U.S. Department
of Transportation

National Highway
Traffic Safety
Administration

DOT HS 808 206
NHTSA Technical Report

December 1994

# Preliminary Evaluation of the Effectiveness of Antilock Brake Systems for Passenger Cars

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

Technical Report Documentation Page

| 1. Report No. | 2. Government Accession No. | 3. Recipient's Catalog No. |
|---|---|---|
| DOT HS 808 206 | | |

| 4. Title and Subtitle | 5. Report Date |
|---|---|
| PRELIMINARY EVALUATION OF THE EFFECTIVENESS OF ANTILOCK BRAKE SYSTEMS FOR PASSENGER CARS | December 1994 |
| | 6. Performing Organization Code |
| 7. Author(s) | 8. Performing Organization Report No. |
| Charles J. Kahane, Ph.D. | |
| 9. Performing Organization Name and Address | 10. Work Unit No. (TRAIS) |
| Evaluation Division, Office of Strategic Planning and Evaluation<br>National Highway Traffic Safety Administration<br>Washington, D.C. 20590 | 11. Contract or Grant No. |
| 12. Sponsoring Agency Name and Address | 13. Type of Report and Period Covered |
| Department of Transportation<br>National Highway Traffic Safety Administration<br>Washington, D.C. 20590 | NHTSA Technical Report |
| | 14. Sponsoring Agency Code |

15. Supplementary Notes

16. Abstract

The accident involvement rates of passenger cars equipped with Antilock Brake Systems (ABS) were compared to the rates of counterpart cars without ABS, based on 1990-92 Florida, Pennsylvania and Missouri data, and the 1989-93 Fatal Accident Reporting System. This statistical analysis of the initial years of exposure of the first groups of cars equipped with ABS showed mixed results. Involvements in multivehicle crashes on wet roads were significantly reduced in the cars equipped with ABS: fatal crashes were reduced by 24 percent, and nonfatal crashes by 14 percent. Fatal collisions with pedestrians and bicyclists were down a significant 27 percent with ABS. However, these reductions were offset by a statistically significant increase in the frequency of single vehicle, run-off-road crashes (rollovers or impacts with fixed objects), as compared to cars without ABS. Fatal run-off-road crashes were up by 28 percent, and nonfatal crashes by 19 percent. It is unknown to what extent this increase is a consequence of ABS, or is due to other causes. In particular, it is unknown to what extent, if any, the increase is due to incorrect responses by drivers to their ABS systems, and, if so, whether the effect is likely to persist in the future. The increase may involve all types of ABS or only certain ABS designs.

| 17. Key Words | 18. Distribution Statement |
|---|---|
| ABS; Antilock Brake Systems; crash avoidance; FARS; handling and stability; accident analysis; statistical analysis; wet roads; pedestrians; rollovers; run-off-road; fixed object; | Document is available to the public through the National Technical Information Service, Springfield, Virginia 22161 |

| 19. Security Classif. (of this report) | 20. Security Classif. (of this page) | 21. No. of Pages | 22. Price |
|---|---|---|---|
| Unclassified | Unclassified | 149 | |

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

TABLE OF CONTENTS

# PREFACE

The National Highway Traffic Safety Administration recently completed this preliminary evaluation of the accident records of passenger cars equipped with antilock brake systems (ABS). The data comprise the initial years of exposure of the first groups of cars equipped with ABS. The analysis suggests that ABS has helped reduce vehicle-to-vehicle collisions on wet roads. Drivers of cars equipped with ABS are not colliding with other vehicles on wet roads as often as drivers of cars without ABS.

The study, however, shows that current ABS-equipped cars have a higher involvement rate, than cars without ABS, in single-vehicle, run-off-road crashes, that typically result in rollovers and collisions with trees or other fixed objects. The increase in run-off-road crashes approximately offsets the reduction of vehicle-to-vehicle collisions. Thus, NHTSA estimates that there has been little or no net accident reduction with ABS, to date. NHTSA's finding is consistent with the accident analysis published by the Insurance Institute for Highway Safety in January 1994.

The increase in run-off-road crashes is surprising in view of the good performance of ABS in stopping tests conducted by the agency and others. NHTSA is not yet certain that the observed increase is a direct consequence of the ABS system and/or the driver's interaction with ABS. NHTSA will continue to study the performance of current cars equipped with ABS to find out why run-off-road crashes have increased, and whether the problem is likely to persist in the future. The increase in run-off-road crashes might not be associated with all ABS systems; some current or future designs may perform differently than others.

It might result, to some extent, from the inappropriate use of ABS systems by drivers, and it could change as drivers gain more experience with their ABS systems.

Several hypotheses have been suggested to explain the increase in run-off-road crashes. One possibility is that some drivers may negotiate curves or change lanes more aggressively because they believe ABS will enable them to stop in a shorter distance or retain control of their vehicle in extreme driving maneuvers. Other drivers, unaware of how ABS functions, may be pumping or releasing their brakes when the ABS begins to cycle. Another hypothesis is that drivers react to an imminent crash threat by abruptly braking and steering; cars without ABS would lock the front wheels and skid straight ahead, but cars equipped with ABS would remain steerable and could leave the road in those circumstances. It must be emphasized that none of these theories has been confirmed to date, by accident or test data, as an explanation for the increase in crashes.

NHTSA has established a program of data analyses and vehicle testing to obtain a better understanding of the performance of ABS in run-off-road crashes:

- o National Accident Sampling System (NASS), Fatal Accident Reporting System (FARS), and narrative sections of North Carolina accident reports will be reviewed in-depth for cases involving ABS-equipped cars which ran off the road.

- o Drivers who complained to the NHTSA's **Auto Safety Hotline** about the performance of their ABS systems will be interviewed.

- Discussions will be held with NASS crash investigators and with police officers who drive ABS-equipped cruisers, or who have investigated crashes involving ABS-equipped vehicles, to gather their insights on possible causes of off-road crashes of ABS-equipped vehicles.

- Recent Human Factors literature will be reviewed to learn how drivers respond (steering and/or braking) to imminent crash threats.

- A research driving simulator will be used to determine average drivers' braking and/or steering responses to simulated crash threats. This study will yield the best objective data likely to be obtained as to what drivers actually do when confronted with an imminent crash threat.

- Combined braking and steering maneuver tests will be conducted with an ABS-equipped vehicle at NHTSA's Vehicle Research and Test Center to establish the range and bounds of maneuvers that can be successfully executed without a loss of directional control.

Follow-up reports will be released by the agency as the results of these efforts become available. It is the agency's ultimate goal to identify appropriate actions that can be implemented by the agency and/or industry to ensure safe, cost-effective braking technology.

In the meantime, NHTSA urges drivers to gain a better understanding of how their ABS systems operate, and to avoid using ABS brakes in a way that could increase accident risk:

- Many drivers think the main purpose of ABS is to reduce stopping distances. **This is a serious misconception.** ABS will only reduce stopping distances significantly in some special road conditions, but may increase distances in others.

- The principal goals of ABS are to prevent skidding and loss-of-control due to locked-wheel braking, and to allow a driver to steer the vehicle during hard braking.

- Drivers should not pump the brake pedal in cars equipped with ABS. This can defeat the purpose of ABS and may reduce braking capability.

- Drivers should know that the ABS system can make noise and vibrate the brake pedal when it is working. They should not take their foot off the brake pedal when they hear noise or feel pedal vibration.

- If a driver makes a car skid for reasons other than braking, such as going around a curve too quickly, ABS will not prevent or relieve the skid.

- Drivers of cars equipped with ABS must maintain the same distance behind vehicles they follow that they would have kept without ABS. They should not expect to stop more quickly because they have ABS.

- Drivers of cars equipped with ABS should not drive around curves, or change lanes, or perform other steering maneuvers any faster or more aggressively than they would have done without ABS. They should not expect ABS to improve their control in these maneuvers.

- Drivers should be aware that extreme steering maneuvers, executed while using ABS brakes, could steer the car off the road.

- ABS can significantly **lengthen** stopping distances on loose surfaces such as gravel or soft snow. Drivers should slow down and allow extra distance between vehicles under those conditions.

The agency is very interested in hearing from consumers about their experience with ABS systems, especially about cases where vehicles equipped with ABS ended up off the road. Consumers are urged to call NHTSA's **Auto Safety Hotline** at 1-800-424-9393 (202-366-0123 in the Washington, DC Metro Area). The **Auto Safety Hotline** can also provide information on the correct use and performance of ABS brakes.

## EXECUTIVE SUMMARY

Antilock Brake Systems (ABS) are a noteworthy development in motor vehicle technology. Since 1985, they have been voluntarily installed by manufacturers on millions of cars and light trucks. They have been welcomed by consumers and have already become standard equipment in many new cars and most light trucks. The Highway Safety Act of 1991 instructed the National Highway Traffic Safety Administration (NHTSA) to contemplate requiring ABS in all passenger vehicles. NHTSA published an Advance Notice of Proposed Rulemaking (ANPRM) at the end of 1993, discussing ABS and other changes in braking technology. The ANPRM stated that the agency did not yet have sufficient data to estimate the safety benefits of ABS. However, ABS was introduced as standard equipment on a number of high-volume family and economy cars during 1991-92; by mid-1994, State data bases had accumulated a sufficient number of accident cases for this preliminary statistical evaluation of the effects of ABS on police-reported crashes and fatalities of passenger cars.

There are two types of ABS. Four-wheel systems, which are almost the only type installed on passenger cars and are becoming increasingly numerous on light trucks, are the subject of this study. Rear-wheel antilock systems, which were the principal type installed on light trucks through model year 1991, were evaluated by NHTSA in December 1993.

The fundamental safety problem addressed by ABS is that few drivers are able to optimize the pressure they apply on the brake pedal, given a sudden emergency situation or unexpectedly slippery surface. When excessive pedal pressure locks the wheels, the vehicle can yaw out of the driver's control (rear-wheel lockup), or go straight ahead, impossible to steer (front-wheel lockup). On most, but not all, road surfaces, a skidding vehicle needs a longer distance to stop than a vehicle with the brakes applied and wheels still rolling. The objective of ABS is to take over the optimization task from the driver. A four-wheel system is intended to keep all the wheels rolling during panic braking, to prevent yawing, to allow steering throughout the emergency and, on many surfaces, to shorten the stopping distance. The combination of efficient stopping and steering is intended to help the driver avoid mobile and fixed obstacles. The effect, however, is not inevitably for the better. ABS confers the capability to steer a car while slamming on the brakes, but the average driver in a panic situation might not always use this capability to advantage, and might even steer the car into a worse situation than the one which the driver was trying to avoid.

During 1988-91, NHTSA performed two extensive series of stopping tests involving vehicles with four-wheel ABS, on various road surfaces. The tests confirmed that ABS was highly effective in preventing yawing and allowing the driver to steer the car during panic braking. Stopping distances decreased substantially with four-wheel ABS on wet surfaces, but decreased only slightly on dry pavement and increased considerably on gravel.

The statistical analyses of the effectiveness of ABS are based on 1990-92 accident data from Florida, Pennsylvania and Missouri and 1989-93 data from the Fatal Accident Reporting System (FARS). The statistical analyses compare the accident involvements of passenger cars of the first 2 model years with ABS to cars of the same makes, models and subseries, but from the last 2 model years before ABS became standard equipment.

The principal findings and conclusions from the statistical analyses of accident data are the following:

- ABS significantly reduced the involvements of passenger cars in **multivehicle crashes on wet roads**. ABS reduced police-reported crash involvements by an estimated 14 percent, and fatal involvements by 24 percent. The finding is consistent with the outstanding performance of ABS in stopping tests on wet roads.

- Certain types of collision involvements on wet roads, such as striking another vehicle in the rear, or striking a stopped vehicle, were reduced by 40 percent or more. This benefit, however, was partially offset by an increased likelihood of being struck in the rear by another vehicle. The better your own braking capabilities, the more likely that a following vehicle with average braking capabilities will hit you.

- ABS had little effect on **multivehicle crashes on dry roads**. The contrast in the results for wet roads and dry roads is consistent with findings in stopping tests, where ABS improved stopping distances and directional control substantially on wet surfaces, but much less so on dry surfaces.

- The risk of **fatal collisions with pedestrians and bicyclists** was reduced by a statistically significant 27 percent in passenger cars with ABS. Unlike the effects for multivehicle crashes, this reduction was about equally large on wet and dry roads.

- All types of **run-off-road crashes** - rollovers, side impacts with fixed objects and frontal impacts with fixed objects - **increased** significantly with ABS. Nonfatal run-off-road crashes increased by an estimated 19 percent, and fatal crashes by 28 percent.

- Rollovers and side impacts with fixed objects - crashes that typically follow a complete loss of directional control - had the highest increases with ABS. Nonfatal crashes increased by 28 percent, and fatal crashes by 40 percent.

- Frontal impacts with fixed objects, where the driver is more likely to have retained at least some directional control prior to impact, increased by about 15-20 percent, both nonfatal and fatal.

- The negative effects of ABS on run-off-road crashes were about the same under wet and dry road conditions.

- The reason for these negative effects is unknown. One possibility is that average drivers may at times steer improperly in panic situations. Because ABS preserves steering control under hard braking, cars may be swerving or heading off the road.

o The observed effects of ABS on **snowy or icy roads**, while not statistically significant, were all similar to the effects on wet roads - i.e., positive for multivehicle collisions, negative for run-off-road crashes.

o The **overall**, net effect of ABS on **police-reported crashes** (including multivehicle, pedestrian and run-off-road crashes) was close to zero.

o The **overall**, net effect of ABS on **fatal crashes** was close to zero.

This report is not the first statistical evaluation of ABS for passenger cars. In late 1993, the Highway Loss Data Institute published an analysis of the effect of ABS on collision and property-damage-liability claims. They found that ABS had little effect on the overall, insurance-reported accident rates of cars. This report's findings on the overall, net effect of ABS corroborate the earlier study. However, this report also shows that ABS is not ineffectual. The net benefit is close to zero, because significant reductions in pedestrian impacts and wet-road multivehicle crashes are nullified by significant increases in run-off-road crashes.

These preliminary results need to be viewed with caution for several reasons. The principal observed effects, both positive and negative, although statistically significant and consistent from State to State, are quite high compared to what is usually seen in evaluations of crash avoidance measures. The increase in run-off-road crashes is surprising in view of the good performance of ABS in stopping tests. Further study is needed, such as interviews with drivers of ABS-equipped cars that were involved in run-off-road crashes, or stopping tests that involve combinations of hard braking and abrupt steering, before the increase can be unequivocally attributed to the ABS system and/or the driver's interaction with ABS. The FARS samples in this report were sometimes too small for conclusive results. The data comprise the initial years of exposure of the first groups of cars equipped with ABS; results could change as drivers gain more experience with the ABS in these cars, or for later cars with different ABS systems. The results of this report apply **only** to passenger cars and should definitely **not** be extended to light trucks equipped with four-wheel ABS. The effectiveness of four-wheel ABS for light trucks will be estimated when sufficient accident data become available.

# CHAPTER 1

## INTRODUCTION, BACKGROUND AND DATA SOURCES

Antilock Brake Systems (ABS) are a noteworthy development in motor vehicle technology. Since 1985, they have been voluntarily installed by manufacturers on millions of cars and light trucks. They have been welcomed by consumers and have already become standard equipment in many new cars and most light trucks. The Highway Safety Act of 1991, Section 2507 instructed the National Highway Traffic Safety Administration (NHTSA) to consider requiring ABS in all passenger vehicles (cars, pickup trucks, sport utility vehicles and vans lighter than 10,000 pounds). As required by the Act, NHTSA published an Advance Notice of Proposed Rulemaking (ANPRM) at the end of 1993 [3], discussing the potential safety and cost impact of ABS and other changes in braking technology. The ANPRM stated that "the agency does not have sufficient data to estimate the safety benefits of requiring mandatory installation of ABS on all light vehicle types...The agency is requesting information on ABS effectiveness and the safety benefits that could be expected for mandatory installation of the technology."

Because ABS has already been installed on millions of passenger cars and light trucks, there are opportunities to evaluate the effects of ABS on accident risk, based on the actual experience of production vehicles, at an early stage in the rulemaking process. There are two types of ABS: four-wheel antilock systems, which are almost the only type installed on passenger cars, and rear-wheel-only systems, which were the principal type installed on light trucks through model year 1991. In late 1993, NHTSA had enough accident data to publish a statistical analysis of **light trucks** equipped with **rear-wheel-only** ABS [7]. That study showed significant reductions of certain types of crashes, but negligible or possibly negative effects in other types. There was no clear net benefit for rear-wheel-only ABS. These results are not directly relevant to passenger cars, which are almost exclusively equipped with four-wheel ABS.

The Highway Loss Data Institute (HLDI) performs statistical analyses of accident claims per 1000 insured vehicle years. By the end of 1993, they had enough data to study the effect of four-wheel ABS on the collision and property-damage-liability claims associated with passenger cars [2]. HLDI found that ABS had little effect on the overall, insurance-reported accident rates of cars. However, the HLDI data mix all types of crashes and contain a large percentage of low-speed collisions that are unlikely to be affected by ABS. The HLDI results do not preclude the possibility that ABS is beneficial in certain crash modes, with offsetting negative effects in others. They do not exclude the chance that ABS could have a nonzero net effect in crashes of higher severity, such as fatal crashes.

As of mid-1994, NHTSA data bases contain a sufficient number of accident cases involving late-model passenger cars equipped with four-wheel ABS for this preliminary evaluation of the effects of ABS by crash mode and severity level. This report only evaluates four-wheel ABS for passenger cars; there are not yet enough accident data to study four-wheel ABS in light trucks.

## 1.1 Objectives of antilock brake systems

The fundamental safety problem addressed by four-wheel ABS is that few drivers are able to modulate pressure on the brake pedal optimally, given a sudden emergency situation or unexpectedly slippery surface. Excessive pedal pressure locks the wheels, while timid braking or inexpert pedal pumping to avoid lockup may lengthen stopping distances. When the wheels lock up, the vehicle can yaw out of the driver's control (rear-wheel lockup), or go straight ahead, regardless of steering input (front-wheel lockup). On most road surfaces, a skidding vehicle needs a longer distance to stop than a vehicle with the brakes applied and wheels still rolling. The objective of ABS is to take over the pedal modulation task from the driver, and keep brake pressure at a level as close as possible to lockup, but with the wheels still rolling.

ABS is intended to prevent yawing, to allow the driver to steer the vehicle throughout the emergency and to shorten the stopping distance on many surfaces. The combination of efficient stopping and steering might help a driver stop short of and/or steer around fixed or mobile obstacles (other vehicles, pedestrians, etc.) or, at least, to make collisions with such objects less severe. The effect of enhanced braking and steering capabilities, however, is not inevitably for the better. An inexpert driver in a panic situation might try an abrupt evasive steering maneuver while slamming on the brakes. Without ABS, the front wheels lock and the car goes straight ahead, essentially ignoring the steering input. With ABS, the vehicle responds to the abrupt, instinctive steering input, possibly running off the road and badly out of control.

Four-wheel ABS has potential to affect (for better or worse) any crash situation in which a driver braked hard enough to activate the ABS mechanism, and that could be influenced by shorter stopping distance, evasive steering maneuvers and/or general directional stability. It might have an effect in multivehicle collisions, run-off-road crashes, and on-road collisions with nonmotorists, animals, etc. ABS will have no effect in crash situations where braking was not involved, such as when a car was standing still prior to the crash.

## 1.2 Results of stopping tests with ABS

NHTSA carried out two extensive series of stopping tests involving 14 vehicles with four-wheel ABS (12 cars and 2 light trucks) [1], [4]. The tests, conducted at East Liberty, Ohio during 1988-91, included a variety of road surfaces, straight-line stops at various speeds, and maneuvers requiring steering plus braking. Each vehicle was tested with the ABS enabled and disabled and with the vehicle empty and fully loaded. The road surfaces included dry concrete, three types of wet asphalt or concrete (different levels of smoothness), two slippery surfaces - wet Jennite and epoxy, and gravel. Wet Jennite (roadway sealant) has a much lower sliding than rolling coefficient of friction; wet epoxy has coefficients of friction similar to ice, although it is not intended as a surrogate for ice. The objectives of the tests were to study the effect of ABS on general directional stability, vehicle response to steering input, and stopping distances.

Tables 1-1 and 1-2 review the performance of four-wheel ABS on a <u>subset</u> of the tests carried out at East Liberty: straight-line <u>spike</u> stops (panic braking with maximum pedal pressure and no effort to modulate pedal pressure) on <u>homogeneous</u> road surfaces. Table 1-1 shows that four-wheel ABS was highly effective in keeping vehicles going straight during panic braking on homogeneous road surfaces. In this subset of 494 tests, on different road surfaces, with the ABS enabled there was not a single case of yawing. With the ABS disabled, some of the vehicles yawed on every surface. There was more yawing on the slippery surfaces. On dry concrete, only 6 of 46 tests with the ABS disabled involved yawing, and always less than 10 degrees. On wet Jennite, 72 of 88 tests resulted in yawing, 11 of them more than 45 degrees.

TABLE 1-1

EFFECT OF FOUR-WHEEL ABS ON VEHICLE YAWING
IN STRAIGHT-LINE SPIKE STOPS
BY TYPE OF ROAD SURFACE

| | | Number of Tests, by Angle of Yaw | | | |
|---|---|---|---|---|---|
| **Road Surface** | **ABS Enabled?** | **No Yaw** | **≤ 10°** | **10-45°** | **> 45°** |
| Dry concrete | **ENABLED** | 46 | | | |
| | **DISABLED** | 40 | 6 | | |
| Wet asphalt/concrete | **ENABLED** | 276 | | | |
| | **DISABLED** | 170 | 99 | 7 | |
| Wet Jennite | **ENABLED** | 88 | | | |
| | **DISABLED** | 16 | 37 | 24 | 11 |
| Wet epoxy | **ENABLED** | 42 | | | |
| | **DISABLED** | 10 | 22 | 5 | 5 |
| Gravel | **ENABLED** | 42 | | | |
| | **DISABLED** | 17 | 21 | 3 | |

TABLE 1-2

EFFECT OF FOUR-WHEEL ABS ON STOPPING DISTANCE
IN STRAIGHT-LINE SPIKE STOPS
BY TYPE OF ROAD SURFACE

| **Road Surface** | **Median % Reduction of Stopping Distance, ABS Enabled vs. ABS Disabled** |
|---|---|
| Dry concrete | 5 |
| Wet asphalt/concrete | 14 |
| Wet Jennite | 43 |
| Wet epoxy | 10 |
| Gravel | -28 |

In addition to these tests on homogeneous surfaces, NHTSA tried stops on surfaces that were more slippery under one side of the vehicle than the other (so-called "split-mu" surfaces). They resemble a roadway with slippery patches. With one exception, ABS was highly effective in preventing or minimizing yaw in panic stops, whereas the yaw was often 180 degrees or more when the systems were disabled. For a test of combined braking and steering, the vehicles with four-wheel ABS were subjected to emergency stops in a curve or lane-change maneuver on wet asphalt or Jennite. In all cases, the vehicles successfully negotiated the maneuvers during panic braking with the ABS enabled.

The effect of four-wheel ABS on stopping distance, in straight-line spike stops, is not uniformly beneficial. Table 1-2 shows the median percentage reduction of stopping distance, by road surface type, for a test with the ABS enabled relative to the corresponding test with the ABS disabled. ABS reduced stopping distances by only 5 percent on dry concrete, but had a substantially larger effect on wet asphalt or concrete (14 percent on the average). Because wet Jennite has a much higher rolling resistance than sliding resistance, the reduction in stopping distance for ABS is 43 percent. Jennite is not extensively used to pave real highways, but there are certain conditions where actual pavements can approach the characteristics of Jennite (wet, highly worn, dirty and/or oily). The much smaller reduction on wet epoxy (10 percent) suggests that the excellent result on Jennite is due to the characteristics of that specific material, and is not true for all slippery materials (e.g., ice). Finally, ABS lengthens stopping distances on gravel by 28 percent: a car with the wheels locked plows into the gravel, reducing the stopping distance (although not necessarily without yawing). It is unknown if other loose materials, such as snow, would have a similar effect.

In summary, NHTSA's tests show that four-wheel ABS is successful in improving overall vehicle stability during braking, preserving steerability, and reducing stopping distances. At first glance, they suggest potential benefits in almost any type of crash situation that could be avoided by enhanced braking or, especially, a combination of braking and steering. The benefits should be substantially larger on wet roads than dry roads, since, on a dry road, even a vehicle without ABS should skid to a stop in close to minimum distance on a fairly straight line.

Nevertheless, the test results do not take into account phenomena that may limit the utility of ABS in actual crashes. The tests were performed by expert drivers who knew precisely what to do and when to do it: slamming on the brakes in combination with relatively delicate evasive steering. The average driver, in an unexpected, instinctive panic situation might have difficulty combining hard braking with delicate steering. Some drivers, as noted above, might steer too abruptly and lose control; others might brake too softly and not even activate the ABS (especially if they don't know that ABS brakes should not be "pumped" [2]). At East Liberty, the ABS-equipped and non-ABS cars approached each maneuver at exactly the same speed. On the highway, a driver who believes that ABS enhances stopping ability and control might conceivably drive faster and follow closer in an ABS-equipped car than in a non-ABS car (risk compensation).

Finally, in the stopping tests, ABS eliminated nearly all yawing because the only source of yaw was locked-wheel braking. On the highway, many skids or yaws are instigated by factors other than braking - steering, acceleration, roadway conditions - and, once the car skids, even ABS brakes may not be helpful in bringing it out of a skid. For example, Table 1-3, which is based on 1990-92 Missouri data, compares the percentage of accidents involving "skidding" in ABS-equipped and non-ABS cars. On dry roads, ABS reduces the likelihood of skidding by a statistically significant 36 percent, but certainly does not completely eliminate it. On wet, snowy and icy roads, a large percentage of accidents involve skidding, with or without ABS.

1.3 Cars equipped with ABS, 1985-92

Four-wheel, electronic ABS has been offered as standard or optional equipment on a large variety of makes, models and subseries in the United States. It was introduced during the 1985 model year on the most luxurious models of Lincoln, Mercedes and BMW, and extended in 1986 to Chevrolet Corvette, all BMW's and most Mercedes. Appendix A shows the percent of cars, by make, model and model year, equipped with ABS; when that percentage is neither 0 nor 100, it specifies whether ABS is optional on all subseries, or standard on specific subseries while unavailable on others. The first high-volume family or economy cars with standard ABS were the 1991 Chevrolet Caprice and the 1992 General Motors J, L and N body cars (e.g., Cavalier, Corsica and Grand Am). These high-volume models play a major role in the selection of a sample of ABS-equipped cars which is fairly representative of the "average" car on the road.

Although many cars have been equipped with ABS, not all models are appropriate for inclusion in a statistical study of the effectiveness with ABS. The presence or absence of ABS must be derivable from make-model and subseries information contained in the VIN, since State accident files do not provide information, other than the VIN, for identifying whether a car is equipped with ABS, or what subseries of a make-model it belongs to. In general, make-models with optional ABS are excluded from the study, since its installation cannot be

TABLE 1-3

**MISSOURI, 1990-92:** EFFECT OF ABS ON CRASHES INVOLVING "SKIDDING" BY ROAD CONDITION

| **Road Condition** | **ABS Equipped?** | **N of Crashes** | **Percent with "Skidding"** | **Change with ABS (%)** | $\chi^2$ | **Stat Sig?** |
|---|---|---|---|---|---|---|
| Dry | **NO** | 4762 | 4.85 | | | |
| | **YES** | 2799 | 3.14 | down 36 | 12.71 | .01 |
| Wet | **NO** | 1364 | 8.43 | | | |
| | **YES** | 719 | 6.68 | down 22 | 2.01 | |
| Snowy/icy | **NO** | 193 | 18.13 | | | |
| | **YES** | 104 | 23.08 | up 35 | 1.04 | |

inferred from the VIN. The analyses include cars up to model year 1992, the last year for which State accident data were available as of July 1994.

For each make-model-subseries in the analysis with standard ABS, there needs to be a comparison group of cars without ABS, preferably of the same make-model-subseries and a similar model year, in order that the distribution of crash involvements can be contrasted for the ABS cars and the comparison groups. Thus, models that always had ABS (e.g., Lexus) are excluded from the analyses. To avoid comparing "new" ABS-equipped cars with substantially "older" non-ABS cars, at most the first 2 model years with ABS are included in the analysis, and at most the last 2 years without ABS are included in the comparison group. When the ABS-equipped and non-ABS cars are of similar age (and the same make-model), any differences in the accident profiles are more likely due to ABS than differences in the drivers or the exposure of the cars.

In all, 48 make-model-subseries groups of 1985-92 cars with ABS, and their non-ABS comparison groups were identified. Appendix B enumerates the criteria for including a make-model, and defines each of the 48 ABS and comparison groups, including the specific VIN characters delineating the groups. Appendix C lists other make-models that had standard or optional ABS and explains why they were not included in the analysis. In summary, the 48 ABS-equipped groups comprise the following cars:

1: Lincoln Town Car, 1991-92
2: Lincoln Mark 7, 1986-87
3: Lincoln Continental, 1986-87
4: Chevrolet Caprice, 1991-92
5: Buick full-sized wagon, 1991-92
6: Oldsmobile Custom Cruiser, 1991-92
7: Cadillac Fleetwood Brougham, 1991-92
8: Chevrolet Cavalier, 1992
9: Pontiac Sunbird, 1992

10: Chevrolet Corvette, 1986-87
11: Buick LeSabre Limited, 1992
12: Oldsmobile Delta 88 Royale LS, 1992
13: Buick Park Avenue (except Ultra), 1991-92
14: Olds 98 (except Touring Sedan), 1991-92
15: Cadillac Fleetwood D'Elegance, 1989-90
16: Cadillac DeVille, 1991-92
17: Buick Skylark, 1992
18: Oldsmobile Achieva, 1992
19: Pontiac Grand Am, 1992
20: Buick Riviera, 1991-92
21: Cadillac Eldorado, 1991-92
22: Oldsmobile Toronado Brougham, 1991-92
23: Cadillac Seville (except STS), 1991
24: Chevrolet Corsica/Beretta, 1992
25: Buick Regal Limited & Gran Sport, 1992
26: Chevrolet Lumina Eurosport and Z34, 1992
27: Oldsmobile Cutlass Supreme International, 1992 - **deleted**
28: Audi 80/90 (selected subseries), 1988-92
29: BMW 300, 1986-87
30: BMW 500, 1985-87
31: BMW 600-700, 1985-86
32: Acura Integra GS, 1990-92
33: Acura Legend L and LS, 1988-90
34: Honda Prelude Si with ABS, 1990-91 - **deleted**
35: Honda Accord EX, 1992
36: Sterling 827, 1987-91
37: Jaguar XJ sedan, 1988-89
38: Jaguar XJ-S coupe, 1989-90
39: Mercedes S, SEL and SEC, 1985-86
40: Mercedes SL, 1985
41: Mercedes basic full-sized sedan, 1986-87
42: Porsche 928, 1986-87
43: Saab 900, 1990-91
44: Saab 9000, 1988-89
45: Volvo 240, 1991-92
46: Volvo 760/780, 1988
47: Volvo 740, 1990-91
48: Mitsubishi Diamante LS, 1992

An important goal of the sample design is to have a similar make-model mix for the ABS-equipped cars and the non-ABS cars - i.e., a fairly uniform ratio for the size of the ABS group to the size of the comparison group. It would be unacceptable, for example, if the non-ABS sample were dominated by economy cars and the ABS-equipped sample by luxury cars. The first step in balancing the sample sizes was to use the same number of full model years of ABS-equipped and non-ABS cars in each <u>calendar year</u> of accident data. For example, ABS group 6 is defined to include the 1991-92 Olds Custom Cruiser and its comparison group is the 1989-90 Custom Cruiser. In calendar year 1992 data, all of these model years would be included (2 MY with ABS, 2 without). In calendar year 1991, only the full model years 1991 (ABS-equipped) and 1990 (non-ABS) would be included (1 full MY with ABS, 1 without). No Custom Cruisers would be drawn from calendar year 1990 or earlier data. Appendix D identifies which model years are included, or excluded in each calendar year of data.

The procedure defined in Appendix D was generally sufficient to assure a uniform ratio of ABS-equipped to non-ABS cars. However, the make-model mix was reviewed in each State, and, occasionally, a model year was deleted for one of the ABS groups or one of the comparison groups to improve uniformity. For example, Florida data had nearly equal numbers of ABS-equipped and non-ABS cars in most of the groups. But the 1988 Saab 900 was dropped from group 43 in Florida because 1988-89 Saab 900's greatly outnumbered 1990-91 models there. Also, groups 27 (Olds Supreme International) and 34 (Honda Prelude SI) were dropped entirely from the study since their ABS-equipped samples were too small.

## 1.4 Accident files for evaluating ABS

Since cars with ABS were still relatively uncommon as of 1992, it is necessary to have very large accident files to have enough cases to detect the effect of ABS in specific crash modes. For the time being, specialized data sets such as the National Accident Sampling System would not furnish adequate samples; it is necessary to rely on files from the larger States, and the Fatal Accident Reporting System (FARS). Since the presence of ABS has to be inferred from the VIN, the files must have VIN information. Large files with VIN information, available for analysis at NHTSA, include FARS, Florida, Pennsylvania, Missouri, Ohio, Illinois and Maryland (Michigan stopped coding the VIN in 1992). However, the Maryland file does not have a large sample of single vehicle crashes, and the Ohio and Illinois files do not explicitly specify a vehicle's impact location (front, side, rear). FARS, Florida, Pennsylvania and Missouri files are most suitable for the analysis. They contain the data elements essential for classifying single- and multivehicle crashes into subgroups: the pre-crash action of the vehicle (e.g., going straight, turning, stopped), the first harmful event (rollover, fixed object, collision with vehicle), the manner of collision (angle, rear-end, etc.) and the impact location (frontal, side, rear).

The Florida file has the unique advantage that pre-crash travelling speeds have been estimated and reported for almost all vehicles. That makes it possible to identify a subset of 2-vehicle crashes in which one vehicle was stopped or going quite slow (ABS not a factor) while the other vehicle was travelling at a speed where braking could make a difference. Another advantage of the Florida file is that collisions between a moving vehicle and an unoccupied, legally parked vehicle are encoded as 2-vehicle crashes, with a complete vehicle-level record on the parked vehicle. These parked cars enlarge the "control group" of crash involvements where ABS is irrelevant. The Pennsylvania file has a smaller sample of multivehicle crashes than Florida (higher reporting threshold; no parked cars), but about the same number of single-vehicle crashes as Florida. Pre-crash travelling speed is reported. The Missouri file has just enough cases for statistically meaningful analyses, and travelling speed is not reported. Pennsylvania and Missouri data are also needed because, unlike Florida, they have at least some crashes on snowy and icy roads. The FARS file is, of course, needed to study the effect of ABS in fatal crashes.

FARS data are complete through 1993 (while State files are only available through 1992) and contain an adequate sample of single-vehicle crashes, although the sample of multivehicle crashes is barely sufficient. Travelling speed is a variable on FARS, but is not reported in about half of the cases.

The analyses are based on Florida, Pennsylvania and Missouri data for 1990-92, and FARS data for 1989-93. In general, the procedure for data reduction is to identify and select the vehicle-level records for the ABS-equipped vehicles, and their comparison groups, based on the VIN. Relevant data elements from the accident-level record, the person-level record and, in some cases, the vehicle-level record on the "other" vehicle in a 2-vehicle collision are then added to the basic vehicle data.

# CHAPTER 2

## ANALYSIS OF MULTIVEHICLE AND PEDESTRIAN CRASHES

When two or more vehicles are on a collision course, or when a pedestrian steps into the path of an oncoming vehicle, there are several ways that four-wheel ABS could help prevent a collision:

- ABS could reduce stopping distances and stop the vehicle(s) short of impact.
- ABS keeps all the wheels rolling during braking and preserves the driver's steering control, allowing the driver to evade the other vehicle or pedestrian by a combination of steering and braking.
- ABS prevents a vehicle from skidding out of its original path and hitting yet another vehicle or pedestrian located to the side of that path.

Conversely, if ABS substantially reduces stopping distances, it could potentially **increase** the risk of being struck in the rear by another vehicle which only has conventional stopping capabilities. Of course, ABS can hardly be expected to prevent all collisions between vehicles. If the drivers never touch their brakes (because they are inattentive to the presence of one another's vehicles, or misinterpret what the other driver is going to do next, or are unable to react to the situation), ABS cannot help. If vehicle 2 suddenly enters the path of vehicle 1, there may not be enough time and space for driver 1 to apply the brakes and possibly to steer around vehicle 2.

Specifically, there is a control group of crash-involved cars that can easily be identified in State or FARS accident data, where ABS is unlikely to have any effect. The control group includes cars that were standing still or were parked prior to being hit by another vehicle (brakes are irrelevant for the nonmoving car). It also includes cars that were moving very slowly prior to impact, as evidenced by a travelling speed of 5 mph or less, or a pre-crash movement such as backing up, leaving or entering a parking space (braking might have been involved, but at those speeds ABS and conventional brakes have about the same stopping capabilities). The number of control-group crash involvements for the ABS-equipped cars, or for their non-ABS comparison cars is a measure of exposure for each category.

Here are four "striking" crash modes which ABS could be intuitively expected to mitigate - i.e., the ratio of these types of crash involvements to control-group involvements ought to be lower for ABS-equipped cars than for non-ABS comparison cars:

- Striking a vehicle in the rear The shorter the stopping distances on the following vehicle, and the longer the distances on the lead vehicle, the less likely a collision will occur. Thus, ABS has an opportunity to reduce the incidence of being the following vehicle in a rear-end collision.

- Striking a vehicle which is turning The striking vehicle is typically moving forward and its driver has an opportunity to brake, while the struck vehicle is typically moving relatively slowly and its driver may be preoccupied with the turn and distracted from braking. Thus, ABS has an opportunity to reduce the incidence of being the striking vehicle in this type of collision.

- Striking vehicle in an "angle" collision When the two vehicles in an intersection collision were moving at unequal speeds before a crash, the odds are that the "striking" (i.e., frontally damaged) vehicle was the faster vehicle and the "struck" (side-damaged) vehicle was the slower one (although that is not always true). Thus, ABS may be somewhat more useful for the "striking" than the "struck" vehicle in an angle collision.

- Other striking involvements as a (frontally damaged) vehicle.

Conversely, one "struck" crash mode might be expected to increase with ABS:

- Being struck in the rear, while moving If ABS substantially reduces stopping distances, it could increase the risk of being struck in the rear by another vehicle which only has conventional stopping capabilities.

In another "struck" crash mode, it is not clear, at first glance, whether ABS ought to have a positive or a negative effect:

- o <u>Being struck in the side, while moving</u> Both vehicles were moving before the crash, but the "struck" vehicle usually moved slower than the "striking" one, as explained above. Thus, ABS is likely, but not necessarily of lesser benefit for the "struck" vehicle in an angle collision.

## 2.1 <u>Florida multivehicle crashes, 1990-92</u>

### 2.1.1 <u>Effect of ABS by crash mode</u>

Table 2-1 contrasts the distribution, by crash mode, of ABS-equipped and non-ABS cars involved in multivehicle crashes during calendar years 1990-92. The ABS-equipped cars belong to the 48 make-model-subseries groups defined in Section 1.3 and Appendix B, and the non-ABS cars belong to the 48 comparison groups, comprising essentially the same makes, models and subseries. The non-ABS cars experienced 4978 control group crashes and the ABS-equipped cars had almost the same amount of exposure (4839 control group crashes).

Non-ABS cars experienced 1347 crash involvements where they frontally impacted the rear of another vehicle; that is a ratio of .2706 to the control group (1347/4978). ABS-equipped cars were striking vehicles in 1222 rear-end collisions, a ratio of .2525 to the control group. The observed effect for ABS is a reduction of

$$1 - [(1222/4839) / (1347/4978)] = 1 - (.2525/.2706) = 7 \text{ percent}$$

The effect is in the intuitively expected direction (i.e., a benefit), but it is not statistically significant: Chi-square ($\chi^2$) for the 2 x 2 table formed by 4978, 4839, 1352 and 1212 is 2.42; $\chi^2$ would have to exceed 3.84 for statistical significance at the .05 level and 6.64 for significance at the .01 level.

TABLE 2-1

**FLORIDA, 1990-92:** EFFECT OF ABS ON MULTIVEHICLE CRASHES BY TYPE OF CRASH INVOLVEMENT

| Type of Crash Involvement | Without ABS N | Without ABS $\frac{N}{N_{control}}$ | With ABS N | With ABS $\frac{N}{N_{control}}$ | Change in $N/N_{control}$ (%) | $\chi^2$ | Stat Sig? |
|---|---|---|---|---|---|---|---|
| Control group (multivehicle - struck while stopped/slow) | 4978 | 1 | 4839 | 1 | | | |
| Front-to-rear: striking | 1347 | .2706 | 1222 | .2525 | down 7 | 2.42 | |
| Strikes a turning vehicle | 1352 | .2716 | 1212 | .2505 | down 8 | 3.33 | |
| Front-to-side, both going straight: striking | 1057 | .2123 | 960 | .1984 | down 7 | 1.93 | |
| Other multivehicle frontals | 675 | .1356 | 586 | .1211 | down 11 | 3.56 | |
| All multivehicle frontals | 4431 | .8901 | 3980 | .8225 | down 8 | 7.06 | .01 |
| Struck in rear while moving | 850 | .1708 | 875 | .1808 | up 6 | 1.21 | |
| Struck in side while moving | 1979 | .3975 | 1963 | .4056 | up 2 | .29 | |
| All non-control group multivehicle involvements | 7260 | 1.4584 | 6818 | 1.4090 | down 3 | 1.72 | |

Very similar effects are observed for the other three types of "striking" (frontal) crash involvements: with ABS, there is an 8 percent reduction in frontally impacting a turning vehicle, a 7 percent reduction in striking the side of a non-turning vehicle, and an 11 percent reduction in other types of frontal impacts with another vehicle. None of these reductions is, by itself, statistically significant. However, when the four types of frontal multivehicle impacts are summed, the reduction of

$$1 - [(3980/4839) / (4431/4978)] = 1 - (.8225/.8901) = 8 \text{ percent}$$

is in the intuitively expected direction and statistically significant ($\chi^2$ = 7.06, $p < .01$).

ABS, however, was associated with unfavorable effects in the two "struck" crash modes. As intuitively expected, cars with ABS were more likely to be struck in the rear, while they were moving, than non-ABS cars. The 6 percent increase is not statistically significant ($\chi^2$ = 1.21). ABS-equipped cars were also 2 percent more likely to be struck in the side, while moving, than non-ABS cars (not a significant difference).

When the four "striking" and two "struck" crash modes are added up, the ABS-equipped cars had 6818 non-control group multivehicle crash involvements and the non-ABS cars had 7260. That is a net reduction of

$$1 - [(6818/4839) / (7260/4978)] = 1 - (1.4090/1.4584) = 3 \text{ percent}$$

and it is not statistically significant ($\chi^2$ = 1.72).

### 2.1.2 Effect of ABS by road condition and crash mode

Table 2-1 showed the overall effect of ABS in multivehicle crashes but it obscured the fact that ABS works quite differently, and may have different effects, on wet and dry roads. The stopping tests, described in Section 1.2, showed that ABS is more effective in reducing yawing and stopping distance on wet roads than on dry roads. Table 2-1W presents the same analyses as Table 2-1, but limits the data to crashes on <u>wet</u> road surfaces. The non-ABS cars experienced 739 control group crashes and, as in Table 2-1, the ABS-equipped cars had almost the same amount of exposure (694 control group crashes).

Non-ABS cars experienced 281 "front-to-rear striking" involvements, a ratio of .3802 to the control group. ABS-equipped cars were striking vehicles in only 155 rear-end collisions, a ratio of .2233 to the control group. The observed effect for ABS is an impressive reduction of

$$1 - [(155/694) / (281/739)] = 1 - (.2233/.3802) = 41 \text{ percent}$$

and it is statistically significant at the .01 level ($\chi^2 = 23.37$). ABS is also beneficial, with somewhat smaller effects, in the other three types of "striking" (frontal) crash involvements: with ABS, there is an 26 percent reduction in frontally impacting a turning vehicle ($\chi^2 = 5.68$, $p < .05$), a 20 percent reduction in striking the side of a non-turning vehicle, and a 9 percent reduction in other types of frontal multivehicle impacts. When the four types of frontal multivehicle impacts are summed, the reduction of

$$1 - [(513/694) / (757/739)] = 1 - (.7392/1.0244) = 28 \text{ percent}$$

is substantial and statistically significant ($\chi^2 = 17.59$, $p < .01$).

As might be expected, the reduction in stopping distance has a price. Cars with ABS are more likely to be struck in the rear, while they were moving, because the car behind them cannot stop as quickly. The 44 percent increase is statistically significant ($\chi^2 = 9.02$, $p < .01$). On the other hand, ABS-equipped cars experienced a nonsignificant 6 percent reduction of involvements as vehicles

TABLE 2-1W

**FLORIDA, 1990-92, WET ROADS:** EFFECT OF ABS ON MULTIVEHICLE CRASHES BY TYPE OF CRASH INVOLVEMENT

| | Without ABS | | With ABS | | Change in $N/N_{control}$ | | |
|---|---|---|---|---|---|---|---|
| **Type of Crash Involvement** | **N** | $\frac{N}{N_{control}}$ | **N** | $\frac{N}{N_{control}}$ | **(%)** | $\chi^2$ | **Stat Sig?** |
| Control group (multivehicle - struck while stopped/slow) | 739 | 1 | 694 | 1 | | | |
| Front-to-rear: striking | 281 | .3802 | 155 | .2233 | down 41 | 22.37 | .01 |
| Strikes a turning vehicle | 188 | .2544 | 131 | .1888 | down 26 | 5.68 | .05 |
| Front-to-side, both going straight: striking | 178 | .2409 | 133 | .1916 | down 20 | 3.29 | |
| Other multivehicle frontals | 110 | .1488 | 94 | .1354 | down 9 | .38 | |
| All multivehicle frontals | 757 | 1.0244 | 513 | .7392 | down 28 | 17.59 | .01 |
| Struck in rear while moving | 145 | .1962 | 196 | .2824 | up 44 | 9.02 | .01 |
| Struck in side while moving | 299 | .4046 | 264 | .3804 | down 6 | .38 | |
| All non-control group multivehicle involvements | 1201 | 1.6252 | 973 | 1.4020 | down 14 | 4.69 | .05 |

that were struck in the side, while moving. All in all, though, the increase in rear impacts does not cancel out the reduction of frontal impacts, and there is a significant "residual" net benefit for ABS. When the four "striking" and two "struck" crash modes are added up, the ABS-equipped cars had 14 percent fewer non-control group multivehicle crash involvements than the non-ABS cars ($\chi^2$ = 4.69, $p < .05$).

Table 2-1D presents the same analyses for crashes on dry road surfaces. The observed effects for ABS are negligible in every crash mode and do not follow a pattern. "Front-to-rear striking" involvements, far from having an impressive reduction, were up a nonsignificant 2 percent with ABS. The other three types of "striking" impacts were slightly reduced. On the average, the four types of multivehicle frontal impacts were reduced by a nonsignificant 3 percent. ABS-equipped cars experienced a 2 percent reduction of "struck in rear while moving," but a 3 percent increase of "struck in side while moving." When the four "striking" and two "struck" crash modes are added up, the reduction of non-control group multivehicle crash involvements was a nonsignificant 1 percent for ABS ($\chi^2$ = 0.23). Indeed, Table 2-1D suggests that the overall, net effect of ABS on multivehicle crashes on dry roads is essentially zero.

### 2.1.3 Overall effect of ABS on wet roads

In the preceding analyses, cars that were struck while stopped or moving slowly were singled out as a control group, and the effect of ABS in all other multivehicle crash modes was tested against that control group. Table 2-1D, however, suggests the net effect of ABS on multivehicle crashes on dry roads is negligible. Thus, all multivehicle crashes on dry roads could be considered a control group. A straightforward way to compute the overall effect

TABLE 2-1D

**FLORIDA, 1990-92, DRY ROADS:** EFFECT OF ABS ON MULTIVEHICLE CRASHES BY TYPE OF CRASH INVOLVEMENT

| | **Without ABS** | | **With ABS** | | **Change in $N/N_{control}$** | | |
|---|---|---|---|---|---|---|---|
| **Type of Crash Involvement** | **N** | $\frac{N}{N_{control}}$ | **N** | $\frac{N}{N_{control}}$ | **(%)** | $\chi^2$ | **Stat Sig?** |
| Control group (multivehicle - struck while stopped/slow) | 4239 | 1 | 4145 | 1 | | | |
| Front-to-rear: striking | 1066 | .2515 | 1067 | .2574 | up 2 | .23 | |
| Strikes a turning vehicle | 1164 | .2746 | 1081 | .2608 | down 5 | 1.18 | |
| Front-to-side, both going straight: striking | 879 | .2074 | 827 | .1995 | down 4 | .53 | |
| Other multivehicle frontals | 565 | .1333 | 492 | .1187 | down 11 | 3.14 | |
| All multivehicle frontals | 3674 | .8667 | 3467 | .8364 | down 3 | 1.22 | |
| Struck in rear while moving | 705 | .1663 | 679 | .1638 | down 2 | .07 | |
| Struck in side while moving | 1680 | .3963 | 1699 | .4099 | up 3 | .68 | |
| All non-control group multivehicle involvements | 6059 | 1.4293 | 5845 | 1.4101 | down 1 | .23 | |

of ABS on multivehicle crashes on wet roads is to employ the dry-road crashes as a control group. Table 2-2 shows that non-ABS cars had a total of 10,595 multivehicle involvements on dry roads, while ABS-equipped cars had a nearly identical 10,300. Non-ABS cars had 1987 involvements on wet roads, whereas ABS-equipped cars had only 1697. That is a reduction of

$$1 - [(1697/10300) / (1987/10595)] = 1 - (.1648/.1875) = 12 \text{ percent}$$

of all types of multivehicle involvements on wet roads (including "striking," "struck while moving" and "struck while stopped"), and it is statistically significant ($\chi^2 = 13.08$, $p < .01$).

### 2.1.4 Collisions between a fast-moving and a slow/stopped vehicle

There is a special subset of multivehicle collision involvements where ABS is especially likely to be effective. It is obtained by limiting the multivehicle crash file to those crashes involving exactly two vehicles, in which one of the vehicles was moving quickly enough that ABS could enhance braking capability, while the other vehicle was standing still or was moving too slowly for ABS to act differently from conventional brakes. The fast-moving vehicles in these crashes are the subset where ABS is likely to be effective: the driver is likely to activate the ABS by slamming on the brakes, and there is a stopped or slow-moving target that the driver must evade by stopping short or steering around it. The stopped/slow vehicles in these crashes are an exceptionally "clean" control group. Analysis of these crashes helps identify the upper limits of ABS effectiveness on wet roads. If ABS is beneficial for <u>any</u> type of crash on dry roads, it is likely to be effective here.

The 1990-92 Florida accident files, which report the pre-crash (travelling) speeds of most crash-involved vehicles, allow identification of this

TABLE 2-2

**FLORIDA, 1990-92:** EFFECT OF ABS ON MULTIVEHICLE CRASHES
BY ROAD CONDITION

| | Without ABS | | With ABS | | Change in $N/N_{dry}$ | | |
|---|---|---|---|---|---|---|---|
| **Type of Crash Involvement** | **N** | $\frac{N}{N_{dry}}$ | **N** | $\frac{N}{N_{dry}}$ | **(%)** | $\chi^2$ | **Stat Sig?** |
| Dry road multivehicle | 10595 | 1 | 10300 | 1 | | | |
| Wet road multivehicle | 1987 | .1875 | 1697 | .1648 | down 12 | 13.08 | .01 |

subset of collisions. The analysis file used in Tables 2-1 and 2-2 was a vehicle-oriented file, with data elements for the accident and the "case" vehicle (a car belonging to the 48 ABS groups or comparison groups). That file is limited to collisions involving exactly two vehicles, and data elements on the "other" vehicle in the crash (which does not necessarily belong to the 48 groups and might not even be a passenger car) are added. Thus, the travelling speeds, precrash actions and impact locations are known for both vehicles in the crash.

The key step in constructing the analysis file was the identification of crashes involving one fast-moving and one stopped/slow-moving vehicle. The travelling speed variable on the Florida file uses the code '0' to denote a stopped vehicle or non-reported speed. If the vehicle movement was "straight ahead," "changing lanes" or "passing," a '0' for travelling speed was interpreted as non-reported speed; otherwise, the '0' was accepted as denoting a stopped vehicle. Crashes in which either vehicle had non-reported speed were not used in the analysis; however, travelling speed is reported for both vehicle in about 95 percent of Florida cases. The threshold speeds at which ABS begins to have potential for improving braking performance were defined to be 20 mph on dry roads, 15 mph on wet roads and 10 mph on snowy/icy roads (not too many of those in Florida). These speeds were suggested by the results of NHTSA's stopping tests (Section 1.2); below threshold speed, it is assumed that a vehicle without ABS will stop in a straight line and in optimum distance, even if the wheels lock part of the time.

Reported travelling speeds in Florida are almost always rounded to the nearest 5 mph. In other words, if two vehicles have different speeds, they will almost always differ by 5 mph or more. If vehicle 1 was above the threshold speed and vehicle 2 was at or below threshold, or if vehicle 1 was at the threshold and vehicle 2 was below threshold, then vehicle 1 was defined to be the fast-moving (ABS-relevant) traffic unit and vehicle 2 was the stopped/slow-moving (ABS-irrelevant) traffic unit. For example, on a wet road, a collision of vehicles going 20 mph and 15 mph, or 15 mph and 10 mph, or, needless to say, 20 mph and 10 mph would be included in the file. But a collision of vehicles going 25 mph and 20 mph would be excluded, since both are above threshold speed; a collision of 10 mph and 5 mph would be excluded since both are below threshold. The corresponding definition was used if vehicle 2 was travelling faster than vehicle 1. As an additional filter, cases were discarded if the speeds were inconsistent with the reported precrash actions - e.g., a fast-moving "stopped," "parked" or "parking" vehicle with a slow-moving vehicle that was "going straight ahead," "changing lanes" or "passing" (fewer than 1 percent were discarded). The 1990-92 Florida files include 23,895 multivehicle crash involvements of passenger cars from the 48 ABS groups or comparison groups; 8,011 (approximately 1/3) of these are in two-vehicle crashes between a fast-moving and a slow or stopped vehicle, as defined above.

The top section of Table 2-3 analyses the two-vehicle collisions on all roads, regardless of surface condition. The non-ABS comparison-group cars experienced 2139 control group involvements (i.e., as the stopped or slow-moving vehicle in this type of two-vehicle crash) and the ABS-equipped cars had almost identical exposure (2136 control group involvements). Non-ABS cars experienced 2069 involvements as the fast-moving vehicle in this type of crash, a ratio of .9673 to the control group. In other words, non-ABS cars are about equally likely to be the "striking" or "struck" vehicle in this type of collision. ABS-equipped cars were only involved 1667 times as the fast-moving vehicle, a ratio

TABLE 2-3

**FLORIDA, 1990-92:** EFFECT OF ABS ON TWO-VEHICLE CRASHES INVOLVING ONE FAST-MOVING VEHICLE AND ONE STOPPED OR SLOW-MOVING VEHICLE

| Type of Crash Involvement | Without ABS N | Without ABS $\frac{N}{N_{control}}$ | With ABS N | With ABS $\frac{N}{N_{control}}$ | Change in $N/N_{control}$ (%) | $\chi^2$ | Stat Sig? |
|---|---|---|---|---|---|---|---|
| **ALL ROADS** | | | | | | | |
| Control group (as the stopped or slow-moving vehicle) | 2139 | 1 | 2136 | 1 | | | |
| As the fast-moving vehicle | 2069 | .9673 | 1667 | .7804 | down 19 | 22.84 | .01 |
| **WET ROADS** | | | | | | | |
| Control group (as the stopped or slow-moving vehicle) | 360 | 1 | 358 | 1 | | | |
| As the fast-moving vehicle | 315 | .8750 | 180 | .5028 | down 43 | 21.63 | .01 |
| **DRY ROADS** | | | | | | | |
| Control group (as the stopped or slow-moving vehicle) | 1779 | 1 | 1778 | 1 | | | |
| As the fast-moving vehicle | 1754 | .9859 | 1487 | .8363 | down 15 | 11.45 | .01 |

of .7804 to the control group. The observed effect for ABS is a reduction of

$$1 - [(1667/2136) \ / \ (2069/2139)] = 1 - (.7804/.9673) = 19 \text{ percent}$$

and it is statistically significant ($\chi^2 = 22.84$, $p < .01$).

The effect of ABS on <u>wet</u> roads is extraordinary. The middle section of Table 2-3 shows that slow/stopped involvements were nearly identical for non-ABS and ABS-equipped cars (360 vs. 358), but fast-moving involvements dropped from 315 to 180. That is a reduction of

$$1 - [(180/358) \ / \ (315/360)] = 1 - (.5028/.8750) = 43 \text{ percent}$$

and it is statistically significant ($\chi^2 = 21.63$, $p < .01$).

The last part of Table 2-3 shows that ABS is effective even on <u>dry</u> roads. Fast-moving involvements were reduced by a statistically significant 15 percent ($\chi^2 = 11.45$, $p < .01$). Although the overall effect of ABS on dry roads may be close to zero, there is a nonzero effect in at least one type of crash.

## 2.2 Pennsylvania multivehicle crashes, 1990-92

### 2.2.1 Effect of ABS by crash mode

Although Florida had a large sample of crashes that generated many statistically significant results, it is desirable to corroborate those findings with data from other States. Pennsylvania has the next largest file of crashes involving ABS-equipped cars. Since Pennsylvania has a towaway-or-injury threshold for accident reporting, the crashes are more severe, on the average, than in Florida. The data elements, including travelling speed, are similar to Florida's. The "manner of collision" variable, however, does not include "strikes a turning vehicle" as a separate category; thus, two "striking" categories defined in Florida (strikes a turning vehicle; front-to-side, both straight) are combined into a single category: front-to-side, striking. Unoccupied parked cars are not included as traffic units on the Pennsylvania file; as a result, the control group is smaller, relative to the other types of crashes, than in Florida.

Table 2-4 compares the crash modes of ABS-equipped and non-ABS cars involved in multivehicle crashes during calendar years 1990-92. The non-ABS cars experienced 1319 control group crashes, while the ABS-equipped cars were involved in 977 control group crashes. (In Pennsylvania, the ABS-equipped cars had less exposure than the comparison-group cars. Many of the ABS-equipped cars are of the latest model year - e.g., model year 1992 in calendar year 1992 - and did not get a full year of exposure because they were sold in the middle of the year. In Florida, the steady increase in population and car sales enlarges the exposure for the latest-model, ABS-equipped cars.)

Just as in Florida (Table 2-1), ABS-equipped cars experienced modest, nonsignificant reductions in each of the "striking" (frontal) crash modes: with ABS, there is a 3 percent reduction in "front-to-rear, striking," a 9 percent reduction in striking the side of a another vehicle, and an 11 percent reduction in other types of frontal impacts with another vehicle. When the three types of frontal multivehicle impacts are summed, the reduction of

$$1 - [(1845/977) / (2694/1319)] = 1 - (1.8884/2.0425) = 8 \text{ percent}$$

is exactly the same as in Florida, although here, with the smaller sample size, the reduction is not statistically significant ($\chi^2 = 2.28$).

Also as in Florida, ABS was associated with slightly unfavorable effects in the two "struck" crash modes: an increased likelihood of being struck

TABLE 2-4

**PENNSYLVANIA, 1990-92:** EFFECT OF ABS ON MULTIVEHICLE CRASHES BY TYPE OF CRASH INVOLVEMENT

| **Type of Crash Involvement** | **Without ABS** N | **Without ABS** $\frac{N}{N_{control}}$ | **With ABS** N | **With ABS** $\frac{N}{N_{control}}$ | **Change in $N/N_{control}$** (%) | $\chi^2$ | Stat Sig? |
|---|---|---|---|---|---|---|---|
| Control group (multivehicle - struck while stopped/slow) | 1319 | 1 | 977 | 1 | | | |
| Front-to-rear: striking | 784 | .5944 | 561 | .5742 | down 3 | .25 | |
| Front-to-side: striking | 1382 | 1.0478 | 934 | .9560 | down 9 | 2.35 | |
| Other multivehicle frontals | 528 | .4003 | 350 | .3582 | down 11 | 1.89 | |
| All multivehicle frontals | 2694 | 2.0425 | 1845 | 1.8884 | down 8 | 2.28 | |
| Struck in rear while moving | 264 | .2002 | 207 | .2119 | up 6 | .31 | |
| Struck in side while moving | 662 | .5019 | 501 | .5128 | up 2 | .09 | |
| All non-control group multivehicle involvements | 3620 | 2.7445 | 2553 | 2.6131 | down 5 | .98 | |

in the rear while moving (6 percent) and being struck in the side while moving (2 percent). When the three "striking" and two "struck" crash modes are added up, the ABS-equipped cars had 2553 non-control group multivehicle crash involvements and the non-ABS cars had 3620. That is a net reduction of

$$1 - [(2553/977) / (3620/1319)] = 1 - (2.6131/2.7445) = 5 \text{ percent}$$

and it is not statistically significant ($\chi^2 = 0.98$).

2.2.2 Effect of ABS by road condition and crash mode

Table 2-4W presents the same analyses as Table 2-4, but limits the data to crashes on wet road surfaces. Non-ABS cars experienced 187 "front-to-rear striking" involvements, a ratio of .5633 to the control group. ABS-equipped cars were striking vehicles in only 84 rear-end collisions, a ratio of .3500 to the control group. That deep reduction of

$$1 - [(84/240) / (187/332)] = 1 - (.3500/.5633) = 38 \text{ percent}$$

is statistically significant ($\chi^2 = 9.34$, $p < .01$), and almost the same magnitude as in Florida (41 percent in Table 2-1W). ABS is also quite beneficial in reducing "front-to-side, striking" involvements (19 percent reduction) and other multivehicle frontals (29 percent reduction, $\chi^2 = 4.41$, $p < .05$). When the three types of frontal multivehicle impacts are summed, the reduction of

$$1 - [(353/240) / (664/332)] = 1 - (1.4708/2.0000) = 26 \text{ percent}$$

is statistically significant ($\chi^2 = 8.22$, $p < .01$) and essentially the same as in Florida (28 percent).

As usual, the reduction in frontal impacts is partially offset by an increase in rear impacts while moving (20 percent) and side impacts while moving (9 percent). Nevertheless, when the three "striking" and two "struck" crash modes are added up, the ABS-equipped cars had 18 percent fewer non-control group

TABLE 2-4W

**PENNSYLVANIA, 1990-92, WET ROADS:** EFFECT OF ABS ON MULTIVEHICLE CRASHES BY TYPE OF CRASH INVOLVEMENT

| | Without ABS | | With ABS | | Change in $N/N_{control}$ | | |
|---|---|---|---|---|---|---|---|
| **Type of Crash Involvement** | **N** | $\frac{N}{N_{control}}$ | **N** | $\frac{N}{N_{control}}$ | **(%)** | $\chi^2$ | **Stat Sig?** |
| Control group (multivehicle - struck while stopped/slow) | 332 | 1 | 240 | 1 | | | |
| Front-to-rear: striking | 187 | .5633 | 84 | .3500 | down 38 | 9.34 | .01 |
| Front-to-side: striking | 320 | .9639 | 188 | .7833 | down 19 | 2.76 | |
| Other multivehicle frontals | 157 | .4729 | 81 | .3375 | down 29 | 4.41 | .05 |
| All multivehicle frontals | 664 | 2.0000 | 353 | 1.4708 | down 26 | 8.22 | .01 |
| Struck in rear while moving | 52 | .1566 | 45 | .1875 | up 20 | .67 | |
| Struck in side while moving | 142 | .4277 | 112 | .4667 | up 9 | .33 | |
| All non-control group multivehicle involvements | 858 | 2.5843 | 510 | 2.1250 | down 18 | 3.72 | |

multivehicle crash involvements than the non-ABS cars (not quite significant, $\chi^2 = 3.72$).

Table 2-4D presents the same analyses for crashes on dry road surfaces. The observed effects for ABS are negligible in every crash mode. When the three "striking" and two "struck" crash modes are added up, the reduction of non-control group multivehicle crash involvements was a nonsignificant 1 percent for ABS ($\chi^2 = 0.07$), which is identical to the result obtained in the Florida data. This is further evidence that the overall, net effect of ABS on multivehicle crashes on dry roads is essentially zero.

2.2.3 Overall effect of ABS, by road condition

Table 2-4D suggests the net effect of ABS on multivehicle crashes on dry roads is negligible. As in Section 2.1.3, the overall effect of ABS on multivehicle crashes on wet roads is estimated by using the dry-road crashes as a control group. Table 2-5 shows that non-ABS cars had a total of 3863 multivehicle involvements on dry roads, while ABS-equipped cars had 2902. Non-ABS cars had 1298 involvements on wet roads, whereas ABS-equipped cars had only 821. That is a reduction of

$$1 - [(821/2902) / (1298/3863)] = 1 - (.2829/.3360) = 16 \text{ percent}$$

of all types of multivehicle involvements on wet roads (including "striking," "struck while moving" and "struck while stopped"), and it is statistically significant ($\chi^2 = 11.43$, $p < .01$). It is about the same reduction as in Florida (12 percent).

Pennsylvania, unlike Florida, experiences a moderate number of multivehicle crashes on snowy and icy roads. They are too few in number to

TABLE 2-4D

**PENNSYLVANIA, 1990-92, DRY ROADS:** EFFECT OF ABS ON MULTIVEHICLE CRASHES
BY TYPE OF CRASH INVOLVEMENT

| | Without ABS | | With ABS | | Change in $N/N_{control}$ | | |
|---|---|---|---|---|---|---|---|
| **Type of Crash Involvement** | **N** | $\frac{N}{N_{control}}$ | **N** | $\frac{N}{N_{control}}$ | **(%)** | $\chi^2$ | **Stat Sig?** |
| Control group (multivehicle - struck while stopped/slow) | 958 | 1 | 724 | 1 | | | |
| Front-to-rear: striking | 572 | .5971 | 461 | .6367 | up 7 | .65 | |
| Front-to-side: striking | 1038 | 1.0835 | 732 | 1.0110 | down 7 | 1.01 | |
| Other multivehicle frontals | 313 | .3267 | 227 | .3135 | down 4 | .17 | |
| All multivehicle frontals | 1923 | 2.0073 | 1420 | 1.9613 | down 2 | .15 | |
| Struck in rear while moving | 195 | .2035 | 155 | .2141 | up 5 | .18 | |
| Struck in side while moving | 507 | .5292 | 380 | .5249 | down 1 | .01 | |
| All non-control group multivehicle involvements | 2625 | 2.7401 | 1955 | 2.7003 | down 1 | .07 | |

TABLE 2-5

**PENNSYLVANIA, 1990-92:** EFFECT OF ABS ON MULTIVEHICLE CRASHES BY ROAD CONDITION

| **Type of Crash Involvement** | **Without ABS** $N$ | **Without ABS** $\frac{N}{N_{dry}}$ | **With ABS** $N$ | **With ABS** $\frac{N}{N_{dry}}$ | **Change in $N/N_{dry}$ (%)** | $\chi^2$ | **Stat Sig?** |
|---|---|---|---|---|---|---|---|
| Dry road multivehicle | 3863 | 1 | 2902 | 1 | | | |
| Wet road multivehicle | 1298 | .3360 | 821 | .2829 | down 16 | 11.43 | .01 |
| Snowy/icy road multivehicle | 188 | .0487 | 125 | .0431 | down 11 | 1.07 | |

analyze by crash mode, but Table 2-5 estimates the overall effect of ABS: an 11 percent reduction. The effect is not statistically significant ($\chi^2 = 1.07$), but it is about the same magnitude as the overall reduction on wet roads.

### 2.2.4 Collisions between a fast-moving and a slow/stopped vehicle

Pennsylvania data contain enough details about precrash actions, including the travelling speeds, to allow a special analysis of two-vehicle crashes in which one of the vehicles was moving quickly enough that ABS could enhance braking capability, while the other vehicle was standing still, parked, or moving slowly. The procedure is almost the same as with Florida data (Section 2.1.4).

The top section of Table 2-6 analyses the two-vehicle collisions on all roads, regardless of surface condition. The non-ABS comparison-group cars experienced 547 involvements as the stopped or slow-moving vehicle in this type of two-vehicle crash, while the ABS-equipped cars had 398 control group involvements. Non-ABS cars experienced 561 involvements as the fast-moving vehicle, a ratio of 1.0256 to the control group - i.e., non-ABS cars are about equally likely to be the "striking" or "struck" vehicle in this type of collision. ABS-equipped cars were only involved 292 times as the fast-moving vehicle, a ratio of .7337 to the control group. The observed effect for ABS is a reduction of

$$1 - [(292/398) / (561/547)] = 1 - (.7337/1.0256) = 28 \text{ percent}$$

and it is statistically significant ($\chi^2 = 11.78$, $p < .01$).

The middle section of Table 2-6 shows that fast-moving involvements on wet roads were reduced by a remarkable 44 percent. That benefit is

TABLE 2-6

**PENNSYLVANIA, 1990-92:** EFFECT OF ABS ON TWO-VEHICLE CRASHES INVOLVING ONE FAST-MOVING VEHICLE AND ONE STOPPED OR SLOW-MOVING VEHICLE

| **Type of Crash Involvement** | **Without ABS** N | **Without ABS** $\frac{N}{N_{control}}$ | **With ABS** N | **With ABS** $\frac{N}{N_{control}}$ | **Change in $N/N_{control}$ (%)** | $\chi^2$ | **Stat Sig?** |
|---|---|---|---|---|---|---|---|
| **ALL ROADS** | | | | | | | |
| Control group (as the stopped or slow-moving vehicle) | 547 | 1 | 398 | 1 | | | |
| As the fast-moving vehicle | 561 | 1.0256 | 292 | .7337 | down 28 | 11.78 | .01 |
| **WET ROADS** | | | | | | | |
| Control group (as the stopped or slow-moving vehicle) | 132 | 1 | 90 | 1 | | | |
| As the fast-moving vehicle | 136 | 1.0303 | 52 | .5778 | down 44 | 7.46 | .01 |
| **DRY ROADS** | | | | | | | |
| Control group (as the stopped or slow-moving vehicle) | 401 | 1 | 305 | 1 | | | |
| As the fast-moving vehicle | 404 | 1.0075 | 238 | .7803 | down 23 | 5.25 | .05 |

statistically significant ($\chi^2 = 7.46$, $p < .01$) and it is nearly identical to the reduction in Florida (43 percent). The last part of Table 2-6 shows that ABS is effective in this crash situation on dry roads in Pennsylvania. Fast-moving involvements were reduced by a statistically significant 23 percent ($\chi^2 = 5.25$, $p < .05$). The observed effect is slightly higher than in Florida (15 percent).

## 2.3 Missouri multivehicle crashes, 1990-92

### 2.3.1 Effect of ABS by crash mode

Missouri, a less populous State than Florida or Pennsylvania, offers a smaller sample of crashes involving ABS-equipped cars. Pre-crash travelling speed is not reported, precluding a special analysis of two-vehicle collisions of a fast-moving and a slow/stopped vehicle. The lack of travelling speed information is compensated by a detailed "directional analysis" variable, which allows the definition of a fifth "striking" crash mode in the basic analysis: "strikes a stopped or slow vehicle." This new category necessitates slight modifications in the some of the other "striking" categories - e.g., "strikes a vehicle in the rear" now becomes "strikes a moving vehicle in the rear."

Table 2-7 compares the crash modes of ABS-equipped and non-ABS cars involved in multivehicle crashes during calendar years 1990-92. The non-ABS cars experienced 1237 control group crashes, while the ABS-equipped cars were involved in 707 control group crashes. ABS-equipped cars experienced a nonsignificant 14 percent reduction of involvements in which they struck a stopped or slow vehicle ($\chi^2 = 2.54$). Three other "striking" (frontal) crash modes were also reduced with ABS: "front-to-rear, both moving, striking" by 8 percent, "strikes a turning vehicle" by 11 percent, and "front-to-side, both straight, striking" by 7 percent. However, "other multivehicle frontals" were up 10 percent. When the

TABLE 2-7

## MISSOURI, 1990-92: EFFECT OF ABS ON MULTIVEHICLE CRASHES BY TYPE OF CRASH INVOLVEMENT

| **Type of Crash Involvement** | **Without ABS** N | **Without ABS** $\frac{N}{N_{control}}$ | **With ABS** N | **With ABS** $\frac{N}{N_{control}}$ | **Change in $N/N_{control}$ (%)** | $\chi^2$ | **Stat Sig?** |
|---|---|---|---|---|---|---|---|
| Control group (multivehicle - struck while stopped/slow) | 1237 | 1 | 707 | 1 | | | |
| Strikes a stopped/slow vehicle | 417 | .3371 | 204 | .2885 | down 14 | 2.54 | |
| Front-to-rear, both moving: striking | 663 | .5360 | 347 | .4908 | down 8 | 1.17 | |
| Strikes a turning vehicle | 173 | .1399 | 88 | .1245 | down 11 | .70 | |
| Front-to-side, both going straight: striking | 870 | .7033 | 461 | .6521 | down 7 | 1.03 | |
| Other multivehicle frontals | 225 | .1819 | 141 | .1994 | up 10 | .62 | |
| All multivehicle frontals | 2348 | 1.8981 | 1241 | 1.7553 | down 8 | 1.77 | |
| Struck in rear while moving | 616 | .4980 | 404 | .5714 | up 15 | 3.00 | |
| Struck in side while moving | 1200 | .9701 | 685 | .9689 | none | .00 | |
| All non-control group multivehicle involvements | 4164 | 3.3662 | 2330 | 3.2956 | down 2 | .16 | |

five types of frontal multivehicle impacts are summed, the reduction of

$$1 - [(1241/707) / (2348/1237)] = 1 - (1.7553/1.8981) = 8 \text{ percent}$$

is exactly the same as in Florida and Pennsylvania, although it is not statistically significant ($\chi^2 = 1.77$).

ABS was associated with a nonsignificant 15 percent increase in the likelihood of being struck in the rear while moving. It had no observed effect on being struck in the side while moving. When the five "striking" and two "struck" crash modes are added up, the net reduction for ABS is a nonsignificant 2 percent.

2.3.2 Effect of ABS by road condition and crash mode

Table 2-7W analyzes multivehicle crashes on wet road surfaces. ABS dramatically reduces the risk of striking a stopped or slow vehicle. The reduction is

$$1 - [(37/138) / (112/259)] = 1 - (.2681/.4324) = 38 \text{ percent}$$

and it is statistically significant ($\chi^2 = 4.90$, $p < .05$). In fact, this is about the same effectiveness observed in the Florida and Pennsylvania special analyses of two-vehicle collisions involving a fast-moving and a stopped/slow vehicle (Tables 2-3 and 2-6). The risk of striking a moving vehicle in the rear was reduced by 24 percent. ABS had negligible effects in the other "striking" crash modes. When the five types of frontal multivehicle impacts are summed, the accident reduction is 14 percent and it is not statistically significant ($\chi^2 = 1.26$).

As in the other States, there was an increase in rear impacts while moving (11 percent). There was no change in "side impacts while moving." When

TABLE 2-7W

**MISSOURI, 1990-92, WET ROADS:** EFFECT OF ABS ON MULTIVEHICLE CRASHES BY TYPE OF CRASH INVOLVEMENT

| **Type of Crash Involvement** | **Without ABS** N | **Without ABS** $\frac{N}{N_{control}}$ | **With ABS** N | **With ABS** $\frac{N}{N_{control}}$ | **Change in $N/N_{control}$ (%)** | $\chi^2$ | **Stat Sig?** |
|---|---|---|---|---|---|---|---|
| Control group (multivehicle - struck while stopped/slow) | 259 | 1 | 138 | 1 | | | |
| Strikes a stopped/slow vehicle | 112 | .4324 | 37 | .2681 | down 38 | 4.90 | .05 |
| Front-to-rear, both moving: striking | 131 | .5058 | 53 | .3841 | down 24 | 2.02 | |
| Strikes a turning vehicle | 30 | .1158 | 15 | .1087 | down 6 | .04 | |
| Front-to-side, both going straight: striking | 181 | .6988 | 95 | .6884 | down 1 | .01 | |
| Other multivehicle frontals | 53 | .2046 | 33 | .2391 | up 17 | .40 | |
| All multivehicle frontals | 507 | 1.9575 | 233 | 1.6884 | down 14 | 1.26 | |
| Struck in rear while moving | 169 | .6525 | 100 | .7246 | up 11 | .41 | |
| Struck in side while moving | 258 | .9961 | 137 | .9928 | none | .00 | |
| All non-control group multivehicle involvements | 934 | 3.6062 | 470 | 3.4058 | down 6 | .23 | |

the five "striking" and two "struck" crash modes are added up, the ABS-equipped cars had 6 percent fewer non-control group multivehicle crash involvements than the non-ABS cars (not significant).

Table 2-7D presents the same analyses for crashes on dry roads. The observed effects for ABS vary more than in Florida and Pennsylvania (as might be expected with the smaller sample), but are nonsignificant in every crash mode. When the five "striking" and two "struck" crash modes are added, the reduction of non-control group multivehicle crash involvements is a nonsignificant 2 percent.

### 2.3.3 Overall effect of ABS, by road condition

Since the net effect of ABS on multivehicle crashes on dry roads appears to be negligible, the overall effect of ABS on multivehicle crashes on wet roads can be estimated by using the dry-road crashes as a control group. Table 2-8 shows that non-ABS cars had 4155 multivehicle involvements on dry roads, while ABS-equipped cars had 2422. Non-ABS cars had 1204 involvements on wet roads, whereas ABS-equipped cars had only 622. That is a reduction of

$$1 - [(622/2422) / (1204/4155)] = 1 - (.2568/.2898) = 11 \text{ percent}$$

of all types of multivehicle involvements on wet roads (including "striking," "struck while moving" and "struck while stopped"), and it is statistically significant ($\chi^2 = 4.72$, $p < .05$). It is about the same reduction as in Florida (12 percent). The observed overall reduction of multivehicle crashes on snowy and icy roads is 22 percent. The effect is not statistically significant ($\chi^2 = 2.72$), but, as in Pennsylvania it has about the same magnitude as the overall reduction on wet roads.

TABLE 2-7D

**MISSOURI, 1990-92, DRY ROADS:** EFFECT OF ABS ON MULTIVEHICLE CRASHES BY TYPE OF CRASH INVOLVEMENT

| | Without ABS | | With ABS | | Change in $N/N_{control}$ | | |
|---|---|---|---|---|---|---|---|
| **Type of Crash Involvement** | **N** | $\frac{N}{N_{control}}$ | **N** | $\frac{N}{N_{control}}$ | **(%)** | $\chi^2$ | **Stat Sig?** |
| Control group (multivehicle - struck while stopped/slow) | 935 | 1 | 552 | 1 | | | |
| Strikes a stopped/slow vehicle | 289 | .3091 | 161 | .2917 | down 6 | .27 | |
| Front-to-rear, both moving: striking | 512 | .5476 | 285 | .5163 | down 6 | .42 | |
| Strikes a turning vehicle | 143 | .1529 | 73 | .1322 | down 14 | .90 | |
| Front-to-side, both going straight: striking | 677 | .7241 | 357 | .6467 | down 11 | 1.78 | |
| Other multivehicle frontals | 159 | .1701 | 99 | .1793 | up 5 | .15 | |
| All multivehicle frontals | 1780 | 1.9037 | 975 | 1.7663 | down 8 | 1.77 | |
| Struck in rear while moving | 437 | .4674 | 295 | .5344 | up 14 | 2.10 | |
| Struck in side while moving | 911 | .9743 | 541 | .9801 | up 1 | .01 | |
| All non-control group multivehicle involvements | 3128 | 3.3455 | 1811 | 3.2808 | down 2 | .10 | |

TABLE 2-8

**MISSOURI, 1990-92:** EFFECT OF ABS ON MULTIVEHICLE CRASHES BY ROAD CONDITION

| **Type of Crash Involvement** | **Without ABS** | | **With ABS** | | **Change in $N/N_{dry}$** | | |
|---|---|---|---|---|---|---|---|
| | **N** | $\frac{N}{N_{dry}}$ | **N** | $\frac{N}{N_{dry}}$ | **(%)** | $\chi^2$ | **Stat Sig?** |
| Dry road multivehicle | 4155 | 1 | 2422 | 1 | | | |
| Wet road multivehicle | 1204 | .2898 | 622 | .2568 | down 11 | 4.72 | .05 |
| Snowy/icy road multivehicle | 147 | .0354 | 67 | .0277 | down 22 | 2.72 | |

## 2.4 Florida-Pennsylvania-Missouri, 1990-92 - combined results

The results on multivehicle crashes from the three States are quite consistent. ABS is definitely effective on wet roads: the risk of hitting a slow or stopped vehicle is reduced about 40 percent with ABS, while the overall risk of a multivehicle crash is reduced by about 10-15 percent. ABS did not have much overall effect on dry roads in any of the States. It would be desirable to combine the data from the three States to obtain more precise and representative effectiveness estimates. There are potential problems, however, in combining data from different States. The precise meanings of data elements such as the impact location, manner of collision, harmful event, or precrash action unavoidably vary from State to State even if, superficially, they look the same. That can bias results if the States also differ in the make-model mix of their crash-involved vehicles.

For example, Florida has a higher percentage of ABS-equipped cars than Pennsylvania and Missouri. Florida also has a higher percentage of "control group" crashes than Pennsylvania and Missouri (see Tables 2-1, 2-4 and 2-7). If the data from the three States are simply combined, Florida data would be overrepresented in the ABS-equipped cars, and Pennsylvania-Missouri data in the non-ABS cars. The ABS-equipped cars would have a higher percentage of control group involvements (because more of them are from Florida) and a lower percentage in the non-control group crash modes. Thus, the various non-control group crash modes would show a reduction relative to the control group, spuriously attributed to ABS.

A remedy is to weight the accident cases so that the number of weighted ABS-equipped and non-ABS accident cases is equal within a State. Also, the weighted make-model mix for ABS-equipped cars in Florida should be the same as the mix of non-ABS cars in Florida and the mix of ABS-equipped and non-ABS cars in the other States. Then, there is no danger that the results will be biased because the ABS-equipped cars have an overrepresentation of Florida vehicles or the non-ABS cars have an excess of a particular make-model. The weighting process was carried out in three steps:

Step 1 Five of the 48 ABS make-model groups, which are quite rare in at least one State and not numerous in the others, were deleted: Olds Delta 88 Royale LS, Olds Toronado Brougham, Olds Supreme International, Honda Prelude SI and Sterling.

Step 2 Within each State, the total sample-size and make-model mix was made equal for the ABS-equipped and non-ABS cars, as follows: Within each ABS make-model group, the sample size was compared for the ABS-equipped and non-ABS cars, and the larger population was weighted to make it the same as the smaller. For example, if there are 1000 Lincoln Town Cars without ABS and 750 with ABS in Florida, weight each non-ABS Town Car by 0.75.

Step 3 No further changes are made to the Florida sample. The Pennsylvania and Missouri samples are further adjusted to have the same make-model mix as Florida, as follows:

$F_i$ = proportion of Step 2-weighted Florida cases in ABS group i
$P_i$ = proportion of Step 2-weighted Pennsylvania cases in ABS group i
$FP_i = .8\ (F_i\ /\ P_i)$ = Step 3 adjustment factor for Pennsylvania

The case weights for Pennsylvania and Missouri are the products of the Step 2 and Step 3 weight factors. The purpose of the constant .8 is to diminish the number of cases with a weight over 1.

This procedure guarantees that the combined accident sample for the three States will have the same number of ABS-equipped and non-ABS weighted accident cases (for all crash modes combined, including single-vehicle): 17,742 each. The ABS-equipped and non-ABS samples each have the same weighted make-model mix. Also, by this procedure, 32 percent of the weighted accident cases (24 percent of the unweighted cases) have a weight of exactly 1; 60 percent of the weighted cases (71 percent of the unweighted cases) have a weight less than

1; only 8 percent of the weighted cases (5 percent of the unweighted cases) have a weight greater than 1; and only 1 percent of the weighted cases (0.4 percent of the unweighted cases have a weight greater than 1.5. In other words, the weighted case counts in the analyses that follow are not inflated numbers; on the contrary, they are usually deflated from the count of actual accident cases. The "Chi-square" statistics in the tables that follow are calculated as if the numbers in the tables were simple, unweighted accident cases; however, since these numbers are, in fact, usually based on larger numbers of actual cases, these "Chi-square" statistics are conservative tests of significance.

2.4.1 <u>Effect of ABS by crash mode</u>

Table 2-9 compares the crash modes of ABS-equipped and non-ABS cars involved in multivehicle crashes during calendar years 1990-92. The non-ABS cars accounted for 5404 <u>weighted</u> control group crashes, while the ABS-equipped cars were involved in a nearly identical 5458 weighted control group crashes. Combining data from the three States really stabilizes the results: there are almost the same moderate reductions in each of the four "striking" (frontal) crash modes. Each of the reductions is significant at the .05 level. With ABS, there is an 8 percent reduction in "front-to-rear, striking" impacts ($\chi^2$ = 4.12); a 9 percent reduction in striking a turning vehicle ($\chi^2$ = 4.30); an 8 percent reduction in striking the side of a vehicle that was going straight ($\chi^2$ = 5.57), and an 11 percent reduction in other types of frontal impacts with another vehicle, a category that includes the Missouri impacts into a stopped/slow vehicle ($\chi^2$ = 6.04). When the four types of frontal multivehicle impacts are summed, the reduction of

$$1 - [(5726/5458) / (6213/5404)] = 1 - (1.0491/1.1497) = 9 \text{ percent}$$

is statistically significant at the .01 level ($\chi^2$ = 11.92).

TABLE 2-9

**FLORIDA-PENNSYLVANIA-MISSOURI, 1990-92:** EFFECT OF ABS ON MULTIVEHICLE CRASHES BY TYPE OF CRASH INVOLVEMENT

(weighted, balanced data)

| **Type of Crash Involvement** | **Without ABS** | | **With ABS** | | **Change in $N/N_{control}$** | | |
|---|---|---|---|---|---|---|---|
| | **N** | $\frac{N}{N_{control}}$ | **N** | $\frac{N}{N_{control}}$ | **(%)** | $\chi^2$ | **Stat Sig?** |
| Control group (multivehicle - struck while stopped/slow) | 5404 | 1 | 5458 | 1 | | | |
| Front-to-rear: striking | 1843 | .3410 | 1721 | .3153 | down 8 | 4.12 | .05 |
| Strikes a turning vehicle | 1221 | .2259 | 1122 | .2056 | down 9 | 4.30 | .05 |
| Front-to-side, both going straight: striking | 2018 | .3734 | 1866 | .3419 | down 8 | 5.57 | .05 |
| Other multivehicle frontals | <u>1131</u> | <u>.2093</u> | <u>1017</u> | <u>.1863</u> | down 11 | 6.04 | .05 |
| All multivehicle frontals | 6213 | 1.1497 | 5726 | 1.0491 | down 9 | 11.92 | .01 |
| Struck in rear while moving | 1154 | .2135 | 1211 | .2219 | up 4 | .71 | |
| Struck in side while moving | <u>2596</u> | <u>.4804</u> | <u>2615</u> | <u>.4791</u> | none | .01 | |
| All non-control group multivehicle involvements | 9963 | 1.8436 | 9552 | 1.7501 | down 5 | 4.73 | .05 |

As in the individual States, ABS was associated with a nonsignificant increase in the likelihood of being struck in the rear while moving (4 percent, $\chi^2 = 0.71$). There was no observed effect on being struck in the side while moving. When the four "striking" and two "struck" crash modes are added up, the ABS-equipped cars had 9552 non-control group multivehicle crash involvements and the non-ABS cars had 9963. That is a net reduction of

$$1 - [(9552/5458) / (9963/5404)] = 1 - (1.7501/1.8436) = 5 \text{ percent}$$

and it is statistically significant ($\chi^2 = 4.73$, $p < .05$).

2.4.2 Effect of ABS by road condition and crash mode

Table 2-9W presents the same analyses as Table 2-9, but limits the data to crashes on wet road surfaces. Non-ABS cars experienced 396 "front-to-rear striking" involvements, a ratio of .4295 to the control group. ABS-equipped cars were striking vehicles in only 232 rear-end collisions, a ratio of .2639 to the control group. As in each of the individual States, the reduction of

$$1 - [(232/879) / (396/922)] = 1 - (.2639/.4295) = 39 \text{ percent}$$

is very substantial and statistically significant ($\chi^2 = 26.41$, $p < .01$). ABS is also beneficial, to a lesser extent, in reducing the other three types of "striking" involvements. With this larger sample, these three effects are quite consistent: a 22 percent reduction in striking a turning vehicle ($\chi^2 = 4.08$, $p < .05$), a 16 percent reduction in striking the side of a vehicle that was going straight, and a 20 percent reduction of other multivehicle frontals ($\chi^2 = 4.42$, $p < .05$). When the four types of frontal multivehicle impacts are summed, the reduction of

$$1 - [(841/879) / (1220/922)] = 1 - (.9568/1.3232) = 28 \text{ percent}$$

is impressive ($\chi^2 = 24.91$, $p < .01$).

TABLE 2-9W

**FLORIDA-PENNSYLVANIA-MISSOURI, 1990-92, WET ROADS:** EFFECT OF ABS ON MULTIVEHICLE CRASHES BY TYPE OF CRASH INVOLVEMENT

(weighted, balanced data)

| **Type of Crash Involvement** | **Without ABS** N | **Without ABS** $N/N_{control}$ | **With ABS** N | **With ABS** $N/N_{control}$ | **Change in $N/N_{control}$ (%)** | $\chi^2$ | **Stat Sig?** |
|---|---|---|---|---|---|---|---|
| Control group (multivehicle - struck while stopped/slow) | 922 | 1 | 879 | 1 | | | |
| Front-to-rear: striking | 396 | .4295 | 232 | .2639 | down 39 | 26.41 | .01 |
| Strikes a turning vehicle | 173 | .1876 | 128 | .1456 | down 22 | 4.08 | .05 |
| Front-to-side, both going straight: striking | 399 | .4328 | 320 | .3641 | down 16 | 3.81 | |
| Other multivehicle frontals | 252 | .2733 | 192 | .2184 | down 20 | 4.42 | .05 |
| All multivehicle frontals | 1220 | 1.3232 | 841 | .9568 | down 28 | 24.91 | .01 |
| Struck in rear while moving | 236 | .2560 | 286 | .3254 | up 27 | 5.80 | .05 |
| Struck in side while moving | 455 | .4935 | 427 | .4858 | down 2 | .04 | |
| All non-control group multivehicle involvements | 1911 | 2.0727 | 1554 | 1.7679 | down 15 | 7.47 | .01 |

The reduction in frontal impacts is partially offset by a statistically significant 27 percent increase in rear impacts while moving ($\chi^2 = 5.80$, $p < .05$). There was little change in side impacts while moving (2 percent reduction). When the four "striking" and two "struck" crash modes are added up, the ABS-equipped cars had 15 percent fewer non-control group multivehicle crash involvements than the non-ABS cars, a statistically significant reduction ($\chi^2 = 7.47$, $p < .01$).

Table 2-9D presents the same analyses for crashes on dry road surfaces. The observed effects for ABS fall short of statistical significance in every crash mode. When the four "striking" and two "struck" crash modes are added up, the reduction of non-control group multivehicle crash involvements was a nonsignificant 3 percent for ABS ($\chi^2 = 1.47$). The overall, net effect of ABS on multivehicle crashes on dry roads is negligible.

2.4.3 Overall effect of ABS, by road condition

Table 2-10 shows that non-ABS cars had a weighted total of 12,821 multivehicle involvements on dry roads, while ABS-equipped cars had 12,897. Non-ABS cars had 2939 weighted involvements on wet roads, whereas ABS-equipped cars had only 2548. With the dry-road crashes used as a control group, that is a reduction of

$$1 - [(2548/12897) / (2939/12821)] = 1 - (.1976/.2292) = 14 \text{ percent}$$

of all types of multivehicle involvements on wet roads (including "striking," "struck while moving" and "struck while stopped"), and it is statistically significant ($\chi^2 = 24.91$, $p < .01$).

Pennsylvania and Missouri experience a moderate number of multivehicle

TABLE 2-9D

**FLORIDA-PENNSYLVANIA-MISSOURI, 1990-92, DRY ROADS:** EFFECT OF ABS ON MULTIVEHICLE CRASHES BY TYPE OF CRASH INVOLVEMENT

(weighted, balanced data)

| | **Without ABS** | | **With ABS** | | **Change in $N/N_{control}$** | | |
|---|---|---|---|---|---|---|---|
| **Type of Crash Involvement** | **N** | $\frac{N}{N_{control}}$ | **N** | $\frac{N}{N_{control}}$ | **(%)** | $\chi^2$ | **Stat Sig?** |
| Control group (multivehicle - struck while stopped/slow) | 4450 | 1 | 4555 | 1 | | | |
| Front-to-rear: striking | 1425 | .3202 | 1472 | .3232 | up 1 | .05 | |
| Strikes a turning vehicle | 1048 | .2355 | 994 | .2182 | down 7 | 2.42 | |
| Front-to-side, both going straight: striking | 1603 | .3578 | 1531 | .3361 | down 7 | 2.79 | |
| Other multivehicle frontals | 838 | .1883 | 783 | .1719 | down 9 | 2.86 | |
| All multivehicle frontals | 4914 | 1.1043 | 4780 | 1.0494 | down 5 | 3.03 | |
| Struck in rear while moving | 905 | .2034 | 913 | .2004 | down 1 | .08 | |
| Struck in side while moving | 2118 | .4760 | 2175 | .4775 | none | .01 | |
| All non-control group multivehicle involvements | 7937 | 1.7836 | 7868 | 1.7273 | down 3 | 1.47 | |

TABLE 2-10

**FLORIDA-PENNSYLVANIA-MISSOURI, 1990-92:** EFFECT OF ABS ON MULTIVEHICLE CRASHES BY ROAD CONDITION

(weighted, balanced data)

| **Type of Crash Involvement** | **Without ABS** $N$ | **Without ABS** $\frac{N}{N_{dry}}$ | **With ABS** $N$ | **With ABS** $\frac{N}{N_{dry}}$ | **Change in $N/N_{dry}$ (%)** | $\chi^2$ | **Stat Sig?** |
|---|---|---|---|---|---|---|---|
| Dry road multivehicle | 12821 | 1 | 12897 | 1 | | | |
| Wet road multivehicle | 2939 | .2292 | 2548 | .1976 | down 14 | 24.91 | .01 |
| Snowy/icy road multivehicle | 160 | .0125 | 144 | .0112 | down 11 | .93 | |

crashes on snowy and icy roads. Table 2-10 shows that multivehicle crashes on snowy and icy roads decreased by 11 percent with ABS, relative to crashes on dry roads. The effect is not statistically significant ($\chi^2 = 0.93$), but it is about the same magnitude as the overall reduction on wet roads.

## 2.5 Fatal multivehicle crashes, 1989-93

The effects of crash-avoidance measures are in some cases quite different in fatal and nonfatal crashes, but in other cases similar. For example, on the one hand, NHTSA's evaluations of side marker lamps [6] and Center High Mounted Stop Lamps [5] did not show fatality reductions, despite significant reductions of nonfatal accidents and injuries. On the other hand, NHTSA's evaluation of dual master cylinders and front disc brakes [8] showed similar effectiveness in fatal, injury and property-damage crashes. Fatal crashes, on the average, involve much higher speeds than nonfatal crashes; there may not be sufficient available stopping distance or reaction time to obtain benefits from the crash-avoidance device (or, conversely, speed may be high enough for the device to achieve its greatest benefits). In many fatal crashes, drivers are impaired, inattentive or reckless to the point where they do not use the crash-avoidance system at all. In general, it is necessary to evaluate crash-avoidance measures separately in fatal and nonfatal crashes.

### 2.5.1 Effect of ABS by crash mode

Fatal Accident Reporting System (FARS) data are available through 1993. The sample size for ABS-equipped cars involved in fatal multivehicle crashes is barely sufficient for preliminary effectiveness analyses. The general approach in the State accident analysis - categorizing crash involvements as "control group" (struck while stopped), "striking" or "struck while moving" - can be attempted with FARS, but there are complications that limit its utility. Most nonfatal collisions involve a relatively "active" vehicle (moving before the crash and impacting frontally), which stands to benefit from ABS, and at least one relatively "passive" vehicle (standing still or moving ≤ 5 mph before the crash and/or struck in the side or rear), which is unlikely to benefit from ABS. A large percentage of fatal collisions, on the other hand, involve two "active" and no "passive" vehicles: e.g., head-on collisions between two moving vehicles. The preferred control group, cars that were stopped or moving slowly before the crash, is too small for meaningful statistical analyses and needs to be supplemented with other "passive" impact types. At the same time, a high percentage of the "active" (frontally impacting) involvements might not really be ABS-relevant, because drivers were too impaired, or had too little reaction time to apply their brakes (but these crashes cannot reliably be identified from the FARS data elements). Thus, the shift from "striking" to "struck" (control group) involvements, with ABS, is unlikely to be as clear as in the State data.

As shown in Table 2-11, multivehicle involvements in 1989-93 FARS data are classified into three larger groups. The classification is based on the "manner of collision," the impact location and pre-crash maneuver of the case vehicle <u>and</u> the impact location and pre-crash maneuver of the "other" vehicle in the collision (vehicle no. 2, if the case vehicle is no. 1; vehicle no. 1, if the case vehicle is no. 2, 3, etc.). In the control group, the case vehicle was struck (passive) and the other vehicle was striking (active). There are 457 control group involvements for the non-ABS comparison cars and 356 for the ABS-equipped cars; in only 168 and 133 of these involvements, respectively, was the case vehicle stopped or slow-moving prior to impact. The second large grouping consists of crashes that are the mirror image of the control group: the case

TABLE 2-11

**FARS, 1989-93:** EFFECT OF ABS ON FATAL MULTIVEHICLE CRASHES BY TYPE OF CRASH INVOLVEMENT

| **Type of Crash Involvement** | **Without ABS** N | **Without ABS** $\frac{N}{N_{control}}$ | **With ABS** N | **With ABS** $\frac{N}{N_{control}}$ | **Change in $N/N_{control}$ (%)** | $\chi^2$ | **Stat Sig?** |
|---|---|---|---|---|---|---|---|
| Struck while stopped/slow | 168 | .3676 | 133 | .3736 | | | |
| Struck in rear while moving | 31 | .0678 | 22 | .0618 | | | |
| Struck while turning | 88 | .1926 | 61 | .1713 | | | |
| Struck in side, going straight | 170 | .3720 | 140 | .3933 | | | |
| Control group: struck cars | 457 | 1. | 356 | 1. | | | |
| Strikes stopped/slow vehicle | 107 | .2341 | 85 | .2387 | | | |
| Front-to-rear: striking | 40 | .1120 | 31 | .0871 | | | |
| Strikes a turning vehicle | 68 | .1488 | 51 | .1433 | | | |
| Front-to-side, both going straight: striking | 127 | .2779 | 132 | .3708 | | | |
| Case car strikes other vehicle | 342 | .7484 | 299 | .8399 | up 12 | 1.18 | |
| Head-on collisions and other collisions of two "striking" vehicles | 513 | 1.1225 | 394 | 1.1067 | down 1 | .02 | |
| All non-control group multivehicle involvements | 855 | 1.8709 | 693 | 1.9466 | up 4 | .21 | |

vehicle strikes the "other" vehicle. The last group, which is the largest, consists of involvements in head-on collisions and other collisions of two fast-moving, frontally impacted vehicles.

Table 2-11 shows 342 involvements of non-ABS cars in the second large group (case vehicle strikes other vehicle), and 299 ABS-equipped cars. Relative to the control groups, this is an effect of

$$1 - [(299/356) / (342/457)] = 1 - (.8399/.7484) = 12 \text{ percent increase}$$

and it is not statistically significant ($\chi^2 = 1.18$). In the third large group (head-on collisions, etc.), a nonsignificant 1 percent reduction was observed with ABS. When the second and third large group are combined, the net effect on "case vehicle striking" involvements relative to the control group is

$$1 - [(693/356) / (855/457)] = 1 - (1.9466/1.8709) = 4 \text{ percent increase}$$

and it is not statistically significant ($\chi^2 = 0.21$). Moreover, there is no consistent trend for ABS among the subgroups that constitute the control group or the "case car strikes other vehicle" group.

Table 2-11W limits the data to crashes on <u>wet</u> roads. The sample is basically insufficient for an analysis by crash mode; for example, there are only 47 control group crashes of ABS-equipped cars. Table 2-11W does not show a reduction of "striking" impacts; in fact, they increased by 16 percent relative to the control group, an effect that falls far short of statistical significance ($\chi^2 = 0.45$).

Table 2-11D analyzes multivehicle involvements on <u>dry</u> roads, by crash mode. Relative to the control group, ABS was associated with a 10 percent increase in "case car strikes another vehicle" but a 1 percent reduction of head-

TABLE 2-11W

**FARS, 1989-93, WET ROADS:** EFFECT OF ABS ON FATAL MULTIVEHICLE CRASHES BY TYPE OF CRASH INVOLVEMENT

| | **Without ABS** | | **With ABS** | | **Change in $N/N_{control}$** | | |
|---|---|---|---|---|---|---|---|
| **Type of Crash Involvement** | **N** | $\frac{N}{N_{control}}$ | **N** | $\frac{N}{N_{control}}$ | **(%)** | $\chi^2$ | **Stat Sig?** |
| Control group: struck cars | 81 | 1 | 47 | 1 | | | |
| Case car strikes other vehicle | 60 | .7407 | 41 | .8723 | up 18 | .36 | |
| Head-on collisions and other collisions of two "striking" vehicles | 105 | 1.2963 | 70 | 1.4894 | up 15 | .36 | |
| All non-control group multivehicle involvements | 165 | 2.0370 | 111 | 2.3617 | up 16 | .45 | |

TABLE 2-11D

**FARS, 1989-93, DRY ROADS:** EFFECT OF ABS ON FATAL MULTIVEHICLE CRASHES BY TYPE OF CRASH INVOLVEMENT

| | **Without ABS** | | **With ABS** | | **Change in $N/N_{control}$** | | |
|---|---|---|---|---|---|---|---|
| **Type of Crash Involvement** | **N** | **$\frac{N}{N_{control}}$** | **N** | **$\frac{N}{N_{control}}$** | **(%)** | $\chi^2$ | **Stat Sig?** |
| Control group: struck cars | 361 | 1 | 297 | 1 | | | |
| Case car strikes other vehicle | 275 | .7618 | 248 | .8350 | up 10 | .61 | |
| Head-on collisions and other collisions of two "striking" vehicles | <u>385</u> | <u>1.0665</u> | <u>313</u> | <u>1.0539</u> | down 1 | .01 | |
| All non-control group multivehicle involvements | 660 | 1.8283 | 561 | 1.8889 | up 3 | .11 | |

on involvements. Neither effect is statistically significant. The net effect on "striking" involvements is a negligible 3 percent increase ($\chi^2 = 0.11$).

### 2.5.2 Overall effect of ABS, by road condition

Although Table 2-11W did not show a reduction of "striking" involvements on wet roads, this is not the best way to evaluate the overall effect of ABS on fatal multivehicle crashes on wet roads - partly, because the accident samples on wet roads are too small for analysis by crash modes; partly, because the analysis method by crash mode, as explained above, may be flawed for fatal accident data. In the State files, the overall effect of ABS on nonfatal crashes on wet roads was estimated by using all dry-road multivehicle crashes as a control group, based on the premise that ABS has little or no effect on dry-road multivehicle involvements (Sections 2.1.3, 2.2.3, 2.3.3 and 2.4.3). In each State file, however, strong evidence had already been presented in support of the premise that ABS has negligible effect on dry roads.

Similarly, by assuming that ABS has little effect on fatal multivehicle crashes on dry roads, it is possible to estimate its net effect on wet roads. There are two pieces of evidence, each partially flawed, to support the premise of a negligible effect on dry roads:

- o In Table 2-11D, ABS had little effect on "striking" impacts, relative to struck impacts (although there are doubts this result is as meaningful for fatal as for nonfatal crashes).
- o Since ABS had little effect on nonfatal multivehicle crashes on dry roads, it is unlikely to have an effect in fatal crashes (although, as noted above, effects in nonfatal and fatal crashes are not necessarily consistent).

Still, the most plausible conclusion is that ABS has, at most, a small effect on fatal multivehicle crashes on dry roads. Table 2-12 shows that non-ABS cars had 1021 fatal multivehicle involvements on dry roads, while ABS-equipped cars had 858. Non-ABS cars had 246 involvements on wet roads, whereas ABS-equipped cars had only 158. That is a rather substantial reduction of

$$1 - [(158/858) / (246/1021)] = 1 - (.1841/.2409) = 24 \text{ percent}$$

of all types of multivehicle involvements on wet roads, and it is statistically significant ($\chi^2 = 5.78$, $p < .05$). This reduction is close to many of the effects seen in the State data analyses of nonfatal crashes.

The FARS files include a meager number of multivehicle crashes on snowy and icy roads. Table 2-12 shows that fatal multivehicle crashes on snowy and icy roads decreased by 13 percent with ABS, relative to dry roads. The effect is not statistically significant ($\chi^2 = 0.34$), but it is similar to the reductions found in Pennsylvania and Missouri.

## 2.6 Fatal pedestrian crashes, 1989-93

Although, technically, collisions of a car with a pedestrian, bicyclist, animal or train are "single-vehicle" crashes, they more closely resemble multivehicle crashes than the run-off-road crashes analyzed in the next chapter. In most cases, the car is proceeding in the roadway and the pedestrian is standing or moving in or across the same roadway, or right next to it. For example, a car could be going straight ahead and under control, when a pedestrian darts in front of it, or the pedestrian may have been there for some time, but is only seen by the driver at short range. In many ways, they are two-party collisions, except the second party is not a motor vehicle. In fact, they most closely resemble a collision between a fast-moving and a stopped/slow vehicle, which is the type where ABS was found to be especially effective for the fast-

TABLE 2-12

**FARS, 1989-93:** EFFECT OF ABS ON FATAL MULTIVEHICLE CRASHES
BY ROAD CONDITION

| **Type of Crash Involvement** | **Without ABS** **N** | **Without ABS** $\frac{N}{N_{dry}}$ | **With ABS** **N** | **With ABS** $\frac{N}{N_{dry}}$ | **Change in** $N/N_{dry}$ **(%)** | $\chi^2$ | **Stat Sig?** |
|---|---|---|---|---|---|---|---|
| Dry road multivehicle | 1021 | 1 | 858 | 1 | | | |
| Wet road multivehicle | 246 | .2409 | 158 | .1841 | down 24 | 5.78 | .05 |
| Snowy/icy road multivehicle | 45 | .0441 | 33 | .0385 | down 13 | .34 | |

moving vehicle, and even beneficial on dry roads (Sections 2.1.4 and 2.2.4). The driver is confronted with a stationary or slow-moving target, that can be evaded by stopping short or by steering around it.

By contrast, most collisions with fixed objects and rollovers occur off the road. The first event is a loss of directional control or inappropriate steering by the driver, which causes the car to head off the roadway. This is followed by an off-road excursion towards the object or rollover-inducing tripping mechanism. The driver may have limited, if any, braking and steering control during the off-road excursion.

The 1989-93 FARS files contained enough cases of collisions with pedestrians, bicyclists or equestrians, trains, and animals (based on the "first harmful event" variable) for a preliminary statistical analysis of the effect of ABS. The overwhelming majority of these crashes (85 percent) involve pedestrians, 9 percent are with bicyclists or equestrians, 4 percent with trains and 2 percent with animals. As in Section 2.5.2, the control group consists of fatal multivehicle involvements on dry roads.

Table 2-13 shows that cars in the 48 comparison groups without ABS had 1021 fatal multivehicle involvements on dry roads, while cars in the 48 ABS-equipped make-model groups had 858. Non-ABS cars struck a total of 259 pedestrians, bicyclists, etc. (on dry, wet, snowy or icy roads), whereas ABS-equipped cars only struck 158. That is a noteworthy reduction of

$$1 - [(158/858) / (259/1021)] = 1 - (.1841/.2537) = 27 \text{ percent}$$

of pedestrian impacts, and it is statistically significant ($\chi^2 = 8.36$, $p < .01$). This benefit is about the same as the reduction of fast-moving involvements in

TABLE 2-13

**FARS, 1989-93:** EFFECT OF ABS ON FATAL COLLISIONS WITH PEDESTRIANS, BICYCLISTS, TRAINS, OR ANIMALS BY ROAD CONDITION

| **Type of Crash Involvement** | **Without ABS** N | **Without ABS** $\frac{N}{N_{control}}$ | **With ABS** N | **With ABS** $\frac{N}{N_{control}}$ | **Change in $N/N_{control}$ (%)** | $\chi^2$ | **Stat Sig?** |
|---|---|---|---|---|---|---|---|
| Control group (fatal multivehicle involvements on dry roads) | 1021 | 1 | 858 | 1 | | | |
| Pedestrian, etc. - all roads | 259 | .2537 | 158 | .1841 | down 27 | 8.36 | .01 |
| Pedestrian, etc. - wet roads | 40 | .0392 | 23 | .0268 | down 32 | 2.06 | |
| Pedestrian, etc. - dry roads | 216 | .2116 | 134 | .1562 | down 26 | 6.50 | .05 |

Pennsylvania collisions between a fast-moving and a slow or stopped vehicle (see Section 2.2.4), which was the best result found for ABS on multivehicle crashes, when all types of road surfaces were included.

The FARS data include a modest number of pedestrian impacts on wet roads. Table 2-13 shows that pedestrian impacts decreased by 32 percent on wet roads with ABS, relative to the control group. The effect falls short of statistical significance ($\chi^2$ = 2.06). The accident sample on dry roads is substantially larger. Table 2-13 shows a statistically significant 26 percent reduction with ABS ($\chi^2$ = 6.50, $p < .05$).

These substantial reductions of fatal pedestrian crashes, on dry as well as wet roads, are one of the most important and favorable findings on ABS. However, they must still be viewed with a degree of caution because they are not directly corroborated by other data sources. (The favorable State data results on collisions between a fast-moving and a stopped or slow vehicle are, at best, an indirect corroboration.) Specifically, the Florida, Pennsylvania and Missouri files contain relatively few cases of collisions with pedestrians, animals, etc. In the file combining data for the three States, as defined in Section 2.4, non-ABS cars had 312 weighted involvements with pedestrians, etc., on all road surfaces, whereas ABS-equipped cars had 324. The control group (multivehicle involvements on dry roads) totaled 12,821 weighted cases for non-ABS cars and 12,897 for ABS-equipped cars. That is an effect of

$$1 - [(324/12897) / (312/12821)] = 1 - (.0251/.0243) = 3 \text{ percent increase}$$

of pedestrian involvements, and it is not statistically significant ($\chi^2$ = 0.16).

## CHAPTER 3

## ANALYSIS OF SINGLE-VEHICLE, RUN-OFF-ROAD CRASHES: ROLLOVERS AND IMPACTS WITH FIXED OBJECTS

The overwhelming majority of single-vehicle rollover crashes and impacts with fixed objects occur after a passenger car runs off the road: there are few tripping mechanisms or fixed objects on the road. The car runs off the road because the driver steered it in the wrong direction or lost steering control or lost directional control of the car (sometimes all of the above). Thus, most run-off-road crashes share two characteristics: the car was the only moving entity directly involved in the crash, and the car was already moving in the wrong direction prior to the actual moment of impact. That distinguishes them from other types of single-vehicle crashes (collisions with pedestrians, bicycles, animals, trains), where a second party may have entered the correct, intended path of the car.

There are several situations where ABS could make the difference between a run-off-road crash and a safe journey:

- Run-off-road induced by brakes that lock the wheels: a driver, who has the vehicle under control and going in the right direction, applies conventional brakes and locks the rear wheels (e.g., by braking too hard on a slippery roadway), loses directional control and yaws off the road. With ABS, directional control need not have been lost. Alternatively, a driver brakes and locks the front wheels while negotiating a curve, loses steering control and proceeds straight off the road; with ABS, steering control need not have been lost.

- Accidents prevented by enhanced braking capability: due to faulty or inattentive steering, a car is headed off the roadway, although still under control with no locked wheels. The driver brakes hard and, possibly, tries to steer. The car begins to yaw (locked rear wheels), or cannot be steered (locked front wheels), or just does not slow down in time. With ABS, yawing might be prevented, stopping distances shortened, and/or steering control maintained. The driver is able to keep the car from running off the road, or, if it has already left the road, the driver can stop short or steer around a tree or ditch.

Of course, ABS can hardly be expected to prevent all run-off-road crashes. If the driver never touches the brakes before or during the off-road excursion (e.g., the driver is too impaired to notice or react to the emergency), ABS cannot help. If excessive steering input and/or adverse road conditions put the car in a skid before the driver touches the brakes, it may keep on skidding regardless of ABS. Even in those situations where ABS helps the driver keep control and possibly reduce stopping distance, there may not be enough room to avoid the roadside hazards, or the driver might still not steer in the right direction. In fact, there are several situations where ABS could potentially increase the risk of running off the road, or increase the risk of a rollover or fixed-object impact subsequent to running off the road:

- A driver is exposed to a panic situation, such as a sudden realization that a slow vehicle or deer is in front of the car, or that the car is heading off the road. Some inexpert drivers instinctively react to these situations by slamming on the brakes and abruptly turning the steering wheel. Without ABS, the front wheels lock and the car goes straight ahead, stopping in a reasonably short distance, essentially ignoring the steering input. With ABS, the vehicle responds to the abrupt, instinctive steering input, possibly running off the road and badly out of control.

- If the car has left the paved roadway, and the shoulder or roadside is covered with loose materials such as gravel, ABS can substantially prolong stopping distances (Section 1.2) and hinder the driver from stopping short of a tree or ditch.

- Risk compensation: a driver who believes ABS significantly enhances handling and control might drive around curves too fast and run off the road. However, the analyses of multivehicle crashes in the preceding chapter did not show any large effects that looked like risk compensation.

State accident files and FARS provide only limited data on what a car was doing before and during its off-road excursion, or what caused it to run off the road. But these files are quite clear about what type of crash happened at the end of the excursion. Thus, run-off-road crashes can be categorized into three crash modes that give a partial indication of how badly a vehicle was out of control before the crash:

- o Rollover crashes are often a result of severe yawing while the vehicle is still on the roadway, which makes the vehicle vulnerable to tripping mechanisms as soon as it leaves the roadway.

- o Side impacts with fixed objects suggest that a vehicle went out of control and into a yaw before contact with the object, although not necessarily before leaving the roadway. Another possibility is that the driver attempted to steer away from the object, but was unsuccessful or lost directional control during the maneuver.

- o Frontal impacts with fixed objects generally involve less yawing than the two preceding groups, or no yawing at all. Nevertheless, the vehicle definitely didn't go where it was supposed to; the driver may have lost steering or directional control, or may have been unsuccessful in attempts to stop the vehicle.

ABS might have some effect on all three types of crashes, although perhaps a stronger effect on the first two types, which usually involve a greater loss of control. Thus, none of these three single-vehicle crash modes is a "control group." The best control group comprises the same multivehicle crash modes that were used as a control group in the preceding chapter: it includes cars that were standing still or were parked prior to being hit by another vehicle (brakes are irrelevant for the nonmoving car). It also includes cars that were moving very slowly prior to impact, as evidenced by a travelling speed of 5 mph or less, or a pre-crash movement such as backing up, leaving or entering a parking space (braking might have been involved, but at those speeds ABS and conventional brakes have about the same stopping capabilities). The number of control-group crash involvements measures the "exposure" of the ABS-equipped cars, and the non-ABS comparison cars.

The analysis technique is to tabulate the crash involvements, for cars equipped with ABS and their counterparts without ABS, in four crash modes:

primary rollovers, side impacts with fixed objects, frontal impacts with fixed objects, and the control group. The ratio of run-off-road crashes to control group involvements is contrasted for the ABS-equipped cars and the non-ABS comparison cars.

"Primary rollovers" are single-vehicle, run-off-road crashes where a rollover was the only really harmful event - excluding rollovers that occurred subsequent to an impact with a vehicle or large object such as a tree, but including crashes where the rollover is the "second harmful event" and a tripping mechanism such as a contact with a ditch is reported as the "first harmful event." "Side impacts with fixed objects" include a small number of rear impacts with fixed objects, but exclude front-corner impacts. "Frontal impacts with fixed objects" include front-corner impacts. A small number of fixed-object collisions are excluded from the analysis: cars with unknown impact location (impossible to classify as "side" or "frontal" impacts), cars that were moving 5 mph or less, parking, leaving a parking space or backing up at the time of impact (speeds at which ABS and conventional brakes have about the same stopping capabilities) and cars that were reported as standing still or parked when they hit a fixed object (data problems). On-road single-vehicle crashes, such as collisions with pedestrians, have already been analyzed in Section 2.6.

The most positive finding in NHTSA's 1993 analysis of light trucks was that nonfatal rollovers and side impacts with fixed objects were substantially reduced with rear-wheel ABS [7]. These results should not be expected to carry over to passenger cars, because there are important differences in the braking and handling of trucks and cars. It may have been quite easy to lock the rear wheels of a non-ABS pickup truck or sport utility vehicle by a slight excess of brake pedal pressure; a substantial proportion of the loss-of-control incidents in light trucks involved brake-induced rear-wheel lockup; once pickup trucks begin to yaw, it is often difficult to bring them back under control before they leave the road; trucks' higher center of gravity makes them more vulnerable to rollover by off-road tripping mechanisms. It is not so easy to lock the wheels of a car, and even if they are locked, a car has a greater tendency to slide straight ahead than to yaw out of control or roll over. In short, light trucks are a vehicle type where ABS has exceptional potential to reduce single-vehicle crashes, even if the ABS is only a rear-wheel system. With cars, the potential to reduce collisions is much smaller, and it might be more than offset by factors that could increase risk.

## 3.1 Florida run-off-road crashes, 1990-92

### 3.1.1 Effect of ABS by crash mode

Table 3-1 contrasts the distribution, by crash mode, of ABS-equipped and non-ABS cars involved in run-off-road crashes during calendar years 1990-92. The ABS-equipped cars belong to the 48 make-model-subseries groups defined in Section 1.3 and Appendix B, and the non-ABS cars belong to the 48 comparison groups, comprising essentially the same makes, models and subseries. The non-ABS cars experienced 4978 control group crashes and the ABS-equipped cars had almost the same amount of exposure (4839 control group crashes).

Non-ABS cars experienced 42 primary rollovers; that is a ratio of .0084 to the control group (42/4978). ABS-equipped rolled over 74 times, a ratio of .0153 to the control group. Clearly, that's a big increase with ABS. The observed effect for ABS is

$$1 - [(74/4839) / (42/4978)] = 1 - (.0153/.0084) = 81 \text{ percent increase}$$

TABLE 3-1

**FLORIDA, 1990-92:** EFFECT OF ABS ON RUN-OFF-ROAD SINGLE-VEHICLE CRASHES

| **Type of Crash Involvement** | **Without ABS** N | **Without ABS** $N/N_{control}$ | **With ABS** N | **With ABS** $N/N_{control}$ | **Change in $N/N_{control}$ (%)** | $\chi^2$ | **Stat Sig?** |
|---|---|---|---|---|---|---|---|
| Control group (multivehicle - struck while stopped/slow) | 4978 | 1 | 4839 | 1 | | | |
| Primary rollover | 42 | .0084 | 74 | .0153 | up 81 | 9.64 | .01 |
| Side impact with fixed object | 131 | .0263 | 142 | .0293 | up 12 | .79 | |
| Rollover or side-fixed-object | 173 | .0348 | 216 | .0446 | up 28 | 5.82 | .05 |
| Frontal impact with fixed object | 432 | .0868 | 485 | .1002 | up 15 | 4.34 | .05 |
| Rollover or fixed-object | 605 | .1215 | 701 | .1449 | up 19 | 8.86 | .01 |

and it is statistically significant at the .01 level: Chi-square ($\chi^2$) for the 2 x 2 table formed by 4978, 4839, 42 and 74 is 9.64; $\chi^2$ has to exceed 3.84 for statistical significance at the .05 level and 6.64 for significance at the .01 level.

Non-ABS cars struck a fixed object sideways 131 times, and ABS-equipped cars, 142 times. Relative to the control group, that is a 12 percent increase. It is not statistically significant ($\chi^2$ = 0.79). However, when rollovers and side impacts with fixed objects, the two types of run-off-road crashes symptomatic of the greatest loss of directional control, are summed, the observed effect of ABS is

$$1 - [(216/4839) / (173/4978)] = 1 - (.0446/.0348) = 28 \text{ percent increase}$$

and it is statistically significant ($\chi^2$ = 5.82, $p < .05$).

Non-ABS cars frontally impacted a fixed object 432 times, and ABS-equipped cars, 485 times. Although this is a smaller effect than for rollovers, it is still a statistically significant 15 percent increase relative to the control group ($\chi^2$ = 4.34, $p < .05$). When all three types of run-off-road crashes are summed, the observed effect of ABS is

$$1 - [(701/4839) / (605/4978)] = 1 - (.1449/.1215) = 19 \text{ percent increase}$$

and it is statistically significant ($\chi^2$ = 8.86, $p < .01$).

### 3.1.2 Effect of ABS by road condition and crash mode

In multivehicle crashes, ABS had a substantial benefit on wet roads and little or no effect on dry roads, consistent with the results of stopping tests showing that ABS is more effective in reducing yawing and stopping distance on wet roads than on dry roads. Are there also divergent effects for run-off-road crashes? Table 3-1W presents the same analyses as Table 3-1, but limits the data to crashes under <u>wet</u> road conditions. The non-ABS cars experienced 739 control group crashes and, as in Table 3-1, the ABS-equipped cars had almost the same amount of exposure (694 control group crashes).

ABS-equipped cars experienced 18 rollovers, as opposed to just 6 for the non-ABS comparison cars. Relative to the control group, the observed effect of ABS is

$$1 - [(18/694) / (6/739)] = 1 - (.0259/.0081) = 291 \text{ percent increase}$$

and it is statistically significant ($\chi^2 = 6.67$, $p < .01$). Side impacts with fixed objects were up 24 percent with ABS. The combined increase in rollovers and side impacts with fixed objects is 51 percent, and it is statistically significant ($\chi^2 = 4.06$, $p < .05$). Frontal impacts with fixed objects increased by 22 percent. Overall, with ABS, run-off-road crashes increased by a statistically significant 32 percent under wet conditions ($\chi^2 = 4.50$, $p < .05$).

Table 3-1D presents the same analyses for crashes under <u>dry</u> road conditions. Unlike the analyses of multivehicle crashes, there are statistically significant effects here, and they are unfavorable to ABS. There were 56 rollovers in the ABS-equipped cars and only 36 in the non-ABS cars. Relative to the control group, that is a statistically significant increase of 59 percent ($\chi^2 = 4.76$, $p < .05$). Side impacts with fixed objects increased by 8 percent, and frontal impacts by 14 percent. All in all, run-off-road crashes increased with ABS by a statistically significant 16 percent on dry roads ($\chi^2 = 5.22$, $p < .05$). The Florida data suggest that ABS is associated with increases in run-off-road crashes under wet <u>and</u> dry conditions, with overall net effects of 32 and 16 percent, respectively. Given the sample sizes for the analyses, no definitive

TABLE 3-1W

**FLORIDA, 1990-92, WET ROADS:** EFFECT OF ABS ON RUN-OFF-ROAD SINGLE-VEHICLE CRASHES

| Type of Crash Involvement | Without ABS N | Without ABS $\frac{N}{N_{control}}$ | With ABS N | With ABS $\frac{N}{N_{control}}$ | Change in $N/N_{control}$ (%) | $\chi^2$ | Stat Sig? |
|---|---|---|---|---|---|---|---|
| Control group (multivehicle - struck while stopped/slow) | 739 | 1 | 694 | 1 | | | |
| Primary rollover | 6 | .0081 | 18 | .0259 | up 219 | 6.67 | .01 |
| Side impact with fixed object | 37 | .0501 | 43 | .0620 | up 24 | .86 | |
| Rollover or side-fixed-object | 43 | .0582 | 61 | .0879 | up 51 | 4.06 | .05 |
| Frontal impact with fixed object | 82 | .1110 | 94 | .1354 | up 22 | 1.56 | |
| Rollover or fixed-object | 125 | .1691 | 155 | .2233 | up 32 | 4.50 | .05 |

TABLE 3-1D

**FLORIDA, 1990-92, DRY ROADS:** EFFECT OF ABS ON RUN-OFF-ROAD SINGLE-VEHICLE CRASHES

| **Type of Crash Involvement** | **Without ABS** | | **With ABS** | | **Change in $N/N_{control}$** | | |
|---|---|---|---|---|---|---|---|
| | **N** | $\frac{N}{N_{control}}$ | **N** | $\frac{N}{N_{control}}$ | **(%)** | $\chi^2$ | **Stat Sig?** |
| Control group (multivehicle - struck while stopped/slow) | 4239 | 1 | 4145 | 1 | | | |
| Primary rollover | 36 | .0085 | 56 | .0135 | up 59 | 4.76 | .05 |
| Side impact with fixed object | 94 | .0222 | 99 | .0239 | up 8 | .26 | |
| Rollover or side-fixed-object | 130 | .0307 | 155 | .0374 | up 22 | 2.70 | |
| Frontal impact with fixed object | 350 | .0826 | 391 | .0943 | up 14 | 3.02 | |
| Rollover or fixed-object | 480 | .1132 | 546 | .1317 | up 16 | 5.22 | .05 |

conclusion can be reached that the effect is greater on wet roads than on dry roads.

### 3.2 Pennsylvania run-off-road crashes, 1990-92

#### 3.2.1 Effect of ABS by crash mode

ABS-equipped cars had a slightly larger number of run-off-road crashes in Pennsylvania than in Florida during 1990-92. That makes the Pennsylvania file an equal partner with Florida for the analyses of this chapter. Although, in absolute terms, Pennsylvania and Florida have about the same number of run-off-road crashes, the ratio of single-vehicle crashes to the control group is much higher in Pennsylvania, since Florida files include many multivehicle "fender benders" that would not be reportable in Pennsylvania. Because there are many urban areas and heavily forested rural areas in Pennsylvania, impacts with fixed objects are relatively more common than in Florida, and rollovers less common.

Table 3-2 compares the accident experience of ABS-equipped and non-ABS cars during calendar years 1990-92. The non-ABS cars experienced 1319 control group crashes, while the ABS-equipped cars were involved in 977 control group crashes. But there were 180 side impacts with fixed objects in both groups of cars. The observed effect for ABS is

$$1 - [(180/977) / (180/1319)] = 1 - (.1842/.1365) = 35 \text{ percent increase}$$

and it is statistically significant at the .01 level ($\chi^2 = 7.02$). Rollovers increased by a nonsignificant 18 percent, relative to the control group. The combined net effect on rollovers and side impacts with fixed objects is a statistically significant 31 percent increase ($\chi^2 = 7.03$, $p < .01$), which is almost identical to the effect in Florida (28 percent in Table 3-1).

TABLE 3-2

**PENNSYLVANIA, 1990-92:** EFFECT OF ABS ON RUN-OFF-ROAD SINGLE-VEHICLE CRASHES

| **Type of Crash Involvement** | **Without ABS** N | **Without ABS** $\frac{N}{N_{control}}$ | **With ABS** N | **With ABS** $\frac{N}{N_{control}}$ | **Change in $N/N_{control}$ (%)** | $\chi^2$ | **Stat Sig?** |
|---|---|---|---|---|---|---|---|
| Control group (multivehicle - struck while stopped/slow) | 1319 | 1 | 977 | 1 | | | |
| Primary rollover | 48 | .0364 | 42 | .0430 | up 18 | .60 | |
| Side impact with fixed object | 180 | .1365 | 180 | .1842 | up 35 | 7.02 | .01 |
| Rollover or side-fixed-object | 228 | .1729 | 222 | .2272 | up 31 | 7.03 | .01 |
| Frontal impact with fixed object | 789 | .5982 | 604 | .6182 | up 3 | .23 | |
| Rollover or fixed-object | 1017 | .7710 | 826 | .8454 | up 10 | 2.14 | |

In Pennsylvania, however, ABS had little effect on frontal impacts with fixed objects: a nonsignificant 3 percent increase was observed. The overall effect of ABS on run-off-road crashes is a 10 percent increase, which is not statistically significant ($\chi^2 = 2.14$).

3.2.2 Effect of ABS by road condition and crash mode

Table 3-2W analyzes Pennsylvania crashes when road surfaces are wet. Unlike the Florida analyses, ABS was not associated here with statistically significant increases in any run-off-road crash mode. In the small sample of rollover crashes, there was a nonsignificant reduction of 21 percent with ABS. Side impacts with fixed objects increased by 47 percent, but the effect falls short of statistical significance ($\chi^2 = 3.14$). Frontal impacts with fixed objects, the most common type of run-off-road crash, decreased by 12 percent. Overall, with ABS, run-off-road crashes decreased by a negligible 2 percent under wet conditions.

Table 3-2D presents the same analyses for dry road surfaces. Primary rollovers increased by 58 percent with ABS, an effect that falls short of statistical significance ($\chi^2 = 3.14$). Side impacts with fixed objects increased by 39 percent, and, because this type of crash is more common than rollovers, the increase is statistically significant ($\chi^2 = 4.87$, $p < .05$). The combined effect on rollovers and side impacts with fixed objects is a significant 43 percent increase ($\chi^2 = 7.15$, $p < .01$). Frontal impacts with fixed objects were up by 7 percent. Overall, run-off-road crashes increased with ABS by a nonsignificant 14 percent when roads were dry ($\chi^2 = 3.02$).

Pennsylvania files include a modest number of crashes under snowy or

TABLE 3-2W

**PENNSYLVANIA, 1990-92, WET ROADS:** EFFECT OF ABS ON RUN-OFF-ROAD SINGLE-VEHICLE CRASHES

| Type of Crash Involvement | Without ABS N | Without ABS $\frac{N}{N_{control}}$ | With ABS N | With ABS $\frac{N}{N_{control}}$ | Change in $N/N_{control}$ (%) | $\chi^2$ | Stat Sig? |
|---|---|---|---|---|---|---|---|
| Control group (multivehicle - struck while stopped/slow) | 332 | 1 | 240 | 1 | | | |
| Primary rollover | 14 | .0422 | 8 | .0333 | down 21 | .27 | |
| Side impact with fixed object | 48 | .1446 | 51 | .2125 | up 47 | 3.14 | |
| Rollover or side-fixed-object | 62 | .1867 | 59 | .2458 | up 32 | 1.88 | |
| Frontal impact with fixed object | 227 | .6837 | 146 | .6083 | down 12 | .74 | |
| Rollover or fixed-object | 289 | .8705 | 205 | .8542 | down 2 | .02 | |

TABLE 3-2D

**PENNSYLVANIA, 1990-92, DRY ROADS:** EFFECT OF ABS ON RUN-OFF-ROAD SINGLE-VEHICLE CRASHES

| Type of Crash Involvement | Without ABS N | Without ABS $\frac{N}{N_{control}}$ | With ABS N | With ABS $\frac{N}{N_{control}}$ | Change in $N/N_{control}$ (%) | $\chi^2$ | Stat Sig? |
|---|---|---|---|---|---|---|---|
| Control group (multivehicle - struck while stopped/slow) | 958 | 1 | 724 | 1 | | | |
| Primary rollover | 26 | .0271 | 31 | .0428 | up 58 | 2.89 | |
| Side impact with fixed object | 97 | .1013 | 102 | .1409 | up 39 | 4.87 | .05 |
| Rollover or side-fixed-object | 123 | .1284 | 133 | .1837 | up 43 | 7.15 | .01 |
| Frontal impact with fixed object | 470 | .4906 | 380 | .5249 | up 7 | .63 | |
| Rollover or fixed-object | 593 | .6190 | 513 | .7086 | up 14 | 3.02 | |

icy road conditions; however, not surprisingly, a large proportion of them are run-off-road crashes, permitting an estimate of the overall effect of ABS, as shown in Table 3-2SI. There are so few control group multivehicle crashes on snow or ice that it is better to use the control group of multivehicle crashes under any road conditions. Relative to this control group, run-off-road crashes on snowy or icy roads increased by 8 percent with ABS. The effect is not statistically significant, but is about the same magnitude as the results on dry and wet roads.

### 3.3 Missouri run-off-road crashes, 1990-92

ABS-equipped cars experienced fewer than half as many run-off-road crashes in Missouri during 1990-92 than in either Florida or Pennsylvania. The sample is just enough for analyzing the effect of ABS for all road conditions, combined, but it is inadvisable to subdivide the data for separate analyses by road condition. Table 3-3 shows that ABS-equipped and non-ABS cars experienced the same number of rollovers, even though the exposure for ABS-equipped cars was considerably smaller. The observed effect for ABS is

$$1 - [(30/707) / (30/1237)] = 1 - (.0424/.0243) = 75 \text{ percent increase}$$

and it is statistically significant ($\chi^2 = 4.65$, $p < .05$). That is the only significant effect in the Missouri data. Side impacts with fixed objects are down 8 percent; frontal impacts are up 12 percent. Overall, the observed net effect of ABS on run-off-road crashes is a nonsignificant 10 percent increase, which is consistent with the increases seen in Florida (19 percent) and Pennsylvania (10 percent).

### 3.4 Florida-Pennsylvania-Missouri, 1990-92 - combined results

Since there are relatively small numbers of run-off-road crashes in

TABLE 3-2SI

**PENNSYLVANIA, 1990-92, SNOWY OR ICY ROADS:** EFFECT OF ABS ON RUN-OFF-ROAD SINGLE-VEHICLE CRASHES

| | **Without ABS** | | **With ABS** | | **Change in $N/N_{control}$** | | |
|---|---|---|---|---|---|---|---|
| **Type of Crash Involvement** | **N** | $\frac{N}{N_{control}}$ | **N** | $\frac{N}{N_{control}}$ | **(%)** | $\chi^2$ | **Stat Sig?** |
| Control group (multivehicle - struck while stopped/slow under <u>any</u> road conditions) | 1319 | 1 | 977 | 1 | | | |
| Rollover or fixed-object on <u>snowy or icy</u> road | 135 | .1024 | 108 | .1105 | up 8 | .32 | |

TABLE 3-3

**MISSOURI, 1990-92:** EFFECT OF ABS ON RUN-OFF-ROAD SINGLE-VEHICLE CRASHES

| | Without ABS | | With ABS | | Change in $N/N_{control}$ | | |
|---|---|---|---|---|---|---|---|
| **Type of Crash Involvement** | **N** | $\frac{N}{N_{control}}$ | **N** | $\frac{N}{N_{control}}$ | **(%)** | $\chi^2$ | **Stat Sig?** |
| Control group (multivehicle - struck while stopped/slow) | 1237 | 1 | 707 | 1 | | | |
| Primary rollover | 30 | .0243 | 30 | .0424 | up 75 | 4.65 | .05 |
| Side impact with fixed object | 150 | .1213 | 79 | .1117 | down 8 | .31 | |
| Rollover or side-fixed-object | 180 | .1455 | 109 | .1542 | up 6 | .20 | |
| Frontal impact with fixed object | 298 | .2409 | 191 | .2702 | up 12 | 1.22 | |
| Rollover or fixed-object | 478 | .3864 | 300 | .4243 | up 10 | 1.15 | |

each of the individual State data files, it would be quite desirable to combine the three files for statistically more precise results. Section 2.4 described a procedure for combining accident data from Florida, Pennsylvania and Missouri, weighting the accident cases to minimize potential biases. The procedure guarantees that the combined accident sample for the three States will have the same number of ABS-equipped and non-ABS weighted accident cases (for all crash modes combined, including single-vehicle) and that the ABS-equipped and non-ABS samples each have the same weighted make-model mix. Also, by this procedure, "Chi-square" statistics calculated for the weighted accident counts (treating them as if they were simple, unweighted accident counts) are almost always conservative tests of statistical significance.

### 3.4.1 Effect of ABS by crash mode

Table 3-4 compares the run-off-road crashes of ABS-equipped and non-ABS cars during calendar years 1990-92. The non-ABS cars accounted for 5404 weighted control group crashes, while the ABS-equipped cars were involved in a nearly identical 5458 weighted control group crashes. Combining data from the three States yields a statistically significant increase, with ABS, in every type of run-off-road crash. There were 79 weighted rollover cases involving non-ABS cars and 119 among the ABS-equipped cars. That is an effect of

$$1 - [(119/5458) / (79/5404)] = 1 - (.0218/.0146) = 49 \text{ percent increase}$$

and it is statistically significant at the .01 level ($\chi^2 = 7.55$). Side impacts with fixed objects increased by a statistically significant 22 percent with ABS ($\chi^2 = 5.70$, $p < .05$). The combined effect on rollovers and side impacts with fixed objects was a significant 28 percent increase ($\chi^2 = 11.46$, $p < .01$).

Frontal impacts with fixed objects increased by a statistically

TABLE 3-4

**FLORIDA-PENNSYLVANIA-MISSOURI, 1990-92:**
EFFECT OF ABS ON RUN-OFF-ROAD SINGLE-VEHICLE CRASHES

(weighted, balanced data)

| | Without ABS | | With ABS | | Change in $N/N_{control}$ | | |
|---|---|---|---|---|---|---|---|
| **Type of Crash Involvement** | **N** | $\frac{N}{N_{control}}$ | **N** | $\frac{N}{N_{control}}$ | **(%)** | $\chi^2$ | **Stat Sig?** |
| Control group (multivehicle - struck while stopped/slow) | 5404 | 1 | 5458 | 1 | | | |
| Primary rollover | 79 | .0146 | 119 | .0218 | up 49 | 7.55 | .01 |
| Side impact with fixed object | 268 | .0496 | 331 | .0606 | up 22 | 5.70 | .05 |
| Rollover or side-fixed-object | 347 | .0642 | 450 | .0824 | up 28 | 11.46 | .01 |
| Frontal impact with fixed object | 875 | .1619 | 1014 | .1858 | up 15 | 7.58 | .01 |
| Rollover or fixed-object | 1222 | .2261 | 1464 | .2682 | up 19 | 15.61 | .01 |

significant 15 percent ($\chi^2$ = 7.58, $p < .01$). The net increase in all types of run-off-road crashes, with ABS, is

1 - [(1464/5458) / (1222/5404)] = 1 - (.2682/.2261) = 19 percent increase

and it is statistically significant at the .01 level ($\chi^2$ = 15.61). With this larger sample, the results for the three types of crashes follow the intuitively expected pattern: rollovers, which typically involve the most severe loss of control during the off-road excursion, have the largest increase (49 percent), followed by side impacts with fixed objects (22 percent), followed by frontal impacts, the type least likely to involve a complete loss of directional control (15 percent increase).

### 3.4.2 Effect of ABS by road condition and crash mode

The combined data file is especially useful for comparing the effect of ABS on wet, dry and snowy/icy roads. Table 3-4W analyzes the effect of ABS on wet roads. Rollovers increased 34 percent with ABS, side impacts with fixed objects are up 26 percent, and frontal impacts, up 22 percent; none of these increases is statistically significant. However, the net effect on all run-off-road crashes is

1 - [(345/879) / (293/922)] = 1 - (.3925/.3178) = 24 percent increase

and it is statistically significant ($\chi^2$ = 5.23, $p < .05$).

Table 3-4D presents the data for dry roads. The effect of ABS follows almost the same pattern as on wet roads. Rollovers are up 54 percent with ABS ($\chi^2$ = 6.29, $p < .05$), side impacts with fixed objects are up 19 percent, and frontal impacts rose 13 percent ($\chi^2$ = 4.56, $p < .05$). The overall increase in run-off-road collisions is a statistically significant 17 percent ($\chi^2$ = 9.64, $p < .01$), which is essentially the same as on wet roads.

TABLE 3-4W

**FLORIDA-PENNSYLVANIA-MISSOURI, 1990-92, WET ROADS:**
EFFECT OF ABS ON RUN-OFF-ROAD SINGLE-VEHICLE CRASHES

(weighted, balanced data)

| **Type of Crash Involvement** | **Without ABS** | | **With ABS** | | **Change in $N/N_{control}$** | | |
|---|---|---|---|---|---|---|---|
| | **N** | **$\frac{N}{N_{control}}$** | **N** | **$\frac{N}{N_{control}}$** | **(%)** | $\chi^2$ | **Stat Sig?** |
| Control group (multivehicle - struck while stopped/slow) | 922 | 1 | 879 | 1 | | | |
| Primary rollover | 19 | .0206 | 24 | .0273 | up 34 | .83 | |
| Side impact with fixed object | 78 | .0846 | 93 | .1058 | up 26 | 1.95 | |
| Rollover or side-fixed-object | 97 | .1052 | 117 | .1331 | up 27 | 2.63 | |
| Frontal impact with fixed object | 196 | .2126 | 228 | .2594 | up 22 | 3.39 | |
| Rollover or fixed-object | 293 | .3178 | 345 | .3925 | up 24 | 5.23 | .05 |

TABLE 3-4D

**FLORIDA-PENNSYLVANIA-MISSOURI, 1990-92, DRY ROADS:**
EFFECT OF ABS ON RUN-OFF-ROAD SINGLE-VEHICLE CRASHES

(weighted, balanced data)

| | **Without ABS** | | **With ABS** | | **Change in $N/N_{control}$** | | |
|---|---|---|---|---|---|---|---|
| **Type of Crash Involvement** | **N** | **$\frac{N}{N_{control}}$** | **N** | **$\frac{N}{N_{control}}$** | **(%)** | $\chi^2$ | **Stat Sig?** |
| Control group (multivehicle - struck while stopped/slow) | 4450 | 1 | 4555 | 1 | | | |
| Primary rollover | 56 | .0126 | 88 | .0193 | up 54 | 6.29 | .05 |
| Side impact with fixed object | 168 | .0378 | 205 | .0450 | up 19 | 2.75 | |
| Rollover or side-fixed-object | 224 | .0503 | 293 | .0643 | up 27 | 7.26 | .01 |
| Frontal impact with fixed object | 616 | .1384 | 715 | .1570 | up 13 | 4.56 | .05 |
| Rollover or fixed-object | 840 | .1888 | 1008 | .2213 | up 17 | 9.64 | .01 |

Table 3-4SI presents, essentially, the combined results from Pennsylvania and Missouri for snowy or icy roads. Since there are few control group multivehicle crashes on snow or ice, it is better to use the control group of multivehicle crashes under any road conditions. Relative to this control group, run-off-road crashes under snowy or icy conditions increased by 19 percent with ABS. Although the increase is not statistically significant, it is virtually the same as on dry and wet roads.

These results contrast with the findings on multivehicle crashes, where there were great differences between wet and dry roads. Whatever mechanism is causing the increase in run-off-road crashes with ABS, it appears to work about the same under all road conditions. Or, alternatively, this mechanism is most severe on wet roads, but is partially offset by the improved stopping distances and directional control that ABS offers on wet roads.

### 3.5 Fatal run-off-road crashes, 1989-93

Crash avoidance measures need to be evaluated separately in fatal and nonfatal crashes, because the effects are in some cases quite different. Section 2.5 provided examples of devices that were less beneficial in fatal than in nonfatal crashes. Fatal run-off-road crashes are of exceptional interest because they account for approximately half of motor vehicle occupant fatalities (whereas the overwhelming majority of nonfatal crashes are multivehicle).

#### 3.5.1 Effect of ABS by crash mode

Fatal Accident Reporting System (FARS) data are available through 1993 and contain a sample of ABS-equipped cars involved in fatal run-off-road crashes that is adequate for preliminary effectiveness analyses. The same approach as

TABLE 3-4SI

**PENNSYLVANIA-MISSOURI-FLORIDA, 1990-92, SNOWY OR ICY ROADS:**
EFFECT OF ABS ON RUN-OFF-ROAD SINGLE-VEHICLE CRASHES

(weighted, balanced data)

| | **Without ABS** | | **With ABS** | | **Change in $N/N_{control}$** | | |
|---|---|---|---|---|---|---|---|
| **Type of Crash Involvement** | **N** | $\frac{N}{N_{control}}$ | **N** | $\frac{N}{N_{control}}$ | **(%)** | $\chi^2$ | **Stat Sig?** |
| Control group (multivehicle - struck while stopped/slow under <u>any</u> road conditions) | 5404 | 1 | 5458 | 1 | | | |
| Rollover or fixed-object on <u>snowy or icy</u> road | 90 | .0167 | 110 | .0202 | up 19 | 1.53 | |

the State accident analysis - comparing rollovers and fixed-object collisions to a "control group" of multivehicle crashes unaffected by ABS - is used with FARS, but the control group is not the same as in the State data analyses. As explained in Section 2.5, for purposes of statistical analyses, FARS contains insufficient cases of cars that were struck by another vehicle while they were stopped or moving slowly. However, the analyses in Section 2.5 presented evidence that ABS has little, if any, overall net effect on multivehicle crashes on dry roads. As in Tables 2-12 and 2-13, this larger group of multivehicle collisions will be used as the "control group" for analyzing the effect of ABS on run-off-road crashes.

Table 3-5 compares the accident experience of ABS-equipped and non-ABS cars during calendar years 1989-93. Table 3-5 shows that non-ABS cars had 1021 fatal multivehicle involvements on dry roads, while ABS-equipped cars had 858 - i.e., "exposure" is about 16 percent lower for the ABS-equipped cars. Non-ABS cars were involved in 97 fatal primary rollovers, whereas ABS-equipped cars were involved in 100. The observed effect of ABS on rollovers is

$$1 - [(100/858) / (97/1021)] = 1 - (.1166/.0950) = 23 \text{ percent increase}$$

and it is not statistically significant ($\chi^2 = 1.87$). Non-ABS cars experienced 94 fatal side impacts with fixed objects, but that increased to 124 in the ABS-equipped cars. The effect of ABS on side impacts with fixed objects is

$$1 - [(124/858) / (94/1021)] = 1 - (.1445/.0921) = 57 \text{ percent increase}$$

and it is statistically significant at the .01 level ($\chi^2 = 9.87$). The combined effect of ABS on rollovers and side impacts with fixed objects is a statistically significant 40 percent increase ($\chi^2 = 9.43$, $p < .01$).

Frontal impacts with fixed objects increased by 19 percent, an effect

TABLE 3-5

**FARS, 1989-93:**
EFFECT OF ABS ON FATAL RUN-OFF-ROAD SINGLE-VEHICLE CRASHES

| | Without ABS | | With ABS | | Change in $N/N_{control}$ | | |
|---|---|---|---|---|---|---|---|
| **Type of Crash Involvement** | **N** | $\frac{N}{N_{control}}$ | **N** | $\frac{N}{N_{control}}$ | **(%)** | $\chi^2$ | **Stat Sig?** |
| Control group (fatal multivehicle involvements on dry roads) | 1021 | 1 | 858 | 1 | | | |
| Primary rollover | 97 | .0950 | 100 | .1166 | up 23 | 1.87 | |
| Side impact with fixed object | 94 | .0921 | 124 | .1445 | up 57 | 9.87 | .01 |
| Rollover or side-fixed-object | 191 | .1871 | 224 | .2611 | up 40 | 9.43 | .01 |
| Frontal impact with fixed object | 240 | .2351 | 239 | .2786 | up 19 | 2.75 | |
| Rollover or fixed-object | 431 | .4221 | 463 | .5396 | up 28 | 9.12 | .01 |

that falls short of statistical significance ($\chi^2 = 2.75$). The overall effect of ABS on run-off-road crashes is a statistically significant 28 percent increase ($\chi^2 = 9.12$, $p < .01$). This effect is about the same, or slightly worse, than the increase of nonfatal run-off-road crashes (19 percent in Table 3-4).

### 3.5.2 Effect of ABS by road condition and crash mode

Table 3-5W analyzes rollovers and fixed-object impacts under wet road conditions. The control group, however, is the same as in Table 3-5: multivehicle crashes on dry roads. The accident samples were small, but not so small as to preclude significant effects. Side impacts with fixed objects doubled with ABS, relative to the control group ($\chi^2 = 4.09$, $p < .05$). The combined effect on rollovers and side impacts is a 90 percent increase, and it is statistically significant ($\chi^2 = 5.13$, $p < .05$). On the other hand, frontal impacts with fixed objects were reduced by a nonsignificant 25 percent. The overall effect of ABS on run-off-road collisions is a nonsignificant 17 percent increase.

Table 3-5D presents the corresponding analysis for dry roads. The likelihood of a fatal rollover increased by a nonsignificant 26 percent with ABS, relative to the control group. Side impacts with fixed objects increased by a statistically significant 42 percent ($\chi^2 = 4.79$, $p < .05$). The combined effect on rollovers and side impacts is a significant 34 percent increase ($\chi^2 = 6.13$, $p < .05$). When roads were dry, frontal impacts with fixed objects increased with ABS by a statistically significant 26 percent ($\chi^2 = 4.37$, $p < .05$). The overall effect of ABS on run-off-road collisions is a 29 percent increase, which reaches significance at the .01 level ($\chi^2 = 8.82$).

TABLE 3-5W

**FARS, 1989-93, WET ROADS:**
EFFECT OF ABS ON FATAL RUN-OFF-ROAD SINGLE-VEHICLE CRASHES

| Type of Crash Involvement | Without ABS N | Without ABS $\frac{N}{N_{control}}$ | With ABS N | With ABS $\frac{N}{N_{control}}$ | Change in $N/N_{control}$ (%) | $\chi^2$ | Stat Sig? |
|---|---|---|---|---|---|---|---|
| Control group (fatal multivehicle involvements on dry roads) | 1021 | 1 | 858 | 1 | | | |
| Primary rollover | 7 | .0069 | 10 | .0117 | up 70 | 1.18 | |
| Side impact with fixed object | 13 | .0127 | 22 | .0256 | up 101 | 4.09 | .05 |
| Rollover or side-fixed-object | 20 | .0196 | 32 | .0373 | up 90 | 5.13 | .05 |
| Frontal impact with fixed object | 35 | .0343 | 22 | .0256 | down 25 | 1.11 | |
| Rollover or fixed-object | 55 | .0539 | 54 | .0629 | up 17 | .62 | |

TABLE 3-5D

**FARS, 1989-93, DRY ROADS:**
EFFECT OF ABS ON FATAL RUN-OFF-ROAD SINGLE-VEHICLE CRASHES

| | Without ABS | | With ABS | | Change in $N/N_{control}$ | | |
|---|---|---|---|---|---|---|---|
| **Type of Crash Involvement** | **N** | $\frac{N}{N_{control}}$ | **N** | $\frac{N}{N_{control}}$ | **(%)** | $\chi^2$ | **Stat Sig?** |
| Control group (fatal multivehicle involvements on dry roads) | 1021 | 1 | 858 | 1 | | | |
| Primary rollover | 82 | .0803 | 87 | .1014 | up 26 | 2.11 | |
| Side impact with fixed object | 79 | .0774 | 94 | .1096 | up 42 | 4.79 | .05 |
| Rollover or side-fixed-object | 161 | .1577 | 181 | .2110 | up 34 | 6.13 | .05 |
| Frontal impact with fixed object | 201 | .1969 | 212 | .2471 | up 26 | 4.37 | .05 |
| Rollover or fixed-object | 362 | .3546 | 393 | .4580 | up 29 | 8.82 | .01 |

The FARS files include a handful of run-off-road crashes under snowy or icy conditions. Table 3-5SI shows that run-off-road crashes increased by 36 percent with ABS, relative to the control group. The increase is not statistically significant, but it is similar to the effects seen on dry and wet roads.

### 3.5.3 Discussion of FARS results

The increases in fatal run-off-road crashes with ABS are obviously a source of concern. Any significant increase would be disturbing, but an increase on the order of 28 percent, as observed in Table 3-4, is surprising, since the overall effects of crash avoidance measures are rarely so large. In Chapter 2, at least, it was intuitively reasonable that the enhanced stopping capabilities with ABS would increase the likelihood of being struck in the rear by another vehicle. But at first glance, the increase in run-off-road crashes runs counter to intuition, because these crashes are often caused by yawing and loss of directional control - just what ABS is supposed to prevent. NHTSA's stopping tests showed that 4-wheel ABS was highly successful in preserving steering and directional control under a variety of road conditions, including highly adverse split-mu surfaces.

The data need to be examined further to see if any biases may have been introduced during the analytic process. The results could hardly be due to sampling error, alone. There is a high degree of statistical significance; increases are found in every type of run-off-road crash; results from three State files, with larger samples, strongly support the FARS analyses.

It might be asked if the use of a "control group" of crashes,

TABLE 3-5SI

**FARS, 1989-93, SNOWY OR ICY ROADS:**
EFFECT OF ABS ON FATAL RUN-OFF-ROAD SINGLE-VEHICLE CRASHES

| | Without ABS | | With ABS | | Change in $N/N_{control}$ | | |
|---|---|---|---|---|---|---|---|
| **Type of Crash Involvement** | **N** | $\frac{N}{N_{control}}$ | **N** | $\frac{N}{N_{control}}$ | **(%)** | $\chi^2$ | **Stat Sig?** |
| Control group (fatal multivehicle involvements on dry roads) | 1021 | 1 | 858 | 1 | | | |
| Rollover or fixed-object | 14 | .0137 | 16 | .0186 | up 36 | .70 | |

supposedly unaffected by ABS, may have systematically biased the results - i.e., that the control group is not a valid measure of "exposure." The same control groups were used in the preceding chapter's analyses of multivehicle crashes, and they worked there, as intuitively expected. In the evaluation of rear-wheel ABS for light trucks [7], the control group was defined by the same procedure, and there were significant reductions, not increases in nonfatal run-off-road crashes.

As a final test of the control group, an "alternative" FARS data set was created, containing a list of make-models slightly resembling the ones used in the preceding tables, except that they did not switch to ABS during the applicable model years. For example, instead of the 1992 Cavalier, Grand Am, Corsica, etc. (which switched to ABS), it contained, among others, the 1992 Escort, Tempo, Shadow, Spirit, etc. (which did not). Instead of the 1991 Caprice and Town Car (which switched to ABS), it contained, among others, the 1991 Taurus and Grand Marquis (which did not). The "comparison" cars for this data set are the 1991 Escort, Tempo, Shadow, Spirit, the 1990 Taurus and Grand Marquis, etc. Run-off-road crashes increased in the "alternative" data set by a negligible 1 percent over their "comparison" cars, relative to the control group.

Another possibility is that, in the FARS data set used for the analyses of this chapter, there are some major differences, other than ABS, in the non-ABS and ABS-equipped cars: confounding factors such as the age of the drivers, the size of the cars, etc. *A priori*, the likelihood of such differences is small, because the 48 ABS-equipped make-model groups and their non-ABS comparison groups were picked to match as closely as possible. Make-models were excluded from the study if they were significantly redesigned, or notably upgraded in size, power, or luxury at the time they got ABS. In the actual sample, too, the ABS-equipped and non-ABS cars involved in multivehicle crashes on dry roads had quite similar characteristics:

| | Percent of Cars | |
|---|---|---|
| | Non-ABS | ABS-Equipped |
| Rural crash location | 47 | 45 |
| Driver younger than 30 | 27 | 22 |
| Male driver | 66 | 68 |
| Drinking driver | 12 | 13 |
| Wheelbase 105 inches or less | 27 | 33 |

The factors that would tend to be associated with a high rate of run-off-road crashes (relative to the control group) are: rural locations; young, male, drinking drivers; and small cars. The ABS-equipped cars had a slightly <u>lower</u> share of rural locations and young drivers than the non-ABS comparison cars, and a slightly higher share of male drivers, drinking drivers, and small cars. The net effect of these, and similar factors would be negligible.

It is conceivable that the ABS-equipped cars might have more run-off-road crashes because they are newer than the non-ABS cars. Specifically, the sample of ABS-equipped cars contains a substantial percentage of cars of the current model year, while the non-ABS sample does not contain any brand-new cars. Cars less than a year old might possibly have more run-off-road crashes because their drivers are not yet familiar with them. The "alternative" FARS data set and its "comparison" cars, as described above (make-models that did <u>not</u> switch to ABS during the applicable model years), also test this hypothesis. The "alternative" data set contains a substantial portion of brand-new vehicles and its "comparison" data set does not contain any; nevertheless, run-off-road crashes only increased in the "alternative" data set by 1 percent over the "comparison" cars.

The FARS data reveal that the increase in run-off-road crashes with ABS was not confined to one specific make-model or group of make-models, but occurred in a wide variety of crash situations. Run-off-road crashes increased in General Motors cars (which constituted about half of the sample) and in Fords and imported cars. Increases were found in all of the following subgroups of crash situations, drivers and vehicles:

| | Percent Increase in Run-Off-Road Crashes with ABS |
|---|---|
| Overall | 28 |
| In rural areas | 19 |
| In urban areas | 47 |
| On straight roads | 21 |
| On curves | 58 |
| Driver younger than 30 | 79 |
| Driver age 30 and up | 11 |
| Male driver | 32 |
| Female driver | 17 |
| Drinking driver | 42 |
| Non-drinking driver | 20 |
| Wheelbase 105 inches or less | 46 |
| Wheelbase more than 105 inches | 20 |
| Make-models getting ABS before 1992 | 20 |
| Make-models getting ABS in 1992 | 54 |

Substantial variations in the observed effect of ABS can be expected among subgroups, given the sample size of the FARS data set, but none of them showed a benefit for ABS.

Since the increase in run-off-road crashes is pervasive, it is appropriate to ask why. Several possibilities were offered at the beginning of this chapter, and in Chapter 1. Risk compensation - drivers going faster because they think ABS will help them avoid a crash - is unlikely to account for more than a small portion of the increase, if any. Risk compensation seems about as likely to increase multivehicle as single vehicle crashes. If there were significant risk compensation, frontal multivehicle involvements would also increase, and they did not. Similarly, the increase is unlikely to be a result of drivers not understanding how to operate ABS - i.e., pumping the brakes or applying them lightly, rather than slamming them. According to a survey, many drivers do not understand how to use ABS [2]. Nevertheless, this misuse would be more likely to create a zero effect for ABS than a large increase in crashes. It would also tend to affect single and multivehicle crashes in the same direction.

It is necessary to look for factors that pertain to run-off-road crashes, but not multivehicle and pedestrian impacts. Two hypotheses were presented at the beginning of this chapter: (1) ABS allows the abrupt, instinctive steering input of an inexpert driver in a panic situation to swing the car off the road and out of control; (2) longer stopping distances on loose surface materials encountered after a car leaves the road. Neither hypothesis can be tested directly by the accident data considered in this report. The mechanisms that link ABS with an increase in run-off-road crashes can only be established through additional studies, such as interviews with drivers of ABS-equipped cars who were involved in run-off-road crashes, or a series of stopping tests involving combinations of hard braking and abrupt steering.

# CHAPTER 4

# THE OVERALL EFFECT OF ABS

The net effect of ABS on nonfatal crashes can be estimated by statistical analyses of 1990-92 State accident files from Florida, Pennsylvania and Missouri. The net effect on fatal crashes may be inferred from 1989-93 FARS data. The analyses of this chapter corroborate an earlier study by the Highway Loss Data Institute that showed little overall effect for ABS [2]. Before proceeding to those analyses, however, it is appropriate to summarize the principal findings of Chapters 2 and 3 on the effectiveness of ABS in individual crash modes. Table 4-1, displaying all the results in multivehicle crashes, pedestrian impacts and run-off-road crashes, provides an impression of the consistency and strength of the various effects, and their tendency to cancel one another.

## 4.1 Summary of principal effectiveness findings

The numbers in Table 4-1 are the percentages of accident reduction in each crash mode. Positive numbers indicate a reduction of risk with ABS, negative numbers an increase. Bold numbers denote statistically significant effects. Whatever the overall effect of ABS, there is no shortage of statistically significant results in the individual crash modes. Specifically, there are significant benefits in multivehicle crashes on wet roads and fatal pedestrian impacts, but significant increases in run-off-road crashes.

The reduction in multivehicle crashes on wet roads is consistently around 15 percent in the State accident files. The reduction may be even higher for fatal crashes. The benefit does not apply equally to all types of

TABLE 4-1

OBSERVED EFFECTS OF ABS ON MULTIVEHICLE, PEDESTRIAN AND RUN-OFF-ROAD CRASHES OF PASSENGER CARS

(Statistically significant effects are in ***bold italics***; positive numbers are reductions, negative numbers are increases)

| | Accident Reduction (%) | | | | |
|---|---|---|---|---|---|
| **Type of Crash Involvement** | **FL** | **PA** | **MO** | **FL-PA-MO** | **FARS** |
| MULTIVEHICLE - WET ROADS | | | | | |
| All involvements | ***12*** | ***16*** | ***11*** | ***14*** | ***24*** |
| All frontal involvements | ***28*** | ***26*** | 14 | ***28*** | |
| Front-to-rear: striking | ***41*** | ***38*** | 24 | ***39*** | |
| Moving fast and striking a stopped or slow-moving vehicle | ***43*** | ***44*** | | | |
| Struck in rear while moving | ***-44*** | -20 | -11 | ***-27*** | |
| MULTIVEHICLE - SNOWY OR ICY ROADS | | 11 | 22 | 11 | 13 |
| MULTIVEHICLE - DRY ROADS | | | | | |
| All frontal involvements | 3 | 2 | 8 | 5 | - 3 |
| Front-to-rear: striking | - 2 | - 7 | 6 | - 1 | |
| Moving fast and striking a stopped or slow-moving vehicle | ***15*** | ***23*** | | | |
| Struck in rear while moving | 2 | - 5 | -14 | 1 | |
| PEDESTRIAN - ALL ROADS | | | | - 3 | ***27*** |
| RUN-OFF-ROAD - ALL ROAD CONDITIONS | | | | | |
| All run-off-road crashes | ***-19*** | -10 | -10 | ***-19*** | ***-28*** |
| Rollover or side-fixed-object | ***-28*** | ***-31*** | -6 | ***-28*** | ***-40*** |
| Primary rollovers | ***-81*** | -18 | ***-75*** | ***-49*** | -23 |
| Side impacts with fixed objects | -12 | ***-35*** | 8 | ***-22*** | ***-57*** |
| Frontal impacts with fixed objects | ***-15*** | - 3 | -12 | ***-15*** | -19 |
| RUN-OFF-ROAD - WET ROAD CONDITIONS | ***-32*** | - 2 | | ***-24*** | -17 |
| RUN-OFF-ROAD - DRY ROAD CONDITIONS | ***-16*** | -14 | | ***-17*** | ***-29*** |
| RUN-OFF-ROAD - SNOWY OR ICY | | - 8 | | -19 | -36 |

multivehicle crashes. The reduction is highest (about 40 percent) for the types of crashes that intuitively seem most preventable with good brakes: hitting another vehicle in the rear, or hitting a stopped or slow-moving vehicle. However, these impressive benefits are partially cancelled because a vehicle with excellent braking capabilities is more likely to be struck in the rear by other vehicles that only have conventional braking capabilities. Thus, the net benefit in multivehicle crashes on wet roads is substantially lower than 40 percent. The benefits on snowy or icy roads, while not statistically significant, are similar to those on wet roads.

ABS has little net effect on multivehicle crashes on dry roads. The only statistically significant findings were 15-20 percent reductions in involvements as a fast-moving vehicle hitting a slow or stopped vehicle. This type of crash, however, only accounts for a modest portion of all multivehicle crashes, and the benefits for ABS do not extend to the other types. The contrast in the results for wet roads and dry roads is consistent with findings in stopping tests, where ABS improved stopping distances and directional control substantially on wet surfaces, but much less so on dry surfaces. It is no surprise that ABS reduced multivehicle crashes on wet roads, but it is perhaps surprising that it had so little effect on dry roads.

Analyses of FARS data showed a statistically significant 27 percent reduction of fatal collisions with pedestrians, bicyclists, trains, etc. (on-road single-vehicle crashes). Unlike the effects for multivehicle crashes, this reduction was about equally large on wet and dry roads. Nonfatal pedestrian crashes account for only a small percentage of all nonfatal crashes, and the State data files did not show a significant reduction with ABS.

Run-off-road crashes of passenger cars - rollovers, side impacts with fixed objects and frontal impacts with fixed objects - were not reduced by ABS. On the contrary, they significantly increased in the ABS-equipped cars. Nonfatal run-off-road crashes increased by about 15-20 percent, and fatal crashes by closer to 25-30 percent. Rollovers and side impacts with fixed objects, which are crashes that typically follow a complete loss of directional control, had the highest increases with ABS. Frontal impacts with fixed objects, where the driver is more likely to have retained at least some directional control prior to impact, had smaller but still significant increases. These negative effects were about the same on wet, dry, snowy and icy roads.

The increases are surprising in view of the outstanding performance of ABS in maintaining directional and steering control during stopping tests. Although hypotheses were offered in Chapter 3, the actual reason for the increase is unknown. Nevertheless, the increase appears to be real. The analysis is based on a set of ABS-equipped make-models that is representative of the "average" car on the road.

## 4.2 Overall effect of ABS on police-reported crashes

In State accident files, where the overwhelming majority of crashes are nonfatal, multivehicle crashes greatly outnumber run-off-road crashes. There are more multivehicle crashes on wet roads, alone, than there are run-off-road crashes under all road conditions. As a result, the number of wet-road multivehicle collisions prevented by ABS more or less cancels the increase in the rollovers and fixed-object impacts.

Table 4-2 examines the overall effect of ABS on Florida crashes during

TABLE 4-2

**FLORIDA, 1990-92:** OVERALL EFFECT OF ABS

| Type of Crash Involvement | Without ABS N | Without ABS $\frac{N}{N_{control}}$ | With ABS N | With ABS $\frac{N}{N_{control}}$ | Change in $N/N_{control}$ (%) | $\chi^2$ | Stat Sig? |
|---|---|---|---|---|---|---|---|
| CONTROL GROUP (dry road multivehicle - struck while stopped/slow) | 4239 | 1 | 4145 | 1 | | | |
| ALL OTHER INVOLVEMENTS | 9369 | 2.2102 | 8973 | 2.1648 | down 2 | .62 | |

calendar years 1990-92. The table counts the accident involvements of ABS-equipped cars belonging to the 48 make-model-subseries groups defined in Section 1.3 and Appendix B, and the non-ABS cars belonging to the 48 comparison groups, comprising essentially the same makes, models and subseries. As in the preceding chapters, the control group includes accident involvements where the case vehicle is standing still, parked, or moving slowly and is struck by another vehicle. However, to "play it really safe," the control group here is limited to this type of involvements on <u>dry roads</u>. Since the pre-crash action, travelling speed or impact location of a car may have been incorrectly reported in some cases, the "control group" may contain a modest proportion of cars that, in fact, should not be there. But such misclassification doesn't matter on dry roads, since ABS was shown to have little effect on multivehicle crash involvements even outside the control group.

Non-ABS cars experienced 4239 control group crashes on dry roads. All other crash involvements of non-ABS cars totaled 9369, including non-control group multivehicle involvements on dry roads (i.e., striking, or struck-while-moving), all multivehicle involvements on wet roads, all single-vehicle crashes (rollover, fixed-object, pedestrian, etc.). Also included are a few crashes that were not classified in any of the specific crash modes defined in the preceding chapters, because of missing or inconsistent data (e.g., "multivehicle involvement with unknown speed and pre-crash action," "struck a fixed object while standing still"). The ratio of "all other involvements" to the control group is 9369/4239 = 2.2102. The ABS-equipped cars had 4145 control group crashes and 8973 other involvements, a ratio of 2.1648. The ratios are nearly the same, with and without ABS. The observed effect for ABS is a reduction of

$$1 - [(8973/4145) / (9369/4239)] = 1 - (2.1648/2.2102) = 2 \text{ percent}$$

a negligible effect that does not come close to statistical significance, even with these generous sample sizes ($\chi^2$ = 0.62).

Table 4-3 performs a similar analysis of 1990-92 Pennsylvania crashes. Non-ABS cars experienced 958 control group crashes on dry roads, while ABS-equipped cars were involved in 724. Crash involvements of all other types totaled 5659 for non-ABS cars and 4128 for ABS-equipped cars. (The control group is relatively smaller in Pennsylvania than in Florida because of the higher reporting threshold for accidents, and because parked cars are not reported as "crash-involved vehicles.") The observed effect for ABS is a reduction of

$$1 - [(4128/724) / (5659/958)] = 1 - (5.7017/5.9071) = 3 \text{ percent}$$

and it is not statistically significant ($\chi^2$ = 0.44).

Table 4-4 repeats the analysis for 1990-92 Missouri crashes. As in Pennsylvania, the observed effect for ABS is a reduction of

$$1 - [(3070/552) / (5384/935)] = 1 - (5.5616/5.7583) = 3 \text{ percent}$$

and it is not even close to statistical significance ($\chi^2$ = 0.36).

Section 2.4 described a procedure for combining accident data from Florida, Pennsylvania and Missouri, weighting the accident cases to minimize potential biases. The procedure guarantees that the combined accident sample for the three States will have the same number of ABS-equipped and non-ABS weighted accident cases, and that the ABS-equipped and non-ABS samples each have the same weighted make-model mix. Table 4-5 shows that non-ABS cars accounted for 4450 weighted control group crashes on dry roads, while ABS-equipped cars accounted for 4555 weighted involvements. All other types of crash involvements reached a weighted total of 13292 for non-ABS cars and 13187 for ABS-equipped cars. The

TABLE 4-3

**PENNSYLVANIA, 1990-92:** OVERALL EFFECT OF ABS

| Type of Crash Involvement | Without ABS N | Without ABS $\frac{N}{N_{control}}$ | With ABS N | With ABS $\frac{N}{N_{control}}$ | Change in $N/N_{control}$ (%) | $\chi^2$ | Stat Sig? |
|---|---|---|---|---|---|---|---|
| CONTROL GROUP (dry road multivehicle - struck while stopped/slow) | 958 | 1 | 724 | 1 | | | |
| ALL OTHER INVOLVEMENTS | 5659 | 5.9071 | 4128 | 5.7017 | down 3 | .44 | |

TABLE 4-4

**MISSOURI, 1990-92:** OVERALL EFFECT OF ABS

| Type of Crash Involvement | Without ABS N | Without ABS $\frac{N}{N_{control}}$ | With ABS N | With ABS $\frac{N}{N_{control}}$ | Change in $N/N_{control}$ (%) | $\chi^2$ | Stat Sig? |
|---|---|---|---|---|---|---|---|
| CONTROL GROUP (dry road multivehicle - struck while stopped/slow) | 935 | 1 | 552 | 1 | | | |
| ALL OTHER INVOLVEMENTS | 5384 | 5.7583 | 3070 | 5.5616 | down 3 | .36 | |

TABLE 4-5

**FLORIDA-PENNSYLVANIA-MISSOURI, 1990-92:** OVERALL EFFECT OF ABS

(weighted, balanced data)

| | **Without ABS** | | **With ABS** | | **Change in $N/N_{control}$** | | |
|---|---|---|---|---|---|---|---|
| **Type of Crash Involvement** | **N** | $\frac{N}{N_{control}}$ | **N** | $\frac{N}{N_{control}}$ | **(%)** | $\chi^2$ | **Stat Sig?** |
| CONTROL GROUP (dry road multivehicle - struck while stopped/slow) | 4450 | 1 | 4555 | 1 | | | |
| ALL OTHER INVOLVEMENTS | 13292 | 2.9870 | 13187 | 2.8951 | down 3 | 1.64 | |

observed effect for ABS is a negligible reduction of

1 - [(13187/4555) / (13292/4450)] = 1 - (2.8951/2.9870) = 3 percent

just like the effects in the three individual State files. The "$\chi^2$" statistic is 1.64, which seems nonsignificant at first glance, but is hard to interpret because the data in Table 4-5 are weighted totals, not simple counts.

In all States, the observed overall effect of ABS was close to zero, and well below the magnitude needed for statistical significance at currently available sample sizes.

4.3 Overall effect of ABS on fatal crash involvements

Multivehicle and run-off-road crashes account for about equal numbers of fatalities. The increase in run-off-road crashes, which happens on all road surfaces, overshadows the reduction of multivehicle crashes, which only happens on wet roads. But pedestrian impacts also account for a substantial portion of fatalities, and the benefit of ABS here combines with the benefit in wet-road multivehicle crashes to cancel the increase in run-off-road accident fatalities.

Table 4-6 computes the overall effect of ABS on fatal crashes during calendar years 1989-93. As in Chapters 2 and 3, the control group includes all multivehicle crash involvements on dry roads. If the control group had been limited to cars that were struck while they were standing still, parked, or moving slowly, it would have been too small for a meaningful statistical analysis, since most fatal multivehicle crashes involve two moving vehicles. Section 2.5 documented that ABS has little, if any effect on multivehicle crashes on dry roads, permitting this large collection of crashes to serve as a control group.

TABLE 4-6

**FARS, 1989-93:** OVERALL EFFECT OF ABS ON FATAL CRASHES

| | Without ABS | | With ABS | | Change in $N/N_{control}$ | | |
|---|---|---|---|---|---|---|---|
| **Type of Crash Involvement** | **N** | $\frac{N}{N_{control}}$ | **N** | $\frac{N}{N_{control}}$ | **(%)** | $\chi^2$ | **Stat Sig?** |
| CONTROL GROUP (any dry road multivehicle) | 1021 | 1 | 858 | 1 | | | |
| ALL OTHER INVOLVEMENTS | 1001 | .9804 | 823 | .9592 | down 2 | .11 | |

Non-ABS cars were involved in 1021 fatal multivehicle crashes on dry roads (control group). All other fatal crash involvements of non-ABS cars totaled 1001, including multivehicle involvements on wet, snowy or icy roads, and all single-vehicle crashes (rollover, fixed-object, pedestrian, etc.). Also included are a few crashes that were not classified in any specific crash mode, because of missing or inconsistent data. The ratio of "all other involvements" to the control group is 1001/1021 = .9804. The ABS-equipped cars had 858 control group crashes and 823 other involvements, a ratio of .9592. The observed effect for ABS is a reduction of

$$1 - [(823/858) / (1001/1021)] = 1 - (.9592/.9804) = 2 \text{ percent}$$

and it does not come close to statistical significance ($\chi^2 = 0.11$).

Thus, nationwide, at least in the FARS data collected so far, the benefits in multivehicle crashes on wet roads and in pedestrian impacts essentially cancel out the negative effects on run-off-road crashes. However, the net effect of ABS can vary from place to place. In States with frequent precipitation and a largely urbanized population, the types of crashes where ABS is beneficial account for a larger percentage of the fatalities, and the benefits would overshadow the negative effects. The opposite would be true in dry States with limited urbanization, where rollovers and impacts with fixed objects account for the majority of the fatalities.

## 4.4 Some general caveats

The results of this report apply <u>only</u> to passenger cars equipped with ABS and should definitely not be extended to light trucks equipped with four-wheel ABS. The braking capabilities, exposure and directional/rollover stability of light trucks is quite different from passenger cars. ABS might have entirely different effects for light trucks. The effectiveness of four-wheel ABS for light trucks will be estimated when sufficient accident data on trucks with four-wheel ABS become available.

These preliminary results need to be viewed with caution for several reasons. The increase in run-off-road crashes needs to be studied further, by interviewing drivers of ABS-equipped cars who were involved in run-off-road crashes, or by conducting tests that involve combinations of hard braking and abrupt steering, before the increase can be unequivocally attributed to ABS. The principal observed effects, both positive and negative, although statistically significant and consistent from State to State, are quite high compared to what is usually seen in evaluations of crash avoidance measures. It is not clear why there are reductions of pedestrian crashes under all road conditions, but multivehicle crashes only under adverse conditions. Definitions of crash modes vary from State to State, and results from different States may not be directly comparable. The FARS analysis of multivehicle crashes by crash mode (striking vs. struck) did not really work. The data cover the experience of the first groups of cars equipped with ABS, when these cars were new, or at least not old, operating in an environment where most vehicles on the road still did not have ABS. Results could change as these cars get older, or for later cars with different ABS systems, or if a large proportion of the vehicle fleet gets ABS. Chapters 2 and 3 isolated run-off-road, multivehicle and pedestrian crashes, analyzing each type independently. In fact, these events need not always occur independently, e.g., the driver of an ABS-equipped car might successfully avoid hitting a pedestrian, but run the car off the road while doing so. The analyses of this chapter show that the effects in the various crash modes are essentially cancelling one another.

## APPENDIX A

## MARKET SHARES FOR ABS, PASSENGER CARS

These tables show the percentage of cars sold with ABS, by "car group" (body platform), make-model and model year (1985-92). Sales data are from Ward's Almanacs [9], "Factory Installed Equipment" tables. The car group and make-model codes are consistent with other NHTSA evaluations.

The "Comments" to the right and, sometimes, above the percentage numbers indicate whether ABS was standard equipment on all cars of a particular make-model-model year (**std**), standard on a specific VIN-identifiable subseries (e.g., on 1990 Mercury Cougar **XR7**, but not other 1990 Mercury Cougars), standard on a selected group of VIN-identifiable subseries (**sel** - for more details, see the attached document on "Car Groups with ABS") - or optional and impossible to identify by VIN (opt).

The Ward's Almanac "model year" includes all sales of a particular make model between October 1 of the previous year and September 30 of the model year. It does not correspond exactly to the true model year as defined by the 10th VIN character - i.e., early introductions are counted with the previous model year, while late sales are counted with the next one. As a result, there is some spillover of ABS cars into the "wrong" model year. These are noted with question marks, as are other Ward's numbers that appear to be inconsistent with other data sources on ABS installation.

### Notes

(1) 85 Lincoln Mark 7 and Continental: ABS standard on "Designer Series" and LSC; these cannot be identified from the VIN, yet constitute a large percentage of the total. Ward's Almanac does not have ABS sales data for MY 85.

(2) ABS on Pontiac 6000 STE began late in MY 86. Only in 87-89 is it standard on <u>all</u> Pontiac 6000 STE.

(3) Not sure how ABS got onto 87 Buick LeSabre, Buick Electra, Cadillac DeVille, Oldsmobile 98; might be 1988's introduced before 10/1/87 (Ward's computes "model year" by sales date, not by actual VIN model year) or might be optional. Same for 89 Pontiac Grand Prix. Same for 87 Acura Legend.

(4) Not sure why 89 Porsche has less than 100 percent ABS; might be leftovers from earlier model years, which did not get sold until after 10/1/88.

(5) Not clear what happened on Volvo 760/780 in 87.

(6) The ABS on Chrysler Conquest and Mitsubishi Starion is Rear-Wheel only.

(7) 1990 Honda Preludes listed as having ABS may actually have been 1991 Honda Preludes that were sold before 10/1/90 (early introduction).

(8) No ABS on 1981-84 passenger cars sold in the United States.

(9) 1990 Pontiac Grand Prix Turbo not easily identified from VIN.

## Market Shares for ABS

| Car Group<br>Make-Model | 85 | 86 | 87 | 88 | 89 | 90 | 91 | 92 | Comments |
|---|---|---|---|---|---|---|---|---|---|
| 618 Aries/Reliant K | | | | | | | | | |
| 616 Chrysler LeBaron coupe | . | . | . | . | . | 0 | 0 | 8 | opt |
| 620 Daytona/Sundance | | | | | | | | | |
| 715 Dodge Daytona | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | opt |
| 621 Dodge Dynasty | | | | | | | | | |
| 618 Chrysler New Yorker C | . | . | . | 14 | 10 | 5 | 10 | 5 | opt |
| 718 Dodge Dynasty | . | . | . | 6 | 2 | 2 | 2 | 8 | opt |
| 622 Plymouth Acclaim | | | | | | | | | |
| 616 Chrysler LeBaron sedan | . | . | . | . | . | 0 | 6 | 6 | opt |
| 719 Dodge Spirit | . | . | . | . | 0 | 0 | 2 | 3 | opt |
| 919 Plymouth Acclaim | . | . | . | . | 0 | 0 | 2 | 3 | opt |
| 623 Chrysler Imperial 109 | | | | | | | | | |
| 620 Chrysler 5th Ave | . | . | . | . | . | 11 | 13 | 13 | opt |
| 620 Chrysler Imperial | . | . | . | . | . | 100 | 100 | 100 | std |
| 1228 Crown Vic/Grand Marquis | | | | | | | | | |
| 1216 Ford Crown Victoria | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 33 | TourSed/opt |
| 1416 Mercury Grand Marquis | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 27 | opt |
| 1230 Lincoln Town Car | | | | | | | | | |
| 1301 Lincoln Town Car | 0 | 0 | 0 | 0 | 0 | 53 | 100 | 100 | opt/std |
| 1232 Lincoln Mark7 | | | | | | | | | |
| 1302 Lincoln Mark7 | ? | 100 | 100 | 100 | 100 | 100 | 100 | 100 | Desig/std |
| 1305 Lincoln Continental | ? | 100 | 100 | . | . | . | . | . | Desig/std |
| 1233 Ford Thunderbird 104 | | | | | | | | | |
| 1204 Ford Thunderbird | 0 | 0 | 19 | 25 | . | . | . | . | Turbo cpe |
| 1235 Ford Taurus | | | | | | | | | |
| 1217 Ford Taurus | . | 0 | 0 | 0 | 0 | 7 | 16 | 23 | SHO/opt |
| 1417 Mercury Sable | . | 0 | 0 | 0 | 0 | 0 | 12 | 31 | opt |
| 1236 Lincoln Continental 109 | | | | | | | | | |
| 1305 Lincoln Continental | . | . | . | 100 | 100 | 100 | 100 | 100 | std |
| 1237 Ford Thunderbird 113 | | | | | | | | | |
| 1204 Ford Thunderbird | . | . | . | . | 17 | 23 | 12 | 14 | Supr cpe |
| 1404 Mercury Cougar | . | . | . | . | 0 | 7 | 9 | 8 | XR7 |

## Market Shares for ABS

| Car Group<br>Make-Model | 85 | 86 | 87 | 88 | 89 | 90 | 91 | 92 | Comments |
|---|---|---|---|---|---|---|---|---|---|
| 1839 GM full-sized sedan 116 | | | | | | | | | |
| 2002 Chev Caprice sedan | 0 | 0 | 0 | 0 | 0 | 0 | 100 | 100 | std |
| 1804 Buick Roadmaster sedan | . | . | . | . | . | . | . | 100 | std |
| 1840 GM full-sized wagon 116 | | | | | | | | | |
| 1802 Buick Estate wagon | 0 | 0 | 0 | 0 | 0 | 0 | 100 | . | std |
| 1804 Buick Roadmaster wagon | . | . | . | . | . | . | . | 100 | std |
| 2002 Chev Caprice wagon | 0 | 0 | 0 | 0 | 0 | 0 | 100 | 100 | std |
| 2102 Olds Custom Cruiser | 0 | 0 | 0 | 0 | 0 | 0 | 100 | 100 | std |
| 1842 Cadillac DeVille 121.5 | | | | | | | | | |
| 1903 Cad Fleetwd Brougham | 0 | 0 | 0 | 0 | 0 | 0? | 100 | 100 | std |
| 1848 GM Compact J cars | | | | | | | | | |
| 2016 Chevrolet Cavalier | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 100 | std |
| 2216 Pontiac Sunbird | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 100 | std |
| 1850 GM Mid-sized A 104.9 | | | | | | | | | |
| 2217 Pontiac 6000 | 0 | 1 | 6 | 2 | 1 | 0 | 0 | . | STE |
| 1851 Chevrolet Corvette Y 96.2 | | | | | | | | | |
| 2004 Chevrolet Corvette | 0 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | std |
| 1852 GM Luxury C and Full-sized H 110.8 | | | | | | | | | |
| 1802 Buick LeSabre | . | 0 | 1? | 2 | 2 | 3 | 3 | 39 | opt/Lim |
| | | | | T | T | T,Ul | | | |
| 1803 Buick Electra | 0 | 0 | 5? | 7 | 13 | 11 | 100 | 100 | T/Ult/std |
| 1903 Cadillac DeVille | 0 | 0 | 5 | 6 | 25 | . | . | . | Fleetwood |
| 1903 Cad DeVille coupe | . | . | . | . | . | 25 | 100 | 100 | Flwd/std |
| 2102 Olds Delta 88 | . | 0 | 0 | 1 | 2 | 5 | 4 | 56 | opt/LS |
| 2103 Olds 98 | 0 | 1? | 4? | 14 | 15 | 2 | 100 | 100 | TourSed/std |
| 2202 Pontiac Bonneville | . | . | 0 | 14 | 19 | 23 | 16 | 61 | SSE?/opt |
| 1854 Pontiac Grand Am N 103.4 | | | | | | | | | |
| 1818 Buick Skylark | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 100 | std |
| 2118 Olds Calais | 0 | 0 | 0 | 0 | 0 | 0 | 2 | . | opt |
| 2121 Olds Achieva | . | . | . | . | . | . | . | 100 | std |
| 2218 Pontiac Grand Am | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 100 | opt/std |
| 1855 GM luxury sports cars E and Cadillac Seville K 108 | | | | | | | | | |
| 1805 Buick Riviera | . | 0 | 0 | 12 | 15 | 18 | 100 | 100 | opt/std |
| 1905 Cadillac Eldorado | . | 0 | 0 | 11 | 15 | 30 | 100 | 100 | opt/std |
| 1914 Cadillac Seville | . | 0 | 0 | 16 | 23 | 23 | 100 | . | STS/std |
| 2105 Oldsmobile Toronado | . | 0 | 0 | 11 | 65 | 10 | 100 | 100 | Trofeo/std |
| 1856 Chev Corsica/Beretta L | | | | | | | | | |
| 2019 Chev Corsica/Beretta | . | . | 0 | 0 | 0 | 0 | 0 | 100 | std |

## Market Shares for ABS

| Car Group<br>Make-Model | 85 | 86 | 87 | 88 | 89 | 90 | 91 | 92 | Comments |
|---|---|---|---|---|---|---|---|---|---|
| 1857 Cadillac Allante V | | | | | | | | | |
| 1909 Cadillac Allante | . | . | 100 | 100 | 100 | 100 | 100 | 100 | std |
| 1858 Buick Reatta EC | | | | | | | | | |
| 1821 Buick Reatta | . | . | . | 100 | 100 | 100 | 100 | . | std |
| 1859 GM Mid-sized W 107.5 | | | | | | | | | |
| 1820 Buick Regal | . | . | . | 0 | 1 | 2 | 5 | 41 | opt/Lim/GS |
| 2020 Chev Lumina | . | . | . | . | . | 0 | 0 | 61 | Euro/Z34 |
| 2120 Olds Cutlass Supreme | . | . | . | 0 | 0 | 4 | 4 | 30 | opt/Internatl |
| | | | | | opt | sel | opt | sel | |
| 2220 Pontiac Grand Prix | . | . | . | 0 | 3 | 7 | 4 | 27 | |
| 1860 Cadillac Sedan 113.8 | | | | | | | | | |
| 1903 Cadillac Sedan | . | . | . | . | . | 25 | 100 | 100 | Flwd/std |
| 1861 Saturn SC coupe | | | | | | | | | |
| 2402 Saturn SC coupe | . | . | . | . | . | . | 0 | 13 | opt |
| 1862 Saturn SL sedan | | | | | | | | | |
| 2401 Saturn SL sedan | . | . | . | . | . | . | 0 | 13 | opt |
| 1863 Cadillac Seville 111 | | | | | | | | | |
| 1914 Cadillac Seville | . | . | . | . | . | . | . | 100 | std |
| 3006 VW Jetta 97.3 | | | | | | | | | |
| 3040 VW Jetta | 0 | 0 | 0 | 0 | 2 | 1 | 1 | 0 | opt |
| 3042 VW Golf/GTI | 0 | 0 | 0 | 0 | 0 | 0 | 8 | 0 | opt |
| 3045 VW Corrado | . | . | . | . | . | 46 | 46 | 92 | opt |
| 3008 VW Passat | | | | | | | | | |
| 3046 VW Passat | . | . | . | . | . | 0 | 17 | 17 | opt |
| 3205 Audi 5000 105.8 | | | | | | | | | |
| 3235 Audi 5000 | 0 | 20 | 30 | 40 | . | . | . | . | selected |
| 3237 Audi 100/200 | . | . | . | . | 30 | 100 | 100 | 100 | sel/std |
| 3206 Audi 80/90 | | | | | | | | | |
| 3236 Audi 80/90 | . | . | . | 50 | 50 | 50 | 37 | 100 | 90/sel/std |
| 3406 BMW 500 103.8 | | | | | | | | | |
| | 535 | std | | | | | | | |
| 3435 BMW 500 | 35 | 100 | 100 | 100 | . | . | . | . | 535/std |
| 3407 BMW 300 101 | | | | | | | | | |
| 3434 BMW 300 | 0 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | std |

## Market Shares for ABS

| Car Group Make-Model | 85 | 86 | 87 | 88 | 89 | 90 | 91 | 92 | Comments |
|---|---|---|---|---|---|---|---|---|---|
| 3408 BMW 600 | | | | | | | | | |
| 3436 BMW 600 | 100 | 100 | 100 | 100 | 100 | . | . | . | std |
| 3409 BMW 700 110 | | | | | | | | | |
| 3437 BMW 700 | 100 | 100 | . | . | . | . | . | . | std |
| 3410 BMW 700 111.5 | | | | | | | | | |
| 3437 BMW 700 | . | . | 100 | 100 | 100 | 100 | 100 | 100 | std |
| 3411 BMW 700L 116 | | | | | | | | | |
| 3437 BMW 700L | . | . | . | 100 | 100 | 100 | 100 | 100 | std |
| 3412 BMW 500 108.7 | | | | | | | | | |
| 3435 BMW 500 | . | . | . | . | 100 | 100 | 100 | 100 | std |
| 3413 BMW 850 | | | | | | | | | |
| 3438 BMW 850 | . | . | . | . | . | . | 100 | 100 | std |
| 3414 BMW 300 106.3 | | | | | | | | | |
| 3434 BMW 300 | . | . | . | . | . | . | . | 100 | std |
| 3515 Nissan 280-300ZX 2+2 99.2 | | | | | | | | | |
| 3534 Nissan 300ZX 2+2 | 0 | 0 | 0 | 0 | . | . | . | . | |
| 3534 Nissan 300ZX | . | . | . | . | 0 | . | . | . | |
| 3522 Nissan Maxima/Stanza 100.4 | | | | | | | | | |
| 3542 Nissan Stanza | . | . | . | . | . | 0 | 11 | 7 | opt |
| 5833 Infiniti G20 | . | . | . | . | . | . | 100 | 100 | std |
| 3524 Nissan Sentra/Pulsar 95.7 | | | | | | | | | |
| 3543 Nissan Sentra | . | . | 0 | 0 | 0 | 0 | 3 | 1 | opt |
| 3544 Nissan Pulsar/NX | . | . | 0 | 0 | 0 | 0 | 36 | 7 | opt |
| 3525 Nissan Maxima 104.3 | | | | | | | | | |
| 3539 Nissan Maxima | . | . | . | . | 13 | 10 | 25 | 30 | opt |
| 3526 Nissan 240SX 97.4 | | | | | | | | | |
| 3532 Nissan 240SX | . | . | . | . | 28? | 1 | 49 | 2 | opt |
| 3527 Nissan 300ZX 96.5 | | | | | | | | | |
| 3534 Nissan 300ZX | . | . | . | . | . | 100 | 100 | 100 | std |
| 3528 Nissan 300ZX 2+2 101.2 | | | | | | | | | |
| 3534 Nissan 300ZX 2+2 | . | . | . | . | . | 100 | 100 | 100 | std |
| 3529 Infiniti M30 | | | | | | | | | |
| 5831 Infiniti M30 | . | . | . | . | . | 100 | 100 | 100 | std |

## Market Shares for ABS

| Car Group Make-Model | 85 | 86 | 87 | 88 | 89 | 90 | 91 | 92 | Comments |
|---|---|---|---|---|---|---|---|---|---|
| 3530 Infiniti Q45 | | | | | | | | | |
| 5832 Infiniti Q45 | . | . | . | . | . | 100 | 100 | 100 | std |
| 3710 Honda Accord 102.4 | | | | | | | | | |
| 5431 Acura Integra sedan | . | . | . | . | . | 31 | 34 | 30 | GS |
| 3711 Acura Legend sedan 108.6 | | | | | | | | | |
| 5432 Acura Legend sedan | . | 0 | 15? | 64 | 82 | 85 | . | . | L/LS |
| 6131 Sterling | . | . | 53 | 70 | 85 | 100 | 100 | . | SL, SLI |
| 3713 Acura Legend coupe 106.5 | | | | | | | | | |
| 5432 Acura Legend coupe | . | . | 15? | 64 | 82 | 85 | . | . | L/LS |
| 3716 Honda Prelude 101 | | | | | | | | | |
| 3733 Honda Prelude | . | . | . | 0 | 0 | 10 | 24 | . | SiHOABS |
| 3717 Acura Integra 2HB 100.4 | | | | | | | | | |
| 3733 Honda Prelude | . | . | . | . | . | . | . | 71 | Si |
| 5431 Acura Integra 2HB | . | . | . | . | . | 31 | 34 | 30 | GS |
| 3718 Honda Accord 107 | | | | | | | | | |
| 3732 Honda Accord | . | . | . | . | . | 0 | 6 | 34 | opt/EX |
| 3719 Acura NSX | | | | | | | | | |
| 5433 Acura NSX | . | . | . | . | . | . | 100 | 100 | std |
| 3720 Acura Legend coupe 111.4 | | | | | | | | | |
| 5432 Acura Legend coupe | . | . | . | . | . | . | 100 | 100 | std |
| 3721 Acura Legend sedan 114.6 | | | | | | | | | |
| 5432 Acura Legend sedan | . | . | . | . | . | . | 100 | 100 | std |
| 3722 Honda Civic 2HB 101.3 | | | | | | | | | |
| 3731 Honda Civic 2HB | . | . | . | . | . | . | . | 3 | EX |
| 3723 Honda Civic sedan 103.2 | | | | | | | | | |
| 3731 Honda Civic sedan | . | . | . | . | . | . | . | 3 | EX |
| 3724 Acura Vigor | | | | | | | | | |
| 5434 Acura Vigor | . | . | . | . | . | . | . | 100 | std |
| 3903 Jaguar XJ Sedan 113 | | | | | | | | | |
| 3932 Jaguar XJ sedan | 0 | 0 | 0 | 100 | 100 | 100 | 100 | 100 | std |
| 3904 Jaguar XJ-S coupe | | | | | | | | | |
| 3931 Jaguar XJ-S | 0 | 0 | 0 | 0 | 100 | 100 | 100 | 100 | std |

## Market Shares for ABS

| Car Group<br>Make-Model | 85 | 86 | 87 | 88 | 89 | 90 | 91 | 92 | Comments |
|---|---|---|---|---|---|---|---|---|---|
| 4112 Mazda RX-7 95.7 | | | | | | | | | |
| 4134 Mazda RX-7 | . | 0 | 0 | 50 | 70 | 76 | 3? | . | Turbo |
| 4113 Mazda 626 101.4 | | | | | | | | | |
| 4137 Mazda 626 | . | . | . | 0 | 20 | 22 | 9 | 10 | opt |
| 4114 Mazda 929 106.7 | | | | | | | | | |
| | | | | 90S | 90S | 90S | S | | |
| 4143 Mazda 929 | . | . | . | 40 | 60 | 75 | 74 | . | 90S/S |
| 4115 Ford Probe | | | | | | | | | |
| 1218 Ford Probe | . | . | . | . | 7 | 13 | 2 | 3 | opt |
| 4144 Mazda MX6 | . | . | . | 25 | 10 | 22 | 2 | 1 | opt |
| 4118 Mazda Miata | | | | | | | | | |
| 4145 Mazda Miata | . | . | . | . | . | 0 | 6 | 8 | opt |
| 4119 Mazda MX3 | | | | | | | | | |
| 4146 Mazda MX3 | . | . | . | . | . | . | . | 10 | opt |
| 4120 Mazda 929 112.2 | | | | | | | | | |
| 4143 Mazda 929 | . | . | . | . | . | . | . | 100 | std |
| 4204 Mercedes SL roadster 96.9 | | | | | | | | | |
| 4233 Mercedes 380SL | 100 | . | . | . | . | . | . | . | std |
| 4210 Mercedes S (super) sedan 115.6 | | | | | | | | | |
| 4237 Mercedes SD/SE | 100 | 100 | 100 | 100 | 100 | 100 | 100 | . | std |
| 4211 Mercedes SEL (long super) sedan 121.1 | | | | | | | | | |
| 4236 Mercedes SDL/SEL | 100 | 100 | 100 | 100 | 100 | 100 | 100 | . | std |
| 4212 Mercedes SEC coupe 112.2 | | | | | | | | | |
| 4236 Mercedes SEC | 100 | 100 | 100 | 100 | 100 | 100 | 100 | . | std |
| 4213 Mercedes 190 | | | | | | | | | |
| | sel | sel | sel | std | | | | | |
| 4239 Mercedes 190 | 18 | 20 | 30 | 99 | 100 | 100 | 100 | 100 | selected |
| 4214 Mercedes basic sedan 110.2 | | | | | | | | | |
| 4231 Mercedes basic sedan | . | 100 | 100 | 100 | 100 | 100 | 100 | 100 | std |
| 4215 Mercedes SL roadster 96.7 | | | | | | | | | |
| 4233 Mercedes 560SL | . | 100 | 100 | 100 | 100 | . | . | . | std |

## Market Shares for ABS

| Car Group<br>Make-Model | 85 | 86 | 87 | 88 | 89 | 90 | 91 | 92 | Comments |
|---|---|---|---|---|---|---|---|---|---|
| 4216 Mercedes basic C coupe 106.9 | | | | | | | | | |
| 4231 Mercedes basic coupe | . | . | . | 100 | 100 | 100 | 100 | 100 | std |
| 4217 Mercedes SL roadster 99 | | | | | | | | | |
| 4233 Mercedes 300SL/500SL | . | . | . | . | . | 100 | 100 | 100 | std |
| 4218 Mercedes SE/SD and SEC 119.7 | | | | | | | | | |
| 4236 Mercedes SEC coupe | . | . | . | . | . | . | . | 100 | std |
| 4237 Mercedes SE/SD | . | . | . | . | . | . | . | 100 | std |
| 4219 Mercedes SEL 123.6 | | | | | | | | | |
| 4236 Mercedes SEL | . | . | . | . | . | . | . | 100 | std |
| 4406 Peugeot 505 sedan | | | | | | | | | |
| 4434 Peugeot 505 sedan | 0 | 0 | 38 | 36 | 43 | 0 | 0 | . | selected |
| 4408 Peugeot 405 | | | | | | | | | |
| 4436 Peugeot 405 | . | . | . | . | 0 | 0? | ? | . | S/Mi in 91 |
| 4501 Porsche 911 | | | | | | | | | |
| 4531 Porsche 911 | 0 | 0 | 0 | 0 | 15? | 100 | 100 | . | std 89- |
| 4503 Porsche 924/944 | | | | | | | | | |
| 4537 Porsche 944 | 0 | 0 | ? | ? | 50? | 100 | 100 | . | std 89- |
| 4504 Porsche 928 | | | | | | | | | |
| 4535 Porsche 928 | 0 | 100 | 100 | 100 | 100 | 100 | 100 | . | std |
| 4505 Porsche | | | | | | | | | |
| 4540 Porsche | . | . | . | . | . | . | . | 100 | std |
| 4609 Eagle Premier | | | | | | | | | |
| 740 Dodge Monaco | . | . | . | . | . | 0 | 1 | 4 | opt |
| 1040 Eagle Premier | . | . | . | . | 8 | 0 | 19 | 15 | opt/Lim |
| 4704 Saab 900 | | | | | | | | | |
| 4731 Saab 900 | 0 | 0 | 0 | 0 | 0 | 100 | 100 | 100 | std |
| 4705 Saab 9000 | | | | | | | | | |
| 4734 Saab 9000 | 0 | 0 | 0 | 100 | 100 | 100 | 100 | 100 | std |
| 4809 Subaru Legacy | | | | | | opt | LS | sel | |
| 4834 Subaru Legacy | . | . | . | . | . | 13 | 29 | 50 | |
| 4810 Subaru SVX | | | | | | | | | |
| 4837 Subaru SVX | . | . | . | . | . | . | . | 100 | std |

## Market Shares for ABS

| Car Group<br>Make-Model | 85 | 86 | 87 | 88 | 89 | 90 | 91 | 92 | Comments |
|---|---|---|---|---|---|---|---|---|---|
| 4920 Toyota Camry 102.4 | | | | | | | | | |
| 4940 Toyota Camry | 0 | 0 | 0 | 0 | 1 | 2 | 8 | . | opt(LE) |
| 5931 Lexus ES-250 | . | . | . | . | . | 100 | 100 | . | std |
| 4922 Toyota Cressida 104.5 | | | | | | | | | |
| 4935 Toyota Cressida | . | 0 | 0 | 0 | 45 | 54 | 51 | 56 | opt |
| 4923 Toyota Supra 102.2 | | | | | | | | | |
| 4934 Toyota Supra | . | 0 | 41? | 60? | 68? | 72 | 82 | 75 | opt/Turbo |
| 4924 Toyota Celica 99.4 | | | | | | | | | |
| 4933 Toyota Celica | . | . | 0 | 3 | 0 | 4 | 5 | 6 | opt |
| 4926 Lexus LS-400 | | | | | | | | | |
| 5932 Lexus LS-400 | . | . | . | . | . | 100 | 100 | 100 | std |
| 4927 Toyota MR-2 94.5 | | | | | | | | | |
| 4941 Toyota MR-2 | . | . | . | . | . | . | 37 | 25 | opt |
| 4928 Toyota Camry 103.1 | | | | | | | | | |
| 4940 Toyota Camry | . | . | . | . | . | . | . | 28 | opt |
| 5931 Lexus ES-300 | . | . | . | . | . | . | . | 100 | std |
| 4929 Lexus SC-300/400 | | | | | | | | | |
| 5933 Lexus SC-300/400 | . | . | . | . | . | . | . | 100 | std |
| 5104 Volvo 240 | | | | | | | | | |
| 5134 Volvo 240 | 0 | 0 | 0 | 0 | 0 | 0 | 100? | 100 | std? |
| 5105 Volvo 740/760 | | | | | | | | | |
| 5138 Volvo 760/780 | 0 | 0 | 3? | 100 | 100 | 100 | 100 | . | std |
| 5139 Volvo 740 | . | 0 | 0 | 35 | 41 | 100 | 100 | 100 | sel/std |
| 5140 Volvo 940/960 | . | . | . | . | . | . | 100 | 100 | std |
| 5206 Mitsubishi Starion | | | | | | | | | |
| 635 Chrysler Conquest | . | . | 100 | 100 | 100 | . | . | . | RWAL |
| 5231 Mitsubishi Starion | 0 | 0 | 72 | 0 | 100 | . | . | . | RWAL |
| 5209 Mitsubishi Galant | | | | | | | | | |
| | | | | opt | opt | opt | sel | VR4 | |
| 5234 Mitsubishi Galant | 0 | 0 | 0 | 30? | 10 | 14 | 6 | 8 | opt/GSR-VR |
| 5212 Mitsubishi Eclipse 97.2 | | | | | | | | | |
| 937 Plymouth Laser | . | . | . | . | . | 0 | 4 | 12 | opt |
| 1037 Eagle Talon | . | . | . | . | . | 0 | 19 | 10 | opt |
| 5237 Mitsubishi Eclipse | . | . | . | . | . | 0 | 4 | 6 | opt |

## Market Shares for ABS

| Car Group<br>Make-Model | 85 | 86 | 87 | 88 | 89 | 90 | 91 | 92 | Comments |
|---|---|---|---|---|---|---|---|---|---|
| 5213 Dodge Stealth | | | | | | | | | |
| 739 Dodge Stealth | . | . | . | . | . | . | 6 | 45 | R/T |
| 5238 Mitsubishi 3000GT | . | . | . | . | . | . | 99 | 98 | opt/SL/VR4 |
| 5214 Mitsubishi LRV | | | | | | | | | |
| 944 Plymouth Colt Vista | . | . | . | . | . | . | . | 0 | opt |
| 1044 Eagle Summit wagon | . | . | . | . | . | . | . | 0 | opt |
| 5244 Mitsubishi Expo LRV | . | . | . | . | . | . | . | 0 | opt |
| 5215 Mitsubishi Diamante | | | | | | | | | |
| 5240 Mitsubishi Diamante | . | . | . | . | . | . | . | 40 | LS |
| 5245 Mitsubishi Expo SP | . | . | . | . | . | . | . | 0 | opt |
| 5603 Merkur XR4Ti | | | | | | | | | |
| 5631 Merkur XR4Ti | 0 | 0 | 0 | 0 | 0 | . | . | . | |
| 5604 Merkur Scorpio | | | | | | | | | |
| 5632 Merkur Scorpio | . | . | . | 100 | 100 | 100 | . | . | std |

## APPENDIX B

## 1985-92 CAR GROUPS WITH ABS - USED IN THE ANALYSES

Criteria for including a make-model in the analysis:

(1) Presence or absence of ABS must be deciphered from VIN.
(2) ABS-equipped cars must be model years 1985-92 (exclude pre-1985 ABS systems, such as the 1969-77 Lincoln Mark 2-4).
(3) Make-model or subseries must have 4-wheel ABS standard, or on over 75% of cars (exclude 1987-89 Mitsubishi Starion, which had rear-wheel-only ABS).
(4) There has to be a "comparison group" of similar cars without ABS. That excludes, for example, Lexus and Infiniti, which have always had ABS.
(5) In most cases, use only the first 2 model years with ABS. For the comparison group, use at most the last 2 model years without ABS. In general, use an equal number of ABS and non-ABS model years (or add/delete a non-ABS year if it helps balance the ABS and non-ABS sample sizes).
(6) If ABS is standard equipment on an entire make-model, the comparison group is pre-ABS cars of the same make-model.
(7) If ABS is standard equipment on a subseries of a make-model, the comparison group is other, non-ABS subseries of the same make-model and model year - or - cars of the same subseries in a previous model year (choose the alternative that best "matches" the ABS cars in both style/image and sample size).
(8) In the lists that follow, "V5" means the 5th VIN character; "V47" means the 4th through 7th VIN characters.

ABS Group 1: Lincoln Town Car, 1991-92 V67=81-83
Comparison group: Lincoln Town Car, 1988-89 V67=81-84
Note: do not use 1990 Town Car, which had about 50% optional ABS installation

ABS Group 2: Lincoln Mark 7, 1986-87 V67=98 in 86; V67=91-93 in 87
Comparison group: Lincoln Mark 7, 1984 V67=98; Lincoln Mark 6 2 door, 1983 V67=98
Note: do not use 1985 Mark 7, which had ABS on the Designer series, but not identifiable by VIN

ABS Group 3: Lincoln Continental, 1986-87 V67=97 in 86; V67=97,98 in 87
Comparison group: Lincoln Continental, 1983-84 V67=97 in 83-84
Note: do not use 1985 Continental, which had ABS on the Designer series, but not identifiable by VIN

ABS Group 4: Chevrolet Caprice sedan and wagon, 1991-92 (introduced mid-90) V4=B V5=L,N,U
Comparison group: Chevrolet Caprice sedan and wagon, 1988-90 V4=B V5=L,N,U

ABS Group 5: Buick wagon, 1991-92 V45=BR
Comparison group: Buick Estate wagon, 1989-90 V45=BR,BV

ABS Group 6: Oldsmobile Custom Cruiser, 1991-92 V45=BP
Comparison group: Oldsmobile Custom Cruiser, 1989-90 V45=BP

ABS Group 7: Cadillac Fleetwood Brougham, 1991-92 V45=DW
Comparison group: Cadillac Fleetwood Brougham, 1988-89 V45=DW
Note: do not use 1990 Fleetwood Brougham, whose ABS status is uncertain

ABS Group 8: Chevrolet Cavalier, 1992 V4=J V5=C,F
Comparison group: Chevrolet Cavalier, 1991 V4=J V5=C,F

ABS Group 9: Pontiac Sunbird, 1992 V4=J V5=B,C,D,U
Comparison group: Pontiac Sunbird, 1991 V4=J V5=B,C,D,U

ABS Group 10: Chevrolet Corvette, 1986-87 V45=YY
Comparison group: Chevrolet Corvette 1984-85 V5=Y in 84; V45=YY in 85

ABS Group 11: Buick LeSabre Limited, 1992 V45=HR
Comparison group: Buick LeSabre Limited, 1991 V45=HR

ABS Group 12: Oldsmobile Delta 88 Royale LS, 1992 V45=HY
Comparison group: Oldsmobile Delta 88 Royale Brougham, 1991 V45=HY

ABS Group 13: Buick Park Avenue (except Ultra), 1991-92 V45=CW
Comparison group: Buick Electra and Park Avenue (except T-type, Ultra), 1989-90 V45=CW,CX
Note: do not use T-type, which had ABS throughout 1988-90, or Ultra, which had ABS throughout 1990-92

ABS Group 14: Oldsmobile 98 (except Touring Sedan), 1991-92 V45=CW,CX
Comparison group: Oldsmobile 98 (except Touring Sedan), 1989-90 V45=CW,CX
Note: do not use Touring Sedan, which had ABS throughout 1988-92

ABS Group 15: Cadillac Fleetwood D'Elegance, 1989-90 V45=CB
Comparison group: Cadillac Fleetwood D'Elegance, 1987-88 V45=CB

ABS Group 16: Cadillac DeVille, 1991-92 V45=CD
Comparison group: Cadillac DeVille, 1989-90 V45=CD

ABS Group 17: Buick Skylark, 1992 V4=N V5=J,M
Comparison group: Buick Skylark, 1991 V4=N V5=C,D,J,M,V

ABS Group 18: Oldsmobile Achieva, 1992 V4=N V5=F,L
Comparison group: Oldsmobile Calais, 1991 V4=N V5=F,K,L,T

ABS Group 19: Pontiac Grand Am, 1992 V4=N V5=E,G,V,W
Comparison group: Pontiac Grand Am, 1991 V4=N V5=E,G,V,W

ABS Group 20: Buick Riviera, 1991-92 V45=EZ
Comparison group: Buick Riviera, 1989-90 V45=EZ

ABS Group 21: Cadillac Eldorado, 1991-92 V45=EL
Comparison group: Cadillac Eldorado, 1988-89 V45=EL
Note: do not use 1990 Eldorado, which had about 30% optional ABS installation

ABS Group 22: Oldsmobile Toronado Brougham, 1991-92 V45=EZ
Comparison group: Oldsmobile Toronado Brougham, 1988,90 V45=EZ
Note: do not use 1989 Toronado Brougham, which had about 50% optional ABS installation

ABS Group 23: Cadillac Seville (except STS), 1991 V4=KS
Comparison group: Cadillac Seville (except STS), 1990 V45=KS
Note: do not use 1992 Seville; it was remodeled as a longer, wider, heavier car

ABS Group 24: Chevrolet Corsica/Beretta, 1992 V4=L V5=T,V,W,Z
Comparison group: Chevrolet Corsica/Beretta, 1991 V4=L V5=T,V,W,Z

ABS Group 25: Buick Regal Limited & Gran Sport, 1992 V45=WD,WF
Comparison group: Buick Regal Limited, 1991 V45=WD

ABS Group 26: Chevrolet Lumina Eurosport and Z34, 1992 V45=WN,WP
Comparison group: Chevrolet Lumina Eurosport and Z34, 1991 V45=WN,WP

ABS Group 27: Oldsmobile Cutlass Supreme International, 1992 V45=WR
Comparison group: Oldsmobile Cutlass Supreme International, 1991 V45=WR
Note: group **deleted**, very few ABS-equipped accident cases

ABS Group 28: Audi 80/90, 1988-92 V7=8 in 92 (all subseries); V7=8 V4=G,H in 88-91 (90); also V7=8, V4=F in 91 (80 Quattro)
Comparison group: Other Audi 80's, 1988-91 V7=8 V4=E in 88-91 (basic 80); also V7=8, V4=F in 88-90 (80 Quattro)

ABS Group 29: BMW 300, 1986-87 V4=A,B V5=A,B,C,D,E,K
Comparison group: BMW 300, 1984-85 V4=A,B V5=A,B,C,D,E,K

ABS Group 30: BMW 500, 1985-87 V4=D in 86-87 (all 500's); V45=DC in 85 (535 only)
Comparison group: BMW 500, 1983-85 V4=D in 83=84; V45=DB,DK in 85

ABS Group 31: BMW 600-700, 1985-86 V45=EC,FG,FH
Comparison group: BMW 600-700, 1983-84 V45=EB,FF

ABS Group 32: Acura Integra GS, 1990-92 V4=D V8=6,7,8
Comparison group: Acura Integra LS, 1990-92 V4=D V8=5

ABS Group 33: Acura Legend L and LS, 1988-90 V4=K V8=5,6,7
Comparison group: Other Acura Legends, 1986-90 V4=K V8=3,4
Note: do not use 1991-92 Legend; car was restyled in 1991 with more weight and wheelbase

ABS Group 34: Honda Prelude Si with ABS, 1990-91 V4=B V8=5
Comparison group: Other Honda Prelude Si, 1990-91 V4=B V8=3,4
Note: do not use 1992 Prelude; car was restyled and is mostly with ABS
Note: group **deleted**, very few ABS-equipped accident cases

ABS Group 35: Honda Accord EX, 1992 V45=CB V8=7
Comparison group: Honda Accord EX, 1991 V45=CB V8=6

ABS Group 36: Sterling 827, 1987-91 all in 91; V6=5,8 in 87-90 (SL and SLI)
Comparison group: Sterling 827S, 1987-89 V6=4

ABS Group 37: Jaguar XJ sedan, 1988-89 V4=F,H,K,M
Comparison group: Jaguar XJ sedan, 1986-87 V4=A

ABS Group 38: Jaguar XJ-S coupe, 1989-90 V4=N,T
Comparison group: Jaguar XJ-S coupe, 1987-88 V4=N

ABS Group 39: Mercedes S, SEL and SEC (luxury models), 1985-86 V4=C
Comparison group: Mercedes S, SEL and SEC, 1983-84 V4=C

ABS Group 40: Mercedes SL (sports), 1985 V4=B
Comparison group: Mercedes SL, 1984 V4=B
Note: do not use 1986 Mercedes SL; it was restyled with much higher horsepower

ABS Group 41: Mercedes basic full-sized sedan, 1986-87 V4=E V6 NE 5
Comparison group: Mercedes basic full-sized sedan, 1984-85 V4=A V56=A3,B2,B3,B9
Note: although these models were restyled, the changes in size, weight and power were minimal

ABS Group 42: Porsche 928, 1986-87 V78=92 V4=J
Comparison group: Porsche 928, 1984-85 V78=92 V4=J

ABS Group 43: Saab 900, 1990-91 V4=A
Comparison group: Saab 900, 1988-89 V4=A

ABS Group 44: Saab 9000, 1988-89 V4=C
Comparison group: Saab 9000, 1986-87 V4=C

ABS Group 45: Volvo 240, 1991-92 V4=A
Comparison group: Volvo 240, 1989-90 V4=A

ABS Group 46: Volvo 760/780, 1988 V4=G,H
Comparison group: Volvo 760/780, 1986 V4=D,G,H
Note: do not use 1985 Volvo, since 740 and 760 cannot be distinguished from VIN; do not use 1987 Volvo since there are uncertainties about ABS installations

ABS Group 47: Volvo 740, 1990-91 V4=F
Comparison group: Volvo 740, 1986-87 V4=F
Note: do not use 1988-89 Volvo 740, since there are uncertainties about ABS installation and VIN interpretation

ABS Group 48: Mitsubishi Diamante LS, 1992 V5=C V6=5
Comparison group: Mitsubishi Diamante, 1992 V5=C V6=4

## APPENDIX C

## 1985-92 CARS WITH ABS - NOT USED IN THE ANALYSES

Criteria for excluding a make-model from the analysis:

(1) If it is not clear from the literature exactly what subseries were ABS-equipped or what VIN codes identify the ABS-equipped cars
(2) If ABS is standard equipment on a specific subseries of a make-model and the potential comparison group comprises other subseries of the same make-model that differ greatly in luxury or "sporty" image (e.g., Thunderbird Super Coupe vs. other Thunderbirds)
(3) If the shift to ABS coincided with a complete restyling and image-change for that make-model (e.g., Nissan 300ZX, which was restyled as a sportier car with higher performance when it got ABS).
(4) If the ABS group and the potential comparison group differ greatly in sample size
(5) If there is no comparison group because this make-model was equipped from the start with ABS and there is no other make-model "just like it" without ABS
(6) Make-models with large numbers of optional ABS (not identifiable from VIN)

| **Model Year-Make-Model-Subseries** | **Reason for Exclusion** |
|---|---|
| 1990-92 Chrysler Imperial | comparison group (Chrysler 5th Avenue) outnumbers Imperial 5-1 |
| 1987-89 Chrysler Conquest | equipped with rear-wheel ABS only |
| 1992 Dodge Stealth | difficulties identifying standard-ABS subseries from VIN; also, many optional ABS on the other subseries |
| 1992 Ford Crown Victoria Touring Sedan | this subseries did not exist in 1991; also, other subseries in 1992 have more than 25% optional ABS; thus, there is no good comparison group |
| 1987-92 Ford T-bird Turbo/Super Coupe | this is a higher-performance car and niche market than the regular Thunderbird, which would be the comparison group |
| 1990-92 Ford Taurus SHO | this is a higher-performance car and niche market than any other Taurus subseries, even LX, which would be the comparison group; there is a substantial percentage of optional ABS on the other Taurus subseries; the other subseries greatly outnumber SHO |
| 1990-92 Mercury Cougar XR7 | this is a higher-performance car and niche market than the regular Cougar; the regular Cougar greatly outnumbers XR7 |
| 1992 Buick Roadmaster sedan | make-model always had ABS |
| 1987-89 Pontiac 6000 STE | this is a higher-performance car and niche market than any other 6000 subseries, even SE, which would be the comparison group; the other subseries greatly outnumber STE |
| 1988-92 Pontiac Bonneville SSE, SSEi | some doubts as to which cars had ABS in 1988-91; in 1992, many Bonneville SE (comparison group) had optional ABS |

| Model Year-Make-Model-Subseries | Reason for Exclusion |
|---|---|
| 1987-92 Cadillac Fleetwood 60 Special | subseries always had ABS |
| 1988-92 Oldsmobile Toronado Trofeo | subseries always had ABS |
| 1990-92 Cadillac Seville STS | subseries always had ABS |
| 1987-92 Cadillac Allante | make-model always had ABS |
| 1988-91 Buick Reatta | make-model always had ABS |
| 1992 Buick Regal Gran Sport | subseries always had ABS |
| 1990-92 Pontiac Grand Prix | some doubts as to which cars had ABS |
| 1986-92 Audi 100/200/5000 | difficulties identifying ABS from VIN; also, the pre-ABS cars greatly outnumber the ABS-equipped cars due to the drop-off in Audi sales |
| 1990-92 Nissan 300ZX | installation of ABS coincided with a restyling for higher horsepower and a shorter wheelbase (more sporty image) |
| 1991-92 BMW 850 | make-model always had ABS |
| 1990-92 Infiniti | all make-models always had ABS |
| 1991-92 Acura Vigor/NSX | make-models always had ABS |
| 1988-90 Mazda RX-7, 929 | unclear which cars had ABS; difficulty identifying ABS from VIN |
| 1986-89 Mercedes 190 | the ABS-equipped cars are mostly in high-horsepower subseries and the non-ABS cars mostly have the basic engine |
| 1987-89 Peugeot 505 STX/Turbo S | the ABS-equipped cars are in high-horsepower subseries and the non-ABS cars mostly have the basic engine |
| 1989-92 Porsche 911/944 | doubts as to which cars had ABS; also, the pre-ABS cars greatly outnumber the ABS-equipped cars due to the drop-off in Porsche sales |
| 1991-92 Subaru Legacy | difficulties identifying ABS-equipped vehicles from VIN |
| 1992 Subaru SVX | make-model always had ABS |
| 1992 Toyota Supra Turbo | there is a large percentage of optional ABS on other Supras |
| 1990-92 Lexus | all make-models always had ABS |
| 1991-92 Volvo 940/960 | make-models always had ABS |
| 1987-89 Mitsubishi Starion | equipped with rear-wheel ABS only |
| 1988-90 Merkur Scorpio | make-model always had ABS |

## APPENDIX D

## CAR GROUPS USED IN THE ANALYSIS - BUT NOT ALL MODEL YEARS IN ALL CALENDAR YEARS

Criteria: (1) In **each calendar year of accident data**, use an equal number of ABS and non-ABS full model years (or add/delete a non-ABS year if it helps balance the ABS and non-ABS sample sizes).

(2) In a specific calendar year, delete the ABS group and the comparison group if ABS had not yet been introduced that year.

(3) In a specific calendar year, delete the ABS group and the comparison group if the ABS-equipped cars are greatly outnumbered by the non-ABS cars in that year (e.g., Buick Electra before 1991).

| | | **Depending on the Calendar Year of the Data File, Use Only the Following Model Years:** | | | |
|---|---|---|---|---|---|
| **ABS Group and Comparison Group** | | **CY 89** | **CY 90** | **CY 91** | **CY 92-93** |
| 1. | Lincoln Town Car | delete | delete | 91-92 | 91-92 |
| | Lincoln Town Car | delete | delete | 89 | 88-89 |
| 4. | Chevrolet Caprice | delete | 91 | 91-92 | 91-92 |
| | Chevrolet Caprice | delete | 89-90 | 89-90 | 88-90 |
| 5. | Buick wagon | delete | delete | 91-92 | 91-92 |
| | Buick Estate wagon | delete | delete | 90 | 89-90 |
| 6. | Oldsmobile Custom Cruiser | delete | delete | 91-92 | 91-92 |
| | Oldsmobile Custom Cruiser | delete | delete | 90 | 89-90 |
| 7. | Cadillac Fleetwood Brougham | delete | delete | 91-92 | 91-92 |
| | Cadillac Fleetwood Brougham | delete | delete | 89 | 88-89 |
| 8. | Chevrolet Cavalier | delete | delete | delete | 92 |
| | Chevrolet Cavalier | delete | delete | delete | 91 |
| 9. | Pontiac Sunbird | delete | delete | delete | 92 |
| | Pontiac Sunbird | delete | delete | delete | 91 |
| 11. | Buick LeSabre Limited | delete | delete | delete | 92 |
| | Buick LeSabre Limited | delete | delete | delete | 91 |
| 12. | Oldsmobile Delta 88 Royale LS | delete | delete | delete | 92 |
| | Oldsmobile Delta 88 Royale Brougham | delete | deiete | delete | 91 |
| 13. | Buick Park Avenue | delete | delete | 91-92 | 91-92 |
| | Buick Park Avenue and Electra | delete | delete | 90 | 89-90 |
| 14. | Oldsmobile 98 | delete | delete | 91-92 | 91-92 |
| | Oldsmobile 98 | delete | delete | 90 | 89-90 |

| ABS Group and Comparison Group | | Depending on the Calendar Year of the Data File, Use Only the Following Model Years: | | | |
|---|---|---|---|---|---|
| | | CY 89 | CY 90 | CY 91 | CY 92-93 |
| 15. | Cadillac Fleetwood D'Elegance | 89-90 | 89-90 | 89-90 | 89-90 |
| | Cadillac Fleetwood D'Elegance | 88 | 87-88 | 87-88 | 87-88 |
| 16. | Cadillac DeVille | delete | delete | 91-92 | 91-92 |
| | Cadillac DeVille | delete | delete | 90 | 89-90 |
| 17. | Buick Skylark | delete | delete | delete | 92 |
| | Buick Skylark | delete | delete | delete | 91 |
| 18. | Oldsmobile Achieva | delete | delete | delete | 92 |
| | Oldsmobile Calais | delete | delete | delete | 91 |
| 19. | Pontiac Grand Am | delete | delete | delete | 92 |
| | Pontiac Grand Am | delete | delete | delete | 91 |
| 20. | Buick Riviera | delete | delete | 91-92 | 91-92 |
| | Buick Riviera | delete | delete | 90 | 89-90 |
| 21. | Cadillac Eldorado | delete | delete | 91-92 | 91-92 |
| | Cadillac Eldorado | delete | delete | 89 | 88-89 |
| 22. | Olds Toronado Brougham | delete | delete | 91-92 | 91-92 |
| | Olds Toronado Brougham | delete | delete | 90 | 88,90 |
| 23. | Cadillac Seville (except STS) | delete | delete | 91 | 91 |
| | Cadillac Seville (except STS) | delete | delete | 90 | 90 |
| 24. | Chevrolet Corsica/Beretta | delete | delete | delete | 92 |
| | Chevrolet Corsica/Beretta | delete | delete | delete | 91 |
| 25. | Buick Regal Limited | delete | delete | delete | 92 |
| | Buick Regal Limited | delete | delete | delete | 91 |
| 26. | Chevrolet Lumina Eurosport/Z34 | delete | delete | delete | 92 |
| | Chevrolet Lumina Eurosport/Z34 | delete | delete | delete | 91 |
| 27. | Olds Cutlass Supreme International | delete | delete | delete | 92 |
| | Olds Cutlass Supreme International | delete | delete | delete | 91 |
| 28. | Audi 80/90 | 88-90 | 88-91 | 88-92 | 88-92 |
| | Audi 80 | 88-90 | 88-91 | 88-91 | 88-91 |
| 32. | Acura Integra GS | delete | 90-91 | 90-92 | 90-92 |
| | Acura Integra LS | delete | 90-91 | 90-92 | 90-92 |
| 34. | Honda Prelude Si with ABS | delete | 90-91 | 90-91 | 90-91 |
| | Honda Prelude Si | delete | 90-91 | 90-91 | 90-91 |

| ABS Group and Comparison Group | Depending on the Calendar Year of the Data File, Use Only the Following Model Years: | | | |
|---|---|---|---|---|
| | CY 89 | CY 90 | CY 91 | CY 92-93 |
| 35. Honda Accord EX | delete | delete | delete | 92 |
| Honda Accord EX | delete | delete | delete | 91 |
| 38. Jaguar XJ-S coupe | 89-90 | 89-90 | 89-90 | 89-90 |
| Jaguar XJ-S coupe | 88 | 87-88 | 87-88 | 87-88 |
| 43. Saab 900 | delete | 90-91 | 90-91 | 90-91 |
| Saab 900 | delete | 89 | 88-89 | 88-89 |
| 45. Volvo 240 | delete | delete | 91-92 | 91-92 |
| Volvo 240 | delete | delete | 90 | 89-90 |
| 47. Volvo 740 | delete | 90-91 | 90-91 | 90-91 |
| Volvo 740 | delete | 87 | 86-87 | 86-87 |
| 48 Mitsubishi Diamante LS | delete | delete | delete | 92 |
| Mitsubishi Diamante | delete | delete | delete | 92 |

## REFERENCES


[1] Arehart, Chuck; Radlinski, Richard; and Hiltner, Ed. *Light Vehicle ABS Performance Evaluation--Phase II*. Report No. DOT HS 807 924. Washington: National Highway Traffic Safety Administration, [1992].

[2] *Collision and Property Damage Liability Losses of Passenger Cars With and Without Antilock Brakes*. Insurance Special Report No. A-41. Arlington, VA: Highway Loss Data Institute, [1994].

[3] *Federal Register* 59 (4 January 1994): 281.

[4] Hiltner, Edward; Arehart, Chuck; and Radlinski, Richard. *Light Vehicle ABS Performance Evaluation*. Report No. DOT HS 807 813. Washington: National Highway Traffic Safety Administration, [1991].

[5] Kahane, Charles J. *An Evaluation of Center High Mounted Stop Lamps Based on 1987 Data*. Technical Report No. DOT HS 807 442. Washington: National Highway Traffic Safety Administration, [1989].

[6] _______. *An Evaluation of Side Marker Lamps for Cars, Trucks and Buses*. Technical Report No. DOT HS 806 430. Washington: National Highway Traffic Safety Administration, [1983].

[7] _______. *Preliminary Evaluation of the Effectiveness of Rear-Wheel Antilock Brake Systems for Light Trucks*. Submission to NHTSA Docket No. 70-27-GR-026. Washington: National Highway Traffic Safety Administration, [1993].

[8] _______. *A Preliminary Evaluation of Two Braking Improvements for Passenger Cars: Dual Master Cylinders and Front Disc Brakes*. Technical Report No. DOT HS 806 359. Washington: National Highway Traffic Safety Administration, [1983].

[9] *Ward's Automotive Yearbook*. Annual Publication. Detroit: Ward's Communications.