National Highway
Traffic Safety
Administration

PRELIMINARY EVALUATION OF THE EFFECTIVENESS OF REAR-WHEEL ANTILOCK BRAKE SYSTEMS FOR LIGHT TRUCKS

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EXECUTIVE SUMMARY

Antilock Brake Systems (ABS) are a promising development for reducing motor vehicle crashes. Since 1985, they have been voluntarily installed by manufacturers on millions of cars and light trucks. They have been welcomed by consumers and are well on their way to becoming standard equipment in most new cars and light trucks. The Highway Safety Act of 1991 instructs the National Highway Traffic Safety Administration (NHTSA) to consider extending this protection to all passenger vehicles, including trucks lighter than 10,000 pounds. This preliminary evaluation of the effectiveness of rear-wheel ABS for light trucks (including pickup trucks, sport-utility vehicles and vans), based on statistical analyses of the accident experience of production vehicles equipped with ABS, is performed in support of NHTSA's regulatory program.

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), or take longer to stop than a vehicle with the wheels still rolling. The objective of ABS is to take over the optimization task from the driver. 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, and rear-wheel antilock (RWAL) system, which were the principal type installed on light trucks through model year 1991. A four-wheel system is intended to keep all the wheels rolling during panic braking, to prevent yawing,

allow the driver to steer the vehicle 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. RWAL, on the other hand, is not designed to prevent lockup of the front wheels, preserve steering control, or significantly reduce stopping distances. RWAL was primarily intended to prevent rear-wheel lockup and severe yawing during braking; it was an important first step for light trucks, which have more problems than cars with directional control (run-off-road crashes). Separate analyses need to be done for RWAL on light trucks, four-wheel ABS on passenger cars and four-wheel ABS on light trucks; only the first of these is carried out here.

During 1988-91, NHTSA performed two extensive series of stopping tests involving vehicles with four-wheel ABS or RWAL, on various road surfaces. The tests confirmed that four-wheel 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 on gravel. RWAL greatly reduced the yaw of pickup trucks during straight-line panic stops, but it did not shorten stopping distances; in fact, they became slightly longer.

The statistical analysis of the effectiveness of RWAL for light trucks is based on 1990-91 accident data from Michigan and Florida, 1989-91 data from Pennsylvania and 1989-mid 92 data from the Fatal Accident Reporting System (FARS). RWAL was installed as standard equipment on most domestic Chevrolet, GMC, Ford and Dodge pickup trucks, sport utility vehicles, and vans during 1987-90. The statistical analysis compares trucks of the first 2 model years with

RWAL to trucks of the same make-model, of the last 2 model years without RWAL.

The situation is not as simple with passenger cars, precluding a detailed effectiveness analysis at this time. As late as model year 1991, installation of ABS as standard equipment was generally limited to luxury and sporty make-models and the top-of-the-line subseries of medium-priced make-models. Cars of that type may attract a special clientele, and their crash experience may not be directly comparable to basic versions of the same make-model, let alone the average car on the road. When high-volume cars with standard ABS, such as the 1991 Chevrolet Caprice and the 1992 Cavalier, Corsica and Grand Am have accumulated sufficient on-the-road experience (in 1995, or possibly 1994), it will be possible to analyze the effectiveness of four-wheel ABS in passenger cars.

The principal findings and conclusions from the analyses of accident data on light trucks are the following:

- RWAL is quite effective in reducing the risk of **nonfatal run-off-road crashes**, for almost every type of light truck, under any type of road condition. Nonfatal rollovers were reduced by about 30-40 percent (up to 50 percent for Ford Ranger), side impacts with fixed objects by 15-30 percent and frontal impacts with fixed objects by 5-20 percent. Many run-off-road crashes of light trucks appear to involve a loss of directional **control during braking**, and RWAL significantly reduces such loss-of-control crashes.

- The accident reductions mostly did not carry over to **fatal run-off-road crashes** of light trucks. Only the Ford Ranger experienced a significant, 29 percent reduction of fatal rollovers and side impacts with fixed objects. The explanation may be that in most fatal run-off-road crashes, drivers do not brake at all, or lose directional control for reasons unrelated to braking, or apply the brakes under conditions that are too severe for RWAL to prevent a loss of directional control.

- RWAL had little or no effect on the **nonfatal multivehicle crashes** of light trucks. Since RWAL is primarily designed to prevent catastrophic loss of control during braking, rather than reducing stopping distances or allowing the driver to steer while braking, it is not surprising that RWAL should be effective against run-off-road crashes, rather than multivehicle collisions.

- The current accident data produced conflicting estimates about the effect of RWAL in **fatal multivehicle crashes**. Some of the analyses showed little or no effect, while others showed significant increases with RWAL.

- The risk of **collisions with pedestrians, animals, bicyclists, trains, or on-road objects** was significantly reduced in light trucks with rear-wheel ABS. The reduction appears to be about 10-20 percent in nonfatal collisions (mostly with animals) and 5-15 percent in fatal collisions (mostly crashes in which a truck contacts and fatally injures a pedestrian or bicyclist).

These preliminary results need to be viewed with caution for several reasons. The FARS samples in this report were sometimes too small for unambiguous or statistically meaningful results; all estimates of fatality reduction might change as more data become available, allowing more detailed analysis methods. The data cover the initial experience of the first groups of trucks equipped with RWAL; results could change as these trucks get older, or for later trucks with different RWAL systems. The results of this report apply **only** to light trucks equipped with RWAL and should definitely **not** be extended to passenger cars or light trucks equipped with four-wheel ABS.

CHAPTER 1

INTRODUCTION, BACKGROUND AND DATA SOURCES

Antilock Brake Systems (ABS) are a promising development for reducing motor vehicle crashes. Since 1985, they have been voluntarily installed by manufacturers on millions of cars and light trucks. They have been welcomed by consumers and are well on their way to becoming standard equipment in most new cars and light trucks. The Highway Safety Act of 1991, Section 2507 instructs the National Highway Traffic Safety Administration (NHTSA) to consider extending this protection to all passenger vehicles (cars, pickup trucks, sport utility vehicles and vans lighter than 10,000 pounds). It obliges NHTSA to publish, by December 31, 1993, an Advance Notice of Proposed Rulemaking concerning potential improvements in its braking standards, such as a requirement for ABS in passenger vehicles. Because ABS has already been installed on millions of vehicles, NHTSA has the opportunity to evaluate the benefits of ABS, based on the actual experience of production vehicles, at an early stage in the rulemaking process. As of late 1993, there are enough accident data for a statistical analysis of light trucks equipped with rear-wheel ABS, but not for passenger cars or light trucks equipped with four-wheel ABS.

1.1 Objectives of antilock brake systems

The fundamental safety problem addressed by 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.

There are two types of ABS: four-wheel antilock systems, which are almost the only type installed on passenger cars, and rear-wheel antilock (RWAL) systems, which were the principal type installed on light trucks through model year 1991. A four-wheel system is intended to keep all wheels rolling during panic braking, 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 is intended to help the driver avoid mobile and fixed obstacles (other vehicles, pedestrians, etc.) or, at least, to make collisions with such objects less severe.

A rear-wheel system will not prevent lockup of the front wheels. Once the front wheels begin to skid, the driver loses steering control, and a reduction of stopping distances cannot be expected. However, as long as the rear wheels keep rolling, severe yawing can be prevented. RWAL was an important first step for light trucks, which had more problems with braking and directional control than cars. Light trucks are harder than cars to bring back under control once they begin to yaw; they are more prone to rollover than cars, once they have gone out of control and left the roadway; and their variety of loaded/unloaded conditions intensifies difficulties of maintaining braking balance between front and rear wheels.

Separate analyses need to be performed for four-wheel ABS and RWAL. Four-wheel ABS has potential to affect any crash situation that could be mitigated by shorter stopping distance, evasive steering maneuvers and/or general directional stability, including multivehicle collisions, run-off-road crashes, and on-road collisions with nonmotorists, animals, etc. RWAL appears primarily targeted at preventing crashes that involve catastrophic loss of control, such as a rollover or skidding sideways into a fixed object.

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) and 3 pickup trucks with RWAL [1], [2]. 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 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. The upper half of Table 1-1 shows that four-wheel ABS was highly

TABLE 1-1

EFFECT OF 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°**
	TEST VEHICLES WITH 4-WHEEL ABS				
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	
	TEST VEHICLES WITH REAR-WHEEL ABS				
Dry concrete	ENABLED	12			
	DISABLED	12			
Wet asphalt/concrete	ENABLED	57	15		
	DISABLED	39	26	2	5
Wet Jennite	ENABLED	1	17	6	
	DISABLED	0	11	10	3
Wet epoxy	ENABLED	1	5		
	DISABLED	0	6		
Gravel	ENABLED	5	7		
	DISABLED	6	6		

TABLE 1-2

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

	Median % Reduction of Stopping Distance, ABS Enabled vs. ABS Disabled	
Road Surface	**4-Wheel ABS**	**RWAL**
Dry concrete	5	- 6
Wet asphalt/concrete	14	- 6
Wet Jennite	43	7
Wet epoxy	10	-12
Gravel	-28	-18

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.

The lower half of Table 1-1 shows that RWAL substantially, but not completely reduced the yaw of pickup trucks. Even with the rear wheels rolling, front-wheel lockup can lead to moderate amounts of yaw. With the RWAL enabled, the amount of yaw was always less than 10 degrees on wet asphalt/concrete and less than 45 degrees on wet Jennite, while there was yawing in excess of 45 degrees on both surfaces with the RWAL disabled. On dry concrete and gravel, however, the tests did not show an advantage for RWAL.

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. RWAL and (with one exception) four-wheel ABS were 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 or 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. Vehicles with RWAL experienced front-wheel lockup during panic braking and could not be steered around the curve or to another lane.

The effect of ABS on stopping distance, in straight-line spike stops, is not uniformly beneficial for four-wheel ABS and, in fact, is somewhat negative for RWAL. 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. Four-wheel 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, four-wheel 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.

RWAL lengthens stopping distances on all surfaces except wet Jennite; the increase is 6 percent on dry or wet concrete/asphalt. In general, a truck with 4 wheels sliding stops a little sooner than a truck with the front wheels sliding and the rear wheels rolling (although the latter condition, at least, reduces yawing).

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. 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 - i.e., almost any type of crash, except where the vehicle was standing still or moving slowly, or the driver had already lost control of the vehicle before even trying to brake. 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.

NHTSA's tests confirm that RWAL is not beneficial in reducing stopping distances or preserving steerability during braking. They suggest little benefit for RWAL in situations that require evading or stopping short of an obstacle on the road (multivehicle crashes, pedestrian accidents). The tests show a modest improvement for RWAL in maintaining overall directional stability and suggest potential benefits in eliminating crashes where a vehicle ran off the road as a result of brake-induced yawing.

1.3 Light trucks equipped with RWAL, 1987-91

Rear-wheel, electronic ABS first became standard equipment in the 1987 model year, on Ford's F-series pickup truck and two of their utility vehicles: Bronco and Bronco 2. By model year 1990, RWAL was standard on most domestic Chevrolet, GMC, Ford and Dodge pickup trucks, sport utility vehicles, and vans (the Caravan/Voyager is the most notable exception). Table 1-3 shows the model year in which RWAL was introduced in domestic truck lines. As of model year 1991, four-wheel ABS was still rare on these vehicles. RWAL was introduced as

TABLE 1-3

RWAL INTRODUCTION YEAR FOR SELECTED LIGHT TRUCKS
(as standard equipment on the entire line)

Make/Model	RWAL Introduction Year
Chevrolet S/T pickup (compact)	1989
Chevrolet C/K pickup (big)	1988
Chevrolet R/V pickup (big)	A
Chevrolet S Blazer utility (compact)	1989
Chevrolet V Blazer utility (big)	1990
Chevrolet Suburban truck-based station wagon	1990
Chevrolet Lumina APV wagon and cargo van (mini)	B
Chevrolet Astro wagon and cargo van (small)	1989[C]
Chevrolet Chevy Van and Sportvan (big van)	1990
GMC Sonoma pickup (compact)	1989
GMC C/K pickup (big)	1988
GMC R/V pickup (big)	A
GMC S Jimmy utility (compact)	1989
GMC V Jimmy utility (big)	1990
GMC Suburban truck-based station wagon	1990
GMC Safari wagon and cargo van (small)	1989[C]
GMC Rally and Vandura (big vab)	1990
Ford Ranger pickup (compact)	1989
Ford F pickup (big)	1987
Ford Bronco 2 utility (compact)	1987
Ford Bronco utility (big)	1987
Ford Explorer utility (compact)	1991[D]
Ford Aerostar van (small)	1990
Ford Econoline and Club Wagon van (big)	1990
Dodge Dakota pickup (compact)	1989
Dodge D/W pickup (big)	1989
Dodge Ramcharger utility (big)	1990
Plymouth Voyager minivan	B
Dodge Caravan (mini)	B
Dodge Ram Van and Wagon (big)	1990

A Not standard as of model year 1991; not included in the analysis, except for MY 1987, which is included as a non-RWAL counterpart for C/K pickups

B Not standard as of model year 1991; not included in the analysis

C Some 1990 models have 4-wheel ABS; these vehicles and their MY 87 counterparts are excluded from the analysis

D Always had ABS; not included in the analysis standard equipment on every subseries of a particular make-model, at the beginning of the model year. That makes the selection of trucks for the evaluation rather easy. Trucks with RWAL are compared to trucks of the same (or quite similar) make-model without RWAL - i.e., from the model years before RWAL was introduced. In most of the analyses, the sample is limited to trucks of the first 2 model years with RWAL vs. trucks of the last 2 model years without RWAL. The purpose of limiting the model years is to avoid comparing "new" trucks with substantially "older" trucks. When the RWAL and non-RWAL trucks are of similar age (and the same make-model), any differences in the accident profiles are more likely due to RWAL than differences in the drivers or the exposure of the trucks. The identification of trucks in the accident files is based on the Vehicle Identification Number (VIN).

The situation is not as simple with passenger cars, precluding a detailed effectiveness analysis at this time. Four-wheel, electronic ABS was introduced during the 1985 model year on the most luxurious models of Lincoln, Mercedes and BMW. In 1986, four-wheel ABS was extended to Chevrolet Corvette, all BMW's and most Mercedes. As late as 1991 (the most recent model year for which State accident data are available as of June 1993), installation of ABS as standard equipment was generally limited to luxury and sporty make-models and the top-of-the-line subseries of medium-priced make-models. Cars of that type may attract a special clientele, and their crash experience may not be directly comparable to basic versions of the same make-model, let alone the average car on the road. The 1991 Chevrolet Caprice and the 1992 General Motors J, L and N body cars (e.g., Cavalier, Corsica and Grand Am) are the first high-volume passenger cars with ABS standard on all subseries. The effectiveness of ABS for passenger cars will be evaluated when these models, among others, have accumulated sufficient on-the-road experience. At this time, however, the accident analysis is limited to RWAL for light trucks.

1.4 Accident files for evaluating RWAL

Since trucks with RWAL are still relatively uncommon, it is necessary to have very large accident files to have a large enough sample to detect the effect of RWAL 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 large files such as those of the larger States, and the Fatal Accident Reporting System (FARS). Since the presence of RWAL has to be inferred from the VIN, the files must have VIN information. Relatively complete VIN information on post-1980 trucks is present on FARS and three of the largest State files available at NHTSA: Michigan, Florida and Pennsylvania. These four files also contain the data elements essential for classifying single- and multivehicle crashes into groups that are more likely or less likely to be affected by RWAL: 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 (RWAL 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 trucks enlarge the "control group" of truck involvements where ABS is irrelevant. The Michigan file is especially useful because it contains a high proportion of crashes involving light trucks, adverse road conditions, and/or off-road excursions. The FARS file is, of course, needed to study the effect of RWAL in fatal crashes.

The analyses are based on Florida and Michigan data for 1990-91, Pennsylvania data for 1989-91, and FARS data for 1989-mid 92. In general, the procedure for data reduction is to identify and select the vehicle-level records for light trucks of the first two model years with RWAL, and the last two model years before the transition to RWAL, 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 SINGLE-VEHICLE, RUN-OFF-ROAD CRASHES

When a light truck runs off the road and subsequently rolls over or hits a fixed object, it is evident that the truck did not go where it was supposed to go. Either the driver steered in the wrong direction or lost steering and/or directional control of the vehicle (sometimes all of the above). Certainly, fixed objects do not jump onto roads and strike vehicles that are travelling in the right direction. Current light trucks are unlikely to roll over by themselves while they are on the road and under control; they need to yaw out of control and/or leave the road and encounter an off-road tripping mechanism. Thus, most run-off-road crashes share two characteristics: the vehicle was the only moving entity in the crash, and it moved in the wrong direction. That distinguishes them from other types of single-vehicle crashes (collisions with animals, bicycles, pedestrians, trains), where a second party may have entered the correct, intended path of the vehicle.

There are several situations where four-wheel ABS or rear-wheel ABS (RWAL) 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 under normal operating conditions, but locks the rear wheels (e.g., due to careless pedal application, slippery roadway, or an unbalanced load in the vehicle), losing directional control and yawing off the road. With RWAL or 4-wheel ABS, rear-wheel lock might have been prevented and directional control not lost. Alternatively, the driver locks the front wheels while negotiating a curve, and proceeds straight off the road; with 4-wheel ABS, steering control would have been maintained.

- Run-off-road prevented by enhanced braking capability: due to faulty or inattentive steering, the vehicle is headed off the roadway, although still under control with no locked wheels. The driver brakes hard and, possibly, tries to steer. The vehicle 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 (RWAL or 4-wheel), stopping distances shortened (primarily 4-wheel), and/or steering control maintained (4-wheel ABS only).

Of course, RWAL 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 truck in a skid before the driver touches the brakes, it may keep on skidding regardless of RWAL. Front-wheel lockup, which can occur with RWAL, could result in a loss of steering control. Even in those situations where RWAL helps the truck from yawing, there may not be enough room for the driver to stop short of roadside hazards. The driver might react to the situation by steering in the right direction, or may have lost all steering control due to front-wheel lockup.

Run-off-road crashes can be further subdivided into three crash modes, partially indicating relative levels of loss-of control:

- <u>Rollover crashes</u> 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.
- <u>Side impacts with fixed objects</u> 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.
- <u>Frontal impacts with fixed objects</u> 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.

It is evident that RWAL could be of some value in reducing <u>all three</u>

types of crashes, although with presumably greater effect for the first two types, which usually involve a greater loss of control. Unlike certain other crash avoidance measures, it is inappropriate to gauge the effect of RWAL only by the reduction in the rate of rollovers per 100 single vehicle accidents (RO/SVA), since RWAL could be reducing other types of single-vehicle accidents, not just rollovers. It is better to compare all three types of run-off-road crash involvements with a control group of crash involvements unaffected by ABS: crashes where a truck is standing still or moving very slowly (5 mph or less, where ABS and conventional brakes work about the same), and is struck by another vehicle.

Thus, the analysis technique is to tabulate the crash involvements, for trucks with RWAL and their counterparts without RWAL, in four crash modes: "primary" rollovers (i.e., single-vehicle, run-off-road crashes where a rollover was the only harmful event - excluding rollovers that occurred subsequent to an impact with a vehicle or object); side impacts with fixed objects (including a small number of rear impacts with fixed objects, but excluding front-corner impacts); frontal impacts with fixed objects (including front-corner impacts); and control-group, multivehicle crash involvements, where the case vehicle was standing still, moving 5 mph or less, parked, parking, or leaving a parking space. On-road single-vehicle crashes, such as collisions with animals and pedestrians, are excluded from these analyses, but are considered in Chapter 4.

Throughout the analyses, light trucks are subdivided into three groups - pickups, sport utility vehicles (SUV) and vans - which have different design characteristics, drivers and exposure. Most light trucks are more prone to roll over than passenger cars, partly because of their relatively higher center of gravity. However, pickup trucks and, especially, SUVs (but not vans) are especially prone to run-off-road accidents because they have many young male drivers, extensive use in rural areas, and lower directional stability than passenger cars. Even though, strictly speaking, most current pickup trucks do not have a rear-brake bias when unloaded, they are still quite vulnerable to rear-wheel lockup. They need strong rear brakes when they are fully loaded and are carrying a large proportion of their weight on their rear wheels, but the strong rear brakes can lock up the rear wheels when the trucks are not loaded. 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 antilock (RWAL) system.

As explained in Section 1.3, the data are limited to model year 1985-91 products of Chevrolet, GMC, Ford and Dodge, which were equipped with RWAL during those years. Jeep, Plymouth and other nameplates did not have enough vehicles with RWAL as of 1991 to contribute substantially to the data base; 4-wheel ABS was uncommon on trucks. Most of the analyses compare "Trucks of the first 2 model years with RWAL" to "Trucks of the last 2 model years [and the same make-model] without RWAL." The 1987 Chevrolet and GMC R/V pickup trucks are similar to C/K trucks, and are counted as being of the "last model year without RWAL."

2.1 Pickup trucks

Michigan offers the largest sample of light trucks in run-off-road crashes among the other three States considered in this report (Florida and Pennsylvania are the other two). Table 2-1 analyzes the crashes of **pickup trucks in Michigan during 1990-91.** It is evident that rollover risk is substantially

TABLE 2-1

MICHIGAN, 1990-91: PICKUP TRUCKS
EFFECT OF RWAL ON SINGLE-VEHICLE CRASHES

	Last 2 MY Without RWAL		First 2 MY With RWAL	
Type of Crash Involvement	**N**	**%**	**N**	**%**
A L L P I C K U P T R U C K S				
Primary rollover	1095	14.5	737	9.6
Side impact with fixed object	759	10.1	633	8.2
Frontal impact with fixed object	2044	27.1	2095	27.3
Control group (multivehicle)	3634	48.3	4215	54.9
	7532	100	7680	100
F O R D R A N G E R				
Primary rollover	528	22.9	224	13.1
Side impact with fixed object	223	9.7	164	9.6
Frontal impact with fixed object	580	25.2	452	26.3
Control group (multivehicle)	974	42.2	874	51.0
	2305	100	1714	100
A L L O T H E R S				
Primary rollover	567	10.8	513	8.6
Side impact with fixed object	536	10.3	469	7.9
Frontal impact with fixed object	1464	28.0	1643	27.5
Control group (multivehicle)	2660	50.9	3341	56.0
	5227	100	5966	100

lower with RWAL. The first part of Table 2-1 (All Pickup Trucks) shows 1095 rollovers among the trucks of the last 2 model years without RWAL, and 737 in the first 2 model years with RWAL. The number of "Control Group" crashes went in the opposite direction: from 3634 to 4215. That is a reduction of

$$1 - [(737/1095) / (4215/3634)] = 42 \text{ percent}$$

for rollovers relative to the control group. Impacts with fixed objects were also reduced, although to a smaller extent than rollovers. Side impacts with fixed objects decreased by 28 percent relative to the control group. Frontal impacts with fixed objects decreased by 12 percent.

Table 2-1 also shows the percentage distribution of the crash modes for RWAL trucks vs. non-RWAL trucks. A qualitative analysis of effectiveness, without producing specific estimates, is accomplished by glancing at the percentages. If the percentage of crashes which are rollovers, side impacts, or frontal impacts with fixed objects goes down (or at least does not go up) with RWAL, while the control group percentage increases, that's a good result for RWAL. Indeed, in Table 2-1, rollovers decreased from 14.5 to 9.6, side impacts decreased from 10.1 to 8.2, frontal impacts stayed about the same, while the control group increased from 48.3 to 54.9 percent of the crashes in the table.

The favorable results in the top portion of Table 2-1, however, are slightly biased in favor of RWAL. "All Pickup Trucks" are not a homogeneous group in terms of accident risk. Ford Rangers (compact pickup) have relatively much higher rollover rates than the other groups considered here (Ford full-sized, GM compact and full-sized, Dodge compact and full-sized, all of which have about the same, lower, rollover rate). The increased rollover risk for Ranger may be due to a combination of circumstances, such as the suspension system, static stability factor, and preponderance of young drivers. At the same time, the Ranger is slightly underrepresented in the "with RWAL" group, possibly because sales were heavier in 1987-88 (without RWAL) than in 1989-90 (with RWAL). It is appropriate to tabulate separate results for Ford Ranger and for all other pickup trucks, to avoid the bias and also to find out if RWAL has different levels of effectiveness for Ranger than for other trucks.

The two lower parts of Table 2-1 show positive results for ABS, even with separate tabulations. Run-off-road accidents of all three types decreased, or at least did not increase relative to the control group, for Ranger <u>and</u> for all others. The Ford Ranger showed a more dramatic reduction in the rollover rate than the other pickup trucks. Ford Rangers experienced a reduction of

$$1 - [(224/528) / (874/974)] = 53 \text{ percent}$$

for rollovers relative to the control group. The reduction is statistically significant (Chi-square for the 2 x 2 table is 67.15, $p < .01$). The relative percentage reduction of rollovers in all other pickup trucks is just over half as large, 28 percent, but it is still statistically significant (Chi-square = 24.60, $p < .01$). The reduction of side impacts with fixed objects is 18 percent in Ford Ranger (nonsignificant, Chi-square = 3.11) and 33 percent for All Others (significant, Chi-square = 28.15, $p < .01$). The reduction of frontal impacts with fixed objects is 13 percent for Ranger (nonsignificant, Chi-square = 3.25) and 11 percent for All Others (significant, Chi-square = 6.45, $p < .05$).

The high rollover reduction for RWAL in pickup trucks, especially Ford Ranger, suggests that (1) it may be quite easy to lock the rear wheels of a pickup truck, especially when it is not heavily loaded, by a slight excess of brake pedal pressure (without RWAL); (2) a substantial proportion of the loss-of-control incidents (before RWAL) involved brake-induced rear-wheel lockup; and, perhaps, (3) when pickup trucks (especially Ranger) begin to yaw, it is often difficult to bring them back under control before they leave the road and get tripped. RWAL evidently is quite effective in preventing many of the rear-wheel lockups.

As a check on the preceding results, Table 2-2 repeats the analyses with the sample limited to pickup trucks of the **last** model year without RWAL and the **first** model year with RWAL, minimizing the vehicle age difference between the two groups. The accident reductions are about the same as in Table 2-1:

	Percent Accident Reduction	
	1st MY RWAL vs. Last MY w/o	1st 2 MY RWAL vs. Last 2 MY w/o
Rollovers - Ranger	52	53
Rollovers - all others	25	28
Side/fixed object - Ranger	24	18
Side/fixed object - all others	30	33

Since the accident reductions for RWAL persist even when the RWAL-equipped and non-RWAL trucks are just a year apart in age, it is clear that the observed reductions are not an artifact of vehicle age differences (e.g., that the older, non-RWAL trucks have a preponderance of rollover-prone young male drivers).

Table 2-3 separates the pickup truck crashes in Michigan **by road condition**: dry vs. wet vs. snowy/icy. Since the coefficient of friction is reduced under adverse conditions, it is reasonable to expect more rollovers and/or side impacts with fixed objects, which typically involve skidding and yawing. Indeed, wet pavement increased the risk of side impacts with fixed

TABLE 2-2

MICHIGAN, 1990-91: PICKUP TRUCKS
EFFECT OF RWAL ON SINGLE-VEHICLE CRASHES
(data limited to 1 MY before/after RWAL installation)

Type of Crash Involvement	Last MY Without RWAL N	Last MY Without RWAL %	First MY With RWAL N	First MY With RWAL %
ALL PICKUP TRUCKS				
Primary rollover	605	15.4	433	10.1
Side impact with fixed object	403	10.3	358	8.3
Frontal impact with fixed object	1049	26.8	1162	27.1
Control group (multivehicle)	1861	47.5	2335	54.5
	3918	100	4288	100
FORD RANGER				
Primary rollover	319	23.9	124	14.0
Side impact with fixed object	126	9.4	77	8.7
Frontal impact with fixed object	336	25.2	237	26.8
Control group (multivehicle)	553	41.5	446	50.5
	1334	100	884	100
ALL OTHERS				
Primary rollover	286	11.1	309	9.1
Side impact with fixed object	277	10.7	281	8.3
Frontal impact with fixed object	713	27.6	925	27.2
Control group (multivehicle)	1308	50.6	1889	55.4
	2584	100	3404	100

TABLE 2-3

MICHIGAN, 1990-91: PICKUP TRUCKS
EFFECT OF RWAL ON SINGLE-VEHICLE CRASHES - **BY ROAD CONDITION**

	Last 2 MY Without RWAL		**First 2 MY With RWAL**	
Type of Crash Involvement	**N**	**%**	**N**	**%**
D R Y R O A D S (ALL PICKUP TRUCKS)				
Primary rollover	430	10.7	288	7.0
Side impact with fixed object	237	5.9	236	5.7
Frontal impact with fixed object	980	24.5	997	24.1
Control group (multivehicle)	2358	58.9	2622	63.3
	4005	100	4143	100
W E T R O A D S (ALL PICKUP TRUCKS)				
Primary rollover	153	10.1	108	6.5
Side impact with fixed object	133	8.8	80	4.8
Frontal impact with fixed object	381	25.2	371	22.5
Control group (multivehicle)	844	55.9	1091	66.1
	1511	100	1650	100
S N O W Y O R I C Y R O A D S (ALL PICKUP TRUCKS)				
Primary rollover	512	25.4	341	18.1
Side impact with fixed object	389	19.3	317	16.8
Frontal impact with fixed object	683	33.9	727	38.5
Control group (multivehicle)	432	21.4	502	26.6
	2016	100	1887	100

objects, while snowy or icy pavement greatly increased the risk of all kinds of run-off-road collisions. Close to half of the rollovers and side impacts with fixed objects in Michigan occurred on snowy or icy roads. Table 2-3 shows that RWAL was quite effective in reducing rollovers and side impacts with fixed objects under all road conditions. Relative to the control group, rollovers decreased by nearly identical 40 percent on dry roads, 45 percent on wet roads and 43 percent on snowy/icy roads. Side impacts with fixed objects decreased by 10 percent on dry roads, 53 percent on wet roads and 30 percent on snow and ice.

Table 2-4 analyzes the crashes of **pickup trucks in Florida during 1990-91.** Florida has about the same number of traffic accidents as Michigan each year, but fewer of them involve light trucks (which have lower sales relative to passenger cars). Run-off-road crashes, especially with fixed objects, are less common because snow and ice are infrequent and, possibly because there are fewer objects by the roadside (e.g., trees). Control group crashes are more common, in part because the Florida file includes records of parked, unoccupied vehicles, if they were struck by another vehicle, while Michigan does not. Rollover risk is substantially lower with RWAL. The middle part of Table 2-4 shows that Ford Rangers experienced a reduction of

$$1 - [(91/177) / (712/711)] = 49 \text{ percent}$$

for rollovers relative to the control group. The reduction is statistically significant (Chi-square = 23.38, $p < .01$). The lower part of Table 2-4 shows that all other pickup trucks had a 31 percent reduction of rollovers with RWAL (significant, Chi-square = 10.51, $p < .01$). These reductions are quite similar to those in Michigan (53 percent for Ranger and 28 percent for other pickups). The reductions of side impacts with fixed objects were 49 percent for Ranger and 23 percent for other pickups. Frontal impacts with fixed objects decreased by

TABLE 2-4

FLORIDA, 1990-91: PICKUP TRUCKS
EFFECT OF RWAL ON SINGLE-VEHICLE CRASHES

	Last 2 MY Without RWAL		First 2 MY With RWAL	
Type of Crash Involvement	**N**	**%**	**N**	**%**
ALL PICKUP TRUCKS				
Primary rollover	368	8.4	230	5.3
Side impact with fixed object	146	3.3	108	2.5
Frontal impact with fixed object	644	14.8	661	15.2
Control group (multivehicle)	3209	73.5	3346	77.0
	4367	100	4345	100
FORD RANGER				
Primary rollover	177	16.0	91	9.5
Side impact with fixed object	35	3.2	18	1.9
Frontal impact with fixed object	185	16.7	140	14.6
Control group (multivehicle)	711	64.2	712	74.1
	1108	100	961	100
ALL OTHERS				
Primary rollover	191	5.9	139	4.1
Side impact with fixed object	111	3.4	90	2.7
Frontal impact with fixed object	459	14.1	521	15.4
Control group (multivehicle)	2498	76.7	2634	77.8
	3259	100	3384	100

24 percent in Rangers but increased by 8 percent in other pickups (not statistically significant).

Table 2-5 repeats the Florida analyses with the sample limited to pickup trucks of the **last** model year without RWAL and the **first** model year with RWAL, minimizing the vehicle age difference between the two groups. The rollover reductions with RWAL are 53 percent for Ranger and 20 percent for other pickup trucks, which is similar to the full Florida sample as well as the Michigan results.

Table 2-6 analyzes pickup truck crashes in Florida **by road condition**: dry roads vs. wet roads. Wet pavement substantially increased the risk of rollover (without RWAL) and more than doubled the risk of a side impact with a fixed object, relative to the control group. RWAL was effective in reducing rollovers on both dry roads (43 percent) and wet roads (30 percent). As in Michigan, the road condition does not greatly influence the effect of RWAL for pickup trucks. This finding is not entirely consistent with NHTSA's stopping tests (Section 1.2), which showed no yawing with or without RWAL in 35 mph stopping tests on dry concrete. However, the sample of the stopping tests was small (2 trucks, 6 stops each), and they involved ideal road and vehicle conditions which are perhaps not representative of actual trucks on the highway.

Table 2-7 describes the accidents of **pickup trucks in Pennsylvania during 1989-91**. Pennsylvania has fewer reported crashes and relatively fewer light trucks than Michigan or Florida; data for 1989 were included to augment the sample. The prevalence of urban areas and heavily forested rural areas tends to increase collisions with fixed objects and decrease rollovers. Table 2-7 shows

TABLE 2-5

FLORIDA, 1990-91: PICKUP TRUCKS
EFFECT OF RWAL ON SINGLE-VEHICLE CRASHES
(data limited to 1 MY before/after RWAL installation)

	Last MY Without RWAL		First MY With RWAL	
Type of Crash Involvement	**N**	**%**	**N**	**%**
A L L P I C K U P T R U C K S				
Primary rollover	236	9.8	143	6.1
Side impact with fixed object	86	3.6	67	2.8
Frontal impact with fixed object	337	14.0	369	15.7
Control group (multivehicle)	1754	72.7	1778	75.4
	2413	100	2357	100
F O R D R A N G E R				
Primary rollover	128	18.6	50	10.3
Side impact with fixed object	22	3.2	10	2.0
Frontal impact with fixed object	108	15.7	72	14.8
Control group (multivehicle)	430	62.5	355	72.9
	688	100	487	100
A L L O T H E R S				
Primary rollover	108	6.3	93	5.0
Side impact with fixed object	64	3.7	57	3.0
Frontal impact with fixed object	229	13.3	297	15.9
Control group (multivehicle)	1324	76.7	1423	76.1
	1725	100	1870	100

TABLE 2-6

FLORIDA, 1990-91: PICKUP TRUCKS
EFFECT OF RWAL ON SINGLE-VEHICLE CRASHES - BY ROAD CONDITION

	Last 2 MY Without RWAL		First 2 MY With RWAL	
Type of Crash Involvement	**N**	**%**	**N**	**%**
DRY ROADS (ALL PICKUP TRUCKS)				
Primary rollover	277	7.7	164	4.5
Side impact with fixed object	96	2.7	72	2.0
Frontal impact with fixed object	538	14.8	548	15.2
Control group (multivehicle)	2712	74.9	2831	78.3
	3623	100	3615	100
WET ROADS (ALL PICKUP TRUCKS)				
Primary rollover	91	12.2	66	9.0
Side impact with fixed object	50	6.7	36	4.9
Frontal impact with fixed object	106	14.3	113	15.5
Control group (multivehicle)	497	66.8	515	70.6
	744	100	730	100

TABLE 2-7

PENNSYLVANIA, 1989-91: PICKUP TRUCKS
EFFECT OF RWAL ON SINGLE-VEHICLE CRASHES

Type of Crash Involvement	Last 2 MY Without RWAL N	%	First 2 MY With RWAL N	%
A L L P I C K U P T R U C K S				
Primary rollover	292	7.5	166	4.8
Side impact with fixed object	443	11.5	333	9.7
Frontal impact with fixed object	1523	39.4	1416	41.2
Control group (multivehicle)	1610	41.6	1519	44.3
	3868	100	3434	100
F O R D R A N G E R				
Primary rollover	129	13.1	44	8.4
Side impact with fixed object	126	12.8	56	10.7
Frontal impact with fixed object	386	39.2	231	44.3
Control group (multivehicle)	343	34.9	191	36.6
	984	100	522	100
A L L O T H E R S				
Primary rollover	163	5.7	122	4.2
Side impact with fixed object	317	11.0	277	9.5
Frontal impact with fixed object	1137	39.4	1185	40.7
Control group (multivehicle)	1267	43.9	1328	45.6
	2884	100	2912	100

that rollover risk is considerably lower when pickup trucks have RWAL. Rollover risk decreased by 39 percent for Ford Ranger, and 29 percent for all other pickups. Side impacts with fixed objects were reduced by 20 percent on Ranger and 17 percent on other pickups. On the other hand, frontal impacts with fixed objects increased by 7 percent on Ranger (not statistically significant) and decreased by just 1 percent on other pickups.

A more detailed classification of the pickup trucks in Michigan and Florida differentiates between those that have 2-wheel drive and those with 4-wheel drive. The rollover rate (relative to the control group) is 50-100 percent higher for 4WD Ford Rangers than 2WD Rangers; for all other pickups, the rollover rate is likewise 50 percent higher with 4-wheel drive than 2-wheel drive. Those differences may reflect the driver characteristics and exposure profile of the 4WD vehicles (young males, rural driving). However, the **effectiveness** of RWAL is about the same for both types of drive train. In Michigan, RWAL reduced rollovers by 48 percent in 2WD Rangers, by 51 percent in 4WD Rangers, by 29 percent in 2WD pickups other than Ranger, and by 19 percent in 4WD pickups other than Ranger.

2.2 Sport utility vehicles

Due to lower sales and exposure, sport utility vehicles (SUV) have substantially smaller accident samples than pickup trucks. SUVs, as defined here, are built up on a shortened pickup-truck chassis and are often purchased for rural, recreational travel. They are particularly popular with young male drivers. The vast majority have 4-wheel drive. They include the Chevrolet Blazer, GMC Jimmy, Ford Bronco/Bronco 2/Explorer and Dodge Ramcharger; the Blazer and Jimmy come in two distinct sizes (compact or full-sized, depending on the pickup chassis they are built on), the Bronco and Ramcharger are full-sized, while the Bronco 2 and its 1991 successor, the Explorer, are compact. The Chevrolet and GMC Suburban, although based on a pickup chassis, are included with vans rather than SUVs because they are typically used like passenger vans (commuter and school carpools, family travel).

Table 2-8 analyzes the crashes of SUVs in Michigan during 1990-91. By the metric used in this evaluation, the Ford Bronco 2, which is built on a Ford Ranger chassis, has a much higher rollover rate in Michigan (36.5 percent without RWAL) than other SUVs (12.8 percent); the rate for Bronco 2 is high, even relative to Ford Ranger (22.9 percent, see Table 2-1). SUVs other than Bronco 2 and Explorer had a slightly higher rollover rate (12.8 percent) than pickup trucks other than Ranger (10.8 percent, see Table 2-1). Table 2-8 shows that all types of run-off-road crashes decreased with RWAL, although not quite as impressively as for pickup trucks. Rollovers of Bronco 2 decreased by 44 percent with RWAL, relative to the control group; the reduction is statistically significant (Chi-square = 14.78, $p < .01$). Bronco 2 side impacts with fixed objects declined by 34 percent and frontal impacts with fixed objects by 22 percent. For SUVs other than Bronco 2, rollovers decreased by 19 percent with RWAL, relative to the control group; side impacts with fixed objects decreased by 20 percent; frontal impacts with fixed objects, by 21 percent (statistically significant, Chi-square = 4.08, $p < .05$); the combined net reduction in all three types of run-off-road crashes, relative to the control group, is also statistically significant (Chi-square = 5.78, $p < .05$).

Florida and Pennsylvania have substantially smaller samples of SUV crashes than Michigan. Both States, nevertheless, show a reduction of rollovers

TABLE 2-8

MICHIGAN, 1990-91: SPORT UTILITY VEHICLES
EFFECT OF RWAL ON SINGLE-VEHICLE CRASHES

	Last 2 MY Without RWAL		**First 2 MY With RWAL**	
Type of Crash Involvement	**N**	**%**	**N**	**%**
A L L S P O R T U T I L I T Y V E H I C L E S				
Primary rollover	318	20.5	255	17.7
Side impact with fixed object	138	8.9	113	7.8
Frontal impact with fixed object	363	23.4	316	21.9
Control group (multivehicle)	730	47.1	757	52.5
	1549	100	1441	100
F O R D B R O N C O 2				
Primary rollover	185	36.5	157	27.1
Side impact with fixed object	45	8.9	45	7.8
Frontal impact with fixed object	121	23.9	142	24.5
Control group (multivehicle)	156	30.7	235	40.6
	507	100	579	100
A L L O T H E R S				
Primary rollover	133	12.8	98	11.4
Side impact with fixed object	93	8.9	68	7.9
Frontal impact with fixed object	242	23.2	174	20.2
Control group (multivehicle)	574	55.1	522	60.5
	1042	100	862	100

and fixed-object impacts for Bronco 2 with RWAL. Table 2-9 shows that, in Florida, rollovers of Bronco 2 decreased by 34 percent, relative to the control group; the reduction is statistically significant (Chi-square = 4.03, $p < .05$). Table 2-10 shows that, in Pennsylvania, rollovers of Bronco 2 decreased by a similar, although nonsignificant 25 percent (Chi-square = 2.24). In both States, lateral and frontal fixed-object impacts decreased with RWAL for Bronco 2.

2.3 Vans

The tables on "vans" include the Chevrolet Astro, Sportvan and Chevy Van; the GMC Safari, Rally and Vandura, Chevrolet-GMC Suburban, Ford Aerostar, Club Wagon and Econoline, and Dodge Ram Wagon and Van. Voyager/Caravan, and Lumina APV are excluded because they did not have standard RWAL during 1985-91. Vans are extensively used on urban roads for family or business travel and have generally low accident involvement rates; in particular, they have less than half the rollover risk (relative to the control group) of pickup trucks and just over half the risk of collisions with fixed objects. Here, too, the Ford compact vehicle (Aerostar) has higher rollover risk than other models.

Table 2-11 analyzes van crashes in Michigan. With RWAL, the rollover rate in Aerostar decreased by a statistically significant 39 percent (Chi-square = 5.87, p < .[illegible] The rollover rate in other vans decreased by 13 percent. Side and frontal [illegible] with fixed objects decreased, relative to the control group, in both types of vans. Since the accident involvement profiles for Aerostar vs. other types of vans do not differ as greatly as, say, Ford Ranger vs. other pickups, it is appropriate to combine all types of vans and look at the net reductions for RWAL (top section of Table 2-11). The rollover risk of all types of vans, combined, declined by a statistically significant 25 percent (Chi-square

TABLE 2-9

FLORIDA, 1990-91: SPORT UTILITY VEHICLES
EFFECT OF RWAL ON SINGLE-VEHICLE CRASHES

	Last 2 MY Without RWAL		First 2 MY With RWAL	
Type of Crash Involvement	**N**	**%**	**N**	**%**
ALL SPORT UTILITY VEHICLES				
Primary rollover	113	10.1	112	10.0
Side impact with fixed object	29	2.6	34	3.1
Frontal impact with fixed object	143	12.7	142	12.7
Control group (multivehicle)	838	74.6	827	74.2
	1123	100	1115	100
FORD BRONCO 2				
Primary rollover	49	19.8	76	15.0
Side impact with fixed object	12	4.9	12	2.4
Frontal impact with fixed object	37	15.0	67	13.3
Control group (multivehicle)	149	60.3	350	69.3
	247	100	505	100
ALL OTHERS				
Primary rollover	64	7.3	36	5.9
Side impact with fixed object	17	1.9	22	3.6
Frontal impact with fixed object	106	12.1	75	12.3
Control group (multivehicle)	689	78.7	477	78.2
	876	100	610	100

TABLE 2-10

PENNSYLVANIA, 1989-91: SPORT UTILITY VEHICLES
EFFECT OF RWAL ON SINGLE-VEHICLE CRASHES

	Last 2 MY Without RWAL		First 2 MY With RWAL	
Type of Crash Involvement	**N**	**%**	**N**	**%**
A L L S P O R T U T I L I T Y V E H I C L E S				
Primary rollover	124	10.5	136	10.7
Side impact with fixed object	142	12.0	148	11.6
Frontal impact with fixed object	404	34.1	453	35.6
Control group (multivehicle)	516	43.4	537	42.1
	1186	100	1274	100
F O R D B R O N C O 2				
Primary rollover	73	16.3	88	14.0
Side impact with fixed object	61	13.6	86	13.7
Frontal impact with fixed object	165	37.0	218	34.6
Control group (multivehicle)	148	33.1	237	37.7
	447	100	629	100
A L L O T H E R S				
Primary rollover	51	6.9	48	7.4
Side impact with fixed object	81	11.0	62	9.6
Frontal impact with fixed object	239	32.3	235	36.4
Control group (multivehicle)	368	49.8	300	46.5
	739	100	645	100

TABLE 2-11

MICHIGAN, 1990-91: VANS
EFFECT OF RWAL ON SINGLE-VEHICLE CRASHES

Type of Crash Involvement	**Last 2 MY Without RWAL** N	%	**First 2 MY With RWAL** N	%
A L L V A N S				
Primary rollover	197	6.6	117	5.4
Side impact with fixed object	245	8.2	140	6.4
Frontal impact with fixed object	534	17.9	338	15.5
Control group (multivehicle)	2000	67.2	1581	72.7
	2976	100	2176	100
F O R D A E R O S T A R				
Primary rollover	85	10.5	38	7.2
Side impact with fixed object	55	6.8	31	5.9
Frontal impact with fixed object	158	19.5	83	15.7
Control group (multivehicle)	513	63.2	377	71.2
	811	100	529	100
A L L O T H E R S				
Primary rollover	112	5.2	79	4.8
Side impact with fixed object	190	8.8	109	6.6
Frontal impact with fixed object	376	17.4	255	15.5
Control group (multivehicle)	1487	68.7	1204	73.1
	2165	100	1647	100

= 5.57, $p < .05$). Side impacts with fixed objects decreased by a statistically significant 28 percent with RWAL (Chi-square = 8.58, $p < .01$); frontal impacts with fixed objects, by a statistically significant 20 percent (Chi-square = 8.30, $p < .01$).

In Florida and Pennsylvania, the accident samples for vans are barely sufficient for analysis (Tables 2-12 and 2-13). The Florida data do not show any substantial differences in the accident distributions of vans without RWAL and vans with RWAL. Rollover risk, for all vans combined, decreased by a nonsignificant 11 percent, relative to the control group. The Pennsylvania results are more favorable for RWAL. All types of run-off-road crashes decreased, relative to the control group; the reduction for rollovers was 28 percent. The net combined reduction of run-off-road crashes, relative to the control group, was a statistically significant 22 percent (Chi-square = 4.69, $p < .05$).

2.4 Fatal crashes of light trucks

Crash-avoidance devices that require a degree of human intervention to "work" (e.g., ABS only works if the driver steps on the brakes) may be less effective in preventing fatalities than in nonfatal crashes. In many fatal crashes, drivers are impaired or inattentive to the point where they do not use the crash-avoidance system at all; in many others, their risk-taking behavior prior to the crash creates an imminent hazard which the crash-avoidance measure is not powerful enough to mitigate. For example, NHTSA's evaluations of side marker lamps [4] and Center High Mounted Stop Lamps [3] did not show fatality reductions, despite significant reductions of nonfatal accidents and injuries.

TABLE 2-12

FLORIDA, 1990-91: VANS
EFFECT OF RWAL ON SINGLE-VEHICLE CRASHES

Type of Crash Involvement	Last 2 MY Without RWAL N	%	First 2 MY With RWAL N	%
	A L L	**V A N S**		
Primary rollover	65	3.1	37	2.7
Side impact with fixed object	23	1.1	17	1.3
Frontal impact with fixed object	116	5.5	76	5.6
Control group (multivehicle)	1917	90.4	1220	90.4
	2121	100	1350	100

TABLE 2-13

PENNSYLVANIA, 1989-91: VANS
EFFECT OF RWAL ON SINGLE-VEHICLE CRASHES

	Last 2 MY Without RWAL		First 2 MY With RWAL	
Type of Crash Involvement	**N**	**%**	**N**	**%**
	ALL VANS			
Primary rollover	39	5.2	22	4.1
Side impact with fixed object	63	8.3	47	8.8
Frontal impact with fixed object	245	32.5	144	27.0
Control group (multivehicle)	408	54.0	321	60.1
	755	100	534	100

Table 2-14 analyzes the run-off-road crashes of **pickup trucks in 1989-mid 92 FARS data.** It compares trucks of the first 2 model years with RWAL to those of the last 2 model years without RWAL, analogous to Table 2-1 (Michigan crashes). However the "control group" used in the analyses of State data (involvements as a stopped, slow or parked vehicle in a multivehicle crash) is too small on FARS, since such involvements are rarely fatal. Instead, the control group is extended to <u>all</u> multivehicle crash involvements of pickup trucks, under the assumption that the risk of involvement in multivehicle crashes is unaffected by RWAL (which will be supported by the data in Section 3.2).

Table 2-14 repeats the pattern of Tables 2-1, 2-4 and 2-7: divergent results for Ford Ranger vs. other pickup trucks. The difference is that all accident reductions are smaller. Ford Ranger has a much higher fatal rollover risk, relative to the control group, than other pickup trucks. With RWAL, the rollover risk in Ford Ranger decreased by 26 percent, relative to the control group, an effect which falls short of statistical significance (Chi-square = 3.53). The risk of a fatal side impact with a fixed object decreased by 42 percent, and a frontal impact with a fixed object, by 7 percent. The net combined reduction of rollovers and side impacts with fixed objects is a statistically significant 29 percent (Chi-square = 5.60, $p < .05$). The rollover reduction in the fatal crashes, 26 percent, is substantially lower than in the three State files (53, 49, and 39 percent).

Fatal rollover risk of pickup trucks other than Ford Ranger was not reduced with RWAL; in fact, it increased by a nonsignificant 17 percent, relative to the control group. Side impacts with fixed objects increased by a nonsignificant 10 percent, and frontal impacts with fixed objects, by a

TABLE 2-14

FARS, 1989-mid 92: PICKUP TRUCKS
EFFECT OF RWAL ON FATAL SINGLE-VEHICLE CRASHES

Type of Crash Involvement	Last 2 MY Without RWAL N	Last 2 MY Without RWAL %	First 2 MY With RWAL N	First 2 MY With RWAL %
A L L P I C K U P T R U C K S				
Primary rollover	362	10.6	370	10.1
Side impact with fixed object	148	4.3	154	4.2
Frontal impact with fixed object	623	18.3	712	19.4
Any multivehicle crash	2273	66.8	2435	66.3
	3406	100	3671	100
F O R D R A N G E R				
Primary rollover	146	18.6	75	15.0
Side impact with fixed object	40	5.1	16	3.2
Frontal impact with fixed object	149	19.0	96	19.2
Any multivehicle crash	450	57.3	312	62.6
	785	100	499	100
A L L O T H E R S				
Primary rollover	216	8.2	295	9.3
Side impact with fixed object	108	4.1	138	4.4
Frontal impact with fixed object	474	18.1	616	19.4
Any multivehicle crash	1823	69.6	2123	66.9
	2621	100	3172	100

nonsignificant 12 percent.

Table 2-15 analyzes the fatal run-off-road crashes of **sport utility vehicles**. Ford Bronco 2, like Ranger, had a much higher rollover risk than other vehicles of its class (25.7 percent of the sample, without RWAL), but, unlike Ranger, the rollover risk is not reduced with RWAL (in fact, it increased by a nonsignificant 17 percent, relative to the control group). Impacts with fixed objects also were about the same with and without RWAL. For SUVs other than Bronco 2, there is likewise little difference in the fatal accident distributions before and after RWAL. Table 2-16 suggests that RWAL had little effect, positive or negative, on the fatal run-off-road crashes of **vans**. In short, the Ford Ranger was the only group for which RWAL was associated with a substantial reduction of fatal run-off-road crashes.

TABLE 2-15

FARS, 1989-mid 92: SPORT UTILITY VEHICLES
EFFECT OF RWAL ON FATAL SINGLE-VEHICLE CRASHES

	Last 2 MY Without RWAL		First 2 MY With RWAL	
Type of Crash Involvement	**N**	**%**	**N**	**%**
A L L S P O R T U T I L I T Y V E H I C L E S				
Primary rollover	121	17.9	152	21.6
Side impact with fixed object	22	3.3	26	3.7
Frontal impact with fixed object	109	16.2	100	14.2
Any multivehicle crash	422	62.6	425	60.5
	674	100	703	100
F O R D B R O N C O 2				
Primary rollover	57	25.7	105	28.8
Side impact with fixed object	5	2.3	12	3.3
Frontal impact with fixed object	35	15.8	51	14.0
Any multivehicle crash	125	56.2	196	53.9
	222	100	364	100
A L L O T H E R S				
Primary rollover	64	14.2	47	13.9
Side impact with fixed object	17	3.8	14	4.1
Frontal impact with fixed object	74	16.4	49	14.5
Any multivehicle crash	297	65.6	229	67.5
	452	100	339	100

TABLE 2-16

FARS, 1989-mid 92: VANS
EFFECT OF RWAL ON FATAL SINGLE-VEHICLE CRASHES

	Last 2 MY Without RWAL		First 2 MY With RWAL	
Type of Crash Involvement	**N**	**%**	**N**	**%**
	A L L	**V A N S**		
Primary rollover	40	6.1	45	8.8
Side impact with fixed object	16	2.4	9	1.8
Frontal impact with fixed object	72	10.9	68	13.4
Any multivehicle crash	530	80.6	387	76.0
	658	100	509	100

CHAPTER 3

ANALYSIS OF MULTIVEHICLE CRASHES

When two or more vehicles are on a collision course, improved braking for any of the vehicles might help prevent the collision. It is not always clear which vehicle would benefit; in some cases more than one. The only vehicles that have no potential benefit from improved braking capabilities are those that are standing still prior to the crash (brakes are irrelevant), or moving very slowly before the crash (ABS and conventional brakes work equally well), or those where the driver never applies the brakes. Traditional categorizations of vehicles in collisions, such as "culpable" vs. "not culpable" or "striking" vs. "struck" are not always useful for identifying potential benefits from improved braking. For example, if Vehicle 1 enters the intersection on red and Vehicle 2 on green, Vehicle 1 is "culpable," but either vehicle might have been able to avoid the crash by improved braking. Similarly, if Vehicle 1 and Vehicle 2 both enter an intersection and Vehicle 1 hits Vehicle 2 in the side, Vehicle 1 is the "striking" vehicle and Vehicle 2 is "struck," but either vehicle might have avoided the crash by improved braking.

It is not intuitively clear that rear-wheel ABS (RWAL) would be effective in multivehicle crashes. Four-wheel ABS might be expected to reduce stopping distances, bringing vehicles to a stop before their paths cross, and preserve drivers' steering control during braking, allowing evasive maneuvers. RWAL, however, has limited, if any, effect on stopping distances and steering control during panic braking. Perhaps, RWAL might help by preventing a truck from yawing out of control and hitting a vehicle in another lane. It might encourage the driver to slam on the brakes rather than engaging in timid braking that would have further prolonged stopping distances.

3.1 Collisions between a fast-moving and a slow/stopped vehicle (Florida)

In many multivehicle collisions, as stated above, it is unclear which vehicle(s) could have benefited from ABS (possibly all of them). However, there is a subset of collisions in which it is rather clear that at most one vehicle could have benefited from ABS: 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 or was moving too slowly for ABS to act differently from conventional brakes. The 1990-91 Florida accident files, which report the pre-crash (travelling) speeds of most crash-involved vehicles, allow identification of this subset of collisions. By limiting the data to these specific two-vehicle crashes, it is possible to reduce the analysis of crash involvements to a simple 2 x 2 table: ABS vs. non-ABS vehicles, ABS-relevant (fast-moving) vs. ABS-irrelevant (stopped or slow-moving) crash involvements. Moreover, the dichotomous form of the dependent variable (ABS-relevant vs. ABS-irrelevant crash involvement) allows the use of logistic regression techniques to distinguish the effect of ABS from the effects of other factors such as driver age and sex. The analysis method will provide estimates of accident reduction for light trucks with RWAL in this subset of multivehicle crashes, and can be extended to cars and trucks with 4-wheel ABS, when sufficient data become available.

The 1990-91 Florida accident files were transformed into a "two-vehicle crash" file, with one record per two-vehicle crash. Each record contains accident-level variables, plus information on vehicle/driver no. 1 and vehicle/driver no. 2. The file was restricted to crashes between model year

1981-91 cars or domestic light trucks with decodable VINs. (The trucks were limited to the Chevrolet, GMC, Ford and Dodge models listed in Table 1-3.)

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 vehicle movements - 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 1990-91 Florida files include 44,467 two-vehicle crashes meeting the criteria, comprising 88,934 records of cars and light trucks. There were 14,361 light trucks, of which 4,847 were equipped with RWAL.

3.1.1 Contingency table analyses

Consistent with intuition about the potential effect of RWAL in multivehicle crashes, the Florida contingency table analyses did not show any statistically significant accident reductions for light trucks. Table 3-1 compares the fast-moving and stopped/slow-moving crash involvements of **pickup trucks** of the first 2 model years with RWAL to those of the last 2 model years without RWAL. (Only one of the two vehicles in a 2-vehicle crash needs to be a pickup truck in the applicable model-year range; the other vehicle in the crash, however, is not included in the tabulation.) The top section of Table 3-1 shows that there were 996 involvements of non-RWAL trucks as the fast-moving vehicle in a collision, and 1075 fast-moving involvements of RWAL-equipped trucks. There were 908 non-RWAL and 979 RWAL-equipped truck involvements as a stopped or slow-moving vehicle. That is a relative change of

$$1 - [(1075/996) / (979/908)] = \text{zero}$$

TABLE 3-1

FLORIDA, 1990-91: PICKUP TRUCKS
EFFECT OF RWAL ON CRASHES OF A FAST-MOVING VEHICLE
AND A STOPPED OR SLOW-MOVING VEHICLE

	Last 2 MY Without RWAL		First 2 MY With RWAL	
Type of Crash Involvement	**N**	**%**	**N**	**%**
ALL PICKUP TRUCKS, ALL ROADS				
As the fast-moving vehicle	996	52.3	1075	52.3
As the stopped/slow-moving vehicle	908	47.7	979	47.7
	1904	100	2054	100

No relative reduction of fast-moving involvements for RWAL
Chi-square = 0.00

	Last 2 MY Without RWAL		First 2 MY With RWAL	
ALL PICKUP TRUCKS, WET ROADS	**N**	**%**	**N**	**%**
As the fast-moving vehicle	161	52.6	166	46.8
As the stopped/slow-moving vehicle	145	47.4	189	53.2
	306	100	355	100

21 percent relative reduction of fast-moving involvements for RWAL
Chi-square = 2.25

- i.e., RWAL had no observed effect on the fast-moving involvements of pickup trucks. The lower section of Table 3-1 is limited to crashes on wet roads. Pickup trucks with RWAL had a 21 percent lower risk of involvement as a fast-moving vehicle than the non-RWAL trucks, but the reduction is not statistically significant (Chi-square = 2.25).

Table 3-2 shows that **sport utility vehicles** with RWAL experienced little or no reduction (2 percent) in fast-moving crash involvements on all types of roads. The small sample size precludes obtaining a statistically meaningful result for crashes on wet roads. The results for **vans**, as shown in Table 3-3, are somewhat more positive, (15 percent reduction on all roads, 33 percent on wet roads), but fall short of statistical significance.

3.1.2 Logistic regression analyses

ABS is just one of several factors that could affect the odds of being the fast-moving vehicle in a collision of a fast with a stopped/slow vehicle. Obviously, driver age is bound to be a factor: the young drive faster and take more risks, while the oldest drivers are especially prone to careless turns and other maneuvers that can result in getting hit while moving slowly. Males drive faster and take more risks than females, and, needless to say, drunk drivers take more risks than sober drivers. The age of the vehicle (to the extent that older vehicles have different types of drivers than new ones) and the type of vehicle (car, pickup, van, utility) could be factors. Certain makes or models could attract especially aggressive (or passive) drivers, even beyond what would be expected, given the age and sex of the drivers.

Before the variables were entered in a multivariate logistic model,

TABLE 3-2

FLORIDA, 1990-91: SPORT UTILITY VEHICLES
EFFECT OF RWAL ON CRASHES OF A FAST-MOVING VEHICLE
AND A STOPPED OR SLOW-MOVING VEHICLE

	Last 2 MY Without RWAL		First 2 MY With RWAL	
Type of Crash Involvement	**N**	**%**	**N**	**%**
ALL SPORT UTILITY VEHICLES, ALL ROADS				
As the fast-moving vehicle	284	54.2	280	53.7
As the stopped/slow-moving vehicle	240	45.8	241	46.3
	524	100	521	100

2 percent relative reduction of fast-moving involvements for RWAL
Chi-square = 0.02

	Last 2 MY Without RWAL		First 2 MY With RWAL	
ALL SPORT UTILITY VEHICLES, WET ROADS				
As the fast-moving vehicle	44	44.9	55	54.4
As the stopped/slow-moving vehicle	54	55.1	46	45.6
	98	100	101	100

-47 percent relative reduction of fast-moving involvements for RWAL
Chi-square = 1.82

TABLE 3-3

FLORIDA, 1990-91: VANS
EFFECT OF RWAL ON CRASHES OF A FAST-MOVING VEHICLE
AND A STOPPED OR SLOW-MOVING VEHICLE

	Last 2 MY Without RWAL		First 2 MY With RWAL	
Type of Crash Involvement	**N**	**%**	**N**	**%**
A L L V A N S, A L L R O A D S				
As the fast-moving vehicle	450	48.6	270	44.5
As the stopped/slow-moving vehicle	476	51.4	337	55.5
	926	100	607	100

15 percent relative reduction of fast-moving involvements for RWAL
Chi-square = 2.49

	Last 2 MY Without RWAL		First 2 MY With RWAL	
A L L V A N S, W E T R O A D S				
As the fast-moving vehicle	75	49.7	45	39.8
As the stopped/slow-moving vehicle	76	50.3	68	60.2
	151	100	113	100

33 percent relative reduction of fast-moving involvements for RWAL
Chi-square = 2.61

they were inspected on an individual basis. When driver age is subdivided into 5-year increments, the probability that the driver's car or truck will be the fast-moving vehicle in the collision decreases strongly as age increases past 20:

Driver Age to the Nearest 5 Years	Percent of Involvements as the Faster-Moving Vehicle
15	55
20	58
25	57
30	56
35	53
40	50
45	47
50	46
55	44
60	42
65	39
70	37
75	36
80	32

The probability of involvement as the faster-moving vehicle is higher for males than females:

Driver's Sex	Percent of Involvements as the Faster-Moving Vehicle
Male	52
Female	48

On this largely nonfatal accident file, only about 4 percent of drivers were reported under the influence of alcohol or drugs. That group was far more likely to be fast-moving than sober drivers:

Alcohol/Drugs	Percent of Involvements as the Faster-Moving Vehicle
Yes	68
No	49

In comparison to the preceding factors, vehicle age had little effect, showing a possible tendency for middle-age vehicles (5 to 7 years) to be the slowest:

Vehicle Age (Yrs)	Percent of Involvements as the Faster-Moving Vehicle
0	49
1	51
2	51
3	51
4	51
5	49
6	48
7	50
8	51
9	51

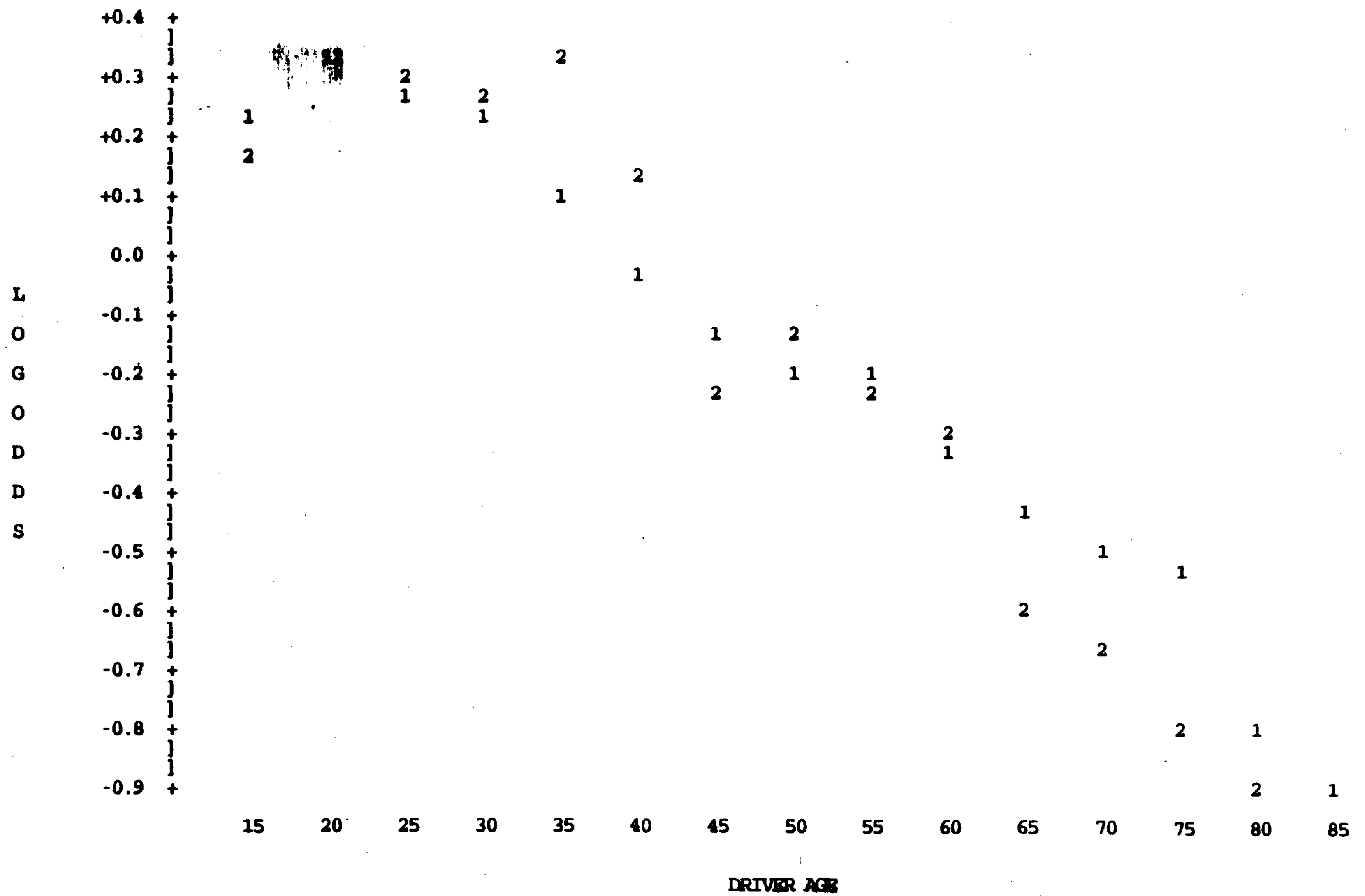
The vehicle type also had relatively little effect:

Vehicle Type	Percent of Involvements as the Faster-Moving Vehicle
Car	50
Pickup	52
Van	49
Utility	53

To the extent that pickups and utilities are often driven by young men, these observed effects may be due more to the driver age and sex than the vehicles themselves.

Driver age is obviously the most important variable. Figure 3-1 shows that the log odds of being the fast-moving vehicle are higher for a 20-year-old driver than a teenage driver. But for all driver ages over 20, the log odds decrease as age increases, at a nearly linear rate. The '1's in Figure 3-1 are the points for cars; the '2's for pickup trucks - they practically coincide (cars and pickups have about the same likelihood of being the faster vehicle, after control for driver age). Figure 3-1 suggests that driver age be entered into the logistic regression model as two variables: a linear term equal to the difference

FIGURE 3-1: LOG ODDS OF BEING THE FAST-MOVING VEHICLE IN A COLLISION
BETWEEN A FAST-MOVING AND A STOPPED/SLOW VEHICLE - BY DRIVER AGE AND VEHICLE TYPE (1=cars, 2=pickups)



in the ages of the two drivers in the crash (which expresses the linear effect above age 20), and a "young driver" variable which equals 1 if the driver of vehicle 1 is 17 or less, -1 if the driver of vehicle 2 is 17 or less, and zero if neither (or both) are under 18 (which expresses the departure from the linear decreasing effect in that age group). Similar trichotomous (1,-1,0) variables are defined for: female driver, drunk/drugged driver, pickup, van, sport utility vehicle (SUV). Vehicle age is entered as a linear term equal to the difference in the age of the two vehicles.

There were 37,636 two-vehicle crashes in which neither vehicle was equipped with 4-wheel ABS or RWAL. Each of these crashes contributes two data points to the regression: once with vehicle 1 as the "case" vehicle and vehicle 2 as the "other" vehicle, and once with these designations reversed (75,272 regression data points). The dependent variable is 1 if the "case" vehicle was fast-moving and the "other" vehicle stopped/slow-moving; the dependent variable is 0 if the "case" vehicle was stopped/slow-moving and the "other" vehicle fast-moving. The intercept term for the logistic regression is exactly zero since each crash contributes two diametrically opposed data points. The regression coefficients (betas) for the other variables, and their associated Chi-squares, are:

Variable	Beta	Chi Square
Driver age	-0.0194	3512.34
Young driver	-0.170	39.05
Female driver	-0.235	436.28
Drunk/drugged driver	+0.780	704.02
Vehicle age	-0.005	5.83
Pickup	-0.037	2.24
Van	-0.106	19.32
SUV	+0.072	2.48

As evidenced by the Chi-squares, driver age, sex and sobriety far outweigh vehicle factors such as vehicle age or type. (Pickup trucks, after controlling for the drivers' age, sex and sobriety, had almost the same likelihood of involvement as the fast-moving vehicle as passenger cars; vans, somewhat less; SUVs, somewhat more.)

The regression equation yields the expected probability, given a two-vehicle collision, that the "case" vehicle was the faster-moving one, based on the age and sex of both drivers, etc. This "expected" probability can be compared to what actually happened in the crash, and the comparative results can be accumulated, over a large number of crashes, to obtain an index of performance for a particular type of vehicle. Table 3-4 shows the performance indices and other statistics for various types of light trucks, with and without RWAL. For example, the first line of data in the upper half of Table 3-4 shows that pickup trucks with RWAL were involved in 3233 crashes on the 1990-91 Florida 2-vehicle crash file. The trucks with RWAL were the faster-moving vehicle in 1714 of the collisions, but were stopped or moving slowly in 1519. The "expected" probabilities, based on the regression equation, are calculated for each of the 3233 collisions and summed, yielding an expected total of 1715.3 fast-moving and 1517.7 stopped/slow-moving involvements for the RWAL-equipped pickup trucks (which are less likely to have older drivers or female drivers than other vehicles on the road, such as cars or vans, and thus have substantially greater than 50 percent expectation of being the slow/stopped vehicle). The 2 x 2 table of actual and expected involvements is:

TABLE 3-4

FLORIDA, 1990-91: LIGHT TRUCKS
EFFECT OF RWAL ON CRASHES OF A FAST-MOVING VEHICLE
AND A STOPPED OR SLOW-MOVING VEHICLE

LOGISTIC REGRESSION ANALYSIS: ALL VEHICLES, ALL ROADS

Vehicle Type/ Braking System	**Crash Involvements**	**Fast-Moving Involvements**		**Slow/Stopped Involvements**	
		Actual	**Expected**	**Actual**	**Expected**
Pickups <u>with</u> RWAL	3233	1714	1715.3	1519	1517.7
Pickups without RWAL	4155	2206	2193.3	1949	1961.7
SUVs <u>with</u> RWAL	966	510	531.3	456	434.7
SUVs without RWAL	1138	621	622.5	517	515.5
Vans <u>with</u> RWAL	648	288	319.9	360	328.1
Vans without RWAL	4179	2006	1986.2	2173	2192.8

Vehicle Type/ Braking System	**Performance Index**	**Reduction for RWAL (%)**	**Average "Relexp"**	**T-Test for Equal Relexp**
Pickups <u>with</u> RWAL	99.8	1.4	-.001	0.30
Pickups without RWAL	101.2		.006	
SUVs <u>with</u> RWAL	91.5	8.0	-.044	0.98
SUVs without RWAL	99.5		-.003	
Vans <u>with</u> RWAL	82.1	**19.4**	-.098	**2.64**
Vans without RWAL	101.9		.009	

	RWAL-Equipped Pickups	Vehicles Colliding with RWAL Pickups
Actual fast-moving involvements	1714	1519
Expected fast-moving involvements	1715.3	1517.7

If the actual and expected numbers of fast-moving involvements had been equal, RWAL-equipped pickup trucks would have been assigned an index of 100. In fact, RWAL-equipped trucks performed just slightly better than expected. There were 1.3 fewer fast-moving involvements than expected among the RWAL-equipped trucks and 1.3 more than expected among the vehicles that collided with these trucks. The performance index for RWAL-equipped pickups, as shown in the first line of data in the lower half of Table 3-4, is

$$[(1714/1715.3) / (1519/1517.7)] \times 100 = 99.8$$

A performance index lower than 100 indicates vehicles are less often involved as the fast-moving vehicle in a fast-slow/stopped collision than average, after controlling for driver age, sex, etc. The second line of data in Table 3-4 indicates that the 4,155 pickup trucks without RWAL likewise have very similar actual and expected crash involvements. Their performance index is 101.2, again nearly "average." In other words, RWAL reduced the risk of being a fast-moving vehicle in a two-vehicle collision by 1 - (99.8/101.2) = 1.4 percent, after controlling for driver age, sex, etc., as shown in the lower half of Table 3-4. The result is consistent with the contingency table analyses on the same data (zero reduction; see Table 3-1).

The statistical significance of this reduction can be tested by computing statistics for the variable "RELEXP" (actual performance relative to expectations), which is computed for each "case" vehicle on the analysis file. If the case vehicle was fast-moving (and the other vehicle slow or stopped), RELEXP = 1 + expected p(other fast) - expected p(case fast)

If the case vehicle was slow or stopped (and the other vehicle fast-moving),

RELEXP = -1 + expected p(other fast) - expected p(case fast)

This variable can range between -2 and 2; if it is negative, the case vehicle did "better than expected" - e.g., it was the slow/stopped vehicle when it was expected to have been the fast-moving one. Over the entire file, and for most of the subsets considered here, RELEXP has a standard deviation very close to .967. The average value of RELEXP is computed for the sample of pickups with RWAL (-.001, as shown in the lower half of Table 3-4) and the sample of pickups without RWAL (.006). The t-statistic for the difference of these two averages,

$$t = [.001 + .006] / [.967 (3233^{-1} + 4155^{-1})^{.5}]$$

is 0.30, indicating that the reduction in fast-moving involvements for pickup trucks with RWAL is not statistically significant.

The sample sizes for sport utility vehicles and vans are smaller than for pickup trucks. Table 3-4 shows that the performance index for SUVs is 91.5 with RWAL and 99.5 without, but that 8 percent improvement is not statistically significant (t = 0.98). Vans with RWAL had a performance index of 82.1 and a statistically significant 19.4 percent reduction of fast-moving involvements, relative to vans without RWAL (t = 2.64, p < .01). The reduction is consistent with the **results of the contingency table analyses** (15 percent, see Table 3-3).

The effectiveness of RWAL on **wet roads** can be estimated by limiting the data to crashes on wet roads and calculating performance indices. The first step in the calculation is to run a separate logistic regression model for the 6,190 2-vehicle crashes on wet roads (12,380 data points) in which <u>neither</u> vehicle was equipped with 4-wheel ABS or RWAL. The rationale for a separate regression is that some of the effects (e.g., driver age, gender or vehicle type) could be different on wet roads than in good weather conditions. The regression coefficients (betas) for the other variables, and their associated Chi-squares, are:

Variable	Beta	Chi Square
Driver age	-0.0204	568.57
Young driver	+0.106	2.71
Female driver	-0.249	79.79
Drunk/drugged driver	+0.951	149.30
Vehicle age	-0.004	.67
Pickup	-0.074	1.50
Van	-0.219	13.28
SUV	-0.070	.45

The regression coefficients are quite close to those calibrated from the entire data set. The most noteworthy change is that the "young driver" effect (age 16-17) was negative on the main regression, positive on wet roads - i.e., these novice drivers, under normal conditions, are less aggressive than 18-20 year-olds, but they do not yet have enough driving experience to make adequate adjustments for wet pavements. Also, not surprisingly, the tendency of drunk or drugged drivers to be the in the faster-moving vehicle is especially strong on wet roads (inattentiveness to road conditions).

Table 3-5 does not show any statistically significant accident reductions for RWAL on wet roads. The performance index of pickup trucks without RWAL is close to average (102.0), while pickup trucks with RWAL have an index of 88.6: an observed reduction of 13 percent. The corresponding observed effects for SUV and vans are -11 percent and 20 percent, respectively. The results are similar to the ones found in the contingency table analyses, but not as extreme, as the adjustments for driver age, etc., "smoothed out" some of the

TABLE 3-5

FLORIDA, 1990-91: LIGHT TRUCKS
EFFECT OF RWAL ON CRASHES OF A FAST-MOVING VEHICLE
AND A STOPPED OR SLOW-MOVING VEHICLE

LOGISTIC REGRESSION ANALYSIS: ALL VEHICLES, **WET ROADS**

Vehicle Type/ Braking System	**Crash Involvements**	**Fast-Moving Involvements**		**Slow/Stopped Involvements**	
		Actual	**Expected**	**Actual**	**Expected**
Pickups with RWAL	574	279	296.3	295	277.7
Pickups without RWAL	706	371	367.5	335	338.5
SUVs with RWAL	181	96	92.0	85	89.0
SUVs without RWAL	215	108	108.7	107	106.3
Vans with RWAL	122	50	55.7	72	66.3
Vans without RWAL	691	313	307.8	378	383.2

Vehicle Type/ Braking System	**Performance Index**	**Reduction for RWAL (%)**	**Average "Relexp"**	**T-Test for Equal Relexp**
Pickups with RWAL	88.6	13.1	-.060	1.29
Pickups without RWAL	102.0		.010	
SUVs with RWAL	109.2	-10.8	.044	0.52
SUVs without RWAL	98.6		-.007	
Vans with RWAL	82.6	19.9	-.094	1.15
Vans without RWAL	103.1		.015	

irregularities in the relatively small samples analyzed here.

3.2 "Striking" vs. "struck" involvements

The preceding analyses are based on a somewhat limited subset of crashes in a single State. The results should be corroborated with other data (other multivehicle crashes, another State), and the effect of RWAL in fatal crashes should be analyzed. For these analyses it is necessary to fall back on more "traditional" classifications of vehicles involved in crashes - by area of damage (front, side, rear) and by vehicle role ("striking" or "struck") - because most accident files, such as Michigan or FARS, do not provide travelling speed information at all, or are missing the information in a large percentage of cases. The objective of the analyses is to see if RWAL is associated with a shift in the distribution of crash involvements, a reduction in the prevalence of various "striking" modes and a compensatory increase in the proportion of various types of "struck" involvements.

Some "striking" crash modes which four-wheel ABS could be intuitively expected to mitigate, and where RWAL might perhaps have a limited effect, include:

- 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 standing still or moving 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 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, four-wheel ABS has an opportunity to reduce the incidence of being the following vehicle in a rear-end collision. RWAL, which does not reduce spike stopping distances, would probably have little benefit here.

- 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 the (frontally damaged) vehicle

Conversely, "struck" crash modes should grow in proportion to other crashes, if vehicles become equipped with four-wheel ABS or, to a more limited extent, with RWAL:

- "Control Group" crash involvements unaffected by ABS or RWAL: where the case vehicle is standing still or moving very slowly (5 mph or less, where ABS/RWAL and conventional brakes work about the same), and is struck by another vehicle. If travelling speed is not reported in the data, it will only be possible to identify the vehicles that were standing still (based on pre-crash vehicle maneuver), not the ones that were moving slowly.

- Being struck in the rear, while moving If four-wheel 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. This is one category where accidents could increase in absolute terms, not just in proportion to other modes. RWAL would not be expected to increase these crashes.

- Being struck in the side, while moving 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.

The analysis technique is to tabulate the multivehicle crash involvements, for trucks with RWAL and their counterparts without RWAL, in the preceding crash modes, to the extent that they can be identified from the variables present on the data files (manner of collision, pre-crash maneuver, impact location). If RWAL is effective, the tables should show a relative increase in "control group" crashes, with RWAL, and relative decreases in other categories of crashes, especially the "striking" categories.

3.2.1 State accident files

Michigan has by far the largest samples of light trucks. Although the Michigan file does not report travelling speed and the "manner of collision" variable is often coded "other," the impact-location, driver-intent and manner-of-collision variables can be used to define three "striking" crash modes (rear-end-striking, angle-striking and other-striking) and three "struck" crash modes: control group (struck while stopped), struck in rear while moving, and struck in side while moving.

Table 3-6 analyzes the crashes of pickup trucks in Michigan during 1990-91, by road condition. Pickup trucks of the first 2 model years with RWAL are compared to trucks of the last 2 model years before the installation of RWAL. Table 3-6 indicates the actual numbers of crashes and the percentage distribution of the crash modes. A qualitative analysis of effectiveness, without producing specific estimates, is accomplished by glancing at the percentages. If the proportions of crash involvements in the "striking" modes decrease (or at least stay the same) with RWAL, while the proportions in the control group and other "struck" modes increase, that's a good result for RWAL. The top section of Table 3-6 shows mixed results: "control group" involvements increased slightly with RWAL, from 20.6 to 21.5 percent relative to other crashes (that is a change in the "right" direction). However, the other two types of "struck" involvements decreased slightly in relative terms. Two out of three types of "striking" involvements increased slightly with RWAL.

Estimates of RWAL effectiveness for specific crash modes can be obtained by measuring the change relative to the control group. For example, in the top section of Table 3-6, there were 3634 control group crash involvements

TABLE 3-6

MICHIGAN, 1990-91: PICKUP TRUCKS
EFFECT OF RWAL ON MULTIVEHICLE CRASHES

BY ROADWAY CONDITION

Type of Crash Involvement	Last 2 MY Without RWAL N	Last 2 MY Without RWAL %	First 2 MY With RWAL N	First 2 MY With RWAL %
ALL ROADS				
Rear-end: striking	1156	6.5	1361	7.0
Angle: striking	1273	7.2	1362	7.0
Other multiveh frontals	5967	33.8	6834	34.9
Struck in side while moving	2335	13.2	2367	12.1
Struck in rear while moving	3291	18.6	3440	17.6
Control group: struck while stopped	3634	20.6	4215	21.5
	17656	100	19579	100
WET ROADS				
Rear-end: striking	293	6.9	343	7.0
Angle: striking	280	6.6	325	6.6
Other multiveh frontals	1519	35.6	1875	38.2
Struck in side while moving	523	12.3	480	9.8
Struck in rear while moving	790	18.6	795	16.2
Control group: struck while stopped	844	19.9	1091	22.2
	4249	100	4909	100
SNOWY OR ICY ROADS				
Rear-end: striking	226	9.1	267	10.1
Angle: striking	174	7.0	167	6.3
Other multiveh frontals	806	32.4	887	33.4
Struck in side while moving	348	14.0	315	11.9
Struck in rear while moving	505	20.3	514	19.4
Control group: struck while stopped	432	17.3	502	18.9
	2491	100	2652	100

in the pickup trucks without RWAL and 4215 in the RWAL-equipped trucks. "Rear-end striking" involvements increased from 1156 without RWAL to 1361 with RWAL. That is a reduction of

$$1 - [(1361/1156) / (4215/3634)] = -2 \text{ percent}$$

relative to the control group (i.e., an increase). However, the other four non-control group crash modes <u>decreased</u> relative to the control group: "angle striking" impacts by 8 percent, "other striking" by 1 percent, "struck in side while moving" by 13 percent and "struck in rear while moving" by 10 percent. On the whole, the net reduction in the five types of non-control group crashes, relative to control group involvements, is

$$1 - [(15364/14022) / (4215/3634)] = 6 \text{ percent}$$

a small but statistically significant effect in the "right" direction (Chi-square $= 4.99$, $p < .05$).

Another estimate of RWAL effectiveness is obtained by comparing the net change in "striking" involvements relative to "struck" involvements. The 4 categories of "striking" involvements add up to 8396 cases without RWAL and 9567 with RWAL. The 3 categories of "struck" involvements add up to 9260 without RWAL and 10,022 with RWAL. That is a relative reduction of

$$1 - [(9567/8396) / (10022/9260)] = -5 \text{ percent}$$

a small but statistically significant effect in the "wrong" direction (Chi-square $= 5.90$, $p < .05$). Thus, no clear effect for RWAL emerges from these analyses.

The middle section of Table 3-6 is limited to crashes on **wet roads**. Here, too, the control group proportionately increased with RWAL, but the other two types of "struck" involvements decreased. The net increase in "striking" relative to "struck" impacts is 11 percent, but there is a 13 percent net reduction in "striking" or "struck while moving" involvements relative to the control group. The last part of Table 3-6 is limited to crashes on snowy or icy roads. The data have the same pattern. There is a 6 percent net increase of "striking" relative to "struck" involvements, but a 10 percent net reduction of non-control group relative to control-group involvements.

Table 3-7 compares the performance of RWAL on Ford Ranger to its performance on other pickup trucks. Unlike the situation with run-off-road crashes (Section 2.1), there is little difference between Ranger and other pickups in the distribution of multivehicle crash modes. With RWAL, Ford Ranger experienced a 5 percent reduction in "striking" relative to "struck" involvements, and an 8 percent reduction in "striking" or "struck while moving" involvements relative to the control group. Other pickups experienced a 7 percent increase in "striking" relative to "struck" involvements, but a 6 percent reduction of "striking" or "struck while moving" involvements relative to the control group.

Table 3-8 examines the performance of RWAL on sport utility vehicles and vans in Michigan. The distributions of multivehicle crashes are quite similar to those of pickup trucks. SUVs had a net 6 percent increase in "striking" relative to "struck" involvements, but a 5 percent reduction of "striking" or "struck while moving" impacts relative to "struck while stopped." Vans had a 6 percent increase of "striking" relative to "struck" impacts, but a statistically significant 7 percent reduction of non-control-group relative to control-group involvements (Chi-square = 4.06, $p < .05$). In other words, the Michigan data do not replicate the fairly large accident reductions for vans with RWAL seen in the Florida analyses of crashes between a fast-moving and a slow or

TABLE 3-7

MICHIGAN, 1990-91: PICKUP TRUCKS
EFFECT OF RWAL ON MULTIVEHICLE CRASHES

BY TYPE OF PICKUP TRUCK

Type of Crash Involvement	Last 2 MY Without RWAL N	Last 2 MY Without RWAL %	First 2 MY With RWAL N	First 2 MY With RWAL %
ALL PICKUP TRUCKS				
Rear-end: striking	1156	6.5	1361	7.0
Angle: striking	1273	7.2	1362	7.0
Other multiveh frontals	5967	33.8	6834	34.9
Struck in side while moving	2335	13.2	2367	12.1
Struck in rear while moving	3291	18.6	3440	17.6
Control group: struck while stopped	3634	20.6	4215	21.5
	17656	100	19579	100
FORD RANGER				
Rear-end: striking	278	6.4	264	7.3
Angle: striking	296	6.9	220	6.1
Other multiveh frontals	1438	33.3	1160	31.9
Struck in side while moving	538	12.5	409	11.3
Struck in rear while moving	792	18.4	708	19.5
Control group: struck while stopped	974	22.6	874	24.0
	4316	100	3635	100
ALL OTHERS				
Rear-end: striking	878	6.6	1097	6.9
Angle: striking	977	7.3	1142	7.2
Other multiveh frontals	4529	34.0	5674	35.6
Struck in side while moving	1797	13.5	1958	12.3
Struck in rear while moving	2499	18.7	2732	17.1
Control group: struck while stopped	2660	19.9	3341	21.0
	13340	100	15944	100

TABLE 3-8

MICHIGAN, 1990-91: SPORT UTILITY VEHICLES AND VANS
EFFECT OF RWAL ON MULTIVEHICLE CRASHES

Type of Crash Involvement	Last 2 MY Without RWAL N	%	First 2 MY With RWAL N	%
ALL SPORT UTILITY VEHICLES				
Rear-end: striking	218	6.3	236	6.9
Angle: striking	223	6.5	221	6.5
Other multiveh frontals	1250	36.3	1272	37.2
Struck in side while moving	407	11.8	379	11.1
Struck in rear while moving	619	18.0	558	16.3
Control group: struck while stopped	730	21.2	757	22.1
	3447	100	3423	100
ALL VANS				
Rear-end: striking	602	6.9	493	7.6
Angle: striking	584	6.7	395	6.0
Other multiveh frontals	2684	30.6	2094	32.1
Struck in side while moving	1296	14.8	823	12.6
Struck in rear while moving	1596	18.2	1141	17.5
Control group: struck while stopped	2000	22.8	1581	24.2
	8762	100	6527	100

stopped vehicle (Tables 3-3 and 3-4).

Table 3-9 analyzes the crashes of **pickup trucks in Florida during 1990-91, by road condition.** Florida data permit the identification of four "striking" crash modes and three "struck" modes, one of which is the control group of stopped or slow-moving vehicles. In Florida, unlike Michigan, unoccupied parked vehicles are counted as "crash-involved" if they are struck by another vehicle. That makes the control group relatively much larger in Florida than in Michigan (35 percent vs. 20 percent of multivehicle involvements). Pickup trucks of the first 2 model years with RWAL are compared to trucks of the last 2 model years before the installation of RWAL. In all, 9389 pickup trucks of the first 2 model years with RWAL were involved in some type of multivehicle crash; that is 4-5 times as large a sample as was available in Table 3-1, which was limited to collisions between a fast-moving and a slow/stopped vehicle. The results for all roads, combined, are not favorable for RWAL. Each of the three types of "struck" impacts, including the control group, decreased slightly in relative terms, while there was a moderate increase in "rear-end striking" cases and a small increase in "strikes a turning vehicle." There was a statistically significant 10 percent net increase in "striking" involvements relative to "struck" involvements (Chi-square = 9.59, $p < .01$) and a nonsignificant 2 percent net increase in non-control group relative to control-group involvements.

On wet roads (lower half of Table 3-9), there was a 5 percent increase in "striking" relative to "struck" involvements; on the other hand, there was a 5 percent reduction in non-control group relative to control-group crash involvements. Either way, the full set of Florida multivehicle crashes does not corroborate the analysis of collisions between a fast-moving and a slow-stopped

TABLE 3-9

FLORIDA, 1990-91: PICKUP TRUCKS
EFFECT OF RWAL ON MULTIVEHICLE CRASHES

	Last 2 MY Without RWAL		First 2 MY With RWAL	
Type of Crash Involvement	**N**	**%**	**N**	**%**
ALL ROADS				
Strikes a turning vehicle	1062	12.0	1167	12.4
Rear-end: striking	1210	13.6	1538	16.4
Angle, both going straight: striking	794	8.9	806	8.6
Other multiveh frontals	590	6.6	569	6.1
Struck in side while moving	1359	15.3	1326	14.1
Struck in rear while moving	652	7.3	637	6.8
Control group: struck while stopped	3209	36.2	3346	35.6
	8876	100	9389	100
WET ROADS				
Strikes a turning vehicle	175	11.2	173	11.0
Rear-end: striking	250	15.9	322	20.6
Angle, both going straight: striking	161	10.3	114	7.3
Other multiveh frontals	128	8.2	122	7.8
Struck in side while moving	228	14.5	185	11.8
Struck in rear while moving	129	8.2	135	8.6
Control group: struck while stopped	497	31.7	515	32.9
	1568	100	1566	100

vehicle, which showed a positive (but not statistically significant) benefit for RWAL in pickup trucks on wet roads (Tables 3-1 and 3-5).

Table 3-10 presents the data on **SUVs and vans in Florida during 1990-91**. The results are almost identical to the Michigan findings. SUVs with RWAL had a net 7 percent increase in "striking" relative to "struck" involvements, but a 6 percent reduction of non-control-group impacts relative to "struck while stopped." Vans with RWAL had a net 7 percent increase in "striking" relative to "struck" involvements, but a 3 percent reduction of non-control-group impacts relative to "struck while stopped." Like Michigan, the full Florida data base suggests that RWAL had little effect on the multivehicle crashes of vans.

3.2.2 Fatal multivehicle crashes

The effects of crash-avoidance measures can be quite different in fatal and nonfatal crashes. Specifically, RWAL was already shown to have different effects on fatal and nonfatal single-vehicle run-off-road crashes (Chapter 2). The sample sizes for RWAL-equipped trucks involved in fatal multivehicle crashes is barely sufficient for preliminary effectiveness analyses. The classification of fatal crash involvements into "striking" and "struck" groups is more complex than for nonfatal crashes. Whereas most nonfatal collisions involve a relatively "active" vehicle (moving before the crash and impacting frontally) and a relatively "passive" vehicle (struck in the side or rear and/or standing still before the crash), a large percentage of fatal collisions involve two "active" vehicles: e.g., head-on collisions between two moving vehicles. As shown in Table 3-11, crash involvements in 1989-mid 92 FARS data are classified into three larger groups, each of which contains 2 or more subgroups. The classification is based on the "manner of collision," the impact

TABLE 3-10

FLORIDA, 1990-91: SPORT UTILITY VEHICLES AND VANS
EFFECT OF RWAL ON MULTIVEHICLE CRASHES

	Last 2 MY Without RWAL		First 2 MY With RWAL	
Type of Crash Involvement	**N**	**%**	**N**	**%**
A L L S P O R T U T I L I T Y V E H I C L E S				
Strikes a turning vehicle	302	12.6	314	13.9
Rear-end: striking	334	14.0	325	14.4
Angle, both going straight: striking	199	8.3	200	8.8
Other multiveh frontals	152	6.4	132	5.8
Struck in side while moving	386	16.1	315	13.9
Struck in rear while moving	181	7.6	149	6.6
Control group: struck while stopped	838	35.0	827	36.6
	2392	100	2262	100
A L L V A N S				
Strikes a turning vehicle	471	10.0	288	9.8
Rear-end: striking	557	11.8	416	14.1
Angle, both going straight: striking	411	8.7	245	8.3
Other multiveh frontals	263	5.6	159	5.4
Struck in side while moving	732	15.5	413	14.0
Struck in rear while moving	380	8.0	212	7.2
Control group: struck while stopped	1917	40.5	1220	41.3
	4731	100	2953	100

TABLE 3-11

FARS, 1989-mid 92: PICKUP TRUCKS
EFFECT OF RWAL ON FATAL MULTIVEHICLE CRASHES

	Last 2 MY Without RWAL		First 2 MY With RWAL	
Type of Crash Involvement	**N**	**%**	**N**	**%**
Strikes a stopped/slow vehicle	224	9.9	257	10.6
Strikes a turning vehicle	139	6.1	184	7.6
Rear-end: striking	66	2.9	87	3.6
Angle, both going straight: striking	352	15.5	447	18.4
Head-on	657	28.9	655	26.9
Other multiveh frontals	310	13.6	321	13.2
Struck in side while moving	183	8.1	168	6.9
Struck in rear while moving	60	2.6	46	1.9
Struck while turning	81	3.6	75	3.1
Struck while stopped/slow	201	8.8	195	8.0
	2273	100	2435	100

	Last MY Without RWAL		First MY With RWAL	
Type of Crash Involvement	**N**	**%**	**N**	**%**
Strikes a stopped/slow vehicle	148	11.4	129	9.9
Strikes a turning vehicle	71	5.5	88	6.8
Rear-end: striking	38	2.9	48	3.7
Angle, both going straight: striking	214	16.5	211	16.2
Head-on	359	27.6	366	28.2
Other multiveh frontals	181	13.9	174	13.4
Struck in side while moving	105	8.1	94	7.2
Struck in rear while moving	36	2.8	28	2.2
Struck while turning	43	3.3	40	3.1
Struck while stopped/slow	105	8.1	122	9.4
	1300	100	1300	100

location and pre-crash maneuver of the case vehicle and 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.). The three large groupings can be described as "case vehicle active, other vehicle relatively passive," "both vehicles active" and "case vehicle passive, other vehicle active." The last group includes, as a subset, the "control group" of trucks that were struck while they were standing still or moving slowly, but that control group accounts less than 10 percent of fatal involvements (as opposed to 20 percent of Michigan and 35 percent of Florida involvements). The objective of the analysis is to see if RWAL is associated with a reduction in the "case vehicle active" and, perhaps, the "both vehicles active" collisions, and a proportionate increase in the "case vehicle relatively passive" involvement types.

Fatal collisions of pickup trucks are addressed by Table 3-11, which is based on 1989-mid 92 FARS data. The upper half of Table 3-11 compares pickup trucks of the first 2 model years with RWAL to trucks of the last 2 model years before the installation of RWAL. It shows an unmistakable trend in the "wrong" direction. Each of the four types of "case vehicle active-other vehicle passive" involvements increased with RWAL, while each of the four types of "case vehicle passive-other vehicle active" involvements decreased in both relative and absolute terms. The net increase in "case vehicle active" relative to "case vehicle passive" involvements is a statistically significant 35 percent (Chi-square = 16.66, p < .01). The net increase in "case or both vehicles active" relative to "case vehicle passive" involvements is a statistically significant 23 percent (Chi-square = 9.28, p < .01).

On the other hand, the lower half of Table 3-11 which is limited to pickup trucks of the **first** model year with RWAL vs. the **last** model year without RWAL, shows nearly the same distribution of crash modes, with and without RWAL. The net increase in "case vehicle active" relative to "case vehicle passive" involvements is merely a nonsignificant 3 percent, consistent with the results in Michigan and Florida multivehicle crashes. The net increase in "case or both vehicles active" relative to "case vehicle passive" involvements is a nonsignificant 2 percent. It is unknown why the ± 2 MY and the ± 1 MY results are so divergent. The difference is unlikely to be due to sampling error, given the sample sizes in Table 3-11. "Vehicle age" effects (e.g., a tendency of older trucks to be driven more aggressively) also seem implausible, since no comparable effect was found in <u>any</u> of the other analyses of pickup trucks. There was little or no difference between the ± 2 MY result and the ± 1 MY result in the Michigan and Florida multivehicle crashes and in the Michigan, Florida, Pennsylvania and FARS single-vehicle crashes. To the extent that the ± 1 MY result most closely focuses on the period of transition to RWAL (little or no vehicle age effect, etc.), while still having an adequate sample size, it should be considered the more accurate estimate, and it is certainly the more intuitively reasonable result. On the other hand, it could be argued that the ± 2 MY result perhaps better reflects the long-term effects of RWAL.

Table 3-12 analyzes **fatal collisions of SUVs**. With smaller sample sizes, the results are similar to the preceding table. In the ± 2 MY comparison (upper half), all four types of "case vehicle active" involvements increased with RWAL, while three of the four types of "case vehicle passive" involvements decreased in both relative and absolute terms. The net increase in "case vehicle active" relative to "case vehicle passive" involvements is a nonsignificant 21

TABLE 3-12

FARS, 1989-mid 92: SPORT UTILITY VEHICLES
EFFECT OF RWAL ON FATAL MULTIVEHICLE CRASHES

	Last 2 MY Without RWAL		**First 2 MY With RWAL**	
Type of Crash Involvement	**N**	**%**	**N**	**%**
Strikes a stopped/slow vehicle	40	9.5	43	10.1
Strikes a turning vehicle	31	7.3	33	7.8
Rear-end: striking	16	3.8	17	4.0
Angle, both going straight: striking	60	14.2	74	17.4
Head-on	123	29.1	116	27.3
Other multiveh frontals	66	15.6	61	14.4
Struck in side while moving	33	7.8	29	6.8
Struck in rear while moving	10	2.4	21	4.9
Struck while turning	14	3.3	7	1.6
Struck while stopped/slow	29	6.9	24	5.6
	422	100	425	100

	Last MY Without RWAL		**First MY With RWAL**	
Type of Crash Involvement	**N**	**%**	**N**	**%**
Strikes a stopped/slow vehicle	23	9.5	22	8.6
Strikes a turning vehicle	19	7.9	26	10.1
Rear-end: striking	8	3.3	10	3.9
Angle, both going straight: striking	41	17.0	39	15.2
Head-on	75	31.1	75	29.2
Other multiveh frontals	29	12.0	35	13.6
Struck in side while moving	19	7.9	17	6.6
Struck in rear while moving	5	2.1	14	5.4
Struck while turning	7	2.9	5	1.9
Struck while stopped/slow	15	6.2	14	5.4
	241	100	257	100

percent (Chi-square = 0.96). On the other hand, the ± 1 MY comparison (lower half of Table 3-12) does not show any consistent trends. "Case vehicle active" decreased by 2 percent relative to "case vehicle passive" involvements.

Table 3-13 does not show a significant effect for RWAL on the fatal multivehicle crashes of **vans**. In the ± 2 MY comparison (upper half), there was a nonsignificant 15 percent increase in "case vehicle active" relative to "case vehicle passive" involvements and a nonsignificant 9 percent increase in "case or both vehicles active" relative to "case vehicle passive." In the ± 1 MY comparison (lower half), these increases were 26 percent and 15 percent, respectively, and were also nonsignificant.

TABLE 3-13

FARS, 1989-mid 92: VANS
EFFECT OF RWAL ON FATAL MULTIVEHICLE CRASHES

	Last 2 MY Without RWAL		First 2 MY With RWAL	
Type of Crash Involvement	**N**	**%**	**N**	**%**
Strikes a stopped/slow vehicle	58	10.9	43	11.1
Strikes a turning vehicle	39	7.4	23	5.9
Rear-end: striking	9	1.7	10	2.6
Angle, both going straight: striking	93	17.6	80	20.7
Head-on	122	23.0	90	23.3
Other multiveh frontals	89	16.8	59	15.3
Struck in side while moving	42	7.9	31	8.0
Struck in rear while moving	19	3.6	13	3.4
Struck while turning	14	2.6	6	1.6
Struck while stopped/slow	45	8.5	32	8.3
	530	100	387	100

	Last MY Without RWAL		First MY With RWAL	
Type of Crash Involvement	**N**	**%**	**N**	**%**
Strikes a stopped/slow vehicle	42	10.8	33	11.9
Strikes a turning vehicle	30	7.7	17	6.1
Rear-end: striking	6	1.5	6	2.2
Angle, both going straight: striking	66	17.0	60	21.7
Head-on	95	24.4	66	23.8
Other multiveh frontals	64	16.5	40	14.4
Struck in side while moving	30	7.7	23	8.3
Struck in rear while moving	13	3.3	7	2.5
Struck while turning	9	2.3	4	1.4
Struck while stopped/slow	34	8.7	21	7.6
	389	100	277	100

CHAPTER 4

COLLISIONS WITH PEDESTRIANS, ANIMALS AND OBJECTS ON THE ROAD

Single-vehicle crashes which do not necessarily involve running off the road include collisions of a light truck with a pedestrian, bicyclist, animal or train that may be standing, crossing, or travelling within the roadway. They also include collisions with objects, such as rocks and debris, that may be temporarily blocking a road. Although, technically, these crashes involve a single motor vehicle, they differ from run-off-road crashes (collisions with fixed objects and rollovers), because they do not presuppose a loss of directional control and/or inappropriate steering by the driver of the motor vehicle. For example, a truck could have been going straight ahead and under control, when an animal suddenly jumped onto the road in front of the truck. In many ways, they are two-party collisions, except the second party is not a motor vehicle. On the other hand, these crashes do not fully resemble multivehicle collisions. Whereas a safe driver constantly monitors the movements of other vehicles on the road and can often take steps to avoid a potential collision, that driver may be startled by the unanticipated presence of an animal or debris on the road, and react with panic maneuvers that could easily lead to loss of control, not unlike a run-off-road situation. In other words, these crashes occupy an intermediate position relative to the ones studied in the preceding chapters.

There are several ways that rear-wheel ABS (RWAL) could help prevent collisions with a pedestrian, bicyclist, animal, train, or object on the road. The knowledge that a truck has RWAL may encourage the driver to slam on the brakes immediately in a panic situation, rather than engaging in timid braking that would prolong stopping distances. RWAL keeps the truck going straight and not yawing into the path of a pedestrian or animal that is slightly off to one side.

As in Chapter 2, the analysis technique is to tabulate the crash involvements, for light trucks with RWAL and their counterparts without RWAL, in single-vehicle on-road collisions vs. a control group of crash involvements unaffected by ABS: multivehicle involvements where the case vehicle is standing still or moving very slowly (5 mph or less, where ABS and conventional brakes work about the same), and is struck by another vehicle. The reduction in single-vehicle, on-road collisions is measured relative to the control group.

The analyses were limited to 1990-91 Michigan data, which include many collisions of vehicles with animals (13 percent of all police-reported accidents), and the 1989-mid 92 FARS files, which include many collisions of vehicles with pedestrians, in which the latter were killed. Florida and Pennsylvania files did not include enough collisions with animals, pedestrians or on-road objects for a statistically meaningful analysis. The definition of a "single-vehicle on-road crash" in the **Michigan** analysis was based on the "first harmful event" variable. It included the codes for collision with an animal, pedestrian/bicyclist, non-fixed object, or train. However, the overwhelming majority of these crashes were collisions with an animal (80 percent), as opposed to collisions with pedestrian/bicyclists (12 percent), non-fixed objects (7 percent) or trains (less than 1 percent).

In the FARS analysis, the definition was based on the "relation-to-roadway" variable (which had to be coded "on the roadway") and the "first harmful event" variable. "Single-vehicle on-road crashes" included collisions with pedestrians, bicyclists or other nonmotorists; trains; and animals. However, FARS includes few collisions with animals, since they are rarely fatal to humans. Collisions with pedestrians, bicyclists or other nonmotorists accounted for 92 percent of the FARS sample, collisions with trains, 7 percent, and collisions with animals, 1 percent. As in Chapter 2, the "control group" used in the analyses of Michigan data (involvements as a stopped, slow or parked vehicle in a multivehicle crash) is too small on FARS, since such involvements are rarely fatal. Instead, the control group is expanded to include all multivehicle crash involvements of light trucks. The analyses of Chapter 3 suggest that multivehicle involvements are, at most, only slightly influenced by RWAL and can be added to the "control group."

Separate analyses are performed for pickups trucks, sport utility vehicles (SUV) and vans - which have different design characteristics, drivers and exposure. The data are limited to model year 1987-91 products of Chevrolet, GMC, Ford and Dodge which were equipped with RWAL, and trucks of the same make-models without RWAL. The analyses generally compare "Trucks of the first 2 model years with RWAL" to "Trucks of the last 2 model years [and the same make-model] without RWAL." The 1987 Chevrolet and GMC R/V pickup trucks are similar, if not identical, to C/K trucks, and are counted as being of the "last model year without RWAL."

Table 4-1 analyzes the crashes of pickup trucks in Michigan during 1990-91, comparing the number of collisions with animals, pedestrians etc. with a control group of involvements as a stopped/slow vehicle in a multivehicle crash. It is evident on-road single-vehicle crashes decreased, relative to the

TABLE 4-1

MICHIGAN, 1990-91: PICKUP TRUCKS
EFFECT OF RWAL ON COLLISIONS WITH ANIMALS, PEDESTRIANS, BICYCLISTS, TRAINS, OR ON-ROAD OBJECTS

Type of Crash Involvement	**Last 2 MY Without RWAL** N	%	**First 2 MY With RWAL** N	%
A L L P I C K U P T R U C K S				
Collision with animal, etc.	4385	54.7	4510	51.7
Control group (multivehicle)	3634	45.3	4215	48.3
	8019	100	8725	100

11 percent relative reduction of collisions with animals, etc. for RWAL
Chi-square = 15.02

F O R D R A N G E R	N	%	N	%
Collision with animal, etc.	1087	52.7	654	42.8
Control group (multivehicle)	974	47.3	874	57.2
	2061	100	1528	100

33 percent relative reduction of collisions with animals, etc. for RWAL
Chi-square = 34.71

A L L O T H E R S	N	%	N	%
Collision with animal, etc.	3298	55.4	3856	53.6
Control group (multivehicle)	2660	44.6	3341	46.4
	5958	100	7197	100

7 percent relative reduction of collisions with animals, etc. for RWAL
Chi-square = 4.15

control group, as trucks became equipped with RWAL. The top half of Table 4-1, based on all types of pickup trucks, indicates a moderately large reduction of

$$1 - [(4510/4385) / (4215/3634)] = 11 \text{ percent}$$

The reduction is statistically significant (Chi-square for the 2 x 2 table is 15.02, $p < .01$).

The two lower sections of Table 4-1 suggest that the effect may be higher in Ford Ranger (33 percent) than in other pickup trucks (7 percent). Nevertheless, both of these reductions are statistically significant (Chi-squares of 34.71 and 4.15, respectively). The results are more favorable than most of the findings on pickup trucks in multivehicle crashes (Tables 3-1, 3-4, 3-6, 3-7 and 3-9), which showed little accident reduction, but not as positive as the findings in run-off-road crashes (Table 2-1), where rollovers were greatly reduced. Another difference from Chapter 2 is that Ford Rangers without RWAL have about the same risk of on-road single vehicle crashes as other pickup trucks (52.7 percent vs. 55.4 percent, according to Table 4-1), whereas Ranger had a much higher risk of rollover than other pickup trucks. Table 4-2, which is limited to pickup trucks of the first model year with RWAL vs. the last model year before RWAL installation, presents virtually the same results, with statistically significant reductions for Ranger and All Other pickup trucks.

Table 4-3 separates the pickup truck crashes in Michigan by road condition. As road conditions get worse, multivehicle "fender benders" increase, and the ratio of collisions with animals, etc. to multivehicle crashes decreases. The reduction in on-road single-vehicle crashes with RWAL is a statistically significant 7 percent on dry roads (Chi-square = 3.87), a significant 25 percent on wet roads (Chi-square = 16.30, $p < .01$) and a nonsignificant 5 percent on snow

TABLE 4-2

MICHIGAN, 1990-91: PICKUP TRUCKS
EFFECT OF RWAL ON COLLISIONS WITH ANIMALS, PEDESTRIANS.
BICYCLISTS, TRAINS, OR ON-ROAD OBJECTS
(data limited to 1 MY before/after RWAL installation)

	Last MY Without RWAL		First MY With RWAL	
Type of Crash Involvement	**N**	**%**	**N**	**%**
ALL PICKUP TRUCKS				
Collision with animal, etc.	2222	54.4	2419	50.9
Control group (multivehicle)	1861	45.6	2335	49.1
	4083	100	4754	100

13 percent relative reduction of collisions with animals, etc. for RWAL
Chi-square = 11.02

FORD RANGER				
Collision with animal, etc.	588	51.5	347	43.8
Control group (multivehicle)	553	48.5	446	56.2
	1141	100	793	100

27 percent relative reduction of collisions with animals, etc. for RWAL
Chi-square = 11.33

ALL OTHERS				
Collision with animal, etc.	1634	55.5	2072	52.3
Control group (multivehicle)	1308	44.5	1889	47.7
	2942	100	3961	100

12 percent relative reduction of collisions with animals, etc. for RWAL
Chi-square = 7.03

TABLE 4-3

MICHIGAN, 1990-91: PICKUP TRUCKS
EFFECT OF RWAL ON COLLISIONS WITH ANIMALS, PEDESTRIANS, BICYCLISTS, TRAINS, OR ON-ROAD OBJECTS - **BY ROAD CONDITION**

	Last 2 MY Without RWAL		First 2 MY With RWAL	
Type of Crash Involvement	**N**	**%**	**N**	**%**
D R Y R O A D S (ALL PICKUP TRUCKS)				
Collision with animal, etc.	3321	58.5	3431	56.7
Control group (multivehicle)	2358	41.5	2622	43.3
	5679	100	6053	100

7 percent relative reduction of collisions with animals, etc. for RWAL
Chi-square = 3.87

	N	%	N	%
W E T R O A D S (ALL PICKUP TRUCKS)				
Collision with animal, etc.	730	47.3	712	39.5
Control group (multivehicle)	844	52.7	1091	60.5
	1574	100	1803	100

25 percent relative reduction of collisions with animals, etc. for RWAL
Chi-square = 16.30

	N	%	N	%
S N O W Y O R I C Y R O A D S (ALL PICKUP TRUCKS)				
Collision with animal, etc.	334	43.6	367	42.2
Control group (multivehicle)	432	56.4	502	57.8
	766	100	869	100

5 percent relative reduction of collisions with animals, etc. for RWAL
Chi-square = 0.31

or ice. The only other analysis of pickup trucks that showed a possibly enhanced effect for RWAL on wet roads was the Florida analysis of two-vehicle collisions. By contrast, the analyses of run-off-road crashes showed large, identical reductions of rollovers under all road conditions.

SUVs have substantially smaller accident samples than pickup trucks. Table 4-4 analyzes the crashes of **SUVs in Michigan during 1990-91.** Ford Bronco 2 has a higher rate of collisions with animals, etc. (56.5 percent without RWAL) than other SUVs (45.5 percent), possibly reflecting extensive use in rural areas. The top part of Table 4-4 shows that on-road single-vehicle crashes of SUVs decreased by a statistically significant 21 percent with RWAL (Chi-square = 9.73, $p < .01$). RWAL appears to be about equally effective for Bronco 2 (29 percent) and other SUVs (22 percent).

Vans, which are extensively used on urban roads for family or business travel, have relatively fewer collisions with animals, etc. than pickup trucks and SUVs. Table 4-5 analyzes **van crashes in Michigan**. With RWAL, on-road single-vehicle collisions decreased in Ford Aerostar compact vans by a statistically significant 23 percent (Chi-square = 4.82, $p < .05$). The rate in other vans decreased by 6 percent, and the average reduction for all vans is 10 percent. It is unknown why RWAL may be especially effective for Aerostar, which has about the same accident involvement profile as other types of vans; however, the results parallel the findings on rollovers and collisions with fixed objects (Table 2-11).

Crash-avoidance devices that require a degree of human intervention to "work" are often less effective in preventing fatalities than in other

TABLE 4-4

MICHIGAN, 1990-91: SPORT UTILITY VEHICLES
EFFECT OF RWAL ON COLLISIONS WITH ANIMALS, PEDESTRIANS, BICYCLISTS, TRAINS, OR ON-ROAD OBJECTS

	Last 2 MY Without RWAL		First 2 MY With RWAL	
Type of Crash Involvement	**N**	**%**	**N**	**%**
ALL SPORT UTILITY VEHICLES				
Collision with animal, etc.	682	48.3	556	42.3
Control group (multivehicle)	730	51.7	757	57.7
	1412	100	1313	100

21 percent relative reduction of collisions with animals, etc. for RWAL
Chi-square = 9.73

	Last 2 MY Without RWAL		First 2 MY With RWAL	
FORD BRONCO 2				
Collision with animal, etc.	203	56.5	218	48.1
Control group (multivehicle)	156	43.5	235	51.9
	359	100	453	100

29 percent relative reduction of collisions with animals, etc. for RWAL
Chi-square = 5.69

	Last 2 MY Without RWAL		First 2 MY With RWAL	
ALL OTHERS				
Collision with animal, etc.	479	45.5	338	39.3
Control group (multivehicle)	574	54.5	522	60.7
	1053	100	860	100

22 percent relative reduction of collisions with animals, etc. for RWAL
Chi-square = 7.41

TABLE 4-5

MICHIGAN, 1990-91: VANS
EFFECT OF RWAL ON COLLISIONS WITH ANIMALS, PEDESTRIANS, BICYCLISTS, TRAINS, OR ON-ROAD OBJECTS

	Last 2 MY Without RWAL		First 2 MY With RWAL	
Type of Crash Involvement	**N**	**%**	**N**	**%**
		ALL VANS		
Collision with animal, etc.	1237	38.2	882	35.8
Control group (multivehicle)	2000	61.8	1581	64.2
	3237	100	2463	100

10 percent relative reduction of collisions with animals, etc. for RWAL
Chi-square = 3.46

	Last 2 MY Without RWAL		First 2 MY With RWAL	
		FORD AEROSTAR		
Collision with animal, etc.	301	37.0	171	31.2
Control group (multivehicle)	513	63.0	377	68.8
	814	100	548	100

23 percent relative reduction of collisions with animals, etc. for RWAL
Chi-square = 4.82

	Last 2 MY Without RWAL		First 2 MY With RWAL	
		ALL OTHERS		
Collision with animal, etc.	936	38.6	711	37.1
Control group (multivehicle)	1487	61.4	1204	62.9
	2423	100	1915	100

6 percent relative reduction of collisions with animals, etc. for RWAL
Chi-square = 1.02

crashes, and, so far, that has been the pattern with ABS. However, for on-road single-vehicle crashes of pickup trucks, RWAL may do as well in fatal crashes (most of which involve pedestrians/bicyclists) as in nonfatal crashes (most of which involve animals). Table 4-6 analyzes the on-road single-vehicle crashes of **pickup trucks in 1989-mid 92 FARS** data. For all types of pickup trucks combined, collisions with pedestrians, etc. were reduced by a statistically significant 16 percent with RWAL, relative to multivehicle involvements (Chi-square = 4.63, $p < .05$). In contrast to the Michigan results, the effectiveness may be lower for Ford Ranger (6 percent) than for other types of pickup trucks (19 percent, Chi-square = 5.92, $p < .05$). Table 4-7 shows that RWAL may be slightly more effective, or perhaps equally effective on **wet roads** (24 percent) as on dry roads (16 percent), consistent with the Michigan results (25 percent on wet roads, 7 on dry: Table 4-3).

The samples of fatal collisions of **SUVs and vans** with pedestrians, bicyclists, trains, etc. are too small for statistically meaningful results. Table 4-8 shows a nonsignificant 28 percent increase in these collisions for SUVs with RWAL, and a nonsignificant 4 percent reduction in vans.

Due mainly to relatively small sample sizes and relatively small effects, **the results for on-road single-vehicle crashes are less consistent than other findings of this report.** Nevertheless, many of the accident reductions are statistically **significant**, and the overall thrust of the results is that RWAL appears to be of at least some value in helping drivers avoid collisions with pedestrians, animals, etc.

TABLE 4-6

FARS, 1989-mid 92: PICKUP TRUCKS
EFFECT OF RWAL ON FATAL COLLISIONS WITH PEDESTRIANS, BICYCLISTS, TRAINS, OR ANIMALS

Type of Crash Involvement	Last 2 MY Without RWAL N	Last 2 MY Without RWAL %	First 2 MY With RWAL N	First 2 MY With RWAL %
ALL PICKUP TRUCKS				
Collision with pedestrian, etc.	372	14.1	335	12.1
Any multivehicle crash	2273	85.9	2435	87.9
	2645	100	2770	100

16 percent relative reduction of collisions with pedestrians, etc. for RWAL
Chi-square = 4.63

Type of Crash Involvement	Last 2 MY Without RWAL N	Last 2 MY Without RWAL %	First 2 MY With RWAL N	First 2 MY With RWAL %
FORD RANGER				
Collision with pedestrian, etc.	55	10.9	36	10.3
Any multivehicle crash	450	89.1	312	89.7
	505	100	348	100

6 percent relative reduction of collisions with pedestrians, etc. for RWAL
Chi-square = 0.06

Type of Crash Involvement	Last 2 MY Without RWAL N	Last 2 MY Without RWAL %	First 2 MY With RWAL N	First 2 MY With RWAL %
ALL OTHERS				
Collision with pedestrian, etc.	317	14.8	299	12.3
Any multivehicle crash	1823	85.2	2123	87.7
	2140	100	2422	100

19 percent relative reduction of collisions with pedestrians, etc. for RWAL
Chi-square = 5.92

TABLE 4-7

FARS, 1989-mid 92: PICKUP TRUCKS
EFFECT OF RWAL ON FATAL COLLISIONS WITH PEDESTRIANS, BICYCLISTS, TRAINS, OR ANIMALS - **BY ROAD CONDITION**

Type of Crash Involvement	**Last 2 MY Without RWAL** N	%	**First 2 MY With RWAL** N	%
D R Y R O A D S (ALL PICKUP TRUCKS)				
Collision with pedestrian, etc.	319	15.4	286	13.3
Any multivehicle crash	1751	84.6	1861	86.7
	2070	100	2147	100

16 percent relative reduction of collisions with pedestrians, etc. for RWAL
Chi-square = 3.75

Type of Crash Involvement	**Last 2 MY Without RWAL** N	%	**First 2 MY With RWAL** N	%
W E T R O A D S (ALL PICKUP TRUCKS)				
Collision with pedestrian, etc.	45	9.9	37	7.7
Any multivehicle crash	410	90.1	445	92.3
	455	100	482	100

24 percent relative reduction of collisions with pedestrians, etc. for RWAL
Chi-square = 1.44

TABLE 4-8

FARS, 1989-mid 92: SPORT UTILITY VEHICLES AND VANS
EFFECT OF RWAL ON FATAL COLLISIONS WITH PEDESTRIANS, BICYCLISTS, TRAINS, OR ANIMALS

Type of Crash Involvement	Last 2 MY Without RWAL N	Last 2 MY Without RWAL %	First 2 MY With RWAL N	First 2 MY With RWAL %
ALL SPORT UTILITY VEHICLES				
Collision with pedestrian, etc.	48	10.2	62	12.7
Any multivehicle crash	422	89.8	425	87.3
	470	100	487	100

-28 percent relative reduction of collisions with pedestrians, etc. for RWAL
Chi-square = 1.49

Type of Crash Involvement	Last 2 MY Without RWAL N	Last 2 MY Without RWAL %	First 2 MY With RWAL N	First 2 MY With RWAL %
ALL VANS				
Collision with pedestrian, etc.	116	18.0	81	17.3
Any multivehicle crash	530	82.0	387	82.7
	646	100	468	100

4 percent relative reduction of collisions with pedestrians, etc. for RWAL
Chi-square = 0.08

CHAPTER 5

SUMMARY OF EFFECTIVENESS FINDINGS

Statistical analyses of the effectiveness of rear-wheel ABS for light trucks (RWAL) were performed with 1990-91 State accident files from Florida, Michigan and Pennsylvania and 1989-mid 92 Fatal Accident Reporting System (FARS) data, as described in Chapters 2-4. RWAL is primarily designed to prevent yawing and loss of directional control during braking, unlike 4-wheel ABS systems, which have the additional benefits of maintaining the driver's steering control during panic braking and significantly reducing stopping distances under certain road conditions. Indeed, the statistical analyses suggest that RWAL has helped light trucks avoid many loss-of-control crashes such as rollovers or side impacts with fixed objects, but have limited, if any, effect on multivehicle crash involvements. A better impression of the consistency and strength of the various effects is obtained by gathering and summarizing the effectiveness estimates.

Tables 5-1 and 5-2 present the effectiveness estimates for RWAL in preventing run-off-road crashes: rollovers, side impacts with fixed objects and frontal impacts with fixed objects. A large number of consistent, statistically significant results lead to the conclusion that RWAL is quite effective in reducing the risk of nonfatal rollovers and side impacts with fixed objects, for almost every type of light truck, under any type of road condition. Reductions of rollovers are typically in the 30-40 percent range, and reductions of side impacts with fixed objects, in the 15-30 percent range. RWAL also appears to be generally effective in reducing nonfatal frontal impacts with fixed objects, with reductions in the 5-20 percent range. The effectiveness appears to be highest for Ford Ranger (35-50 percent rollover reduction), followed by Ford Bronco 2,

TABLE 5-1

REDUCTIONS OF ROLLOVERS FOR LIGHT TRUCKS WITH RWAL

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

Vehicle Type	Road Condition	Accident Reduction (%)			
		MI	FL	PA	FARS
Ford Ranger		**53**	**49**	**39**	26*
Other pickup truck		**28**	**31**	**29**	-17
Any pickup truck	Dry	**40**	**43**		
Any pickup truck	Wet	**45**	**30**		
Any pickup truck	Snowy or Icy	**43**			
Ford Bronco 2		**44**	**34**	25	-17
Other SUV		19	19	-15	5
Ford Aerostar		**39**			
Other van		13			
Any van		**25**	11	28	-54

* Combined reduction of rollovers and side impacts with fixed objects is statistically significant

TABLE 5-2

REDUCTIONS OF COLLISIONS WITH FIXED OBJECTS FOR LIGHT TRUCKS WITH RWAL

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

Vehicle Type	Road Condition	Accident Reduction (%) MI	FL	PA	FARS
		SIDE IMPACTS WITH FIXED OBJECTS			
Ford Ranger		18	**47**	13	42*
Other pickup truck		**33**	23	17	-10
Any pickup truck	Dry	10	**28**		
Any pickup truck	Wet	**53**	31		
Any pickup truck	Snowy or icy	**30**			
Ford Bronco 2		34		12	
Other SUV		20		6	
Any SUV			-19		-17
Ford Aerostar		23			
Other van		**29**			
Any van		**28**	-16	5	23
		FRONTAL IMPACTS WITH FIXED OBJECTS			
Ford Ranger		13	**24**	- 7	7
Other pickup truck		**11**	- 8	1	-12
Any pickup truck	Dry	10	2		
Any pickup truck	Wet	**25**	- 3		
Any pickup truck	Snowy or icy	8			
Ford Bronco 2		22	23	17	7
Other SUV		**21**	- 2	-21	14
Ford Aerostar		**29**			
Other van		**16**			
Any van		**20**	- 3	**25**	-29

* Combined reduction of rollovers and side impacts with fixed objects is statistically significant

pickup trucks other than Ranger, vans, and sport utility vehicles (SUV) other than Bronco 2. In short, a high percentage of run-off-road crashes of light trucks appear to have involved a loss of directional control during braking, and RWAL is a rather good "fix." The vehicles with the greatest risk of run-off-road crashes had the highest RWAL effectiveness.

Nevertheless, the accident reductions mostly do not carry over to fatal run-off-road crashes of light trucks. Only the Ford Ranger experienced a clearly positive reduction of rollovers and side impacts with fixed objects, on the order of 25 percent. Apparently, in most fatal run-off-road crashes, drivers do not brake at all, or lose directional control for reasons unrelated to braking, or apply the brakes under conditions that are too severe for RWAL to prevent a loss of directional control.

Tables 5-3 and 5-4 present the effectiveness estimates for RWAL in **multivehicle** crashes. Out of 32 estimates based on State data in the two tables, 17 are positive and 15 are negative. That suggests the net effect of RWAL in nonfatal multivehicle crashes is probably close to zero. Since RWAL is primarily designed to prevent catastrophic loss of control during braking, rather than reducing stopping distances or allowing the driver to steer while braking, it is reasonable that RWAL should be effective against run-off-road crashes, rather than multivehicle collisions. Three metrics were used to study the effect of RWAL in multivehicle crashes. Table 5-3 is limited to two-vehicle crashes in which a fast-moving vehicle hit a stopped or slow-moving vehicle; with RWAL, there were generally positive, but mostly nonsignificant reductions in fast-moving crash involvements. Table 5-4 considers all types of multivehicle crashes. The upper half of Table 5-4 shows small, mostly nonsignificant

TABLE 5-3

REDUCTIONS OF INVOLVEMENTS AS A FAST-MOVING VEHICLE
HITTING A STOPPED OR SLOW-MOVING VEHICLE
FOR LIGHT TRUCKS WITH RWAL

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

Vehicle Type	**Road Condition**	**Accident Reduction (%) Florida**
Pickup truck	Any	1
Pickup truck	Wet	13
Sport utility vehicle	Any	8
Sport utility vehicle	Wet	-11
Van	Any	**19**
Van	Wet	20

TABLE 5-4

REDUCTIONS OF INVOLVEMENTS AS A MOVING
OR "STRIKING" VEHICLE IN A MULTIVEHICLE COLLISION
FOR LIGHT TRUCKS WITH RWAL

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

REDUCTIONS OF INVOLVEMENTS AS A "STRIKING" VEHICLE

		Accident Reduction (%)		
Vehicle Type	**Road Condition**	**MI**	**FL**	**FARS**
Ford Ranger		5		
Other pickup truck		- 7		
Any pickup truck		**- 5**	**-10**	- 2
Any pickup truck	Dry	- 3	-11	
Any pickup truck	Wet	**-11**	- 5	
Any pickup truck	Snowy or Icy	- 6		
Sport utility vehicle		- 6	- 7	2
Van		- 6	- 7	-15

REDUCTIONS OF INVOLVEMENTS AS A MOVING VEHICLE

		Accident Reduction (%)	
Vehicle Type	**Road Condition**	**MI**	**FL**
Ford Ranger		8	
Other pickup truck		**6**	
Any pickup truck		**6**	- 2
Any pickup truck	Dry	1	- 4
Any pickup truck	Wet	**13**	5
Any pickup truck	Snowy or Icy	10	
Sport utility vehicle		5	6
Van		**7**	3

increases for RWAL-equipped trucks being involved as "striking" vehicles (moving and frontally impacting) as opposed to "struck" vehicles (stopped, or damaged in the rear or side). The lower half of Table 5-4 shows small reductions for RWAL-equipped trucks being involved as a moving vehicle, as opposed to a stopped vehicle. Road condition appears to be of little influence on these effects.

The data on fatal multivehicle crashes are inconclusive. The FARS results in Table 5-4, which show little or no effect for RWAL, are based on a comparison of trucks of the first model year with RWAL and the last model year before they became equipped with RWAL. However, when the data are extended to two model years before and after the transition to RWAL, the results are significantly negative (see Section 3.2.2).

Table 5-5 shows reductions of **collisions with pedestrians, animals, bicyclists, trains, or on-road objects** (on-road single-vehicle crashes). There are quite a few statistically significant reductions for light trucks with RWAL in both nonfatal collisions (mostly with animals) and fatal collisions (mostly with pedestrians and bicyclists). Although there is some variation between the estimates, the overall reduction of nonfatal crashes appears to be around 10-20 percent. Nonfatal accident reductions are significant on dry and wet roads. The estimates of fatality reduction are still "soft" due to limited data, but appear to be in the 5-15 percent range.

In summary, **the "best" estimates of RWAL effectiveness, based on light trucks up to model year 1991, are listed in Table 5-6.** These preliminary results need to be viewed with caution for several reasons. Definitions of crash modes vary from State to State, and results from different States may not be directly

TABLE 5-5

REDUCTIONS OF COLLISIONS WITH PEDESTRIANS, ANIMALS, BICYCLISTS, TRAINS, OR ON-ROAD OBJECTS
FOR LIGHT TRUCKS WITH RWAL

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

Vehicle Type	**Road Condition**	**Accident Reduction (%) Michigan**	**Accident Reduction (%) FARS**
Ford Ranger		**33**	6
Other pickup truck		**7**	**19**
Any pickup truck		**11**	**16**
Any pickup truck	Dry	**7**	16
Any pickup truck	Wet	**25**	24
Any pickup truck	Snowy or Icy	5	
Ford Bronco 2		**29**	
Other SUV		**22**	
Any SUV		**21**	-28
Ford Aerostar		**23**	
Other van		6	
Any van		10	4

TABLE 5-6

"BEST" ESTIMATES OF EFFECTIVENESS
REAR-WHEEL ABS FOR LIGHT TRUCKS

(based on vehicles up to model year 1991)

Type of Crash	Type of Vehicle	Reduction (%)
Rollover (nonfatal)	Ford Ranger	35-50
	Other pickup	20-30
	Ford Bronco 2	30-40
	Other SUV	10-20
	Van	15-30
Side/fixed object (nonfatal)	Light truck	15-30
Frontal/fix obj (nonfatal)	Ranger, Bronco 2	10-20
	Other light truck	5-15
Fatal rollover	Ford Ranger	20-30 (limited data)
	Other light truck	none
Fatal side/fix obj	Ford Ranger	20-30 (limited data)
	Other light truck	none
Striking a vehicle (nonfatal)	Light truck	none
Striking a vehicle (fatal)	Light truck	unknown, maybe negative
Hit animal, etc. (nonfatal)	Light truck	10-20
Hit pedestrian, etc. (fatal)	Light truck	5-15 (limited data)

comparable. The FARS samples in this report were sometimes too small for statistically meaningful results; all estimates of fatality reduction might change as more data become available, allowing more detailed analysis methods. The data cover the initial experience of the first groups of trucks equipped with RWAL, operating in an environment where most vehicles on the road still did not have ABS. Results could change as these trucks get older, or for later trucks with different RWAL systems, or as the rest of the vehicle fleet also gets ABS. The study isolated run-off-road, multivehicle and pedestrian/animal crashes, analyzing each type independently. In fact, these events need not always occur independently, e.g., if RWAL-equipped trucks are less prone to yaw off the road than trucks with conventional brakes, that could make them more likely to hit another vehicle on the road.

The results of this report apply **only** to light trucks equipped with RWAL and should definitely **not** be extended to passenger cars or light trucks equipped with four-wheel ABS. As explained in Section 1.3, the accident samples for cars and trucks with four-wheel ABS were insufficient for detailed statistical analyses. The passenger cars initially equipped with ABS were largely expensive and/or high-performance vehicles; neither the cars nor their drivers are fully representative of the "average" car and driver. It will be several years before the ABS-equipped fleet includes a large percentage of family and economy cars. Four-wheel ABS was just beginning to appear on light trucks in model years 1990-91.

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