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An Evaluation of the Effects of Glass-Plastic Windshield Glazing in Passenger Cars

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An agency staff review of existing Federal regulations performed in compliance with Executive Order 12291 (recently superseded by Executive Order 12866).

16. Abstract

Following revision of the applicable Federal safety standard in 1983, two motor vehicle manufacturers equipped some of their cars with glass-plastic windshields for testing in rental fleets. One company also installed the windshield in regular production cars for a brief period. The windshield was thought to have high potential for reducing windshield-caused lacerations to occupants involved in crashes. There were also concerns over the durability of the product. This study is an evaluation of the safety, durability, and cost of glass-plastic windshield glazing. It is based on analyses of data from State crash files, fleet tests, and other sources. The study findings are:

- Safety. Crash data indicate that the injury reduction potential of glass-plastic windshields is substantially less than predicted.
- Durability. Fleet and warranty claim data indicate that durability problems are greater than anticipated.
- Costs. A glass-plastic windshield adds $65 to the cost of a new car. Additional "durability" costs would also accrue. Replacement cost is estimated to exceed $1,700.
- Today's high rates of safety belt use, coupled with the growing number of air bag-equipped cars, mean that windshield-caused injuries have decreased and will continue to decline.

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EXECUTIVE SUMMARY

Introduction

Under Executive Order 12866 (and prior Executive Order 12291), the National Highway Traffic Safety Administration (NHTSA) has been directed to carry out periodic reviews of the automotive safety regulations which it has issued. These reviews provide a means of measuring the impacts of those regulations, in terms of the benefits which accrue to, and the costs which are imposed upon, the American public.

This study is a review of the effects of glass-plastic windshield glazing. It is NHTSA's second review of the effects of windshield glazing in passenger cars. The first study, published in 1985, evaluated the safety benefits and costs of conventional windshield glazing which has been standard equipment in American-made vehicles since 1966. The conventional windshield, often referred to as the "HPR" (or High Penetration Resistant) windshield, was found to be a major safety improvement over previous glazing designs, and was credited with bringing about a major reduction in the frequency and severity of head and facial injuries which resulted from occupants being thrown against the windshield in crashes. The primary benefit of the HPR design was a large reduction in the more severe facial lacerations and fractures, with a more modest reduction in less severe, or minor lacerations. These benefits were attributed to improved production techniques which significantly increased the penetration resistance of the windshield. Occupant penetration of the windshield is generally associated with more severe injury.

Federal Motor Vehicle Safety Standard (FMVSS) No. 205, issued by NHTSA in January 1968, prescribes safety requirements for all glazing materials used in motor vehicles, including the windshield, the windows, and any interior partitions. The purpose of this standard is to: (1) reduce injuries resulting from impact with the glazing surfaces; (2) minimize the possibility of occupants being thrown through the windshield in collisions; and (3) ensure a necessary degree of transparency in the glazing for driver visibility. In 1983, the agency amended FMVSS No. 205 to permit the use of a new type of glazing, known as "glass-plastic" glazing. This change to the standard did not require the use of glass-plastic glazing, but rather permitted the use of this material at the option of the motor vehicle manufacturer.

The essential promising aspect of the glass-plastic windshield was its considered potential to further reduce windshield-induced lacerations. While the HPR windshield had substantially reduced these types of injuries, a considerable number still remained, primarily those in the minor severity category. The conventional windshield is a three-ply design consisting of two plies of glass sandwiched around a thin interply of plastic (polyvinylbutyral). The glass-plastic windshield is of similar design with the exception of an inner plastic liner (polyurethane) that is bonded to the inside glass ply -- i.e., the side of the windshield which faces the passenger compartment. The inner plastic liner would be expected to provide additional protection (over that afforded by the HPR design) against cuts from broken glass shards produced when occupants collide with the windshield during crashes. The plastic liner would provide a "containment mechanism" for the broken pieces of glass, thereby reducing the occupant's chances of coming into direct contact with the sharp edges of these glass fragments. While glass-plastic windshields were expected to substantially reduce lacerative injuries, there was concern that the inner plastic layer, being a much softer material than glass, could be susceptible to damage that could degrade driver visibility and reduce windshield durability. There was also some concern that the stiffer surface presented by the 4-ply glass-plastic windshield might contribute to a greater incidence of blunt impact injuries (i.e., concussions, contusions, complaint of pain). Overall, however, the potential safety gain from glass-plastic glazing was believed to far outweigh possible durability and other problems, and, therefore, the agency elected to permit (but not require) its use in order that real-world data might be developed to provide an evaluation of these issues.

Glass-plastic glazing was first developed in France by the Saint Gobain Vitrage Company, and some of the European car companies (among them, Peugeot, Porsche, and Mercedes) had fitted a limited number of their vehicles with glass-plastic windshields in the late 1970's and early 1980's to test the material in the market place. In the early 1980's, two domestic companies, General Motors and Ford, equipped a number of their vehicles with glass-plastic windshields and placed them in rental fleets to field test the windshields. Later, in 1984, General Motors introduced the glass-plastic windshield to the general public, by making it standard equipment on one of its luxury car models, the Cadillac Seville Elegante. Early in the 1985 model year, the windshield was made standard on all Seville models, and for model years 1986 and 1987, the company expanded its use of the plastic windshield glazing, making it standard on all Cadillac Eldorados, all Buick Rivieras, all Oldsmobile Toronados, and all

Pontiac 6000 STE's. At the end of the 1987 model year, however, General Motors discontinued all use of glass-plastic windshields in its regular production vehicles. GM stated that the reason for discontinuing installation of the windshield was because of its high replacement costs for customers and high warranty costs for the company. It is estimated that approximately 210,000 regular production GM cars with glass-plastic windshields were produced before the company halted use of the windshield. No other car companies, domestic or import, have since equipped any of their U. S. marketed regular production vehicles with glass-plastic glazing.

Study Objectives and Data Sources

The objectives of this study are threefold:

(1) to estimate the extent to which glass-plastic windshield glazing could reduce lacerative injuries resulting from occupant contact with the windshield in crashes,

(2) to assess the nature, extent, and consequence of durability problems that could be experienced if glass-plastic windshields were installed in vehicles on a volume basis, and

(3) to estimate the costs that would be incurred from the use of glass-plastic windshields in motor vehicles.

The injury reduction effect of glass-plastic windshields is primarily based on the analysis of police reported crash data from three States, New York, Pennsylvania, and Indiana. State data -- in particular data from New York State -- constituted a major source of the information utilized in NHTSA's earlier study of the effects of HPR windshield glazing. Although not without certain limitations, these States provide detailed injury data in their automated crash files, such as type of injury and body location of injury, which are necessary to estimate the effect of the windshield glazing. The analyses are based on comparing the rate of bleeding injuries (primarily to the head and face) sustained by front seat occupants of glass-plastic vehicles (1985, 1986, and 1987 GM vehicles) with the rates of similar types of injuries sustained by front seat occupants of a control sample of vehicles. Bleeding injuries are considered to be generally synonomous with lacerative injuries. The control vehicles are GM cars of similar size, weight, and price range, which are equipped with conventional (i.e., HPR) windshields. The crash and injury results of special fleet tests of vehicles equipped with glass-plastic windshields are also reviewed.

The durability information is based primarily on the GM and Ford rental fleet field tests, together with other information, including warranty data, obtained from these manufacturers. The costs of glass-plastic glazing are based on earlier estimates made by the agency, on information solicited from the motor vehicle manufacturers, and on data on the aftermarket replacement costs of the glazing. A consumer survey of vehicle owners had originally been planned to obtain "first-hand" information on owner experience with the windshields, but budgetary priorities precluded the agency from conducting the survey.

It should be noted that major advances in motor vehicle safety have occurred since the agency amended FMVSS 205 in 1983 to permit the use of glass-plastic glazing. Safety belt use has increased to levels of over 60 percent, compared to a low 14 percent in 1983. Also, air bags not only have received wide acceptance, but will be required in all new cars and light trucks by the late 1990's. These significant increases in occupant protection mean that the numbers of occupants who impact the windshield (thereby being exposed to lacerative injuries from broken glass) have been substantially reduced and will continue to diminish. Hence, the magnitude of the safety problem originally targeted by glass-plastic windshield glazing is being substantially reduced. This situation contrasts rather sharply with the occupant restraint picture in 1983 when NHTSA amended Standard 205. At that time, the agency recognized that substantial changes in the availability and use of passive restraints could alter the need for the additional occupant protection qualities expected from glass-plastic glazing. However, if automatic restraints were eventually installed in passenger cars, the agency believed that they would primarily be passive belt designs (as opposed to air bag systems) and that a substantial portion of motorists would elect not to use them. This was also prior to the period of State Mandatory Restraint Use Laws and other developments which have since fostered marked increases in the use of safety belt systems, both active and passive.

Following are the principal findings and conclusions of this study:

Findings

Injury Reduction

- The analysis of available crash data from three States found no reduction in bleeding (or lacerative) injuries for vehicles equipped with glass-plastic windshields as compared to vehicles equipped with conventional windshields. Small sample sizes of injury data plus other restrictions in the data serve to limit the reliability of this finding, and the results are not interpreted as precluding that glass-plastic windshields may have a beneficial effect in reducing lacerative injuries.

- Data from fleet operations were insufficient for analyses with respect to the injury reduction potential of glass-plastic glazing. However, these data did provide limited evidence that lacerations do indeed result from glass-plastic glazing. Lacerations from glass-plastic glazing were described as "skin-splitting", or "tearing-type" injuries, resulting from blunt impact with the plastic inner liner of the windshield, rather than lacerations from broken glass. In these injury cases, the windshield glass was broken, but the broken pieces did not penetrate through the plastic inner liner.

Durability

- Although not necessarily representative of the motoring public in general, data from rental fleet operations indicates that durability issues associated with glass-plastic windshields could be of significant concern. Primarily, these issues revolve around the susceptibility of the plastic inner liner to damage (i.e., cuts, scratches) from the everyday operating environment:
    - in one fleet, an estimated 42 percent of the windshields were found to have moderate-to-heavy scratches and cuts after 15 months of operation. The vehicle manufacturer was concerned that this damage might not be acceptable to longer term owners.
    - in another fleet, 44 to 48 percent of the windshields were replaced due to damage occurring during fleet operations, and in order to "prepare the vehicles for resale" at the end of the one to one and one-half year test period. Available data indicate a replacement rate of 10 to 15 percent for conventional windshields in comparable rental fleet service.
    - all glass-plastic windshields replaced in the rental fleets were replaced with conventional windshields.

- Warranty claim data from the one manufacturer which briefly introduced glass-plastic windshield glazing to the general public also indicated that durability of the material was a concern. Warranty claim rates of 12.6 percent, based on 12 months/12,000 miles of service, were more than four times as high as for conventional windshields. Vehicle owners cited poor visibility and scratching/scoring as the primary reasons for windshield replacement.

Costs

- It is estimated that a glass-plastic windshield, if installed in volume quantities, would add $65 to the cost of a new car. Additional consumer costs would be expected due to damaged windshields that would have to be replaced after the new vehicle warranty period expired, or for damage not covered under the warranty.

- Data on aftermarket windshield replacement show the cost of replacing a glass-plastic windshield to be over $1,700, or more than $1,200 above the cost of replacing a conventional windshield. To what extent this high cost is due to limited production quantities or to glass replacement shop inexperience/unfamiliarity with the glass-plastic glazing, as opposed to lower durability characteristics of the glass-plastic windshield, cannot be answered with available data. Due to this very high cost, it is believed that almost all aftermarket replacements of glass-plastic windshields have been made with conventional windshields rather than the original equipment glass-plastic windshields.

- Both motor vehicle and glass manufacturers cited high costs as the reason why the market for glass-plastic windshields failed to develop.

Conclusions

- Analyses of available crash information, because of small sample sizes and other limitations in the data, are insufficient to support firm conclusions. Nevertheless, the analyses of State crash data, together with limited evidence from fleet crash data, do suggest that the actual lacerative injury reduction benefits from glass-plastic glazing are likely to be substantially less than the essential elimination of windshield-caused lacerations, as originally projected by the agency. While there is evidence that the inner plastic liner does serve to reduce the occupant's chances of coming into contact with broken glass shards, lacerations can still occur from blunt impact with the inner liner. Data are insufficient to determine whether these injuries differ from the lacerations due to conventional windshields, with respect to severity or facial scarring potential.

- Data from rental fleet operations and manufacturer warranty claims indicate that durability problems are greater than originally anticipated by the agency. Potential solutions to these durability concerns, including windshield warning labels and "special care" information in the vehicle owners manual, did not appear sufficient to prevent damage from occurring to the plastic inner liner, nor warranty claim rates several times higher than for conventional windshields. The high replacement cost of glass-plastic windshields is also believed to reflect, at least partially, the lower durability characteristics of the glazing.

- Depending on the nature and extent, damage to the plastic inner liner of the glass-plastic windshield could degrade driver visibility, thereby creating a safety concern. Insufficient data are available to quantify the significance of this issue. Also, the indicated widespread replacement of damaged glass-plastic windshields with conventional windshields, due to cost or other considerations, has the effect of negating any safety benefits inherent in the glass-plastic glazing.

- The higher component and durability costs of the glass-plastic windshield, compared to that for a conventional windshield, would appear to be high relative to the injury reduction benefits that might be realized from the glazing.

- Today's high rates of safety belt use, together with the universal acceptance of air bags -- in contrast to the situation in 1983 when the agency permitted the use of glass-plastic glazing -- mean that the size of the lacerative injury problem due to occupant-windshield contact is substantially smaller than it was a decade ago and will continue to diminish.

CHAPTER 1

INTRODUCTION

This report is another in a continuing series of studies that have been undertaken in recent years by the National Highway Traffic Safety Administration (NHTSA) for the purposes of reviewing the Federal motor vehicle safety regulations which it has issued. NHTSA, along with other Federal agencies, are required to carry out such studies in order to assess the impact of their regulations, in terms of the benefits and costs to the American public. Guidelines for conducting the studies are contained in Executive Order 12291 (recently superseded by Executive Order 12866.

This study is a review of the effects of glass-plastic windshield glazing. Motor vehicle glazing is regulated under Federal Motor Vehicle Safety Standard (FMVSS) No. 205. The purpose of the standard is threefold [1]:

(1) to reduce injuries resulting from occupant impact with glazing surfaces during vehicle crashes;

(2) to ensure a necessary degree of transparency in motor vehicle windows for driver visibility, and;

(3) to minimize the possibility of occupants being thrown through the vehicle windshield in collisions.

The standard type of windshield glazing used in today's passenger cars is known as "HPR", or High Penetration Resistant glazing. The safety effects of conventional (HPR) windshield glazing, which has been standard equipment in passenger cars since 1966, were studied in an earlier (1985) report published by the agency. That report, entitled "An Evaluation of Windshield Glazing and Installation Methods for Passenger Cars," found that HPR glazing greatly reduced the risk of serious lacerations to the face, scalp, and mouth, as well as fractures of the facial bones and nose, and occular avulsions [2]. It was estimated that the introduction of the HPR windshield reduced these types of injuries by 50 to 75 percent, as compared to the number of injuries that would have been expected to occur with pre-HPR windshield glazing. These rather dramatic findings were attributed to an improved method of bonding together the two glass outer plies and the single plastic (polyvinylbutyral) interply which comprise the windshield. This production achievement substantially increased the impact velocity required for an occupant's head to tear through and penetrate the plastic interlayer, given a crash event. Serious windshield injuries are typically associated with windshield penetration. In addition to the serious injury reduction, the HPR windshield design was also credited with a 25 percent reduction in minor severity windshield-induced lacerations. This secondary benefit was attributed to another characteristic of the HPR design which caused the glass to crack into smaller, less injurious pieces, than in pre-HPR glazing. Minor windshield lacerations are typically associated with impacts sufficient to break the inner glass ply, but not sufficient to cause windshield penetration [2].

In 1980, the Saint Gobain Vitrage Company (France) petitioned the NHTSA to amend FMVSS 205 to permit the use of a new glazing product developed by the company. The product, tradenamed "Securiflex," was a new type of glazing generically referred to as "glass-plastic" glazing. Glass-plastic glazing differs from conventional, 3-ply windshield glazing in that the inside glass surface -- i.e., the side which faces the vehicle passenger compartment -- is covered with a thin plastic sheet of polyurethane. The primary safety benefit anticipated from the addition of the plastic film is a reduction in lacerative injuries to occupants who contact the windshield during crashes. The plastic inner layer is expected to contain broken glass shards and keep them from coming into contact with the occupants' skin. Following further study of glass-plastic glazing, including a review of public comments solicited on the subject, the agency, in 1983, amended FMVSS 205 to permit the use of glass-plastic glazing at the option of the motor vehicle manufacturer.

Study Objectives

The objectives of this study are:

(1) to estimate the extent to which glass-plastic windshield glazing could reduce lacerative injuries resulting from occupant contact with the windshield in motor vehicle crashes,

(2) to assess the nature, extent, and consequence of durability problems associated with the widespread use of glass-plastic windshields in motor vehicles,

(3) to estimate the costs of using glass-plastic windshhield glazing in motor vehicles, as compared with the costs of conventional windshield glazing.

When the agency authorized the use of glass-plastic glazing in 1983, it believed that the new material, if used in the windshields of all passenger cars, had the potential to essentially eliminate all lacerative type injuries resulting from occupant-windshield contact occurring in motor vehicle crashes. According to the agency's earlier evaluation study of conventional (HPR) windshield glazing, an estimated 450,000 lacerations per year -- the large majority of which were minor in nature -- still occurred after the HPR windshield was incorporated into the vehicle fleet. Most of the more serious lacerations were found to have been eliminated by the HPR windshield.

While the agency projected a dramatic reduction in lacerations, it also recognized that the softer nature of the plastic inner liner could result in durability problems from scratching or other types of abrasion that could result from the day-to-day motor vehicle operational environment. Such damage, if significant, could adversely affect driver visibility as well as customer satisfaction with the product. There was also some concern that the stiffer inner surface presented by the 4-ply glass-plastic windshield might contribute to an increase in head injuries generally associated with blunt impact trauma (i.e., concussions, contusions, complaint of pain). While it was recognized that these problems could arise, the potential safety benefit from glass-plastic glazing was believed to far outweigh any durability or other problems that might be associated with the material. Also, by permitting, but not requiring, glass-plastic glazing to be installed in vehicles, the agency provided a basis whereby actual, in-use data could be developed to permit an evaluation of the safety and durability issues.

Data Sources

Data for this study come from three principal sources -- State crash files; special fleet tests; and other information solicited from vehicle manufacturers, glass companies, and other sources. State crash files provide the primary source for estimating the injury reduction potential of glass-plastic glazing. State crash files (including one of the States used in this study) were also a primary source of data for the agency's 1985 evaluation study of conventional (HPR) windshield glazing. One motor vehicle manufacturer, General Motors, equipped certain of its luxury carlines with glass-plastic windshields during the 1984-1987 model years. The models involved were the Cadillac Seville, Cadillac Eldorado, Buick Riviera, Oldsmobile Toronado, and Pontiac 6000 STE. Altogether, the company sold approximately 210,000 of these vehicles to the general public before discontinuing installation of the glass-plastic windshield at the end of the 1987 model year. GM stated that the reason for not continuing to use the windshield was because it had resulted in high replacement costs for customers and high warranty costs for the company.

Three States, New York, Pennsylvania, and Indiana, contain sufficient detail in their motor vehicle accident data files to permit estimation of the bleeding (or lacerative) injury rate in these cars as compared to the estimated lacerative injury rate in a control sample of GM vehicles -- i.e., GM vehicles of similar size, weight, and price range, but with standard windshields. Two principal advantages of the data from these States are that their crash files list the type of injury sustained and also the area, or region of the body affected. Another advantage is that the State data offer the maximum sample sizes available for on-road crash experience of vehicles equipped with glass-plastic windshields. A fourth advantage is that the State files afford adequate sample sizes of crash-involved vehicles equipped with conventional (HPR) windshields, a necessity for providing representative baseline data from which to measure the effect of glass-plastic glazing on injury reduction.

There are also limitations to the State data which should be noted. Although type and location of injury are given in the three files, only one injury -- the most severe -- is recorded for each injured occupant. While this will result in underestimation of the actual lacerative injury rates in the two vehicle groups, it should not bias a statistical comparison of injury rates between the two groups of vehicles. A second limitation is that the data files do not identify the contact source of the injury -- i.e., the vehicle component causing the injury. To partially compensate for this limitation, the analyses are restricted to injuries which primarily occur to the head and face on the accident victims. Windshield lacerative injuries are most likely to involve these body areas. Also, only injuries to front seat occupants are considered. The inclusion of lacerative injuries from other than windshield contacts should not bias a comparison of injury rates between the glass-plastic vehicles and the conventional windshield vehicles. However, the limitation will result in a less discriminating analysis in that a statistically significant effect (i.e., injury reduction) for the glass-plastic vehicles can be expected to be detected only if the effect is reasonably large. The agency's original expectation was that the safety effect of the windshield would indeed be large -- it was projected that the glazing would essentially eliminate (i.e., be 100 percent effective) windshield-caused lacerations.

The crash injury experience of special rental fleet tests of vehicles equipped with glass-plastic windshields is also reviewed and evaluated in this study. Both General Motors and Ford conducted such fleet tests, primarily to obtain data on the durability aspects of the glazing.

During the 1980's, approximately 100,000 vehicles with glass-plastic windshields were also sold in Europe. However, no crash experience or other data were available on the European experience with glass-plastic windshields.

Information on durability problems experienced with glass-plastic windshields is based on the rental fleet tests noted above. An additional source of durability information was General Motors' warranty claims experience of its 1984-1987 vehicles equipped with glass-plastic windshields which were sold to the general public. A survey of the owners of these vehicles had been planned to obtain "first-hand" information on consumer experience with the windshields, but budgetary constraints precluded the agency from conducting of the survey.

Cost data on glass-plastic windshields are based on: (1) information contained in NHTSA's 1983 rulemaking analysis, supporting the decision to permit glass-plastic glazing, (2) General Motors' new vehicle warranty claims experience, (3) other data obtained from the vehicle manufacturers, and (4) data on the aftermarket replacement costs of glass-plastic glazing.

Report Outline

The study is presented in the three following chapters. Chapter 2 contains the analysis of the State crash data, fleet data, and other crash data to estimate injury reducing benefits of glass-plastic glazing. Chapter 3 discusses durability issues and Chapter 4 contains information on the costs of glass-plastic glazing. The Executive Summary contains the study findings and conclusions.

CHAPTER 2

INJURY REDUCTION EFFECTS

2.0 INTRODUCTION

This chapter describes the analyses and other available information used to estimate the injury reduction effects of glass-plastic windshields. The primary estimates of injury reduction are based on analyses of State data files which compare the crash injury experience between occupants of vehicles equipped with glass-plastic windshields and occupants of vehicles equipped with conventional windshields. The vehicles equipped with glass-plastic windshields, referred to as the "TEST" group, were comprised of the following vehicles:

Make Models	Model Years
Cadillac Seville	1985, 1986, 1987
Cadillac Eldorado	1986, 1987
Buick Riviera	1986, 1987
Oldsmobile Toronado	1986, 1987

Due to limitations on vehicle identification coding, it was not possible to include the Pontiac 6000 STE in the analysis.

The vehicles equipped with conventional windshields, referred to as the "CONTROL" group, were represented by the following vehicles:

Make Models	Model Years
Cadillac Deville	1985, 1986, 1987
Buick Electra	1986, 1987
Oldsmobile 98	1986, 1987

The CONTROL vehicles were selected on the basis of being most representative of the TEST vehicles in terms of vehicle type, size, weight, etc. It is also believed that the CONTROL vehicles and TEST vehicles would generally be similar in terms of driver demographic and socio-economic factors. Table A-1 of the Appendix lists the specifications of all vehicles used in the analyses of data from State crash files.

The principal benefit expected from glass-plastic glazing is a reduction in lacerative injuries, primarily to the head, face, or neck areas of front seat occupants. Most of these injuries are minor, being equivalent to a code of 1 on the Abbreviated Injury Scale (AIS). Three States, Indiana, Pennsylvania, and New York, record in their motor vehicle crash files, sufficient detail to permit identification of the nature of the injury sustained together with the part of the body affected. All three State files report one injury -- the most severe injury sustained -- per vehicle occupant. Typically, this degree of detail would only be found in specially designed accident investigation data bases, such as NHTSA's National Accident Sampling System (NASS). However, NASS files would contain far too few cases of crashes involving the TEST vehicles to permit a useful analysis of the effect of glass-plastic glazing. In terms of both sample size and data detail required, the crash files from Indiana, Pennsylvania, and New York represent the best source available. Copies of Indiana and Pennsylvania crash files are among those provided to NHTSA on a routine basis for use in analyses of safety topics such as this study of glass-plastic glazing. New York State does not routinely make available copies of its accident files for general investigative use, but did consent to provide NHTSA with a special extract in support of this study.

The following sections describe the analyses of data from these three States which compare the rates of bleeding injuries, generally to the head, face, or neck, for front seat occupants of vehicles equipped with glass-plastic windshields versus front seat occupants of the CONTROL group of vehicles. Bleeding injuries, a category of injury contained in all three of the State files, is considered to be generally synonymous with lacerative injuries, the essential type of injury expected to be reduced by glass-plastic glazing. As discussed in Chapter 1, bleeding injuries from New York State crash data were a primary source for the agency's 1985 study of the effects of HPR glazing. Webster defines laceration as "a break or wound made by lacerating." The definition of lacerate is "to tear or rend roughly, or wound jaggedly." A laceration is a "torn or ragged wound." In human skin tissue, laceration would almost always be accompanied by bleeding. Also, a review of the injury code levels reported in the three State files (see Tables A-2 through A-4 of the Appendix) supports the use of bleeding injuries as a reasonable surrogate for lacerative injuries. Further, a check of one of the States, Indiana, shows that the majority (96 percent) of the bleeding injuries reported are minor in nature, which is consistent with prior information that the majority of windshield - caused lacerations were of minor severity. Finally, the Indiana code manual definitions equate bleeding with wounds, per Webster's definition (see Table A-4, Appendix A). While lacerations will almost always be accompanied by bleeding, it is also noted that certain bleeding head injuries (for example, bloody noses) may also result from non-lacerative injuries.

In the following analyses, bleeding injuries to the face, head, etc. are the total number of bleeding injuries reported for these body regions -- i.e., due to all impact sources within the vehicle. The State data files do not report the injury-producing contact points within the vehicle. For all police reported passenger car crashes, it has been estimated that approximately 30 percent of all lacerative injuries to the head and face result from windshield contacts [3]. However, that estimate is based on a more severe crash reporting threshhold (i.e., towaway crashes) than exists for police reported crashes, and hence, the 30 percent estimate may not be representative. Since the great majority of head and facial lacerations are minor injuries (and minor injuries are more likely to be associated with minor severity crashes), it may be that the 30 percent figure is an underestimate of the proportion of head and face lacerations that result from windshield contacts for police reported data. Also, in the following analyses, the numbers of bleeding injuries are those which occur in all types of impacts. Generally, injuries resulting from occupant contact with the windshield would be expected to occur in frontal collisions. Due to sample size limitations and the fact that an impact direction variable was not available for all three data bases, no attempts were made to filter the data to represent frontal-only impacts. Other data sources indicate that frontal collisions (i.e., 11:00, 12:00, and 1:00 o'clock directions) account for approximately 2/3 of all police reported passenger car crashes and that over 1/2 of all occupant injuries occur in frontal impacts [4,5]. A consequence of the data limitations discussed here is that statistical analyses can reasonably be expected to detect a positive effect (i.e., injury reduction) of the glass-plastic windshield only if that effect is reasonably large. The agency had indeed predicted a large effect for the windshield, believing that it would be essentially 100 percent effective in preventing windshield caused lacerations.

The focus of the analyses will be to determine if occupant bleeding injury rates for the TEST vehicles are significantly lower than occupant injury rates for the CONTROL vehicles.

2.1 DATA FROM NEW YORK

Crash data from the State of New York for calendar years 1986, 1987, and 1988 were analyzed. The following table (2-1) summarizes the number of front seat occupants for the TEST vehicles and for the CONTROL vehicles, together with the number of those occupants who sustained bleeding injuries and the number of occupants who were not injured. For the New York data, bleeding injuries consisted of two degrees of severity -- minor bleeding and severe bleeding, and these injuries were coded as having occurred to the head, face, neck, eyes, lower arm, or hand. The lower arm/hand body areas were included in an effort to maximize the injury sample size. Other accident reports indicate that occupants sometimes thrust their hands in front of their face to shield themselves from impending impact. Such an action could result in lower arm/hand laceration.

Table 2-1 State of New York		
Comparison of Bleeding Injuries to Front Seat Occupants -- TEST Vehicles Versus CONTROL Vehicles		
	TEST	CONTROL
Occupants with Bleeding Injuries	41	172
Non-injured Occupants	945	4736
TOTAL OCCUPANTS	986	4908

The general statistical procedure in the analyses of State crash data will be to determine whether the proportion of total exposed front seat occupants (i.e, both injured and non-injured) sustaining bleeding injuries to the body areas most likely to have come in contact with the windshield is significantly lower for the TEST vehicles (i.e., vehicles equipped with glass-plastic windshields) than for the CONTROL vehicles. For the New York data, it is seen that the proportion of occupants with bleeding injuries in the TEST group (41/986 = 4.16 percent) is numerically higher than the corresponding proportion for the CONTROL group (172/4908 = 3.50 percent). There is therefore no need to proceed with a test of significance for these data -- they do not support a reduction in lacerative injuries for occupants of vehicles with glass-plastic windshields. The relative difference in injury rates between the two groups -- i.e., the difference between the TEST and CONTROL injury rates divided by the CONTROL injury rate -- is 18.9 percent. The 95 percent confidence limits on this difference are - 55.4 percent to 17.6 percent.

2.2 DATA FROM PENNSYLVANIA

Crash data from the State of Pennsylvania for four calendar years (1985, 1986, 1987 and 1988) were analyzed. Table 2-2 summarizes the total number of front seat occupants and the number of these sustaining bleeding injuries in the TEST vehicle group and in the CONTROL vehicle group.

Table 2-2 State of Pennsylvania

Comparison of Bleeding Injuries to Front Seat Occupants -- TEST Vehicles Versus CONTROL Vehicles

	TEST	CONTROL
Occupants with Bleeding Injuries	44	123
Non-injured Occupants	827	2517
TOTAL OCCUPANTS	871	2640

For the Pennsylvania data, bleeding injuries are coded only as a single injury type -- no distinction as to minor bleeding or severe bleeding is given. Also, the body areas for the bleeding injuries represented here are the head, neck or face. Eyes, hand, and lower arm are not separately coded as they were for the New York data.

Comparing the bleeding injury rates for the TEST group (44/871 = 5.05 percent) with the bleeding injury rate for the CONTROL group (123/2640 = 4.66 percent) gives a result similar to that found for the New York data. Namely, the injury rate for the TEST group vehicles is numerically higher than the injury rate for the CONTROL group vehicles. As with the New York data, further statistical analyses are unnecessary; these results from the Pennsylvania crash data do not support the hypothesis that glass-plastic windshields reduced lacerative injuries in actual on-road crashes. The relative difference in injury rates between the two groups is - 8.4 percent, with 95 percent confidence limits of - 43.3 percent to 26.6 percent.

2.3 DATA FROM INDIANA

The third set of crash data analyzed in this study comes from Indiana. Five calendar years (1985 through 1989) were used. The variable levels in the Indiana files for the degree of bleeding (minor and severe) and for the body area affected (head, face, neck, eye, elbow, lower arm, hand) were quite similar to the variable levels available from the New York data. However, the Indiana files differ from New York (and also from Pennsylvania) in that occupant data are coded for passengers (i.e., non-drivers) only if they are injured. For this reason, the exposure base for the Indiana injury rates is all exposed drivers, rather than all exposed front seat occupants as used in the New York and Pennsylvania analyses.

Table 2-3 summarizes the injury comparison between the TEST vehicles and the CONTROL vehicles, based on the Indiana data.

Table 2-3 State of Indiana		
Comparison of Bleeding Injuries to Drivers -- TEST Vehicles Versus CONTROL Vehicles		
	TEST	CONTROL
Drivers with Bleeding Injuries	7	18
Non-injured Drivers	535	1158
TOTAL DRIVERS	542	1176

For these data, the bleeding injury rate for the TEST vehicles (7/542 = 1.29 percent) is less than the bleeding injury rate for the CONTROL vehicles (18/1167 =1.53 percent) -- a result consistent with the hypothesis that glass-plastic windshields reduce lacerations. However, the difference between the injury rates (.24/1.53 = 15.7 percent) is far from being statistically significant (i.e., the difference in injury rates of 15.7 percent is not significantly different from zero) with a chi-square value of only .149. In order for the rates to be significantly different (assuming a confidence level of 95 percent), a chi-square value equal to or greater than 3.84 would have to be obtained. Therefore, the analytical results for the Indiana data are the same as the results for the New York data and the Pennsylvania data -- no statistically significant evidence is found that glass-plastic windshields have reduced lacerative injuries. The relative difference in injury rates between the two groups of 15.7 percent has corresponding 95 percent confidence limits of -64.1 percent to 95.4 percent. These larger bounds for the Indiana data, compared with the New York and Pennsylvania data are due to the smaller sample size (i.e., number of exposed drivers in crashes) together with the lower injury rates for the Indiana sample.

2.4 COMBINED DATA

The analyses of data from all three States are consistent in that none showed significant differences in injury rates between the TEST (glass-plastic windshield) vehicles and the CONTROL (conventional windshield) vehicles. However, two of the States, New York and Pennsylvania also produced results which are quite similar in terms of overall injury rates and in terms of the difference in injury rates between the TEST and CONTROL vehicles. Given this similarity and in order to increase sample size and the reliability of the results, an analysis is included on the combined data from these two States. Table 2-4 summarizes the combined data.

Table 2-4 States of New York and Pennsylvania		
Comparison of Bleeding Injuries to Front Seat Occupants -- TEST Vehicles Versus CONTROL Vehicles		
	TEST	CONTROL
Occupants with Bleeding Injuries	85	295
Non-injured Occupants	1857	7548
TOTAL DRIVERS	1942	7843

For the combined data, the sample sizes are increased to approximately 1,950 occupants for the TEST vehicles and about 7,850 for the CONTROL vehicles, with total injuries of 85 and 295, respectively. The injury rates are 4.58 percent for the TEST group versus 3.91 percent for the CONTROL group, giving a relative difference (CONTROL minus TEST) of -17.1 percent. The corresponding 95 percent confidence limits are -42.7 percent to 8.4 percent. Here, it is seen that the negative relationship between the CONTROL and TEST vehicles is reinforced, compared to the results from the separate States -- due, in part, to the increase in sample size.

2.5 OTHER CRASH DATA ON CARS EQUIPPED WITH GLASS-PLASTIC WINDSHIELDS

In the early-to-mid 1980's, a number of small fleet studies were established to obtain on-the-road experience with glass-plastic windshields. These efforts were primarily sponsored or supported by the automobile manufacturers, and, for the most part, their main purpose was to obtain durability information on glass-plastic windshields rather than information on their potential to reduce lacerative injuries. Nevertheless, some crash injury data were recorded from these fleet trials, and although they are considered anecdotal with respect to providing statistically valid data on the effectiveness of glass-plastic windshields in reducing lacerative injuries, these data, along with a few other isolated crash cases of vehicles with glass-plastic windshields, are summarized in this study in order to document all known, available data on the crash experience of vehicles equipped with these windshields.

General Services Administration Fleet The General Services Administration (GSA) purchased 5,000 1985 Ford Tempo sedans. This purchase was a cooperative agreement between the GSA and NHTSA to provide a fleet field test of air bags, which were installed in the driver position of all 5,000 vehicles. In addition, 2,300 to 2,500 of the vehicles were equipped with glass-plastic windshields manufactured by Saint-Gobain Vitrage (France) -- trade name, "securiflex" windshields. Special accident investigation reports, sponsored by NHTSA, GSA, and Ford were written on the crash experience of vehicles in this GSA fleet, primarily to document data on air bag functioning and effect. Data were also collected on occupant injury and contact point(s) within the vehicle. Four instances were recorded where occupant contact was made with a glass-plastic windshield [6]. No lacerative injuries occurred from these contacts. In one of these cases, the occupant sustained no injury. In another, a contusion of the forehead occurred due to windshield impact. In the third case, the occupant suffered a headache, sore neck, and sore shoulders. In the last case, windshield impact caused a contusion of the arm -- the occupant had thrust his arm in front of his face to cushion the impact.

Two other apparent instances of occupant-windshield contact occurred, but injury data were not reported for these cases -- i.e., it was not known whether or not injury occurred [6]. Although special field team reporting was employed for the GSA fleet crashes, it was not consistently recorded as to whether or not the involved vehicle was equipped with a glass-plastic windshield. It is suspected that some of the other reported crashes involved vehicles equipped with the test windshields, but investigators failed to note this in their accident reports. This belief is further supported by the fact that Securiflex vehicles accounted for only about 25 percent of the total fleet reported crashes. Since approximately 50 percent of the GSA fleet was equipped with the test windshields, it would be expected that the total reported accidents would be about evenly split between Securiflex vehicles and standard windshield vehicles.

<u>General Motors Fleet Vehicles</u> General Motors placed approximately 3,000 1983 passenger cars in a number of rental fleets throughout the U.S. for a field evaluation of durability issues concerning glass-plastic windshields. The majority of these vehicles (2,500) were equipped with windshields manufactured by Saint-Gobain Vitrage; these vehicles were leased to Hertz, Avis and National Car Rental companies. The remaining vehicles were fitted with windshields manufactured by Libby-Owens-Ford (LOF Glass), the same type of windshields installed in General Motors' 1984-1987 model year luxury vehicle carlines. This second

group of vehicles was leased to Alamo and to General Car Rental. After the first eight months (equivalent to about 16,000 miles per vehicle) of operation of the fleet of 2,500 vehicles, 16 instances of occupant contact with the windshield (sufficient to break or crack the windshield) were noted, as a consequence of crashes. These cases were investigated by General Motors personnel. No lacerative injuries were reported due to broken glass. Whether or not other types of injuries (such as abrasions, concussions) occurred was not stated [7].

Later, after one year of operation (or an average of 24,000 miles per vehicle), General Motors (in a letter to the Administrator, NHTSA) updated its fleet experience to a total of 19 accidents involving 25 occupant-to-windshield contacts sufficient to break or crack the windshield glass [8]. It was reported that none of the 19 cases resulted in tears to the inner plastic layer, nor was the plastic layer cut open by broken windshield glass. Eighteen of the 19 cases were investigated by company research personnel who reported no lacerations due to broken windshield glass. However, in 6 of the accidents (or 33 percent), lacerations did occur due to skin tissue splitting from impact pressures resulting from the contacts with the windshield and other interior surfaces. While the exact number of occupants who impacted the windshield in these 18 vehicles was not reported, the total number of exposed occupants was given as 25 (18 drivers plus 7 right-front passengers). The number of these 25 occupants who sustained lacerations was also not specifically reported, but from the data which were reported, this number is estimated to be at least 7 and possibly as many as 10 -- i.e., between 28 percent and 40 percent of total exposed occupants received lacerative injuries. Some occupants received contusions and abrasions, but exact numbers were not given.

The 1985 General Motors update of its 2,500 vehicle fleet test (this was also the company's final report on the crash experience of the vehicles) also included an analysis of the data, accumulated at that time, to estimate the effectiveness of the glass-plastic windshield in reducing lacerative injury [9]. General Motors used a "matched case" method of analysis wherein occupants of the fleet vehicles were matched with occupants of control vehicles selected from a separate set of collision data (known as Motorists Insurance Corporation, or "MIC" data) which the company maintained. Matching criteria included: (1) occupant-induced windshield cracking/breakage in both fleet and control vehicles, and (2) similarity in vehicle deformation patterns, extent of damage, and impact direction. The analysis also converted lacerative injuries from the AIS scale to a "tissue damage sale" (TDS) in order to introduce a degree of gradation in lacerative injuries. Under the AIS scale, the large majority (i.e., 96.5 percent in the MIC data) of lacerative injuries are coded AIS = 1, thereby precluding any analysis with respect to the severity, or degree of laceration.

General Motors' matched case analysis found that while the overall proportion of occupants injured (primarily abrasions or lacerations) was essentially the same between the two vehicle groups, lacerative injuries were 63 percent fewer for the glass-plastic group -- i.e., 32.1 percent for matched occupants versus 11.8 percent for Securiflex occupants. This figure was taken as an estimate of effectiveness of glass-plastic windshields in reducing lacerative injuries. Also, the analysis concluded that the extent of laceration was greater (i.e., more likely to require stitches) for the control group. However, a review of the analysis discloses several factors which indicate that the findings are likely to be biased.

First, and of key importance, a substantial portion of the glass-plastic group ocupants were omitted from the matched-pair analysis because no satisfactory matches could be found from the control (i.e., MIC) data. Eight (32 percent) of the 25 occupants and five (28 percent) of the 18 vehicles in the Securiflex sample were omitted. Most importantly, however, was the reduction in the injury portion -- i.e., those cases where occupants lacerative injury -- of the Securiflex sample. Five (83 percent) of the six Securiflex vehicles in which lacerative injuries were reported to have occurred, and between five and eight (71 to 80 percent) of the injured occupants of these vehicles were omitted from the matched case analysis. These deletions made an already small Securiflex sample much smaller still -- the seven to ten lacerative injuries being reduced to only two lacerative injuries, both occurring in the same vehicle. While the deletions were made to conform to the requirements of the matched-case analysis methodology, it nonetheless follows that the loss of the majority of injury data from the Securiflex sample could seriously distort the results. For example, the overall lacerative injury rate of 28 to 40 percent for Securiflex occupants is seen to be about the same as the overall lacerative injury rate of 32 for the matched-case occupants -- a result indicative of little or no effectiveness for glass-plastic windshields. It is also interesting to note that this result is in general agreement with the results of the State data analysis -- i.e., no significant difference between the injury rates for glass-plastic windshields and conventional windshields

-- and contrasts with the 11.8 percent lacerative injury rate for Securiflex vehicles versus 32 percent for matched case occupants as reported in the GM matched-case analysis.

A second concern with the analysis is the subjective nature of assigning the TDS (tissue damage scale) code which resulted in a code value ranging from 1 (no injury) to a code value of 6 (lacerations with/without stitches and underlying fractures) for each occupant based on a written description of the injuries. Code level 5 (laceration with stitches, or should have stitches) represented the key severity level in the study's conclusion that the control group occupants had lacerations which were more severe than the lacerations in the glass-plastic group. However, another windshield study, which also used the TDS, defined code level 5 as "lacerations with stitches" -- the distinction, "or should have stitches" was not part of the definition. This study also noted the imprecise nature of the TDS scale, and that a number of factors (such as precise position and orientation of injury on face, age, sex, and beauty of patient) will influence whether or not the injury should be stitched. The length and depth of the laceration are also factors affecting whether or not an injury should be stitched [10]. Given these influencing factors, it seems doubtful that a reviewer could reliably determine whether or not an injury should have been stitched, based solely on a written description of the injuries.

A third factor which could bias the results of the matched-case analysis is that the control group of vehicles consisted primarily of General Motors "A-cars" and "X-cars," which are larger and heavier than the "J-cars", which comprised the test vehicles. Since a criterion of the matching methodology was that the windshield had to be broken or cracked (from occupant contact), it is possible that the control group represented somewhat more severe collisions (and hence greater chance of occupant injury) than the test group. Fourthly, the average TDS for the test group (2.2) was only 12 percent less than the average TDS for the control group (2.5), both of which represent injuries of a non-lacerative nature. The definition of a TDS of two is, "contusion only or complaint of pain (no penetration of skin)"; a TDS of three is defined as a "minor abrasion (tissue damage, but no lacerations)".

For the above four reasons -- in particular, the deletion of most of the Securiflex injury cases -- the findings of General Motors' matched-pair analysis are considered to be inconclusive insofar as estimating the effectiveness of glass-plastic glazing in reducing lacerative injuries. Furthermore, as stated previously, if all of the injury data for the Securiflex vehicles are utilized, it is seen that there is no apparent difference in lacerative injury rate between the Securiflex vehicles and the control vehicles. This concludes the crash experience of the General Motors' fleet vehicles. Apparently, no crash records were kept for the second fleet of approximately 500 cars leased to Alamo and to General Car Rental.

Ford Fleet Vehicle Study Ford Motor Company placed approximately 2,400 1984 Ford LTD's, equipped with glass-plastic windshields, in a rental fleet field test. One instance of occupant contact with the windshield was noted, but is was unknown as to whether glass breakage or lacerative injury occurred [11].

Maryland State Police Fleet In the period, 1981 to 1982, 50 new Ford LTD's and 50 new Plymouth Grand Fury's were retrofitted with glass-plastic (i.e., "Securiflex") windshields, and tested in the Maryland State Police fleet [12,13]. During the study period, one instance of occupant (i.e., head)-to-windshield contact occurred. A "large" area of the windshield was shattered, but no laceration occurred. The trooper was belted but still struck the steering wheel with his chin, and the windshield with the top of his head. He sustained a slight head bruise from the windshield impact and a chin laceration from the steering wheel impact. The impact speed for the crash was estimated at 45-50 mph, with a delta-V of 17-20 mph [12]. The Maryland State Police test also included a comparison (or "control") sample of 50 Ford LTD's and 50 Plymouth Grand Fury's equipped with standard windshields. No accident information was reported for these comparison vehicles, with respect to occupant-windshield contact and injury/non-injury outcome. It was reported that "documentation of incidents involving comparison vehicles was not as detailed as those involving Securiflex vehicles" [13].

It was also reported that several windshields had been cracked by external impacts from stones or other small airborne objects. In at least five of these instances involving the Securiflex test vehicles, no glass fragments were found inside the vehicle. The extent to which glass fragments entered the passenger compartment from similar exterior impacts to conventional windshields was not reported, neither was the frequency of such impacts. One other incident involving a comparison vehicle was reported where an external impact from a steel cable resulted in the shattering of glass fragments into the interior of the vehicle. As noted previously, the documentation of incidents involving comparison vehicles was less detailed than for incidents involving the Securiflex-equipped test vehicles. While it is entirely reasonable to expect the plastic film to better contain and prevent glass fragments from entering the passenger compartment, the reporting of the Maryland police fleet experience is insufficient to permit quantification of this effect.

Los Angeles Police Fleet Seventy-eight 1985 Ford LTD Crown Victorias were retrofitted with glass-plastic windshields and operated by the Los Angeles City police. Data were unavailable as to occupant-to-windshield contacts, or whether lacerative injuries occurred [12].

National Accident Sampling System In 1987, the field teams of NHTSA's National Accident Sampling System (NASS) were requested to look for, and report on, accidents which occurred in their area of jurisdiction and which involved one of the 1984 through 1987 General Motors cars equipped with glass-plastic windshields. A query of the NASS files in 1990 produced six cases of crashes reported to involve these vehicles. Upon further review, however, this was reduced to four cases -- two of the original cases did not involve vehicles with glass-plastic windshields. One of the six cases involved a Pontiac 6000 -- only the Pontiac 6000 STE model came equipped with a glass-plastic windshield. The other case involved a Cadillac DeVille -- only Cadillac Seville and Eldorado models were equipped with glass-plastic windshields.

For the four remaining NASS crashes involving GM vehicles with glass-plastic windshields, a hardcopy review of the case files produced the following results:

(1) 1986 Toronado - Occupants (driver and front passenger) were reported to not have made contact with the windshield. Both wore 3-point restraints.

(2) 1987 Toronado - Unrestrained front seat passenger was reported to have contacted the glass-plastic windshield and sustained a laceration. There was some uncertainty, however, in the reporting of the injury source, as to whether or not the windshield contact produced the laceration.

(3) 1986 Riviera - Unrestrained driver sustained fatal injuries in severe crash -- involved massive damage to front of vehicle, with rollover. It was uncertain as to whether the driver made contact with the windshield. Fatal injuries were reported as likely due to contact with steering column, A-pillar, and instrument panel.

(4) 1987 Seville - No reported windshield contact and no reported injury.

Summarizing these four NASS cases: no windshield contact occurred in two of the crashes; windshield contact, or injury therefrom, was unknown in one crash; and windshield contact, possibly resulting in laceration, occurred in the fourth crash.

Other Reports In 1985, a Michigan couple were involved in a frontal collision in their 1985 Cadillac Seville Elegante, which came factory-equipped with a glass-plastic windshield. This incident was reported by the DuPont Company, manufacturer of the plastic inner liner used in the windshields, in their magazine publication [14]. The husband, restrained by his seat belt, did not contact the windshield and received only bruised hands from the steering wheel. His wife, who was not wearing a seat belt, was propelled into the windshield. She sustained a concussion, severe bruise on her forehead, a swollen face, abrasions on both knees and a sprained ankle, but suffered no cuts to the head or face. Her injuries rendered her unconscious for an unspecified period of time. Photographs of the windshield displayed a large "cobweb" area of cracked glass. The inner layer of plastic remained intact, protecting the wife from direct contact with the cracked glass shards, whose sharp edges were detectable on the outer surface of the windshield.

Two additional collision experiences involving glass-plastic glazing were reported by individual vehicle owners. The first incident involved a rock ("about the size of a fist") being dropped from an overpass and striking the windshield of the vehicle as it passed by on the Interstate road underneath. The rock shattered, but did not penetrate, the windshield in front of the driver's face. The driver was uninjured and remained in control of his vehicle [15].

The second incident was similar to the one described above, -- i.e., the windshield of the driven vehicle being impacted by an external object. Additional detail on this experience was not given, other than the statement that the object did not penetrate the windshield, and the inner plastic shield contained the broken glass segments [15].

European Experience Information provided to the NHTSA by Saint Gobain Vitrage indicated that approximately 95,000 of their glass-plastic windshields (i.e., Securiflex) were installed in European cars (Peugeot, Opel, Daimler Benz, etc.) in the 1981 to 1987 period. However, no data were collected on the crash experience of these vehicles [16].

2.6 DISCUSSION OF ANALYSES OF STATE CRASH DATA AND OTHER INFORMATION ON CRASH EXPERIENCE OF GLASS-PLASTIC GLAZING

To close this chapter, some summary and interpretive comments are offered on the analyses and other information developed to estimate the effect of glass-plastic glazing in reducing lacerative injuries. Included in the discussion are other factors and conditions which could affect the analyses, and the use of other (i.e., fleet) data to assess the effects of glass-plastic windshields.

State Data: Primary Considerations

The State crash data constitute the preferred basis for estimating the injury-reducing effects of glass-plastic glazing. These data provide for the comparison of injury rates between crash-involved occupants of vehicles equipped with glass-plastic windshields and crash-involved occupants of vehicles similar in other respects, but equipped with conventional windshields -- i.e., a control group. The three States used provided for common exposure bases, or populations, from which to compare the crash experiences of the two types of vehicles. In terms of quantity of data, both for exposed occupants and injured occupants, the States provide, by far, the largest amount available. These three States also provided sufficient detail in their automated files to permit the analysis to be conducted on the types of injuries expected to be reduced by glass-plastic glazing -- i.e., bleeding injuries (considered to be generally synonymous with lacerative injuries), primarily to the head, face or neck areas. This degree of detail for injury reporting is uncommon among State motor vehicle accident reporting systems, being available to NHTSA only from the three States of New York, Pennsylvania, and Indiana.

The analyses of data from these three States gave statistically consistent results -- i.e., no significant difference in injury rates between vehicles equipped with glass-plastic windshields and vehicles equipped with standard windshields. For the two largest States (New York and Pennsylvania), the injury rates were numerically higher (by 8 to 19 percent) for the vehicles with glass-plastic windshields, whereas for the remaining State (Indiana), injury rates were lower (by 16 percent) for the glass-plastic vehicles. Collectively, these results are not supportive of the hypothesis that glass-plastic windshields substantially reduce lacerative injuries.

However, due to limitations in the data, the results are not interpreted to mean that the windshields have no effect at all in reducing lacerations. As discussed in Section 2.0, since the State files did not identify vehicle contact source for injuries, all bleeding injuries to the head and face are used as the dependent variable in the analyses. The assumption is thus made that any reduction in total bleeding injuries to the head and face found for the TEST vehicles would be due to the glass-plastic windshields in these vehicles -- the corollary assumption being that non-windshield lacerative injuries would occur at the same rate between the two vehicle groups. This condition can affect the analysis in two ways. Since the majority of injuries do not result from windshield contact, the capability of the analysis to detect a (significant) difference between the two groups (if a true difference existed between the two vehicle populations) could be impaired. This effect would be greatest for small samples, and would decrease as sample sizes became larger. Secondly, any positive difference found for the glass-plastic vehicles (i.e., lower lacerative injury rate) would underestimate the true difference.

Another limitation in the data, also previously pointed out, is that the non-availability of impact type information from some States, together with sample size restrictions, precluded controlling the analyses for frontal impacts only. Windshield injuries would generally be expected to result from frontal impacts. Since: (1) in the general population of crashes, both the majority of injuries and the majority of impacts occur in the frontal mode, and (2) it is reasonable to assume that the distribution of impact types is similar for both the TEST and CONTROL vehicle groups, it is not believed that the lack of control for this variable would significantly affect the results.

The overall effect of the above limitations is to reduce the capability of the analyses to detect a statistically significant effect (i.e., injury reduction) for the glass-plastic windshield, given there is such an effect. In fact, such an effect would likely be detected only if the effect were reasonably large. It will be recalled that the agency did indeed project a (very) large effect for the glazing, believing that it had the potential to be 100 percent effective, or the potential to essentially eliminate windshield-caused lacerative injuries. Therefore, considering, collectively: (1) the results of the statistical analyses (no significant injury reductions, including two numerically negative reductions); (2) the limitations in the data; and (3) NHTSA's very optimistic benefit projection for glass-plastic glazing, it is deemed reasonable to conclude that the results of the State data analyses are not supportive of the hypothesis that glass-plastic windshields substantially reduce lacerative injuries. At the same time, the results do not preclude that the glazing may have a beneficial effect in reducing lacerative injuries.

State Data: Secondary Considerations

For a brief period of time at the beginning of the 1985 model year, General Motors did not install the glass-plastic windshields as standard equipment on one model of its Cadillac Seville. This means that it is possible that some 1985 Sevilles, included in the TEST group of vehicles in the State analysis, could have been equipped with standard (i.e., non glass-plastic) windshields. Compared to all vehicles in the TEST group, however, the inclusion of such vehicles would be expected to represent only a small fraction, and therefore would not be expected to have any significant impact on the analyses results. A somewhat similar situation, analytically, occurred with the data from Pennsylvania. In 1987, that State changed its coding procedures such that Cadillac Devilles and Cadillac Broughams were combined within a single, make model category. This means that for the Pennsylvania data for calendar years 1987 and 1988, the CONTROL group of vehicles (as used in the analyses) contains some 1987 Cadillac Broughams, which are larger, heavier vehicles than the other CONTROL group vehicles -- i.e., Cadillac Eldorados, Cadillac Devilles, Buick Electras, and Oldsmobile 98's (see Table A-1 of the Appendix). To the extent that the heavier Cadillac Broughams afforded better occupant protection than the other cars in the CONTROL group, the analysis results of the Pennsylvania data could include a bias. The effect of such a bias is believed to be small, however, since the expected number of Cadillac Broughams in the data would be small relative to the total number of vehicles in the CONTROL sample. This is inferred from: (1) sales figures which show Cadillac Brougham sales low relative to sales of the other make models comprising the CONTROL group; (2) the other two years of the

Pennsylvania data (1985 and 1986) were not subject to the combining of Cadillac Deville and Cadillac Brougham models into a single category; and (3) for the CONTROL group of vehicles, only the 1987 model year would have been affected.

Two other factors, not controlled for in the analyses of State data, could potentially affect the outcome of the analyses. Restraint usage and occupant age can affect injury outcome in crashes. The reliability of restraint usage data in police reported accidents is generally considered poor -- especially in non-injury and minor injury crashes. Regardless of the reliability of police reported data on restraint usage, it is reasonable to assume that the reliability would not vary as a function if whether a person was an occupant of a TEST group vehicle or an occupant of a CONTROL group vehicle.

Table A-5, in the appendix, summarizes occupant restraint usage data, as reported in the three State files analyzed, for the TEST vehicle group and the CONTROL vehicle group. Within each State, restraint usage for both occupants of TEST vehicles and occupants of CONTROL vehicles is seen to be quite similar. Table A-6, also in the Appendix, lists the average age for occupants of the TEST vehicle group and the CONTROL vehicle group for each State. As was true for the restraint use data, occupant age is seen to be quite similar for the TEST and CONTROL groups of vehicles. Statistical tests of distributional equivalency between the TEST and CONTROL vehicle groups have not been performed -- for either restraint use or for average occupant age. Even if statistical significance were found, no significance of a practical nature could be attached to the results, owing to the numerical closeness of the distributions. It is therefore concluded that neither occupant age nor restraint usage has affected the analyses results of the State data in estimating the effect of glass-plastic windshields on lacerative injury reduction.

Sample sizes for the analyses of data from the three States were reasonable for total exposed occupants in each of the TEST and CONTROL vehicle groups, ranging from a low of 542 for the Indiana TEST group, to a high of 4,908 for the New York CONTROL group. These were the total numbers of front seat occupants (except for Indiana which was confined to total drivers) that were exposed to possible injury in the vehicle crashes studied from the three States. The total number of exposed occupants for all three States was 11,114. The total number of injured occupants was 406; larger numbers would have been desirable here, especially since lacerative injuries to the head or face resulting from windshield contact may comprise only about 30 percent of total lacerative injuries to the head or face from all contact sources (see prior discussion). Of course the primary determinants of statistical precision are the total numbers of crash-exposed occupants and these were reasonably large. One factor which could have decreased the sample sizes for injured occupants is the increased use of safety belt systems that has taken place over the last several years. Increased belt use would prevent more injuries of all types, including lacerative injuries to the head and face.

Another factor of potential interest in evaluating the results of the State analyses concerns the inclusion of lacerative injuries to the lower arm/hand, in addition to lacerative injuries to the head, neck, and face. Other data have indicated that the lower arm/hand can receive lacerations due to windshield contact -- for example, when occupants thrust their arms forward to protect from an impending crash. Therefore, in order to maximize the injury sample sizes, lower arm/hand injuries were included for the two States (New York and Indiana) which code these injury locations. A review of the data showed that lower arm/hand injuries comprised only six to ten percent of all the injuries reported from these two States. For this reason, and also since it is reasonable to assume that lower arm/hand contacts with the windshield would be equally likely for the TEST and CONTROL groups, inclusion of these injury locations is not considered to have had any biasing effect on the analyses.

A final issue of potential impact on the State data analyses involves the question of whether some of the TEST group vehicles may have been equipped with conventional windshields, rather than glass-plastic windshields, at the time they were involved in the crashes. This could happen once the vehicle was out of the new vehicle warranty period, or if under the warranty period, the windshield required replacement for cause other than that covered under warranty -- stone breakage, for example. Under these conditions, windshield replacement would normally be done under the motorist's automobile insurance policy and in such cases, glass-plastic windshields were typically replaced with conventional windshields, rather than the original factory equipped glass-plastic windshields. This resulted from the fact that insurance companies refused to cover the unusually high cost charged by glass shops to install a new glass-plastic windshield (see Chapter 4 on COSTS). With respect to the impact on the analyses of TEST group vehicles with conventional windshields, a review of available information indicates that any such effect would be very small. Based on: (l) the age of the vehicles at the time of the crash, and (2) the estimated yearly insurance replacement rate of windshields (three percent), it is estimated that no more than three to six percent of the TEST vehicles in any of the three States would have been fitted with conventional windshields at the time of the crash.

Other Data on Crash Experience of Glass-Plastic Glazing

Due primarily to a general lack of control data, the fleet and individual consumer experiences of vehicles equipped with glass-plastic glazing (discussed in Section 2.4) cannot appreciably aid in the analysis of the injury reduction potential of glass-plastic glazing. For example, the GSA fleet data recorded four instances of occupant contact with the glass-plastic windshield with no lacerative injuries occurring. However, it was not possible to compare this experience with that of similar vehicles with conventional windshields. Were these contacts of sufficient force such that glass breakage and lacerative injury would have occurred had the vehicles been equipped with conventional windshield? Not all windshield contacts are sufficient to produce lacerations. For example, one source of data indicated that nearly two-thirds of windshield contacts -- even when the contact force is sufficient to break or crack the windshield glass -- result in either no injury, or only minor contusions with no penetration of the skin [9]. Therefore, without an adequate and representative control sample of vehicles, no inferences can be drawn. Although approximately one-half of the total GSA fleet had glass-plastic windshields, only about one-fourth of the reported crashes were for glass-plastic vehicles. The primary thrust of the accident reporting was to evaluate air bag experience, and windshield type (conventional or glass-plastic) was inconsistently reported.

As discussed earlier, the findings from the one instance where a control sample (i.e., "matched-case") type of analysis was performed (on one set of GM fleet data) must be considered inconclusive due to sample size limitations and other methodological concerns. Most of the lacerative injuries in the glass-plastic vehicle sample were deleted, prior to performing the analysis, in order to satisfy the conditions of the analysis methodology. In an already very small sample, this deletion could have introduced serious bias into the analysis, as evidenced by the fact that the original, overall lacerative injury rate for the glass-plastic sample was approximately the same as the injury rate for the matched (i.e., control) sample.

However, one result of note from the GM fleet sample is that lacerative injuries can indeed occur from contact with the glass-plastic glazing. The 28 to 40 percent lacerative injury rate experienced in the fleet sample contrasts rather sharply with the agency's projection that the glazing could essentially eliminate such injuries [3]. The lacerations in the GM data were described as not due to cracked or broken glass -- i.e., the inner plastic liner was said to not have been torn nor penetrated. Rather, the lacerations were described as "splitting" or "tearing" wounds, which apparently resulted from blunt impact with the plastic surface or the sliding of the head (or face) against the plastic inner liner. The injuries, however, were still described as <u>lacerations</u> by General Motors field staff who personally investigated those crashes where at least one occupant was reported to have made contact with the glass-plastic windshield and windshield damage (i.e., broken glass) occurred. The field investigations also included interviews with the drivers of the crash involved vehicles to obtain information on occupant injury.

The one instance of occupant contact with the windshield in the Ford test fleet provided no insight since it was not reported whether or not injury (lacerative or otherwise) occurred.

For the Maryland police fleet, the one instance of officer head contact with no laceration is supportive of an injury reduction benefit of glass-plastic glazing. Although the officer was belted, the conditions surrounding the crash were reasonably severe (estimated delta-V of 17-20 m.p.h.), and the officer's only reported injury from the windshield was a slight head bruise. Again, however, any effect cannot be quantified. While the Maryland police fleet test did include a control sample of vehicles with standard windshields, accident information for these vehicles was generally not reported.

The National Accident Sampling System data reported one crash where the occupant contacted the glass-plastic windshield. The occupant also sustained a facial laceration, but the report was unclear as to whether the injury resulted from the windshield or another vehicle component. The one crash report by the DuPont Company involving a 1985 Cadillac was another instance supportive of the laceration reduction potential of glass-plastic windshields. The occupant received no cuts, although her impact with the windshield created a large area of cracked glass. Also, none of the glass fragments penetrated the plastic liner.

While laceration did not occur, it should be noted that the occupant sustained other head injuries, including a concussion, a severe bruise on her forehead, a swollen face, and she was rendered unconscious by the impact with the windshield. One of the concerns of the agency when it elected to permit the use of glass-plastic glazing was that the stiffer inner windshield surface created by the plastic inner liner could potentially contribute to more "closed head" (e.g., concussions) than the conventional HPR windshield. This one case obviously cannot provide any reliable inference, but the occupant, while not sustaining lacerative injuries, did receive other head injuries of a reasonably serious nature. Whether these other injuries would have been lower had the vehicle been equipped with a conventional windshield is a question that cannot be answered without more data.

2.7 SUMMARY COMMENTS ON INJURY REDUCTION EFFECTS OF GLASS-PLASTIC GLAZING

Based on analysis of available State reported crash data for vehicles equipped with glass-plastic windshields and vehicles equipped with conventional windshields, no statistically significant reduction in lacerative injuries attributable to glass-plastic glazing is indicated. As discussed in the previous Section (2.6), these results are not considered conclusive due to the inability to distinguish between bleeding injuries from windshield contact and bleeding injuries from contact with other vehicle components, and due to other data limitations previously discussed. Although none of the three States showed statistically significant results, it is interesting that, numerically, the results were mixed. Indiana, with a small sample size, showed a numerically lower injury rate for the glass-plastic vehicles, whereas the two States with much larger sample sizes, New York and Pennsylvania, gave numerically higher injury rates for the glass-plastic group. These two States also produced injury rates which were quite similar. When these two States were combined to provide a larger sample (and hence a more precise estimate), this numerical relationship was made even stronger. While the analyses would not be expected to detect a positive effect of the glass-plastic windshield unless that effect were reasonably large -- due to the data limitations previously discussed -- at the same time, one would not expect to find numerical differences that were negative. Although firm conclusions can not be drawn, these mixed results, especially with the largest two States showing higher injury rates for the glass-plastic vehicles, do tend to suggest, however, that any actual benefit for the glazing may be substantially less than the near elimination (i.e., 100 percent reduction) of lacerative injuries as originally projected by the agency. In 1983, when NHTSA permitted the use of glass-plastic glazing, the agency based its opinion largely on the results of laboratory tests using anthropomorphic dummies whose faces were covered with a chamois material to simulate human skin. A research study on facial injuries from windshields, not available at the time the agency published its 1983 Regulatory Evaluation, found that the trajectories of dummies do not accurately reflect the trajectories of real people in collisions [10]. This could partially account for the very optimistic projection of effectiveness for glass-plastic windshields made by NHTSA in 1983. Also, a review of the agency's Final Rulemaking Analysis on glass-plastic glazing reveals that early results of the GM fleet test showed one instance where an occupant sustained lacerative injury from contact with the inner surface of the windshield, out of 9 total crashes where the potential for laceration was considered to exist. In retrospect, it does appear that the agency's original projection that glass-plastic glazing would eliminate lacerative injuries was overly optimistic. In the real world of motor vehicle crashes, any safety device that achieves 100 percent effectiveness is, after all, very difficult, if not impossible, to produce.

With respect to the other crash data on glass-plastic glazing (e.g., fleet tests, NASS), small sample sizes plus a lack of control data for vehicles with conventional windshields precludes their use, insofar as providing any quantitative estimates of the effects of the glazing. Whereas several instances of windshield contact, with glass breakage but without lacerative injury, were recorded in these data, it is not possible to project how many of these contacts would have resulted in laceration had the vehicles been equipped with conventional windshields. Such information is necessary in order to quantify the injury reduction potential of glass-plastic glazing. For example, in the General Motors matched-case data discussed in Section 2.5, the majority (68 percent) of occupant windshield contacts in a sample of conventional windshields were sufficient to break the glass, yet did not produce lacerations.

Although insufficient for comparative statistical statistical analysis, the General Motors fleet experience did provide evidence that lacerative injuries can indeed occur from contacts with glass-plastic windshields. The overall lacerative injury rate noted in the GM data -- i.e., 28 to 40 percent based on occupants impacting and breaking the windshield -- also tends to indicate (as did the State results) that any true injury reduction benefit of glass-plastic glazing is considerably less than the elimination of these injuries, as originally projected.

Furthermore, the 28 to 40 percent injury rate for the glass-plastic vehicles is similar to the 32 percent injury rate noted for the sample of conventional windshield vehicles in the GM study. This result is also in general agreement with the analysis of the State data which found no significant difference between the lacerative injury rate for the two types of windshield glazing. The lacerations in the GM data were described as pressure splitting of the tissue due to blunt impact or the sliding of the head against the inner plastic surface of the windshield, rather than incised wounds from broken glass. These injuries could involve more tearing of the skin, and perhaps result in more jagged wounds, as opposed to the sharper, "clean" cuts caused by broken glass fragments. Whether there is any reason to differentiate between the types of lacerations resulting from impacts with glass-plastic windshields (with respect to scarring, the need for stitches, or other concerns) is unknown at this juncture. All that can be said is that the injuries from both types of glazing were described as lacerations.

The vast majority of lacerative injuries resulting from windshield impacts are minor, being graded at level 1 on the Abbreviated Injury Scale, the lowest level of severity. The agency, in approving the use of glass-plastic glazing, stated that there was some concern that the material, while decreasing lacerative injury, could increase blunt trauma or closed head injury -- which could be more severe. The plastic inner layer, while providing protection from broken glass shards, could, at the same time, result in a windshield of increased stiffness that might not yield sufficiently under impact. This could increase HIC levels. The one DuPont Company report involving the crash of a 1985 Seville appears to be an example where this phenomenon could occur, but no conclusions can be reliably drawn on the basis of this one sample.

Another potential safety benefit hypothesized for glass-plastic windshields was a reduction in the likihood of occupant ejection, which is associated with more severe injury. The volume of data available for this study was insufficient to address this issue. However, it is believed that glass-plastic windshields would have negligible effect on ejection since this phenomenon is primarily a function of the method of bonding the windshield to the vehicle, and the bonding method for glass-plastic windshields does not differ from the method used for conventional windshields..

To summarize, the analyses of available crash information -- because of certain limitations in the data -- are insufficient to support firm conclusions with respect to quantitative estimates of the injury reduction potential of glass-plastic glazing. Nevertheless, the analyses of State data, together with the results of other available crash data, do suggest that the actual benefits from the glazing are substantially less than the essential elimination of windshield-caused lacerative injuries, as originally projected by the agency. While the fleet data were insufficient to support comparative statistical analysis, these data did provide specific evidence that lacerative injuries do occur from occupant contact with glass-plastic windshields. In the General Motors fleet test, 28 to 40 percent of the occupants who contacted the glass-plastic windshield with sufficient force to break the glass sustained lacerations, due to blunt impact with the plastic inner liner.

A final issue with respect to the potential safety benefit realizable from the use of glass-plastic glazing in motor vehicle windshields concerns the area of occupant restraints. In 1983, when the agency approved the glass-plastic glazing, it believed that future installation of passive restraints would consist mainly of belt systems, which could be easily detached by unwilling occupants. These occupants would still represent a segment of the motoring population that could benefit from glass-plastic windshields. Unforeseen, at that time, were not only the high rates of restraint usage that would eventually occur (due to mandatory use laws and other factors), but also that air bags would see a breakthrough so significant that they would be in all new passenger cars and light trucks by the late 1990's. Aside from the fact that the extent of the safety benefit of glass-plastic windshields has still not been established, it seems rather apparent that such benefit would be substantially eclipsed by the high use of occupant restraints together with the "coming of air bags." It also seems reasonable that the increasing rates of seat belt use served to reduce the sample sizes (especially the numbers of <u>injured</u> occupants) for the state crash data analyzed in this study.

CHAPTER 3

DURABILITY ISSUES

3.0 INTRODUCTION

When the agency amended FMVSS 205 in 1983, it recognized that certain durability issues could arise from the use of glass-plastic glazing. Since plastic is a softer material than glass, there was concern that over time it might be susceptible to damage or degradation effects which could potentially affect driving visibility, and also reduce the useful life of the windshield. Reduced driving visibility could have safety implications, and reduced durability could mean that windshields would require more frequent replacement -- an added cost for consumers. Among the specific durability issues cited in the agency's 1983 rulemaking analysis were: (1) haze and visibility, (2) attachment and removal of decals, (3) delamination, (4) ultraviolet radiation, (5) resistance to chemical attack, (6) attachment of rear view mirror, (7) paint shop bake oven temperatures, and (8) mechanical removal of frost.

In order to deal with the higher levels of haze (due to scratches and other forms of abrasion) that would be expected to develop on the plastic inner liner of glass-plastic windshields, the abrasion requirement of FMVSS 205 was relaxed. The maximum of two percent haze permitted for glass after 1,000 cycles of an abraser was increased to four percent maximum, for glass-plastic glazing after 100 cycles of an abraser. The four percent requirement was in agreement with the European standard in effect at that time. Also, a research study sponsored by NHTSA concluded that a four percent haze level seemed generally satisfactory for visual driving tasks, with the exception of certain rare conditions such as nighttime driving toward oncoming traffic with lights on high beam which could produce disabling glare [17].

The attachment and removal of decals was considered to be a definite problem. The plastic inner liner would stand a high probability of being cut by the typical blade scraper used to remove most decals. In addition to degrading the optical quality of the windshield, such cuts could also foster delamination or chemical attack which could cause clouding effects. NHTSA considered several possible remedies for the decal problem, but none was considered satisfactory. Consequently, an "advisory/warning" label was required to be affixed to all glass-plastic windshields, together with information in the vehicle owners manual which warned owners of the special care required.

In order to combat the potential problem of delamination (i.e., bonding separation between plastic and glass plies), the agency added two additional requirements to FMVSS 205 when it amended the standard to permit glass-plastic glazing. These tests dealt with weathering and temperature change.

Prolonged and intensive exposure to ultraviolet radiation can cause plastic to become yellow or cloudy. The weathering test (discussed above) was required to ensure that glass-plastic glazing met the performance requirements for this environmental phenomenon.

Plastic is more susceptible than glass to chemical attacks which could degrade the optical qualities of the inner liner. To minimize this problem, the agency added to FMVSS 205 a requirement that glass-plastic glazing display minimum resistance to attacks from certain chemicals (i.e., one percent solution of non-abrasive soap, kerosene, undiluted denatured alcohol, gasoline), including one which simulates commercial window cleaners.

The agency recognized that the attachment of the rearview mirror, using conventional adhesives, could pose a problem. The adhesives used to bond the mirror to glass might be incompatible with the inner plastic liner of glass-plastic windshields. Three potential solutions were seen for this problem -- the development of a new adhesive or the relocation of the rearview mirror to the windshield header (where it had been mounted for many years prior to its relocation to the windshield glass). It was also envisaged that a hole could be pre-cut in the plastic at the mounting location and conventional adhesive used.

The agency was also concerned that the plastic inner liner could be damaged by the mechanical removal of frost -- i.e., using a scraper. Limited tests showed that the liner did develop fine scratches after a limited number of scraping cycles. Because of this concern, the agency required a warning label to be affixed to the glazing along with a section on special care and cleaning instructions in the owners manual.

3.1 FIELD DATA ON DURABILITY

The field data on durability of glass-plastic windshields comes mainly from the manufacturer fleet tests plus warranty claims experience of the GM vehicles sold to the general public. A survey of owners of GM vehicles fitted with glass-plastic windshields had been proposed to obtain a representative sample of in-use experience as to the types of problems encountered by consumers. However, due to NHTSA budgetary priorities, it was not possible to conduct the survey.

GM Fleet Experience. In 1983, General Motors placed 2,500 of its "J" cars, equipped with glass-plastic windshields, in rental fleets to gain field experience with this type of glazing (see earlier discussion). The windshields in these vehicles were produced by Saint Gobain Vitrage. The program involved three rental fleets and 15 cities. The use of rental fleets permitted the accelerated acquisition of field data due to the higher exposure environment for these vehicles (compared to the general population), and also facilitated distribution of the vehicles geographically, in order to test the effect of climatic extremes on the glass-plastic glazing. The use of rental fleets also provided a convenient control for accessing the vehicles for inspection purposes, or for windshield replacement in the event problems developed.

One of the primary goals of the fleet tests was to evaluate the degree to which haze developed on the plastic inner liner, as a result of it being more susceptible to abrasion (from cleaning, etc.) than the glass ply used in conventional windshields. Based on tests of a small number of windshields which had been in the fleet for about eight months, or about 16,000 miles per vehicle, haze buildup did not appear to be a problem. The short period of exposure, however, was insufficient to provide adequate information on whether haze buildup would remain within acceptable levels over a long enough period to ensure satisfactory performance for the plastic glazing [7,8]. After another four months of fleet exposure, four reports of bond separation between the rearview mirror and the plastic inner liner were recorded. Five incidences of damage were also reported--four due to scratches and burns, described as malicious in nature, and one was cut in an attempt to remove a decal. Ten windshields also developed stress cracks [8].

Table 3-1 summarizes the disposition status of GM's J-car fleet (Fleet No. 1) as of January 11, 1985. According to GM, approximately 850 of the vehicles were removed from the fleet after one year of operation and auctioned off to the public; another 338 were placed on a second lease to the State of West Virginia. The remainer of the vehicles were kept in the rental fleet for an additional five months, after which they were also auctioned off to the public [8]. Company representatives inspected the vehicles prior to the auction sales, and

Table 3-1

General Motors Rental Fleet No. 1
(Hertz, Avis, National)

(Glass-Plastic "Securiflex" Windshields)
Status as of January 11, 1985

Vehicle Disposition	Number of Vehicles	
Original Fleet Size		**2,500**
On second lease -- to State Government of West Virginia		338
Total vehicles inspected -- of this number:		1,735
Still had glass-plastic windshield installed	1,303	
Glass-plastic windshield required replacement	329	
Remaining vehicles with glass-plastic windshields sold to the public	974	
Awaiting inspection		150
In GM fleet		2
Totalled during fleet test program		80
Glass-plastic windshields replaced without inspection (at GM's request)		133
Unaccounted for		62

Note:

The orginal "Securiflex" fleet was fielded in April 1983 and remained in service for a period of 12 to 18 months. Average miles per vehicle per month was approximately 2,000. Most of the vehicle resales to the public took place near the end of the first 12 months, as did the second lease to West Virginia.

Source:

Reference [8].

any windshields found to have "appearance" or "vision" problems were replaced. Table 3-1a is an estimate of the total number of windshields replaced, based on the data from Table 3-1. Note that this estimate of the proportion of windshields replaced ranges from 44 percent to as high as 48 percent. This would seem to be a very high number -- nearly half of the original number of windshields. At the end of the first year, the company noted that approximately 12 percent of the windshields required replacement, primarily due to cracking or breakage resulting from impacts with outside, airborne debris (stones, etc.). At this rate the total proportion of windshields that would have required replacement at the end of the 17-month fleet life would be 17 percent. Comparing this to the total estimated proportion of windshields replaced, 44 to 48 percent, raises the question of why the additional large percentage (27 to 31 percent) of replacements were made. Although not specifically stated in the GM data on Rental Fleet No. 1, it is reasonable to assume that these additional replacements were made due to the windshields not passing the pre-sale inspection -- i.e., they exhibited "appearance" or "vision" problems. It is further reasonable to assume that most of these "appearance" or "vision" problems were related to the plastic inner liner. (See also information on GM Fleet No. 2, and "Warranty Data," in the following sections.) All of the windshields were replaced with <u>conventional</u> (i.e., non glass-plastic) windshields.

Subsequent to fielding the fleet of 2,500 vehicles, General Motors added another 600 "A" cars, also in rental fleets. This latter group of vehicles were fitted with glass-plastic windshields manufactured by Libby-Owens-Ford. Due to rearview mirror mounting

Table 3-1a

Computation of Number of "Securiflex" Windshields Replaced

General Motors Rental Fleet No. 1

(Based on Table 3-1)

Vehicle Disposition	Number of Vehicles	
Total Inspected	1,735	
Number still having windshield	1,303	
Number requiring replacement of Securiflex windshield	329	(25% of vehicles inspected)
Number of Securiflex windshields replaced prior to inspection	432	(1,735 - 1303)
Total number of Securiflex windshields replaced/needing replacement	761	(432 + 329)
Overall total number of Securiflex windshields replaced	894	(432 + 329 + 133)
Percent of total Securiflex windshields replaced:	Percent Replaced	
(1) Base no. 1 = 2,500 - (338 + 150 + 2 + 80 + 62) = 1,868	48% = 894/1868	
(2) Base no. 2 = 1,735	44% = (432 + 329)/1,735	

Source:

Reference [8].

problems, the sample of 600 cars was reduced to 480. The mounting problem was solved by leaving a hole in the inner liner to permit attachment of the mirror button directly to the glass surface --the same procedure used in conventional windshields. Following approximately 13 months exposure (14,000 miles per car), it was reported that 26 of the test windshields had been replaced due to crazing, six for customer damage, one for edge distortion, and seven for stress cracks. Eleven windshields were tested for haze and found to compare favorably with control windshields measured at the beginning of the test [8]. Table 3-2 summarizes the data on windshield replacement, showing the reason for replacement for glass-plastic windshields and for standard windshields. Subtracting the 11 glass-plastic windshields that were retrieved for haze tests, the replacement rate for these windshields was 8.3 percent, compared to 5.8 percent for the standard windshields. The replacement rate for glass-plastic windshields was 43 percent higher than the replacement rate for the standard windshields, although both rates were reasonably small.

The problem of crazing was said to be a quality control problem at the production source of the plastic lining material. The problem was said to have been positively identified and resolved. However, GM stated that all (i.e., 100 percent) of the glass-plastic windshields would nevertheless be replaced with conventional windshields at the conclusion of fleet service (and prior to their resale to the public) to prevent possible occurrences of customer dissatisfaction when the vehicles were resold to the general public. It will be recalled that a high proportion (44 to 48 percent) of the glass-plastic windshields from the fleet of 2,500 cars were also replaced, but no specifics (as to crazing, or other problems) were given for

Table 3-2

General Motors Rental Fleet No. 2
(Alamo, General)

(Libby-Owens-Ford "Inner Shield" Windshield)

Status as of January 11, 1985

Total Exposure: Approximately 13 Months or 14,000 Miles Per Car

Windshield Replacement Reason	Number (Percent)			
	Conventional Windshield		Glass-Plastic Windshield	
Accidents	1	(0.83%)	4	(0.83%)
Crazing	0	(0.00%)	26	(5.42%)
Customer Damage	0	(0.00%)	6	(1.25%)
Edge Distortion	0	(0.00%)	1	(0.21%)
Stone Damage	4	(3.33%)	7	(1.46%)
Stress Cracks	0	(0.00%)	7	(1.46%)
Windshield Retrieval for Haze Tests	0	(0.00%)	11	(2.29%)
Unknown/Miscellaneous	2	(1.67%)	2	(0.42%)
TOTAL	**7**	**(5.83%)**	**64**	**(13.33%)**
Total Cars in Fleet	120*	(182)	480*	(418)

Notes:

* - Due to a rearview mirror mount problem during factory build of the vehicles, 182 vehicles were produced with conventional windshields. Sixty-two of the 182 vehicles were later retrofitted with the glass-plastic (Inner Shield) windshield, making the total test feet 480 vehicles, rather than 600, as originally planned. Therefore, the percentages given, which are based on total cars of 120 and 480, are somewhat high for the conventional windshield group and somewhat low for the glass-plastic group.

\- GM directed that as all vehicles came off the lease agreement to the rental companies and before their resale to the public, that <u>all</u> "Inner Shield" windshields were to be replaced with conventional windshields.

Source: Reference [8].

the replacement. The indication was that these replacements were due to "appearance" or "vision" problems with the windshields. Since the two fleets represented two different windshield manufacturers, it is possible that the problem of crazing was unique to the second fleet of 600 vehicles.

Ford Fleet Experience. Ford fielded a test sample of approximately 2,400 1984 Ford LTD's for purposes of obtaining experience on glass-plastic windshields (see also Section 2.4). These vehicles were placed in rental fleets and distributed geographically to test climatic effects, similar to the GM tests [12].

Ford representatives visited six of the rental fleet locations and inspected a total of 274 vehicles as to the condition of the windshield. Table 3-3 summarizes the inspection results. The vehicles averaged 22,000 miles at the time of inspection. All 274 windshields were said to have exhibited no loss of transparency, showing no evidence of discoloration, haze, or fogging. However, 205 (75 percent) exhibited minor scratches and abrasions; 116 (42 percent) showed moderate-to-heavy scratches and cuts; and 12 (4.4 percent) had delamination around the edge of the plastic inner liner. With respect to rearview mirror attachment, 18 (6.6 percent) evidenced adhesion problems between the mirror button and the plastic liner. Three (one percent) of the windshields had surface irregularities, known as the "orange peel" effect. (A commenter to the Docket during the agency's rulemaking process of amending

Table 3.3

Ford Rental Fleet (Hertz)
With Glass-Plastic (Securiflex) Windshields

Final Summary of Inspection Results
October 14, 1986

Total Vehicles: 2,353
Total Exposure: Approximately 22,000 Miles, or 15 Months Per Car

Inspection Results	Number (percent) Vehicles	
Total Vehicles Inspected	**274**	**(100%)**
Plastic film exhibits good resistance to staining, smoke, chemicals, and solvents	262	(95.6%)
No loss of transparency	274	(100%)
Absence of discoloration, haze, or fogging	274	(100%)
Good film to glass adhesion, except around edges	274	(100%)
Delamination around edge of plastic film	12	(4.4%)
Film exhibits minor scratches and abrasions	205	(74.8%)
Film exhibits moderate-heavy scratches and cuts	116	(42.3%)
Decal usage on film:		
Use of decals noted	227	(82.8%)
Decal glue residue noted on film	207	(91.2%)
Decal plaques used on film	130	(57.3%)
Decal plaques removable at inspection without damage to film	1	(0.08%)
Incomplete rearview mirror adhesive bond to film (9 non-adhesions, 8 partial adhesions, 1 replacement)	18	(6.6%)
Film shows surface irregularities ("orange peel" effect)	3	(1.1%)

Source: Reference [11]

FMVSS 205 stated that certain solvents available in commercial window cleaning agents could produce this orange peel effect.)

While a number of the windshields had been replaced, the reasons, with respect to the plastic inner liner, were not broken out in the Ford data. As was true for the GM fleets, all replacements were made with conventional windshields. In summarizing its fleet results, Ford noted the following concerns with respect to the glass-plastic windshield [11].

(1) Attempts to remove decals or decal plaques often result in damage to the plastic film.

(2) Rearview mirror attachments sometimes result in only partial adhesion to the plastic film.

(3) Accumulation of scratches/abrasions over time may be unacceptable to long-term owners. (Ford stated that they were concerned that a large proportion -- i.e., 116/274 = 42 percent -- of the windshields had moderate or heavy scratches or cuts after approximately 22,000 miles and 15 months in service.)

(4) Decal plaques, when used, are frequently wrinkled and unsightly.

GSA Fleet Experience. Very scant information was available with respect to durability problems experienced in the GSA fleet of 2,500 1985 Ford Tempos (discussed in Section 2.4). Information obtained from GSA stated that "2 or 3," of the windshields, when received from the factory were damaged by personnel in attempting to remove factory stickers. These windshields were replaced by Ford under warranty agreement with GSA. This occurred prior to GSA being notified by Ford that a special solvent was to be used for sticker removal.

Maryland State Police Fleet Experience. During the Maryland State Police Fleet test, it was reported that several of the plastic inner liners of the test windshields had gouge marks which resulted from the placement of radar units on the dashboards of vehicles used for speed limit enforcement. Examination of standard windshields from the comparison sample of vehicles indicated small scratches in the same area of the windshields. The gouge damage versus small scratch damage is apparently a reflection of the difference in abrasion resistance between the plastic film and standard windshield glass.

A final part of the police fleet test involved the comparison of visibility characteristics of the two types of windshields after a period of fleet operational exposure. This was accomplished by taking gloss measurements with the aid of a portable reflectometer and converting these measurements into percent haze measurements. Readings taken from 13 to 15 months of fleet operation (equivalent to approximately 37,000 miles per vehicle) showed no statistically significant difference in haze levels between the Securiflex windshields and the conventional windshields. (To be noted here is that General Motors determined that haze levels derived from field measurements of gloss were not satisfactory -- the method suffered from repeatability problems [7,8,19]. For this reason, the company conducted its haze measurements in a laboratory environment using windshields removed from vehicles and shipped to the laboratory.)

Insurance Replacement Experience. Earlier, in Section 2.6, it was noted that when insurance replacement of damaged glass-plastic windshields was required, the insurers refused to pay the unusually high cost charged by glass shops. Consequently, the glass-plastic windshields were replaced with conventional windshields. While the small volume of glass-plastic windshields produced (and hence, glass replacement shop unfamiliarity with installing them), may have contributed to their high installation costs, it is also likely that the handling, storage, and shipment of these windshields may have contributed to a higher component cost, due to greater susceptibility of the plastic inner liner to damage during these processes, compared to the glass plies of a conventional windshield. It will be recalled that all the GM and Ford rental fleet windshield replacements also used conventional windshields. Although the companies were interested in any windshield "appearance" or "vision" problems being remedied to ready the vehicles for resale, the cost (labor and parts) of replacing the windshields could well have been a factor.

New Vehicle Warranty Experience. A final source of information from GM concerning the durability of glass-plastic windshields came from the company's new vehicle warranty experience. At a point approximately halfway through the 1987 model year, the company reported that for the 1986 and 1987 model years, it had replaced approximately 6,000 of the windshields under warranty. Based on the estimated number of vehicles produced to that point, NHTSA estimated that the warranty replacement rate was in the vicinity of five percent. The reasons for replacement (as opposed to a conventional windshield) were: poor visibility (45 percent of replacements) and scored or scratched (10 percent of replacements) [18]. Considering the young age of the vehicles for which these warranty replacements were made, the eventual replacement rate would be expected to be considerably greater than five percent. This was later confirmed by data submitted by General Motors, in response to an agency request for update information on the windshields [19]. For the entire 1987 model year, the company replaced 9,227 glass-plastic windshields, or 12.6 percent of the total production for that year. The replacement rate for conventional windshields was approximately three percent. Hence, the warranty replacement rate for glass-plastic windshields was 4.2 (or 420 percent) times the replacement rate for conventional windshields. The reasons given by customers for replacement of the 1987 model year windshields were the same as had been cited in the earlier data -- poor vision and scoring or scratching. An additional consideration is that once the warranty period had expired, there would still be the concern for windshield damage that could entail visibility impairment, owner dissatisfaction, and possible windshield replacement. In the event the windshield required replacing, it is likely that it would have to be done at owner expense, as insurance (comprehensive) coverage would not be expected to cover damage related to the plastic inner liner.

GM also stated that with respect to non-warranty complaints, the major customer objection to the windshield seemed to be that it was too delicate and too susceptible to damage (scratches, etc.) through normal use and as a result of sticker removal [18].

Summary of Durability Experience. The field experience with respect to the durability issues associated with glass-plastic windshield glazing is somewhat limited. It was not possible to conduct the originally planned survey of owners of vehicles equipped with glass-plastic windshields as to their experience with the glazing. The fleet experiences, while describing some of the problems that can occur with the glazing, generally do not provide for an adequate (i.e., control-group) comparison with problems that occur with conventional windshields. Also, the rental fleet environment, being more harsh than the individual vehicle owner environment, could exaggerate the types (or rates) of durability problems likely to be experienced by the general population of vehicles owners. Certainly, it is reasonable to say that rental fleet exposure would reveal problems earlier than the exposure conditions of privately owned and operated vehicles, this being an important reason for the manufacturer's choice of these fleets as a testbed for the glass-plastic glazing.

Notwithstanding these caveats, the rental fleet experience is believed to provide a reasonable indication of the types of durability concerns that can be expected to occur if glass-plastic windshields were introduced in large numbers into the general driving population. The types of problems (scratching/abrasions, cuts to the plastic liner, rearview mirror mounting/adhesion problems, decal attachment/removal, delamination of plastic liner) noted in the fleet operations generally correspond to the types of concerns recognized by the agency when it amended FMVSS 205 to permit the use of glass-plastic glazing. Cuts, scratches, and abrasions, together with decal attachment/removal would appear to be the primary concerns -- concerns for which no satisfactory solutions appeared in the fleet tests. Windshield warning labels and owners manual cautions, while apt to draw less attention from vehicle renters than from individual vehicle owners, may still not be sufficient to provide an adequate safeguard against damage.

The greater susceptibility of the plastic liner to abrasion appears to be the essential problem here. GM stated that many of the problems experienced by its customers were the result of the inner shield's sensitivity to abrasion [20]. Of course, both the long-term safety impacts of, and owner satisfaction with, glass-plastic glazing are a function of the aggregate of the different types of durability problems (including delamination, mirror mounting problems, orange peel effect, etc.) that are peculiar to glass-plastic glazing. Most of the problems encountered in the fleet tests would not appear to be significant durability concerns for conventional (glass) windshields. One potential concern, the formation of haze, was not found to be an issue in the fleet tests. However, the methods of assessing haze were generally limited, and the duration of the fleet tests was not sufficient to ensure that haze formation would not be of concern over a longer period, or a period equivalent to the average life of the vehicle.

The problems encountered in the insurance replacement of glass-plastic windshields, coupled with the fact that these replacements -- as well as all rental fleet replacements -- used conventional windshields, provide further evidence of the durability concerns associated with the glass-plastic glazing.

The warranty data from General Motors shows that the replacement rate for glass-plastic windshields was more than four times as high as the warranty replacement rate for conventional windshields. The primary reasons for replacement, as stated by the vehicle owners, were "poor vision" and "scored or scratched," which accounted for over half of the warranty replacements. With respect to non-warranty complaints, the company stated that the major customer objection to the windshield seemed to be that it was too delicate and too susceptible to damage (scratches, etc.) through normal use, and as a result of the removal of stickers. Finally, the types of problems noted are, to a large extent, time related which means that durability problems would likely continue to occur throughout the life of the vehicle.

CHAPTER 4

THE COST OF GLASS-PLASTIC GLAZING

4.0 INTRODUCTION

The conventional windshield that has been in use in automobiles since the 1960's consists of two glass plies bonded to an interlayer of plastic (polyvinylbutyral). It is often referred to as the HPR (High Penetration Resistant) windshield. The glass-plastic windshield is similar in construction to the HPR windshield except for the addition of a thin layer of plastic (polyurethane) to the inner glass ply (i.e., the windshield surface facing the occupant, or passenger compartment).

4.1 WEIGHT PENALTY COSTS

The additional weight of the glass-plastic windshield, compared to a conventional windshield has been estimated to range from six ounces to two pounds [12,15,18]. However, it is possible to reduce the thickness of the glass plies so that the added weight of the inner plastic layer is partially, or wholly offset [15]. Consequently, the extra vehicle weight, and potential fuel penalty, resulting from the use of a glass-plastic windshield is considered insignificant. This means that the cost of additional fuel consumption due to added vehicle weight -- an element of cost in almost all effectiveness studies of safety standards -- is inconsequential in the case of glass-plastic windshields.

4.2 COMPONENT COSTS

Based on information available from the sole manufacturer of glass-plastic windshields at that time, (i.e., Saint Gobain Vitiage), NHTSA, in 1983, estimated that a glass-plastic windshield would cost the consumer about $38 to $45 more than a conventional windshield. Updating this estimate to 1992 economics gives a cost range of $55 to $65. It should be noted that these estimates assume that the windshields would be produced in volume quantities (i.e., 500,000 to 1,000,000 units annually) sufficient to realize economy of scale in manufacturing operations.

Later, in 1987, two additional cost estimates of glass-plastic windshields were made. Libby-Owens-Ford, a second company which began producing glass-plastic windshields, estimated that the windshield would cost about $50 more than the conventional windshield. In 1992 economics, the cost would be $63, which is close to NHTSA's earlier estimate [3]. The one car manufacturer, General Motors, that did introduce the glass-plastic windshield as standard equipment on selected carlines for a brief period, estimated that the additional cost to the consumer was approximately $100, or in 1992 economics, $121. The company also estimated the replacement cost for the glass-plastic windshield at $375 (1992 cost = $454) above the cost of replacing a conventional windshield [18,19]. The production volume of General Motors' vehicles fitted with glass-plastic windshields as standard equipment was in the vicinity of 75,000 annually, which was considerably less than the volumes NHTSA had assumed. Also, at the time the General Motors' cost estimates were made, the company had already made the decision to discontinue producing vehicles with glass-plastic windshields.

The above cost estimates of glass-plastic windshields include all costs (material, production, etc.) incurred in the manufacture of the windshield plus an allowance for profit. In its 1983 rulemaking analysis, the agency assumed that minimum modifications to the existing manufacturing process for HPR windshields would be required in order to produce glass-plastic windshields.

4.3 DURABILITY COSTS

Chapter 3 discusses the types of durability problems encountered with the glass-plastic windshields which were tested in a rental fleet environment, and also the types of concerns expressed by vehicle buyers who has glass-plastic windshields replaced under warranty. The primary types of problems cited in the fleet experience were scratches and cuts, decal use and rearview mirror attachment. Warranty customers cited poor visibility and scratches or scoring of the inner liner. Chapter 3 also discusses the high costs encountered in the insurance or non-warranty replacement of the windshields which could partially reflect durability problems of the glazing with respect to storage, handling, shipment, and installation. There are three potential categories of costs associated with the types of durability problems encountered.

First, there is the dollar, or out-of-pocket cost to the individual vehicle owner who may be faced with replacing a damaged windshield after the new vehicle warranty period expires, or, while still under warranty if the damage involved is not covered under the vehicle warranty. For non-warranty cases, replacement costs could be defrayed by insurance coverage. This could apply to the original new car purchaser, or to a subsequent purchaser. It could also apply to a dealer or distributor who, for purposes of vehicle resale, decides that the windshield should be replaced in order to improve the condition of the vehicle and make it more attractive to prospective buyers. It will be recalled that a large proportion of vehicles in the rental fleets (see Chapter 3) had their windshields replaced before they were resold to the public. Based on the manufacturer component estimate cited earlier, together with the high cost encountered under insurance replacement, such replacement cost would likely be quite significant. Recent data on windshield replacement by glass replacement shops show that the standard cost (i.e., time and materials) of installing a glass-plastic windshield was $1,716, or $1,227 higher than the cost of installing a conventional windshield. Standard labor hours for installing a glass-plastic windshield were 4.0 versus 3.6 hours for installing a conventional windshield [21]. This indicates that most of the cost difference is due to the component cost. Replacement costs could be reduced if the windshield were replaced with a conventional windshield, and, in fact, this is apparently what has been done in essentially all cases. All of the rental fleet replacements were made with conventional windshields. Also, it is assumed that essentially all private owners of vehicles originally equipped with glass-plastic windshields would have replaced them with conventional windshields, refusing to pay the $1,227 premium price for the glass-plastic windshield. It was stated previously that automobile insurance companies refused to cover the cost of replacement using glass-plastic windshields. It has also been previously stated that General Motors cited the high replacement costs for consumers as one reason for discontinuing to install the windshields in its luxury carlines following the end of the 1987 model year production. Of course, it should be noted that replacing with a conventional windshield negates any safety advantage of the glass-plastic windshield in the first instance.

Secondly, there is a potential "safety cost" associated with reduced visibility to the driver from a sufficiently scratched or otherwise damaged windshield. Rather than a safety cost, this could also be considered a negative safety benefit. Reduced visibility, particularly under nighttime, dusk/dawn, adverse weather, or other restricted light conditions, could increase the chances of an accident.

Thirdly, there is the cost, more intangible in nature, of adversely affecting owner satisfaction/acceptance of the vehicle. This would primarily be a potential cost and concern to the vehicle manufacturer. If an owner experienced sufficient durability problems with the glass-plastic windshield -- and this could vary with the individual and his tolerance level -- it could serve to lower the owner's respect for the manufacturer in producing quality vehicles.

Since the vehicle owner survey was not conducted, there are no available data with which to estimate any of these 3 durability costs associated with glass-plastic windshield. However, there is sufficient information to indicate that durability costs would not be inconsequential. With respect to the safety cost and the windshield replacement cost, these would probably be subject to a trade-off consideration for the individual owner so affected. Because of the indicated high cost of replacing the windshield, the individual might well continue to drive the vehicle with windshield visibility degraded beyond that which otherwise might be accepted if the replacement cost was not so high. Continuing to drive the vehicle could represent an increased safety risk.

4.4 OTHER COST ISSUES

Manufacturer Actions

Of the two major U.S. automobile companies, GM and Ford, which conducted rental car fleet tests of glass-plastic windshields, only GM elected to take the next step of introducing the new windshield to the general public. As discussed in this report, the company installed the glass-plastic windshield (referred to as "Inner-Shield Windshield") in selected models of its personal luxury carlines in the 1984 to 1987 period. The company discontinued use of the glass-plastic windshield at the end of the 1987 Model Year. In a 1988 submission to NHTSA's Docket Section concerning a related rulemaking issue, General Motors stated that its decision to discontinue use of the windshield, "was reached after customer problems with the product resulted in high replacement costs for customers and high warranty costs for GM." The company also stated that, "Many of the problems experienced by the customers were the result of the Inner-Shield's sensitivity to abrasion, and that they were also aware of concerns regarding poor vision through the glazing and increased difficulty in cleaning the plastic surface." [20].

In another letter to the agency, Saint-Gobain Vitrage, commenting on the European experience with the glass-plastic windshield, stated that, "the market development of the Securiflex (i.e., glass-plastic) windshield is restrained by its cost, which according to the car manufacturer, does not offer an attractive safety advantage versus cost ratio" [16]. Saint-Gobain Vitrage is the company which first developed the glass-plastic windshield, and which provided the windshields used in the GM and Ford rental fleet tests.

Benefits Versus Cost Considerations

Available data do not permit specific estimates of the injury reduction potential of glass-plastic windshield glazing. Hence, the potential safety benefit, in terms of lacerative injuries reduced, can not be estimated. Nonetheless, it is still possible to compare the potential benefits of the glazing with its costs, by assuming a range of effectiveness values for the glazing.

The Final Regulatory Evaluation which supported the agency's decision to permit use of glass-plastic windshield glazing estimated that, if installed in all passenger cars, the glazing could potentially eliminate all windshield-caused lacerations. The agency's earlier evaluation study of conventional windshield glazing estimated that some 450,000 of these injuries still occurred annually, after accounting for those lacerations prevented by the HPR windshield [2]. These remaining lacerative injuries are typically minor in nature, with an AIS rating of 1. The Regulatory Evaluation estimated that the average cost of a windshield-caused laceration in 1982 was $70 [3]. This was the total cost of requisite medical services, including: (1) examination and cleaning (25 percent of lacerations); (2) examination and suturing (60 percent of lacerations); and (3) examination and referral for further treatment (15 percent of lacerations). Using the above estimates, the equivalent one-year dollar savings, in injuries avoided, if glass-plastic windshields were installed in all new passenger cars, and if their effectiveness were 100 percent is given by:

Cost Savings = ENfcP

where,

E = effectiveness value for glass-plastic glazing

= 1 (i.e., 100 percent) for purposes of this example

N = annual number of windshield-caused lacerations in the car population

= 450,000

f = fraction of total passenger car fleet represented by 1 year's sales of 10,000,000 cars = 1/12 [22]

c = average cost of lacerative injury (1982 economics)

= $70

P = GDP adjustment to update cost to 1993 economics = 1.44

Substituting these values, gives:

Cost Savings = 1.0 (450,000) (1/12) ($70) (1.44)

= $3,780,000 ≅ $3.8 million

If the actual effectiveness of the glazing were 50 percent, or 25 percent, the corresponding cost savings estimates would be $1,900,000, and $950,000, respectively.

The corresponding cost of the glazing, using the $65 per windshield cost estimate developed previously would be:

Cost = $65/car (10,000,000 cars)

= $650 million

In considering these estimates, the following additional points should be kept in mind:

(a) the total cost of the glazing would be higher due to durability costs, not included included in these estimates.

(b) the total cost savings would be less due to today's target population of lacerative windshield injuries being smaller -- a consequence of higher belt use and accelerating air bag installations.

(c) the effectiveness of glass-plastic glazing is likely to be substantially below 100 percent. The indicated replacement of damaged glass-plastic windshields with conventional windshields, over time, would reduce the overall effectiveness, and related injury and cost savings.

(d) pain and suffering consequences of the lacerative injuries are not accounted for in these computations.

Although injury cost savings beyond the initial year of vehicle life are not considered in the above example, it is readily apparent that total, vehicle lifetime savings would amount to no more than a small fraction of the total costs of the glass-plastic glazing.

REFERENCES

1. Federal Motor Vehicle Safety Standard No. 205, Glazing Materials, 49 Code of Federal Regulations, Parts 400 to 999, Revised as of October 1991.

2. Kahane, C. J., An Evaluation of Windshield Glazing and Installation Methods for Passenger Cars, DOT HS 806 693, February 1985.

3. Final Regulatory Evaluation, Anti-Lacerative Glazing, FMVSS 205, Office of Program and Rulemaking Analysis, NHTSA, September 1983.

4. Parsons, G., Motor Vehicle Fires in Traffic Crashes and the Effects of the Fuel System Integrity Standard, DOT HS 807 675, November 1990.

5. National Accident Sampling System - 1985: A Report on Traffic Crashes and Injuries in the United States, DOT HS 807 074, February 1987.

6. "Special Accident Investigation Reports of General Services Administration Ford Tempo Vehicles Equipped with Glass-Plastic Windshields," 23 Reports of Accidents Occurring in 1985, 1986, 1987, 1988, Case Numbers: FR 87-32, FR 86-11, DS 85AB10, SW 8803AB, FRC 88-22, FRC 88-12, DS 88AB06, SWRI 8822AB, ARVICALSPAN SO16-082685, Tran Ctr (University of Tennessee), CALSPAN SO11-041385, FRC 87-24, SWRI 8706AB, ESIS 20H01-13, Franklin 87-4, Franklin 87-5, Franklin 87-6, GSA Vehicle (2/21/86), GSA/Ford Photos 4/25/86, GSA Vehicle (1/15/87), GSA Vehicle (4/13/87), ARVICALSPAN S017-090185, GSA Vehicle (9/20/85).

7. Doolittle, E. P., T. B. Horton, and H. P. Bloom, "Anti-Lacerative Windshield Materials; Field Evaluation by General Motors," Society of Automotive Engineers Technical Paper Series 840391, International Congress and Exposition, Detroit, Michigan, February 27-March 2, 1984.

8. Letter from David E. Martin, Director, Automotive Safety Engineering, General Motors, to Honorable Diane Steed, Administrator, NHTSA, USG 2201, Part III, April 10, 1985 (Subject: Fleet Tests of Anti-lacerative Windshield Glazing).

9. "Matched-Case Analysis of Securi-Flex Field Accident Data," December 17, 1984 (Included as attachment in letter from David E. Martin, Director, Automotive Safety Engineering, General Motors, to Honorable Diane Steed, Administrator, NHTSA, USG 2201 Part III, April 10, 1985).

10. MacKay, G. M. and C. A. Smith, "Facial Injuries from Windshields," 27th Annual Proceedings, American Association for Automotive Medicine, San Antonio, Texas, October 3-6, 1983.

11. Letter from R. H. Munson, Director, Automotive Safety Office, Ford Motor Company, to Barry Felrice, Associate Administrator for Rulemaking, NHTSA, October 14, 1986 (Subject: Hertz Rental Car "Securiflex" Test Fleet).

12. Letter from R. H. Munson, Director, Automotive Safety Office, Ford Motor Company, to Adele Speilberger, Associate Administrator for Plans and Programs, NHTSA, June 25, 1987, (Subject: Answers to NHTSA Questions on Glass-Plastic Windshields).

13. Jones, I. S., H. S. Stein, and J. J. O'Neill, "Maryland State Police In-Use Experience with the Securiflex Windshield -- October 1981 to Present", Society of Automotive Engineers Technical Paper Series 840389, International Congress and Exposition, Detroit, Michigan, February 27 - March 2, 1984.

14. "Face-Saving Windshields," Du Pont Magazine, Volume 80, No. 5, September/October 1986.

15. Letter from J. W. Herbert, Vice President, Advanced Technical Planning, Libby-Owens-Ford Company, to Adele Speilberger, Associate Administrator for Plans and Programs, NHTSA, July 22, 1987, (Subject: Answers to NHTSA Questions on Glass-Plastic Windshields).

16. Letter from Roger Orain, R and D Manager, Automotive and Architectural Glazings, Saint Gobain Vitrage (Paris), to Adele Spielberger, Associate Administrator for Plans and Policy, NHTSA, September 2, 1987.

17. Wakely, H., L. Wolf, and S. Godin, Optical Engineering Research on New and Used Automotive Glazing, IIT Research Institute, (Contract No. DTNH 82-C-07045), Final Report DOT HS-806 690, April 1983.

18. Letter from Robert A. Rogers, Director, Automotive Safety Engineering, General Motors Corporation, to Adele Spielberger, Associate Administrator for Plans and Policy, NHTSA, June 15, 1987, (Subject: Answers to NHTSA Questions on GM Vehicles Equipped with Glass-Plastic Windshields).

19. Letter from Robert A. Rogers, Director, Automotive Safety Engineering, General Motors Corporation, to Michael M. Finkelstein, Associate Administrator for Plans and Policy, NHTSA, April 26, 1990, (Subject: Answers to NHTSA Questions For Update on GM Fleet and Sales Experience with Glass-Plastic Windshields).

20. Letter from Robert A. Rogers, Director, Automotive Safety Engineering, General Motors Corporation, to Barry Felrice, Associate Administrator for Rulemaking, NHTSA, October 18, 1988, (Re: Advanced Notices of Proposed Rulemaking, Docket 88-06, Notices 3 and 4).

21. Telephone Conversation between Mr. Edward Egan, Glass Replacement Association, Vienna, Virginia, and Mr. Glenn G. Parsons, Office of Plans and Policy, NHTSA, June 17, 1993.

22. AAMA Motor Vehicle FACTS & FIGURES '93, American Automobile Manufacturers Association.

23. Automotive News, Market Data Book, 1985, 1986, and 1987.

APPENDIX A

DATA TABLES

Table A-1

Specifications of Vehicles Used in Study

YEAR MAKE/MODEL	BODY STYLE	CURB WEIGHT	WHEEL BASE	LENGTH	ENGINE TYPE	DISPLACE-MENT	DRIVE TYPE
* 1985							
Cadillac Seville	4-dr	3804	114.0	204.8	8	249	F
Cadillac Eldorado	2-dr	3734	114.0	204.5	8	249	F
Cadillac DeVille	2 dr/4 dr	3324	110.8	195.0	8	249	F
1986							
Cadillac Seville	4 dr	3428	108.0	188.2	8	249	F
Cadillac Eldorado	2 dr	3365	108.0	188.2	8	249	F
Cadillac Deville	2 dr/4 dr	3324	110.8	195.0	8	249	F
Buick Riviera	2 dr	3309	108.0	187.2	6	231	F
Buick Electra	2 dr/4 dr	3243	110.8	197.4	6	231	F
Olds Toronado	2 dr	3177	107.9	187.9	6	231	F
Olds Ninety-eight	2 dr/4 dr	3268	110.8	196.4	6	231	F
1987							
Cadillac Seville	4 dr	3419	108.0	188.2	8	250	F
Cadillac Eldorado	2 dr	3360	108.0	188.2	8	250	F
Cadillac DeVille	2 dr/4 dr	3312/3420	110.8	196.5	8	250	F
Cadillac Brougham	4 dr	4029	121.5	221.0	8	307	R
Buick Riviera	2 dr	3309	108.0	187.2	6	231	F
Buick Electra	2 dr/4 dr	3243	110.8	197.4	6	231	F
Olds Toronado	2 dr	3352	108.0	187.5	6	231	F
Olds Ninety-eight	2 dr/4 dr	3285/3320	110.8	196.4	6	231	F

NOTES:

* - Denotes TEST vehicle -- i.e., vehicles factory equipped with glass-plastic windshields
Curb Weight in pounds
Wheel base in inches
Length in inches
Engine type = number of cylinders
Displacement of engine in cubic inches
Drive type: F= front wheel drive; R=rear wheel drive

SOURCE: "Market Data Book" (annual publications of Automotive News for years 1985, 1986, and 1987)[23].

Table A-2

Injury Location and Injury Type Codes
for
Motor Vehicle Accident Statistics Files

State of New York

Location of Most Severe Physical Complaint		Type of (Most Severe) Physical Complaint	
1	Head	1	Amputation
2.	Face	2.	Concussion
3.	Eye	3.	Internal
4	Neck	4.	Minor Bleeding
5.	Chest	5.	Severe Bleeding
6.	Back	6.	Minor Burn
7.	Shoulder - Upper Arm	7.	Moderate Burn
8	Elbow - Lower Arm - Hand	8.	Severe Burn
9	Abdomen - Pelvis	9.	Fracture - Dislocation
10.	Hip - Upper Leg	10.	Contusion - Bruise
11.	Knee - Lower Leg - Foot	11.	Abrasion
12.	Entire Body	12.	Complaint of Pain
		13.	None Visible

Source:

New York State Department of Motor Vehicles, Data Element Dictionary, Files Inventory, Accident Statistics File

Table A-3

Injury Location and Injury Type Codes
for
Motor Vehicle Accident Statistics Files

State of Pennsylvania

Area of Apparent Injury (Most Severe)	Type of Apparent Injury (Most Severe)
00 - None	00 - No Injury
01 - Face	01 - Amputation
02 - Head	02 - Bleeding
03 - Neck	03 - Broken Bones
04 - Back	04 - Burns
05 - Arm(s)	05 - Concussion
06 - Leg(s)	06 - Shock
07 - Chest/Stomach	07 - Dizziness
08 - Internal	08 - Abrasion/Bruises
09 - Entire Body	09 - Complaint of Pain
98 - Other	98 - Other Injury
99 - Unknown	99 - Unknown Injury

Source:

Pennsylvania State Motor Vehicle Accidents, Code Dictionary

Table A-4

Location and Nature of Most Severe Injury
for
Motor Vehicle Accidents

State of Indiana

Location of the Most Severe Injury		Nature of the Most Severe Injury	
1.	Chest	1.	Severed
2.	Neck	2.	Internal
3.	Eye	3.	Minor Burn
4.	Face	4.	Severe Burns
5.	Head	5.	Abrasion
6.	Back	6.	Minor Bleeding
7.	Shoulder - Upper Arm	7.	Severe Bleeding
8.	Elbow - Lower Arm - Hand	8.	Fracture - Dislocation
9.	Abdomen - Pelvis	9.	Contusion - Bruise
10.	Hip - Upper Leg	10.	Complaint of Pain
11.	Knee - Lower Leg - Foot		
12.	Entire Body		

Note:

The Indiana Accident Report Manual includes additional definitions or the Nature of Injury Codes. The definitions of the bleeding injuries are:

6 - Minor Bleeding: bleeding of a small wound with no evidence of major blood vessel (a large vein or an artery) involved.

7 - Severe Bleeding: a large wound or a wound involving a large vein or an artery which has to be controlled by a constant use of direct pressure or tourniquet.

Source:

Indiana Officer's Standard Accident Report Instruction Manual.

Table A-5 Occupant Restraint Use* for TEST and CONTROL Vehicles						
STATE	CONTROL Vehicles			TEST Vehicles		
	Restraint Used	Restraint NOT Used	Unknown Other	Restraint Used	Restraint NOT Used	Unknown Other
Pennsylvania (all front seat occupants)	50.27	22.73	27.01	45.35	24.80	29.84
Indiana (all drivers)	42.33	13.80	43.96	46.31	13.28	40.41
New York (all front seat occupants)	84.11	6.87	9.02	83.06	7.20	9.74

* Percent of study occupants per each restraint use category, as reported in crash data files.

Table A-6 Occupant Age* for TEST and CONTROL Vehicles		
STATE	CONTROL Vehicles	TEST Vehicles
Pennsylvania (all front seat occupants)	45.98	42.76
Indiana (all drivers)	46.45	43.15
New York (all front seat occupants)	45.91	45.08

* Average age, in years, of occupants -- as reported in crash data files.

*U.S. G.P.O.:1994-301-717:80498