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NHTSA Technical Report

The Long-Term Effectiveness of Center High Mounted Stop Lamps in Passenger Cars and Light Trucks

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EXECUTIVE SUMMARY

Center High Mounted Stop Lamps (CHMSL) have been standard equipment on all new passenger cars sold in the United States since model year 1986 and all new light trucks since model year 1994, as required by Federal Motor Vehicle Safety Standard 108. The purpose of CHMSL is to safeguard a car or light truck from being struck in the rear by another vehicle. When brakes are applied, the CHMSL sends a conspicuous, unambiguous message to drivers of following vehicles that they must slow down. NHTSA was especially encouraged to promulgate the CHMSL regulation in 1983 by three highly successful tests of the lamps in taxicab and corporate fleets, showing 48 to 54 percent reductions of "relevant" rear-impact crashes in which the lead vehicle was braking prior to the crash, as reported by the study participants. Since nearly two-thirds of all rear impact crashes involve pre-impact braking by the lead vehicle, these results are equivalent to a 35 percent reduction of rear-impact crashes of all types.

The Government Performance and Results Act of 1993 and Executive Order 12866 (October 1993) require agencies to reevaluate the effectiveness, benefits and costs of their programs and regulations after they have been in effect for some time. NHTSA has already published two effectiveness evaluations based on the early police-reported crash experience of cars with production CHMSL. In the first study, based on Summer 1986 data, CHMSL-equipped cars were 15 percent less likely to be struck in the rear than cars without CHMSL. In the second study, based on calendar year 1987 data from eleven States, the reduction in police-reported rear-impact crashes of all types was 11.3 percent.

These levels of crash avoidance were still high enough to assure an excellent ratio of benefits to costs. Nevertheless, the decline in effectiveness from the fleet tests to the evaluations was clear-cut, even taking into account that the data bases were not perfectly comparable (participant-reported vs. police-reported crash data). That raised questions: as more and more cars on the road have CHMSL, do drivers "acclimatize" to the lamps and pay somewhat less attention to them? Would effectiveness continue to decline? A 1996 study by the Insurance Institute for Highway Safety, showing an average 5 percent crash reduction for CHMSL during 1986-91, strongly suggested a continued decline.

The principal objective of this report is to assemble enough crash data to allow an accurate estimate of the effectiveness of passenger car CHMSL **in each calendar year** from 1986 through 1995. That would make it possible to track the trend in effectiveness over time, find out when and if that trend leveled out, and determine the long-term crash reduction for CHMSL. The analysis is based on police-reported crash data from the eight States that furnished their files to NHTSA throughout 1986-95 and have the data elements needed for the analysis:

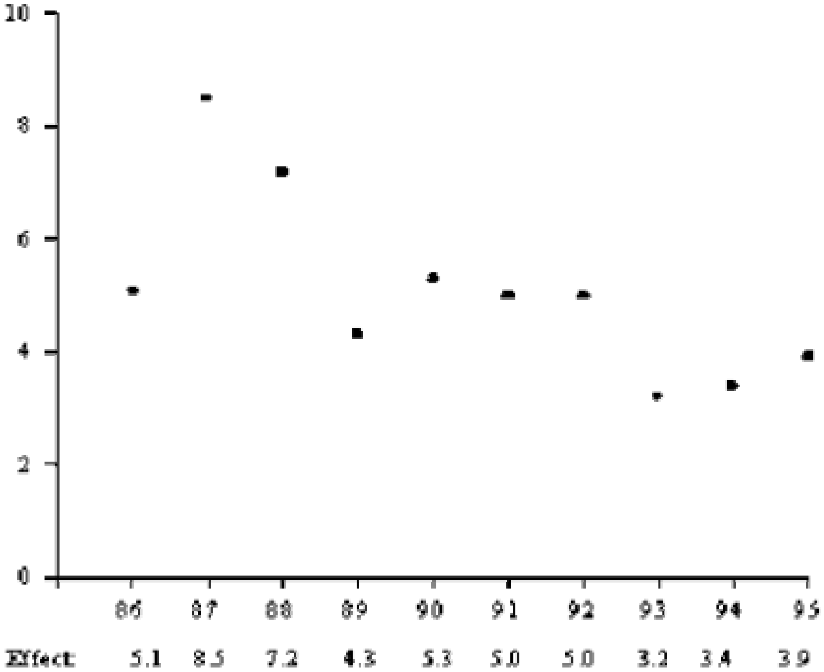
Florida **Indiana** **Maryland**
Missouri **Pennsylvania** **Texas**
Utah **Virginia**

In each State and calendar year of data, the ratio of rear impacts to non-rear impacts for model year 1986-89 cars (all CHMSL equipped) is compared to the corresponding ratio in 1982-85 cars (mostly without the lamps), after the ratios have been adjusted for vehicle age. Other objectives of this report are: (1) Compare the effectiveness of passenger car CHMSL in various crash types, environmental conditions, etc. (2) Obtain an initial estimate of the effectiveness of CHMSL for light trucks (pickup trucks, vans and sport utility vehicles). CHMSL only began to appear on some light trucks in model year 1991 and they have been required since model year 1994. There has been some question as to whether they would be as effective in light trucks as cars. (3) Estimate the crash and injury reducing benefits of CHMSL and assess their long-term cost effectiveness.

The most important finding of the evaluation is that, in the long term, passenger car CHMSL reduce rear impacts by 4.3 percent (confidence bounds: 2.9 to 5.8 percent). Even though that effectiveness is well below the levels in earlier studies, and CHMSL can no longer be considered a "panacea" for the rear-impact crash problem, the benefits of CHMSL still far exceed the modest cost of the lamps, and CHMSL will continue to be a highly cost-effective safety device. The principal findings and conclusions of the study are the following:

PASSENGER CAR CHMSL: YEAR-BY-YEAR TREND OF OVERALL EFFECTIVENESS

By **calendar year**, the effectiveness of passenger car CHMSL (average percent reduction of police-reported rear impact crash rates in eight States) was:



The effectiveness of passenger car CHMSL did not have a statistically significant downward trend during 1989-95. The average effectiveness in 1989-95 was 4.3 percent. It may be concluded that the lamps reached their long-term effectiveness level of 4.3 percent in 1989.

Passenger car CHMSL were significantly more effective for the period 1987-88 than for 1989-95. The effect in 1987, 8.5 percent, was nearly double the long-term effect.

Effectiveness of passenger car CHMSL, and its confidence bounds, by calendar year:

CY Group	Rear Impact Reduction (%)	Confidence Bounds
1986	5.1	2.5 to 7.7
1987	8.5	6.1 to 10.9
1988	7.2	4.8 to 9.5
1989-95	4.3	2.9 to 5.8

There was little State-to-State variation in the effectiveness of passenger car CHMSL.

PASSENGER CAR CHMSL: LONG-TERM EFFECTIVENESS BY CRASH TYPE, ETC.

The long-term effectiveness of passenger car CHMSL is about equal in property-damage and nonfatal-injury crashes.

The lamps had little or no effect on fatal rear-impact crash rates at any time during 1986-95.

CHMSL are more effective in daytime than in nighttime crashes. They are more effective at locations away from traffic signals than at locations equipped with traffic signals. Since 1989, they have been more effective in preventing two-vehicle crashes than in preventing crashes involving three or more vehicles.

The lamps may be somewhat more effective in towaway than in nontowaway crashes. They may be somewhat more effective on wet roads than on dry roads. Effectiveness may be slightly higher in rural than in urban crashes.

In general, the simpler the accident scene, the more effective the CHMSL. The more a driver is distracted by other lights or traffic features, the less effective the CHMSL.

CHMSL effectiveness in the struck vehicle in a front-to-rear collision is about the same whether the driver of the striking vehicle is young or old, male or female.

LIGHT TRUCK CHMSL

Initial crash data from six States show that light trucks equipped with CHMSL have 5 percent lower rear-impact crash rates than light trucks without CHMSL. The reduction is statistically significant (confidence bounds: 0.3 to 9.4 percent).

Although the observed point estimate of effectiveness for CHMSL in light trucks (5.0 percent) is close to the lamps' long-term effectiveness in passenger cars (4.3 percent), the uncertainty in the light-truck estimate, at this time, does not yet permit the inference that the lamps are equally effective in cars and trucks.

These initial analyses did not show any significant variations in CHMSL effectiveness by light truck type (pickup, van, sport utility) or size (full-sized, compact).

LONG-TERM BENEFITS AND COSTS

At the long-term effectiveness level (4.3 percent reduction of rear-impact crashes), the public would obtain the following annual benefits when all cars and light trucks on the road have CHMSL:

	Police-Reported	**Unreported**	**Police-Reported Plus Unreported**
Crashes avoided	92,000 - 137,000	102,000	194,000 - 239,000
Injuries avoided	43,000 - 55,000	15,000	58,000 - 70,000
Property damage and associated costs avoided (1994 $)			$655,000,000

The annual cost of CHMSL in cars and trucks sold in the United States is close to $206 million.

Since the value of property damage avoided, alone, far exceeds the cost of CHMSL, the lamps still are and will continue to be highly cost-effective safety devices.

CHAPTER 1
INTRODUCTION AND BACKGROUND

Center High Mounted Stop Lamps (CHMSL) have been standard equipment on all new passenger cars manufactured on and after September 1, 1985 for sale in the United States. They are required by an October 1983 amendment [11] of Federal Motor Vehicle Safety Standard 108 [5]. CHMSL have also been standard equipment on all new light trucks (pickup trucks, vans and sport utility vehicles)manufactured on and after September 1, 1993 for sale in the United States, following an April 1991 amendment [12] of FMVSS 108. CHMSL are red stop lamps mounted on the center line of the rear of a vehicle, generally higher than the stop lamps on the sides of that vehicle. They are activated when the driver steps on the brake pedal and they are off at other times. The purpose of

CHMSL is preventing crashes by reducing the reaction time for drivers to notice that the vehicle in front of them is braking.

There are several hypotheses why CHMSL might stimulate a quicker reaction than conventional stop lamps. The central and raised location of CHMSL puts them "in an area of the forward visual field toward which a following driver most often glances [6]." Since its central location makes "the CHMSL separate and distinct from all other rear lamps and signals, any possible ambiguity of the signal is reduced," especially, the "likelihood that the signal will be interpreted as a directional signal [6]" (turn signal or tail lamp). The CHMSL, in combination with the two lower side mounted lamps, forms a triangle which could be an additional cue to get the driver's attention. The high mounting of the lamp might make it visible through the windows of a following vehicle and enable the driver of the third vehicle in a chain to react to the first car' s braking. Some drivers may interpret the high mounted lamp as a warning to keep their distance;

by following at a safer distance, they have more room to stop.

1.1 Evaluation of CHMSL

The Government Performance and Results Act of 1993 [16] and Executive Order 12866 (October 1993) [13] require agencies to evaluate their existing programs and regulations. The objectives of an evaluation are to determine the actual benefits - lives saved, injuries prevented, damages avoided - and costs of safety equipment installed in production vehicles in connection with a rule. This report tracks the effectiveness, benefits and costs of passenger-car CHMSL during 1986-95. At the beginning of that 10-year period, only a small number of cars with CHMSL were on the road, but by 1995, the majority of cars on the road were CHMSL-equipped. The report completes the evaluation of passenger car CHMSL, following up on NHTSA's preliminary evaluation based on CHMSL performance in mid 1986 [18] and interim evaluation based on 1987 performance [19]. In addition, this report presents early effectiveness results for light truck CHMSL, based on statistical analyses of crash data.

The CHMSL rule has evolved through the full cycle of experimental research, test fleets, regulatory analysis, rulemaking and evaluation. During 1974-79, experimental research with CHMSL-equipped passenger cars showed significant reductions in reaction time relative to conventional stop lamps [15], pp. III-19 - III-23, [6]. In 1976-79, NHTSA sponsored installation of CHMSL on test fleets comprising over 3000 cars. The CHMSL equipped cars had significantly fewer rear impacts than control groups with conventional lamps. The Regulatory Impact Analysis, published in 1983, included detailed projections of the crashes, injuries and damages that might be avoided with CHMSL, as well as a cost estimate [15]. It concluded that CHMSL would almost certainly be cost effective. When the CHMSL rule was promulgated in 1983 (with an effective date of September 1, 1985), a comprehensive evaluation plan [7] was published at the same time, outlining statistical and engineering analyses to determine the actual effectiveness and cost of production CHMSL. The earlier evaluations [18], [19] as well as this report follow the guidelines of the evaluation plan.

CHMSL retrofit kits are relatively easy to manufacture and install. Favorable public opinion and support by motorist groups such as the American Automobile Association helped create a substantial market for retrofit CHMSL. Inquiries to lamp manufacturers and the AAA revealed that approximately 4,000,000 CHMSL retrofit kits had been manufactured or imported into the United States by mid 1986 and most of them were installed on model year 1980-85 cars [18], p. 5. More cars have been retrofitted since then. It is likely that 10 percent of model year 1980-85 cars (or at least 1984-85 cars) had been retrofitted by mid 1987. As will be shown in Section 2.4, the percent of retrofits is one of the variables in the formula for estimating CHMSL effectiveness from crash data.

1.2 Results of earlier effectiveness and cost studies - passenger cars

The initial effectiveness studies were based on the 1976-79 test fleets [15],III-8 - III-18. The first test fleet consisted of Washington taxicabs [27]. Some taxis were equipped with CHMSL or other distinctive stop lamps, while a control group of the same makes, models and driver characteristics had conventional stop lamps. Drivers reported all crash involvements. The most important finding of the field test with Washington taxicabs was that the CHMSL equipped cars had 36 percent fewer rear impacts per million miles than the control group.

NHTSA validated the first study with a larger test fleet of telephone company cars (2,500 with CHMSL) in 4 regions of the United States [30]. The results were nearly identical: the CHMSL equipped cars had 35 percent fewer rear impacts per million miles than the control group.

The Insurance Institute for Highway Safety sponsored a field test with New York City taxicabs and obtained an average 34 percent reduction of rear-impact crashes [29]. (Actually, the three preceding studies measured effectiveness as a reduction of "CHMSL relevant" crashes, where the driver was braking before being struck. Since the data in those studies indicated that two-thirds of all rear impacts are "CHMSL relevant," and since no effect can be expected in crashes where the driver was not braking, the percentage reduction of **all** rear impacts is two-thirds the percentage reduction of "CHMSL relevant" rear impacts.)

NHTSA's Final Regulatory Impact Analysis (FRIA), dated October 1983 [15] based its effectiveness estimate on the field tests and its cost estimate on analyses of prototypes. Benefits (crashes, injuries and damages avoided) were projected from conservative assumptions about the types of crashes in which CHMSL would be effective. The main predictions of the FRIA were:

Overall effectiveness 33 percent reduction of rear-impact crashes (field test results rounded down)

Cost per car $4.13-6.76 in 1982 dollars, which is equivalent to $6.34-10.37 in 1994 dollars

Damage reduction $434 million per year (conservative estimate of $282 average damage per crash involved vehicle; conservative assumption of the number of rear impact crashes; no effectiveness assumed in rural crashes)

Injury reduction 40,000 per year (33 percent effectiveness was not assumed to apply to injury crashes; instead, NHTSA postulated a speed distribution for injury crashes and projected how improved reaction times with CHMSL would change this distribution)

NHTSA's preliminary evaluation of CHMSL [18] was based on police-reported crashes that occurred at the 50 National Accident Sampling System (NASS) areas during June-August 1986, a nationally representative data set. The involvement rate in rear impacts for model year 1986 cars (all CHMSL equipped) is compared to 1985 cars (mostly without the lamps). The sample included 1571 CHMSL equipped cars with rear impact damage (15 times larger than the sample in the field tests, but 1/50 as many cases as NHTSA's second evaluation report). The principal findings were:

Overall effectiveness 15 percent reduction of rear-impact crashes

Confidence bounds Not explicitly stated, but appear to be at least as wide as 7-22 percent if the data are treated as a simple random sample and perhaps wider, given that the data derived from a cluster sample

In specific situations CHMSL likely to be more effective in crashes involving 3 or more vehicles than in 2 vehicle crashes; no big differences in the effect of CHMSL between rural and urban areas

NHTSA's second evaluation report was based on a full calendar year 1987 of crash data from 11 States [19]. There were enough data to estimate the effectiveness of CHMSL with reasonably narrow confidence bounds. The statistical procedure was to compare the proportion of crashes that are rear impacts in model year 1986-87 cars (with CHMSL) to model year 1980-85 cars (without CHMSL), after adjusting those proportions for vehicle age effects. The cost of CHMSL was estimated by a detailed inspection of a sample of lamps from production vehicles, and a cost-effectiveness analysis was performed. The principal findings were:

Overall effectiveness 11.3 percent reduction of rear-impact crashes

Confidence bounds 8.8 to 13.8 percent, based on the State-to-State variation of the effectiveness estimate

In specific situations CHMSL somewhat more effective in 3+ vehicle crashes, in daylight crashes, rural roads, nonsignalized locations; equally or more effective in injury crashes than in property-damage crashes, but no effect on fatalities

Cost per car $10.48 in 1987 dollars, which is equivalent to $13.60 in 1994 dollars

Damage reduction $910 million per year (when all cars, no light trucks have CHMSL)

Injury reduction 79,000 - 101,000 per year

The unmistakable trend in these results is that CHMSL effectiveness declined: from 34-36 percent in the field tests, to 15 percent in the first evaluation, to 11.3 percent in the second. To some extent, perhaps, the conclusion may be hedged because the various studies derived from different types of data, but such differences alone could hardly explain the downward trend, especially when the second evaluation showed fairly similar levels of CHMSL effectiveness over a wide variety of crash types and severities. The results raised obvious questions. As more and more cars on the road have CHMSL, do drivers "acclimatize" to the lamps and pay somewhat less attention to them [17]? Would effectiveness continue to decline, and if so, what would be its "long-term" level? Needless to say, the results of NHTSA's second evaluation report did not yet constitute a "final" assessment of CHMSL effectiveness. As recommended in that report and in NHTSA's 1983 Evaluation Plan [7], p. 3, follow-up analyses needed to be performed.

At least two evaluations of the effectiveness of CHMSL have been performed by agencies outside the United States government, based on North American crash data. Transport Canada analyzed the effect of CHMSL in calendar year 1987, based on crash data from seven Provinces [28]. The time frame (CY 1987) and analysis methods were quite similar to NHTSA's second evaluation. So was the result: a 10.5 percent reduction of rear-impact crashes attributed to CHMSL.

However, the first comprehensive analysis to include data collected **after** 1987 was performed by Farmer at the Insurance Institute for Highway Safety, covering the 1986-91 time frame [9]. The data base consisted of over 400,000 property-damage liability claims filed with insurance companies by owners of model year 1984-87 passenger cars. The statistical procedure was to compare the proportion of claims that are rear impacts in model year 1986 cars (with CHMSL) to model year 1985 cars (without CHMSL), after adjusting those proportions for vehicle age effects. Over the full 1986-91 time frame, CHMSL was associated with a **5.1 percent reduction** of rear-impact crashes. That's well below the 11.3 percent reduction found in NHTSA's second evaluation for 1987. Farmer did not have enough data to obtain accurate year-by-year estimates or to draw definitive conclusions about whether effectiveness was changing over time and whether or not it had reached its long-term level. Nevertheless, this authoritative study served notice that the long-term effect of CHMSL would be well below the levels seen in NHTSA's two evaluations, and quite possibly below 5 percent.

1.3 Extension of CHMSL to light trucks

Many of the safety standards that originally applied only to passenger cars were subsequently extended to light trucks (pickup trucks, vans and sport utility vehicles). The process accelerated after 1980, as light trucks became increasingly popular vehicles for personal transportation. To the extent that light trucks have the same types of crashes as cars, and similar driving exposure, it is often plausible to argue, without extensive additional research, that safety measures effective in cars are also likely to be effective in light trucks. In some cases, however, issues arise that complicate the feasibility of a standard in light trucks, or raise doubts about its potential benefits or costs.

Following the successful debut of CHMSL on passenger cars in model years 1986-87, it became natural to consider extending the requirement to light trucks. The principal issue that complicated the extension to light trucks was the location of the CHMSL. It was not a problem for the smaller vans and sport utility vehicles, whose backsides are similar to station wagons. But on pickup trucks, the question arose whether to locate the CHMSL near the cab roof, where it might be less than perfectly conspicuous to the following driver (too high and too far forward, especially relative to the other rear lights), or on the tailgate, where there might be problems of durability and cost, and where the effect would be lost when the tailgate is open. Also, on certain large vans, there was a question if the CHMSL would be too high up to be fully conspicuous.

In 1988, NHTSA conducted extensive tests of the reaction times of volunteers to simulated light trucks with CHMSL or with conventional brake lights. The reaction time for drivers following a truck with CHMSL was 0.09 seconds shorter than for drivers following a truck without CHMSL. That is just a slightly lower benefit than in passenger cars, where the reduction in reaction time with CHMSL was 0.11 seconds [14], p. 2.

On the basis of this research and other information, the Final Regulatory Impact Analysis (FRIA) for light truck CHMSL asserted that the problems concerning location could be resolved and that the lamps would be effective for trucks, but granted that it might be slightly less effective than in cars (i.e., 9/11 as effective) [14], p. 21. The FRIA also asserted that in most light trucks the cost of CHMSL would be about the same as in passenger cars, but granted that costs might increase by about 50 percent in trucks that are produced in multiple stages - i.e., where the truck is modified prior to sale, obscuring the original CHMSL and requiring it to be moved to another location [14], p. 30.

The April 1991 Final Rule allowed 2½ years lead time, till September 1993, for installation of CHMSL. In fact, CHMSL were phased in over a three-year period, MY 1991-94, since some trucks already had them before the Rule was published, while others did not get them until the effective date. That contrasts with the nearly simultaneous implementation of CHMSL in passenger cars (MY 1986 in all models except Cadillacs and very few others). Dodge Caravan, Plymouth Voyager, Chrysler Town & Country and Ford Explorer were the first to get CHMSL, in MY 1991. Ford's full-sized pickup trucks, vans and sport utility vehicles got them in 1992, and all other make-models got them in 1993 or 1994.

CHAPTER 2

THE INITIAL AND LONG-TERM OVERALL EFFECTIVENESS OF PASSENGER CAR CHMSL

Statistical analyses of calendar year 1986-95 crash records from eight States indicate that CHMSL have reduced the frequency of rear-impact crashes every year since their 1986 introduction, but the initial effect was about twice as large as the long-term effectiveness. In calendar year 1987, CHMSL-equipped cars were approximately 8½ percent less likely to be struck in the rear than cars without CHMSL. In 1988, the effect had declined to 7 percent. By 1989, the effect had declined to its long-term level of approximately 4 percent, and it stayed at that level throughout 1989-95. All of these reductions are statistically significant, and the 1987-88 effectiveness is significantly higher than the long-term effect.

2.1 Data sources

The analyses require large samples of crash data that specify the model year of a passenger car (1985 or earlier - i.e., not CHMSL-equipped vs. 1986 or later - i.e., CHMSL-equipped) and the impact location (rear impact vs. other). The goal is to discover if there are proportionately fewer rear impacts among the CHMSL-equipped cars than among the cars without CHMSL - and with a large enough sample, those differences can be discovered, even if the effect of CHMSL is small. The data need to be available for a time-series of calendar years, preferably every year from 1986 onwards, to allow tracking the effect of CHMSL over time. State files are the only data source available to NHTSA that can furnish an adequate number of cases for statistical analyses. The agency currently receives data from 17 States and maintains them for analysis. However, data from nine States were not used in the analysis: North Carolina, because NHTSA does not have their files prior to 1992; Michigan, because the vehicle's model year is not specified in the 1992-95 data; California, Georgia, Illinois, Kansas, New Mexico, Ohio and Washington, because they do not specify the impact location (rear impact vs. other). The remaining eight State files were included in the analysis:

Florida
Missouri
Utah
Indiana
Pennsylvania
Virginia
Maryland
Texas

These States had an aggregate population of 65,371,000 in 1990, or 26 percent of the population of the United States. Their areas included a wide variety of urbanization, climate and topography. Within these eight States, passenger cars experience approximately 300,000 police-reported rear impacts in each calendar year: plenty of data for statistical analyses.

The critical parameters that must be defined in each State file - impact location, passenger car, "in transport," model year - will now be discussed, in that order.

Every State has its own unique ways of coding a vehicle's impact location. We cannot define "rear impact" exactly the same way in each State, but at least we can make the definitions as similar as possible. It is also desirable to make the "rear impact" category as inclusive as possible - any crash where the impact encompasses at least part of the rear portion of the car, and where the driver of the other vehicle might at least have had a chance to see a CHMSL, ought to be included among the rear impacts, because there is a chance that CHMSL could have been beneficial. Thus, "rear-corner" impacts and, in some cases, even impacts resulting in damage to the back portion of the side of the car are included among the rear impacts. State-by-State, the following definitions of "rear impact" are reasonably uniform, as evidenced by the similar percentages of all crash involvements that are rear impacts, and also as inclusive as possible. Cars with unknown impact locations and parked cars (see below) are excluded from the analysis:

	Definition of "Rear Impact"	**Percent of Involvements that Are Rear Impacts**
Florida	impact = 7,8,9	22.6
Indiana	impact = 5,6,7	24.7
Maryland 86-92	impact & veh_dam1 both 7-9, or one is 7-9 and one is blank	23.4
Maryland 93-95	impact & veh_dam1 both 7-12, or one is 7-12 and one is blank	22.6
Missouri	veh_dam1 = 7,8,9	21.4
Pennsylvania	impact = 4,5,6,7,8	21.7
Texas	veh_dam1 = 'B--' or 'LB-' or 'RB-'	24.7
Utah	impact & impact2 both 7-9, or one is 7-9 and one is blank	22.6
Virginia	impact = 4,5,6	24.2

It is also necessary to single out passenger cars (that got CHMSL in model year 1986) from other vehicles, such as light trucks (that did not). One possibility would be to analyze Vehicle Identification Numbers (VIN) and pick only the vehicles with valid passenger-car VINs. However, that would limit the study to the five VIN States (Florida, Maryland, Missouri, Pennsylvania, Utah) and, even in some of those States, the VIN is often blank or incomplete. A more inclusive approach is to accept every vehicle coded on the file as a "passenger car," recognizing that some of the vehicles were not, in fact, passenger cars, and subsequently adjusting the results for those miscodes. In five States, the code for passenger cars is veh_type = 1. In Utah, veh_type = 1,2,6 are passenger cars; in Maryland, veh_type = 2,3; in Missouri, during 1986-89, veh_type = 1,2,3, and during 1990-95, veh_type = 1,2. The degree of error in those codes was tested by examining the VINs, in calendar years 1989 and 1994, in the five VIN States: ten State-year combinations. Among the vehicles coded as "passenger cars" according to veh_type, and with valid, decipherable VINs, the percentage that were, in fact, not passenger cars according to the VIN ranged from 1.6 to 6.3, with a median of 3.7. (Most of them were light trucks or vans.) In other words, 96.3 percent of the vehicles alleged to be passenger cars according to their veh_type were, indeed, passenger cars.

In Florida, Indiana, Maryland, Missouri and Utah, vehicles struck while they were parked and unoccupied are counted as crash-involved vehicles, and account for 4 to 10 percent of the vehicle records on the file. In Texas and Virginia, they are not counted as vehicle records, and in Pennsylvania, only a small number of illegally parked vehicles are counted. Since CHMSL cannot be expected to have any value in preventing an unoccupied vehicle from being struck in the rear (since there is nobody to apply the brakes and activate the lamp), and since it is undesirable to have obvious State-to-State discrepancies on what constitutes a "crash-involved vehicle," all of the records for parked vehicles, regardless of the impact location, are deleted from the analysis. State-by-State, the codes for parked vehicles are:

	Parked Vehicles (exclude)	**Percent Parked**
Florida	veh_man1 = 8,9	6.4
Indiana	veh_man1 = 19, 21	7.2
Maryland	veh_man1 = 10	9.6
Missouri	veh_man1 = 13 or veh_man2 = 13 or veh_man3 = 13	6.5
Pennsylvania	veh_man1 = 19	0.3
Texas	N/A	none
Utah	veh_man1 = 11	4.3
Virginia	N/A	none

State data do not identify exactly which cars have CHMSL; they only specify the model year (MY) and the make-model. All cars from MY 1986 onwards have CHMSL. Up through MY 1985, about 10 percent of the fleet has been retrofitted with CHMSL; also, 1985 Cadillacs and a small number of other cars had them as original equipment (see Section 1.1). The best that can be done with State data is to exclude Cadillacs from the analysis, compare rear-impact involvement rates for a pre-CHMSL (1985 or earlier) and a CHMSL-equipped (1986 or later) model year, and subsequently adjust the results to account for the retrofits (see Section 2.6).

The model year, like the vehicle type, was not decoded from the VIN, but taken directly from the mod_yr variable on the State files. The degree of error in that variable was tested by comparing it with the model year derived from the VIN. Among the vehicles with mod_yr 82-89 and with valid, decipherable VINs, the percentage that had mod_yr 82-85 but a VIN-derived MY of 1986 or later, or mod_yr 86-89 but a VIN-derived MY of 1985 or earlier ranged from 0.1 to 2.1, with a median of 1.1. In other words, based on mod_yr, 98.9 percent of the cars would be correctly classified as to whether or not they had CHMSL.

In the five VIN States, records with Cadillac VINs (i.e., starting with 1G6) were excluded. In Texas and Indiana, exclusion was based on the make and/or model codes. Only in Virginia was it impossible to exclude cases of Cadillacs.

The Virginia file specifies the age of a vehicle rather than its model year. For the most part, the model year is easily derived by subtracting the vehicle age from the calendar year. However, all vehicles age 1 year or less (e.g., MY 94 and 95 vehicles, plus the small number of MY 96 vehicles in calendar year 95) are coded 1 for vehicle age. The exact model year for those vehicles cannot be determined; in the analyses that follow, when vehicle age is coded 1, model year is set to calendar year minus ½, - i.e., the "average" of the model years for zero and one year old cars. In particular, the 1986 Virginia data cannot be used for CHMSL analyses, since the cars coded 1 for vehicle age include both MY 1985 (without CHMSL) and 1986 (with CHMSL).

Seven State files were analyzed over the full 1986-95 time frame. Virginia data could not be used for 1986, as explained above, but 1987-95 files were analyzed.

2.2 The basic contingency table

The analysis objective is to compare the involvement rates of CHMSL-equipped vs. non-CHMSL cars as rear-impacted vehicles in front-to-rear collisions with other vehicles. CHMSL are assumed to have little or no effect on crash involvements other than rear impacts, such as: single-vehicle crashes, or involvements as the striking car in a front-to-rear collision, or as either vehicle in a front-to-side collision. These other crash modes can be considered a control group. Passenger car involvements in crashes are tabulated by vehicle type (without CHMSL; CHMSL-equipped) and crash type (rear impact; other crash type). The basic contingency table is:

Number of Crash Involvements

Type of Car	Rear Impacts	Others (Control Group)
Without CHMSL	N_{11}	N_{12}
CHMSL-equipped	N_{21}	N_{22}

The number of control-group involvements is a surrogate for the "exposure" of a group of vehicles. The CHMSL-equipped cars have N_{22} / N_{12} times as much exposure as the cars without CHMSL. Based on this exposure ratio, the expected number of rear impacts in the CHMSL-equipped cars is $(N_{22} / N_{12}) \times N_{11}$. In fact, there are only N_{21} rear impacts in the CHMSL-equipped cars. That is a reduction of

$$1 - [(N_{21} / N_{11}) / (N_{22} / N_{12})]$$

in the rear-impact involvement rate. This is the basic definition of "CHMSL effectiveness."

As explained above, State data, do not identify exactly which cars have CHMSL; as a surrogate, the model year is used to distinguish the cars that have CHMSL (1986 or later) from the cars that mostly do not have them (1985 or earlier). For example, the Florida data for calendar year (CY) 1987 yield the following contingency table:

Number of Crash Involvements in Florida, 1987

Model Year	Rear Impacts	Others (Control Group)
1985 (without CHMSL)	6,773	22,959
1986 (CHMSL-equipped)	7,161	25,989

In other words, the MY 1986 cars had 25,989/22,959 = 1.132 times as much exposure as the MY 1985 cars. Based on the exposure ratio of MY 1986 to 1985, the expected number of rear impacts for MY 1986 cars would be 1.132 x 6,773 = 7,667. In fact, there were only 7,161 rear impacts in the MY 1986 cars. That is a reduction of

$$1 - (7{,}161/7{,}667) = 1 - [(7{,}161/6{,}773) / (25{,}989/22{,}959)] = 7 \text{ percent}$$

The MY 1986 cars had a 7 percent lower risk of being involved in a rear-impact collision than the MY 1985 cars.

2.3 Controlling for the vehicle age effect

The preceding contingency table of MY 1985 vs. 1986 is only one of many tables that could have been extracted from CY 1986-95 State files. Any of the model years from 1986 onwards could have been used as the CHMSL-equipped group, and any of the model years up to 1985 as the pre-CHMSL comparison group. Ideally, if the data were unbiased - if there were no factors other than CHMSL that affect the proportion of crash involvements that are rear impacts - **each** of those tables would be expected to yield about the same effectiveness estimate. The simple arithmetic average of those estimates for a specific State and calendar year (or the estimate based on a single table pooling all the data) would accurately indicate the effect of CHMSL for that State and CY.

There are, however, biases in the data. They are quite evident in the following series of estimates from the 1987 Florida file, in which MY 1986 CHMSL-equipped cars are compared to pre-CHMSL model years from 1985 back to 1980:

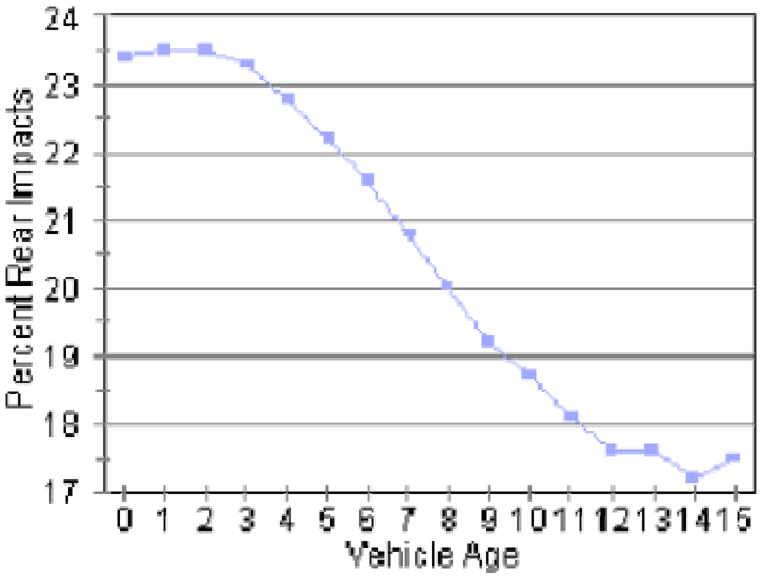
Model Years Compared	Observed "Effect" of CHMSL on Rear-Impact Crashes
1986 vs. 1985	7 percent reduction
1986 vs. 1984	4 percent reduction
1986 vs. 1983	8 percent increase
1986 vs. 1982	
1986 vs. 1981	12 percent increase
1986 vs. 1980	20 percent increase

There is an obvious trend toward increasingly unfavorable "results" for CHMSL as the vehicle age gap between the two selected model years increases (reduction = favorable; increase = unfavorable). The reason for that trend is simple: as cars get older, their distribution of crash involvements includes proportionately fewer rear impacts and more impacts of other types (single vehicle, side, front-to-rear striking). For example, when Florida data for CY 1986-95 are combined, the proportion of crash involvements that are rear impacts declines with vehicle age as shown in the following table and in Figure 2-1.:

Vehicle Age	Percent Rear Impacts	Vehicle Age	Percent Rear Impacts
0	23.4	8	20.0
1	23.5	9	19.2
2	23.5	10	18.7
3	23.3	11	18.1
4	22.8	12	17.6
5	22.2	13	17.6
6	21.6	14	17.2
7	20.8	15	17.5

In other words, the greater the age difference between two groups of cars, the greater the excess in the proportion of rear impacts in the newer cars - an "effect" in the opposite direction of the CHMSL effect (which is supposed to reduce rear impacts in the newer, CHMSL-equipped cars).

The trend in Figure 2-1 is one manifestation of what is called the "vehicle age effect." It occurs in several forms and it is often seen in statistical analyses of crash rates [9], [20], [21], [22], [23], [24],[25]. Older vehicles have proportionately fewer rear impacts, side impacts and reported non-injury crashes; they have proportionately more single-vehicle crashes and injury crashes. Three important characteristics of the vehicle age effect need to be mentioned: (1) It derives not from theory or intuition but from plain observation of actual data, such as Figure 2-1. It is definitely there; it doesn't matter how it got there. Failure to adjust for it properly will bias any analysis of crash rates of vehicles produced "before" vs. "after" the introduction of a safety device - i.e., part of the change in crash rates attributed to the device will really be the change associated with the vehicle age effect. (2) We do not have specific evidence that any, let alone all of this effect is a direct consequence of vehicle aging or deterioration *per se*. A probable cause is that as cars age and become less valuable, they are increasingly sold to more aggressive, younger drivers or "handed down" to younger family members (which would tend to increase the absolute number of single-vehicle and frontal impacts and, as a result, decrease the proportion of rear to non-rear impacts), or the cars are sold to people in regions with lower traffic density (which would tend to decrease the number of rear impacts, since there would be fewer "other" vehicles on the road to hit them). All of these are factors that would decrease the proportion of rear-impact crashes relative to single-vehicle and/or frontal involvements. Additionally, minor crashes of older vehicles may go unreported, skewing the distributions of reported crashes toward more severe types. In short, the vehicle age effect is a statistical phenomenon and it does not necessarily imply that cars become intrinsically more dangerous with age. (3) The vehicle age effect is clearly **nonlinear**, as evidenced by Figure 2-1. The trend toward a lower percentage of rear-impact crashes is weak for the first few years, reaches its maximum strength as cars get 5-8 years old, and again flattens out as vehicle age passes 10 years.



In view of these considerations, we cannot concur with the approach of Theeuwes [33] that was also the basis for comments by Mercedes-Benz [8]. Theeuwes did not adjust for the vehicle age effect because "there is no convincing explanation for the occurrence of this phenomenon" and that it might "disappear when the accuracy of registering accidents would be the same regardless of the age of the vehicle" [33], p. 24. The inability to explain a phenomenon, or the fact that it might not be there in other data, does not justify ignoring it in the existing data. As a result, Theeuwes underestimated the effect of CHMSL.

On the other hand, NHTSA's 1989 evaluation of CHMSL erred by assuming a **linear** age effect [19], pp. 13-16. Essentially, that analysis computed the average annual effect for cars 0-7 years old and applied that factor every year. As shown in Figure 2-1, the actual, nonlinear vehicle-age effect is weaker than average for 0-3 year old cars. Since NHTSA's evaluation was based on CY 1987 data, the MY 1986-87 cars equipped with CHMSL, and even the MY 1984-85 cars just before the transition to CHMSL were all 0-3 years old. The linear correction factor is too strong in those model years, and the evaluation somewhat overstated the effectiveness of CHMSL.

A principal task of this evaluation is to calibrate the nonlinear vehicle age effect accurately. That will provide appropriate correction factors for new cars as well as old cars - for CY 1986 data, when CHMSL-equipped cars were all brand new, as well as for CY 1995 data, when CHMSL-equipped cars could be as much as 9 years old.

The vehicle age effect is calibrated separately in the eight State files. The first step in the calibration is to tabulate passenger car involvements in crashes by model year (ranging from 0 to 15 year old cars) and impact type (rear vs. other) in each calendar year and State. A typical example, Table 2-1 shows the distribution of CY 1992 Florida crash involvements of cars from MY 1977 through 1992. Among the oldest cars, MY 1977-81 (11-15 years old), the proportion of involvements that are rear impacts increases slowly, and not too steadily, from 17.55 to 18.36 percent. Then come several years of substantial increases: 19.78 in MY 82, 20.16 in 83, 21.62 in 84, 22.86 in 85. With the introduction of CHMSL, in MY 86, the percentage drops back to 22.50, but then resumes its annual increase: 23.02 in 87, 23.62 in 88, 24.24 in 1989. Finally, in the newest cars (MY 89-92), there is little change in the proportion of rear impacts. Table 2-1 demonstrates well the nonlinear vehicle age effect, and it also shows how the benefit of CHMSL works against the vehicle age trend. If there had been no CHMSL, it is safe to say that the proportion of rear impacts in MY 86 would have increased, rather than decreased relative to 85, and likewise, in every model year after 1986, the proportion would have been higher than it actually was. Similar tables are obtained for all eight State files in all available calendar years from 1986 to 1995.

The next step is to compute the actual vehicle age effect: the relative change, from one model

TABLE 2-1: FLORIDA 1992, PASSENGER CAR INVOLVEMENTS IN CRASHES
BY MODEL YEAR AND IMPACT LOCATION

REAR IMPACT?

Frequency Row Pct	**NO**	**YES**	Total
77	3988 82.45	849 17.55	4837
78	5966 83.14	1210 16.86	7176
79	7551 81.93	1665 18.07	9216
80	7399 81.69	1658 18.31	9057
81	8276 81.64	1861 18.36	10137
82	8629 80.22	2128 19.78	10757
83	10181 79.84	2571 20.16	12752
84	14318 78.38	3949 21.62	18267
85	14981 77.14	4439 22.86	19402
86	16423 77.50	4768 22.50	21191
87	16944 76.98	5068 23.02	22012
88	17452 76.38	5396 23.62	22848
89	16018 75.76	5125 24.24	21143
90	13660 75.93	4330 24.07	17990
91	14599	4757	19356

	75.42	24.58	
92	13798 75.74	4419 24.26	18217
Total	190183	54193	244376

year to the next, in the proportion of involvements that are rear impacts. **Log odds ratios** are a good way to measure this effect because they can be averaged, significance-tested, entered into regression analyses, etc. When vehicle age = j, R(j) = number of rear impacts of j-year-old cars, X(j) = number of other-than-rear impacts of j-year-old cars,

$$\text{LOGODDS}(j) = \log R(j) - \log X(j)$$
$$\text{LOGODDS}(j+1) = \log R(j+1) - \log X(j+1)$$
$$\text{D\_LOGODDS}(j) = \text{LOGODDS}(j) - \text{LOGODDS}(j+1) = [\log R(j) - \log X(j)] - [\log R(j+1) - \log X(j+1)]$$

For example, in the CY 1992 Florida data shown in Table 2-1, in a comparison of 4-year-old cars (MY 1988) cars and 5-year-old cars (MY 1987),

$$\text{D\_LOGODDS}(4) = [\log 5{,}396 - \log 17{,}452] - [\log 5{,}068 - \log 16{,}944] = 0.033$$

In this section as well as the next two, all statistics, including the "preliminary" effectiveness estimates for CHMSL will be log-odds ratios. However, this is a departure from the simple contingency table analysis described above, where the customary definition of CHMSL effectiveness was based on an odds ratio, $1 - [(N_{21} / N_{11}) / (N_{22} / N_{12})]$, not a log odds ratio. Therefore, one of the steps of computing the "final" effectiveness estimates in Section 2.6 will be converting the log odds ratios back to odds ratios, mimicking the customary definition of effectiveness.

Similar statistics are calculated for each adjacent pair of model years in Table 2-1 **except MY 86 vs. 85**, because, of course, the introduction of CHMSL alters the usual age-related trend. Thus, Table 2-1 provides 14 measurements of the age effect, for j = 0 (MY 92 vs. 91) through j = 14 (MY 78 vs. 77), but excluding j = 6. The process is repeated for the other calendar years of Florida data, yielding a total of 140 measurements, 9 each for j = 0-9 and 10 each for j = 10-14. Figure 2-2 is a scattergram of those 140 data points. It shows a pattern, somewhat obscured by "noise" in the data points, of effects that tend to increase for age 0-5 and decrease after age 10.

The trend in the age effect becomes more visible if, for each value of vehicle age, we average the data points for the various calendar years, as is shown in Figure 2-3. For example, the effect for vehicle age 0 is the average of the D_LOGODDS of MY 87 vs. MY 86 in CY 87, MY 88 vs. MY 87 in CY 88, etc. Although there is still some "noise" in the average values, the pattern unmistakably resembles an upside-down parabola. That suggests a regression analysis is likely to indicate a good fit between D_LOGODDS and a quadratic function of vehicle age.

The quadratic regression is performed on the original 140 data points by the General Linear Model (GLM) procedure of the Statistical Analysis System (SAS) [32], with VEHAGE and VEHAGE^2 as the independent variables. Since there are more crashes involving young cars than old cars (see Table 2-1), it might have been appropriate to weight the data points by the number of crashes on which they were based; however, this was not done because we were reluctant to "drown out" the trend among the older cars by the trend established among newer cars. R^2 for this regression is

.275, quite satisfactory considering the "noise" seen at first glance in the 140 data points of Figure 2-2. Regression coefficients and their significance levels are:

FIGURE 2-2: VEHICLE AGE EFFECT - CHANGE IN LOG ODDS OF A REAR IMPACT, RELATIVE TO CARS ONE YEAR OLDER, FLORIDA 1986-95, CARS 0-14 YEARS OLD

When VEHICLE AGE = j, R(j) = number of rear impacts of j-year-old cars,

X(j) = number of non-rear impacts of j-year-old cars,

D_LOGODDS = [log R(j) - log X(j)] - [log R(j+1) - log X(j+1)]

Legend: • = 1 obs, = 2 obs, = 3 obs

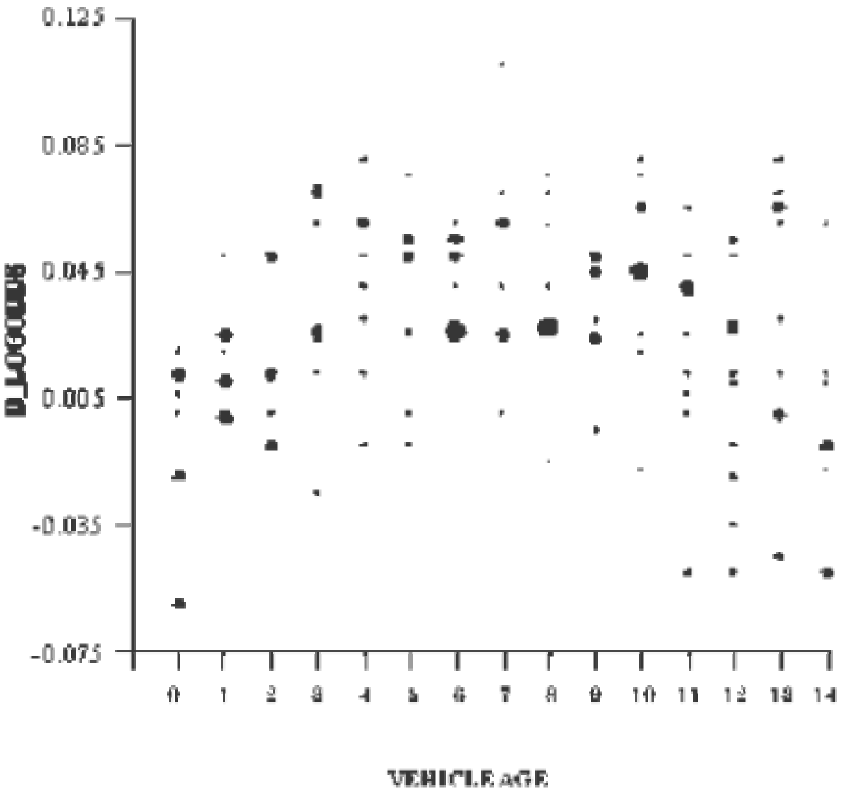
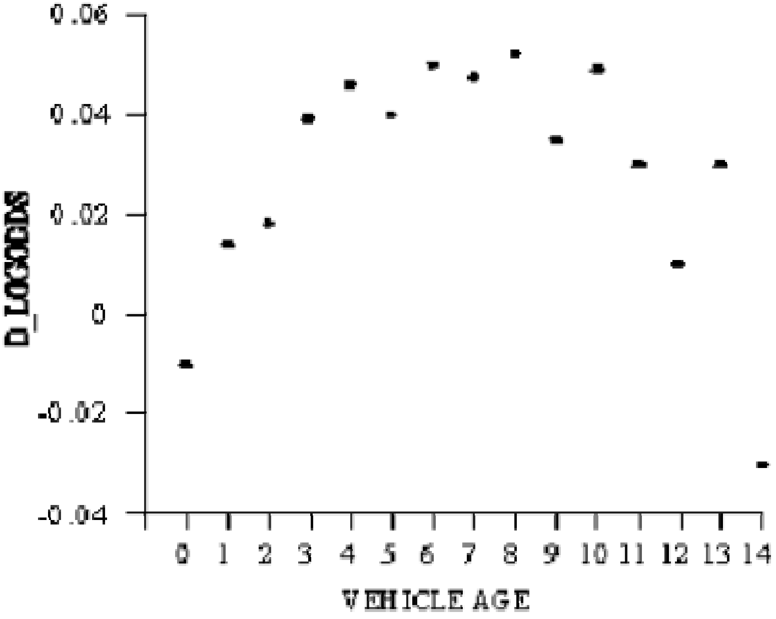


FIGURE 2-3
AVERAGE VEHICLE AGE EFFECT, FLORIDA 1986-95, CARS 0-14 YEARS OLD



Parameter	Estimate	T for HO: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT	-.0073427493	-0.96	0.3380	0.00763717
VEHAGE	0.0169290080	6.74	0.0001	0.00251294
VEHAGE*VEHAGE	-.0012319781	-7.17	0.0001	0.00017190

In other words, there is a highly significant, positive linear term and a highly significant, negative quadratic term - conditions that produce an upside-down parabola. Figure 2-4 shows how well the data fit the quadratic regression curve. The small dots are the parabola generated by the regression equation. The large dots are the actual average effects from Figure 2-3. The actual averages, calibrated values and residuals are shown in Table 2-2. The actual and calibrated age effects escalate rapidly from -1 percent in new cars to a value between 4 and 5 percent in 4-year-old cars, stay there for several years, and then drop rapidly after age 10. The residuals (actual minus calibrated) show no particular pattern, indicating a good fit between actual and calibrated. There are no groups of 3 or more consecutive values above or below zero, and most of the residuals are between -1 and +1 percent. Figure 2-5 confirms that the residuals have no recognizable pattern, except that they diverge more strongly from zero (but in both directions) for older cars, consistent with the smaller data samples that the statistics for the older cars are based on.

Table 2-2 points out the flaw in the age effects computed in NHTSA's 1989 evaluation of CHMSL [19], pp. 14-16. A constant, 4.88 percent effect was assumed in Florida data. Table 2-2 indicates that this is rather accurate for 4-9 year old cars, but quite overstated for new or nearly new cars.

Exactly the same procedure is used to calibrate the vehicle age effect in data from Indiana, Maryland, Missouri, Pennsylvania, Texas and Utah. In the Virginia data, as described in Section 2.1, it is impossible to tabulate crashes separately for 0 and 1 year old cars. There, the vehicle age effect is calibrated from the data on 2-14 year old cars, and the resultant regression curve is extrapolated to vehicle ages 0 and 1. Table 2-3 presents the regression equation for each State and, as examples, shows the calibrated effect for cars age 0, 5 and 10. In seven States, a quadratic regression was used to calibrate the age effect; in Utah, the age^2 coefficient was negligible and a linear regression was sufficient.

In all eight States, the regression curve gave a good calibration of the actual trends, as evidenced by an examination of the residuals: no strings of consecutive values more positive than .01 or more negative than -.01. In States with smaller data samples, viz. Maryland and Utah, some residuals were understandably larger than in Florida, but there were no examples of misfit.

Six of the States had the upside-down parabola trend seen in Florida, with the vehicle age effect reaching a maximum at about 5 years. Indiana and Utah, however, started with positive age effects in new cars that got steadily less positive as vehicles aged. The Pennsylvania trend most closely resembles Florida's: a negative initial effect plus strong linear and quadratic terms. Texas and Maryland start with age effects close to zero. The other four States have a positive age effect even in new cars. These State-to-State variations could be due to reporting

FIGURE 2-4
CALIBRATED VS. AVERAGE OBSERVED VEHICLE AGE EFFECT
FLORIDA 1986-95, CARS 0-14 YEARS OLD

• = Calibrated effect = -.00734+.01693*VEHAGE-.001232*VEHAGE^2

= Average observed effect

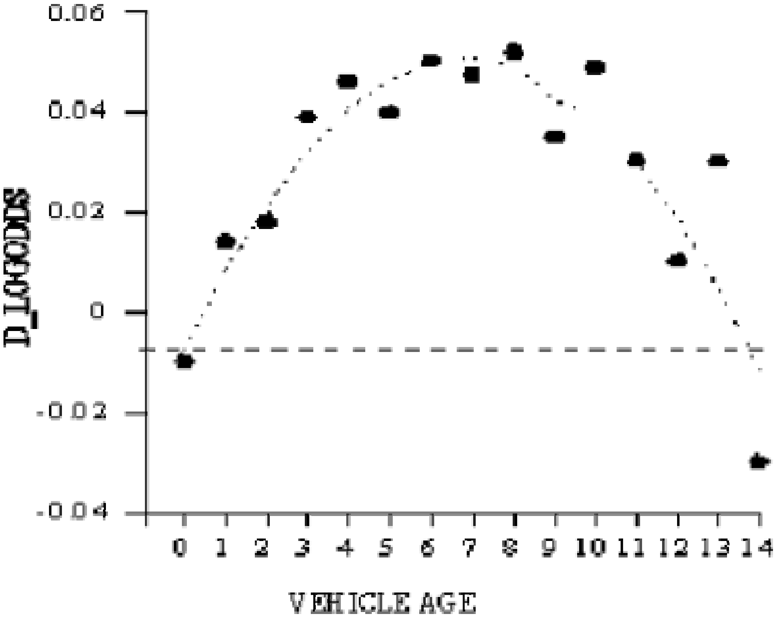


TABLE 2-2
AVERAGE ACTUAL, CALIBRATED, AND RESIDUAL
VEHICLE AGE EFFECTS, FLORIDA 1986-95, CARS 0-14 YEARS OLD

Vehicle Age	N of Data Points	Average Actual Effect	Calibrated Effect	Residual
0	9	-0.011171	-0.007340	-0.003831

1	9	0.014120	0.008358	0.005762
2	9	0.017858	0.021592	-0.003734
3	9	0.037430	0.032362	0.005068
4	9	0.045276	0.040668	0.004608
5	9	0.039002	0.046510	-0.007508
6	9	0.050363	0.049888	0.000475
7	9	0.048819	0.050802	-0.001983
8	9	0.051087	0.049252	0.001835
9	9	0.033252	0.045238	-0.011986
10	10	0.047401	0.038760	0.008641
11	10	0.030073	0.029818	0.000255
12	10	0.009004	0.018412	-0.009408
13	10	0.030862	0.004542	0.026320
14	10	-0.027553	-0.011792	-0.015761

FIGURE 2-5
DIFFERENCE BETWEEN THE CALIBRATED
AND THE OBSERVED VEHICLE AGE EFFECT
FLORIDA 1986-95, CARS 0-14 YEARS OLD

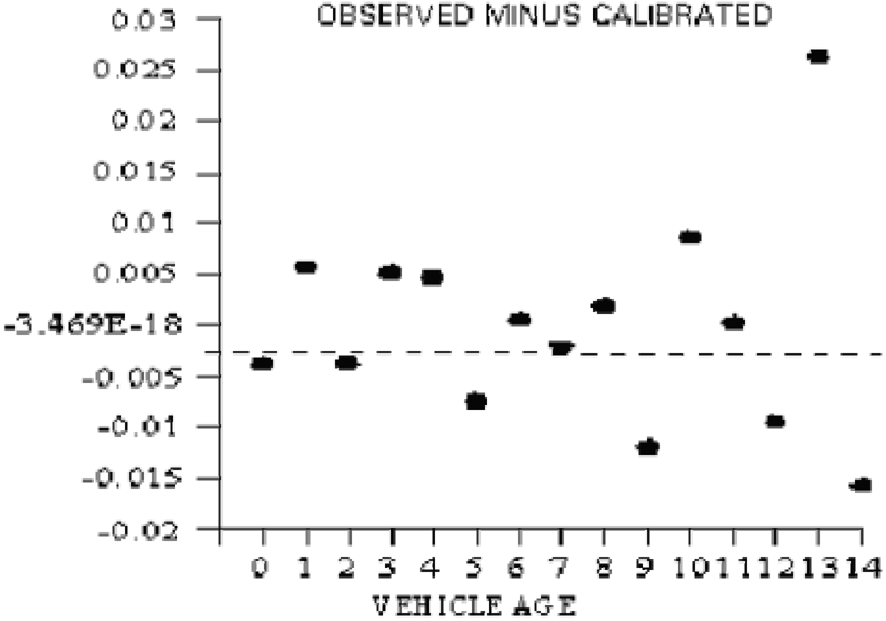


TABLE 2-3
VEHICLE AGE EFFECT BY STATE: REGRESSION EQUATION AND
CALIBRATED VALUES FOR CARS AGE 0, 5 AND 10

	Regression Equation	Calibrated Value at Age =			
			0	5	10
Florida	d_logodds = - .00734 + .01693 vehage - .001232 vehage^2	-.007	+.047	+.039	

Indiana	d_logodds = +.03380 - .00059 vehage - .000174 vehage^2	+.034	+.027	+.011
Maryland	d_logodds = +.00270 + .00786 vehage - .000607 vehage^2	+.003	+.027	+.021
Missouri	d_logodds = +.02698 + .00753 vehage - .000714 vehage^2	+.027	+.047	+.031
Pennsylvania	d_logodds = - .00493 + .01471 vehage - .001092 vehage^2	- .005	+.041	+.033
Texas	d_logodds = +.00465 + .00717 vehage - .000589 vehage^2	+.005	+.026	+.017
Utah	d_logodds = +.02908 - .00215 vehage	+.029	+.018	+.008
Virginia	d_logodds = +.01788 + .00571 vehage - .000539 vehage^2	+.018	+.033	+.021

differences, demographic or socioeconomic factors, etc. In any case, it is clear that the vehicle age effect is not uniform from State to State, and it is appropriate to perform the next steps of the analysis separately in each State.

2.4 Computation of the preliminary effectiveness estimates

The "preliminary" effectiveness estimate is the average reduction in the age-adjusted log odds of a rear impact for an MY 1986 or later car relative to a pre-1986 car, as calculated from the tabulated data by the procedure described in this section. Later, in Section 2.6, the preliminary estimates will transformed to "final" estimates by converting the log odds ratios back to odds ratios and correcting for: pre-1986 cars retrofitted with CHMSL, miscoded vehicle types, miscoded model years. A "preliminary" estimate is calculated separately for each calendar year in each State, based on statistics derived from the crash experience of MY 1982-89 passenger cars in that calendar year - i.e., cars of the last four MY before CHMSL vs. cars of the first four MY with CHMSL. Florida data from CY 1992 will be used throughout this section to illustrate the computational process.

The starting point for this process is the tabulation, by impact location and model year, of actual crash records of MY 1982-89 cars. The log odds of a rear impact is calculated in each model year. The tabulation for 1992 Florida data is an excerpt from Table 2-1:

REAR IMPACT?						
MODEL YEAR	**Frequency** **Row Pct**	**NO**	**YES**	**Total**	**LOGODDS**	
		82	8629 80.22	2128 19.78	10757	-1.400
		83	10181 79.84	2571 20.16	12752	-1.376
		84	14318	3949	18267	-1.288

			78.38	21.62		
		85	14981 77.14	4439 22.86	19420	-1.216
		86	16423 77.50	4768 22.50	21191	-1.237
		87	16944 76.98	5068 23.02	22012	-1.207
		88	17452 76.38	5396 23.62	22848	-1.174
		89	16018 75.76	5125 24.24	21143	-1.140

The percent of rear impacts escalates steadily from MY 82 to 89, and the log odds of a rear impact becomes steadily less negative, except for a brief interruption in MY 1986, the year cars got CHMSL. Figure 2-6 graphs these unadjusted log odds, indicated by "U," and it clearly shows how the vehicle age effect, over the years, is much stronger than the effect of CHMSL. (The vertical line between MY 85 and 86 indicates the effective date of CHMSL, and the U's jog slightly down from their otherwise upward trend.)

The next step is to adjust each of the log odds for the vehicle age effect. The regression equation of the preceding section estimated an "age effect" that is in fact the year-to-year **change** in the log odds as a function of vehicle age. In Florida, for a j-year-old car, the estimated age effect is:

$$\text{D\_LOGODDS} = -\ .00734 + .01693\ j - .001232\ j^{2}$$

The cumulative vehicle age effect for a j-year-old car is the integral, from 0 to j, of that function:

$$\text{adjusted logodds} = \text{actual logodds} - .00734\ j + \tfrac{1}{2}\ (.01693\ j^{2}) - (.001232\ j^{3})$$

In other words, the cumulative adjustment factor tells us what the log odds of a rear impact would have been if the cars were brand new (0 years old) instead of j years old. The actual and adjusted log odds in the 92 Florida data are:

Model Year	Vehicle Age	Actual Log Odds	Cumulative Age Adjustment	**Adjusted Log Odds**
82	10	-1.3999	.3624	**-1.0375**
83	9	-1.3762	.3200	**-1.0560**
84	8	-1.2881	.2728	**-1.0153**
85	7	-1.2164	.2226	**-0.9938**
86	6	-1.2368	.1720	**-1.0648**
87	5	-1.2070	.1236	**-1.0834**

88	4	-1.1738	.0798	**-1.0940**
89	3	-1.1396	.0431	**-1.0965**

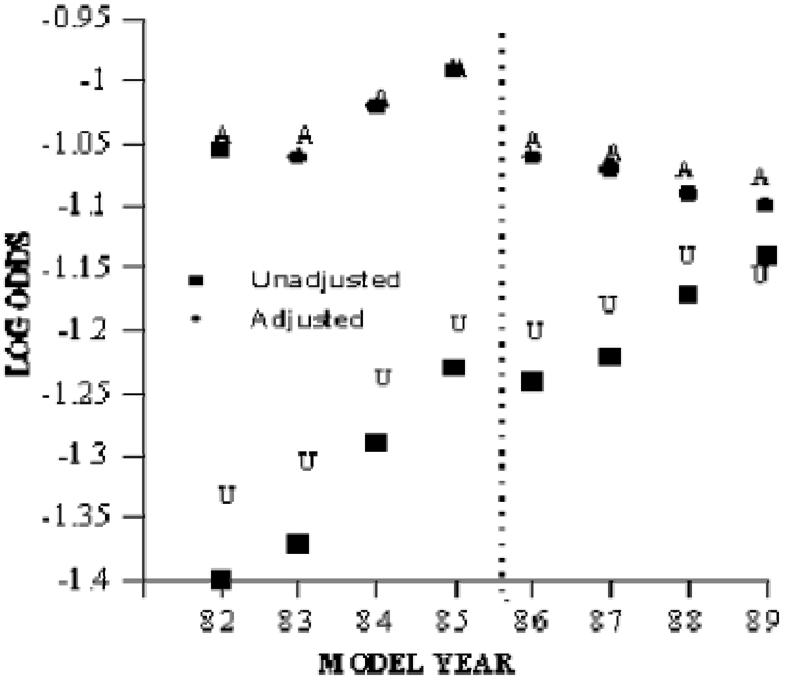
Figure 2-6 graphs the adjusted log odds, indicated by "A." The adjustment more or less flattens out the effect of vehicle age and highlights the effect of CHMSL. All four of the MY 86-89 values are more negative than any of the MY 82-85 values. Give or take some residual noise, the adjusted log odds with CHMSL (MY 86-89) are all close to -1.08, while without CHMSL (MY 82-85) they are close to -1.02, suggesting a reduction of rear impacts by something close to 6 percent with CHMSL.

The last step in this portion of the analysis is to define a composite statistic CHMSLAVG derived from the eight adjusted log-odds numbers that will serve as **the** preliminary estimate of CHMSL effectiveness. Let:

AVG(- 1) = ADJODDS(85) = -0.9938

AVG(+1) = ADJODDS(86) = -1.0648

FIGURE 2-6
LOG ODDS OF A REAR IMPACT - BEFORE AND AFTER ADJUSTMENT FOR VEHICLE AGE
1992 FLORIDA CRASHES, MODEL YEAR 1982-89 PASSENGER CARS
(U = UNADJUSTED, A = ADJUSTED FOR VEHICLE AGE)



AVG(- 2) = ½ [ADJODDS(84) + ADJODDS(85)] = -1.0045

AVG(+2) = ½ [ADJODDS(86) + ADJODDS(87)] = -1.0741

AVG(- 3) = [ADJODDS(83) + ADJODDS(84) + ADJODDS(85)] = -1.0217

AVG(+3) = [ADJODDS(86) + ADJODDS(87) + ADJODDS(88)] = -1.0807

AVG(- 4) = ¼ [ADJODDS(82) + ADJODDS(83) + ADJODDS(84) + ADJODDS(85)] = -1.0257

AVG(+4) = ¼ [ADJODDS(86) + ADJODDS(87) + ADJODDS(88) + ADJODDS(89)] = -1.0847

CHMSL1 = AVG(- 1) - AVG(+1) = .07095

CHMSL2 = AVG(- 2) - AVG(+2) = .06953

CHMSL3 = AVG(- 3) - AVG(+3) = .05902

CHMSL4 = AVG(- 4) - AVG(+4) = .05901

CHMSLAVG = ¼ [CHMSL1 + CHMSL2 + CHMSL3 + CHMSL4] = .06463

In other words, the effect of CHMSL in 1992 Florida data is about 6.5 percent. CHMSL1 is a simple comparison of the MY 86 and 85 adjusted log odds: first year with CHMSL vs. last year without CHMSL. CHMSL2 compares the arithmetic average of the adjusted log odds for the first two MY with CHMSL to the corresponding average for the last two MY without CHMSL, etc. CHMSLAVG is an unweighted arithmetic average of CHMSL1, CHMSL2, CHMSL3 and CHMSL4, but it does **not** give equal weight to each of the model years. Since MY 85 and 86 data are used to compute all of CHMSL1, but also contribute part to CHMSL2, CHMSL3 and CHMSL4, they have a higher net contribution to CHMSLAVG than MY 82 and 89 data, which only are used in computing CHMSL4. The relative weights of the model years are:

MY 85 and 86: 25 parts

MY 84 and 87: 13

MY 83 and 88: 7

MY 82 and 89: 3

Although CHMSLAVG is **the** estimate of CHMSL effectiveness in this report, it is, of course, just one of the many statistics that could have been chosen for that purpose. It would have been possible to consider a wider range of model years (as in NHTSA's 1989 evaluation [19], p. 15), or a narrower one, or even limit the analysis to a comparison of MY 86 vs. 85, as Farmer did [9]; the various model years could have been given different weights than the above, or even given equal weights. Many statistics will produce unbiased estimates, but some may be more reliable than others. CHMSLAVG was selected because it offers an intuitively good balance between concentrating on MY 85 and 86, where the effect of CHMSL is least diluted by other factors that might have become involved over time, and extending the comparison to adjacent model years to increase the sample of data included in the analysis.

Another issue is whether or not to include all make-models. Farmer included only those make-models that did not undergo a redesign at the time they received CHMSL [9]. In a way, that is ideal, but it does cut down on available data, especially in State files where the make-model is often unknown (Farmer did not analyze State files, but insurance data, where make-models are known). It can be reasoned, however, that the inclusion of all make-models will neutralize biases that may occur in individual make-models that were redesigned. For example, if a certain model became much more sporty in 1986, it might attract more aggressive drivers and it will have proportionately fewer rear impacts. However, the less aggressive drivers who chose this model before 1986 will eventually buy some other car; thus, while aggressiveness may vary from year to year on individual models, it probably changes little from one model year to the next in the entire passenger car fleet.

CHMSLAVG was computed separately for every State, in every calendar year, always relying on the MY 82-89 crash statistics. The formulas need to be modified, however, in the CY 86, 87 and 88 analyses, since data are not available for the later model years (e.g., MY 87-89 in CY 86). In those years, the CHMSL-equipped average log-odds are based only on the model years that are available. In CY 86,

$$AVG(+1) = AVG(+2) = AVG(+3) = AVG(+4) = ADJODDS(86)$$

In CY 87, AVG(+1) = ADJODDS(86) and

$$AVG(+2) = AVG(+3) = AVG(+4) = \frac{1}{2} [ADJODDS(86) + ADJODDS(87)]$$

In CY 88, AVG(+1) = ADJODDS(86), AVG(+2) = ½ [ADJODDS(86) + ADJODDS(87)], and

$$AVG(+3) = AVG(+4) = [ADJODDS(86) + ADJODDS(87) + ADJODDS(88)]$$

Table 2-4 shows the preliminary effectiveness estimates for each State and calendar year. As explained above, no estimate could be made for 1986 Virginia data. Whereas a detailed statistical analysis of the findings, including computation of averages and significance tests, will only be performed on the "final" effectiveness estimates in Section 2.6, two phenomena are immediately apparent from Table 2-4. The estimates are almost all positive: of 79 individual numbers, only 2 are negative, and even those are barely below zero. The effect in CY 1987 is consistent across States (6 to 10 percent) and it is almost always higher than the effects in subsequent years.

2.5 Tests for spurious effectiveness before MY 1985 and after MY 1986

Although the preliminary estimates are almost uniformly positive, the somewhat complex model for calculating effectiveness might engender concerns about possible hidden biases. It is appropriate to test that this model does **not** find spurious differences in rear-impact crashes among groups of vehicles that ought not be different. It is especially appropriate given that the "vehicle age effect" has been critiqued as an unwarranted inflator of the CHMSL effectiveness estimates [8], [33]. As in NHTSA's 1989 evaluation of CHMSL [19], pp. 19-20 and Farmer's study [9], the test consists of applying the model to compare cars of two different model years with the **same** CHMSL status - e.g., MY 1984 vs. 1985 (neither CHMSL-equipped) or MY 1986 vs. 1987 (both CHMSL-equipped).

TABLE 2-4
PRELIMINARY CHMSL EFFECTIVENESS ESTIMATES BY STATE AND CALENDAR YEAR
(After correction for the "vehicle age effect," but prior to adjustments
for pre-1986 retrofits and vehicle type/model year miscoding)

	Florida	Indiana	Maryland	Missouri	Pennsylvania	Texas	Utah	Virginia
1986	.0134	.0645	.0835	.0677	.0660	.0281	.0504	.
1987	.0734	.0643	.0989	.0807	.0855	.0728	.0714	.0606
1988	.0623	.0389	.0470	.0498	.0637	.0707	.0658	.0881

1989	.0407	.0442	.0577	.0465	.0010	.0317	.1451	.0594
1990	.0665	.0425	.0343	.0321	.0421	.0411	.0589	.0514
1991	.0412	.0195	.0064	.0653	.0460	.0533	.1133	.0366
1992	.0646	.0529	.0254	.0444	.0437	.0358	.0018	.0399
1993	.0243	- .0075	- .0135	.0040	.0443	.0413	.0360	.0459
1994	.0255	.0334	.0270	.0365	.0044	.0465	.0048	.0427
1995	.0411	.0163	.0682	.0227	.0287	.0220	.0596	.0597

In particular, we will compute the average of the difference in the vehicle-age-adjusted log odds of a rear impact for four pairs of model years: 1983 vs. 84, 1984 vs. 85, 1986 vs. 87 and 1987 vs. 88. (Of course, we omit the 1985 vs. 86 comparison because that was the year in which cars did change their CHMSL status.) Again, Florida data from CY 1992 will be used to illustrate the computational process. Let:

DEL8384 = ADJODDS(83) - ADJODDS(84) = -1.0560 - (- 1.0153) = - .0407

DEL8485 = ADJODDS(84) - ADJODDS(85) = -1.0153 - (- 0.9938) = - .0215

DEL8687 = ADJODDS(86) - ADJODDS(87) = -1.0648 - (- 1.0834) = +.0186

DEL8788 = ADJODDS(87) - ADJODDS(88) = -1.0834 - (- 1.0940) = +.0106

DELAVG = ¼ [DEL8384 + DEL8485 + DEL8687 + DEL8788] = - .0082

In other words, after correcting for the vehicle age effect, the log-odds of a rear impact increased by 4 percent from MY 83 to 84 and by 2 percent from 84 to 85; however it decreased by 2 percent from 86 to 87 and by 1 percent from 87 to 88. On the average, after controlling for the vehicle age effect, the log odds of a rear impact **increased** by 0.8 percent per year in the model years where CHMSL status did not change. That is a rather trivial change relative to the 6.5 percent **reduction** that the model attributes to CHMSL in the 1992 Florida data (CHMSLAVG), and moreover, it is in the opposite direction. In 1992 Florida data, the computational methods of this model, including the adjustment for the vehicle age effect, do not spuriously show a positive effect when CHMSL status did not change; therefore, it may be inferred that the positive effect associated with CHMSL is not inflated with biases introduced by the computational method.

The preceding formulas need to be modified in the CY 86 and 87 analyses, since data are not available for the later model years. In CY 86, DELAVG = ½ [DEL8384 + DEL8485]; and in CY 87, DELAVG = [DEL8384 + DEL8485 + DEL8687].

DELAVG, the measure of spurious effectiveness generated by our model, is computed separately in every State file, in every calendar year, as shown in Table 2-5. In 45 of 79 cases, DELAVG has absolute value less than 1 percent (i.e., it is between -.01 and +.01): essentially trivial, in practical terms, because the CHMSL effectiveness is usually around

+5 percent. However, even those cases where DELAVG exceeds 1 percent do not necessarily suggest that the method for computing effectiveness is biased. Every statistic in this report, including DELAVG, is derived from tabulations of finite numbers of crash records and as such is subject to "noise." Individual values can be expected to deviate randomly from what they "ought" to be (zero, in the case of DELAVG). Each individual value of DELAVG need not be close to zero, but it is important that the **average** value of DELAVG converge on zero.

A simple, nonparametric test of whether DELAVG diverges from zero is to note that 44 of the 79 observed values are negative and 35 are positive. This result is well within the acceptance region for a binomial distribution with p = .5 and two-sided = .05. Only if we had seen at least 49 negatives [or positives] would we have rejected the null hypothesis that DELAVG is equally likely to be positive or negative.

TABLE 2-5
TESTS FOR SPURIOUS "EFFECTIVENESS" IN MODEL YEARS WHERE CHMSL STATUS DID NOT CHANGE

(Average annual reduction in the log odds of a rear impact from MY 83 to 85 and from MY 86 to 88
- when cars' CHMSL status remained the same - after correction for the "vehicle age effect")

8 State Pop-Wtd

	Florida	Indiana	Maryland	Missouri	Pennsylvania	Texas	Utah	Virginia	**Average**	**t-test**
1986	- .0083	.0037	.0070	- .0071	- .0122	.0053	- .0222	.	**- .0031**	**- .92**
1987	- .0123	.0029	- .0310	- .0318	- .0275	.0154	- .0215	- .0110	**- .0096**	**-1.43**
1988	.0005	.0033	.0206	.0017	.0023	.0103	- .0005	.0086	**.0060**	**2.75***
1989	.0071	.0058	.0057	.0179	.0055	.0087	- .0281	.0222	**.0084**	**2.77***
1990	.0066	- .0204	.0091	.0201	.0149	.0005	- .0141	.0055	**.0048**	**1.23**
1991	.0039	- .0147	- .0045	.0000	- .0036	.0007	- .0201	- .0056	**- .0023**	**-1.06**
1992	- .0082	- .0314	.0045	- .0068	- .0074	- .0085	- .0050	- .0112	**- .0093**	**-3.23***
1993	.0307	.0034	- .0081	- .0029	- .0170	- .0030	.0115	.0014	**.0021**	**.36**
1994	- .0044	- .0263	- .0256	- .0243	.0046	- .0020	- .0096	- .0005	**- .0069**	**-1.68**
1995	.0016	- .0227	- .0385	- .0157	- .0242	- .0053	- .0264	- .0151	**- .0139**	**-3.01***
10 Year										
Average	**.0017**	**- .0096**	**- .0061**	**- .0049**	**- .0065**	**.0022**	**- .0136**	**- .0006**	**- .0023**	
t-test	**.67**	**-2.05**	**- .99**	**- .94**	**-1.49**	**.93**	**-3.40***	**- .16**		**-1.59**

*Statistically significant difference from zero (two-sided p < .05)

To compute a meaningful average of the 79 values of DELAVG, States that contribute more data ought to be given a higher weight. The 1990 population is a readily available statistic, and it is intuitively well correlated with on-the-road exposure, since our eight States do not differ greatly in per capita vehicle ownership, mileage, etc. These populations were:

Florida	13,003,000	Pennsylvania	11,862,000
Indiana	5,564,000	Texas	17,060,000
Maryland	4,799,000	Utah	1,728,000
Missouri	5,138,000	Virginia	6,217,000

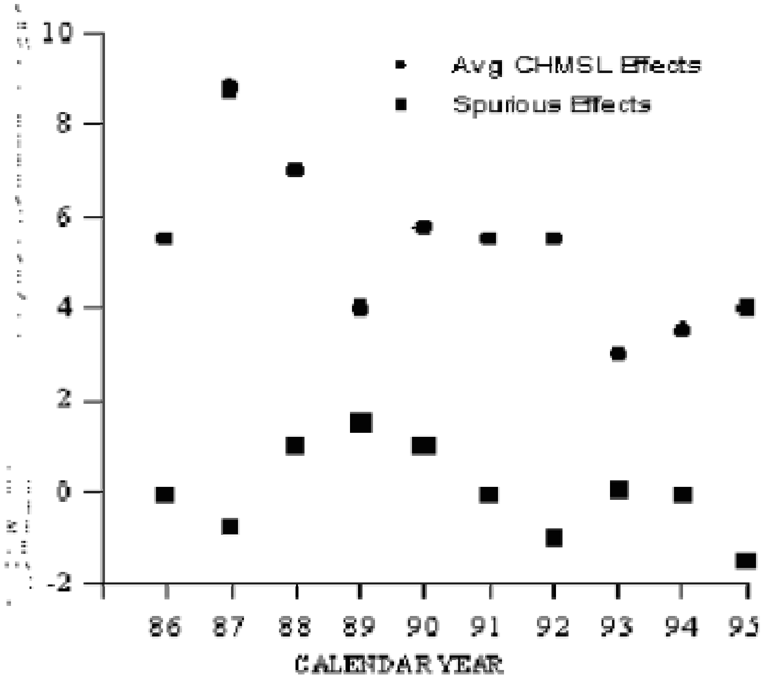
The population-weighted average of the 79 observations of DELAVG is -.0023, as shown in the lower right-hand corner of Table 2-5. For all practical purposes, this average bias is essentially zero, given that the average effect of CHMSL is on the order of +.0500. A standard deviation and t-test for those 79 weighted numbers can be obtained by running the General Linear Model (GLM) procedure of the Statistical Analysis System (SAS) [32] with DELAVG as the dependent variable, no independent variables, 1990 population as the weight factor, and exercising the "INT" option to obtain statistics on the intercept. Table 2-5 shows this t-value is -1.59, and it implies that, given the noise in the 79 individual values, their average is not significantly different from zero.

In addition to a nonsignificant overall average, DELAVG should ideally not be significant within any State or within any calendar year, and there ought not be significant differences between States or between calendar years. DELAVG comes close to achieving that ideal within and between States. The two last rows of Table 2-5 show the 10-year average values (in Virginia, 9-year average) in each State, and the t-test result. Only Utah has an average with absolute value greater than 1 percent, and only Utah's average is significantly different from zero ($p < .05$); however, one "significant" result in eight tests could easily happen by chance alone. Also, the GLM procedure can be used to run, essentially, analyses of variance on the population-weighted DELAVG values: the differences between the States are nonsignificant in a univariate analysis ($F = 1.49$; df = 7,71; $p > .05$). The State effect is likewise nonsignificant in a bivariate analysis including the CY variable ($F = 1.98$; df = 7,62; $p > .05$).

DELAVG is a bit less close to achieving that ideal within and between CY. The two right columns of Table 2-5 show the 8-State average values (in 1986, 7-State average) in each CY, and the t-test result. Four of the ten averages are significantly different from zero ($p < .05$), two positive and two negative. In the analyses of variance based on GLM, the CY effect achieves significance in a univariate analysis ($F = 3.27$; df = 9,69; $p < .05$) as well as in a bivariate analysis including the State variable ($F = 3.59$; df = 9,62; $p < .05$). Another indication of the model's slight misfit is that DELAVG is rather consistently negative in Indiana, Maryland, Missouri and Texas in the later years. Nevertheless, all of these biases are fairly trivial. Figure 2-7 graphs the 8-State average values of DELAVG (represented by the O's) by calendar year, on the same scale as the best estimates of CHMSL effectiveness that will be defined in the next section (represented by the 's).

DELAVG is always much closer to zero than the effect of CHMSL. The 8-State average of DELAVG is less than 1 percent in every CY except 1995 - and in that year it is still only -1.4 percent. Also, unlike the results for some individual States, the 8-State average goes back and forth between positive and negative throughout 1986-95 in a sine-wave pattern of low amplitude.

FIGURE 2-7
AVERAGE CHMSL EFFECTIVENESS IN EIGHT STATES ()
PASSENGER CARS, BY CALENDAR YEAR
(Percent reduction in the risk of a police-reported rear impact)
SPURIOUS "EFFECTIVENESS" IN MY WHERE THE CHMSL STATUS DID NOT CHANGE (O)



2.6 Adjusting the estimates for retrofits and other factors

The preceding discussion hopefully demonstrated that the "vehicle age effect" has been properly accounted for and factored into the model. We now return to the computation of the effectiveness of CHMSL. The preliminary estimates in Table 2-4 are average reductions in the age-adjusted log odds of a rear impact for an MY 1986 or later car relative to a pre-1986 car. However, the customary definition of "effectiveness, " as discussed, for example, in Section 2.2 ("The Basic Contingency Table") is a reduction E_1 in the probability of a rear impact, not the reduction E_0 in the log-odds. The formula to derive E_1 from E_0 is:

$$E_1 = 1 - \exp (-1^* E_0)$$

For example, in the 1992 Florida data, $E_0 = .0646$, as shown in Table 2-4, and $E_1 = .0626$. Whenever E_0 is relatively small, E_0 and E_1 are practically identical, but as E_0 increases the shortfall of E_1 relative to E_0 gradually escalates. When $E_0 = .1$, which is about as high as it gets in Table 2-4, $E_1 = .0952$.

Section 2.1 pointed out that a vehicle's model year is occasionally miscoded in State data files. Approximately 1.1 percent of the cars coded MY 82-85 are in fact MY 86 and they are CHMSL equipped. Conversely, 1.1 percent of the cars coded MY 86-89 are in fact MY 85 and they are not CHMSL equipped. Thus, E_1 measures the reduction in rear impacts for a fleet that is 98.9 percent CHMSL-equipped relative to a fleet that is 1.1 percent CHMSL equipped. What we really want is E_2, the reduction for a 100 percent CHMSL fleet relative to a fleet with no CHMSL at all. Because $1 - E_1 = [.011 + .989 (1 - E_2)] / [.989 + .011 (1 - E_2)]$,

$$E_2 = E_1 / (.978+.011*E_1)$$

In the 1992 Florida data, $E_1 = .0626$ and $E_2 = .0639$. This is a small upward adjustment that more or less compensates for the earlier one.

Section 2.1 also pointed out that the vehicle type is occasionally miscoded. Approximately 3.7 percent of the MY 82-89 vehicles coded as "passenger cars" are in fact light trucks or other vehicles, and did not have CHMSL even if MY 86. Thus, E_2 in fact only measures the reduction in rear impacts for a fleet that is 96.3 percent CHMSL-equipped relative to a fleet with no CHMSL. What we really want is E_3, the reduction for a 100 percent CHMSL fleet relative to a fleet with no CHMSL. Because $1 - E_2 = .037 + .963 (1 - E_3)$,

$$E_3 = E_2 / .963$$

In the 1992 Florida data, $E_2 = .0639$ and $E_3 = .0664$. This is a slightly larger upward adjustment.

Finally, Section 2.1 mentioned that approximately 10 percent of MY 82-85 cars were retrofitted with aftermarket CHMSL. Thus, E_3 in fact only measures the reduction in rear impacts for a fleet that is 100 percent CHMSL-equipped relative to a fleet that is 10 percent CHMSL-equipped. What we really want is E_4, the reduction for a 100 percent CHMSL fleet relative to a fleet with no CHMSL. Because $1 - E_3 = [1 - E_4] / [.9 + .1 (1 - E_4)]$,

$$E_4 = E_3 / (.9 + .1*E_3)$$

In the 1992 Florida data, $E_3 = .0664$ and $E_4 = .0732$. This is the largest of the upward adjustments, but even this one does not result in a dramatic change from the preliminary estimate.

E_4, the "best" estimate of the reduction in rear impacts attributed by our model to CHMSL, is computed separately in every State file, in every calendar year, as shown in Table 2-6. Unlike the numbers in Table 2-5, these estimates are positive in 77 of 79 cases. The population-weighted average of the 79 estimates is 5.11 percent. Ten-year averages were calculated in each of the eight States, and they are remarkably consistent, ranging from 4.22 percent in Indiana to 6.78 percent in Utah; the averages for the other six States vary only from 4.84 (Pennsylvania) to 6.12 percent (Virginia).

A population-weighted 8-State average is computed for each calendar year and shown on the right side of Table 2-6. Effectiveness is positive in every year, but there is substantial variation, from 3.18 percent in CY 1993 to 8.53 percent in CY 1987. Figure 2-7 graphs the 8-State average effectiveness by calendar year ('s). Several phenomena are immediately visible from the graph: (1) Effectiveness is always well above zero. (2) The effectiveness is clearly higher in CY 1987 and 1988 than in 1986 or 1989-95. (3) Effectiveness is more or less the same throughout 1989-95, with no clear pattern during those years. By the naked eye alone, it is hard to discern whether effectiveness was essentially constant during 1989-95 or if there was a slight decreasing trend within those years. According to the lower section of Table 2-6, the population-weighted average effectiveness for 1989-95 was 4.33 percent, and it was positive in each individual State, ranging from 3.30 (Indiana) to 6.65 percent (Utah).

2.7 Confidence bounds and statistical tests - based on State-to-State and CY-to-CY variation of the effectiveness estimates

Even a cursory perusal of Table 2-6 suggests that CHMSL have had a significant benefit in every year since their 1986 introduction. Computation of variances enables us to provide confidence bounds for the estimates and test the extent to which effectiveness has changed over time. The computation method in this section relies directly on the 79 individual effectiveness estimates by State and CY in Table 2-6, treating them as if they were simply repeated observations of a single variate. In fact, however, these estimates are statistics derived from fairly complex estimation formulas including an adjustment for vehicle age. Additionally, the vehicle age adjustment formula is derived just once in each State, combining data from all the CY for that State; thus, the CHMSL effectiveness estimates within each State are not fully independent from one CY to another, to the extent that they employ shared data in the computation of the age adjustment. The customary critical values of t, intended for use with simple, fully independent variates, may

TABLE 2-6: CHMSL EFFECTIVENESS ESTIMATES BY STATE AND CALENDAR YEAR, 1986-95
(Corrected for the "vehicle age effect," pre-1986 retrofits and vehicle type/model year miscoding)

8 State Pop-Wtd

	Florida	Indiana	Maryland	Missouri	Pennsylvania	Texas	Utah	Virginia	**Average**	**t-test**

1986	.0156	.0731	.0935	.0765	.0747	.0325	.0575	.	**.0506**	**4.57***
1987	.0828	.0729	.1098	.0905	.0956	.0821	.0806	.0689	**.0853**	**21.64***
1988	.0707	.0448	.0538	.0569	.0722	.0799	.0746	.0984	**.0716**	**13.81***
1989	.0468	.0507	.0656	.0533	.0012	.0366	.1566	.0675	**.0430**	**4.07***
1990	.0752	.0489	.0396	.0371	.0484	.0472	.0670	.0587	**.0534**	**11.41***
1991	.0474	.0227	.0075	.0740	.0527	.0608	.1246	.0421	**.0505**	**6.46***
1992	.0732	.0603	.0295	.0509	.0502	.0413	.0021	.0459	**.0502**	**8.77***
1993	.0282	- .0089	- .0161	.0047	.0509	.0475	.0416	.0526	**.0318**	**3.61***
1994	.0296	.0385	.0314	.0421	.0052	.0533	.0057	.0490	**.0344**	**5.25***
1995	.0473	.0190	.0771	.0264	.0332	.0256	.0678	.0679	**.0397**	**5.87***
10 yr. avg.	**.0517**	**.0422**	**.0492**	**.0513**	**.0484**	**.0507**	**.0678**	**.0612**	**.0511**	
t-test	**7.11***	**5.22***	**4.01***	**6.38***	**5.19***	**8.48***	**4.52***	**10.71***		**18.08***
89-95 avg.	**.0496**	**.0330**	**.0335**	**.0412**	**.0345**	**.0446**	**.0665**	**.0548**	**.0433**	
t-test	**7.04***	**3.67***	**2.78***	**4.98***	**4.08***	**10.29***	**3.05***	**14.21***		**15.06***

*Statistically significant difference from zero (two-sided p < .05)

not be entirely appropriate for these statistics, and as a result the confidence bounds and levels of significance calculated in this section might understate the uncertainty in the results.

The average of the 79 effectiveness estimates, weighted by the States' 1990 populations, is .0511. A standard deviation and t-test for those 79 weighted numbers can be obtained by running the GLM procedure of SAS with no independent variables and 1990 population as the weight factor, as explained in Section 2.5. The standard deviation is .00282; the t-value is 18.08, as shown in Table 2-6. Effectiveness is significantly higher than zero (p < .05); in fact, p < .0001 - the t-value is very large compared to significance levels normally seen in NHTSA evaluations of crash data.

Moreover, as shown in Table 2-6:

The population-weighted 8-State average effectiveness is statistically significant in each individual calendar year, with t-values ranging from 3.61 (1993) to 21.64 (1987).

The average effectiveness for CY 1989-95, 4.33 percent, is statistically significant, with a t-value of 15.06

The 10-year average effectiveness is statistically significant in each of the eight individual States, with t-values ranging from 4.52 (Utah) to 10.71 (Virginia).

The 1989-95 average is positive and statistically significant in each of the eight individual States, with t-values in the other States ranging from 2.78 (Maryland) to 14.21 (Virginia).

The GLM procedure can be used to run, essentially, analyses of variance on the population-weighted effectiveness estimates to check for significant differences **between** States or **between** calendar years. A glance at Table 2-6 shows few differences between States. Analyses of variance confirm that impression. The differences between the States are nonsignificant in a univariate analysis (F = 0.42; df = 7,71; p > .05). The State effect is likewise nonsignificant in a bivariate analysis including the CY variable (F = 0.63; df = 7,62; p > .05).

Table 2-6 and Figure 2-7 show strong differences between calendar years 1987, 1988 and 1989-95, but relatively little change from 1989 to 1995. Again, analyses of variance confirm the visible differences and clarify what is going on during 1989-95.

Let us look first at the effectiveness estimates from CY **1989-95 only**: 56 effectiveness estimates from eight States. We have a choice of entering CY in the GLM procedure as a categorical or a linear independent variable. With CY as a categorical variable, the analysis merely asks if the average differences between calendar years are larger than expected given the "noise" in the 56 estimates. They are not: the categorical CY effect is nonsignificant in a univariate analysis (F = 1.26; df = 6,49; p > .05) as well as in a bivariate analysis including the State variable (F = 1.20; df = 6,42; p > .05).

The "eyeball" inspection of Figure 2-7 suggested that just maybe, but not necessarily, effectiveness was declining toward the end of the 1989-95 period. With CY as a linear variable, the analysis tests whether that trend is significant. In fact, the linear CY effect falls short of significance in a univariate analysis (F = 2.82; df = 1,54; p > .05) as well as in a bivariate analysis including the State variable (F = 2.89; df = 1,47; p > .05).

With these results, we may accept the null hypothesis that CHMSL effectiveness stayed about the same throughout CY 1989-95. The conclusion is more tentative than any other in this report, partly because acceptance of the null hypothesis is by definition more tentative than rejection, partly because the linear CY effects, although short of significance, were "not that far away from it" (an F value of 4 would have been significant with two-sided = .05). It is concluded that the 1989-95 average effectiveness of 4 percent is the "long-term" value that will persist into the future, but it cannot be ruled out, based on the results of this chapter alone, that effectiveness could continue to decline quite slowly (the nonsignificant regression coefficient for CY was -.0024, i.e., a continuing decline of ¼ percent per calendar year). Additional evidence that CHMSL effectiveness is **not** declining comes from Chapter 4, which will show a 4.2 percent effectiveness for light truck CHMSL **in CY 1994-96**: actually higher than the car CHMSL effect in 1993, 1994 or 1995. The issue will be discussed in more detail in Chapter 4.

If we accept that CHMSL effectiveness was essentially unchanged throughout CY 1989-95, and that the long-term reduction of rear impacts is 4 percent, we may proceed to compare the 1989-95 effect with the results for earlier calendar years. The question, "Did CHMSL effectiveness change significantly over time?" is addressed by defining a variable CY_group with four categories: 1986, 1987, 1988 and 1989-95. When GLM analyses of variance are performed on the 79 effectiveness estimates in Table 2-6, the effect of CY_group is statistically significant in a univariate analysis (F = 12.18; df = 3,75; p < .05) as well as in a bivariate analysis including the State variable (F = 11.74; df = 3,68; p < .05). Effectiveness definitely changed over time.

In addition, we may compare the effectiveness in any two CY_groups, by doing the GLM univariate analysis of variance on the effectiveness estimates from those two groups:

In CY 1987, the average effectiveness of CHMSL was 8.53 percent and in 1989-95, 4.33 percent. Is that a significant decline? Definitely: in the analysis of the 64 data points with CY_group = 87 or 89-95, (F = 29.14; df = 1,62; p < .05).

In CY 1988, the average effectiveness of CHMSL was 7.16 percent and in 1989-95, 4.33 percent. This is also a significant decline: (F = 12.91; df = 1,62; p < .05).

The 8.53 percent effectiveness in CY 1987 is borderline-significantly higher than the 7.16 percent in CY 1988: (F = 4.43; df = 1,14; one-sided p < .05).

The 8.53 percent effectiveness in CY 1987 is significantly higher than the 5.06 percent in CY 1986: (F = 9.60; df = 1,13; p < .05).

The final step of the analysis is to develop confidence bounds (two-sided = .05) for the four principal effectiveness estimates: for CY 1986, 1987, 1988 and 1989-95. The empirical approach is to obtain them directly from the 79 individual effectiveness estimates by State and CY in Table 2-6. The GLM procedure of SAS, run with no independent variables, allows calculation of the standard deviation of the population-weighted average effectiveness in any calendar year or group of calendar years. Although there are some departures from homoscedasticity and normality in the Table 2-6 estimates (different-size States, slightly nonlinear adjustment factors) it still appears safe to use the customary critical values of the t distribution, especially if we extend to a two-sided 95 percent confidence interval rather than the one-sided 95 percent interval generally used in NHTSA evaluations. For example, in CY 1987, there are estimates from all eight States. The population-weighted average effectiveness is .0853 and its standard deviation is .00394. Since there are 7 degrees of freedom, the 95 percent confidence interval includes 2.365 standard deviations on either side of the point estimate: a range from .0760 to .0946. The point and interval estimates of CHMSL effectiveness are:

CY	Point Estimate	Std Dev	df	Critical t (=.05)	Confidence Bounds		
						Lower	Upper
1986	.0506	.01108	6	2.447	.0235	.0777	
1987	.0853	.00394	7	2.365	.0760	.0946	
1988	.0716	.00518	7	2.365	.0593	.0839	
1989-95	.0433	.00287	55	2.010	.0375	.0491	

The exceptionally tight confidence bounds for the effectiveness estimates (compared to other NHTSA evaluations, where the standard deviation has typically been 15 to 30 percent as large as the point estimate) are a consequence of the vast numbers of crash records used in the analyses and the remarkable State-to-State consistency of the results. However, as stated above, there are reasons for suspecting that these confidence bounds may understate the uncertainty in the estimates. The next section develops confidence bounds based on a simpler estimation procedure; although the bounds will be wider, there will not be the same questions about their validity. Ultimately, this report will rely on the confidence bounds in the next section.

2.8 Confidence bounds and statistical tests - based on an eight-State, paired-comparisons estimator

The Appendix of this report offers alternative procedures for computing point estimates of CHMSL effectiveness as well as their standard errors, by calendar year. As described in the Appendix, the method is to aggregate the data for all eight States, estimate the effectiveness of CHMSL (controlling for vehicle age) by a simple ratio-of-ratios of four cell counts from two adjacent CY, and, where necessary, use only half of the available data for the estimate in each CY in order to assure that no crash case is used in more than one of the estimates. In contrast to the preceding section, every estimate is based on a standard estimation formula and can be assumed (in view of the large sample size) to have normal properties, and every estimate is statistically independent from all the other ones. Thus, we can be sure that the customary z statistics will not understate the true confidence bounds. On the contrary, because the data were used quite inefficiently, the level of uncertainty is in a sense overstated. But there is "room to spare": even with these "relaxed" confidence bounds, CHMSL effectiveness is shown to be significant throughout 1986-95, and significantly lower averaged over 1989-95 than in 1987-88.

The strategy in this section is to apply the standard errors from the Appendix to the point estimates of this chapter. Alternatively, it would have been possible to use the point estimates from the Appendix, (which are quite similar to those from this chapter);

however, it is believed that the point estimates in this chapter still represent the "best" estimates (most accurate, least biased) of CHMSL effectiveness.

The first finding of the Appendix was to accept the null hypothesis that CHMSL effectiveness remained unchanged throughout 1989-95, and to calculate a standard error for the pooled 1989-95 result. The standard errors for CHMSL effectiveness in the Appendix, by calendar year, are:

Calendar Year	Standard Error
1986	.01319
1987	.01211
1988	.01187
1989-95 combined	.00729

Application of these standard errors, using the customary critical value of 1.96 for z, generates the following confidence bounds, that will also be used in the Executive Summary of this report:

CY	Point Estimate	Std Dev	Confidence Bounds		
				Lower	Upper
1986	.0506	.01319	.0247	.0765	
1987	.0853	.01211	.0616	.1090	
1988	.0716	.01187	.0483	.0949	
1989-95	.0433	.00729	.0290	.0576	

In other words, the effect of CHMSL is statistically significant in 1986 (z = 3.84), 1987 (z = 7.04), 1988 (z = 6.03) and 1989-95 (z = 5.94). Moreover, effectiveness is significantly higher in 1987 than in 1989-95 (the difference in the effectiveness is .0420, the standard error of this difference is .01413, and z = 2.97). The average effectiveness in 1987-88, .07845 (with standard error .00848), is also significantly higher than the effectiveness in 1989-95 (z = 3.14).

2.9 Comparison with earlier analyses

Table 2-6 shows that, over the full 1986-95 time frame, CHMSL reduced police-reported rear impacts in eight States by an average of 5.11 percent. This result is remarkably consistent with Farmer's principal finding that CHMSL reduced insurance-reported rear impacts by 5.1 percent during the 1986-91 time frame [9].

Farmer was noncommittal on whether the effectiveness of CHMSL changed over time. On the one hand, he observed that "except for calendar year 1991, there is a ... steady decrease in effectiveness." The observed decreases, however, were not large relative to the sampling error in his study (which was based on substantially fewer crash records than this report) when the data were disaggregated by calendar year. "Thus, if there is a novelty effect, it is not strong enough to be detected [i.e., conclusively, with statistical significance] from [his] data." Nevertheless, the observed calendar-year trends in his results are consistent with the trend here.

This report's 8.5 percent reduction for CHMSL in CY 1987 is somewhat lower than the 11.3 percent reduction found in NHTSA's *Evaluation of Center High Mounted Stop Lamps Based on 1987 Data* [19] (16.95 percent reduction of "relevant" rear impacts = 11.3 percent reduction of **all** rear impacts). As discussed in Section 2.3 of this report, NHTSA's earlier study assumed a linear vehicle age effect, and thus overcorrected for vehicle age. With a more accurate vehicle age correction, the results of NHTSA's earlier study would have been quite close to this report's findings for CY 1987.

The only finding in this study that differs from expectations is the relatively low 5.06 percent effectiveness for CHMSL in CY 1986. In general, the intuition is that CHMSL effectiveness may have decreased, over time, as an ever increasing proportion of the vehicle fleet was equipped with them: from the very high effectiveness seen in the pre-1986 test fleets, to fairly high levels immediately following the effective date of CHMSL as standard equipment, to the "long-term" effectiveness in 1989 and later years. Yet, in this study, the observed effect in 1986 is significantly lower than in 1987. Also, at first glance, this study produces a substantially lower estimate than NHTSA's preliminary evaluation of CHMSL, which was based on a relatively small but nationally representative sample of police-reported crashes during the summer of 1986 and attributed a 14.8 percent reduction in rear-impact crashes to CHMSL [18], p. 11. The two studies use similar types of data and similar analysis methods. However, the current study is based on about 25 times as many crash records, and has far less sampling error. In fact, confidence bounds on the estimate in NHTSA's preliminary evaluation would extend down to 7 percent or less - comparable to the results of this chapter. Additionally, Farmer's results for CY 1986 seem to be more in line with this report than with the preliminary NHTSA evaluation. It must be concluded that the estimate of this chapter is more precise than NHTSA's preliminary assessment of CHMSL effectiveness in CY 1986.

CHAPTER 3

THE EFFECTIVENESS OF PASSENGER CAR CHMSL IN SPECIFIC SITUATIONS

Statistical analyses of calendar year 1989-95 crash records from five States indicate that the long-term effectiveness of CHMSL is higher in 2-vehicle crashes than in 3-vehicle crashes; during the daytime than at night; and at non-signalized places than at locations equipped with traffic signals. CHMSL effectiveness in the struck vehicle in a front-to-rear collision is about the same whether the driver of the striking vehicle is young or old, male or female. Effectiveness is about equal in injury and noninjury crashes.

Analyses of 1986-95 FARS data suggest that CHMSL have had little or no life-saving benefit.

3.1 Analyses of five State files: method

The overall effectiveness of passenger car CHMSL had declined to 4 percent by 1989, but it stayed close to that "long-term" level throughout 1989-95, as was shown in Chapter 2. In other words, when all types of roadways, drivers, weather conditions, etc. are taken into consideration, a car equipped with CHMSL is 4 percent less likely to have a rear-impact crash than a car without CHMSL. We will now pool the CY 1989-95 data and compute the long-term CHMSL effectiveness separately for daytime vs. nighttime crashes, wet vs. dry roads, etc.

In Chapter 2, where effectiveness had to be separately calculated and meaningfully compared from one calendar year to another, a premium was placed on obtaining as many crash records from as many States as possible (eight States). Here, with the data pooled across seven calendar years, sample size is less of an issue, and it is worthwhile to take several steps that improve data quality or reduce the potential for biases in the analysis, even if those steps reduce available sample size. The analyses in this chapter will be:

Limited to the subset of five States that encode VINs on their crash files (Florida, Maryland, Missouri, Pennsylvania, Utah), and limited to records of passenger cars with good VINs, and whose VIN-defined model year agrees with the police-reported model year.

Limited to cars of model year 1985 (the last year before all cars were CHMSL-equipped) and 1986 (the first year that CHMSL was standard equipment)

Limited to crashes involving two or more vehicles, and where the first harmful event is a collision between vehicles.

The advantage of using only the records of passenger cars with good VINs is that the findings are not obscured by the inclusion of light trucks inadvertently coded as "cars," or vehicles coded as MY 1986 or later (i.e., with CHMSL) when they were actually pre-1986, or vice-versa. (It was shown in Section 2.1, however, that only a small percentage of vehicles are thus misclassified.) Comparing only MY 1985 and 1986 cars simplifies the analysis and avoids biases that may enter when longer series of model years are included. In Chapter 2, the "control group" in the analysis (vehicles with other than rear impact damage) included cars involved in single-vehicle crashes, or in multivehicle crashes whose first harmful event was not necessarily a collision between vehicles. Excluding those cars perhaps reduces bias because it makes the control group (collision-involved vehicles with side or front damage) more directly comparable to the CHMSL-affected group (collision-involved vehicles with rear damage). The codes used to limit the data to crashes in which the first harmful event was a collision between vehicles are:

Florida	exclude event1 = 4,11,12,14,15,34
Maryland	include event1 = 1
Missouri	include event1 = 7
Pennsylvania	include event1 = 13-19
Utah	include event1 = 2

The method for comparing CHMSL effectiveness in specific situations will be illustrated by an example: daylight vs. nighttime crashes in Pennsylvania. The starting point for the analysis is the basic contingency table for MY 1985 vs. 1986, pooling all the data from CY 1989-95:

ALL CRASHES

MODEL YEAR	**REAR IMPACT?**				
	Frequency Row Pct	NO	YES	Total	LOGODDS
	85	45775 74.57	15607 25.43	61382	-1.0760
	86	52383 74.89	17562 25.11	69945	-1.0928

The log odds of a rear impact is log(15607/45775) = -1.0760 in MY 85 and -1.0928 in MY 86. The observed reduction in the log odds of a rear impact is

$$D\_LOGODDS_{OBS} = (-1.0760) - (-1.0928) = .0168$$

However, this observed D_LOGODDS somewhat underestimates the overall effectiveness of CHMSL in 1989-95 because it has not been adjusted for the "vehicle age effect" described in Section 2.3. Our best effectiveness estimate, as shown in the last rows of Table 2-6, is that CHMSL reduced rear impacts by 3.45 percent in Pennsylvania during 1989-95. That percentage reduction corresponds to a log-odds reduction:

$$D\_LOGODDS_{EST} = - \log (1 - .0345) = .0351$$

The "correction factor"

$$CF = D\_LOGODDS_{EST} - D\_LOGODDS_{OBS} = .0351 - .0168 = .0183$$

will be added to the $D\_LOGODDS_{OBS}$ in any contingency table based on subsets of the Pennsylvania data to "bring the effectiveness up" to the level estimated in Table 2-6. For example, in Pennsylvania crashes during daylight:

DAYLIGHT CRASHES

MODEL YEAR		**REAR IMPACT?**			
	Frequency Row Pct	NO	YES	Total	LOGODDS
	85	33048 73.95	11640 26.05	44688	-1.0435
	86	37769 74.35	13031 25.65	50800	-1.0641

$D\_LOGODDS_{OBS} = .0206$ is somewhat higher than it was in all crashes (.0168). After adding the correction factor .0183 and converting the reduction in log odds to a percentage reduction in crashes the effectiveness estimate for CHMSL in daylight becomes

$$E = 1 - \exp(- [.0206 + .0183]) = 3.82 \text{ percent}$$

During times of reduced light (nighttime, dawn or dusk):

NIGHTTIME CRASHES

MODEL YEAR		**REAR IMPACT?**			
	Frequency Row Pct	NO	YES	Total	LOGODDS
	85	12551 76.36	3885 23.64	16436	-1.1726
	86	14397 76.46	4433 23.54	18830	-1.1779

$D\_LOGODDS_{OBS} = .0053$ is lower than it was in daytime crashes. Even after adding the correction factor, the effectiveness estimate for CHMSL in at night is only

$$E = 1 - \exp(- [.0053 + .0183]) = 2.33 \text{ percent}$$

Correction factors are similarly computed in the other State files, and they are:

	Florida	Maryland	Missouri	Pennsylvania	Utah
Effectiveness estimate % (Table 2-6)	4.96	3.35	4.12	3.45	6.65
Equivalent log odds	.0508	.0341	.0421	.0351	.0688
Observed 85-86 log odds	.0088	.0301	.0143	.0168	.0641
Correction factor: ADD	.0420	.0040	.0278	.0183	.0047

One caveat for this method is that it assumes the same correction factor (adjustment for the vehicle age effect) in all the various subsets of crashes within a State. It is conceivable that the vehicle age effect could vary among subsets. For example, the effect in Pennsylvania nighttime crashes could be larger (or smaller) than in daytime crashes. That would be a "second-order" difference. We are not asking here if the proportion of daytime to nighttime crashes changes as cars get older - nor if the proportion of crash involvements that are rear impacts is different in the daytime and the nighttime. We are only asking if the trend towards proportionately fewer rear impacts as cars get older is stronger (or weaker) in daytime crashes than in nighttime crashes.

In general, the vehicle age effect does not vary between subsets. The effect was examined by averaging D_LOGODDS for MY 1985 vs. 1984 and for MY 1987 vs. 1986 (i.e., in both cases, two adjacent model years where the CHMSL status did not change). For all types of crashes, the population-weighted average of this quantity for the five States was -.040: approximately a 4 percent "age effect" per year in the pooled 1989-95 data. Within each of the subsets considered in Section 3.2 - daytime, nighttime, injury crashes, noninjury crashes, etc. - this quantity was always between -.049 and -.031, except in rural crashes, where it was -.020. These small variations in the observed "vehicle age effect" are well within the "noise" range of the data.

The strategy in the next section is to compute CHMSL effectiveness in the various subsets (e.g., daytime vs. nighttime crashes): separately in each State, and population-weighted averages for the five States. In general, it will only be concluded that effectiveness is higher in one subset than another if it is higher in all five States, or in every State except one of the smaller ones (Utah or Maryland) and if the 5-State average is substantially higher in one subset than the other(s). Otherwise, it is appropriate to conclude that effectiveness is about the same in the two (or more) subsets.

3.2 Analyses of five State files: results

NHTSA's earlier evaluations both found that CHMSL initially may have been more effective in collisions involving 3 or more vehicles than in 2 vehicle collisions. The preliminary report, based on CY 1986 data, said that CHMSL reduced the probability of being the lead vehicle in a 3+ vehicle collision by 25.7 percent; of being one of the middle vehicles in such a collision by 17.5 percent; but CHMSL only reduced the probability of being the struck vehicle in a front-to-rear 2 vehicle collision by 13.2 percent [18], pp. 14-18. (However, the sample sizes were small, and those observed differences in effectiveness were not statistically significant.) In NHTSA's evaluation based on CY 1987 data, CHMSL reduced the probability of being a rear-impacted car in a 3+ vehicle collision by 14.6 percent, but only reduced the probability of being the rear-impacted car in a 2 vehicle collision by 9.8 percent; in 9 of the 11 State files analyzed, effectiveness was higher in the 3+ vehicle collisions [19], pp. 28-29. It was hypothesized that "CHMSL are especially effective in preventing chain collisions because they enable a driver to see if the car two vehicles ahead is braking" [19], p. 29.

In the long term, these effects are reversed:

Reduction (%) of Rear Impacts with CHMSL

	In 2 Vehicle Collisions	In 3+ Vehicle Collisions
Florida	6.51	2.34
Maryland	3.41	2.54
Missouri	5.20	3.80
Pennsylvania	5.09	2.16
Utah	8.19	1.06
5-State weighted average	5.54	2.45

In the CY 1989-95 data analyzed in this chapter, the effectiveness was higher in 2 vehicle than in 3+ vehicle crashes in each of the five States. In Florida, Pennsylvania and Utah, it was more than double, while in Maryland and Missouri it was slightly higher in the 2 vehicle crashes. The five-State, population-weighted averages: CHMSL reduces the risk of being rear-impacted by 5.54 percent in 2 vehicle collisions and 2.45 percent in 3+ vehicle collisions.

What might have happened between CY 1986-87 and CY 1989-95? It was shown in Chapter 2 that the overall effectiveness of CHMSL dropped in half during those years. That phenomenon has been described as "acclimatization" [17] or a "novelty effect" [7], [9], [31]. In other words, as CHMSL became more common in vehicles on the road, drivers became more accustomed to seeing the lamps. They might "tune out" rather than being spurred to action by the lamps. It could be argued that the acclimatization will be stronger if the precrash situation is more complex. When the vehicle with CHMSL is directly in front of you, it is hard not to see the lamps, but when it is two vehicles ahead of you it becomes easier to "tune them out." Another factor that may have reduced effectiveness in some 3+ vehicle collisions is that the increased popularity of tall vans, sport utility vehicles, and heavily tinted glass may be making it harder for drivers to see through the next vehicle to the one ahead of it.

NHTSA's previous evaluation presented strong evidence that, during 1987, CHMSL were more effective in daylight (13.2 percent) than under reduced lighting conditions (5.6 percent) [19], pp. 34-35. The trend has continued during 1989-95. In our five State files, "daylight" and "reduced light" (night, dawn or dusk) are defined as follows:

	Daylight	Reduced Light
Florida	light=1	light=2-5
Maryland 1989-92	light=1	light=2-6
Maryland 1993-95	light=1	light=2-4
Missouri	light=1	light=2-4
Pennsylvania	light=2	light=1,3,4,5
Utah	light=1	light=2-5

In the five States, CHMSL are, on the average, twice as effective in daylight as at other times, and they are more effective in daylight in each individual State except Utah:

Reduction (%) of Rear Impacts with CHMSL

	Daylight	Reduced Light
Florida	5.31	3.44
Maryland	3.99	1.38
Missouri	5.40	- 1.21
Pennsylvania	3.82	2.33
Utah	6.65	7.40
5-State weighted average	4.73	2.34

NHTSA's earlier evaluation hypothesized that "the driver's field of view is less cluttered by lamps during daylight: CHMSL and the triangle they make with the regular stoplamps are the only lights in front of the driver. At night, street lights, headlamps and taillamps of other vehicles may distract the driver. A second possibility is that regular stoplamps are hard to see during the daytime, because they are not that much brighter than ambient surfaces; thus, the CHMSL (directly in front of the driver) provides extra help by day. Another factor, undoubtedly, is that a substantial percentage of nighttime drivers are insufficiently alert or defensive because of alcohol or other factors; they don't react to the CHMSL at all or not in time" [19], pp. 34-35. Those hypotheses still sound reasonable.

CHMSL are less effective near traffic signals (including traffic lights, stop signs, flashing lights, yield signs and railroad crossings, but excluding lane markings, advisory signs, speed limit signs, etc.) than at locations away from signals. That was a tentative finding in NHTSA's previous evaluation [19], pp. 35-36, and it is strongly confirmed by the present data. The presence of a traffic signal is defined as follows:

	At Signal	Away from Signal
Florida	tra_con=3-8	tra_con=1,2,9
Maryland 1989-92	tra_con=1-4,10,11	other
Maryland 1993-95	tra_con1=Y	tra_con1=N
Missouri	trfcntl1=1-5	trfcntl1=6-9
Pennsylvania	tra_con=1-6	tra_con=0,7
Utah	tra_con1=1-7	tra_con1=9,A,B,C,D,E

In the five States, CHMSL are more effective away from traffic signals:

Reduction (%) of Rear Impacts with CHMSL

	At Signal	Away from Signal
Florida	1.88	6.66
Maryland	2.28	4.49
Missouri	.23	6.19
Pennsylvania	1.63	5.76
Utah	4.70	7.82
5-State weighted average	1.75	6.07

Two hypotheses help explain the results. On the one hand, the signal diverts the driver's attention from the CHMSL of the vehicle directly to the front. Other traffic may also be diverting the driver's attention (since signals are usually near an intersections). On the other hand, the signal itself is sending a message to the driver to be cautious or slow down, reinforcing information that might be sent by the CHMSL. But on the open road, away from signals, the driver is more likely to focus straight ahead, where the next car's CHMSL is.

NHTSA's earlier evaluation suggested that CHMSL were slightly more effective in rural than urban areas [19], pp. 36-37. That trend continues in the three larger States (Florida, Missouri, Pennsylvania). The rural/urban definitions are:

	Rural	Urban
Florida	rur_urb=1	other
Maryland 1989-92	locality=5	locality=1-4
Maryland 1993-95	N/A	N/A
Missouri	pop_grp=12,99	other
Pennsylvania	rur_urb=1	other
Utah	locality=5,6	locality=1-4,7-9

The Maryland analysis is flawed because rural/urban is not defined in the 1993-95 files. In Utah, the preceding definition makes most crashes "urban." The effectiveness estimates are:

Reduction (%) of Rear Impacts with CHMSL

	Rural	Urban
Florida	6.33	3.88
Maryland (CY 89-92)	- 6.60	4.03
Missouri	10.56	2.26
Pennsylvania	5.09	3.06
Utah	2.12	7.30
5-State weighted average	4.62	3.57

The 5-State average effectiveness is slightly higher in rural than in urban areas, but the difference is in the "noise" range. Rural effectiveness is higher, though, in the three larger States. The working hypothesis here is that rural roads will have fewer diversions (e.g., multilane traffic, parked cars, city lights) of the driver's attention from the CHMSL.

The four preceding analyses show a consistent pattern for CHMSL during CY 1989-95: the simpler the situation, and the fewer the diversions of the driver's attention from the vehicle directly in front, the more powerful the effect of the CHMSL.

CHMSL may be more effective on wet roads than dry roads (although the results are short of conclusive). The codes for road surface condition are:

	Dry	Wet	Snowy/Icy
Florida	rd_sur1=1	rd_sur1=2,3,4	N/A
Maryland	rd_sur1=2	rd_sur1=1,5	rd_sur1=3,4
Missouri	rd_sur1=1	rd_sur1=2,5	rd_sur1=3,4

Pennsylvania	rd_sur1=1	rd_sur1=2,3	rd_sur1=4-8
Utah	rd_sur1=1	rd_sur1=2,3,6	rd_sur1=4,5

Florida actually has codes for "snowy" and "icy" but they are too infrequent for a meaningful statistical analysis. The effectiveness estimates are:

Reduction (%) of Rear Impacts with CHMSL

	Dry	Wet	Snowy/Icy
Florida	4.10	7.51	.
Maryland	5.23	- .55	- 1.51
Missouri	3.99	5.95	- 8.29
Pennsylvania	2.17	6.15	8.68
Utah	6.78	7.47	2.14
5-State weighted average	3.73	5.79	2.42

The observed effectiveness is higher on wet roads than on dry roads in every State except Maryland. (Even outside Florida, the sample size for snowy and icy roads is too small for a reliable effectiveness estimate.) If CHMSL are indeed more effective on wet roads than on dry, snowy or icy roads, the following explanations may be considered: (1) On dry, snowy or icy roads drivers maintain a distance from the car in front of them commensurate with their stopping capabilities. On wet roads, even if they follow less closely than on dry roads, they do not add distance commensurate with their reduced braking capability. Since the margin of safety is smaller, the reduction in response time with CHMSL provides an extra "edge." (2) Rain, glare, foggy windshields, etc. may make it harder to see conventional brake lights on wet roads, enhancing the advantage of CHMSL.

The age or sex of the driver of the rear-impacted vehicle ought to have little direct influence on the effectiveness of CHMSL, since the actions of this driver are, for the most part, not directly responsible for causing the collision. But the age or sex of the **other** driver, the one in the frontally impacting vehicle in a front-to-rear collision, could be relevant. On the one hand, CHMSL might be more effective when the other driver is young and/or male: since young/male drivers tend to be more aggressive, and have less of a safety margin in their following distance, they might obtain an extra "edge" from the improved response time with CHMSL. On the other hand, older and/or female drivers, because of their shorter seated height, might have more trouble seeing conventional brake lights and get an extra advantage from CHMSL. Additionally, older drivers have generally slower response and reaction times and might be helped more than others by the visual cues from CHMSL. The five State files, however, show little difference in CHMSL effectiveness by age or gender of the other driver. In other words, the factors suggested above are negligible or cancel one another out. (The analyses are limited to 2 vehicle crashes, since it is often not easy to determine the "striking" vehicle in a 3+ vehicle crash.)

Reduction (%) of Rear Impacts with CHMSL

	Other Driver Age 15-24	Other Driver Age 25-54	Other Driver Age 55+
Florida	7.29	4.98	10.88
Maryland	- 4.14	7.32	5.73
Missouri	5.49	5.99	7.78
Pennsylvania	7.99	5.63	- .41
Utah	8.97	7.05	10.45
5-State weighted average	5.84	5.74	6.08

(Note that the effectiveness within each age group is just slightly higher than the average effectiveness estimate in all 2-vehicle crashes, 5.54 percent. The other driver's age was unreported in a moderate proportion of these crashes, and in that group [not shown above] the observed effectiveness estimate happened to be lower than average.)

Reduction (%) of Rear Impacts with CHMSL

	Other Driver Male	Other Driver Female
Florida	6.60	6.36
Maryland (CY 89-92)	5.60	1.20
Missouri	6.09	6.35
Pennsylvania	4.70	4.04
Utah	8.79	7.54
5-State weighted average	5.88	4.98

NHTSA's evaluation of 1987 data found that CHMSL were at least as effective in towaway as nontowaway crashes and probably more effective in preventing injury crashes than property-damage-only (PDO) crashes [19], pp. 25, 26, 28. Those were encouraging results for anyone who feared that CHMSL might only be effective in the lowest severity crashes. The 1989-95 data more or less continue those trends, showing perhaps slightly higher effectiveness in towaways than nontowaways and nearly equal effectiveness in PDO and injury crashes. Crash damage severity is defined in every State except Utah; the codes are:

	Towaway	Nontowaway
Florida	sev_dam=1	other
Maryland 1989-92	dam_sev=1	other
Maryland 1993-95	dam_sev=4,5	other
Missouri	towaway=Y	other
Pennsylvania	towaway=1	other

In Florida, "towaway" means any vehicle involved in the crash was towed; in the other three States, "towaway" means the rear-impacted car was towed. The effectiveness estimates are:

Reduction (%) of Rear Impacts with CHMSL

	Towaway	Nontowaway
Florida	6.84	3.63
Maryland	2.93	3.07
Missouri	5.32	3.55
Pennsylvania	2.81	2.03
4-State weighted average	4.70	3.00

Effectiveness is higher in towaway crashes in the three larger States (Florida, Missouri, Pennsylvania) and about the same in Maryland. The 4-State weighted average is somewhat higher in towaway crashes.

The definitions of an "injury crash" and a "property-damage-only" crash are:

	Injury Crash	Property Damage Only
Florida	severity=2-6	other
Maryland	severity=2-5	severity=1
Missouri	severity=1,2	severity=3
Pennsylvania	severity=1-4	severity=6
Utah	severity=2-5	severity=1

In all five States, "injury" crashes are those in which any occupant is injured or killed, an occupant of the rear-impacted vehicle and/or an occupant of any other vehicle. In a PDO crash, no occupant of any vehicle is injured or killed. The effectiveness estimates are:

Reduction (%) of Rear Impacts with CHMSL

	Injury Crashes	Property Damage Only
Florida	4.82	4.65
Maryland	4.65	1.49
Missouri	4.76	3.77
Pennsylvania	2.10	4.89
Utah	7.09	6.42
5-State weighted average	4.01	4.27

In four States, effectiveness is higher in preventing injury crashes, but in populous Pennsylvania, the situation is reversed. The 5-State average effectiveness is virtually identical in PDO and injury crashes. It may be concluded that CHMSL are effective across a fairly wide spectrum of crash severities. Intuitively, that makes sense. If CHMSL provide an extra "edge" of quicker response, they ought to reduce injury crashes to PDO crashes, and PDO crashes to fender benders just as well as they reduce fender benders to "close calls."

3.3 The effect of CHMSL in fatal crashes

NHTSA's previous evaluation did not find any effect for CHMSL on fatalities in CY 1986-87 data [19], pp. 26-27. The report suspended any definitive conclusion, however, because the quantity of data available for that analysis was small. Relatively few people die in rear-impact crashes.

With CY 1986-95 data now available, a new analysis can be performed with about 5 times as many crash records. The Fatality Analysis and Reporting System (FARS), a census of the nation's fatal crashes, is the data source [10]. (Of course, the eight State files used in the other analyses of this report contain only a fraction of the fatality cases in FARS.) The analysis procedure with FARS data is essentially identical to the process for any of the individual State files in Chapter 2.

The first step is to identify all records of passenger cars (body_type = 1-9,12 in 1991-95 FARS and body_type = 1-9,13 in 1986-90 FARS) involved in a multivehicle fatal crash in which this car's "most harmful event" was a collision with a motor vehicle in transport (m_harm = 12). Parked cars (veh_man = 7) are excluded. Cadillacs (make = 19) are also excluded, because they got CHMSL as standard equipment in MY 1985 rather than 1986. Rear impacts need to be distinguished from other impacts. As in Chapter 2, the definition of "rear impact" is quite inclusive: any vehicle whose initial damage (impact1) and/or principal damage (impact2) is on the rear, the rear-corner, or the side towards the rear (impact1 = 4-8 or impact2 = 4-8). Intuitively, impact1 is the more important variable, but since it is less completely reported than impact2 on FARS, the latter variable has been added to minimize missing data. Cases with unknown principal damage location (impact2 = 99) are excluded. The 1986-95 FARS files comprise 17,735 records of cars 0-15 years old involved in fatal rear-impact crashes: substantial data, but not many in comparison to the 3,000,000 nonfatal rear-impact cases available for the analyses of Chapter 2.

The next step is to calibrate the "vehicle age effect." Section 2.3 describes this effect in nonfatal crash data and explains how it is calibrated. A similar effect exists in fatal crashes: older cars have fewer rear-impact crashes relative to frontal and side impacts with other vehicles. The 1986-95 FARS data are tabulated by calendar year and model year (cars 0-15 years old). For example, Table 3-1 shows the percentage of rear impacts for MY 1977-92 cars in CY 1992. Three phenomena may be detected when these numbers are compared to Table 2-1 (nonfatal Florida data): (1) The proportion of fatal involvements that are rear impacts is only about half as large as the proportion of nonfatal crashes that are rear impacts, even after excluding fatal single-vehicle crashes. (2) Because there are fewer cases in each cell, the proportion of fatalities that are rear impacts varies with little pattern from one MY to the next; based on one CY of data, it is hard to discern the vehicle age trend. (3) Needless to say, it is also impossible to detect the effect of CHMSL in MY 1986.

However, when the data are pooled across the ten calendar years and graphed by vehicle age, as in Figure 3-1, a reasonably clear pattern emerges. The vehicle age effect - i.e., the rate of decline in the percentage of crashes that are rear impacts - is strongest when cars are new (unlike Florida nonfatal crashes, where the effect is strongest for 5-8 year old cars; see Figure 2-1). A quadratic regression is used to calibrate D_LOGODDS, the rate of change in the percentage of crashes that are rear impacts, by vehicle age. The regression equation is

$$\text{d\_logodds} = +.04614 - .01223 \text{ vehage} + .000692 \text{ vehage}^2$$

It somewhat resembles the equation for the Indiana nonfatal data (see Table 2-3).

As in Sections 2.4 and 2.5, the preceding equation is used to adjust the log odds of a rear impact for j-year-old cars to what it would have been if the cars had been brand new instead of j years old. The adjusted log odds of a rear impact are computed in each of the model years 1982-89 in each of the calendar years. The "preliminary effectiveness estimate" CHMSLAVG, a weighted average of the difference in adjusted log odds for MY 82-85 (without CHMSL) and MY 86-89 (with CHMSL) is computed in each calendar year. So is DELAVG, the average annual reduction in the adjusted log odds of a rear impact from MY 83 to 85 and from MY 86 to 88 - when cars' CHMSL status remained the same. CHMSLAVG measures the effectiveness of CHMSL (positive numbers indicate a benefit, a reduction of rear impact crashes). DELAVG measures whether the model is producing spurious benefits. The values of these statistics in the ten individual calendar years, and their averages over the ten years, are the following:

TABLE 3-1: FARS 1992, PASSENGER CAR INVOLVEMENTS IN FATAL MULTIVEHICLE CRASHES, BY MODEL YEAR AND IMPACT LOCATION

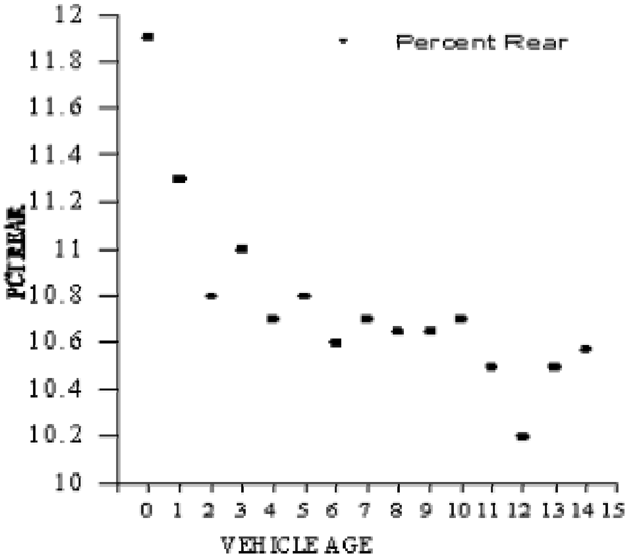
REAR IMPACT?					
MODEL YEAR	Frequency Row Pct	NO	YES	Total	
		77	357 91.07	35 8.93	392
		78	481 87.93	66 12.07	547
		79	603 90.00	67 10.00	670
		80	540 90.76	55 9.24	595
		81	596 88.04	81 11.96	677
		82	630 89.11	77 10.89	707
		83	750 90.80	76 9.20	826
		84	1035 89.69	119 10.31	1154
		85	1110 90.54	116 9.46	1226
		86	1168 90.47	123 9.53	1291
		87	1145 89.17	139 10.83	1284
		88	1160	124	1284

			90.34	9.66	
		89	1130 90.54	118 9.46	1248
		90	914 90.58	95 9.42	1009
		91	987 90.30	106 9.70	1093
		92	668 88.48	87 11.52	755
		Total	**13274**	**1484**	**14758**

FIGURE 3-1

PERCENT OF FATAL MULTIVEHICLE INVOLVEMENTS THAT ARE REAR IMPACTS

BY VEHICLE AGE, FARS 1986-95, CARS 0-15 YEARS OLD



CHMSLAVG DELAVG

	CHMSLAVG	DELAVG
Calendar Year	CHMSL Effectiveness	Spurious Effectiveness
1986	- .0009	.1007
1987	.0597	- .0029

1988	.0651	.0360
1989	.0245	.0207
1990	- .0014	.0408
1991	- .1370	.0520
1992	- .0242	- .0138
1993	- .0853	.0433
1994	.1449	- .0238
1995	- .0163	.0530
10 Year Average	**.0029**	**.0306**

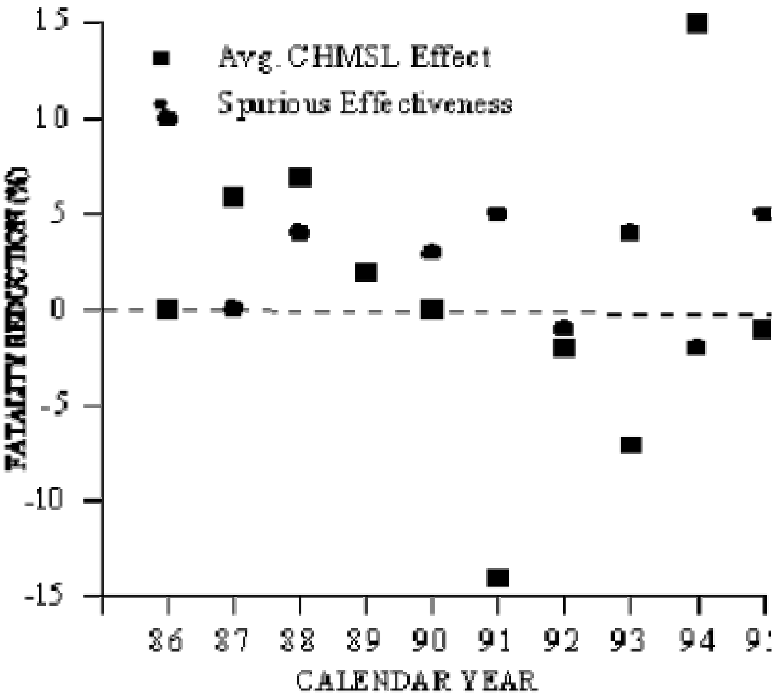
Figure 3-2 graphs CHMSLAVG () and DELAVG (O) by calendar year. It makes quite a contrast with Figure 2-7, the corresponding results for (almost exclusively) nonfatal crashes from the eight State files. In Figure 3-2, the 's and the O's are scattered all over the diagram, without any recognizable pattern (except, perhaps, just a hint of positive CHMSLAVG values in 1987-88). In Figure 2-7, the 's were clearly positive, with a peak in 1987 and flat after 1989, while the O's were always close to zero.

In the fatal crashes, the observed effectiveness of CHMSL is positive in four years and negative in six. In the nonfatal crashes, effectiveness was positive in all ten years.

In the fatal crashes, CHMSLAVG is more positive than DELAVG in four years and less positive in six. In other words, there is no evidence that the effect from MY 85 to 86 (when CHMSL became standard equipment) is any different than the effect from MY 84 to 85, or 86 to 87, etc. In the nonfatal crashes, CHMSLAVG was always more positive than DELAVG; in fact, DELAVG was always much closer to zero than to CHMSLAVG.

The facts that CHMSLAVG is positive in four of ten years, and that CHMSLAVG is more positive than DELAVG in four of ten years are nonparametric tests suggesting that the effect of CHMSL is nonsignificant. Additional insight may be gained by statistical testing and confidence intervals based on the variance of the ten individual CHMSLAVG values. The first question is whether the slightly more positive results for CY 1987 and 1988, as seen in Figure 3-2, are significantly more positive than the CHMSLAVG values in the other calendar years. The GLM procedure of SAS [32] is used to run an analysis of variance on CHMSLAVG across two CY groups: "1987-88" and "other." The difference between the two groups is not statistically

FIGURE 3-2
AVERAGE CHMSL EFFECTIVENESS IN FARS ()
PASSENGER CARS, BY CALENDAR YEAR
(Percent reduction in the risk of a fatal rear impact)
SPURIOUS "EFFECTIVENESS" IN MY WHERE THE CHMSL STATUS DID NOT CHANGE (O)



significant (F = 1.49; df = 1,8; p > .05), and we may assume that CHMSLAVG is essentially invariant throughout CY 1986-95, except for "noise."

Thus, the ten individual values of CHMSLAVG may be treated as repeated measurements and used to compute a point estimate and confidence bounds. The point estimate of CHMSL effectiveness is the arithmetic average of the ten values: a 0.29 percent reduction of rear-impact crashes. This point estimate is, of course, not significantly different from zero: the t value for the ten individual estimates is 0.12 (p > .05). One standard deviation of the point estimate is 2.63 percent. With 9 degrees of freedom, the 95 percent confidence bounds for effectiveness are 0.29 ±2.262 standard deviations:

confidence bounds: from -5.66 to +6.24 percent reduction of fatal rear impact crashes

The most appropriate conclusion continues to be that CHMSL had little or no effect on fatal crashes.

Given that CHMSL are about equally effective in property-damage-only and nonfatal-injury crashes, it might seem surprising, at first glance, that effectiveness is nonsignificant in fatal crashes. Several characteristics of fatal rear impacts, however, substantially reduce the potential effect of CHMSL, as evidenced by a comparison of FARS and Florida (nonfatal crash) data:

The struck car was stopped, slowing or turning (and thereby presumably activating the CHMSL) in only 37 percent of the fatal crashes, as opposed to 73 percent of the nonfatal crashes.

The striking vehicle was traveling 55 mph or faster in 51 percent of the fatal crashes, as opposed to about 10 percent of the nonfatal crashes. A modest reduction in the collision severity with CHMSL might not prevent the fatality.

The striking vehicle was a heavy truck or a motorcycle in 25 percent of the fatal crashes, but only 5 percent of the nonfatal crashes. When there is a severe weight mismatch (the struck vehicle being a passenger car), there is a high probability of a fatality in the lighter vehicle, and it is unlikely to be prevented by a modest reduction in the collision severity.

The driver of the striking vehicle had been drinking, and might have become inattentive to the CHMSL, in 23 percent of the fatal crashes but only 10 percent of the nonfatal crashes.

44 percent of the fatal crashes happened at night, when CHMSL is least effective, but only 25 percent of the nonfatal crashes.

While these factors, by themselves, might not necessarily reduce CHMSL effectiveness all the way to zero, they could easily lower it into the "noise" range, undetectable given the quantity of data available for the FARS analyses.

CHAPTER 4

THE EFFECTIVENESS OF CHMSL FOR LIGHT TRUCKS

Before the CHMSL requirement was extended from passenger cars to light trucks (pickup trucks, vans and sport utility vehicles), there were questions if CHMSL would be as effective in trucks as in cars, or even if it would be effective in trucks at all. By now, CHMSL have been in light trucks for several years. Statistical analyses of calendar year 1994-96 crash records from six States indicate that light trucks equipped with CHMSL were approximately 5 percent less likely to be struck in the rear than light trucks without CHMSL. This point estimate of CHMSL effectiveness in light trucks is statistically significant, and it is very close to the long-term effectiveness in passenger cars (4.3 percent). Nevertheless, the uncertainty in the light truck estimate precludes the inference that CHMSL are as effective in trucks as in cars.

4.1 Analyses of six State files: method

The launch of CHMSL on light trucks differs from their introduction on passenger cars in several important features that will influence the analysis method.

When passenger cars were first equipped with CHMSL, model year 1986, the lamps were a new experience for the motoring public. The initial reaction to the lamps was perhaps quite different from what would happen when drivers became acclimatized to them. That made it critical to estimate effectiveness separately in each calendar year, to distinguish between the initial and the long-term effectiveness. By the time that the first CHMSL appeared on light trucks - in the MY 1991 Dodge Caravan, Plymouth Voyager, Chrysler Town & Country and Ford Explorer - the public was already acclimatized to the lamps (on cars). It is less important to estimate effectiveness separately in each calendar year, since it may be assumed that the long-term effectiveness was reached immediately.

CHMSL implementation in passenger cars was nearly simultaneous: MY 1986 in all models (except Cadillacs and very few others). In light trucks, CHMSL were phased in over a three-year period, MY 1991-94, since some manufacturers installed them on certain models up to three years before the MY 1994 effective date. We must know the specific make-model of each truck to determine if it had CHMSL (unlike cars, where it was basically good enough just to know the model year). State files that include the Vehicle Identification Number (VIN) on their crash records allow identification of truck make-models by decoding of the VIN. NHTSA has access to six State files that include VINs, document the impact location on the vehicle, and are available for some or all of the calendar years 1994-96:

Florida	Maryland	Missouri
North Carolina	Pennsylvania	Utah

The Indiana and Texas files employed in Chapter 2 include "make-model" codes, but they are not detailed enough to distinguish between all the specific truck models addressed in this chapter; the Virginia file does not contain make-model information.

The basic contingency table analyses of Chapters 2 and 3 compared the proportion of crashes that were rear impacts in all cars of the first year with CHMSL - MY 1986 - to the corresponding proportion in all cars of the last year without CHMSL - MY 1985. Here, too, we will compare all trucks of the first year with CHMSL to all trucks of the last year without CHMSL, but both of these groups will include a mix of model years, since different models got CHMSL in different years.

The "vehicle age effect" - the trend of decreasing proportions of rear impacts as cars get older, for reasons unrelated to CHMSL - was calibrated for passenger cars in Chapter 2 by looking at this trend for cars 0-15 years old in many calendar years of data. It cannot be assumed that light trucks will have the same "vehicle age effect" as cars. At the same time, it is not necessarily appropriate to use a similar calibration procedure for trucks as for cars. The method of Chapter 2 assumes that CHMSL were introduced in all vehicles at the same time (correct for cars, but not for trucks). In addition, major changes in the truck population since 1985 raise doubts whether the effect in recent years should be calibrated from older data. Instead, the method for handling the vehicle age effect will be essentially the same as in Farmer's evaluation of passenger car CHMSL [9]. This method, as will be described below, relies entirely on data for the last two MY without CHMSL and the first two MY with CHMSL.

The starting point for the analysis is a list of make-models that were equipped with CHMSL. Information on CHMSL installations was obtained from Chrysler, Ford, General Motors, Mazda, Nissan and Toyota. The make-models of pickup trucks, vans and sport utility vehicles (SUV) included in the analyses are listed in Table 4-1. For example, Dodge Caravan and Plymouth Voyager were equipped with CHMSL in MY 1991; thus, the last two MY without CHMSL are 1989-90 and the first two MY with CHMSL are 1991-92. Note that all GM and Mazda trucks, and a substantial proportion of the other trucks, got CHMSL in MY 1994, simultaneous with the Federal requirement.

Excluded from the analyses are the Jeep Grand Cherokee, Ford Explorer, Ford Windstar and Toyota T-100, which had CHMSL from their inception, and which did not have a similar predecessor vehicle without CHMSL. Also excluded is the Dodge Ram Van and Wagon, which got CHMSL in the middle of MY 1993 (thus making it impossible to define a first MY with CHMSL and an adjacent last MY without CHMSL). On the other hand, Table 4-1 includes models that got CHMSL as part of a major redesign, as long as the redesign did not fundamentally change the model's size, function or market class (e.g., Dodge Ram Pickup, Ford full-sized van/wagon). Also included are models that merely changed their names, without any substantial redesign (e.g., Chevrolet K-Blazer to Tahoe).

As stated above, the range of model years on the data file must include the first two MY with CHMSL. For the many make-models that got CHMSL in 1994, that is only possible in the CY 1995 and 1996 data files. Those two calendar years are the mainstay of the analysis. Since the sample drawn from those two CY alone is somewhat limited, CY 1994 data have been added to the analysis. However, the CY 1994 data is restricted to the make-models that had at least 2 MY with CHMSL by 1994 - i.e., the models that got CHMSL in 1993 or earlier. For example, none

TABLE 4-1
LIGHT TRUCK MAKE-MODELS THAT GOT CHMSL IN 1991-94
MODEL YEARS INCLUDED IN THE EFFECTIVENESS ANALYSES

Mfr.	Model	**Last 2 MY** without CHMSL	**First 2 MY** with CHMSL	
Chrysler	Caravan/Voyager	1989-90	1991-92	
		Grand Caravan / Town&Country / Grand Voyager	1989-90	1991-92
		Dakota	1992-93	1994-95
		Ram pickup	1992-93	1994-95
		Cherokee (excl. Grand Cherokee)	1992-93	1994-95
		Wrangler	1992-93	1994-95

Ford	F pickup	1990-91	1992-93	
		Full-sized van/wagon	1990-91	1992-93
		Bronco (full-sized)	1990-91	1992-93
		Ranger	1991-92	1993-94
		Aerostar	1992-93	1994-95
GM	C/K pickup	1992-93	1994-95	
		S/T pickup	1992-93	1994-95
		Full-sized van / wagon	1992-93	1994-95
		Astro / Safari van	1992-93	1994-95
		Lumina APV / Silhouette / TransSport	1992-93	1994-95
		K Blazer / Yukon / Tahoe	1992-93	1994-95
		Suburban	1992-93	1994-95
		S/T Blazer/Jimmy	1992-93	1994-95
		Geo Tracker	1992-93	1994-95
Mazda	Pickup	1992-93	1994-95	
		MPV	1992-93	1994-95
Nissan	Pathfinder	1991-92	1993-94	
		Pickup	1992-93	1994-95
Toyota	Previa	1991-92	1993-94	
		Landcruiser	1991-92	1993-94
		Pickup (compact)	1992-93	1994-95
		4-Runner	1992-93	1994-95

of the GM trucks are included in the CY 1994 data. As of December 1997 data were available for the following calendar years:

Florida	94-96	Maryland	94-96	Missouri	94-96
North Carolina	94	Pennsylvania	94-96	Utah	94-95

Crash involvements are tabulated by impact type: rear vs. other. Trucks with unknown impact locations and parked trucks are excluded from the analysis. The definitions of "rear impact" are:

Florida	impact = 7,8,9
Maryland	impact & veh_dam1 both 7-12, or one is 7-12 and one is blank
Missouri	veh_dam1 = 7,8,9
North Carolina	veh_dam1 = 10-13
Pennsylvania	impact = 4,5,6,7,8
Utah	impact & impact2 both 7-9, or one is 7-9 and one is blank

The vehicles deleted because they were "parked" are:

Florida	veh_man1 = 8,9
Maryland	veh_man1 = 10
Missouri	veh_man1 = 13 or veh_man2 = 13 or veh_man3 = 13
North Carolina	contfact = 7,10,11
Pennsylvania	veh_man1 = 19
Utah	veh_man1 = 11

These definitions are the same as in Chapter 2 (except in the case of North Carolina; data from that State were not used in the Chapter 2 analyses). The basic tabulation of crash involvements of vehicles listed in Table 4-1, by impact type and YT, the truck's model year **relative to** the transition MY to CHMSL for that make-model, combines the data for all six States in all the CY that these data were available:

YT	**REAR IMPACT?**		
		NO	**YES**
-2 (Two MY before CHMSL)	X(-2)	R(-2)	
-1 (Last MY before CHMSL)	X(-1)	R(-1)	
0 (First MY with CHMSL)	X(0)	R(0)	
1 (Second Mywith CHMSL)	X(1)	R(1)	

For example, since the Dodge Caravan got CHMSL in 1991, YT = -2 when MY = 1989; the MY 1989 cases go into the X(-2) and R(-2) cells, the MY 1990 cases into the X(-1) and R(-1) cells, the MY 1991 cases into the X(0) and R(0) cells, and the MY 1992 cases into the X(1) and R(1) cells. Since the Dodge Dakota got CHMSL in 1994, the MY 1992 cases go into the X(-2) and R(-2) cells, the MY 1993 cases into the X(-1) and R(-1) cells, etc.

The unadjusted effect of CHMSL is the actual, observed reduction in the log odds of a rear impact from the last MY before CHMSL (YT = -1) to the first MY with CHMSL (YT = 0):

$$E_U = [\ \log R(-1) - \log X(-1)\ ] - [\ \log R(0) - \log X(0)\ ]$$

Generally speaking, E_U will understate the actual benefit of CHMSL, because there is a "vehicle age effect" working in the opposite direction. That effect can be estimated by comparing trucks of the second year to the first year before CHMSL (when neither had CHMSL); or by comparing trucks of the first year to the second year with CHMSL (when both had CHMSL). The age effect is the average of those two statistics:

$$\mathrm{DEL}_{\mathrm{BEFORE}} = [\ \log R(-2) - \log X(-2)\ ] - [\ \log R(-1) - \log X(-1)\ ]$$
$$\mathrm{DEL}_{\mathrm{AFTER}} = [\ \log R(0) - \log X(0)\ ] - [\ \log R(1) - \log X(1)\ ]$$
$$\mathrm{DEL}_{\mathrm{AVG}} = \tfrac{1}{2}\,[\ \mathrm{DEL}_{\mathrm{BEFORE}} + \mathrm{DEL}_{\mathrm{AFTER}}\ ]$$

The adjusted effect of CHMSL is the difference of the unadjusted effect and the age effect:

$$E_A = E_U - \mathrm{DEL}_{\mathrm{AVG}}$$

Since $\mathrm{DEL}_{\mathrm{AVG}}$ is usually negative, E_A will generally be more positive than E_U. Finally, the percentage reduction of rear impacts attributed to CHMSL is calculated by converting the log odds ratios back to odds ratios:

$$E_{\%} = 1 - \exp(-1 * E_A)$$

The statistical significance of the adjusted effectiveness estimate for CHMSL is tested by performing a CATMOD analysis of the preceding 4 x 2 tabulation of YT by impact location [32]. The dichotomous dependent variable is REARIMP (1 for rear impacts, 0 for other locations). The independent variables are YT (4 groups, but treated as a linear or "direct" variable with values -2, -1, 0 and 1) and CHM (= 0 when YT = -2 or -1; = 1 when YT = 0 or 1). Essentially, YT models the "vehicle age effect" and CHM models the true effect of the lamps after controlling for vehicle age. The effect of the lamps is significant when the coefficient for CHM has a statistically significant ^{2} value in the CATMOD analysis.

The preceding analysis could be biased because it aggregates data from all the States. For example, pre-CHMSL trucks could be overrepresented in a State where vehicles of all types have lower-than-average proportions of rear impact crashes. To adjust for biases like that, a CATMOD analysis is performed on the 6 x 4 x 2 table of State by YT by impact location. The dependent variable is again REARIMP. The independent variables are State (a nominal variable with six categories), YT (a linear variable), and CHM (a dichotomous variable). The effect of the lamps is significant, after controlling for State and the vehicle age effect, when the coefficient for CHM has a statistically significant ^{2} value in this analysis.

4.2 Overall effectiveness

The basic table of crash involvements by impact type and YT, the truck's model year **relative to** the transition MY to CHMSL, combining the data for six States in all CY, looks like this:

	REAR IMPACT?	
YT Frequency Row Percent	**NO**	**YES**
-2 (Two MY before CHMSL)	27871 74.21	9685 25.79
-1 (Last MY before CHMSL)	29882 73.90	10554 26.10
0 (First MY with CHMSL)	35116 74.40	12080 25.60
1 (Second MY with CHMSL)	33195 73.78	11796 26.22

Although the table includes over 44,000 rear impact cases, the sample is nevertheless much smaller than what was available for the passenger car analyses of Chapter 2 (where a table spanning MY 84-87 and aggregating the eight States would have included 800,000 rear impact cases over a ten CY period, or an average of 80,000 per calendar year). Correspondingly, we can expect the overall effectiveness estimate based on this table to be less precise than the passenger car estimate in any single calendar year, let alone an aggregation of calendar years, such as 1989-95.

It is obvious from an inspection of the row percentages that the estimate of CHMSL effectiveness will be positive. The percent of crash involvements that were rear impacts declined from 26.10 in the last MY before CHMSL to 25.60 in the first MY with CHMSL - despite a vehicle age trend in the opposite direction, as evidenced by an increase in the percentage of rear impacts from YT -2 to YT -1 and another increase from YT 0 to YT 1.

The unadjusted effect of CHMSL is:

$$E_U = [\log 10554 - \log 29882] - [\log 12080 - \log 35116] = .0264$$

The statistics used for estimating the "vehicle age effect" are:

$$DEL_{BEFORE} = [\log 9685 - \log 27871] - [\log 10554 - \log 29882] = -.0163$$
$$DEL_{AFTER} = [\log 12080 - \log 35116] - [\log 11796 - \log 33195] = -.0325$$
$$DEL_{AVG} = \tfrac{1}{2}[(-.0163) + (-.0325)] = -.0244$$

The adjusted effect of CHMSL is the difference of the unadjusted effect and the age effect:

$$E_A = .0264 - (-.0244) = .0508$$

The percentage reduction of rear impacts attributed to CHMSL is calculated by converting E_A back to an odds ratio:

$$E_{\%} = 1 - \exp(-1 * .0508) = \mathbf{4.95\ percent}$$

This point estimate is very close to the long-term, 1989-95 effectiveness estimate for passenger car CHMSL, 4.3 percent (see Table 2-6). The similarity of the point estimates, however, may be deceptive, because the light truck estimate is subject to considerable sampling error (whereas the passenger car estimate had 95 percent confidence bounds ranging from 2.9 to 5.7 percent). When the statistical significance of the light truck estimate is tested by a CATMOD analysis of the preceding 4 x 2 table with YT and CHM as the independent variables, the coefficient for CHM has ^{2} = 4.51, slightly more than the ^{2} needed for statistical significance at the two-sided .05 level (3.89 - the critical value customarily used in NHTSA evaluations). Similarly, in the CATMOD analysis of the 6 x 4 x 2 table of State by YT by impact location, the coefficient for CHM has ^{2} = 4.62, again somewhat more than the ^{2} needed for statistical significance.

Confidence bounds for effectiveness may be obtained by noting that the standard deviation of the CHM coefficient in the first CATMOD analysis is .0245. In other words, the confidence bounds on E_A are .0508 ± (1.96 x .0245): a range from .0028 to .0988. When these changes in the log odds ratio are converted to percentage reductions in rear impacts, the confidence bounds for effectiveness, $E_{\%}$ range from **0.3 percent to 9.4 percent**.

These levels of uncertainty preclude definitive inferences about the effectiveness of CHMSL for light trucks. There may be some support for temporarily accepting, as a "null" hypothesis, that CHMSL are about equally effective in trucks than cars. But it is also conceivable that they are less effective in trucks than in cars, or, for that matter, more effective than in cars.

4.3 Effectiveness by truck type and size

Given that all the light truck data combined were not really sufficient for a precise effectiveness estimate, limited returns can be expected if the data are subdivided by truck type or size. Nevertheless, it is worth doing at least a preliminary analysis to see if there are any conspicuous outliers (in either a positive or a negative direction).

Table 4-2 performs the basic effectiveness analysis separately for pickup trucks, sport utility vehicles (SUV's) and vans. For example, an inspection of the row percents in the top section of

TABLE 4-2: CHMSL EFFECTIVENESS BY TRUCK TYPE (CY 1994-96 data from six States)

PICKUP TRUCKS

	REAR IMPACT?		$DEL_{BEFORE} = -.0455$ $E_u = .0223$ $DEL_{AFETR} = -.0394$ $DEL_{AVG} = -.0425$ $E_A = .0648$
YT Frequency Row Percent	NO	YES	
-2 (Two MY before CHMSL)	13978 75.25	4597 24.75	
-1 (Last MY before CHMSL)	14878 74.39	5121 25.61	
0 (First MY wtih CHMSL)	20897 74.82	7034 25.18	
1 (Second MY with CHMSL)	18370 74.07	6432 25.93	

observed effectiveness = $E_{\%}$ = **6.27 percent**

SPORT UTILITY VEHICLES

	REAR IMPACT?		$DEL_{BEFORE} = -.0196$ $E_u = -.0006$ $DEL_{AFETR} = -.0352$ $DEL_{AVG} = -.0274$ $E_A = .0268$
YT Frequency Row Percent	NO	YES	
-2 (Two MY before CHMSL)	4165 74.07	1458 25.93	
-1 (Last MY before CHMSL)	4737 73.69	1691 26.31	
0 (First MY wtih CHMSL)	5994 73.68	2141 26.32	
1 (Second MY with CHMSL)	5665 72.99	2096 27.01	

observed effectiveness = $E_{\%}$ = **2.64 percent**

VANS

	REAR IMPACT?		DEL_{BEFORE} = .0235 E_{u} = .0314 DEL_{AFETR} = -.0101 DEL_{AVG} = .0067 E_{A} = .0247
YT Frequency Row Percent	NO	YES	
-2 (Two MY before CHMSL)	9728 72.83	3630 27.17	
-1 (Last MY before CHMSL)	10267 73.29	3742 26.71	
0 (First MY wtih CHMSL)	8225 73.90	2905 26.10	
1 (Second MY with CHMSL)	9160 73.70	3268 26.30	

observed effectiveness = $E_{\%}$ = **2.44 percent**

Table 4-2 makes it clear that the CHMSL effectiveness estimate will be positive. The percentage of crash involvements that were rear impacts dropped from 25.61 to 25.18 in the model year that CHMSL were introduced, in spite of the fact that it was on a rising trend the year before, and rose again the year after. The unadjusted log odds reduction for CHMSL is .0223 and the average age effect is -.0425. The point estimate is that CHMSL reduced rear impacts in pickup trucks by 6.27 percent. This reduction is not statistically significant: in the CATMOD analysis of the 4 x 2 table for pickup trucks, with YT and CHM as the independent variables, the coefficient for CHM has ^{2} = 3.64.

Similarly, the middle section of Table 4-2 analyzes the crash involvements of SUV's. The point estimate is that CHMSL reduced rear impacts in SUV's by 2.64 percent. This reduction is not statistically significant: in the CATMOD analysis, the coefficient for CHM has ^{2} = 0.23. The lower section indicates a 2.44 percent reduction of rear impacts for CHMSL in vans. This point estimate is also nonsignificant (^{2} = 0.22).

The differences between the three point estimates, 6.27, 2.64 and 2.44 percent, are very much in the "noise" range. In a CATMOD analysis of the 3 x 4 x 2 table of truck type by YT by impact location, with TRKTYP, YT, CHM as the independent variables, the coefficient for the interaction term TRKTYP * CHM had ^{2} = 0.67. That falls well short of the ^{2} needed for statistical significance. In other words, no significant differences in effectiveness by truck type were detected.

Table 4-3 compares the effect of CHMSL in compact and full-sized light trucks. The observed effectiveness of CHMSL in compact pickup trucks, SUV's and vans is 3.34

percent. This point estimate is not statistically significant (^{2} = 1.41). The effectiveness in full-sized light trucks, 7.28 percent, is likewise nonsignificant (^{2} = 3.32).

The differences between these two point estimates, 3.34 and 7.28 percent, is in the "noise" range. In a CATMOD analysis of the 2 x 4 x 2 table of truck size by YT by impact location, the coefficient for the interaction term SIZE * CHM had a nonsignificant ^{2} = 0.66.

While the data are still insufficient to distinguish the CHMSL effects in different types or sizes of trucks, one trend in the results is encouraging. All five point estimates (pickup, SUV, van, compact, full-sized) were positive. In four of the five analyses, even the unadjusted CHMSL effects were positive, showing a reduction in the proportion of rear impacts in the model year that CHMSL were first installed.

TABLE 4-3
CHMSL EFFECTIVENESS BY TRUCK SIZE
(CY 1994-96 data from six States)

COMPACT TRUCKS

	REAR IMPACT?		DEL$_{BEFORE}$ = -0084 E$_u$ = .0129 DEL$_{AFETR}$ = -.0339 DEL$_{AVG}$ = -.0211 E$_A$ = .0340
YT Frequency Row Percent	NO	YES	
-2 (Two MY before CHMSL)	17719 73.63	6347 26.37	
-1 (Last MY before CHMSL)	20245 73.46	7313 26.54	
0 (First MY wtih CHMSL)	22500 73.71	8023 26.29	
1 (Second MY with CHMSL)	20192 73.05	7448 26.95	

observed effectiveness = E $_{\%}$ = **3.34 percent**

FULL-SIZED TRUCKS

	REAR IMPACT?		DEL$_{BEFORE}$ = -.0226 E$_u$ = .0448
YT Frequency Row Percent	NO	YES	
-2 (Two MY before CHMSL)	10152	3338	

	75.26	24.74	$DEL_{AFETR} = -.0391$ $DEL_{AVG} = -.0308$ $E_A = .0756$
-1 (Last MY before CHMSL)	9637 74.83	3241 25.17	
0 (First MY wtih CHMSL)	12616 75.67	4057 24.33	
1 (Second MY with CHMSL)	13003 74.94	4348 25.06	

observed effectiveness = $E_{\%}$ = **7.28 percent**

THE LONG-TERM BENEFITS AND COSTS OF CHMSL

When all cars and light trucks have CHMSL, the lamps will prevent an estimated 92,000-137,000 police-reported crashes per year, and approximately 102,000 unreported crashes. CHMSL will reduce property damage and its associated societal costs by approximately $655,000,000 per year (in 1994 dollars) in reported and unreported crashes. The lamps will prevent 58,000-70,000 injuries per year. CHMSL add $12 to the price of a car or light truck and one pound to its weight. The annual cost of CHMSL to consumers is about $206,000,000, and it is a fraction of the benefits. Even though the effectiveness of CHMSL has declined substantially from its initial level, this still is and will continue to be a highly cost-effective safety device.

Crashes avoided

Police-reported crashes: NHTSA's most recent analysis of the economic cost of motor vehicle crashes estimates that 9,701,040 crashes were reported to the police during 1994 in the United States [2], p. 9. However, CHMSL only has a potential for effectiveness in those crashes where at least one car or light truck had rear-impact damage. CHMSL cannot be expected to have any effect on crashes where all the involved vehicles had only frontal, side, or rollover damage, or on crashes where the only vehicles with rear-impact damage were heavy trucks, motorcycles, etc. The percentage of police-reported crashes in which at least one car or light truck had rear-impact damage is estimated from 1995 data from the same eight States whose files were employed in the effectiveness analyses of Chapter 2, using the same definitions of "rear-impact damage" as in that chapter:

	Population	Proportion of Crashes in which a Car or Light Truck had Rear-Impact Damage
Florida	13,003,000	.3189
Indiana	5,564,000	.3468
Maryland	4,799,000	.3070
Missouri	5,138,000	.3062
Pennsylvania	11,862,000	.2910
Texas	17,060,000	.3453
Utah	1,728,000	.3240
Virginia	6,217,000	.3795
Population-weighted average		.3271

Thus, there were .3271 x 9,701,040 = 3,173,000 crashes in which at least one car or light truck had rear-impact damage. The long-term (1989-95 and onwards) effect of passenger car CHMSL, as estimated in Chapter 2, is to reduce these crashes by 4.33 percent. Let us assume, for the time being, a similar effectiveness in light trucks. As a result, the annual benefit is estimated to be

.0433 x .3271 x 9,701,040 = 137,000 fewer police-reported crashes each year.

For a more conservative estimate of benefits, we can utilize the estimate of police-reported crashes generated by NHTSA's General Estimates System (GES) and reported in *Traffic Safety Facts* [34], p. 14. (NHTSA's economic cost study, however, presents various reasons why the direct GES number is a substantial underestimate of actual police-reported crashes [2], pp. 16-21.) According to GES, there were 6,492,000 police-reported crashes in the United States in 1994. In that case the estimated long-term crash reduction for CHMSL would be

.0433 x .3271 x 6,492,000 = 92,000

Unreported crashes: NHTSA's economic cost study estimates that 7,173,091 crashes that occurred in the United States during 1994 were not reported to the police [2], p. 9. The average unreported crash tends to have lower severity than the average police-reported crash: e.g., crashes that do not result in enough damage to meet a State's reporting threshold would not be reported. However, the analyses of Chapter 3 did not show any substantial differences in CHMSL effectiveness as a function of crash severity (except for zero effectiveness in fatal crashes) Let us assume the same 4.33 percent reduction in unreported crashes as in police-reported crashes, and also that the proportion of rear impact is the same in reported and unreported crashes. In that case the estimated long-term benefit of CHMSL would be

.0433 x .3271 x 7,173,091 = 102,000 fewer unreported crashes each year.

Police-reported plus unreported crashes: The preceding calculations suggest a range of 92,000 to 137,000 police-reported and 102,000 unreported crashes avoided each year. That adds up to a range of 194,000 to 239,000 crashes avoided per year.

Property damage avoided

Police-reported plus unreported crashes: NHTSA's analysis of the economic cost of crashes estimates that the total cost of property damage resulting from all motor vehicle crashes in the United States during 1994 was $52,119,000,000 [2], p. 7. (The study does not apportion that sum between police-reported and unreported crashes.) The eight State files analyzed in Chapter 2 do not supply any data on the cost of property damage in rear impacts vs. other impacts, but the 1994 North Carolina file (analyzed in Chapter 4) has nearly complete records of the estimated total damage in each crash: the sum of the damages to the various vehicles and other property. In North Carolina, the average property damage in crashes where at least one car or light truck was rear-impacted was only 84.07 percent as high as the average property damage in all other crashes. Let us assume that the same cost ratio prevails in other States' reported crashes, and also in unreported crashes. In that case, even though rear impacts account for 32.71 of all crashes, they only account for

[.8407x.3271] / [.8407x.3271 + (1 - .3271)] = 29.01 percent of all property damage

Since, in the long term, CHMSL reduces rear impacts by 4.33 percent, the annual value of property damage avoided is:

.0433 x .2901 x $52,119,000,000 = $655,000,000

(When CHMSL succeeds in preventing a crash, there is a twofold benefit: the CHMSL-equipped vehicle escapes being struck in the rear and damaged, but so does the would-be striking vehicle.)

Injuries avoided

Police-reported crashes: NHTSA's economic cost analysis estimates that 4,089,930 people were injured, nonfatally, in police-reported crashes in the United States during 1994 [2], p. 9. CHMSL only has a potential for effectiveness in those crashes where at least one car or light truck had rear-impact damage; however, if CHMSL successfully prevents such a crash it will not only save the occupants of the rear-impacted vehicle from injury, but also the occupants of the other vehicles involved in the crash. The proportion of crash injury victims who were involved in crashes in which at least one car or light truck had rear-impact damage is estimated from 1995 data from the eight States:

	Population	Proportion of Crash Injury Victims

		Involved in Crashes where at least one Car or Light Truck had Rear-Impact Damage
Florida	13,003,000	.3386
Indiana	5,564,000	.3059
Maryland	4,799,000	.3321
Missouri	5,138,000	.2840
Pennsylvania	11,862,000	.3194
Texas	17,060,000	.3605
Utah	1,728,000	.3621
Virginia	6,217,000	.3536
Population-weighted average		.3353

Thus, there were .3353 x 4,089,931 = 1,371,000 people injured in reported crashes in which at least one car or light truck had rear-impact damage. The long-term (1989-95 and onwards) reduction of **injury** crashes by passenger car CHMSL, as estimated in Chapter 3, is 4.01 percent. Let us assume a similar effectiveness in light trucks. The annual benefit is estimated to be

.0401 x .3353 x 5,215,931 = 55,000 fewer people injured each year.

For a more conservative result, we can use the estimated number of people injured in police-reported crashes, as generated by NHTSA's General Estimates System (GES) and reported in *Traffic Safety Facts* [34], p. 15. (According to NHTSA's economic cost study, the direct GES number is a substantial underestimate [2], pp. 16-21.) Based on GES, 3,215,000 people were injured in police-reported crashes in the United States in 1994. In that case the estimated long-term injury reduction for CHMSL would be

.0401 x .3353 x 3,215,000 = 43,000

Unreported crashes: NHTSA's economic cost study estimates that 1,126,000 people were injured in unreported motor vehicle crashes during 1994 [2], p. 9. Let us assume the same 4.01 percent injury-crash reduction for CHMSL in unreported crashes as in police-reported crashes, and also that the proportion of injuries occurring in rear impacts is the same in reported and unreported crashes. In that case the estimated long-term benefit of CHMSL would be

.0401 x .3353 x 1,126,000 = 15,000 fewer unreported injuries each year.

Police-reported plus unreported crashes: The preceding calculations suggest a range of 43,000 to 55,000 fewer people injured per year in police-reported crashes and 15,000 in unreported crashes. That adds up to a range of 58,000 to 70,000 injuries avoided per year.

Cost analysis

During 1985-88, a NHTSA contractor estimated the purchase price increase and weight added to passenger cars by CHMSL, based on detailed inspection and disassembly of the lamps in a representative set of 30 make-models [4], [26]. NHTSA's 1989 evaluation of CHMSL took a sales-weighted average of those estimates [19], pp. 46-49. On average, the lamps added $9.05 (in 1987 dollars) to the purchase price and 0.95 pounds to the weight of a car. The added weight resulted in a small penalty of added fuel consumption over the life of the car, amounting to a net present value of 95 cents. One additional consumer cost was identified: CHMSL bulbs may burn out and require replacement. The net present value of that replacement cost was estimated at 48 cents. In 1987 dollars, the lifetime consumer cost per car, equal to the sum of the purchase price increase, the fuel penalty and bulb replacement, was $9.05 + .95 + .48 = $10.48 per car. Each of those costs can be inflated to 1994 dollars, based on price indices supplied by the Bureau of Labor Statistics [3]. The index for consumer goods, such as lamps and replacement bulbs, rose from 113.6 in 1987 to 148.2 in 1994. The average price of a gallon of fuel rose from 98 cents in July 1987 to $1.199 in July 1994. Thus, the lifetime consumer cost of CHMSL, in 1994 dollars, is:

$11.81 (purchase price) + 1.16 (fuel) + .63 (replacement bulbs) = $13.60 per car

NHTSA's *Final Regulatory Impact Analysis* for light truck CHMSL predicted that CHMSL could be provided for the overwhelming majority of pickup trucks, vans and sport utility vehicles at the same price as for passenger cars. However, in certain multistage vehicles, produced at the rate of 300,000 per year, there might be complications that could increase the cost by 50 percent [14], pp. 28-32.

Almost exactly 15,000,000 passenger cars and light trucks were sold annually in the United States during 1994-96 [1]. We can assume that the lifetime cost of CHMSL was $13.60 in 14,700,000 of those vehicles, and $20.40 in the 300,000 multistage trucks. Thus, the total annual cost of CHMSL is

$13.60 x 14,700,000 + $20.40 x 300,000 = $206,000,000

That is just a fraction of the estimated property damage reduction of $655,000,000. Since the damage reduction alone pays for the lamps several times over and, in addition, the lamps prevent many nonfatal injuries, it is obvious that CHMSL, despite the substantial decline in their effectiveness from 1987 values, are still highly cost effective.

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APPENDIX

Chapter 2 of the main report estimated the CHMSL effect by assuming a functional (polynomial) form for the vehicle age effect and adjusting the data to correct for this effect. This approach permits use of all available data for each year's estimate. However, questions about the goodness of fit of the model arise, and such questions are generally difficult to answer. The use of age-adjusted data introduces an extra component of variance which is not accounted for in the t-statistics. Additionally, since the adjustment is based on several years of data, the point estimates created by this method are not independent between calendar years and, therefore, cannot be combined by standard methods.

For these reasons, the estimates of relative risk and their t-values were recomputed in this Appendix. The goal of this Appendix is to validate the results of the main report and provide error estimates. Since the method used in the Appendix does not rely on any modeling assumptions and uses only part of the data, the new error estimates will be conservative. These error estimates will also be used for the point estimates in the main report.

Estimates of relative risk were computed by two similar methods:

Method 1 estimates CHMSL effectiveness in CY n in the following way. Let:

N1 = number of MY 86 vehicles in the eight states in rear crashes in CY n,

N2 = number of MY 85 vehicles in non-rear crashes in CY n,

N3 = number of MY 85 vehicles in rear crashes in CY n-1,

N4 = number of MY 84 vehicles in non-rear crashes in CY n-1.

Then the CY n estimate of the relative risk for a rear crash with a CHMSL compared to without

is (N1/N2)/(N3/N4). The log of this estimate has standard error 1/N1 +1/N2 +1/N3 +1/N4.

The reasoning is as follows: consider, for example, the calendar year n = 91. Then N1 is the number of rear crashes in CY 91 among 5 year old cars. N2 is the number of non-rear crashes in CY 91 among 6 year old cars. N3 is the number of rear crashes in CY 90 among 5 year old cars. N4 is the number of non-rear crashes in CY 90 among 6 year old cars. Therefore, both N1/N2 and N3/N4 are ratios for some CY of the quantity

> {rear crashes among 5 year old cars}/{non-rear crashes among 6 year old cars}.

The only difference between them is that N1 comes from the only CHMSL MY involved. Therefore, that should account for any significant difference between N1/N2 and N3/N4. This method makes no assumptions about the nature of the vehicle age effect, such as assuming that the change is the same from (e.g.) age 4 to 5 as from age 6 to 7, or even that it is monotonic. The disadvantage of this method is that only the data involving three MYs are used. As a result, larger standard errors can be expected than those in the main report, which were based on a wider range of MYs. Method 1 can be applied with the available data for CY 87-95.

Method 2 estimates CHMSL effectiveness in CY n as follows. Let:

N1 = number of MY 86 vehicles in the eight states in rear crashes in CY n,

N2 = number of MY 85 vehicles in non-rear crashes in CY n,

N3 = number of MY 87 vehicles in rear crashes in CY n+1,

N4 = number of MY 86 vehicles in non-rear crashes in CY n+1.

Then the CY n estimate of the relative risk for a rear crash with a CHMSL compared to without

is (N1/N2)/(N3/N4). The log of this estimate has standard error 1/N1 +1/N2 +1/N3 +1/N4.

The reasoning behind method 2 is similar to that for method 1 except that the denominator comes from data in which both MYs are CHMSL. Method 2 can be applied with the available data for CY 86-94.

One goal of the analysis was to test if the CHMSL effect reached a level at which it remained stable after the first three years. For that purpose, independent estimates for the calendar years 1989-95 were created. In order to create these independent estimates, the data were divided at random into four databases called 1, 2, 3 and 4. Estimates for each calendar year were calculated according to the following plan:

Databases Used in Each Estimate

CY	Method 1	Method 2
86	N/A	all combined
87	1 and 3 combined	2 and 4 combined
88	1 and 3 combined	2 and 4 combined
89	1	2
90	3	4
91	1	2
92	3	4
93	1	2
94	3	4
95	1 and 2 combined	N/A

For each year that had two estimates (87-94), a combined final estimate was formed in the standard way by taking a weighted average of the two with weights inversely proportional to the variances. This resulted in a set of final estimates for each CY 86-95.

The estimates for CYs 86, 87 and 88 were created with the maximum possible data in this scheme. The estimates for CY 89-95 were created to be mutually independent so that they could be combined; it can be verified that no crash in the data was used in the final estimate for more than one of the years 1989-95. It should be observed that, since essentially half the available data were used in each CY 1989-95, standard errors are higher than they would be with a more efficient use of the data. The combined estimate (over CYs 1989-95) was created by a standard method (Ref J. Fleiss, Statistical Methods for Ratios and Proportions). The method creates, in addition to the combined estimate and its standard error, a chi square for homogeneity that tests if each of the individual estimates are really estimates of the same parameter and can correctly be combined. In this case, the chi square for homogeneity is 4.92152 on 6 degrees of freedom so that there is no reason to reject the null hypothesis of homogeneity across years 1989-95.

The log relative risk is the logarithm of the effect of CHMSL on the probability of a rear impact crash (point estimate). Negative numbers indicate a benefit for CHMSL. SE is the standard error of the point estimate. T is the value of the t statistic, obtained as the ratio of the point estimate to its standard error. The results are displayed:

CHMSL Effectiveness Estimates

1986-95, Eight States Combined

CY	Log Rel. Risk	SE	T
86	-0.050997	0.013185	-3.86780
87	-0.071421	0.012107	-5.89915
88	-0.045253	0.011872	-3.81183
89	-0.019157	0.017266	-1.10957
90	-0.044590	0.018134	-2.45901
91	-0.059731	0.018968	-3.14904
92	-0.067590	0.019493	-3.46737
93	-0.042086	0.019922	-2.11248
94	-0.042328	0.020529	-2.06182
95	-0.078990	0.021636	-3.65086
1989-95 combined	-0.048790	0.0072864	-6.69602

The point estimates generated by these models are quite consistent with those in the main report. CHMSL reduced the log relative risk of a rear impact by 5 percent in 1986, 7 percent in 1987, 5 percent in 1988 and an average of 5 percent in 1989-95. The standard errors are 1.3 percent for 1986, 1.2 percent for 1987, 1.2 percent for 1988 and 0.7 percent for 1989-95. As expected, these conservative standard error estimates are larger than those computed in Chapter 2. However, it is confirmed that the point estimates for 1986, 1987, 1988 and 1989-95 are all statistically significant.