each data point - each model year (MY)/calendar year (CY) combination, the dependent variable is

$$P_i = \frac{Bi}{Ni}\ \% = \frac{\text{number of defective brake accident involvements (MY, CY)}}{\text{number of accident involvements (MY,CY)}}\ \%$$

The independent variables are

DUAL (%) = DUAL (MY) = percent of a model year's production equipped with dual master cylinders (see Table 1-1).

DISC (%) = DISC (MY) = percent of model years' production equipped with disc brakes (see Table 1-1)

AGE = CY - MY +1 = vehicle age

AGE^2, because Figure 2-1 clearly suggests that the effect of vehicle age on brake defects is nonlinear

WEIGHT = WEIGHT (MY, CY) = average weight (pounds) of cars of model year MY in North Carolina accidents during CY.

POWER (%)=POWER (MY) = percent of cars with power brakes (see Table 1-1).

CY 71, CY 72, CY73-78 - indicating calendar year. For example, CY 73-78 = 1 for 1973 - 78 accidents, 0 otherwise. The categories correspond to periods in which the North Carolina accident report did not change.

The regression weight factor is

$$\frac{Ni}{Pi\ (100 - Pi)}$$

An initial regression run generated a negligible coefficient for power brakes, whereas all other variables had statistically significant coefficients. The regression was rerun without the power brake variable. The equation that best fits the observed, weighted data is

$$P = 2.629 - .007\ DUAL\ (\%) - .006\ DISC\ (\%)$$
$$+ .01\ AGE^2\ - .0002\ WEIGHT$$
$$- .619\ CY71 - .487\ CY72 - .357\ CY\ 73\text{-}78$$

and $R^2 = .96$ and df = 144 (i.e., the equation fits the data extremely well).

In other words, the proportion of all accidents which are due to brake defects is .7 percent lower in a fleet with 100 percent dual master cylinders than in a fleet with no dual master cylinders: essentially, dual master cylinders eliminate .7 percent of all accidents.

Similary, the regression suggests that disc brakes lower the proportion of accidents due to brake defects by .6 percent.

The F - values (with df = 1, 144) of the dual and disc brake terms are 93.6 and 83.6, respectively. Thus, the accident reductions for dual and disc brakes are statistically significant ($p < .05$; in fact, $p < .0001$).

Based on the preceding regression formula and given the age and weight distribution of cars in North Carolina during 1971-79, the model makes the following predictions about the overall proportion of accidents due to brake failure:

- o If no cars had dual or disc brakes: 2.0%
- o If all cars had dual but none had disc: 1.3%
- o If all cars had dual and disc: 0.7%

(See [20], pp. 9-11.)

The baseline proportion of brake failure accidents (2.0%) is fairly consistent with the 2.6 percent found in Level B of the Indiana tri-level study (see the preceding section). In other words, the police reporting of brake defects in North Carolina is not far below what was found in more detailed investigations by technicians at Indiana. The North Carolina file, then, may be an adequate indicator of the incidence of brake defect accidents.

Likewise, the 0.7 percent accident reduction attributed by the statistical analysis to dual master cylinders is consistent with the proportion of accidents (1 percent) that in-depth investigators at Indiana felt could have been prevented if the cars had had dual master cylinders. In view of the high statistical significance of the result, its consistency with in-depth investigation findings and the obvious effect of dual brakes noticeable by looking at Figure 2-1, it is safe to say that the accident reduction attributed to dual master cylinders by the model is probably valid.

On the other hand, the 0.6 percent accident reduction attributed by the model to front disc brakes, although statistically significant, may be questioned for several reasons. The Indiana in-depth investigations of brake defect accidents do not reveal that large a potential effect for disc brakes. The data in Figure 2-1 do not unambiguously show that disc brakes were effective: since the device was gradually installed in the fleet over a period of numerous model years, it is relatively easy for the statistical model to confuse the effects of disc brakes and vehicle age. Thus, additional statistical analyses are needed, especially, to test the validity of the disc brake effect.

The first test is to determine whether some of the effect attributed to disc brakes is actually due to other braking improvements made in response to Standard 105-75. The improvements may have consisted of superior brake lining materials, modifications of proportioning and metering values to prevent brake imbalance or, in a few cases, using larger rear drums. They were generally implemented in the 1975 or 1976 model year [22]. Thus, the regression is rerun with an additional independent variable

$$\text{STD 105-75} = \begin{cases} 0 \text{ if MY} \leq 74 \\ \text{unknown if MY} = 75 \\ 100 \text{ if MY} \geq 76 \end{cases}$$

The regression attributed an 0.02 percent increase in brake defect accidents, of utterly no statistical significance, to STD 105-75 and left all the other coefficients virtually unchanged [20], pp. 26-29.

That essentially rules out the possibility that the benefits of subsequent brake improvements were wrongly attributed to disc brakes.

A second test is to add "nuisance variables" to the regression. Two model years are selected arbitrarily and it is pretended that significant braking "improvements" were made in those two years. Thus, independent variables are added to the model to gauge the "effects" of those "improvements." If the model ignores the two new variables and continues assigning significant effects to dual and disc brakes, it is evidence that the latter effects may be real. But if the model now assigns diminished importance to dual and disc brakes and a significant effect to the new variables, it is evidence that the original reductions were not really due to dual and disc brakes--i.e., that the original model merely "used" DUAL and DISC to express an effect that was really due to vehicle age or other factors and that the new model is equally happy to use something else for the same purpose.

The nuisance variables are

$$D1 = \begin{cases} 1 \text{ if } MY < 1969 \\ 0 \text{ otherwise} \end{cases}$$

$$D2 = \begin{cases} 1 \text{ if } MY < 1975 \\ 0 \text{ otherwise} \end{cases}$$

The regression attributes a significant 0.7 percent accident reduction to DUAL (same as in the original model), a significant 0.5 percent reduction to DISC (down from 0.6), a nonsignificant 0.01 percent increase to D1 and a nonsignificant 0.07 percent reduction to D2 (Table AD-1 in Appendix A).

In other words, the model shows no inclination at all to diminish the effect of DUAL and a very slight inclination to diminish the effect of DISC. Both dual and disc brakes appear to pass this test.

2.2.2 Defective brakes, by make and model of car

A factor that complicated the preceding analyses is the gradual introduction of disc brakes. Their implementation spanned the period from 1965 to 1977. That gives the regression an opportunity to confuse the effects of DISC and vehicle age or calendar year.

A remedy is to further subdivide the accident data by vehicle make and model. Whereas the introduction of disc brakes was gradual for the fleet as a whole, it took place over distinct, relatively short time periods for individual makes and models. For example, Lincolns and Thunderbirds received disc brakes in 1965, full-sized Chevrolets mainly in 1970-71 and Mavericks primarily in 1975-76.

Stewart subdivided domestic passenger cars into 20 make/model groups. Each group contains models that are similar with respect to car size and percent having disc brakes [20], pp. 11-18. The data are limited to model years 1967-81, because detailed make/model codes are usually unavailable for pre-1967 cars in North Carolina. As a result, all cars in the data set have dual master cylinders and DUAL is omitted from the list of independent variables.

Otherwise, the regression is similar to the preceding ones, except that there are now 2066 data points corresponding to the various calendar year--model year--make/model combinations. There are 19 additional independent variables, whose values are 0 or 1 depending on the make/model group. The regression was performed in November 1982: by that time calendar year 1980 and 81 data were available and were added to the analysis. (See Table ADC-1 in Appendix A.)

The regression indicates a significant reduction in brake defect accidents as a consequence of front disc brakes ($F = 19.4$, $df = 1, 2032$, $p < .05$). The magnitude of the accident reduction, however, is only 0.17 percent, which is less than a third of what was found in the preceding analyses. The inclusion of the make/model variables reduced the predicted effect of disc brakes. The effects of vehicle age, calendar year, etc., were about the same as before.

The significant accident reduction of 0.17 percent seems consistent with the potential effect of disc brakes found in the Indiana in-depth investigations of brake defect accidents and appears to be a more reliable estimate than the 0.6 percent found in the preceding analyses.

As before, the results were put to two tests. First, STD 105-75 was added as an independent variable (see Table ADC-3 in Appendix A). That regression produced an 0.15 percent accident reduction for disc brakes--almost the same as above. It also indicated a significant 0.07 percent increase in brake defect accidents for STD 105-75: a result which appears to be more of statistical than practical significance.

Then, the regressions were rerun with the nuisance variables D1 and D2 (see Table ADC-2 in Appendix A). Neither nuisance variable was given a significant "effect" while DISC was given a significant 0.15 percent accident reduction (again, virtually unchanged). The results of the two tests further support the validity of the disc brake effectiveness obtained by analyzing the data by make and model.

2.2.3 Injury accidents

The North Carolina data were then restricted to accidents in which at least one person was injured (not necessarily an occupant of a case vehicle). The regressions were rerun for injury-producing accidents in order to check whether the accident reductions previously observed for dual and disc brakes in accidents of all severity levels also apply to accidents of higher severity.

In the basic regression, accident involvements were grouped by calendar year and model year and the independent variables included DUAL, DISC, AGE, AGE^2, etc. In the model that best fit the data and where nonsignificant independent variables were omitted (Table ID-3 in Appendix A), there was a statistically significant 0.6 percent accident reduction for dual master cylinders and a significant 0.5 percent accident reduction for front disc brakes - virtually the same reductions as when property damage accidents were included.

Next, the accident involvements were grouped by calendar year, model year and make/model group (Table IDC-1 in Appendix A). The regression indicated a statistically significant 0.14 percent accident reduction for disc brakes - again, about the same as in the analysis for all types of accidents.

The introduction of 2 "nuisance" variables did not substantially change any of the above reductions nor did it attribute significant coefficients to the nuisance variables.

It is concluded that the braking improvements prevent approximately the same proportion of injury producing accidents as they do of property damage accidents.

2.2.4 Accidents on wet roads

One of the objectives of disc brakes is to improve water resistance: to reduce the likelihood or duration of losses of friction capability when braking surfaces are exposed to water. If disc brakes indeed provide a large safety benefit in that area, it should be reflected in the accident data. Specifically, the reduction of brake defect accidents, for disc brakes, might be especially large on wet roads.

The basic regression on North Carolina accidents was rerun with the data set limited to accidents occurring in wet weather or on wet roads. The baseline rate for brake defect accidents and the reductions for dual and disc brakes are shown side by side with the results from the original regression [20], pp. 7-11.

	Wet Roads	All Roads
Baseline proportion of brake defect accidents (%)	1.5	2.0
Reduction for dual master cylinders	0.3	0.7
Reductions for disc brakes	0.6	0.6

The regressions attribute identical reductions (0.6%) to disc brakes on wet and dry roads. The only suggestion that disc brakes might be more effective is that they elinimate a relatively higher proportion of the brake defect accidents (0.6 / 1.5, which is 40 percent, as opposed to 0.6 / 2.0, which is 33 percent). Nevertheless, it is evident that the safety benefits of improved water resistance for disc brakes are not large in absolute terms.

The finding is consistent with the Indiana tri-level data, where none of the brake-related accidents were attributed to water contact. Some emplanations of why accidents due to water-related braking losses are rare could include:

- It is uncommon for the brakes to be immersed in water
- Many drivers know that immersion may cause friction losses and they take necessary steps (pumping the brakes) until friction is regained
- Even drum brakes can be designed for good water resistance properties. Drum brakes could and did comply with relatively stringent water resistance requirements of Standard 105-68 and, apparently, 105-75.

2.2.5 Accidents in hilly regions

Another objective of disc brakes is to provide better ventilation for the friction surfaces and reduce the likelihood of brake fade due to overheating. If disc brakes indeed provide a large safety benefit through fade resistance, it might be most evident in hilly regions, where brakes are used repeatedly on long, curving downgrades. The reduction of brake defect accidents might be especially large, for disc brakes, in hilly regions.

The basic North Carolina regression was rerun with the data set limited to accidents occurring in the hilly western third of the State. The baseline rate for brake defect accidents and the reductions for dual and disc brakes are shown side-by-side with the results from the original regression [20], pp. 7 - 11.

	Hilly Regions	Entire State
Baseline proportion of brake defect accidents (%)	2.2	2.0
Reduction for dual master cylinders	0.9	0.7
Reduction for disc brakes	0.6	0.6

The regressions attribute identical reductions (0.6%) to disc brakes in hilly and flat regions of the State. It is evident that the safety benefits of improved fade resistance for disc brakes are not large.

The finding is consistent with the Indiana tri-level data, where no accidents were attributed to brake fade (although, to be sure, the area around Bloomington, Indiana does not create many opportunities for overusing brakes till they fade). Some explanations of why accidents due to brake fade are rare could include:

o Drum brakes can be designed for good fade resistance. Drum brakes could and did comply with the relatively stringent fade resistance requirements of Standard 105-68 and, apparently, 105-75.

o The fade resistence requirements specified in the standard are stringent enough to cover most braking tasks encountered by passenger cars in actual operation.

o Many drivers know about the danger of brake fade and use lower gears on long, steep descents. Also, the buildup of pedal pressure can provide sufficient advance notice of potential fade problems, when correctly interpreted by drivers.

2.3 Texas accidents

Automated Texas accident files were available for access by NHTSA for the calendar years 1972, 1974 and 1977. Regression analyses quite similar to those for North Carolina were performed. To the extent that the Texas analyses are based on 3 calendar years of data and North Carolina analyses on 9-11 years, the results of the North Carolina analyses should be given greater weight.

2.3.1 Overall incidence of defective brakes

Figure 2-2 is a graph of the percentages of domestic passenger cars involved in accidents for which brake defects were a contributing factor, by vehicle age. The vertical axis indicates vehicle age (in years) and the horizontal axis, the percent of accident-involved cars in which defective brakes contributed to the accident, according to Texas police. The graph combines 1972, 74 and 77 data. Each point is denoted by a number which indicates the type of brakes in the fleet for that model year, as follows:

0 = Few or no dual master cylinders, few or no disc brakes (pre 1966)

1 = Some dual, few disc

2 = all dual, $<$ 25% disc (model years 1967-68)

3 = all dual, 25-49% disc (1969-70)

4 = all dual, 50-74% disc (1971-72)

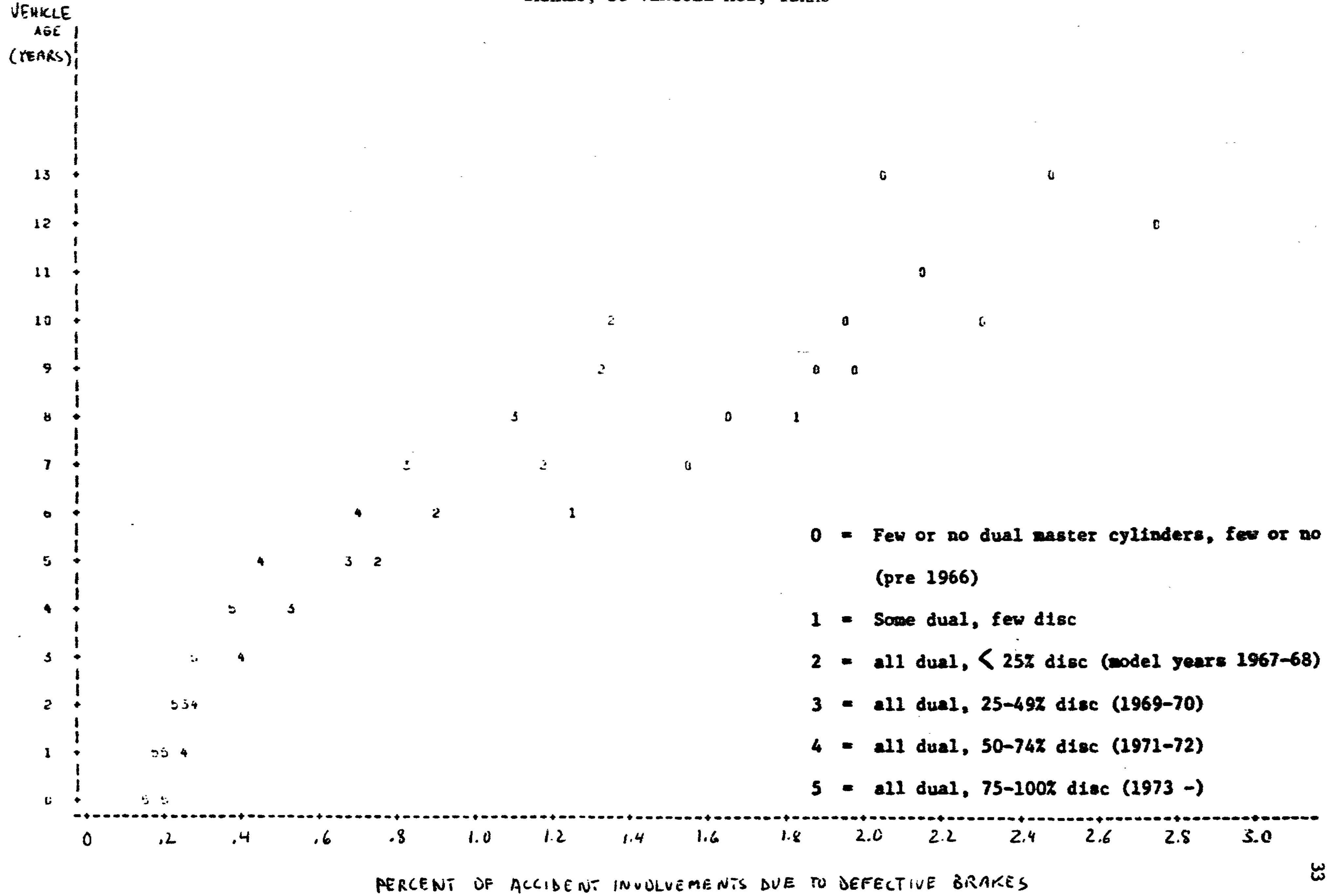
5 = all dual, 75-100% disc (1973 -)

The following trends are evident from Figure 2-2:

o The percent of cars with accident-contributory brake defects increases steeply as vehicle age increases. Moreover, the rate of

FIGURE 2—2

PERCENT OF ACCIDENT INVOLVEMENTS DUE TO DEFECTIVE BRAKES, BY VEHICLE AGE, TEXAS



increase gets larger as vehicle age increases (see also Section 2.1).

- o There is a substantial gap between the cars without dual master cylinders (points labelled 0) and those with them (2,3,4,5). Obviously, dual master cylinders significantly reduced accidents.

- o There is a moderate tendency for model year cohorts with high disc brake installation (labelled 4,5) to have lower accident rates than cohorts of the same age with fewer disc brakes (labelled 2,3). It is possible but not necessarily obvious that disc brakes reduced brake defect accidents. (The difference might also be partly explained by the fact that the data were collected in different calendar years, for example.)

In short, the trends are almost the same as in North Carolina.

The data points in Figure 2-2 are subjected to regression analysis in order to isolate the effects of dual and disc brakes from the effect of vehicle age and other factors. The procedure is almost the same as for North Carolina data. The individual data points are model year (MY) / calendar year (CY) combinations. The range of model years is 1960-72 for calendar year 1972, 1964-74 for calendar year 1974 and 1967-77 for calendar year 1977. In addition, there was a single data point for all pre-1964 cars in 1974 and all pre-1967 cars in 1977. These 2 points were assigned an average value for vehicle age, dual and disc brake installation. For each data point, the dependent variable is

$$P_i = \frac{B_i}{N_i} \% = \frac{\text{number of defective brake involvements (MY, CY)}}{\text{number of accident involvements (MY,CY)}} \%$$

The independent variables are

DUAL (%) = DUAL (MY) = percent of cars of that MY with dual master cylinders (see Table 1-1)

DISC (%) = DISC (MY)

AGE = CY - MY

AGE^2, because Figure 2-2 clearly suggests the age effect is nonlinear

CY 74, CY 77 - indicating calendar year. For example,

CY 74 = 1 if CY = 74; 0 otherwise

The regression weight factor is N_i.

The equation that best fits the observed, weighted data and has significant coefficients for all control variables is

$$P = 0.9 - .007 \text{ DUAL } (\%) - .0018 \text{ DISC } (\%) + .086 \text{ AGE} + .0026 \text{ AGE}^2 + .055 \text{ CY } 74 - .0049 \text{ CY } 77$$

and $R^2 = .98$ with df = 30 (a very close fit).

In other words, dual master cylinders are estimated to eliminate 0.7 percent of all accidents - exactly the same as the reduction obtained from North Carolina data. The reduction for dual master cylinders is statistically significant ($F = 53.6$, df = 1,30, $p < .05$).

Disc brakes, on the other hand, are estimated to eliminate just 0.18 percent of accidents - nearly the same as was found in the North Carolina analysis by make and model (0.17). The reduction, however, is not statistically significant in Texas ($F = 0.8$, df = 1,30, $p \geq .05$).

Based on the above regression formula and an average car age of 7 years, the model makes the following predictions about the overall proportion of accidents due to brake failure:

- If no cars had dual or disc brakes: 1.6%
- If all cars had dual but none had disc: 0.9%
- If all cars had dual and disc: 0.7%

These predictions are just slightly lower than those of the North Carolina model (where the baseline was 2.0%), indicating a relatively high degree of consistency, between the two States, in how often police believed an accident was caused by defective brakes.

As in North Carolina, the results are tested by rerunning the regression with added "nuisance" variables D1 and D2, where

$$D1 = \begin{cases} 1 & \text{if MY} < 1969 \\ 0 & \text{otherwise} \end{cases}$$

$$D2 = \begin{cases} 1 & \text{if MY} < 1975 \\ 0 & \text{otherwise} \end{cases}$$

Neither nuisance variable had a significent regression coefficient. However, the addition of D1 and D2 slightly diminished the effect of DUAL from -0.7% to - 0.55%, which is still a significant accident reduction. It changed the effect of DISC from -0.18 (a nonsignificant reduction) to +0.12 (a nonsignificant increase). In other words, the addition of nuisance variables did not substantially change the effect of dual master cylinders but it eliminated the already nonsignificant effect of disc brakes. Thus, only dual master cylinders pass the test.

2.3.2 Defective brakes, by make and model of car

Just as in the North Carolina data, there is concern that the gradual introduction of front disc brakes could cause the regression to confuse the effects of vehicle age and disc brakes.

Again, the remedy is to subdivide the accident data by vehicle make and model. The same 20 make/model groups that Stewart defined for North Carolina ([20], pp. 11-18) can readily be defined from Texas codes. As before, the data are limited to model years 1967-81: all cars have dual master cylinders and DUAL is omitted from the list of independent variables.

The regression indicates a nonsignificant 0.05 percent accident reduction as a consequency of disc brakes ($F = 0.84$, $df = 1, 405$, $p > .05$). As in North Carolina, the reduction in this regression is about one third as large as the reduction obtained for disc brakes when the data were not subdivided by make and model (0.18%).

Even this nonsignificant 0.05 percent accident reduction vanished when "nuisance" variables D1 and D2 were added to the regression.

2.3.3 Injury accidents

The Texas data were restricted to injury-producing accidents and the regressions were rerun to see if the effects of dual and disc brakes persisted at higher severity levels.

In the basic regression, accident involvements were grouped by calendar year and model year and the independent variables were DUAL, DISC, AGE, AGE^2 and CY. The last of these did not make a significant contribution to the regression and was omitted.

In the model that best fit the data, there was a statistically significant 0.6 percent accident reduction for dual master cylinders ($F = 43.1$, $df = 1,32$, $p < .05$) - exactly the same as in North Carolina injury accidents and almost the same as in all Texas accidents.

There was a nonsignificant 0.1 percent accident reduction for disc brakes ($F = 0.7$, $df = 1, 32$, $p > .05$), consistent with the result obtained for all types of Texas accidents.

When the injury accidents were grouped by calendar year, model year and make/model group, there was a nonsignificant 0.06 percent accident reduction for disc brakes ($F = 0.2$, $df = 1, 443$, $p > .05$)- again consistent with the results for all types of Texas accidents.

In summary, the Texas analyses strongly confirm and in fact, duplicate the North Carolina findings that dual master cylinders eliminate about 0.7 percent of all accidents, including severe ones. The Texas results are consistent with the conclusion, from North Carolina, that disc brakes eliminate about 0.17 percent of all accidents.

2.4 Fatal accidents

The Fatal Accident Reporting System (FARS) is a census of the nation's fatal traffic accidents. In September 1982, FARS data were available for calendar years 1975-81. Regression analyses quite similar to those for North Carolina and Texas were performed on FARS, in order to check whether the previously observed effects for dual and disc brakes extend to fatal accidents. To the extent that vehicle defects contributing to accidents appear to be underreported in many States, the FARS results should not be considered as authoritative as the North Carolina findings. Since a year of FARS contains only one fifth as many accidents as a year of North Carolina data, the results are also less statistically precise.

The involvements of domestic passenger cars in fatal accidents during 1975-81 are subdivided by calendar year and model year. As before, the dependent variable is the percentage of involvements in which defective brakes contributed to the accident. The initial list of independent variables is DUAL, DISC, AGE, AGE^2 and CY 76, ..., CY 81, defined as in Texas. The regression weight factor is the number of involvements of a given model year in a given calendar year, as in Texas.

Initial regression runs showed that AGE^2 and the calendar year variables were not making significant contributions to the model, so they were dropped. The equation that best fits the observed, weighted data and has significant coefficients for all control variables is

$$P = 0.9 - .0034 \text{ DUAL } (\%) - .0055 \text{ DISC } (\%) + .034 \text{ AGE}$$

and $R^2 = .82$ with df = 129 (an excellent fit)

In other words, dual master cylinders are estimated to eliminate 0.34 percent of all accidents. The reduction is statistically significant ($F = 21.1$, df = 1, 129, $p < .05$). Disc brakes are estimated to eliminate 0.55 percent of all accidents - also a statistically significant reduction ($F = 37.7$, df = 1, 129, $p < .05$)

Based on the preceding regression formula and an average car age of 7 years, the model makes the following predictions about the overall proportion of accidents due to brake failures:

- If no cars had dual or disc brakes: 1.1%
- If all cars had dual but none had disc: 0.8%
- If all cars had dual and disc: 0.25%

The baseline prediction (1.1%) is about half as large as the comparable prediction for North Carolina (2.0%), most likely reflecting the underreporting of vehicle defects in accidents in many States. If the accident rates and, likewise, the reductions for dual and disc were to be doubled on FARS, it would lead to a 0.7 percent accident reduction for dual brakes - identical to what was observed in North Carolina and Texas for nonfatal accidents. At any rate, the FARS data confirm that dual master cylinders significantly reduce accidents.

The accident reduction for disc brakes on FARS, however, is substantially larger than the reductions that were obtained in Texas and in the analysis by make and model in North Carolina. Unfortunately, the FARS sample of brake defect accidents is much too small to be further subdivided by make/model groups, so it cannot be determined whether the large effect of disc brakes would persist or would be cut by two thirds as in North Carolina and Texas. The specific reduction for disc brakes found in FARS should be viewed with caution, but the positive finding can be regarded as supporting the conclusion, based on North Carolina data, that disc brakes are at least somewhat effective in reducing accidents.

2.5 Other approaches to regression

The North Carolina, Texas and FARS data were all analyzed by the same regression model. It was a linear model (except to the extent that it contained AGE^2). In other words, it assumed that a change from no dual braking to dual master cylinders would result in a contant reduction, in absolute terms, in the dependent variable -i.e. the proportion of accidents due to brake defects - regardless of vehicle age. In other words, the model says things like: a 10-year-old car has 2.5 percent of its accidents due to brake defects if it is not equipped with dual master cylinders and 1.8 percent if it is equipped; a 5-year old car has 1.5 percent if not equipped, 0.8 percent if equipped. In either case, the accident reduction for dual brakes is 0.7 percent.

The linear model is certainly the most attractive from an analytic viewpoint, because the coefficients assigned DUAL and DISC give the actual accident reductions (except for a trivial correction factor which has been ignored throughout the chapter). But is it consistent with intuition?

The review of in-depth cases (Section 2.1) suggested that most brake defect accidents are due to inadequate or improper maintenance and that dual and disc brakes might be effective because they compensate for or reduce the severity of maintenance problems. (For example, neglecting the condition of hoses could lead to a catastrophic braking loss with single master cylinders, but just to a partial loss with dual.) This tendency suggests that the effect of DUAL and DISC could increase with AGE -i.e., as cars get older and develop more maintenance problems, there is more potential accident avoidance for dual and disc.

Analytically, the problem is addressed by adding interaction terms - DUAL * AGE and DISC * AGE - to the model. The Texas regressions were rerun with those interaction terms. The results were as follows:

o Consistent with intuition, the effects of dual and disc brakes increased slightly as vehicle age increased, however

- The interaction terms were not statistically significant

- The interaction model and the linear model produced virtually identical fleetwide estimates of brake defect accidents when no cars have dual or disc; all have dual, none have disc; all have dual and disc.

Thus, although the runs support intuition that a modest interaction may exist, the nonsignificance of the interaction and the lack of impact on overall results suggest that the simpler, linear model is to be preferred.

Another way to model possible interaction between vehicle age and braking improvements is to use log-linear regression. The dependent variable is the logarithm of the proportion of involvements due to brake defects. This model produces an effect for braking improvements that is constant relative to the number of brake defect accidents without the improvement. In other words, if 10 year old cars have twice as many brake defects as 5 year old cars, they will get double the net benefit from dual master cylinders.

The log-linear model is very undesirable from an analytic viewpoint because it focuses inordinately on relatively new cars. New cars' fluctuations of the proportion of brake defect accidents, which are trivial in absolute terms, are large in relative terms. These fluctuations are given a great deal of attention by the model and assigned to spurious causes, while the obvious large reductions for dual master cylinders in earlier years are given little attention.

The log-linear model was tried out on North Carolina (Table ID-4 of Appendix A), Texas and FARS data with very mixed results (in contrast to the high degree of consistency, between files, for the linear model).

In North Carolina, the log-linear model attributed a nonsignificant 0.15 percent accident reduction to dual master cylinders, a nonsignificant

0.5 percent accident <u>increase</u> to disc brakes and a significant 1.7 percent reduction to power brakes! Obviously, it confused the effects of vehicle age and power brakes.

In Texas, the log-linear model produced results that were not too different from the linear model, attributing a 0.5 percent accident reduction to dual master cylinders and a 0.4 percent reduction to disc brakes.

On FARS, the log-linear model attributed a nonsignificant 0.2 percent accident reduction to dual master cylinders and a significant 0.6 percent accident reduction to disc brakes.

The log-linear model cannot be relied upon to produce meaningful results on defective brake accidents.

2.6 Best estimates and confidence bounds for effectiveness

The most reliable estimate of <u>dual master cylinder</u> effectiveness, from both a statistical and intuitive viewpoint, came from the basic regression of North Carolina accidents, subdivided by calendar year and model year (Section 2.2.1). It was estimated that dual master cylinders eliminated 0.7 percent of all accidents. The F-value associated with the effect of dual brakes was 93.6 and df = 144. Thus, the standard deviation of the effectiveness is

$$0.7 \; / \; \sqrt{93.6} \; = \; .072$$

The lower confidence bound for effectiveness is

$$0.7 - 1.66\,(.072) = 0.58 \text{ percent}$$

where 1.66 is the 95th percentile of a t distribution with 144 df.

The upper bound is

$$0.7 + 1.66\,(.072) = 0.82 \text{ percent.}$$

The most statistically reliable and intuitively reasonable estimate of disc brake effectiveness came from the regression of North Carolina accidents, subdivided by calendar year, model year and make/model group (Section 2.2.2). It was estimated that disc brakes eliminated 0.17 percent of all accidents. The F value associated with this effect was 19.4 and df = 2032. Thus, the standard deviation of the effectiveness is

$$0.17 / \sqrt{19.4} = .039$$

The lower confidence bound for effectiveness is

$$0.17 - 1.65\ (.039) = 0.10 \text{ percent}$$

where 1.65 is the 95th percentile of a t distribution with 2032 df. The upper bound is

$$0.17 + 1.65\ (.039) = 0.24 \text{ percent.}$$

The effectiveness estimates are applicable to property damage, injury and fatal accidents.

Finally, it was estimated that 2.0 percent of vehicle involvements in North Carolina accidents would have been due to brake defects if no cars had been equipped with dual master cylinders or disc brakes (confidence bounds: 1.9 - 2.1 percent [20], p. 11). In other words, dual master cylinders eliminated 35 percent (0.7/2.0) of brake defect accidents and disc brakes eliminated 9 percent (0.17/2.0) of them.

CHAPTER 3

ANALYSES OF TWO-CAR FRONT-TO-REAR COLLISIONS IN NORTH CAROLINA

3.1 Rationale and analysis method

Disc brakes have a more linear relationship between pedal pressure and vehicle deceleration than do drum brakes. The improved "pedal feel" may help drivers judge stopping distances better and enable them to avoid a collision due to misjudging the appropriate pedal pressure or locking the wheels prematurely. If so, the car with disc brakes in a two-car front-to-rear collision would less likely be the striking car. That is because a misjudgment of pedal pressure by the driver of the striking car could be a causative factor in the accident, whereas the struck car's driver has no comparable task.

There are other factors, though, that affect the probability of being the struck or striking car, such as vehicle age. Certain makes and models tend to be purchased by more aggressive drivers and are more likely to be the striking car.

The effect of disc brakes is isolated from the other effects by regression: specifically, a regression of the probabilities, given a 2-car front-to-rear collision, that a car of a given model year, calendar year, and make/model will be the striking vehicle--as a function of disc brake installation and vehicle age.

J. R. Stewart of the Highway Safety Research Center performed the regressions under contract to NHTSA [20], pp. 11-21. The data consisted of 1967-79 model year domestic passenger cars involved in 2-car front-to-rear crashes during calendar years 1971-79. The data were subdivided by calendar year (CY), model year (MY), and make/model group (MM), using the same 20 groups as in the defective brake analysis (Section 2.2.2).

The dependent variable, for a given CY, MY and MM, is

$$p_i = \frac{F_i}{N_i}\ \% = \frac{\text{number of frontal involvements (MY, CY, MM)}}{\text{number of involvements (MY, CY, MM)}}\ \%$$

i.e., the percentage of front-to-rear collisions of this type of car in which it is the striking vehicle.

The independent variables are

DISC (%) = DISC (MY) = percent of model year's production equipped with disc brakes (see Table 1-1)

AGE = CY - MY + 1 = vehicle age

AGE^2

POWER (%) = POWER (MY) = percent with power brakes (see Table 1-1)

WEIGHT = WEIGHT (MY, CY, MM) in pounds

Calendar year indicators

Make/model group indicators

3.2 Regression results

Only vehicle age, AGE^2 and the make/model group had any significant effects on the likelihood of being the striking car. As Stewart's Table 10 indicates, the percentage was as high as 57 for one group and as low as 44 for another [20].

The regression attributed to disc brakes an 0.2 percent reduction in the likelihood of being the striking car. (See Table 9 of Appendix A.) The effect is in the right direction but it is not statistically significant ($F = 0.09$, $df = 1,1336$, $p \geqslant .05$). When the data are restricted to injury accidents, wet roads or hilly regions, the regressions attributed to disc brakes increases in the likelihood of being the striking car by 0.2-0.7 percent. None of those increases were statistically significant, either.

In short, the North Carolina data do not support a conclusion that disc brakes significantly reduced accidents, other than those due to brake defects.

CHAPTER 4

COSTS AND BENEFITS

One of the goals of the evaluation is to estimate the actual costs and actual benefits of braking improvements in a manner that allows a meaningful comparison of costs and benefits.

The cost of a braking improvement is the average annual fleetwide cost of the equipment which was actually installed to bring about the improvement. The cost includes the increase in the initial purchase price of a car, the incremental fuel consumption due to the weight of the equipment and any growth in repair and maintenance costs. All costs are expressed in 1982 dollars.

Similarly, the benefits of a braking improvement are the fatalities, injuries and damages to property that will be prevented annually when all cars have that improvement.

4.1 Costs

A 1979 study performed under contract to NHTSA gave estimates of the purchase price increase and weight added to passenger cars by brake systems [9]. From that report, NHTSA gleaned 10 models that had single master cylinders in 1966 and dual master cylinders in 1968. Seven models were identified that had front drum brakes in 1966 and front disc brakes in 1968 (the latter, not necessarily as standard equipment, but they were installed in the specimen vehicle studied by the contractor).

Table 4-1 shows, for each of the above 10 models, the weight and cost of the single master cylinder in the 1966 car and of the dual master cylinder in the 1968 car. The "cost," which is meant to approximate the purchase price increase, includes materials, labor, tooling, assembly, overhead, manufacturer's and dealer's markups and taxes. The cost is expressed in 1979 dollars.

The two right columns of Table 4-1 show the weight and cost differences between 1968 and 1966. They represent the added weight and cost of dual over single master cylinders. Finally, the arithmetic averages of the 10 incremental cost and weight estimates are computed at the lower right. The average weight increase is 2.25 pounds and the price increase is \$7.66 in 1979 dollars. The price increase is converted from 1979 to 1982 dollars by multiplying by the ratio of the Consumer Price Index for automobiles, which was 159.8 in 1979 and 198.1 in 1982. In other words, for dual master cylinders,

$$\text{Price increase (1982 dollars)} = \frac{198.1}{159.8} \times 7.66 = \$9.50$$

Each incremental pound of weight results in the consumption of an average of one additional gallon of fuel over the lifetime of a car [8], pp. VII-43-46. Table VII-16 of [8] calculates the discounted present value of consuming an additional gallon of fuel over the lifetime of a car. When the costs in that table are changed to reflect 1982 fuel prices (\$1.21 per gallon in February [13], p. 82), it is found that each

TABLE 4-1

COST AND WEIGHT INCREASES ATTRIBUTABLE TO
DUAL MASTER CYLINDERS

(1979 dollars)

Make/Model	Single Master Cylinder (1966)		Dual Master Cylinder (1968)		Increase	
	Weight (Pounds)	Cost	Weight (Pounds)	Cost	Weight (Pounds)	Cost
Plymouth Valiant	4.01	$11.54	5.95	$19.33	1.94	$ 7.79
Ford Falcon	3.60	13.33	5.59	16.62	1.99	3.29
Chevrolet Chevy II	4.15	12.17	5.94	18.30	1.79	6.13
Chevrolet Chevelle	4.10	11.46	5.95	19.34	1.85	7.88
Plymouth Fury	3.98	11.54	6.05	16.69	2.07	5.15
Chevrolet Caprice	4.10	11.46	5.94	21.04	1.84	9.58
Pontiac Bonneville	4.05	11.65	7.64	15.31	3.59	3.66
Buick Electra	3.54	12.93	5.96	13.83	2.42	.90
Toyota Corona	1.67	9.79	5.36	21.34	3.69	11.55
Volkswagen	1.67	10.44	2.95	21.12	1.28	10.68
				AVERAGE INCREASE	2.25 pounds	$7.66 (1979 dollars)

incremental pound of weight adds $1.00 to the discounted lifetime cost of owning and operating a car. Since dual master cylinders add 2.25 pounds to the weight,

Fuel penalty = $2.25

Finally, a master cylinder is an item that must occasionally be replaced. The Hunter service job analysis indicates that 4 million master cylinders are replaced per year [17]. Since 10 million cars are sold per year, it means there is a probability of .4 that the cylinder will be replaced sometime during the life of the car. Typically, replacement could occur in the car's 7th year, at the time of its second brake job. Since this is 6 years after purchase, it should be discounted by .546, assuming a 10 percent discount rate. Finally, an analysis of Chilton's labor and parts guides suggests that the retail price of an aftermarket master cylinder is 2.5 times as large as the "purchase price contribution" of a master cylinder in a new car (the numbers in Table 4-1). It is assumed that the difference in aftermarket prices of dual and single is likewise 2.5 times as large as for new cars. Thus, for <u>dual</u> master cylinders,

Added repair cost = .4 x .546 x 2.5 x $9.50 = $5.20

And, the <u>total</u> consumer cost per car for dual master cylinders is

purchase price increase + fuel + repairs
= $9.50 + 2.25 + 5.20 = $16.95 (in 1982 dollars)

Since 10 million cars are sold annually in the United States, the total cost of dual master cylinders is about $170 million per year.

Table 4-2 shows the weight and purchase price of the front wheel brake assemblies for the 7 models that were equipped with drum brakes in 1966 and disc brakes in 1968. The two right columns show the weight and price differences between 1968 and 1966 and represent the effect of changing over from drum to disc. Clearly, there is no consistent pattern in the price changes, with 4 models becoming more expensive and 3 less. That is because there are considerable variations within the designs of drum and disc brakes, leaving many choices to the manufacturers. The average for the 7 models was an increase of $2.35 (in 1979 dollars), but it is not certain whether the estimate is accurate or, for that matter, if disc brakes increased the purchase price for the vehicle fleet, as a whole. The weight changes are more consistently positive (although one is negative) and average to a gain of 5.21 pounds.

In 1982 dollars, for <u>disc</u> brakes

$$\text{Price increase} = \frac{198.1}{159.8} \times 2.35 = \$2.90$$

Fuel penalty = $5.21

Finally, disc brakes add to the cost of vehicle maintenance. Inquiries to service stations, tire centers, new car dealers and independent garages in the Washington area indicated that a front disc brake job costs about $10 more than a front drum brake job. Typically, a car requires two brake jobs during its lifetime regardless of whether equipped with disc or drum brakes, very likely during its 4th and 7th years of operation (see also statistics on "shoes relined or pads replaced" in Hunter's service job analysis [17]: 75 million per year, with 4 wheels to a car,

TABLE 4-2

PURCHASE PRICE AND WEIGHT CHANGES ATTRIBUTABLE TO FRONT DISC BRAKES

(1979 dollars)

Front Wheel Brake Assemblies with:

Make/Model	Drum Brakes (1966)		Disc Brakes (1968)		Change	
	Weight (Pounds)	Cost	Weight (Pounds)	Cost	Weight (Pounds)	Cost
Ford Falcon	51.92	$85.70	64.52	$104.00	+12.60	+$18.30
Chevrolet Chevy II	54.58	72.29	56.07	66.28	+ 1.49	- 6.01
Chevrolet Chevelle	32.09	71.29	45.77	56.29	+13.68	- 15.00
Ford Galaxie	70.66	95.23	77.94	103.42	+ 7.28	+ 8.19
Chevrolet Caprice	63.94	77.69	75.91	57.64	+11.97	- 20.05
Pontiac Bonneville	73.37	78.74	73.54	82.10	+ .17	+ 3.36
Buick Electra	86.07	76.41	75.38	104.04	-10.69	+ 27.63
				AVERAGE INCREASE	5.21 pounds	$2.35 (1979 dollars)

means each car gets a 4-wheel brake job once in 5 years, twice over its lifetime). If the two incremental downstream expenditures of $10 each are discounted, their net present value is:

Added repair cost for disc = .751 x $10 + .546 x $10 = $12.97

Thus, the <u>total</u> consumer cost per car for disc brakes is

purchase price increase + fuel + repairs

= $2.90 + 5.21 + 12.97 = $21.08 (in 1982 dollars)

On the basis of 10 million car sales annually in the United States, the total cost of front disc brakes is about $210 million per year.

4.2 Benefits

The best estimates of effectiveness (from Section 2.6) were that dual master cylinders eliminate 0.7 $\pm$ 0.12 percent of all accidents involving passenger cars. Disc brakes eliminate 0.17 $\pm$ 0.07 percent of all accidents. Benefits are calculated hy applying these reductions to the casualties and damages in accidents involving passenger cars.

For example, there has been an average of 50,000 persons killed in motor vehicle accidents during the past 10 years. According to FARS data, about 75 percent, or 37,500 of those fatalities are in accidents involving at least one passenger car [4]. (The fatality is not necessarily a passenger car occupant--e.g., it could be a pedestrian struck by a car.)

Since dual master cylinders eliminate 0.7 percent of all accidents, they prevent 0.7 percent of 37,500--i.e., 260 fatalities per year. Since the confidence bounds on effectiveness are 0.58 and 0.82 percent, the confidence bounds on life savings are 220 and 310, respectively.

Similarly, disc brakes, which eliminate 0.17 percent of accidents, save an estimated 64 lives per year.

Table 4-3 carries out the calculation of benefits, and their confidence bounds, for fatalities, hospitalizations, injuries, police-reported accidents and the value of property damage. The data on property damage are based on a recent NHTSA study on the societal cost of accidents [3] and have been converted from 1980 to 1982 dollars by using the Consumer Price Index for automobiles. The data on hospitalizations are based on the 1979-80 annual report on the National Accident Sampling System [15].

Dual master cylinders, according to Table 4-3, annually prevent 260 fatalities and 2500 nonfatal hospitalizations and result in a savings of $132 million in property damage. The benefits of disc brakes are about one-fourth as large.

4.3 Cost-effectiveness

Safety equipment designed for crash avoidance has the potential to produce a wide variety of benefits: fewer fatalities and serious injuries, fewer nonserious injuries and a reduction in property damage. By contrast, crashworthiness equipment has little effect on property damage and, in some cases, alleviates only fatal and serious injuries or, in others, only nonserious injuries.

TABLE 4-3

BENEFITS OF DUAL MASTER CYLINDERS AND DISC BRAKES

	Annual Occurrences	Occurrences in Accidents Involving at Least One Passenger Car		Annual Benefits			
				Dual Master Cylinder[1]		Disc Brakes[2]	
		Percent	Annual Number	Best Estimate	Confidence Bounds	Best Estimate	Confidence Bounds
Fatalities	50,000	75[3]	37,500	260	220–310	64	38–90
Hospitalizations (nonfatal)	423,000[4]	85[4]	360,000	2500	2100–3000	610	360–860
Injuries (nonfatal, but includes hospitalizations)	3,970,000[5]	85[4]	3,370,000	24,000	19,000–28,000	5700	3400–8100
Police-reported accidents	6,773,000[4]	85[4]	5,760,000	40,000	33,000–47,000	9800	5800–13,800
Value of property damage (1982 dollars)	$22,200M[5]	85[4]	$18,900M	$132M	$110–155M	$32M	$19–45M

[1]Effectiveness: $0.7 \pm 0.12\%$

[2]Effectiveness: $0.17 \pm 0.07\%$

[3]Source: FARS [4]

[4]Source: NASS [15]

[5]Source: NHTSA Societal Cost Study [3]

Three measures of cost effectiveness are applied to braking improvements here: reduction of fatal and serious injuries; nonserious injuries; property damage. The three cost-effectiveness measures will not be combined into a single number in this report, but will be discussed together for a qualitative assessment of whether the improvements are cost effective.

Fatal and serious injuries can be expressed in Equivalent Fatality Units (EFU) [12], pp. 398-401. Each fatality is a contribution of 1 EFU; each nonfatal hospitalization is 0.0592 EFU. Since dual master cylinders save 260 lives and eliminate 2500 nonfatal hospitalizations per year, their annual benefits are 408 EFU (confidence bounds: 344 - 488; see Table 4-3). They cost $170 million per year. The number of EFU eliminated per million dollars of cost is

$$\frac{408}{170} = 2.4 \text{ (confidence bounds: } 2.0 - 2.9)$$

This benefit, by itself, would appear to make dual master cylinders as cost-effective or more so than many public safety and health programs. But dual master cylinders have the additional benefit of eliminating 21,500 injuries that do not require hospitalization--i.e., 130 injuries per million dollars of cost. Finally, the $132 million reduction in property damages, by itself, comes close to paying for dual master cylinders. When all three of these benefits are combined, it is obvious that dual master cylinders are a cost-effective safety device.

Disc brakes cost more than dual master cylinders and have substantially smaller safety benefits. Since disc brakes prevent an estimated 64 fatalities and 610 hospitalizations annually, the benefit is 100 EFU (confidence bounds: 59 - 141). They cost $210 million per year. The number of EFU eliminated per million dollars of cost is

$$\frac{100}{210} = 0.5 \quad \text{(confidence bounds: } 0.3 - 0.7\text{)}$$

In addition, disc brakes eliminate 5100 nonserious injuries annually (24 per million dollars of cost). Finally, their $32 million reduction in property damage is about 15 percent of their $210 million cost. Thus, disc brakes have moderately substantial safety benefits in addition to enhancing customers' satisfaction with the handling and quality of their cars.

CHAPTER 5

FINDINGS AND CONCLUSIONS

The results of the evaluation of dual master cylinders and front disc brakes are presented and discussed in this chapter. The findings are based on statistical analyses of North Carolina, Texas and Fatal Accident Reporting System (FARS) data; a review of in-depth accident analyses in the Indiana Tri-Level Study of the Causes of Accidents; a component cost analysis of a representative sample of vehicles; and data about repair frequency and cost.

5.1 Principal findings

Effectiveness of dual master cylinders

- The fleetwide installation of dual master cylinders eliminated 0.7 percent of accidents involving passenger cars (confidence bounds: 0.58-0.82 percent). The accidents eliminated were those in which "brake defects were a contributing factor" to the crash.

- Effectiveness was approximately the same in property damage, injury and fatal crashes.

Effectiveness of front disc brakes

- The fleetwide introduction of front disc brakes eliminated 0.17 percent of accidents involving passenger cars (confidence bounds: 0.10-0.24 percent). The accidents eliminated were those in which "brake defects were a contributing factor" to the crash.

o Effectiveness was approximately the same in property damage, injury and fatal crashes.

o Effectiveness was just as great on dry roads in flat regions as on wet roads (possible water exposure conditions) or in hilly regions (possible fade conditions).

o In two-car front-to-rear collisions, disc brakes were not found to have any effect on the likelihood that a car is the striking vehicle. In other words, disc brakes did not lead to a reduction of these types of accidents.

Cost of braking improvements

o The costs per car (in 1982 dollars) for dual master cylinders and front disc brakes are the following:

	Dual Master Cylinders	Front Disc Brakes
Initial purchase price increase	$9.50	$2.90
Lifetime fuel consumption due to weight increase	2.25	5.21
Lifetime repair cost increase	5.20	12.97
TOTAL COST PER CAR	$16.95	$21.08

o The annual costs of the improvements in the United States are $170 million for dual master cylinders and $210 million for front disc brakes.

Benefits of braking improvements

o The annual benefits, when all cars on the road in the United States have dual master cylinders and front disc brakes, will be:

	Dual Master Cylinders		Front Disc Brakes	
Reduction of	Best Estimate	Confidence Bounds	Best Estimate	Confidence Bounds
Fatalities	260	220-310	64	38-90
Nonfatal hospitalizations	2500	2100-3000	610	360-860
Injuries (any type)	24,000	19,000-28,000	5700	3400-8100
Police-reported accidents	40,000	33,000-47,000	9800	5800-13,800
Property damage	$132M	$110-155M	$32M	$19-45M

Cost-effectiveness

o An "Equivalent Fatality Unit" corresponds to 1 fatality or 16.9 nonfatal hospitalizations. Dual master cylinders eliminate 2.4 Equivalent Fatality Units per million dollars of cost (confidence bounds: 2.0-2.9).

o Front disc brakes eliminate 0.5 Equivalent Fatality Units per million dollars of cost (confidence bounds: 0.3-0.7).

5.2 Discussion

5.2.1 Effectiveness of dual master cylinders

Federal Motor Vehicle Safety Standard 105 specifies that passenger cars must have a dual braking system in order that cars may be stopped by the other system if there is a hydraulic failure in either one. Dual master cylinders are the chief component of a dual braking system.

The purpose of dual master cylinders, then, is to prevent accidents due to a catastrophic brake failure, specifically, a failure in the hydraulic system. (See Section 1.3.)

The in-depth accident analyses of the Indiana Tri-Level Study of the Causes of Accidents clearly identified accidents attributable to catastrophic loss of braking following hydraulic failure. It estimated that something on the order of 1 percent of accidents could be avoided by dual master cylinders. (See Section 2.1.)

The statistical procedure used for the effectiveness estimates of this evaluation is a comparison of the percentage of accident involvements attributed to "brake defects" by police, for cars with single and dual master cylinders. Since vehicle age and other factors may also influence this percentage, regression analysis is used to isolate the effect of dual master cylinders. The analyses were performed on North Carolina, Texas and FARS data--the accident files for which multiple calendar years of data were available to NHTSA. (See Sections 1.5 and 2.2.)

North Carolina had the largest number of accidents and the longest series of calendar years of data. Dual master cylinders were found to eliminate 0.7 percent of the accidents in North Carolina. The reduction is highly statistically significant and consistent with the prediction from the Indiana in-depth study. Texas, with a smaller sample, produced an identical result. In FARS, the observed reduction was about half as large, but so was the observed baseline rate of brake defects for pre-standard cars--suggesting that brake defects may have been under-reported by 50 percent. When the North Carolina and Texas files were limited to injury-producing accidents, the accident reduction again was close to 0.7 percent. Attempts to introduce "nuisance" variables into the regressions did not affect these results. (See Sections 2.2-2.6.)

In short, the analyses suggest that dual master cylinders reduced accidents by 0.7 percent and the result is both intuitively and statistically reliable.

5.2.2 Effectiveness of front disc brakes

Standard 105 does not specify that passenger cars must have front disc brakes. Nevertheless, the changeover from front drum to disc brakes is one of the most important and universal braking modifications of recent years. It took place in domestic cars during 1965-77 and the years with the most intense changeovers were 1969-72. To the extent that the relatively stringent water and fade resistance requirements of Standard 105-75 can be met with greater ease by disc than drum brakes, the standard may have been one of the motivating factors for the changeover.

Disc brakes appear to have been installed partly for safety reasons and partly for other reasons. The safety reasons include:

o A possible alleviation of brake defect accidents involving severe side-to-side imbalance

- A reduction of catastrophic braking losses due to water

- A reduction of catastrophic braking losses due to fade

- A better pedal "feel," allowing a better judgment of stopping distance and preventing brakes from locking prematurely--resulting, for example, in a reduction in the likelihood of being the striking vehicle in a front-to-rear collision.

The other reason for changing to disc brakes was customer demand, probably in response to their better handling qualities and pedal feel (see Section 1.4).

The in-depth accident analyses at Indiana did not indicate any specific crashes which the investigators thought could have been avoided by disc brakes. There were, for example, no accidents due to brake fade or exposure to water. There were, however, a number of cases of severe brake imbalance due to maintenance and adjustment problems which, perhaps, could have been reduced in severity by disc brakes. Maybe something less than 0.5 percent of all accidents were in that category. Also, about 4 percent of the accidents were attributed to premature locking of the brakes--indicating a potential for disc brakes to somewhat reduce this percentage in front-to-rear collisions (see Section 2.1).

The regression analyses for disc brakes were more complicated than for dual master cylinders. Disc brakes were introduced over a long time period (but dual master cylinders, mostly in 1966-67). In order to avoid confounding between the disc brake and vehicle age variable, the data were further subdivided by make and model: for individual models, disc brakes were introduced over much shorter time periods than for the fleet as a whole.

The North Carolina regression by make and model indicated that disc brakes eliminate 0.17 percent of all accidents. The reduction is statistically significant and consistent with the indications from the Indiana study. The reduction is unaffected when "nuisance" variables are added to the regression or when the data are limited to injury accidents (see Sections 2.2.2 and 2.2.3). The Texas and FARS results are statistically consistent with the North Carolina findings, although they are based on samples too small for a statistically significant analysis by make and model (see Sections 2.3 and 2.4).

When the North Carolina data were limited to accidents on wet roads or in hilly regions, no additional effectiveness was found for disc brakes. The most likely explanations are that accidents due to brake fade or exposure to water are rare and that drum brakes of the late 1960's and early 1970's had fade and water resistance properties nearly as good as those of disc brakes (see Sections 2.2.4 and 2.2.5).

Disc brakes were not found to have any effect on the likelihood that a car is the striking vehicle in two-car front-to-rear collisions in North Carolina (see Chapter 3).

In short, the analyses suggest that front disc brakes may have reduced accidents by 0.17 percent, possibly by alleviating cases of severe side-to-side brake imbalance due to maintenance and adjustment problems. The result is statistically significant and intuitively reasonable, although much less firm than the finding on dual master cylinders.

5.2.3 Costs, benefits and cost-effectiveness

There are three major components of the cost of braking improvements: the increase in the purchase price of a new car, the lifetime fuel consumption due to weight increases and the lifetime repair and maintenance costs. Earlier NHTSA evaluations did not include repair costs because they dealt with crashworthiness equipment that, in almost all cases, lasted as long as a car. But braking equipment does require repairs.

The first two components of cost--purchase price increase and fuel consumption due to weight increase--were obtained by detailed examination of the actual master cylinders and front wheel brake assemblies of a representative sample of 1966 model cars (single, drum) and comparable 1968 model cars (dual, disc). The cost and weight increases for dual master cylinders were quite consistent across makes and models (see Table 4-1), indicating that the average values are probably an accurate estimate of the actual cost and weight. The cost and weight changes for disc brakes were much less consistent (see Table 4-2) and could not confidently be traced to disc brakes. The average for the 7 models indicates a slight cost and weight increase for disc brakes but it is not clear that the estimate is accurate or, in fact, whether disc brakes increased production costs at all.

The estimate of added repair costs for dual master cylinders is based on national repair data and is probably accurate. The estimate of added repair costs for disc brakes--the most important cost component for disc brakes--is partly based on inquiries to local repair facilities and may not be as accurate, nationwide. (See Section 4.1.)

The benefits of braking improvements were obtained in a straightforward manner. The accident reduction effectiveness--which was shown to be consistent across accident severity levels--is applied to the totals of fatalities, injuries and damages in accidents involving passenger cars. Note that "accidents involving passenger cars" include those in which a car fatally injures a pedestrian or motorcyclist, without injury to the car driver.

Cost-effectiveness was somewhat difficult to define for braking improvements. Earlier NHTSA evaluations concerned devices that primarily mitigated deaths and serious injuries (e.g., side door beams) or non-serious inuries (head restraints) or property damage (bumpers). Braking improvements have the potential to mitigate all three types of losses. The approach in this evaluation has been to concentrate on the reduction of Equivalent Fatality Units (fatalities and prorated serious injuries) per million dollars of cost--while also taking note of the nonserious injury and property damage reduction.

Dual master cylinders are clearly a cost-effective safety device. They eliminate 2.4 Equivalent Fatality Units per million dollars of cost (superior to the 1.7 for side door beams [12]) while, at the same time, eliminating nonserious injuries as efficiently as adjustable head restraints (130 per million dollars [11]) and eliminating an amount of property damage that, by itself, comes close to paying for the cost of dual master cylinders.

In discussing the cost-effectiveness of front disc brakes, it is important to keep in mind that they were not mandated by Federal regulation and were not installed purely for reasons of safety. Disc brakes were desired by auto purchasers and they improved a car's handling. Their 0.5 Equivalent Fatality Units eliminated per million dollars of cost and their prevention of 5100 nonserious injuries and $32 million in property damage each year, although smaller benefits than for dual master cylinders, are definite pluses when viewed in combination with their nonsafety benefits.

5.2.4 *Strengths and weaknesses of the evaluation*

The evaluation achieved strong results on dual master cylinders. A safety problem was clearly identified and its magnitude assessed from in-depth accident investigations. Initial graphs of the police-reported accident data (Figures 2-1 and 2-2) clearly indicated an effect for dual master cylinders. The regression analyses on 3 data files produced effectiveness estimates that were statistically significant, consistent with one another, and consistent with the in-depth accident data. The cost analysis likewise produced consistent results.

The results on front disc brakes are less firm. The only conclusions that can really be firmly drawn are that disc brakes do not have "large" safety benefits (such as eliminating 1 percent or more of the accidents) nor are they harmful. Disc brakes were identified with the possible amelioration of a variety of safety problems, but the in-depth data only partially confirmed those problems. The regression analyses did not produce results quite as consistent with one another as the analyses for dual brakes. The analysis of North Carolina data, by make and model, produced a statistically significant result that was more defensible than other estimates and was used as the "best" estimate of effectiveness. The cost analysis, likewise, was open to a number of questions about consistency and accuracy.

This preliminary evaluation of braking improvements is limited to dual master cylinders and front disc brakes. It does not address other modifications that may have been made in response to Standard 105-68 or Standard 105-75. Since the other improvements, generally, were of lesser magnitude than the two considered in this evaluation and were introduced very gradually in many cases, it is difficult to see how they could be evaluated by statistical analyses of accident data of the type performed in this report.

5.3 Conclusions

Dual master cylinders

o Dual master cylinders have accomplished their objective of significantly reducing accidents due to brake failure.

- o Dual master cylinders are a cost-effective safety device.

Disc brakes

- o Front disc brakes appear to have been effective in reducing accidents due to brake failure.

- o Front disc brakes do not significantly reduce the number of accidents due to brake fade or exposure to water, relative to drum brakes of the late 1960's and early 1970's.

- o Disc brakes do not appear to have had a significant effect in accidents that did not involve brake defects. The better "feel" and handling qualities of disc brakes did not result in a measurable safety payoff.

- o It is tentatively concluded that the primary benefit of disc brakes is a reduction in accidents due to severe side-to-side brake imbalance.

- o Disc brakes increase the cost of owning and operating a car primarily because their repair and maintenance costs are higher than for drum brakes.

REFERENCES

[1] Ballard, C. and Andrade, D. "Systems and Hardware Effects of FMVSS 105-75." SAE Paper 760216, Society of Automative Engineers, Warrendale, Pennsylvania, 1976. (DOT HS-020 026)

[2] Chilton's Auto Repair Manuals, 1963 and 1970. Chilton Company, Radnor, Pennsylvania.

[3] "The Economic Cost to Society of Motor Vehicle Accidents." National Highway Traffic Safety Administration, Washington, Publication expected in 1983.

[4] "Fatal Accident Reporting System 1979." Government Printing Office, Washington, 1981. (DOT HS-805 570)

[5] "Federal Motor Vehicle Safety Standards and Regulations" Government Printing Office, Washington, 1982. (DOT HS-806 165)

[6] Federal Register, Volume 32, February 3, 1967, page 2408.

[7] Federal Register, Volume 46, February 17, 1981, page 13193.

[8] "Final Regulatory Impact Analysis: Part 581 Bumper Standard." National Highway Traffic Safety Administration, Washington, 1982.

[9] Harvey, M.R., Lesczhik, J.A. and McLean, R.F. "Cost Evaluation for Nine Motor Vehicle Safety Standards Volume 1: FMVSS 105." National Technical Information Service, Springfield, Virginia, 1979. (DOT HS-805 315)

[10] Ichter, K.D. "Evaluation of Hydraulic Brake System Tests of Used 1973 and 1978 Vehicles." National Technical Information Service, Springfield, Virginia, 1982 (DOT HS-806 164)

[11] Kahane, C.J. "An Evaluation of Head Restraints: Federal Motor Vehicle Safety Standard 202." National Technical Information Service, Springfield, Virginia, 1982. (DOT HS-806 108)

[12] Kahane, C.J. "An Evaluation of Side Structure Improvements in Response to Federal Motor Vehicle Safety Standard 214." National Technical Information Service, Springfield, Virginia, 1982. (DOT HS-806 314)

[13] Monthly Energy Review. Department of Energy, Washington, June 1982.

[14] National Traffic and Motor Vehicle Safety Act of 1966. Public Law 89-563, September 9, 1966.

[15] "Report on Traffic Accidents and Injuries for 1979-1980." Government Printing Office, Washington, 1982. (DOT HS-806 176)

[16] SAS User's Guide, 1979 Edition. SAS Institute, Inc., Raleigh, 1979.

[17] "SJA78 - The 1978 Service Job Analysis." Hunter Publishing Company, Chicago, 1979.

[18] Stewart, J.R. Manuscript data submitted to NHTSA under Contract DTNH22-81-C-06006, June 1981.

[19] Stewart, J.R. Material submitted to NHTSA under contract DTNH22-82-P-06027 and published as Appendix A of this report, November 1982.

[20] Stewart, J.R. "Statistical Evaluation of Federal Motor Vehicle Safety Standard 105 (Passenger Car Hydraulic Brakes)." National Technical Information Service, Springfield, Virginia, 1982.

[21] Thomas, T.H. "Disc Brakes Two Years After." SAE Paper 670197, Society of Automotive Engineers, New York, 1967. (DOT HS-002 130)

[22] Thompson, H. (NHTSA) Remarks to C.J. Kahane, NHTSA, February 1982.

[23] Treat, J.R. et al. "A Tri-Level Study of the Causes of Traffic Accidents," Volume 1. National Technical Information Service, Springfield, Virginia, 1977. (DOT HS-805 085)

[24] Ward's Automotive Yearbooks, 1960-82. Ward's Communications, Detroit.

APPENDIX A

Previously Unpublished North Carolina Regression Runs

Contents:

J. Richard Stewart, Ph.D.
Highway Safety Research Center
University of North Carolina

GENERAL LINEAR MODELS PROCEDURE

Rerun of Table 9

DEPENDENT VARIABLE: PCTFRNT
WEIGHT: WATE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	23	739.36279728	32.14620858	22.07	0.0001	0.275355	2.4108
ERROR	1336	1945.76247302	1.45640904		STD DEV		PCTFRNT MEAN
CORRECTED TOTAL	1359	2685.12527030			1.20681773		50.05904434

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
CLASS	19	677.15578821	24.47	0.0001	19	452.63582505	16.36	0.0001
AGE	1	20.79089420	14.28	0.0002	1	46.96732547	32.25	0.0001
AGE*AGE	1	39.29472269	26.98	0.0001	1	37.76750762	25.93	0.0001
DISCBRAK	1	0.85231601	0.59	0.4444	1	0.12390334	0.09	0.7706
POWRBRAK	1	1.26907617	0.87	0.3507	1	1.26907617	0.87	0.3507

PARAMETER		ESTIMATE		T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
INTERCEPT		49.46181807	B	37.64	0.0001	1.31393176
CLASS	1	1.22162422	B	1.28	0.2002	0.95315955
	2	2.35863288	B	2.28	0.0226	1.03345114
	3	9.94452051	B	8.44	0.0001	1.17871309
	5	3.59015964	B	3.53	0.0004	1.01574021
	6	1.93635689	B	1.91	0.0563	1.01365017
	7	6.71402229	B	5.63	0.0001	1.19341256
	8	2.21847043	B	1.74	0.0830	1.27858558
	9	-3.14190034	B	-3.12	0.0019	1.00747573
	13	9.52450348	B	5.64	0.0001	1.68983966
	17	1.62168105	B	1.70	0.0898	0.95530686
	20	1.21746028	B	1.06	0.2905	1.15141596
	21	-2.55258704	B	-2.36	0.0185	1.08280660
	25	-2.49655258	B	-1.42	0.1547	1.75339670
	31	4.20771612	B	2.98	0.0030	1.41377178
	32	0.21780971	B	0.21	0.8353	1.04751636
	33	1.36587963	B	1.05	0.2952	1.30437414
	34	9.33168562	B	5.24	0.0001	1.78224167
	35	5.41860176	B	4.45	0.0001	1.21716102
	36	5.76567359	B	3.77	0.0002	1.52887463
	37	0.00000000	B	.	.	.
AGE		-1.14603790		-5.68	0.0001	0.20181003
AGE*AGE		0.08438540		5.09	0.0001	0.01657104
DISCBRAK		-0.00233214		-0.29	0.7706	0.00799568
POWRBRAK		0.01197885		0.93	0.3507	0.01283255

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: PERCENTB   PERCENT OF TOTAL WITH DEFECTIVE BRAKES
WEIGHT: TOTAL2

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	16	2509.28190829	156.83011927	95.76	0.0001	0.901715	61.7353
ERROR	167	273.50726576	1.63776806		STD DEV		PERCENTB MEAN
CORRECTED TOTAL	183	2782.78917405			1.27975312		2.07296963

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
ACCYEAR	10	243.49901630	14.87	0.0001	10	55.11223695	3.37	0.0005
AGE	1	2124.70700694	1297.32	0.0001	1	21.08936771	12.88	0.0004
AGE*AGE	1	68.84165400	42.03	0.0001	1	21.05613024	12.86	0.0004
WTMEAN	1	22.97460258	14.03	0.0002	1	2.91586961	1.78	0.1839
DUALBRAK	1	44.63035201	27.25	0.0001	1	48.48834659	29.61	0.0001
DISCBRAK	1	4.59520635	2.81	0.0958	1	3.20391912	1.96	0.1638
POWRBRAK	1	0.03407010	0.02	0.8855	1	0.03407010	0.02	0.8855

PARAMETER		ESTIMATE		T FOR H0: PARAMETER=0	PR > ITI	STD ERROR OF ESTIMATE
INTERCEPT		1.90625666	B	4.91	0.0001	0.38826544
ACCYEAR	1971	-0.22089371	B	-1.12	0.2637	0.19695210
	1972	-0.17867935	B	-1.04	0.2990	0.17150255
	1973	-0.08758954	B	-0.56	0.5770	0.15674622
	1974	-0.03378216	B	-0.24	0.8115	0.14140934
	1975	-0.21306851	B	-1.69	0.0931	0.12615092
	1976	-0.11384294	B	-0.95	0.3453	0.12029340
	1977	-0.14618396	B	-1.39	0.1674	0.10543075
	1978	-0.19398936	B	-2.10	0.0371	0.09228746
	1979	0.11003071	B	1.23	0.2215	0.08967179
	1980	0.13216090	B	1.54	0.1250	0.08572520
	1981	0.00000000	B	.	.	.
AGE		0.09047331		3.59	0.0004	0.02521244
AGE*AGE		0.00481633		3.59	0.0004	0.00134324
WTMEAN		-0.00021127		-1.33	0.1839	0.00015834
DUALBRAK		-0.00604334		-5.44	0.0001	0.00111067
DISCBRAK		-0.00314772		-1.40	0.1638	0.00225052
POWRBRAK		-0.00056872		-0.14	0.8855	0.00394310

Table ID-1
Brake defects in injury accidents - all dependent variables

NOTE: THE X'X MATRIX HAS BEEN DEEMED SINGULAR AND A GENERALIZED INVERSE HAS BEEN EMPLOYED TO SOLVE THE NORMAL EQUATIONS. THE ABOVE ESTIMATES REPRESENT ONLY ONE OF MANY POSSIBLE SOLUTIONS TO THE NORMAL EQUATIONS. ESTIMATES FOLLOWED BY THE LETTER B ARE BIASED AND DO NOT ESTIMATE THE PARAMETER BUT ARE BLUE FOR SOME LINEAR COMBINATION OF PARAMETERS (OR ARE ZERO). THE EXPECTED VALUE OF THE BIASED ESTIMATORS MAY BE OBTAINED FROM THE GENERAL FORM OF ESTIMABLE FUNCTIONS. FOR THE BIASED ESTIMATORS, THE STD ERR IS THAT OF THE BIASED ESTIMATOR AND THE T VALUE TESTS H0: E(BIASED ESTIMATOR) = 0. ESTIMATES NOT FOLLOWED BY THE LETTER B ARE BLUE FOR THE PARAMETER.

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: PERCENTB   PERCENT OF TOTAL WITH DEFECTIVE BRAKES
WEIGHT: TOTAL2

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	15	2511.13541791	167.40902786	103.34	0.0001	0.900646	61.9687
ERROR	171	277.01486376	1.61996996		STD DEV		PERCENTB MEAN
CORRECTED TOTAL	186	2788.15028167			1.27278041		2.05390991

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
ACCYEAR	10	233.80659239	14.43	0.0001	10	53.74789768	3.32	0.0006
AGE	1	2129.61604860	1314.60	0.0001	1	25.02527859	15.45	0.0001
AGE*AGE	1	71.70641876	44.26	0.0001	1	20.78346312	12.83	0.0004
WTMEAN	1	26.81620068	16.55	0.0001	1	4.48445810	2.77	0.0980
DUALBRAK	1	44.72861771	27.61	0.0001	1	48.67431545	30.05	0.0001
DISCBRAK	1	4.46153978	2.75	0.0988	1	4.46153978	2.75	0.0988

PARAMETER		ESTIMATE	T FOR H0: PARAMETER=0	PR > ITI	STD ERROR OF ESTIMATE
INTERCEPT		1.95448832 B	5.34	0.0001	0.36635189
ACCYEAR	1971	-0.21676418 B	-1.18	0.2384	0.18320392
	1972	-0.17643942 B	-1.10	0.2710	0.15976210
	1973	-0.08619306 B	-0.59	0.5558	0.14600940
	1974	-0.03323874 B	-0.25	0.8024	0.13262003
	1975	-0.21299299 B	-1.80	0.0735	0.11829397
	1976	-0.11390309 B	-1.01	0.3133	0.11263485
	1977	-0.14902337 B	-1.47	0.1429	0.10125642
	1978	-0.19905362 B	-2.22	0.0280	0.08962008
	1979	0.10309770 B	1.17	0.2422	0.08785854
	1980	0.11594805 B	1.39	0.1660	0.08335538
	1981	0.00000000 B	.	.	.
AGE		0.09250025	3.93	0.0001	0.02353460
AGE*AGE		0.00476300	3.58	0.0004	0.00132977
WTMEAN		-0.00023532	-1.66	0.0980	0.00014144
DUALBRAK		-0.00604728	-5.48	0.0001	0.00110322
DISCBRAK		-0.00324608	-1.66	0.0988	0.00195601

Table ID-2
Brake defects in injury accidents – Power brakes omitted.

NOTE: THE X'X MATRIX HAS BEEN DEEMED SINGULAR AND A GENERALIZED INVERSE HAS BEEN EMPLOYED TO SOLVE THE NORMAL EQUATIONS. THE ABOVE ESTIMATES REPRESENT ONLY ONE OF MANY POSSIBLE SOLUTIONS TO THE NORMAL EQUATIONS. ESTIMATES FOLLOWED BY THE LETTER B ARE BIASED AND DO NOT ESTIMATE THE PARAMETER BUT ARE BLUE FOR SOME LINEAR COMBINATION OF PARAMETERS (OR ARE ZERO). THE EXPECTED VALUE OF THE BIASED ESTIMATORS MAY BE OBTAINED FROM THE GENERAL FORM OF ESTIMABLE FUNCTIONS. FOR THE BIASED ESTIMATORS, THE STD ERR IS THAT OF THE BIASED ESTIMATOR AND THE T VALUE TESTS H0: E(BIASED ESTIMATOR) = 0. ESTIMATES NOT FOLLOWED BY THE LETTER B ARE BLUE FOR THE PARAMETER.

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: PERCENTB   PERCENT OF TOTAL WITH DEFECTIVE BRAKES
WEIGHT: TOTAL2

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	14	2506.65095981	179.04649713	109.40	0.0001	0.899037	62.2864
ERROR	172	281.49932187	1.63662396		STD DEV		PERCENTB MEAN
CORRECTED TOTAL	186	2788.15028167			1.27930605		2.05390991

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
ACCYEAR	10	233.80659239	14.29	0.0001	10	87.54987407	5.35	0.0001
AGE	1	2129.61604860	1301.23	0.0001	1	21.41810135	13.09	0.0004
AGE*AGE	1	71.70641876	43.81	0.0001	1	24.61974660	15.04	0.0001
DUALBRAK	1	51.77643431	31.64	0.0001	1	57.46293293	35.11	0.0001
DISCBRAK	1	19.74546575	12.06	0.0007	1	19.74546575	12.06	0.0007

PARAMETER		ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
INTERCEPT		1.51014389 B	5.99	0.0001	0.25206371
ACCYEAR	1971	-0.40467823 B	-2.79	0.0058	0.14498814
	1972	-0.34014666 B	-2.69	0.0079	0.12651292
	1973	-0.23455924 B	-2.02	0.0451	0.11620816
	1974	-0.17144242 B	-1.65	0.1008	0.10391418
	1975	-0.34206325 B	-3.81	0.0002	0.08976355
	1976	-0.23716749 B	-2.78	0.0060	0.08527527
	1977	-0.25327563 B	-3.17	0.0018	0.07994839
	1978	-0.28419791 B	-3.83	0.0002	0.07419453
	1979	0.04720998 B	0.58	0.5636	0.08160004
	1980	0.08957447 B	1.09	0.2777	0.08225387
	1981	0.00000000 B	.	.	.
AGE		0.06993308	3.62	0.0004	0.01933155
AGE*AGE		0.00511715	3.88	0.0001	0.00131935
DUALBRAK		-0.00642782	-5.93	0.0001	0.00108479
DISCBRAK		-0.00529893	-3.47	0.0007	0.00152556

Table ID-3
Brake defects in injury accident
Power brakes and vehicle
weight omitted.

NOTE: THE X'X MATRIX HAS BEEN DEEMED SINGULAR AND A GENERALIZED INVERSE HAS BEEN EMPLOYED TO SOLVE THE NORMAL EQUATIONS. THE ABOVE ESTIMATES REPRESENT ONLY ONE OF MANY POSSIBLE SOLUTIONS TO THE NORMAL EQUATIONS. ESTIMATES FOLLOWED BY THE LETTER B ARE BIASED AND DO NOT ESTIMATE THE PARAMETER BUT ARE BLUE FOR SOME LINEAR COMBINATION OF PARAMETERS (OR ARE ZERO). THE EXPECTED VALUE OF THE BIASED ESTIMATORS MAY BE OBTAINED FROM THE GENERAL FORM OF ESTIMABLE FUNCTIONS. FOR THE BIASED ESTIMATORS, THE STD ERR IS THAT OF THE BIASED ESTIMATOR AND THE T VALUE TESTS H0: E(BIASED ESTIMATOR) = 0. ESTIMATES NOT FOLLOWED BY THE LETTER B ARE BLUE FOR THE PARAMETER.

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: LNTB
WEIGHT: TOTAL2

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.
MODEL	16	4119.90711687	257.49419480	61.05	0.0001	0.854002	721.02
ERROR	167	704.32843852	4.21753556		STD DEV		LNTB ME
CORRECTED TOTAL	183	4824.23555539			2.05366394		0.284824

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR >
ACCYEAR	10	867.73872690	20.57	0.0001	10	272.52007468	6.46	0.00
AGE	1	2963.81349538	702.74	0.0001	1	304.87146019	72.29	0.00
AGE*AGE	1	123.28261669	29.23	0.0001	1	150.10249096	35.59	0.00
WTMEAN	1	130.08317427	30.84	0.0001	1	30.19771041	7.16	0.00
DUALBRAK	1	1.41714262	0.34	0.5629	1	1.04363374	0.25	0.61
DISCBRAK	1	0.21984928	0.05	0.8197	1	5.61505102	1.33	0.25
POWRBRAK	1	33.35211173	7.91	0.0055	1	33.35211173	7.91	0.00

PARAMETER		ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
INTERCEPT		1.76366710 B	2.83	0.0052	0.62306293
ACCYEAR	1971	-0.20679250 B	-0.65	0.5138	0.31605583
	1972	-0.20261820 B	-0.74	0.4626	0.27521606
	1973	-0.04285632 B	-0.17	0.8649	0.25153606
	1974	-0.03580502 B	-0.16	0.8748	0.22692444
	1975	-0.47627233 B	-2.35	0.0198	0.20243874
	1976	-0.21454184 B	-1.11	0.2680	0.19303896
	1977	-0.25977666 B	-1.54	0.1266	0.16918836
	1978	-0.40276103 B	-2.72	0.0072	0.14809687
	1979	0.27242635 B	1.89	0.0601	0.14389942
	1980	0.21217796 B	1.54	0.1249	0.13756619
	1981	0.00000000 B	.	.	.
AGE		0.34399101	8.50	0.0001	0.04045927
AGE*AGE		-0.01285939	-5.97	0.0001	0.00215554
WTMEAN		-0.00067989	-2.68	0.0082	0.00025409
DUALBRAK		-0.00088661	-0.50	0.6195	0.00178233
DISCBRAK		0.00416709	1.15	0.2502	0.00361148
POWRBRAK		-0.01779397	-2.81	0.0055	0.00632762

Table ID-4
Brake defects in injury accidents - loglinear model

NOTE: THE X'X MATRIX HAS BEEN DEEMED SINGULAR AND A GENERALIZED INVERSE HAS BEEN EMPLOYED TO SOLVE THE NORMAL EQUATIONS. THE ABOVE ESTIMATES REPRESENT ONLY ONE OF MANY POSSIBLE SOLUTIONS TO THE NORMAL EQUATIONS. ESTIMATES FOLLOWED BY THE LETTER B ARE BIASED AND DO NOT ESTIMATE THE PARAMETER BUT ARE BLUE FOR SOME LINEAR COMBINATION OF PARAMETERS (OR ARE ZERO). THE EXPECTED VALUE OF THE BIASED ESTIMATORS MAY BE OBTAINED FROM THE GENERAL FORM OF ESTIMABLE FUNCTIONS. FOR THE BIASED ESTIMATORS, THE STD ERR IS THAT OF THE BIASED ESTIMATOR AND THE T VALUE TESTS H0: E(BIASED ESTIMATOR) = 0. ESTIMATES NOT FOLLOWED BY THE LETTER B ARE BLUE FOR THE PARAMETER.

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: PERCENTB PERCENT OF TOTAL WITH DEFECTIVE BRAKES
WEIGHT: TOTAL2

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	16	2507.83810246	156.73988140	95.06	0.0001	0.899463	62.5194
ERROR	170	280.31217922	1.64889517		STD DEV		PERCENTB MEAN
CORRECTED TOTAL	186	2788.15028167			1.28409313		2.05390991

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
ACCYEAR	10	233.80659239	14.18	0.0001	10	78.38754471	4.75	0.0001
AGE	1	2129.61604860	1291.54	0.0001	1	18.33295389	11.12	0.0010
AGE*AGE	1	71.70641876	43.49	0.0001	1	23.95691655	14.53	0.0002
DISCBRAK	1	14.05896713	8.53	0.0040	1	11.54529005	7.00	0.0089
DUALBRAK	1	57.46293293	34.85	0.0001	1	38.45539816	23.32	0.0001
D1	1	0.03761657	0.02	0.8801	1	0.17695974	0.11	0.7436
D2	1	1.14952608	0.70	0.4049	1	1.14952608	0.70	0.4049

PARAMETER		ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
INTERCEPT		1.41861338 B	4.25	0.0001	0.33415769
ACCYEAR	1971	-0.31365433 B	-1.63	0.1057	0.19282094
	1972	-0.25552108 B	-1.49	0.1385	0.17169080
	1973	-0.15885706 B	-1.02	0.3110	0.15633435
	1974	-0.10020248 B	-0.71	0.4763	0.14036712
	1975	-0.28355153 B	-2.39	0.0180	0.11869670
	1976	-0.19680441 B	-1.94	0.0540	0.10141817
	1977	-0.22154202 B	-2.44	0.0157	0.09076493
	1978	-0.26387857 B	-3.33	0.0011	0.07934285
	1979	0.06127189 B	0.73	0.4670	0.08404518
	1980	0.09740560 B	1.17	0.2436	0.08324963
	1981	0.00000000 B	.	.	.
AGE		0.08048278	3.33	0.0010	0.02413700
AGE*AGE		0.00506321	3.81	0.0002	0.00132833
DISCBRAK		-0.00505685	-2.65	0.0089	0.00191106
DUALBRAK		-0.00612870	-4.83	0.0001	0.00126907
D1		-0.02933452	-0.33	0.7436	0.08954436
D2		-0.05688459	-0.83	0.4049	0.06812895

Table I-D-5

Brake defects in injury accidents - tests of nuisance variables

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: PERCENTB   PERCENT OF TOTAL WITH DEFECTIVE BRAKES
WEIGHT: TOTAL2

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V
MODEL	15	2430.19146124	162.01276408	97.60	0.0001	0.899815	60.811
ERROR	163	270.57547335	1.65997223		STD DEV		PERCENTB MEA
CORRECTED TOTAL	178	2700.76693459			1.28839910		2.1186632

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR >
ACCYEAR	10	192.82143415	11.62	0.0001	10	71.47264612	4.31	0.000
AGE	1	2097.07133833	1263.32	0.0001	1	16.02325143	9.65	0.002
AGE*AGE	1	66.83036944	40.26	0.0001	1	21.93703855	13.22	0.000
DUALBRAK	1	52.46764001	31.61	0.0001	1	37.66656431	22.69	0.000
DISCBRAK	1	20.09256942	12.10	0.0006	1	11.25893378	6.78	0.010
S75	1	0.90810990	0.55	0.4606	1	0.90810990	0.55	0.460

PARAMETER		ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
INTERCEPT		1.28765351 B	3.30	0.0012	0.39033794
ACCYEAR	1971	-0.27861283 B	-1.31	0.1927	0.21301684
	1972	-0.22262479 B	-1.17	0.2439	0.19034482
	1973	-0.12695347 B	-0.74	0.4628	0.17250099
	1974	-0.06754216 B	-0.43	0.6653	0.15585468
	1975	-0.26677075 B	-1.98	0.0497	0.13494774
	1976	-0.15656802 B	-1.37	0.1712	0.11390640
	1977	-0.20638225 B	-2.11	0.0363	0.09776602
	1978	-0.22792251 B	-2.70	0.0077	0.08443862
	1979	0.09400348 B	1.06	0.2890	0.08837485
	1980	0.11800514 B	1.37	0.1724	0.08609902
	1981	0.00000000 B	.	.	.
AGE		0.08307246	3.11	0.0022	0.02673820
AGE*AGE		0.00494141	3.64	0.0004	0.00135929
DUALBRAK		-0.00600332	-4.76	0.0001	0.00126027
DISCBRAK		-0.00470885	-2.60	0.0101	0.00180808
S75		0.00059143	0.74	0.4606	0.00079962

Table I-D-6

Brake defects in injury accidents - test of 1975 improvements

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: PERCENTB   PERCENT OF TOTAL WITH DEFECTIVE BRAKES
WEIGHT: TOTAL2

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V
MODEL	16	6986.17738798	436.63608675	188.59	0.0001	0.946667	79.827
ERROR	170	393.58521555	2.31520715		STD DEV		PERCFNTB MEA
CORRECTED TOTAL	186	7379.76260353			1.52158048		1.9860984

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR >
ACCYEAR	10	578.77922593	25.00	0.0001	10	259.63616481	11.21	0.000
AGE	1	5827.59021028	2517.09	0.0001	1	23.10142356	9.98	0.001
AGE*AGE	1	302.33350333	130.59	0.0001	1	118.83702022	51.33	0.000
DISCBRAK	1	47.75730347	20.63	0.0001	1	33.72833422	14.57	0.000
DUALBRAK	1	223.97456436	96.74	0.0001	1	137.10295974	59.22	0.000
D1	1	0.90321549	0.39	0.5331	1	0.24252217	0.10	0.746
D2	1	4.83936511	2.09	0.1501	1	4.83936511	2.09	0.150

PARAMETER		ESTIMATE	T FOR H0: PARAMETER=0	PR > ITI	STD ERROR OF ESTIMATE
INTERCEPT		1.51336532 B	6.67	0.0001	0.22684696
ACCYEAR	1971	-0.35247597 B	-2.70	0.0075	0.13035047
	1972	-0.23854614 B	-2.03	0.0439	0.11752894
	1973	-0.14704491 B	-1.40	0.1646	0.10535757
	1974	-0.09649385 B	-1.01	0.3156	0.09587184
	1975	-0.18293541 B	-2.19	0.0301	0.08362782
	1976	-0.20155271 B	-2.82	0.0054	0.07149592
	1977	-0.26268656 B	-4.28	0.0001	0.06138267
	1978	-0.23731259 B	-4.28	0.0001	0.05548017
	1979	0.12424836 B	2.14	0.0342	0.05818770
	1980	0.09387165 B	1.63	0.1055	0.05768606
	1981	0.00000000 B	.	.	.
AGE		0.05242712	3.16	0.0019	0.01659707
AGE*AGE		0.00659517	7.16	0.0001	0.00092054
DISCBRAK		-0.00486117	-3.82	0.0002	0.00127362
DUALBRAK		-0.00656025	-7.70	0.0001	0.00085250
D1		0.01831376	0.32	0.7466	0.05658440
D2		-0.06610164	-1.45	0.1501	0.04572064

Table AD-1
Brake defects in all acciden
D1 + D2 included

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: PERCENTB PERCENT OF TOTAL WITH DEFECTIVE BRAKES
WEIGHT: TOTAL2

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	33	3320.15525541	100.61076532	77.35	0.0001	0.556780	114.3746
ERROR	2032	2642.97700294	1.30067769		STD DEV		PERCENTB MEAN
CORRECTED TOTAL	2065	5963.13231835			1.14047257		0.98849559

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
ACCYEAR	10	532.57808553	40.95	0.0001	10	161.02870492	12.38	0.0001
CARCLASS	19	405.17322990	16.40	0.0001	19	356.91113491	14.44	0.0001
AGE	1	2137.29813271	1643.22	0.0001	1	4.80630325	3.70	0.0547
AGE*AGE	1	170.17609828	130.84	0.0001	1	146.34770097	112.52	0.0001
WTMEAN	1	49.67609192	38.19	0.0001	1	17.20398971	13.23	0.0003
DISCBRAK	1	25.25361707	19.42	0.0001	1	25.25361707	19.42	0.0001

PARAMETER		ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
INTERCEPT		0.98916085 B	5.93	0.0001	0.16684554
ACCYEAR	1971	-0.20047772 B	-3.97	0.0001	0.05055646
	1972	-0.10691679 B	-2.21	0.0270	0.04832484
	1973	-0.10213725 B	-2.30	0.0213	0.04431268
	1974	-0.06713275 B	-1.54	0.1241	0.04363160
	1975	-0.12496531 B	-3.08	0.0021	0.04053314
	1976	-0.13831684 B	-3.51	0.0005	0.03941364
	1977	-0.16042361 B	-4.26	0.0001	0.03768902
	1978	-0.15794054 B	-4.38	0.0001	0.03602533
	1979	0.13849489 B	3.37	0.0008	0.04108306
	1980	0.07453216 B	1.81	0.0707	0.04121316
	1981	0.00000000 B	.	.	.
CARCLASS	1	-0.22846703 B	-2.79	0.0054	0.08194756
	2	-0.06367766 B	-0.75	0.4511	0.08448903
	3	-0.23740378 B	-2.55	0.0108	0.09309237
	4	-0.15089512 B	-1.48	0.1388	0.10189501
	5	-0.02942822 B	-0.33	0.7401	0.08869433
	6	-0.20556179 B	-2.38	0.0176	0.08651577
	7	-0.19849649 B	-2.24	0.0249	0.08844941
	8	-0.35044452 B	-3.70	0.0002	0.09468640
	9	-0.16454565 B	-2.01	0.0448	0.08194466
	10	-0.04143055 B	-0.48	0.6296	0.08589670
	11	-0.24008197 B	-2.27	0.0234	0.10585146
	12	-0.38806750 B	-3.49	0.0005	0.11123973
	13	0.01570916 B	0.18	0.8568	0.08704329
	14	0.10151802 B	1.21	0.2249	0.08361881
	15	0.12396260 B	1.30	0.1924	0.09507472
	16	0.08320432 B	0.92	0.3589	0.09067352
	17	-0.15945697 B	-1.35	0.1777	0.11826895
	18	-0.38365782 B	-3.64	0.0003	0.10538791
	19	-0.21567249 B	-2.17	0.0301	0.09935469
	20	0.00000000 B	.	.	.
AGE		0.01840174	1.92	0.0547	0.00957278
AGE*AGE		0.00903085	10.61	0.0001	0.00085137
WTMEAN		-0.00013458	-3.64	0.0003	0.00003700
DISCBRAK		-0.00174820	-4.41	0.0001	0.00039675

Table ADC-1
Brake defects by carclass in all accidents.
Basic model

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: PERCENTB PERCENT OF TOTAL WITH DEFECTIVE BRAKES
WEIGHT: TOTAL2

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	35	3326.23351341	95.03524324	73.16	0.0001	0.557800	115.2986
ERROR	2030	2636.89880494	1.29896493		STD DEV		PERCENTB MEAN
CORRECTED TOTAL	2065	5963.13231835			1.13972143		0.98849559

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
ACCYEAR	10	532.57808553	41.00	0.0001	10	153.71483506	11.83	0.0001
CARCLASS	19	405.17322990	16.42	0.0001	19	346.99067701	14.14	0.0001
AGE	1	2137.29815271	1645.39	0.0001	1	5.59615286	4.31	0.0381
AGE*AGE	1	170.17609828	131.01	0.0001	1	138.79936593	106.85	0.0001
WTMEAN	1	49.67609192	38.24	0.0001	1	15.30252693	11.78	0.0006
DISCBRAK	1	25.25361707	19.44	0.0001	1	18.69578876	14.39	0.0002
D1	1	5.18655357	3.99	0.0458	1	3.30634290	2.55	0.1108
D2	1	0.89170443	0.69	0.4075	1	0.89170443	0.69	0.4075

PARAMETER		ESTIMATE	T FOR H0: PARAMETER=0	PR > ITI	STD ERROR OF ESTIMATE
INTERCEPT		0.93732816 B	5.55	0.0001	0.16882837
ACCYEAR	1971	-0.17780928 B	-2.67	0.0077	0.06668417
	1972	-0.08352741 B	-1.32	0.1862	0.06316773
	1973	-0.07744273 B	-1.33	0.1848	0.05837662
	1974	-0.04345855 B	-0.77	0.4411	0.05640691
	1975	-0.10513741 B	-2.08	0.0379	0.05060057
	1976	-0.12482049 B	-2.77	0.0056	0.04504844
	1977	-0.15220531 B	-3.74	0.0002	0.04067655
	1978	-0.15262332 B	-4.06	0.0001	0.03763148
	1979	0.14279200 B	3.42	0.0006	0.04170711
	1980	0.07712778 B	1.86	0.0625	0.04138175
	1981	0.00000000 B	.	.	.
CARCLASS	1	-0.23234149 B	-2.84	0.0046	0.08193418
	2	-0.06875068 B	-0.81	0.4160	0.08451064
	3	-0.23594867 B	-2.53	0.0113	0.09310997
	4	-0.14567449 B	-1.43	0.1529	0.10188840
	5	-0.02813355 B	-0.32	0.7512	0.08871860
	6	-0.20497949 B	-2.37	0.0179	0.08651411
	7	-0.20017648 B	-2.26	0.0238	0.08847931
	8	-0.33550424 B	-3.53	0.0004	0.09492608
	9	-0.16946129 B	-2.07	0.0388	0.08196313
	10	-0.05190424 B	-0.60	0.5462	0.08600038
	11	-0.22100902 B	-2.08	0.0375	0.10617324
	12	-0.37700998 B	-3.39	0.0007	0.11130838
	13	0.01522653 B	0.17	0.8611	0.08703227
	14	0.09572427 B	1.14	0.2525	0.08363484
	15	0.12825491 B	1.35	0.1775	0.09507646
	16	0.08113773 B	0.89	0.3709	0.09066452
	17	-0.14901547 B	-1.26	0.2081	0.11833805
	18	-0.36874661 B	-3.49	0.0005	0.10563664
	19	-0.20409736 B	-2.05	0.0403	0.09944807
	20	0.00000000 B	.	.	.
AGE		0.02202476	2.08	0.0381	0.01061122
AGE*AGE		0.00884912	10.34	0.0001	0.00085606
WTMEAN		-0.00012752	-3.43	0.0006	0.00003715
DISCBRAK		-0.00154702	-3.79	0.0002	0.00040778
D1		0.05869809	1.60	0.1108	0.03679161
D2		-0.02586686	-0.83	0.4075	0.03121993

Table ADC - 2
Brake defects by carclass in all accidents. Tests of D1 + D2

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: PERCENTB   PERCENT OF TOTAL WITH DEFECTIVE BRAKES
WEIGHT: TOTAL2

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	34	3212.84729112	94.49550856	71.60	0.0001	0.563323	112.2340
ERROR	1887	2490.53149159	1.31983651		STD DEV		PERCENTB MEAN
CORRECTED TOTAL	1921	5703.37878271			1.14884138		1.02361264

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
ACCYEAR	10	469.63668257	35.58	0.0001	10	137.72462877	10.43	0.0001
CARCLASS	19	455.60220303	18.17	0.0001	19	372.45335736	14.85	0.0001
AGE	1	2064.52077294	1564.22	0.0001	1	10.86162116	8.23	0.0042
AGE*AGE	1	150.16567430	113.78	0.0001	1	130.39789580	98.80	0.0001
WTMEAN	1	44.59933077	33.79	0.0001	1	11.62381949	8.81	0.0030
DISCBRAK	1	21.97917153	16.65	0.0001	1	16.16448738	12.25	0.0005
S75	1	6.34325599	4.81	0.0285	1	6.34325599	4.81	0.0285

PARAMETER		ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
INTERCEPT		0.76510677 B	3.93	0.0001	0.19456289
ACCYEAR	1971	-0.09072987 B	-1.33	0.1849	0.06841069
	1972	-0.00090076 B	-0.01	0.9890	0.06517058
	1973	-0.00334550 B	-0.06	0.9558	0.06031878
	1974	0.02657829 B	0.46	0.6487	0.05833506
	1975	-0.04500916 B	-0.84	0.4011	0.05359545
	1976	-0.07306165 B	-1.52	0.1298	0.04820696
	1977	-0.11164204 B	-2.63	0.0086	0.04242646
	1978	-0.11374060 B	-2.91	0.0037	0.03910788
	1979	0.17093811 B	3.93	0.0001	0.04344828
	1980	0.10820641 B	2.52	0.0119	0.04297146
	1981	0.00000000 B	.	.	.
CARCLASS	1	-0.23490109 B	-2.84	0.0046	0.08278430
	2	-0.06321387 B	-0.74	0.4603	0.08560415
	3	-0.22986816 B	-2.42	0.0156	0.09501106
	4	-0.10767711 B	-1.03	0.3041	0.10475467
	5	0.00988846 B	0.11	0.9133	0.09084024
	6	-0.20159258 B	-2.29	0.0220	0.08792175
	7	-0.19455047 B	-2.15	0.0320	0.09066435
	8	-0.31543839 B	-3.21	0.0013	0.09825149
	9	-0.17193716 B	-2.08	0.0380	0.08278822
	10	-0.06528215 B	-0.75	0.4537	0.08711321
	11	-0.21642225 B	-1.98	0.0483	0.10952924
	12	-0.36452475 B	-3.16	0.0016	0.11537486
	13	0.01894739 B	0.21	0.8305	0.08850498
	14	0.11080123 B	1.31	0.1910	0.08470416
	15	0.20484242 B	2.09	0.0371	0.09818606
	16	0.09410586 B	1.02	0.3092	0.09252350
	17	-0.11155369 B	-0.90	0.3674	0.12372557
	18	-0.34970326 B	-3.14	0.0017	0.11132005
	19	-0.18537043 B	-1.83	0.0681	0.10155945
	20	0.00000000 B	.	.	.
AGE		0.03199898	2.87	0.0042	0.01115447
AGE*AGE		0.00873444	9.94	0.0001	0.00087874
WTMEAN		-0.00011774	-2.97	0.0030	0.00003967
DISCBRAK		-0.00147081	-3.50	0.0005	0.00042028
S75		0.00077354	2.19	0.0285	0.00035285

Table ADC-3
Brake defects by carclass in all accidents. Test of 1975 improvements.

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: PERCENTB PERCENT OF TOTAL WITH DEFECTIVE BRAKES
WEIGHT: TOTAL2

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	33	543.66912899	16.47482209	15.25	0.0001	0.199067	103.1065
ERROR	2025	2187.41162448	1.08020327		STD DEV		PERCENTB MEAN
CORRECTED TOTAL	2058	2731.08075347			1.03932828		1.00801467

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
ACCYEAR	10	59.08103378	5.47	0.0001	10	17.21853200	1.59	0.1023
CARCLASS	19	77.97303777	3.80	0.0001	19	103.78419640	5.06	0.0001
AGE	1	351.75046519	325.63	0.0001	1	0.41448642	0.38	0.5357
AGE*AGE	1	24.73002744	22.89	0.0001	1	20.14857250	18.65	0.0001
WTMEAN	1	23.27976823	21.55	0.0001	1	10.22930532	9.47	0.0021
DISCBRAK	1	6.85479659	6.35	0.0118	1	6.85479659	6.35	0.0118

PARAMETER		ESTIMATE		T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
INTERCEPT		0.77593801	B	3.50	0.0005	0.22174280
ACCYEAR	1971	-0.06618363	B	-0.95	0.3403	0.06939631
	1972	-0.02317105	B	-0.36	0.7190	0.06438449
	1973	-0.04828315	B	-0.82	0.4120	0.05884856
	1974	-0.00351247	B	-0.06	0.9506	0.05674120
	1975	-0.03052112	B	-0.58	0.5611	0.05251086
	1976	-0.01419064	B	-0.28	0.7784	0.05041034
	1977	-0.04841045	B	-1.02	0.3101	0.04768082
	1978	-0.02390791	B	-0.52	0.6042	0.04611030
	1979	0.06539373	B	1.32	0.1879	0.04964841
	1980	0.10508931	B	2.10	0.0361	0.05012163
	1981	0.00000000	B	.	.	.
CARCLASS	1	-0.00049478	B	-0.00	0.9960	0.09901253
	2	0.01861554	B	0.18	0.8554	0.10156292
	3	-0.18339669	B	-1.61	0.1082	0.11411348
	4	-0.13073502	B	-1.02	0.3067	0.12785702
	5	0.06456842	B	0.59	0.5524	0.10864884
	6	-0.11485070	B	-1.08	0.2781	0.10585992
	7	-0.08250788	B	-0.77	0.4438	0.10771854
	8	-0.24999621	B	-2.13	0.0330	0.11720586
	9	0.09761940	B	0.98	0.3290	0.09999154
	10	0.11396082	B	1.08	0.2799	0.10543492
	11	-0.23119208	B	-1.77	0.0777	0.13097613
	12	-0.26579310	B	-1.88	0.0598	0.14112181
	13	0.13308647	B	1.25	0.2119	0.10657135
	14	0.21490760	B	2.10	0.0362	0.10110087
	15	0.08244639	B	0.71	0.4755	0.11552759
	16	0.15617791	B	1.42	0.1560	0.11004490
	17	-0.17940249	B	-1.20	0.2321	0.15007166
	18	-0.32261275	B	-2.48	0.0132	0.13001382
	19	-0.12287177	B	-0.98	0.3267	0.12525954
	20	0.00000000	B	.	.	.
AGE		0.00808841		0.62	0.5357	0.01305752
AGE*AGE		0.00478163		4.32	0.0001	0.00110715
WTMEAN		-0.00015702		-3.08	0.0021	0.00005103
DISCBRAK		-0.00137779		-2.52	0.0118	0.00054694

Table IDC-1
Brake defects by carclass
in injury accidents.
Basic model

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: PERCENTB   PERCENT OF TOTAL WITH DEFECTIVE BRAKES
WEIGHT: TOTAL2

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	23	526.45059700	22.88915639	21.13	0.0001	0.192763	103.2568
ERROR	2035	2204.63015648	1.08335634		STD DEV		PERCENTB MEAN
CORRECTED TOTAL	2058	2731.08079347			1.04084405		1.00801467

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
CARCLASS	19	73.97079492	3.59	0.0001	19	107.85562947	5.24	0.0001
AGE	1	392.34840082	362.16	0.0001	1	1.00501100	0.93	0.3356
AGE*AGE	1	27.32887735	25.23	0.0001	1	22.51021424	20.78	0.0001
WTMEAN	1	29.56084076	27.29	0.0001	1	16.95102300	15.65	0.0001
DISCBRAK	1	3.24168315	2.99	0.0838	1	3.24168315	2.99	0.0838

PARAMETER		ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
INTERCEPT		0.79585250 B	3.71	0.0002	0.21447367
CARCLASS	1	0.01638806 B	0.17	0.8683	0.09880438
	2	0.02973688 B	0.29	0.7692	0.10155390
	3	-0.18064380 B	-1.59	0.1118	0.11354558
	4	-0.14177174 B	-1.12	0.2638	0.12683140
	5	0.07957966 B	0.74	0.4614	0.10801964
	6	-0.09210235 B	-0.88	0.3792	0.10470679
	7	-0.08516444 B	-0.79	0.4288	0.10760566
	8	-0.23351781 B	-2.03	0.0428	0.11520962
	9	0.12655515 B	1.27	0.2031	0.09940746
	10	0.14621976 B	1.40	0.1620	0.10453421
	11	-0.22100319 B	-1.71	0.0866	0.12890363
	12	-0.29229828 B	-2.11	0.0352	0.13869598
	13	0.14291982 B	1.35	0.1774	0.10593165
	14	0.23378332 B	2.32	0.0203	0.10067008
	15	0.10116817 B	0.88	0.3793	0.11504739
	16	0.17731068 B	1.62	0.1060	0.10964094
	17	-0.21724279 B	-1.47	0.1414	0.14767410
	18	-0.30105012 B	-2.35	0.0191	0.12855287
	19	-0.11339733 B	-0.92	0.3596	0.12374651
	20	0.00000000 B	.	.	.
AGE		0.01217577	0.96	0.3356	0.01264145
AGE*AGE		0.00502334	4.56	0.0001	0.00110202
WTMEAN		-0.00019016	-3.96	0.0001	0.00004807
DISCBRAK		-0.00065927	-1.75	0.0838	0.00038112

Table IDC-2
Brake defects by carclass
in injury accidents
accident year omitted

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: PERCENTB   PERCENT OF TOTAL WITH DEFECTIVE BRAKES
WEIGHT: TOTAL2

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	22	525.44558600	23.88389027	22.05	0.0001	0.192395	103.2558
ERROR	2036	2205.63516747	1.08331786		STD DEV		PERCENTB MEAN
CORRECTED TOTAL	2058	2731.08075347			1.04082557		1.00801467

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
CARCLASS	19	73.97079492	3.59	0.0001	19	107.26604335	5.21	0.0001
AGE*AGE	1	418.46761534	386.28	0.0001	1	289.70542425	267.42	0.0001
WTMEAN	1	28.99900129	26.77	0.0001	1	16.24145019	14.99	0.0001
DISCBRAK	1	4.00817445	3.70	0.0546	1	4.00817445	3.70	0.0546

PARAMETER		ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
INTERCEPT		0.80870654 B	3.78	0.0002	0.21405425
CARCLASS	1	0.01480390 B	0.15	0.8809	0.09878893
	2	0.02726517 B	0.27	0.7879	0.10131961
	3	-0.17853386 B	-1.57	0.1159	0.11352243
	4	-0.13877313 B	-1.09	0.2739	0.12679093
	5	0.07895298 B	0.73	0.4649	0.10801576
	6	-0.09246263 B	-0.88	0.3773	0.10470427
	7	-0.08616043 B	-0.80	0.4234	0.10759878
	8	-0.23330897 B	-2.03	0.0430	0.11520737
	9	0.12372947 B	1.25	0.2132	0.09936239
	10	0.14167620 B	1.36	0.1750	0.10442586
	11	-0.22055706 B	-1.71	0.0872	0.12890050
	12	-0.28505932 B	-2.06	0.0397	0.13848973
	13	0.14201749 B	1.34	0.1802	0.10592563
	14	0.23202290 B	2.31	0.0213	0.10065170
	15	0.10161927 B	0.88	0.3772	0.11504440
	16	0.17374990 B	1.59	0.1130	0.10957665
	17	-0.21128283 B	-1.43	0.1523	0.14754178
	18	-0.30120712 B	-2.35	0.0190	0.12835049
	19	-0.11290021 B	-0.91	0.3617	0.12374324
	20	0.00000000 B	.	.	.
AGE*AGE		0.00602372	16.35	0.0001	0.00036835
WTMEAN		-0.00018496	-3.87	0.0001	0.00004777
DISCBRAK		-0.00072222	-1.92	0.0546	0.00037547

Table IDC-3

Brake defects by car class in injury accidents

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: PERCENTB PERCENT OF TOTAL WITH DEFECTIVE BRAKES
WEIGHT: TOTAL2

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	24	531.18844181	22.13283924	20.46	0.0001	0.194497	103.1712
ERROR	2034	2199.89261166	1.08155979		STD DEV		PERCENTB MEAN
CORRECTED TOTAL	2058	2731.08075347			1.03998067		1.00801467

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
CARCLASS	19	73.97079492	3.60	0.0001	19	102.03081616	4.97	0.0001
AGE*AGE	1	418.46761534	386.91	0.0001	1	262.65997227	242.88	0.0001
WTMEAN	1	28.99940129	26.81	0.0001	1	12.97391279	12.00	0.0005
DISCBRAK	1	4.00817445	3.71	0.0544	1	3.06165896	2.83	0.0926
D1	1	3.40940470	3.15	0.0760	1	2.59982842	2.40	0.1212
D2	1	2.33315111	2.16	0.1421	1	2.33315111	2.16	0.1421

PARAMETER		ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
INTERCEPT		0.78180976 B	3.62	0.0003	0.21600688
CARCLASS	1	0.00429909 B	0.04	0.9654	0.09903046
	2	0.01090146 B	0.11	0.9146	0.10161441
	3	-0.18860827 B	-1.66	0.0972	0.11365427
	4	-0.13912821 B	-1.10	0.2724	0.12673232
	5	0.07064484 B	0.65	0.5147	0.10840328
	6	-0.10428578 B	-0.99	0.3220	0.10527531
	7	-0.09220087 B	-0.86	0.3919	0.10767618
	8	-0.22887792 B	-1.97	0.0494	0.11638688
	9	0.10652789 B	1.07	0.2866	0.09994237
	10	0.11620403 B	1.11	0.2692	0.10515317
	11	-0.21067481 B	-1.62	0.1052	0.12996308
	12	-0.26884913 B	-1.94	0.0525	0.13855639
	13	0.13174885 B	1.24	0.2148	0.10616829
	14	0.21550874 B	2.13	0.0330	0.10102297
	15	0.10014522 B	0.87	0.3850	0.11526142
	16	0.15604894 B	1.42	0.1564	0.11006036
	17	-0.19547972 B	-1.32	0.1855	0.14758152
	18	-0.30220003 B	-2.34	0.0193	0.12906829
	19	-0.12294619 B	-0.99	0.3220	0.12410777
	20	0.00000000 B	.	.	.
AGE*AGE		0.00599141	15.58	0.0001	0.00038447
WTMEAN		-0.00016785	-3.46	0.0005	0.00004846
DISCBRAK		-0.00078567	-1.68	0.0926	0.00046697
D1		0.07277946	1.55	0.1212	0.04694202
D2		-0.03926033	-1.47	0.1421	0.02673054

Table IDC-4
Brake defects by car class
in injury accidents
D1 + D2 included

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: PERCENTB   PERCENT OF TOTAL WITH DEFECTIVE BRAKES
WEIGHT: TOTAL2

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	23	515.54256584	22.41489417	20.08	0.0001	0.196260	101.4157
ERROR	1891	2111.29616996	1.11649718		STD DEV		PERCENTB MEAN
CORRECTED TOTAL	1914	2626.83873580			1.05664430		1.04189386

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
CARCLASS	19	79.18348943	3.73	0.0001	19	110.09965625	5.19	0.0001
AGE*AGE	1	402.11184674	360.15	0.0001	1	283.31592711	253.75	0.0001
WTMEAN	1	26.69924176	23.91	0.0001	1	10.12291375	9.07	0.0026
DISCBRAK	1	4.21204598	3.77	0.0522	1	7.26343831	6.51	0.0108
S75	1	3.33594192	2.99	0.0841	1	3.33594192	2.99	0.0841

PARAMETER		ESTIMATE		T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
INTERCEPT		0.74277180	B	3.21	0.0014	0.23171846
CARCLASS	1	0.00259832	B	0.03	0.9795	0.10100903
	2	0.01366661	B	0.13	0.8952	0.10377400
	3	-0.18069630	B	-1.53	0.1257	0.11793862
	4	-0.12415267	B	-0.94	0.3458	0.13166868
	5	0.08061307	B	0.72	0.4703	0.11164362
	6	-0.11517096	B	-1.07	0.2854	0.10778184
	7	-0.09805977	B	-0.88	0.3785	0.11131894
	8	-0.25241694	B	-2.11	0.0350	0.11962304
	9	0.09934505	B	0.98	0.3294	0.10183964
	10	0.11105384	B	1.03	0.3027	0.10772588
	11	-0.23168144	B	-1.72	0.0848	0.13435830
	12	-0.26304419	B	-1.80	0.0716	0.14590774
	13	0.14456947	B	1.32	0.1866	0.10942936
	14	0.22151288	B	2.15	0.0317	0.10306095
	15	0.11056839	B	0.93	0.3542	0.11932463
	16	0.19282553	B	1.69	0.0917	0.11427299
	17	-0.17888732	B	-1.14	0.2548	0.15703655
	18	-0.32432821	B	-2.40	0.0166	0.13526439
	19	-0.12151186	B	-0.95	0.3401	0.12735421
	20	0.00000000	B	.	.	.
AGE*AGE		0.00611422		15.93	0.0001	0.00038383
WTMEAN		-0.00016040		-3.01	0.0026	0.00005327
DISCBRAK		-0.00114727		-2.55	0.0108	0.00044980
S75		0.00051141		1.73	0.0841	0.00029586

Table IDC-5
Brake defects by carclass
in injury accidents
Test of 1975 improvements

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: PERCENTF PERCENT OF TOTAL WITH FRONTAL IMPACT
WEIGHT: WATE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	34	400.27962917	11.77293027	8.89	0.0001	0.184659	2.2996
ERROR	1335	1767.38844667	1.32388648		STD DEV		PERCENTF MEAN
CORRECTED TOTAL	1369	2167.66807584			1.15060266		50.03579823

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
CARCLASS	19	380.40180289	15.12	0.0001	19	200.23409425	7.96	0.0001
ACCYEAR	10	8.80971111	0.67	0.7573	10	7.34641685	0.55	0.8512
AGE	1	0.84972176	0.64	0.4232	1	5.02882975	3.80	0.0515
AGE*AGE	1	9.30089755	7.03	0.0081	1	9.21431662	6.96	0.0084
WTMEAN	1	0.13340511	0.10	0.7510	1	0.32612367	0.25	0.6197
DISCBRAK	1	0.74280718	0.56	0.4540	1	0.75469996	0.57	0.4504
POWRBRAK	1	0.04122358	0.03	0.8600	1	0.04122358	0.03	0.8600

PARAMETER		ESTIMATE		T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
INTERCEPT		45.23923816	B	6.51	0.0001	6.94625891
CARCLASS	1	7.18864821	B	2.14	0.0326	3.36076869
	2	9.68186792	B	2.84	0.0046	3.41021524
	3	19.53577013	B	5.18	0.0001	3.77310633
	4	10.20955419	B	2.51	0.0121	4.06540186
	5	9.35908601	B	2.65	0.0081	3.53130163
	6	6.08525875	B	1.72	0.0859	3.54106119
	7	13.83586501	B	3.62	0.0003	3.82314447
	8	12.38977566	B	3.08	0.0021	4.02549010
	9	3.36366675	B	1.00	0.3193	3.37658747
	10	6.52969525	B	1.79	0.0736	3.64669174
	11	12.29655703	B	2.79	0.0054	4.41477151
	12	12.11959782	B	2.49	0.0130	4.87489330
	13	4.57723515	B	1.29	0.1970	3.54590809
	14	5.37607104	B	1.60	0.1091	3.35281019
	15	8.44390899	B	2.28	0.0229	3.70720047
	16	2.16079595	B	0.61	0.5419	3.54180648
	17	20.79238071	B	4.22	0.0001	4.92992953
	18	9.18158389	B	2.02	0.0437	4.54773050
	19	8.01555440	B	1.99	0.0470	4.03222609
	20	0.00000000	B	.	.	.
ACCYEAR	1971	-1.12246437	B	-0.53	0.5974	2.12472355
	1972	0.75907595	B	0.39	0.6972	1.95054826
	1973	0.64435743	B	0.35	0.7285	1.85580472
	1974	-0.41222405	B	-0.24	0.8138	1.75018785
	1975	-0.36330308	B	-0.22	0.8265	1.65722182
	1976	-0.36432570	B	-0.24	0.8131	1.54068813
	1977	-0.55576628	B	-0.38	0.7031	1.45805524
	1978	-1.47645892	B	-1.00	0.3164	1.37324647
	1979	-0.92992329	B	-0.64	0.5248	1.46200242
	1980	-0.02784506	B	-0.02	0.9850	1.48382846
	1981	0.00000000	B	.	.	.
AGE		-0.69752160		-1.95	0.0515	0.35789000
AGE*AGE		0.06852892		2.64	0.0084	0.02597572
WTMEAN		-0.00080600		-0.50	0.6197	0.00162395
DISCBRAK		0.01271855		0.76	0.4504	0.01684519
POWRBRAK		-0.00450596		-0.18	0.8600	0.02553526

Table IFR-1
Front-Rear injury accidents
Basic Model

NOTE: THE X'X MATRIX HAS BEEN DEEMED SINGULAR AND A GENERALIZED INVERSE HAS BEEN EMPLOYED TO SOLVE THE NORMAL EQUATIONS. THE ABOVE ESTIMATES REPRESENT ONLY ONE OF MANY POSSIBLE SOLUTIONS TO THE NORMAL EQUATIONS. ESTIMATES FOLLOWED BY THE LETTER B ARE BIASED AND DO NOT ESTIMATE THE PARAMETER BUT ARE BLUE FOR SOME LINEAR COMBINATION OF PARAMETERS (OR ARE ZERO). THE EXPECTED VALUE OF THE BIASED ESTIMATORS MAY BE OBTAINED FROM THE GENERAL FORM OF ESTIMABLE FUNCTIONS. FOR THE BIASED ESTIMATORS, THE STD ERR IS THAT OF THE BIASED ESTIMATOR AND THE T VALUE TESTS H0: E(BIASED ESTIMATOR) = 0. ESTIMATES NOT FOLLOWED BY THE LETTER B ARE BLUE FOR THE PARAMETER.

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: PERCENTF   PERCENT OF TOTAL WITH FRONTAL IMPACT
WEIGHT: WATE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	23	392.58176079	17.06877221	12.94	0.0001	0.181108	2.2951
ERROR	1346	1775.08631505	1.31878627		STD DEV		PERCENTF MEAN
CORRECTED TOTAL	1369	2167.66807584			1.14838420		50.03579823

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
CARCLASS	19	380.40180289	15.18	0.0001	19	252.51303275	10.08	0.0001
AGE	1	1.29914116	0.99	0.3211	1	7.40717235	5.62	0.0179
AGE*AGE	1	10.38472150	7.87	0.0051	1	10.43563972	7.91	0.0050
DISCBRAK	1	0.11064994	0.08	0.7721	1	0.48541158	0.37	0.5442
POWRBRAK	1	0.38544531	0.29	0.5889	1	0.38544531	0.29	0.5889

PARAMETER		ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
INTERCEPT		42.91797611 B	11.66	0.0001	3.68199363
CARCLASS	1	7.31065171 B	2.21	0.0274	3.31115169
	2	9.90838820 B	2.94	0.0033	3.36475802
	3	19.98544383 B	5.68	0.0001	3.51642656
	4	10.72226511 B	2.91	0.0036	3.67954925
	5	9.66792853 B	2.88	0.0041	3.36057009
	6	6.49609954 B	1.94	0.0525	3.34726935
	7	14.13065348 B	3.83	0.0001	3.68760369
	8	12.47635041 B	3.34	0.0009	3.73460213
	9	3.37092792 B	1.01	0.3146	3.35054371
	10	6.11759783 B	1.70	0.0890	3.59461846
	11	12.50391525 B	3.16	0.0016	3.95686858
	12	12.80153747 B	3.01	0.0026	4.24955909
	13	4.80963159 B	1.41	0.1586	3.40992589
	14	5.51773663 B	1.66	0.0967	3.31944307
	15	8.60577968 B	2.42	0.0158	3.56096043
	16	2.17325246 B	0.62	0.5339	3.49304559
	17	21.53078045 B	5.00	0.0001	4.30540638
	18	9.32843157 B	2.20	0.0281	4.24259487
	19	8.25364292 B	2.21	0.0274	3.73683211
	20	0.00000000 B	.	.	.
AGE		-0.78430747	-2.37	0.0179	0.33093853
AGE*AGE		0.07006506	2.81	0.0050	0.02490744
DISCBRAK		0.00851209	0.61	0.5442	0.01403034
POWRBRAK		-0.01226204	-0.54	0.5889	0.02268132

Table IFR-2
Front-Rear injury accidents
accident year and vehicle
weight omitted

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: PERCENTF   PERCENT OF TOTAL WITH FRONTAL IMPACT
WEIGHT: WATE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	22	392.19631548	17.82710525	13.52	0.0001	0.180930	2.2945
ERROR	1347	1775.47176036	1.31809336		STD DEV		PERCENTF MEAN
CORRECTED TOTAL	1369	2167.66807584			1.14808247		50.03579823

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
CARCLASS	19	380.40180289	15.19	0.0001	19	373.66263121	14.92	0.0001
AGE	1	1.29914116	0.99	0.3210	1	7.24920836	5.50	0.0192
AGE*AGE	1	10.38472150	7.85	0.0051	1	10.33780235	7.84	0.0052
DISCBRAK	1	0.11064994	0.08	0.7721	1	0.11064994	0.08	0.7721

PARAMETER		ESTIMATE		T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
INTERCEPT		42.27227845	B	12.14	0.0001	3.48198351
CARCLASS	1	7.40145421	B	2.24	0.0253	3.30602021
	2	9.78685161	B	2.92	0.0036	3.35635750
	3	20.26832646	B	5.83	0.0001	3.47636428
	4	11.23041050	B	3.16	0.0016	3.55653930
	5	9.86894314	B	2.96	0.0032	3.33905971
	6	6.44417388	B	1.93	0.0543	3.34501195
	7	14.13376130	B	3.83	0.0001	3.68663033
	8	12.88694190	B	3.53	0.0004	3.65560115
	9	3.13054658	B	0.94	0.3459	3.32003701
	10	6.11485091	B	1.70	0.0891	3.59367042
	11	13.14417807	B	3.48	0.0005	3.77448510
	12	13.91309547	B	3.74	0.0002	3.71807214
	13	5.15865575	B	1.54	0.1235	3.34737347
	14	5.64913263	B	1.71	0.0881	3.30966354
	15	8.94051421	B	2.55	0.0109	3.50579706
	16	2.21021347	B	0.63	0.5268	3.49145888
	17	22.75161618	B	6.21	0.0001	3.66469392
	18	9.83184555	B	2.38	0.0176	4.13805795
	19	8.79762160	B	2.45	0.0146	3.59786814
	20	0.00000000	B	.	.	.
AGE		-0.77480404		-2.35	0.0192	0.33038450
AGE*AGE		0.06971185		2.80	0.0052	0.02489233
DISCBRAK		0.00242425		0.29	0.7721	0.00836708

Table IFR-3
Front-Rear injury accidents
Power brakes omitted

NOTE: THE X'X MATRIX HAS BEEN DEEMED SINGULAR AND A GENERALIZED INVERSE HAS BEEN EMPLOYED TO SOLVE THE NORMAL EQUATIONS. THE ABOVE ESTIMATES REPRESENT ONLY ONE OF MANY POSSIBLE SOLUTIONS TO THE NORMAL EQUATIONS. ESTIMATES FOLLOWED BY THE LETTER B ARE BIASED AND DO NOT ESTIMATE THE PARAMETER BUT ARE BLUE FOR SOME LINEAR COMBINATION OF PARAMETERS (OR ARE ZERO). THE EXPECTED VALUE OF THE BIASED ESTIMATORS MAY BE OBTAINED FROM THE GENERAL FORM OF ESTIMABLE FUNCTIONS. FOR THE BIASED ESTIMATORS, THE STD ERR IS THAT OF THE BIASED ESTIMATOR AND THE T VALUE TESTS H0: E(BIASED ESTIMATOR) = 0. ESTIMATES NOT FOLLOWED BY THE LETTER B ARE BLUE FOR THE PARAMETER.

DISCUSSION

In order to further investigate the effectiveness of Federal Motor Vehicle Safety Standard 105 a series of regression models were developed following along the lines of those reported by Stewart (1982). The results of these analyses are contained in several series of tables which follow and which are briefly described below. The first series, (tables ID-1 through ID-6), are models of the percent of cars in model year by accident year groups that were involved in injury producing accidents, and were found to have defective brakes. These, and all subsequent, analyses were based on North Carolina accidents using data from calendar years 1971-1981. Table ID-1 contains results from the initial linear model with all the potential independent variables included. The next two tables show models with some of the non-significant variables omitted. In table ID-3 all of the remaining effects are highly significant, and are quite similar to those shown in table 4 of Stewart (1982).

Table ID-4 shows the results of a log-linear model with all of the independent variables included. The model shows all variables to be highly significant except dual brakes and disc brakes. This result seems to be due to the fact that in the transformed data the bulk of the variation corresponds to the more recent model year cars, whereas in the untransformed data relatively more of the variation occurred when dual brakes and disc brakes were increasing.

The models shown in tables ID-5 and ID-6 contain, respectively two dummy variables defined by

$$D1 = \begin{cases} 1 \text{ if model year } <1969 \\ o \text{ otherwise} \end{cases},$$

and

$$D2 = \begin{cases} 1 \text{ if model year } <1975 \\ o \text{ otherwise} \end{cases},$$

and a variable indicating the 1975 brake improvements. None of these variables is signifincant.

Table AD-1 shows a model that represents an extension of the model of Table 4 in Stewart (1982) to include data from 1980 and 1981 and dummy variables D1 and D2. Neither of the dummies is significant.

Models for the percentage of cars in groups (defined by car class, model year, and calendar year) having defective brakes in any N.C. accidents are shown in tables ADC-1 through ADC-3. The car classes are the same as in Stewart (1982). The basic model is shown in ADC-1, where the disc brake variable is seen to be significant, but with a considerably smaller effect than in the previous models. Dummy variables D1 and D2 are not significant in this case as can be seen in table ADC-2. Table ADC-3 shows the 1975 brake improvement variable (S75) to be significant, but with a positive coefficient.

Tables IDC-1 through IDC-5 show models for the percent of brake defects by car class in injury accidents. Disc brakes is significnat in the basic model (Table IDC-1) and has about the same effect as in the all accident case. It looses significance when accident year is omitted from the model, (table IDC-2) and becomes marginally significant in table IDC-3 when age is omitted. When D1 and D2 are added to the model neither is significant, but then neither is disc brakes. On the other hand, when S75 is included it is not significant, but disc brakes is.

Tables IFR-1 through IFR-3 show a sequence of models for the percent of front damaged cars by car class in injury accidents. The sequence progresses by removing non-significant variables from the model. In none of the models is disc brakes significant.

In summary, additional regression analyses of an updated N.C. accident file showed dual brakes and disc brakes to be statistically significant with respect to reducing the percentage of cars in model year by calendar year groups having brake defects in accidents. The effects of these variables are quite similar in both injury accidents and in all accidents, and correspond quite closely to the values given in table 4 of Stewart (1982). When the car groups are further subdivided by car class considerably more variation is introduced into the data. In this case disc brakes generally retains its significance, but its effect is greatly reduced. No effects due to disc brakes are found in the front-to-rear analyses.

Reference

Stewart, J. Richard (1982). Statistical Evaluation of Federal Motor Vehicle Safety Standard 105 (Passenger Car Hydraulic Brakes). Chapel Hill: University of North Carolina Highway Safety Research Center.