U.S. Department of Transportation

National Highway Traffic Safety Administration

Pedestrian Injury Reduction Research

Report to the Congress
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PREFACE

The National Highway Traffic Safety Administration (NHTSA) has prepared this report on the status of research efforts investigating the possibility of reducing pedestrian injuries and fatalities in response to the Senate Appropriations Committee request that,

> NHTSA submit a report on data it has collected and research conducted regarding ways of reducing pedestrian deaths and injuries through making vehicles more forgiving by removing sharp edges, softening the hood and cowl area, increasing the space between the hood and engine components, and other approaches, the cost of such designs in new cars, and on the numbers of deaths and injuries currently by type of injury and by vehicle type causing the injuries. The report shall include information on vehicle designs for pedestrian protection in other countries.

This report presents 1) highlights of research conducted to date to explore the technology and feasibility of modifying vehicle designs to better protect pedestrian impact victims, and 2) highlights of research and programs to avoid pedestrian-vehicle impacts through behavioral modification.

After an introduction, the section of the report dealing with vehicle changes that would lessen pedestrian fatalities and injuries presents information on head injury reduction, thoracic injury reduction, and leg injury reduction. The section of the report dealing with avoiding pedestrian-vehicle impacts presents information on behavioral modification research and programs that NHTSA recommends to States and communities that are based on this research.

EXECUTIVE SUMMARY

Pedestrian Injury Reduction Research

BACKGROUND

In 1991, pedestrian-vehicle impacts resulted in 5,797 pedestrian fatalities and 92,000 pedestrians injured. The cost of these impacts in terms of lost human capital and pain and suffering is great. Pedestrian fatalities have declined 26 percent and injuries have declined 39 percent in the last 10 years, and a portion of the decline is likely due to NHTSA programs to modify pedestrian behavior to avoid pedestrian-vehicle impacts.

About 38 percent (2,182) of pedestrian fatalities occurring in 1991 involved alcohol consumption by the pedestrian. Fifty-three percent of pedestrians fatally injured in 1991 were struck by passenger cars, and a majority of the impacts were frontal.

Children and elderly people are frequently involved in pedestrian impacts. In 1991, 10 percent of pedestrian fatalities and 20 percent of injured pedestrians were under the age of 10 years. Young people 9 - 16 years are under-represented, which suggests that pedestrian safety awareness created in the school years may be effective. The most over-represented group are those over 64 years of age. About 22 percent of pedestrian fatalities and 10 percent of pedestrians injured involved persons 65 years or older.

There is general agreement that injuries to the head and thorax are the most important, followed by those to the legs and neck.

The primary approach that NHTSA has taken to reduce the number of fatalities and injuries is to reduce the number of pedestrian-vehicle impacts. Over the years, NHTSA has conducted numerous research programs and demonstration programs that have resulted in recommendations to communities and States, and, in some cases, in grants to implement these programs at the State and community level. A research program directed toward exploring the feasibility of reducing the consequences of pedestrian-vehicle impacts also has been conducted by NHTSA. Whether it is worthwhile to promote particular vehicle-based countermeasures is not known at this time, because the number of vehicles that have been tested is small, and the costs associated with the development of such countermeasures have not been calculated. The research program directed toward exploring the feasibility of reducing the consequences of pedestrian-vehicle impacts was suspended during the summer of 1992 pending agency review of the direction of the program and its priority among other agency programs.

This report covers both the efforts directed toward reducing the number of involvements and the efforts to investigate the feasibility of reducing the fatalities and injuries given that an involvement has occurred.

HEAD INJURY RESEARCH

When a vehicle runs into a pedestrian, initial contact typically occurs as the bumper hits the knee or lower leg. The pedestrian then wraps around the front of the vehicle. The head of adult-sized pedestrians typically strikes the hood surface, fender tops, or cowl. In collisions below 48.3 km/h (30 mph), the impact location can be closely approximated by a "wrap-around-distance" equivalent to the pedestrian's standing height. The "wrap-around-distance," or WAD, is a linear measurement from the ground up and around the front profile of the vehicle. The speed with which the head hits the surface is usually no more than 90 percent of the speed of the vehicle at the time of impact [i.e., a 48.3 km/h (30 mph) impact will typically result in a head-to-hood impact speed of about 43.5 km/h (27 mph)].

Head impacts into hood/fender tops and cowls of passenger cars and light trucks (excluding vans) are responsible for an average of 732 fatalities annually based on 1984 to 1986 FARS data. This includes pedestrians, pedalcyclists, and motorcyclists. Four hundred fifty-three of these occur in impacts where the vehicle speed is less than 48.3 km/h (30 mph). Serious injuries involving head impacts at all speeds into the hood/fender tops and the cowl are about 1,500 per year for passenger cars and light trucks. Fatalities caused by head impacts to the hood/fender tops and the cowl are about 17 percent of all pedestrian head impacts, and about 10 percent of all pedestrian fatalities.

Baseline Injury Causation

To understand the injury causation contribution of representative vehicles, it was necessary to conduct testing of vehicles that represent the new car fleet. This was accomplished by selecting vehicles of various types and measuring the head impact responses of these vehicles in the hood and fender top areas of interest.

A head impact simulator was developed for this purpose. The impact device is equipped to measure velocity at impact, acceleration, and displacement. The head impact simulator was developed to replicate the damage to hoods from real-world head impacts in pedestrian collisions.

A central hood test zone that includes 14 test points to represent the major center section of the hood was developed, and eight 1989 and one 1988 model year passenger cars were tested using the head impact simulator. The results showed that, for the group of nine passenger cars, between 14 percent and 86 percent of the 14 test points had a Head Injury Criterion (HIC) of 1,000 or less for a head impact speed of 37 km/h (23 mph). A HIC of 1,000 is considered the threshold for serious head injury.

Early work with simulated pedestrian head impacts revealed that the hood/fender and rear hood areas tended to be considerably stiffer and potentially more dangerous than the central hood. A series of tests was conducted to characterize the hood/fender and rear hood regions of contemporary vehicles. Ten impacts were conducted with each of eight sample passenger cars. Five of the impact locations were in the hood/fender area and five were in the rear hood region. The average HIC from these 80 tests was 2,085 compared to an average of about 1,020 from the central hood areas of the 9 cars in the central hood sample. An analysis of the test work revealed that for impacts at 37 km/h (23 mph) 5.84 cm (2.3 inches) of displacement on average was needed to produce a HIC of no more than 1,000. Measurement of the space available under the hood of the nine-car sample revealed that individual cars had between 60 percent and over 90 percent of the area under the hood with 5.84 cm (2.3 inches) of clearance. The testing and analysis also revealed that significant reductions in HIC are possible with small increases in deflection in hard fender and cowl areas for improved protection in the more frequent low speed impacts.

Injury Countermeasure Efforts

The hood of a typical passenger car can be separated into three areas - the Central Hood Area, the Rear Hood, or Cowl Area, and the Hood/Fender Area. The agency has directed efforts to identify ways to improve the head impact performance in each area.

The testing of nine vehicles in the central hood area showed that one vehicle had a HIC score below 1,000 for more than 80 percent of the impacts in its central hood area. Three other vehicles had HIC scores below 1,000 for more than 70 percent of the impacts. However, four vehicles had HIC scores below 1,000 for 50 percent or less of the impacts. This work also showed that hood material, architecture, and under-hood clearance all influenced the impact response. A sampling of under-hood clearance from the nine vehicles showed that many had enough clearance under the hood to achieve the same performance levels as the best vehicle.

In the hood/fender and cowl areas, current design practices inherently produce much stiffer impact responses compared to the central hood area, and the areas are typified by relatively heavy structures immediately under and supporting the surface. Baseline head impact response in these areas tend to be much more severe than in central hood areas. The Ford Taurus was chosen to demonstrate hood/fender and rear hood head injury countermeasures because it was thought to exemplify mainstream vehicle design. It was also the hardest of several contemporary vehicles tested in the hood/fender area. Furthermore, the Taurus is well represented in the current fleet of passenger vehicles.

Impacts to the hood/fender of the Ford Taurus showed that the head form struck a very stiff structure beneath the fender skin, and consequently experienced a very high HIC indicating a high potential for severe head injuries. The space between the struck surface and the hidden structure had to be increased and the structure softened to reduce impact severity. The demonstration illustrated that modifying the underlying structure provided the impacting head form sufficient clearance to allow a less severe injury.

The apparent stiffness of the struck locality was altered with two changes to structures in the Taurus hood/fender region. Both the hood edge and the fender skin were modified. The combination of clearance and stiffness modifications that were applied to the demonstration Taurus produced a 60 percent reduction of the baseline HIC response for adult impacts and a 29 percent reduction in peak head acceleration for a 6-year-old pedestrian surrogate.

As with impacts to the hood/fender seam, the most important factors influencing cowl area impact performance are apparent stiffness and clearance between the exterior surface and hidden rigid components. The first phase of NHTSA's Taurus demonstration consisted of modifying under-hood components. The firewall was modified so it could be crushed by the impinging head form and still meet most other performance requirements of the baseline firewall extension. The results of tests with the modified vehicle showed 45-55 percent reduction of HIC. In a second phase, the stiff firewall structure was replaced by a hood under-side extension. Several variations of this modification resulted in at least a 25 percent reduction in HIC compared to baseline.

Early in this program, testing indicated that plastic or composite plastic hoods would produce much higher average HICs compared to steel hoods. Testing of plastic and composite plastic hoods and fenders later in the program revealed the potential for these materials to perform as well as steel counterparts.

Benefits and Costs

An analysis was done by the agency to quantify the lives saved and injuries eliminated by changes to the central hood region. This analysis was done in 1989, and considerable additional research on pedestrian impact protection has been done since that time that has shown that more benefits may be available in the stiffer fender/hood and cowl areas if feasible and reasonable-cost modifications can be applied. The analysis concluded that the most likely savings would be between 11 and 30 lives saved and between 21 and 77 injuries prevented annually. If all vehicles performed as well as the "best" vehicle, the savings would be 129 fatalities and 409 injuries annually. However, this may not be a realistic assumption, considering the current design trend toward more aerodynamic vehicles with lower hoodlines.

No work has been done to modify any vehicles to improve central hood performance. Therefore, the actual feasibility in terms of engineering of the changes, the impact on production, the impact on styling, and the impact on costs has not been determined. Conceptually, however, with sufficient lead time it is anticipated that motor vehicle costs would not be substantially affected if future vehicles resemble, in general design, the model year 1989 vehicles tested. However, there is a trend toward more aerodynamic designs for improved fuel economy which may have very limited hood-to-component clearances. Modifying such vehicles to improve central hood performance could be costly. The feasibility in terms of side effects and production and the costs associated with the development of hood/fender and cowl countermeasures have not been addressed.

An additional analysis was conducted in which the benefits of vehicle modifications to reduce the consequences of pedestrian head impacts were estimated on the basis of total cost to society instead of projecting lives saved and injuries reduced. In this anaylsis, the total cost to society from head impacts to vehicle hood/fender areas was calculated using test data from this research program, pedestrian accident data, cost of injury data, and other data. The reduced cost to society from application of three hypothetical countermeasures was then calculated and the reduction in cost determined by comparison to the baseline cost to society. This procedure produced estimates of reduced cost to society of 16 percent, 37 percent, and 33 percent for the hypothetical countermeasures considered. This procedure is experimental at this time and does not conform to the method NHTSA currently uses to compute benefits. Also, there are some important limitations in the data and assumptions used to calculate the cost to society.

Design of Vehicles in Other Countries

The agency is not aware of extensive efforts in other countries by manufacturers to modify vehicle designs for pedestrian protection. It is aware, however, that Mercedes-Benz cars have incorporated some pedestrian protection features similar to those developed for the Taurus for the fenders and the cowl. In addition, both Japan and Europe require swing-away rear view mirrors, and Europe prohibits sharp exterior corners on vehicles.

Computer Modeling Efforts

Improved computer models were developed that allow the study of the interaction of the pedestrian and the vehicle during impact. Analyses conducted with the models showed that head impact speeds for impacts with contemporary vehicle designs with short, sloping hoods are similar to impact speeds with older designs, but that thorax impact speeds are now likely lower than with older vehicle designs. Impacts are now likely further from the front of the vehicle and there are now likely more windshield impacts.

New Head Impactor

With the likelihood of more head impacts into the windshield with contemporary design vehicles, it was felt that the head impactor originally developed would give erroneous injury results for windshield impacts. This is because of the high stiffness of the windshield and the fact that the headform originally developed does not absorb any energy as would a human head. An attempt was made to develop a headform that would absorb some energy, but the results were mixed, and more work would be necessary.

THORAX INJURY RESEARCH

At impact speeds of less than 48 km/h (30 mph), the location of impact for the thorax, like the head, is approximated by a wrap around-distance equivalent to the distance measured between the ground and the middle of the pedestrian's torso. Typically, the thoraxes of adults and older children impact the hood or fender top. Thorax impact locations for younger children depend on the child's stature and the front profile of the vehicle. Smaller children are more likely to experience thorax impact against the front face of the vehicle.

Baseline Injury Causation

Pedestrian thorax simulators (surrogates) have been developed that represent the torso of an adult male and the torsos of 12-year, 9-year, 6-year, and 3-year old children. The simulators are instrumented to measure accelerations of various components as well as the relative position between components.

Simulated pedestrian thorax impact tests were conducted with a sample of vehicles which was representative of the on-the-road passenger car fleet. The impact locations for each simulator was determined by the WAD corresponding to the chest height of the typical subject age group. Five impact locations across the hood from right-to-left were tested. All of the impacts were at a speed of 32.2 km/h (20 mph). The test results were evaluated with the Thoracic Trauma Index (TTI). The serious injury threshold is considered to be a TTI of 85 g - 90 g for adults and 60 g for children.

The results of the adult impacts were that most produced TTI values less than 90 g. The exceptions were primarily hood/fender impacts. The wide range of results, from well below 90 g to more than 120 g, suggests that some protection for pedestrians may be available by incorporating design characteristic from the vehicles which produced lower TTI scores.

Results of tests with the 6-year old pedestrian and 12-year old pedestrian simulators were that none of the vehicle impact responses fell below the injury threshold value determined by reconstruction tests. Again, however, the injury criteria scores had wide ranges, suggesting that some improvements in impact response could be achieved.

Baseline testing included plastic and composite plastic hoods. This testing showed only a small possibility of increased injury severity for thorax impacts.

Some baseline testing was done at higher and lower speeds than the nominal 32 km/h (20 mph). The testing showed that, for the child surrogates, higher and lower speeds produced approximately proportional higher and lower injury scores respectively. For the adult surrogate testing, the lower speed impacts produced approximately proportional lower injury readings, but the higher speed only slightly raised the injury scores in areas where there was lower structural stiffness and space to absorb energy.

Injury Countermeasure Efforts

The same modifications to the hood/fender areas of the Ford Taurus were tested for their influence on TTI for the adult and 12-year old surrogates. The testing showed that the TTI for the child surrogate was reduced about 20 percent, but was still above the 60 g injury threshold. Even at a lower test speed of 24 km/h (15 mph), the TTI score was still above 60 g. For the adult surrogate the testing showed that TTI was reduced slightly less than for the child surrogate, but was below the serious injury threshold.

A Pontiac Sunbird/Buick Skylark with a plastic front end was modified to determine the effects for 3-year old and 6-year old child surrogate impacts. A number of modifications were made to make the front end less stiff and able to absorb energy in a controlled manner. The testing results revealed that when the impact energy was sufficiently high, the modifications produced significant TTI reductions, but only a few were below the 60 g serious injury threshold.

Countermeasure Effectiveness Model

An analysis was undertaken similar to that done for head impacts in which benefits of TTI reductions are projected based on cost to society. Since little countermeasure demonstration research was done, the reduced costs to society were calculated for TTI reductions for adults and children of 10 percent and 20 percent. The resulting reduced costs to society projected were between 16 percent and 41 percent.

LEG INJURY RESEARCH

Studies of accident data have continually demonstrated the importance of lower limb injuries in terms of frequency and long term consequence. These studies have shown that the types of leg injuries commonly suffered by pedestrians often result in long periods of disability and affect victims of all ages.

A pedestrian lower leg impactor was developed by modifying the leg from a Hybrid III dummy. Hybrid III dummies are used extensively for assessing injury potential in a crash. The modifications allowed lower leg injuries, especially knee injuries, to be measured in simulated pedestrian-vehicle impacts.

A series of baseline tests was done in order to characterize the performance of the current fleet and to identify any features of current vehicles that produce reduced lower leg injury results. The testing showed that impacts at or just below the knee caused the highest knee accelerations, and that vehicles that strike the leg relatively low, and with flexible bumpers, result in less knee bending.

The research completed has not allowed a full understanding of the factors that cause lower leg injuries. No research has been done to modify vehicles for improved lower leg protection. In addition, more work needs to be done to develop lower leg injury criteria.

AVOIDING PEDESTRIAN IMPACTS

The agency's program directed at avoiding pedestrian-vehicle impacts has taken a behavioral approach. Research began with a pioneering study completed in 1971. This study developed a behavioral model of the impact situation. The model considered the things a pedestrian and driver have to do to avoid hitting each other. These included such functions as: search, detection, evaluation, decision making, action, and vehicle response.

The study identified seven major types of pedestrian impacts such as Dart-Outs where the pedestrian appears suddenly, usually from between parked cars and Intersection Dash where a pedestrian runs across the intersection, is seen too late by the driver, and is struck. The seven major types became the research targets for the 1970s and 1980s.

NHTSA and the Federal Highway Administration (FHWA) share responsibilities for pedestrian safety. NHTSA's program responsibilities in the pedestrian area led it to develop three kinds of countermeasures: training programs, public information and educational materials (PI&E), and model traffic safety regulations. Countermeasures related to the street and highway environment (signals, signs, markings, etc.) were pursued concurrently by the FHWA. Both agencies have cooperated extensively by sharing the cost and management of numerous pedestrian projects.

Countermeasure Research

NHTSA's countermeasure development research in the 1970s and 1980s has focused on correcting or canceling out the effects of the errors leading to the impacts. Research was based on conceiving of a potential behavioral solution, developing countermeasures (training, PI&E, regulation), conducting limited field tests, and if successful, conducting larger field tests with entire cities often used as "test beds." The research program produced several effective countermeasures that reduced particular impact types by 20 to 77 percent.

Ongoing research and demonstration programs are directed toward reducing the risks for older pedestrians and addressing the problem of alcohol involvement. In addition, FHWA and NHTSA are jointly developing a pedestrian and bicyclist safety training course for all levels of government personnel and public interest groups. Finally, a study is underway to support a report to the Congress on how the Department of Transportation can best fulfill its stated policies relating to bicycling and walking.

Current Operational Programs

Pedestrian and bicycle safety was made a National 402 Priority Program area on November 4, 1991, through the combined efforts of NHTSA and FHWA, thus making it easier for States to use 402 funds for these areas.

There are a number of programs by which NHTSA promotes pedestrian safety to States and communities. These include a program that teaches basic pedestrian skills to five through eight year olds, with an emphasis on the look-left-right-left sequence of safe street crossing. It is directed specifically at reducing dart-out situations, the most prevalent type for this age group. This program also teaches older children (ages 9-12) advanced pedestrian skills so that they can cross safely in more complex traffic situations. In another program, NHTSA and FHWA developed a joint grant program to address pedestrian safety problems throughout the country. A total of twelve $30,000 grants were competitively awarded in 1990-1991 for the purpose of establishing pedestrian safety demonstrations in various locations across the Nation. Transferring research results to states and communities remains a priority of the Pedestrian Safety Program.

1.0 BACKGROUND

In 1991, pedestrian-vehicle impacts resulted in 5,797 pedestrian fatalities [1]* and 92,000 pedestrians injured [2]. Additionally, there may be a large number of minor pedestrian injuries not reported each year. The cost of these impacts in terms of lost human capital and pain and suffering is great. It is important to know that pedestrian fatalities and injuries have declined substantially in the last 10 years, in a manner similar to the long term downward trend in total fatalities. For example, in 1981, there were 7,837 [3] pedestrian fatalities and 151,000 [4] pedestrians injured. The reduction from 1981 to 1991 is 26 percent for fatalities and 39 percent for injuries. Undoubtedly, some of this decline can be attributed to such improvements as reduced drinking and driving. However, the agency has pursued a program to avoid pedestrian-vehicle impacts through behavioral modification with components in education and enforcement, and the Federal Highway Administration (FHWA) has pursued programs to improve roadway engineering pertaining to pedestrians. It is felt that these programs have also contributed to the large decline in pedestrian fatalities and injuries.

Historically, the majority of pedestrian impact victims have been male. In 1991, males comprised 69 percent of all pedestrian fatalities and 59 percent of all injuries.

About 38 percent (2,182) of pedestrian fatalities occurring in 1991 involved alcohol consumption by the pedestrian. Of these, 1,845 were intoxicated, and 337 had consumed some amount of alcohol.

Of the 5,797 pedestrians fatally injured in 1991, 53 percent (3,078) were struck by passenger cars, the remaining were struck by light trucks or vans, motorcycles, school buses, or medium/heavy trucks. An analysis of impact points in these crashes indicates that most of these crashes were frontal (4,299).

Children and elderly people are frequently involved in pedestrian impacts. Collectively, these two age groups represented about 33 percent of all pedestrian fatalities while comprising only 32 percent of the total population in 1991. In 1991, 10 percent of pedestrian fatalities and 20 percent of injured pedestrians were under the age of 10 years. Young children (5 - 8 years old) constitute the largest number of persons involved in both fatal and nonfatal pedestrian impacts [5].

Comparison of the age distribution of the United States [6] with the age distribution of the nation's fatal pedestrian impact victims [7] indicates that young people 9 - 16 years of age are under-represented, which suggests that pedestrian safety awareness created in the school years may be effective. On the other hand, the most over-represented group are those over 64 years of age. About 22 percent of pedestrian fatalities and 10 percent of pedestrian injuries involved persons 65 years or older. This problem may grow as the average age of the population increases over the next several years. This suggests that countermeasures directed at older persons and the effects of aging on the severity of injuries to pedestrian

* *Note: Numbers in brackets indicate bibliographic references listed at the end of the report.*

impact victims are important in considering injury prevention strategies. The agency already has programs directed toward older persons.

Numerous attempts have been made to assess the relative importance of injuries to various body areas for pedestrian impact victims. The precise numbers vary, but there is general agreement that injuries to the head and thorax are the most important, followed by those to the legs and neck. The head and thorax injuries are roughly equivalent in importance representing about 35 percent and 40 percent of the total pedestrian injury problem respectively, while the legs constitute about 12 percent and the neck about 7 percent of the total problem [8].

Head injuries typically cause a serious threat to life, and recovery is often incomplete, resulting in long term disabilities. Thoracic injuries also pose high threat to life, but unless the injuries are fatal, recovery is usually complete or near complete. Leg injuries are seldom fatal, but long term disability is common. Neck injuries are frequently fatal, and extensive long term disability is common in nonfatal cases.

About 75 to 80 percent of the injury and fatality losses result from direct contact with the striking vehicle, and "The vehicle front areas from the front bumper back to the windshield dominated (injury) importance with over 60 percent of the total." [9]

Pedestrian fatalities and injuries are a function of involvement in a pedestrian-vehicle impact, the severity of the impact, and the protection provided to minimize injuries. The primary approach that NHTSA has taken to reduce the number of fatalities and injuries is to reduce the involvement portion. This approach is based on the fact that a pedestrian is in such an inferior situation relative to a motor vehicle regarding mass and strength. Over the years, NHTSA has conducted numerous research programs to understand how pedestrian-vehicle impacts occur and has conducted numerous research and demonstration programs directed toward reducing the number of pedestrian-vehicle impacts. These have resulted in recommendations to communities and States, and, in some cases, in grants to implement these programs at the State and community level. A portion of the long-term reduction in pedestrian fatalities and injuries is likely due to these programs. A research program directed toward exploring the feasibility of reducing the consequences of pedestrian-vehicle impacts also has been conducted by NHTSA. The research program directed toward exploring the feasibility of reducing the consequences of pedestrian-vehicle impacts was suspended during the summer of 1992 pending agency review of the direction of the program and its priority among other agency programs. The programs directed toward reducing the involvement portion are currently being promoted by NHTSA as the most effective.

This report covers both the efforts directed toward reducing the number of involvements and the efforts to investigate the feasibility of reducing the fatalities and injuries given that an involvement has occurred. Because of the interest of the Congress in the latter, it is covered first in this report. A later section describes the research and application efforts directed toward reducing the number of involvements.

2.0 PEDESTRIAN INJURY REDUCTION RESEARCH

NHTSA has conducted a study of pedestrian injuries which result from contact with the vehicle to examine the feasibility of altering vehicle design to reduce the likelihood and severity of these injuries. The program has concentrated on head, thorax, and leg injuries, in that order. Neck injuries have not yet been addressed because of their infrequency and because injury mechanisms are not well understood.

The research is most advanced in the area of head injury severity reduction. The head injury problem is defined in sufficient detail to provide guidance in designing the research approach, and various injury prevention strategies have been evaluated. In the thoracic injury prevention research program, procedures have been developed to test the likelihood of injury to pedestrians of various ages from 3 years old to adult. Available pedestrian impact data have been analyzed and some testing with production cars has been done in order to better define the thorax injury problem. Theoretical studies of possible injury reduction strategies also have been done, along with some experimental exercises to determine feasibility.

Although leg injuries are not as important in terms of threat to life, they are the most numerous of all pedestrian injuries, and they often result in long term disability. The International Organization for Standardization (ISO), and most pedestrian injury reduction research conducted in other countries, have focused most heavily on leg injury prevention. NHTSA research has developed a lower leg impactor, and some baseline vehicle testing has been done to better understand the problem and to provide insights into possible injury reduction strategies.

2.1 Pedestrian Head Injury Reduction Research

2.1.1 Nature of the Event

When a vehicle runs into a pedestrian, initial contact typically occurs as the bumper hits the knee or lower leg. The pedestrian then wraps around the front of the vehicle (Figure 1). The pelvis hits the forward edge of the hood, the thorax rotates downward onto the top hood or fender surface, finally the head comes down on the hood top, fender surface, or windshield. In impacts where the vehicle speed is less than 48.3 km/h (30 mph), the location of head impact is closely approximated by the "wrap around distance" (WAD), equal to the standing height of the person's head. The WAD is measured from the ground up-and-around the front profile of the vehicle [10].

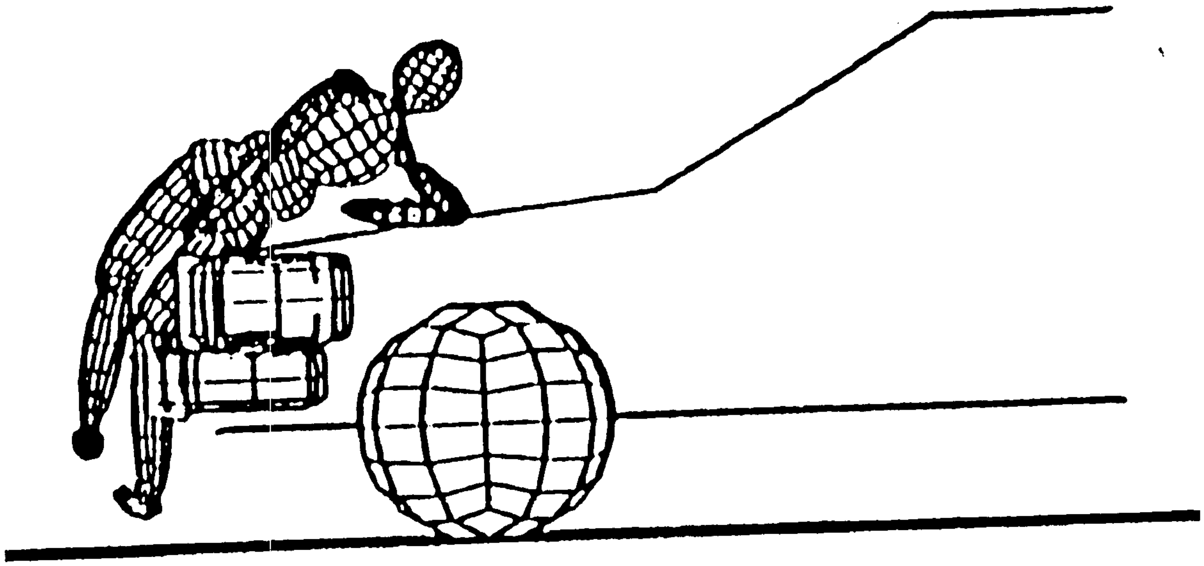

Figure 1: Typical Pedestrian Kinematics from Computer Simulation

Most head impacts occur at wrap around distances between 102 and 230 cm (40 and 90 inches) [11]. There appears to be a bias toward the passenger side of the vehicle, otherwise, head impacts appear to be fairly evenly distributed within a zone between 102 and 230 cm (40 to 90 inch) WAD. The WAD is important in transferring the information in pedestrian impact data bases that were developed in the late 1970s and early 1980s to today's vehicles. The vehicles in these data bases mainly had upright frontal areas and long hoods with little slope. The WAD permits an estimate of the percentage of pedestrian impacts that would still hit the hood areas. With more smaller cars on the road today, some of the pedestrian head impacts to the hood of older cars would be on the cowl or into the windshield of some of today's cars. The WAD also permits the development of a target test zone of head impacts onto hood areas of vehicles as described later.

The impact speed of the head against the hood or fender surface is usually no more than 90 percent of the speed of the vehicle at the time of impact [12]. The distribution of head impact speeds in pedestrian impacts has been approximated from the distribution of vehicle speeds for all pedestrian impacts for which data exist [11]. This is shown in Figure 2. It is important to note that more than 80 percent of all head impact injuries occur at speeds of 43.5 km/h (27 mph) and below.

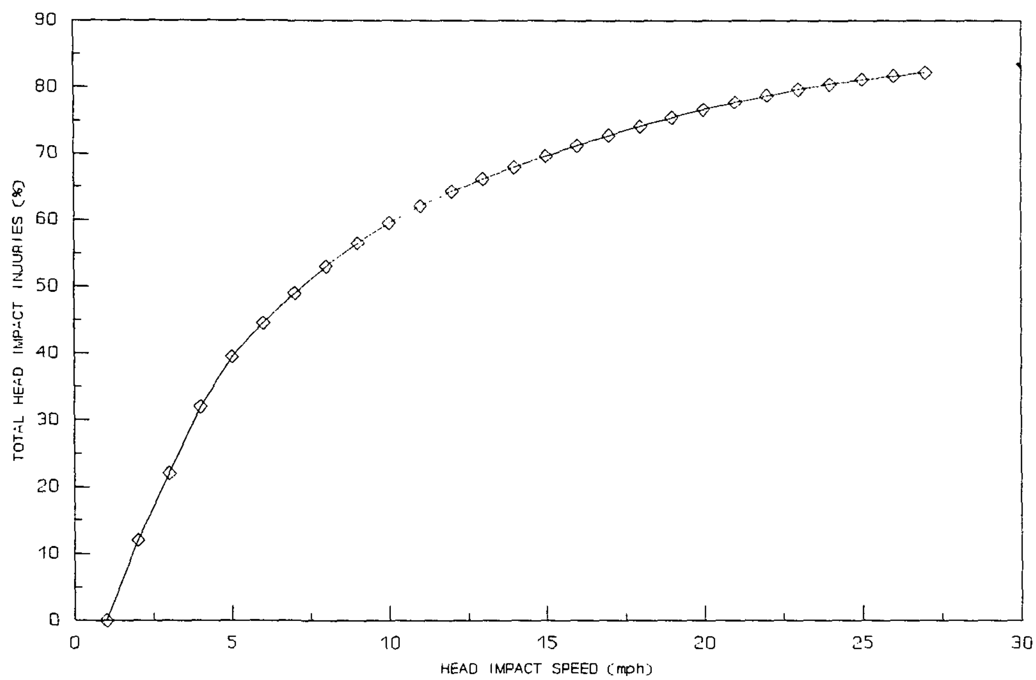

Figure 2: Distribution of Vehicle Speeds for Pedestrian Accidents

2.1.2 Size of the Problem

The importance of pedestrian head injuries was estimated from the National Accident Sampling System (NASS), the Fatal Accident Reporting System (FARS) and the Pedestrian Injury Causation Study (PICS) [13] data bases. These are data bases developed and continually updated by NHTSA, except for the PICS data base which was a one-time study. The fatality and injury data in this section and the sections to follow are from earlier work by NHTSA as recorded in reference 14. They also include pedestrians, pedalcyclists, and motorcyclists since impacts involving the latter two also involve direct contact by a person with a vehicle. The fatality and injury figures for pedestrians and pedalcyclists are averages from 1984 to 1986 FARS [15, 16, 17] and NASS data [18, 19, 20]. For motorcyclists, 1988 FARS [21] and NASS data [22] have been used.

From FARS, there are approximately 6,864 pedestrian fatalities each year. From PICS and NASS it is estimated that head impacts by pedestrians, pedalcyclists, and motorcyclists against hood/fender tops and the cowl caused 732 of these fatalities. About 85 percent of the fatalities are pedestrians. These data are for passenger cars and light trucks, excluding vans, and about 90 percent of the fatalities involve passenger car impacts. Four hundred fifty-three of these occur in impacts where the vehicle speed is less than 48.3 km/h (30 mph). Serious injuries involving head impacts at all speeds into the hood/fender tops and the cowl are about 1,500 per year for passenger cars and light trucks.

Fatalities caused by head impacts to other vehicle components are about 31 percent of all pedestrian fatalities. Fatalities caused by head impacts to the roadway are about 15 percent of all pedestrian fatalities. Thus, fatalities caused by head impacts to the hood/fender tops and the cowl are about 17 percent of all pedestrian head impacts, and about 10 percent of all pedestrian fatalities.

2.1.3 Baseline Injury Causation Profile

The final step in defining the pedestrian head injury problem is to determine the relative head injury contribution of specific areas on the hood/fender surfaces of representative real-world vehicles. Accident data defining this for a sample of on-the-road representative vehicles does not exist. Therefore, it was necessary to conduct testing to understand the head injury problem presented by the hood/fender areas of vehicles that represent the new car fleet. This was accomplished by selecting vehicles of various types and measuring the head impact responses of these vehicles in the hood and fender top areas of interest.

The device for measuring the impact response of hood/fender surfaces is shown in Figure 3. This head impact simulator consists of a pneumatically-activated piston which is used to accelerate a rigid head impact simulation device up to a specified velocity. The impact device is equipped to measure velocity at impact, acceleration, and displacement. The head impact simulator was developed to replicate the damage to hoods from real-world head impacts in pedestrian collisions. In this effort, experimental reconstructions of selected pedestrian-vehicle impacts were performed. Fourteen cases were selected from the PICS data base, and, using the head impact simulator, the mass of the headform and the velocity of impact were adjusted until the damage profile in the testing matched that of the real-world impacts. The acceleration of the headform was recorded and the HIC for the impact calculated. This was

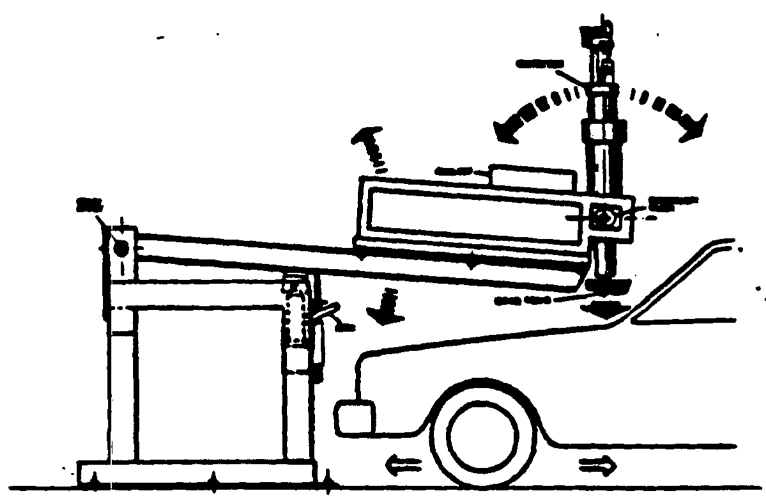

Figure 3: Pedestrian Head Impact Simulator

then related to the injury levels in the real-world impacts. It was found that the HIC value calculated correlated well with a combination of head injury measures in the real-world impacts.

The hood/fender areas of a number of vehicles have been tested during this program. Early tests were run at a head impact speed of 43.5 km/h (27 mph) which is equivalent to a vehicle speed of 48.3 km/h (30 mph). However, subsequent testing has focused on a head impact speed of 37 km/h (23 mph) which is equivalent to a vehicle speed of 40.2 km/h (25 mph).

The results from early testing, combined with pedestrian impact data, were used to establish a central hood test zone where some level of head impact protection already exists. The central hood test zone and test locations are shown in Figure 4. The front boundary is a curved line defined by measuring a 102 cm (40 inch) wrap around distance at several locations across the width of the vehicle's front surface. The rear boundary is a curve parallel to the front boundary, passing through the point on the centerline of the hood that is either 15.2 cm (6 inches) forward of the hood's rear edge or at a wrap around distance of 230 cm (90 inches), whichever is the shorter wrap around distance. The side boundaries are 15.2 cm (6 inches) from the side edges of the hood, since impact readings closer than 15.2 cm (6 inches) produced high HICs that would be difficult to reduce to a low probability of death level at higher impact speeds. This zone covers the area where 52 percent of pedestrian head impacts occur.

Also shown in Figure 4 is the grid and the 14 test points established to represent the head impact response of the entire test zone area. These impact points, although chosen somewhat arbitrarily, reflect the head impact response results from earlier vehicle testing in the program which indicated that such a grid would reveal the areas on a hood that would show variations in head impact protection. Earlier testing in the program revealed that each impact

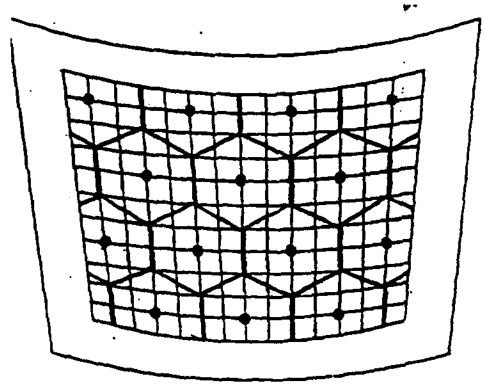

Figure 4: Test Pattern Points

reasonably represents an area within 15.2 cm (6 inches) to 20.3 cm (8 inches) of the impact. Thus, a grid of 14 test points represents the entire central area of the hood reasonably well.

The results of the testing during this program are exemplified by tests of eight 1989 and one 1988 model year passenger cars. These nine passenger cars were selected on the basis of 1987 and 1988 sales figures to be representative of the U.S. new car fleet in terms of manufacturer representation, vehicle size distribution, and the ratio of domestic to imported vehicles. The selected vehicles were:

1989 Nissan Sentra	1989 Ford Escort
1989 Ford Taurus	1989 Plymouth Reliant
1989 Oldsmobile Ciera	1989 Buick LeSabre
1988 Chevrolet Celebrity	1989 Chevrolet Corsica
1989 Hyundai Excel	

The head impact response of each cell in the central hood test grid of each sample vehicle was measured in a 37.0 km/h (23 mph) simulated pedestrian head impact. This represents an impact in which the pedestrian is struck by a vehicle moving at 40.2 km/h (25 mph). The test results are evaluated in terms of the Head Injury Criterion (HIC). A value of 1,000 is interpreted as the threshold of serious head injury through experimental reconstructions of real pedestrian impacts involving adults and children [23]. Figure 5 shows the results of the central hood tests with the 9 vehicle sample in terms of the percentage of the 14 cells that had HIC less than 1,000 in the 37.0 km/h (23 mph) tests [11].

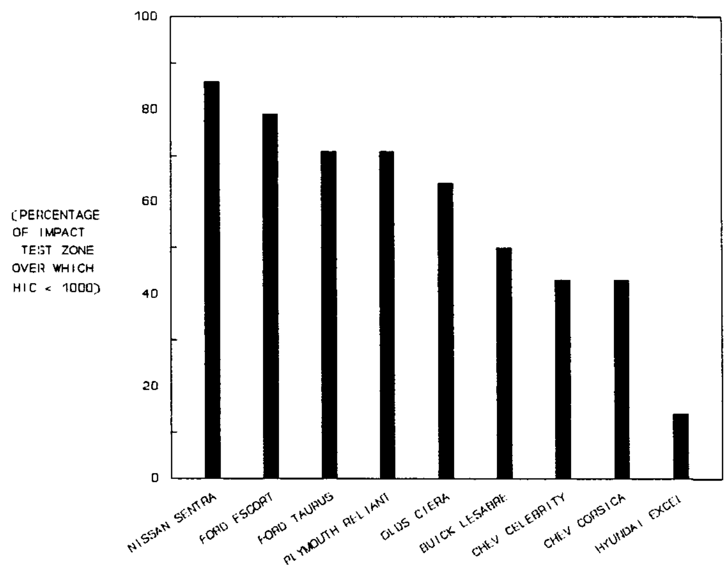

Figure 5: Central Hood Area Impact Test Results - Percent HIC<1000

Early work with simulated pedestrian head impacts revealed that the hood/fender and rear hood areas tended to be considerably stiffer and potentially more dangerous than the central hood [12, 10]. A series of tests was conducted to characterize the hood/fender and rear hood, or cowl, regions of contemporary vehicles. Ten impacts were conducted with each of eight sample passenger cars. Five of the impact locations were in the hood/fender area and five were in the cowl region as shown in Figure 6. The average HIC from these 80 tests was 2,085 compared to an average of about 1,020 from the central hood areas of the 9 cars in the central hood sàmple. The results of these tests are summarized in Table 1. Only 4 of the 80 tests produced a HIC value of less than 1,000. Over 60 percent produced a HIC greater than 1,500.

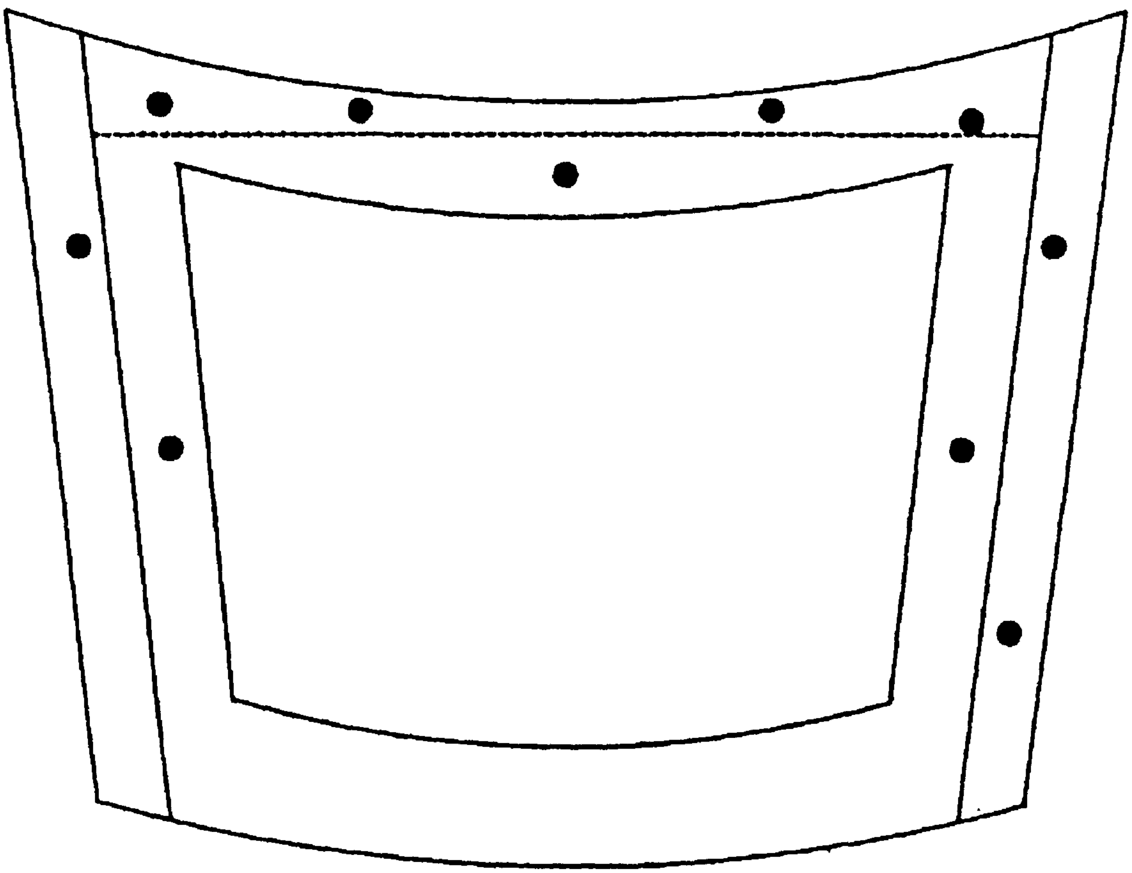

Figure 6: Approximate Location of Rear Hood and Hood/Fender Survey Impacts

The test results for the central hood region for the nine 1989 model year passenger cars, and for the hood/fender and rear hood areas for the eight passenger cars, are representative of all testing forming the basic baseline information used by the agency to understand the potential for injury and fatality in impacts with pedestrians presented by the current fleet of vehicles on the road against which improvement potential could be measured.

Table 1: Summary of Hood/Fender Testing

MAKE	MODEL	YEAR	MAXIMUM HIC
FORD	ESCORT	1987	1352
	ESCORT	1987	1576
	ESCORT	1987	1318
	ESCORT	1987	2312
	ESCORT	1987	1557
	ESCORT	1987	3195
	ESCORT	1987	3258
	ESCORT	1987	1728
	ESCORT	1987	925
	ESCORT	1987	1287
CHEVROLET	BERETTA	1989	2123
	BERETTA	1989	1199
	BERETTA	1989	2195
	BERETTA	1989	1546
	BERETTA	1989	1334
	BERETTA	1989	4575
	BERETTA	1989	4593
	BERETTA	1989	1099
	BERETTA	1989	2442
	BERETTA	1989	1918
HYUNDAI	EXCEL	1988	2000
			1694
			2615
			2832
			1795
			3595
			2364
			1896
			3456
			1987
OLDSMOBILE	CIERA	1987	1144
			819
			2094
			1862
			2868
			1465
			2269
			1224
			1001
			928

MAKE	MODEL	YEAR	MAXIMUM HIC
FORD	TAURUS	1987	1808
FORD	TAURUS	1987	2749
FORD	TAURUS	1987	1472
FORD	TAURUS	1987	4257
FORD	TAURUS	1987	3765
FORD	TAURUS	1987	1333
FORD	TAURUS	1987	2409
FORD	TAURUS	1987	2850
FORD	TAURUS	1987	3884
FORD	TAURUS	1987	1357
CHEVROLET	CAPRICE	1991	1348
CHEVROLET	CAPRICE	1991	893
CHEVROLET	CAPRICE	1991	4055
CHEVROLET	CAPRICE	1991	4909
CHEVROLET	CAPRICE	1991	1021
CHEVROLET	CAPRICE	1991	2766
CHEVROLET	CAPRICE	1991	1551
CHEVROLET	CAPRICE	1991	1325
CHEVROLET	CAPRICE	1991	1123
CHEVROLET	CAPRICE	1991	1056
PLYMOUTH	RELIANT	1986	2212
PLYMOUTH	RELIANT	1986	1918
PLYMOUTH	RELIANT	1986	2668
PLYMOUTH	RELIANT	1986	2207
PLYMOUTH	RELIANT	1986	3447
PLYMOUTH	RELIANT	1986	1409
PLYMOUTH	RELIANT	1986	1948
PLYMOUTH	RELIANT	1986	4017
PLYMOUTH	RELIANT	1986	1509
PLYMOUTH	RELIANT	1986	1332
CHEVROLET	CELEBRITY	1985	1833
CHEVROLET	CELEBRITY	1985	1161
CHEVROLET	CELEBRITY	1985	1369
CHEVROLET	CELEBRITY	1985	3132
CHEVROLET	CELEBRITY	1985	1023
CHEVROLET	CELEBRITY	1985	2669
CHEVROLET	CELEBRITY	1985	1749
CHEVROLET	CELEBRITY	1985	1274
CHEVROLET	CELEBRITY	1985	1817
CHEVROLET	CELEBRITY	1985	2925

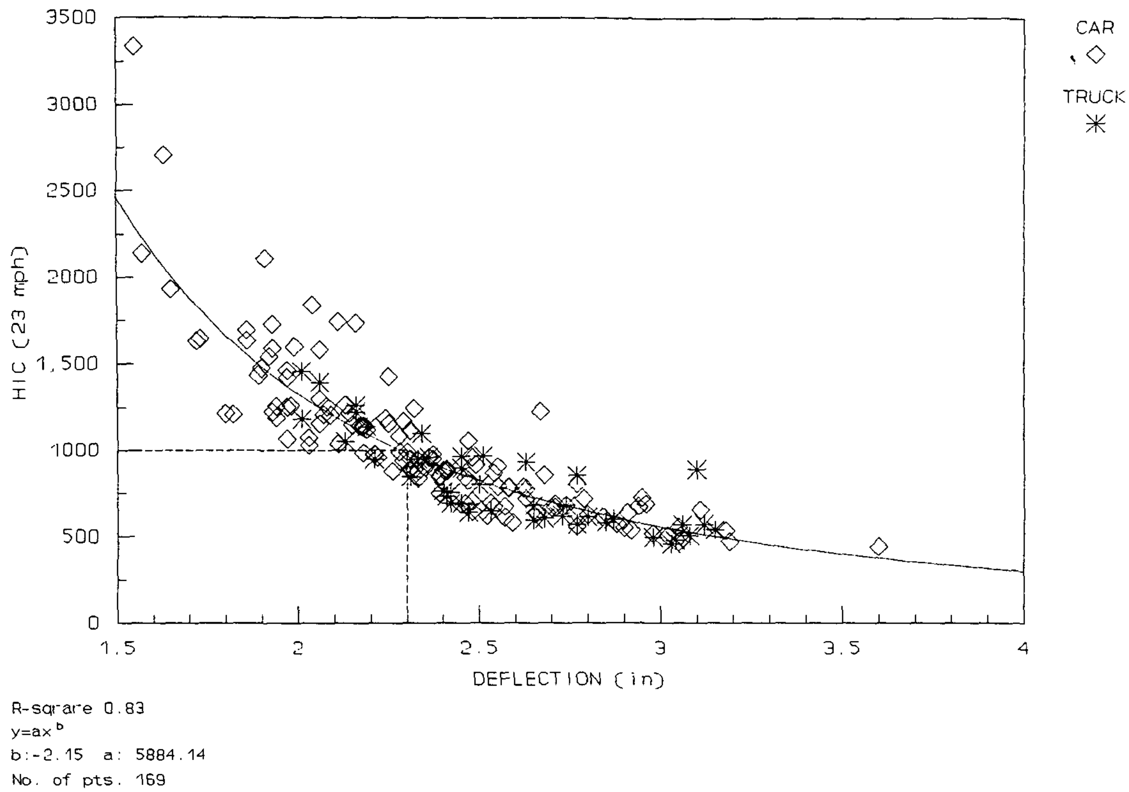

Figure 7: HIC Expressed as a Function of Dynamic Deflection-from Central Hood Data

2.1.4 Space Requirements for HIC

The objective of this work was to examine the feasibility of changing the design of vehicles to reduce the likelihood and severity of pedestrian head injuries. The areas addressed were the hood and fender tops.

For tests of production vehicles in the central hood area, the dynamic deflection of the hood during the impact at 37 km/h (23 mph) was found to correlate well with the measured injury severity. HIC results for the central hood testing are shown as a function of dynamic deflection in Figure 7. [11] This curve is based on the nine passenger car data plus results from 3 light truck hoods tested.

The relationship shows that a HIC value of 1,000 is associated with a dynamic deflection value of 5.84 cm (2.3 inches), on average. This suggests that, on average, HIC values below 1,000 may be obtained when 5.84 cm (2.3 inches) of under-hood clearance are available.

Under-hood clearance was measured for each of the nine vehicles in the central hood test sample. The area percentages of each hood test zone for which clearance was greater than 5.84 cm (2.3 inches) are shown in Figure 8. This figure also shows the percentage of 14 impact test zones that measured HIC less than 1,000 in the 37.0 km/h (23 mph) tests. This data suggests that, for many vehicles, improvements in head impact response can be achieved by modifying the construction of the hood, without modifying the under-hood configuration of the vehicle. The modification would consist of reducing the stiffness of the under-hood supporting structure. Although vehicles were tested that exhibited the combination of under-hood clearance and low-stiffness under-hood supporting structure, no vehicle not exhibiting these characteristics was modified to demonstrate the feasibility of the modifications.

The hood/fender seam and rear hood areas are a greater challenge because they are inherently more stiff in current designs. However, Figure 7 shows that for high initial HIC values, large reductions in HIC at head impact speeds of 37 km/h (23 mph) can be achieved with relatively small increases in dynamic deflection. This was examined theoretically for extremely severe impacts at stiff hood locations at low impact speeds. An example of the results of this analysis is that, for 12.9 km/h (8 mph) impacts, a HIC of 2,000 produced with a dynamic deflection of 0.254 cm (0.1 inches) could be reduced to a HIC of 1,000 with only 0.254 cm (0.1 inches) of additional deflection. The results of this theoretical analysis are shown in Figure 9.

The hard areas of the structure produce high HIC responses even at lower speeds for which the frequency of impacts is higher, and significant improvements in the HIC responses can be achieved with relatively little increase in deflection in these areas as Figure 9 indicates.

Before moving on to describe the countermeasure research, a summary of what is described to this point will help set the scene for the sections to follow. First, many central hood areas already provide good head protection against serious head injury at impact speeds of 37 km/h (23 mph). Second, the under-hood clearance is available in many cars to improve head protection at these impact speeds. Finally, significant reductions in HIC appear possible with small increases in deflection in hard fender and cowl areas for improved protection in the more frequent low speed impacts.

2.1.5 Experimental Countermeasure Demonstrations

Each countermeasure demonstration effort is associated with a particular area on the front of the vehicle structure. The hood of a typical passenger car is divided into three areas - the Central Hood Area, the Rear Hood, or Cowl Area, and the Hood/Fender Area - as shown in Figure 10.

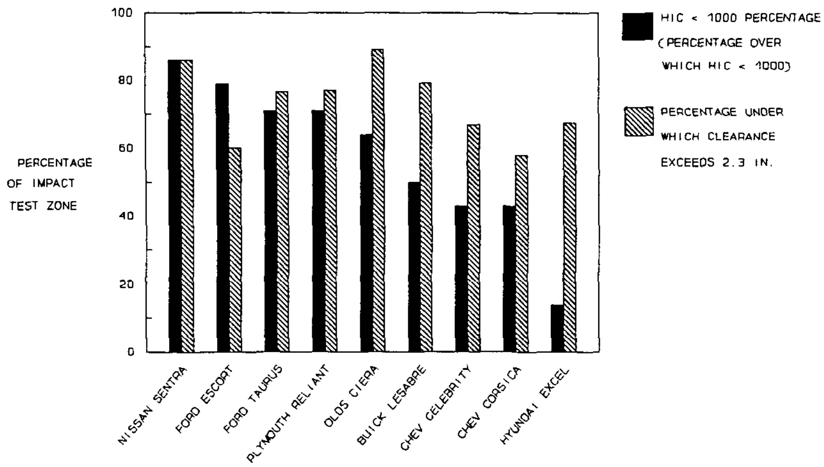

Figure 8: Under-hood Clearance - Percent Area with Greater than 5.8 cm Clearance

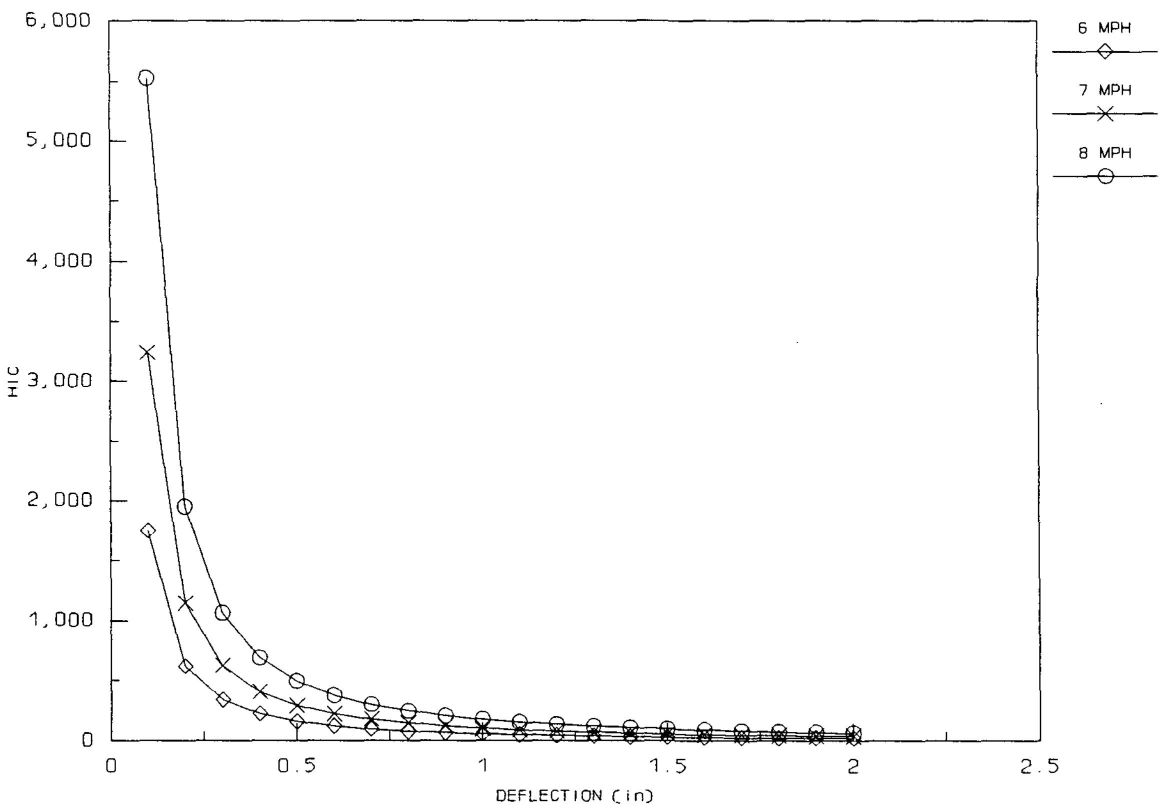

Figure 9: Theoretical HIC vs. Dynamic Deflection, at 10, 11, & 13 km/h

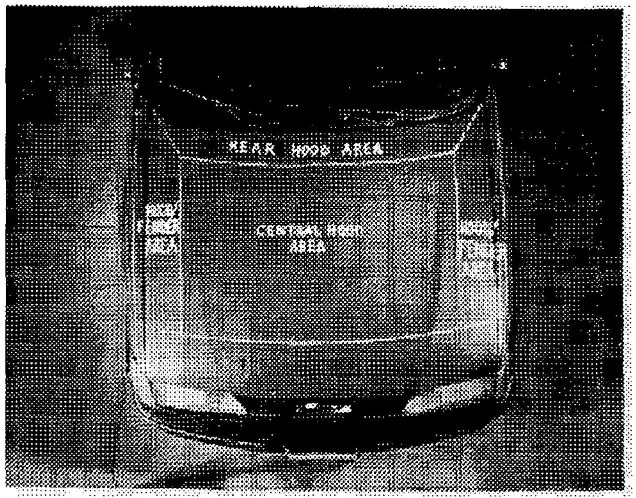

Figure 10: Designation of Central Hood, Hood/Fender, & Rear Hood Areas

2.1.5.1 Central Hood Countermeasures

The nine passenger cars tested that are representative of the testing done to date in this program, as described in Section 2.1.3, had percentages of HIC below 1,000 ranging between 14 percent and 86 percent (see Figure 5), illustrating the large variation in impact response among different vehicles. If the central hoods of all vehicles achieved performance levels of those with the fewest HIC values over 1,000, a reduction of pedestrian injury severity could be realized. This work suggested that hood material, architecture, and under-hood clearance all influenced the impact response. A sampling of under-hood clearance from several vehicles, as described in Section 2.1.4, showed that many vehicles in the new car fleet had enough clearance under enough of the hood to achieve substantially improved performance levels.

Design characteristics of production hoods that produce varying levels of impact response have been identified. The specific material, design, and mounting of the hood itself are very important. In one example, two "sister" vehicles from one manufacturer had somewhat different hood bracing designs. Although the two hoods were interchangeable, and the engine compartment of one vehicle was indistinguishable from the other, their HIC values were quite different. The differences were due to design choices.

2.1.5.2 Fender Top and Cowl Area Countermeasures

In the hood/fender and cowl areas (see Figure 10), current design practices inherently produce much stiffer impact responses, and the areas are typified by relatively heavy structures immediately under and supporting the surface. Baseline head impact responses in these areas, as shown in Table 1, tend to be much more severe than in central hood areas.

Modifications were made to a Ford Taurus to show that the head impact response of the hood/fender area could be improved. The Ford Taurus was chosen because it was thought to exemplify mainstream vehicle design. It also produced some of the highest HICs of vehicles tested in the hood/fender area. Furthermore, the Taurus is well represented in the current fleet of passenger vehicles.

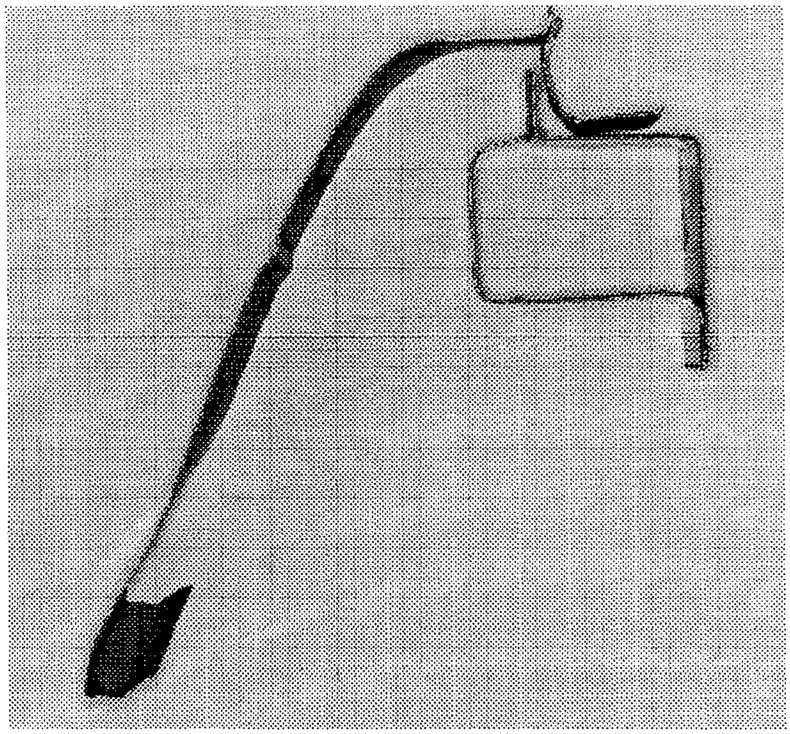

Figure 11: Cross-Section of Impacted Taurus Fender

Impacts to the hood/fender of the Ford Taurus showed that, when tested with the head impact simulator, the head form's travel was arrested when it struck the structure to which the fender is attached just below the surface of the fender skin. The resulting sudden deceleration of the head form produced a very high HIC indicating a high potential for severe head injuries. The space between the hood/fender struck surface and the hidden structure below it had to be increased to reduce impact severity. In order to gain the 5.84 cm (2.3 inches) of clearance necessary for a HIC of 1,000 in a 37 km/h (23 mph) impact, a number of modifications were made. The original hood/fender configuration is shown in cross section in Figure 11, and the modified configuration is shown in cross section in Figure 12.

The other factor that influences the severity of pedestrian head strikes on the front surfaces of motor vehicles is the apparent stiffness of the struck locality. Two changes to structures in the Taurus hood/fender region were used to reduce the local stiffness in this demonstration. Both the hood edge and the fender skin were modified. The resulting hood/fender region was considerably less stiff than the production vehicle hood/fender.

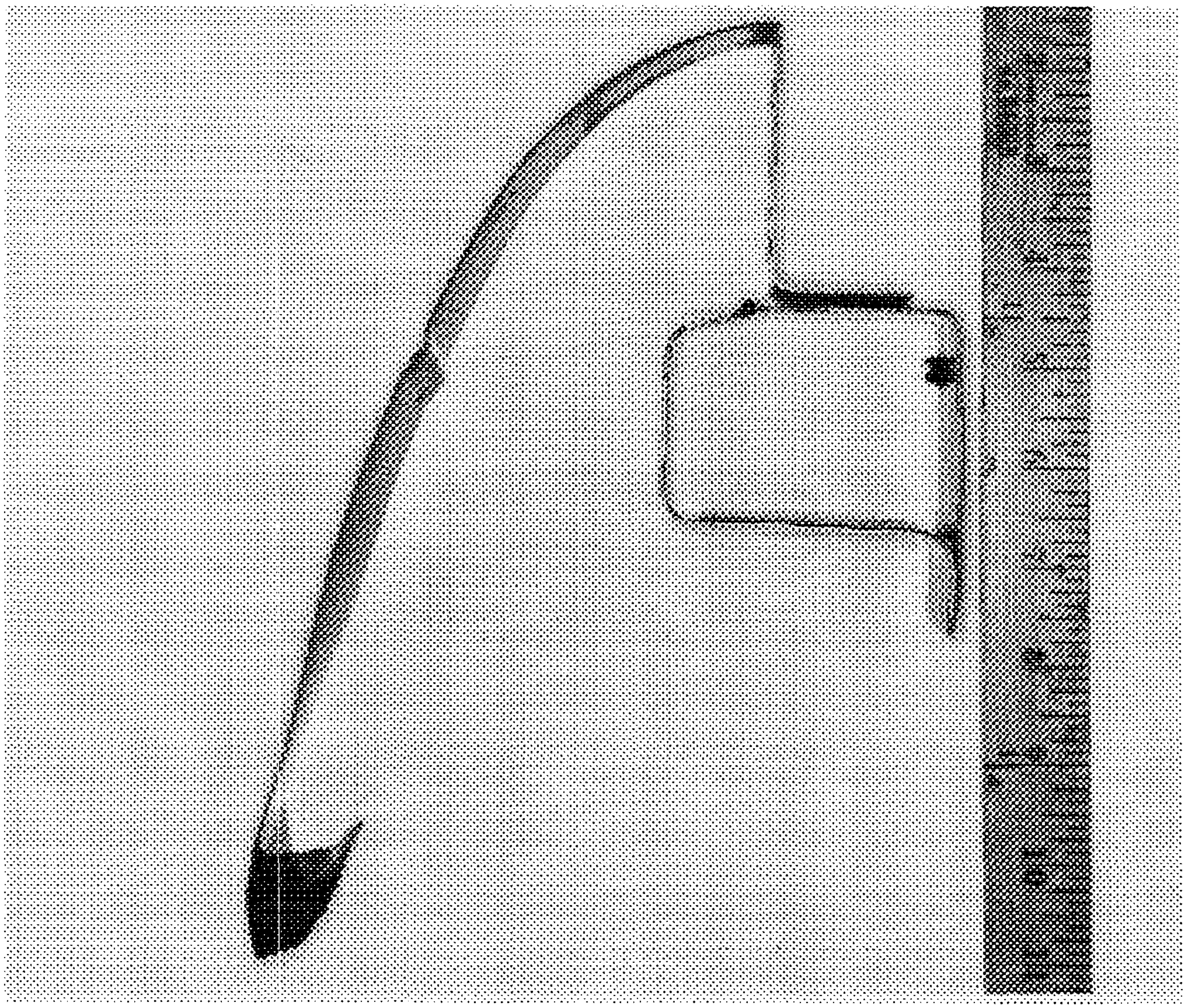

Figure 12: Cross-Section of Modified Taurus Fender & Apron

Hood modification consisted of removing the vertical flange at the hood's side edge. Removing this material reduced the local stiffness of the hood edge by altering its geometry. The other effect of this modification was to eliminate interference between the hood edge and the structure to which the fender is attached, thus allowing the increased clearance modifications described above to be fully realized. This modification is illustrated in Figure 13. The original Taurus hood side edge is shown in cross section in the lower part of the picture. The edge was modified to be like the Ford Tempo side hood edge shown in cross section in the upper part of the picture.

Modification of the fender skin consisted of lightening the interior vertical surface by removing material as shown in Figure 14. The effect of this modification is a local reduction of the impact resistance of the fender sheet metal without significantly affecting other performance aspects.

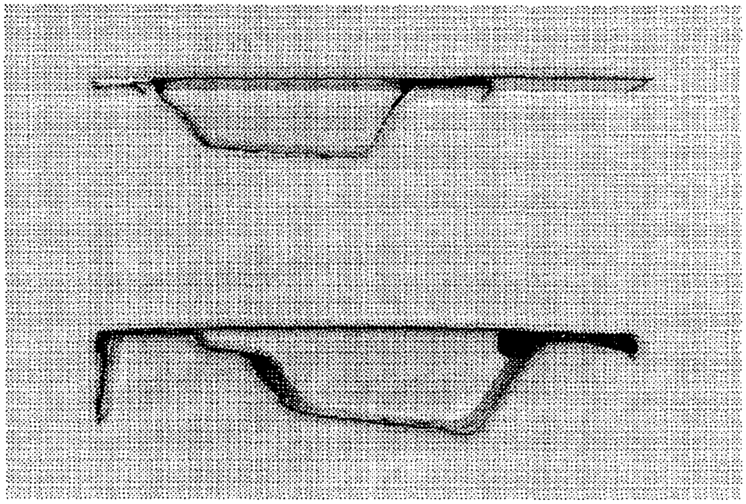

Figure 13: Comparison of Taurus Hood Edge (bottom) with Tempo Hemmed Hood Edge (top)

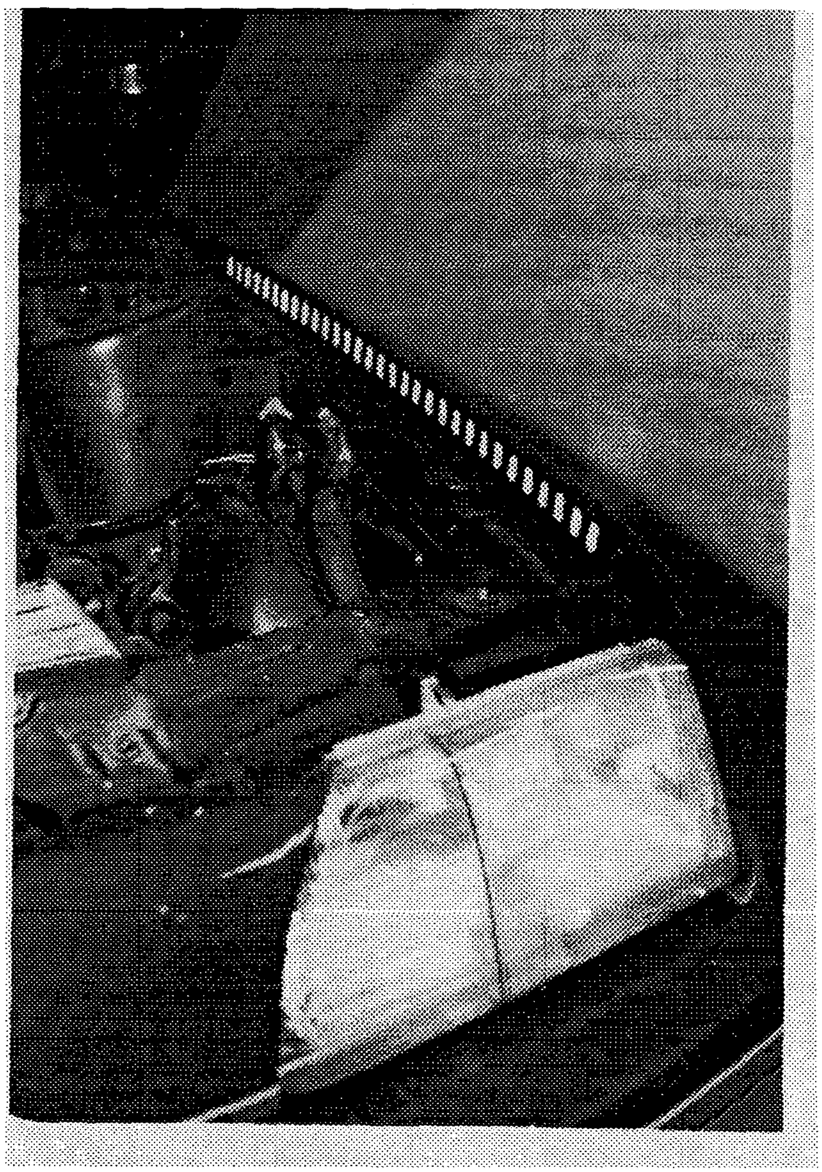

Figure 14: Lightening Holes on Inside Fender Flange

Impact tests were conducted at velocities of 6.7, 8.9, and 10.3 m/s (15, 20, and 23 mph) to evaluate the effectiveness of the Taurus hood/fender modifications. The results of those tests are summarized in Table 2. With all modifications, HIC values in 10.3 m/s (23 mph) impacts were lowered considerably.

Table 2: Baseline & Modified Taurus Hood/Fender Impact Response

Condition	Parameter	Impact Speed		
		15 mph	**20 mph**	**23 mph**
Baseline	HIC	1010	2251	3097
Modified		no test	878	1145
Baseline	Dynamic Defl. (mm)	19	25	30
Modified		no test	42	53

In addition to tests using adult head surrogates, a series of four tests was done to assess the injury-reducing potential of the hood/fender modifications for impacts by children. A headform with a weight representing a 6-year old pedestrian was used. The results showed that peak head accelerations were reduced by 29 percent for impacts of 24 km/h (15 mph) and 37 km/h (23 mph).

As with impacts to the hood/fender, the most important factors influencing cowl area impact performance are apparent stiffness and clearance between the exterior surface and hidden rigid components.

Clearance under the Taurus hood was limited by a vertical extension of the firewall meant to isolate engine fumes from the occupant compartment air intake and provide a mounting surface for various accessory components. Table 3 illustrates that, without the interference of the upper firewall, HIC values below 1,000 were possible without modification of the cowl area. The next stage modification replaced the firewall extension with an aluminum panel which could be crushed by the impinging head form. The HIC produced with this panel also is shown in Table 3.

Table 3: Baseline & Modified Taurus Cowl Area Impact Response

Test Condition	HIC	Dynamic Defl. (mm)
Baseline	1936	44
No Firewall Extension	563	71
Aluminum Replacement	861	58

Results of the aluminum replacement test suggest that the engine compartment seal may be maintained by a frangible structure that will collapse under pedestrian head impact loads. Therefore, an alternative engine compartment seal was fabricated from ABS plastic. Despite its superior impact response, the alternative seal arrangement could not be implemented on both sides of the example vehicle without relocating the windshield wiper motor. The ABS plastic used in the prototype may be sturdy enough to support stationary accessory components, but it could not sustain the torque applied by the windshield wiper motor. While a workable arrangement for the wiper motor is certainly feasible, this consideration illustrates the complexity of contemporary vehicle packaging design. The results of impact tests with this panel are shown in Table 4.

Table 4: Baseline & Modified Taurus Cowl Area Impact Response: Alternative ABS Cowl-Vent-Grill & Engine Seal

Test Condition	**Parameter**	**Impact Speed**		
		15 mph	**20 mph**	**23 mph**
Baseline	HIC	564	1534	1936
Modified		378	1229	1030
Baseline	Dynamic Defl. (mm)	34	38	44
Modified		42	50	53

Other concerns about the firewall replacement concept were manufacturing complexity, durability, and integrity of the engine compartment seal along the upper edge of the firewall. The air intake for the passenger compartment environmental control system is located directly behind the firewall. Engine compartment fumes are prevented from entering the passenger compartment by a rubber seal which is compressed between the hood under-side and the upper edge of the firewall when the hood is closed. There was concern that a frangible firewall which could be crushed by the impact of a pedestrian's head may not provide a durable foundation for the seal.

To address these concerns, another design for the hood under-side support panel was devised. In this design, the vertical extension of the firewall was replaced by an extension of the rear under-side of the hood. The engine compartment seal remains as originally designed in this case. The hood under-side extension was designed to be less stiff than the vertical firewall extension it replaced. Several variations of this design were tested in 37 km/h (23 mph) impacts, all of which resulted in at least a 25 percent reduction in HIC compared to the baseline.

2.1.5.3 Plastics Investigations

In early testing by the agency of plastic hoods, it was found that the impact response in terms of HIC was generally significantly greater than for steel hoods. This was brought to the attention of the automotive industry as a concern since there has been a trend to more plastic or composite plastic hood and fender applications.

Since the early tests by the agency, a number of tests have been conducted in which composite plastic hoods have been compared to steel hoods, and plastic fenders have been tested. In these tests, the composite plastic and plastic components have performed as well as steel versions. Although there is the possibility that plastic components will not absorb energy as well as steel, the agency's latest testing has shown that current applications are not any more likely to produce injuries than steel components.

2.1.5.4 Benefits and Costs

An analysis was done by NHTSA to quantify the potential savings of lives and injuries from modifying the central hood region. This analysis [14] was done in 1989, and considerable additional research on pedestrian protection has been done since that time. This analysis only addressed the central hood area, and later research has shown that more benefits can be achieved in the harder fender/hood and cowl areas if feasible and reasonable-cost modifications can be applied. The benefits analysis reported in the next section uses considerably more of the research results available.

The analysis concluded that 11, 18, or 30 lives could be saved annually, depending on whether measurements at 9, 10, or 11 of the 14 test points shown in Figure 4 are required to show a HIC reading of 1,000 or less, and assuming no benefits at impact speed above 48.3 km/h (30 mph). When applied to injuries, under the same conditions, the same analysis shows that 21, 44, or 77 injuries could be reduced annually.

The methodology used in the analysis is based on the minimum that a manufacturer would have to do to "pass" the test, i.e., to improve the best failing scores to a HIC of 1,000. This would probably involve lowering substructure components that are located beneath the points on the central hood area at which measurements were taken, or, if sufficient underhood space was available, hood reinforcements probably would be modified to be less stiff.

If all vehicles performed as well as the best vehicle tested, the projected savings would be 129 fatalities and 409 injuries annually. Whether this is a realistic assumption is not known, given design trends toward more "areodynamic" vehicles with lower hoodlines for improved fuel economy.

With regard to the central hood region, although the results of the central hood testing and the measurement of underhood clearance all suggest opportunities for improving central hood head impact performance, the agency has not undertaken to modify any vehicles to improve central hood performance. Therefore, the actual feasibility in terms of engineering of the changes, the impact on production, the impact on styling, and the impact on costs has not been determined. Conceptually, with sufficient lead time, motor vehicle costs would not be substantially affected if future vehicles resemble, in general design, the model year 1989 vehicles tested. However, for styling and fuel economy reasons, there is a trend toward more aerodynamic vehicles in the industry. Such vehicles may have very limited hood-to-component clearances. Modifying such vehicles to improve central hood performance could be costly and reduce fuel economy.

One countermeasure is to redesign the hood reinforcements, resulting in initial engineering costs. Based on a comparison of the designs with passing test results versus designs with failing test results in the open hood area, the passing designs have much less hood reinforcements. Thus, it is anticipated that hoods designed to lower HIC scores potentially could have less reinforcements and would have less material and production costs and lower weight. Manufacturing costs could go down, and fuel economy could be improved slightly. However, this is dependent upon the influence of the aerodynamic design trend on the ability to redesign hood reinforcements.

A second countermeasure would be to redesign substructures under failing points to make them lower and allow more dynamic displacement of the hood. There would initially be engineering costs to redesign the substructure components. The impact on material and production costs and on weight are unknown and have not been estimated.

Another option is to raise the hood to provide the necessary clearance to facilitate large dynamic displacement that produces low HIC numbers. However, as noted above, this does not fit well with aerodynamic and fuel economy goals.

The feasibility in terms of side effects and production, and the costs associated with the development of hood/fender and cowl countermeasures have not been addressed. From an engineering perspective, they are feasible means of improving the pedestrian head impact performance of these areas. It must be kept in mind, however, that the modifications described are abstractions used to demonstrate the effect of vehicle design on pedestrian head impact response. The particular modifications described in Section 2.1.5.2 are not suggested as exact engineering solutions. For example, removing flanges might affect a vehicle's body stiffness and frontal crash response, and there may not be sufficient clearance to move structural components. Furthermore, these changes would require substantial redesign of the vehicle and may involve styling changes, production changes, and high cost and long lead time.

It is important to remember that the areas on the front of a vehicle are largely influenced by styling and fuel economy considerations of vehicle design. They must also accommodate the engine and front suspension systems of the vehicle, and sustain normal day-to-day treatment in real-world use. Therefore, changes in structural configuration and profile may have profound implications on other important design factors.

2.1.5.5 Harm Analysis for Hood/Fender Head Impacts

In addition to the traditional benefits analysis described above, as part of the research effort, an approach was developed for a "harm" analysis to assess potential benefits of changes to vehicles for pedestrian protection. In a harm analysis, instead of assessing benefits in terms of lives saved and injuries reduced, the current level of fatalities and injuries are measured in terms of "cost to society" and then compared to the reduced cost to society of lower levels of fatalities and injuries resulting from the application of vehicle countermeasures. In this type of analysis, the benefit of eliminating fatalities and injuries is assessed on a cost savings basis, as is reducing some injuries, for example, from severe injuries to moderate injuries. The costs included in this analysis were medical/hospital costs, vocational rehabilitation costs, lost household productivity and wages, insurance and administrative costs, work place costs, the costs of emergency services, travel delays costs, and the costs of legal/court services. Costs for pain and suffering and for property damage were not included. This analysis included hypothetical changes to the hood peripheral areas that were not included in the analysis described in Section 2.1.5.2.

The analysis used hood/fender head impact test data, pedestrian accident data, cost of injury data, and other data to develop mathematical relationships for computing the total cost to society for pedestrian impacts to the hood/fender areas for each of the nine cars in the baseline test fleet for impacts at vehicle speeds of 48.3 km/h (30 mph) or less. For these calculations, the hood/fender areas were represented by the 14 central hood impact test points for each car plus 10 points selected to represent peripheral hood areas for a total of 24 impact points representing the hood/fender surface.

The next step was to compute a fleet-wide cost index for the 24 hood/fender impact points on the assumption that the nine cars in the baseline test fleet represent the entire fleet of cars on the road. The cost index is a representation of the total cost to society, for the cost categories listed above, for all pedestrian head impacts to the hood/fender areas of the fleet of cars on the road for all pedestrian impacts at vehicle speeds of 48.3 km/h (30 mph) or less. The cost index developed was normalized to the value 100. By normalizing the cost index to the value 100, the cost index calculated for a particular countermeasure represents the effectiveness of the countermeasure in reducing societal cost. For example, a fleet-wide cost index of 60 for a particular countermeasure can be interpreted to mean that societal costs of pedestrian injuries have been reduced to 60 percent of what they were. The normalized, fleet-wide cost index distribution for the nine baseline cars for the 24 impact points is shown in Figure 15. In this figure, each bar on the chart represents one of the 24 impact points with the lighter bars representing the 14 central hood points and the darker bars representing the peripheral hood areas. The location of the bars on the chart depicts the relative position of the impact points on the hood/fender area of a car. Note that the sum of the heights of the bars is 100.

This analysis was continued to evaluate several "what if" scenarios in which hypothetical countermeasures were evaluated. In the first scenario, HIC was restricted to a maximum of 1,000 in 18 of the 24 hood/fender impact points at a head impact speed of 37 km/h (23 mph).

The normalized, fleet-wide cost index distribution for this scenario compared to the baseline scenario is shown in Figure 16. The difference in column heights translates into a 16 percent lower cost index. Two other scenarios, the first in which 18 of 24 impact point HICs at 37 km/h (23 mph) are restricted to less than 1,000 with the remaining six limited to between 1,000 and 1,500 and the second in which the HICs at 37 km/h (23 mph) for all impact points over 1,000 are reduced by 40 percent or to 1,000 whichever is greater, resulted in theoretical societal cost reductions of 37 percent and 33 percent, respectively.

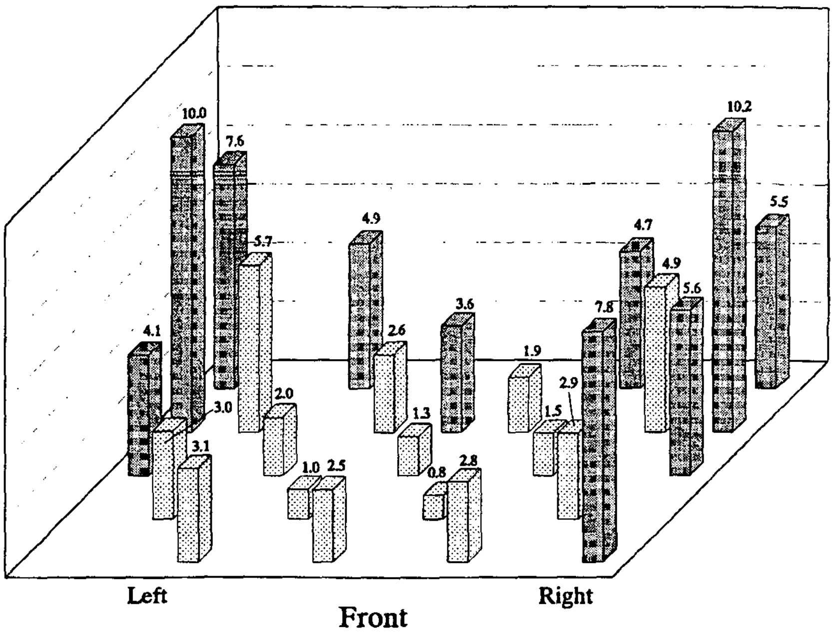

Figure 15: Baseline Distribution of Injury Cost From PICEM

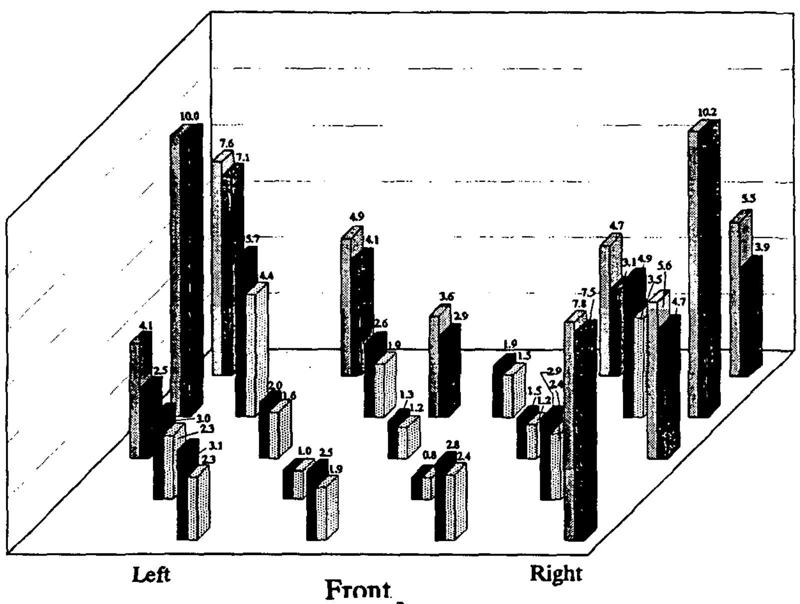

Figure 16: Comparison of Baseline Injury Cost with Scenario #1 Injury Cost

It should be pointed out that this methodology does not conform to the method NHTSA currently uses to compute benefits. Also, there are some assumptions upon which the calculations are based that caution against their accuracy. The sample is limited and probably does not represent the fleet sufficiently. The scenarios are somewhat arbitrary and assume reductions in HIC, in some cases, in the harder hood/fender areas for which the feasibility of improvements has not been demonstrated. Also, the costs to make any of these improvements has not been determined and would be necessary for a cost/benefit analysis. All the data for deriving the relationships needed to determine the societal cost indices are limited.

2.1.5.6 Design of Vehicles in Other Countries

The agency is not aware of extensive efforts in other countries by manufacturers to modify vehicle designs for pedestrian protection. It is aware, however, that Mercedes-Benz cars have incorporated some pedestrian protection features.

Mercedes-Benz has incorporated fender modifications similar to that shown in Figure 13. A 30 percent reduction of peak pedestrian impact forces has been reported for impacts to the Mercedes-Benz 124 compared to the 123 model which do not have this pierced fender design [20]. Similarly, Mercedes-Benz has reported that styling of the rear hood sheet steel which provided about 10 mm (0.4 inches) more clearance between the hood surface and under-hood components (wiper hub and reinforced cross member), reduced impact forces by 20 percent. Japan and Europe require swing-away rearview mirrors, and Europe prohibits sharp exterior corners on vehicles

2.1.6 Computer Modeling Efforts

An important aspect of the study of pedestrian-vehicle impacts is the study of the interaction between the pedestrian and the striking vehicle. This study helps develop realistic component level impact conditions and impact simulations. Past computer simulations efforts are no longer very useful because of the inferior modeling of the pedestrian and their application to impacts with cars of the 1970s. An effort was undertaken to improve past computer simulations of pedestrian-vehicle impacts to be used to study the different motions expected of the pedestrian when struck with vehicles of contemporary design. The primary goal of this effort was the determination of head and thoracic impact locations and velocities of both adult and children for current vehicle model designs. Adult and child pedestrian models were developed and validated and applied in a parametric study in which pedestrian stature, stance, and vehicle front-end geometry were examined.

While the computer simulations need further refinement, the results of the parametric study show that essentially the same impact speed can be expected for head impacts for contemporary vehicles versus older designs. However, lower thoracic hood impact speeds can be expected for more modern-profiled vehicles compared to those of the past.

An important trend revealed by this modeling, however, but not unexpected, is that, for a given speed, impact locations are moving farther from the front of the vehicle and from the hood to the windshield for modern vehicle designs. This is to be expected with the shorter, more sloping hoods of current vehicle designs. The trend to the even shorter hoods of the "cab forward" designs could exaggerate this trend. Figures 17 and 18 show this effect by comparing the impact locations of the older LeMans design to the Taurus, Civic, Astro van, Lumina van, and Saturn designs. These are for adult impacts, and a similar trend exists for child impacts.

This trend in design calls into question the early head impact research in this program that focused on hood and hood/fender areas. It appears that rear hood/cowl and windshield impacts may be of more concern.

2.1.7 New Head Impactor

With more windshield impacts expected, there is concern that the rigid headform used in prior testing may give improper results for windshield impacts. Windshields tend to be very stiff. Consequently, impacts against windshields often result in very high impactor accelerations. Modifying the windshield poses a problem similar to other stiff regions of the vehicle front end such as the fender/hood area and the rear hood areas. Namely, these structures cannot easily be modified to improve impact response without affecting critical functional aspects of the components. However, experimental data and analytical examinations have shown that modifications needed to produce relatively large reductions in injury costs only require small increases in dynamic deflection.

The human skull is not completely rigid compared to the stiffest vehicle components and is likely to experience deformation which will dissipate some of the impact energy. Potential windshield deflections are quite small and a nearly rigid headform may underestimate the benefits of these deflections since the head form itself does not absorb impact energy. A more life-like headform may better evaluate the injury potential of small deflection or high stiffness impact conditions. Such a design should reproduce the energy absorbing characteristics of the human head as well as its acceleration responses.

An effort was directed to develop a headform that would absorb some of the impact energy. However, this effort was not entirely successful in that test results showed it to produce lower HICs in impacts with rigid surfaces, but higher HICs in impacts with less rigid surfaces. Apparently, the headform is actually more stiff than the rigid headform in some impact conditions. Further work would be needed to study this phenomenon and to devise a better design.

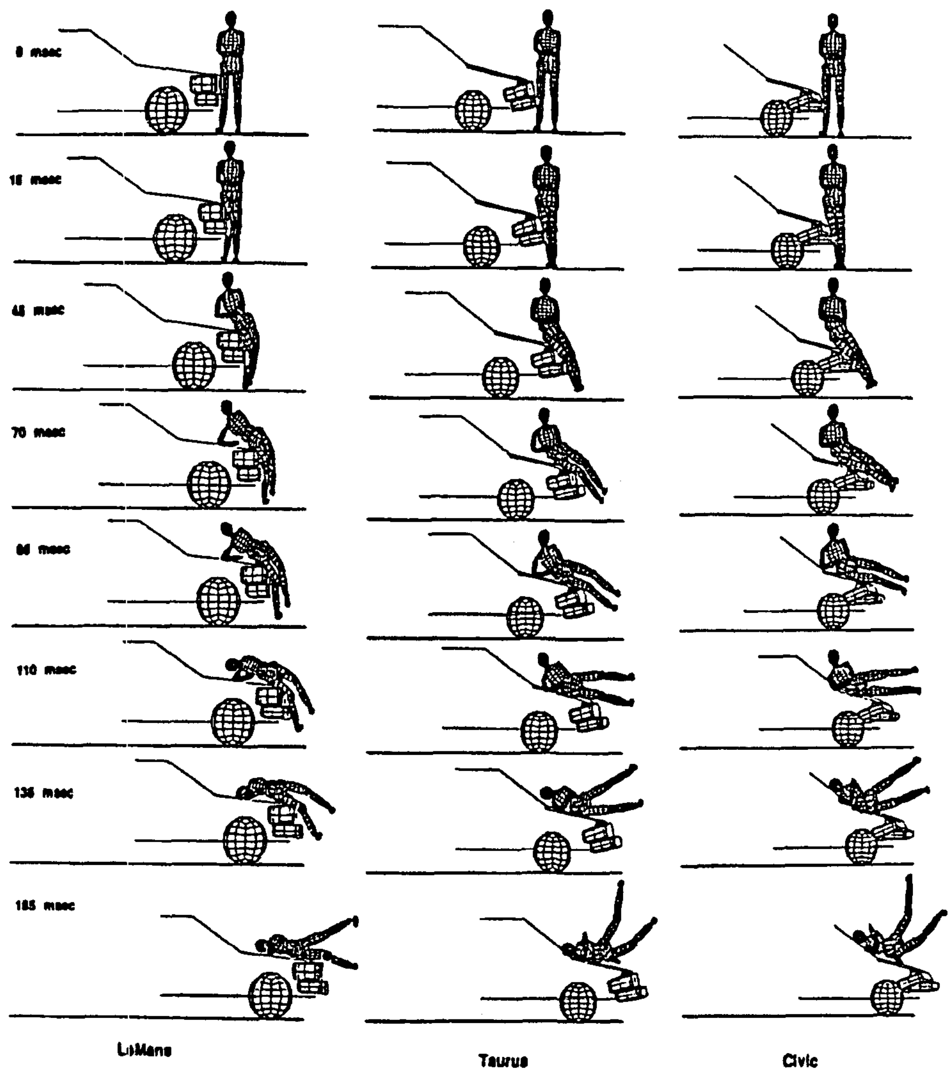

Figure 17: Adult-Pedestrian Kinematics from MADYMO Analysis - LeMans, Taurus, and Civic

2.2 PEDESTRIAN THORAX INJURY RESEARCH

Surveys of pedestrian injury patterns indicate that thoracic injury comprises a significant portion of the pedestrian risk for severe and fatal injuries [8]. As described previously and shown in Figure 1, when a pedestrian is struck by a vehicle, the front bumper first strikes the pedestrian's leg(s). Then the pedestrian's body wraps around the front profile of the

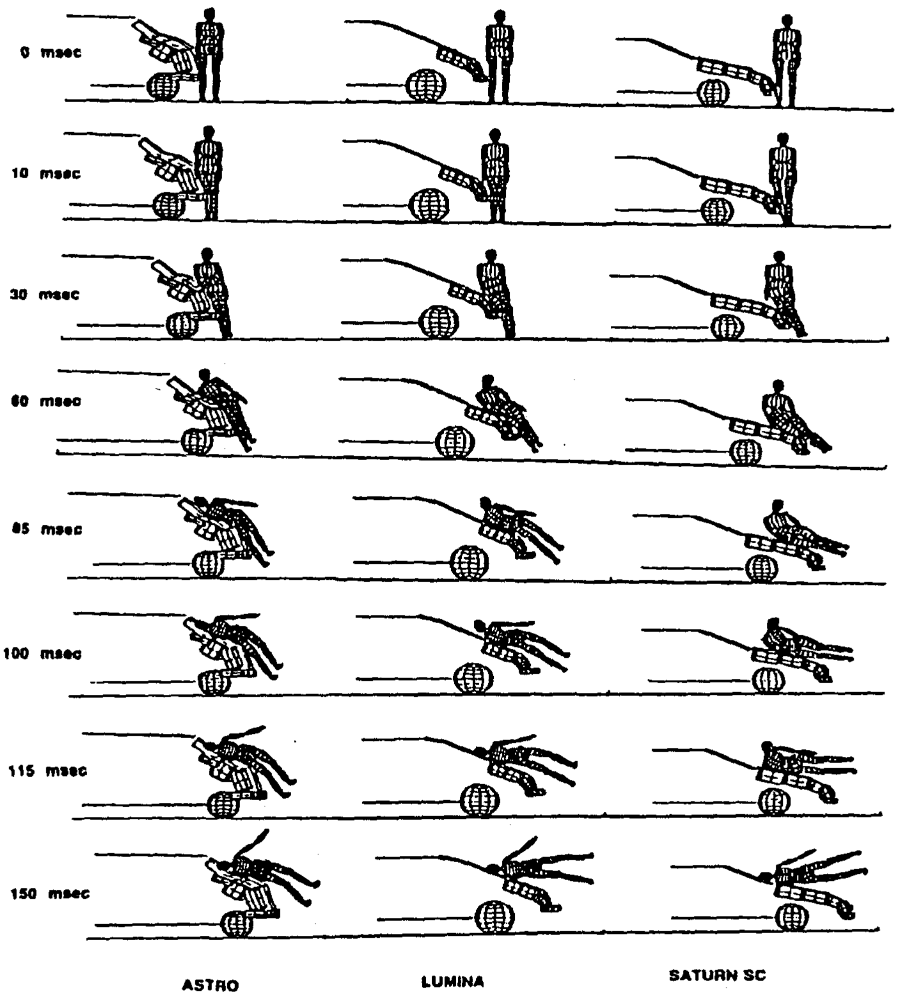

Figure 18: Adult-Pedestrian Kinematics from MADYMO Analysis - Astro, Lumina APV, and Saturn

vehicle, with the thigh or hip striking the front hood edge, the thorax coming down onto the hood or fender top surface, and the head finally striking the hood or fender top surface. At impact speeds of less than 48.3 km/h (30 mph), the location of impact for the thorax is approximated by the "wrap-around-distance" (WAD), equal to the standing height above the ground of the thorax. The "wrap-around-distances" associated with pedestrian thorax impacts average 84 cm (33 inches) for 6-year-old pedestrians, 112 cm (44 inches) for 12-year-old pedestrians and 137 cm (54 inches) for adults.

The thoraxes of adults and older children usually impact the hood or fender top. For younger children, thorax impact location depends on the child's structure and the front profile geometry of the vehicle. Smaller children are more likely to experience thorax impact against the front face of the vehicle, which tends to be more aggressive than the hood and fender top surfaces. A review of NHTSA pedestrian impact data files [13, 24] confirm that small children appeared to show a relatively higher risk of severe thoracic injury.

Design trends influenced heavily by fuel economy considerations are producing significant changes in the front-end geometry of current vehicles. The resulting lower hood heights and increased hood slope have reduced the segment of the child population at risk to a full frontal impact. An increasingly larger segment of the child population is being exposed to the type of impact experienced by adult pedestrians. The thorax is rotated down into the relatively flat and compliant upper hood and fender surfaces as the body is lifted onto the hood of the striking vehicle. As was the case with head impacts, one of the primary concerns is the amount of additional surface deflection required to achieve reduced fatalities and injuries. Of course this relates directly to the stiffness of the surface, which must also meet normal operational and functional requirements.

2.2.1 Adult Thoracic Surrogate

An adult thoracic surrogate was designed to represent the 50th percentile adult male. Figure 16 shows a schematic of the adult thoracic surrogate. The rib plate assembly (guide rods, rib plate, rib foam, and skin) of the surrogate is meant to represent the skeletal structure of the human rib cage and its associated musculature. The block of foam between the rib assembly and carriage is designed to provide a force/compression response characteristic of the human rib structure and thoracic viscera. The total mass of the impactor of 17.3 kg (38 lb) is equivalent to that portion of an adult's total mass that is expected to interact with the vehicle surface during the thorax impact phase. The rib plate is 308 square cm (48 square inches) which represents the contact area of the side of the chest, while the foam insert's thickness represents the average chest breadth of 203 mm (8 inches). The surrogate is designed to allow impacts to the front of a vehicle as well as the upper hood and fender regions. The surrogate's instrumentation allows the measurement of spinal acceleration, rib acceleration, and relative displacement of the rib and spine (crush). It also estimates dynamic deflection of the impacted surface. This device was designed to represent an adult thorax and matches quite well the surrogate performance guidelines developed from cadaver testing and recommended by ISO [25]. It also matches quite well the cadaver responses developed by the agency for its side impact program [26, 27].

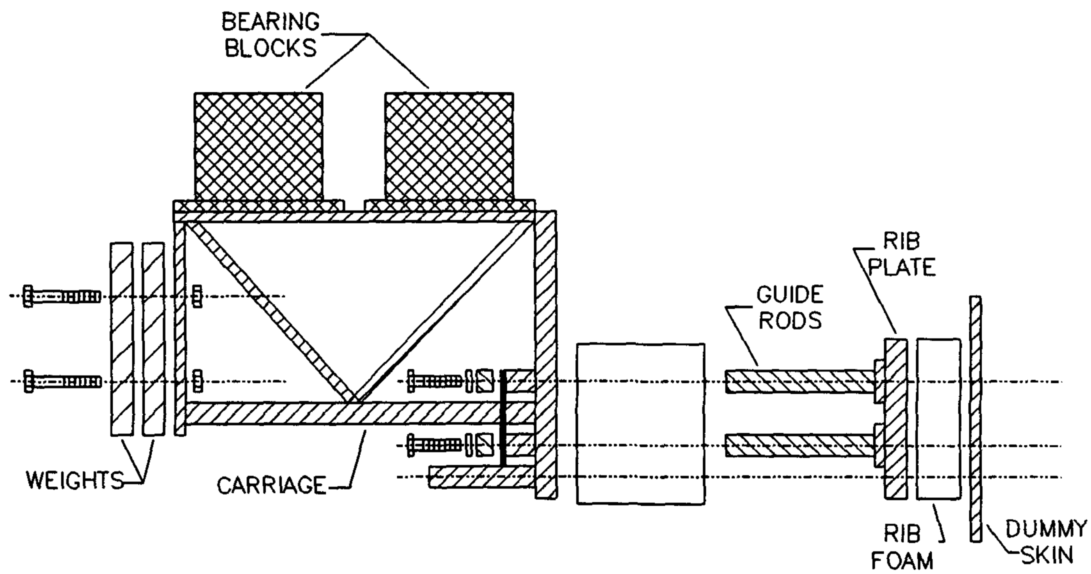

Figure 19: Schematic Drawing of Adult Pedestrian Thoracic Simulator

2.2.2 Child Thoracic Surrogates

A family of child thoracic surrogates was developed to represent average 3-year old, 6-year old, 9-year old, and 12-year old children [28,29]. The surrogate is designed to allow impacts to the front of a vehicle as well as the upper hood and fender regions. These surrogates were designed to match adult cadaver data [30] scaled to represent the physiological differences between adults and children. This is necessary because relatively little work has been done in the field of child impact response, and cadaver response data is not available for children.

2.2.3 Injury Criteria

The relevant injury criterion to study thoracic impact is TTI, which is an averaged value of the peak measured acceleration of the rib and spine masses. Based on child pedestrian impact reconstructions in which the damage in a real-world impact was replicated using the child thoracic surrogates, it appears that a TTI of 60 g is a reasonable threshold of serious thoracic injury. Unfortunately, this was based on only six cases, so the accuracy of this injury measure is unknown, and is likely to be refined over time. For adults, a reasonable threshold is 85 g - 90 g. The TTI values for adults are those used in the agency's side impact safety standard for passenger cars.

2.2.4 Vehicle Testing

In the first phase of vehicle testing in this program, a selection of twenty-nine domestic and imported passenger cars, light trucks, and vans were impacted with thoracic surrogates [31].

The impact simulations represented full lateral thoracic involvement which is characterized by the front of the vehicle striking the thorax with minimum rotation of the upper body. These impacts were designed to simulate small children being struck by the vehicle face with full thoracic involvement. The headlight structure, grille area, and leading hood edge are considered the primary points of contact for a small pedestrian child. Because various sized vehicles were being compared, the mean height of the childs' chest was matched to the leading hood edge heights of the test vehicles. The appropriate surrogate age configuration, e.g. 3-, 6-, 9-, or 12-year-old, was selected based on this matching.

Results of the initial baseline testing demonstrated the relative severity of child thoracic impact by the front facia of a vehicle. Tests with all of the vehicles predicted severe injury potential for impact speeds greater than 29-32 km/h (18-20 mph). Still, a significant range of potential impact severity levels was observed for this selection of vehicles, demonstrating that injury severity could be reduced for much of the vehicle fleet.

For the next series of baseline tests, eleven passenger vehicles were selected for a series of pedestrian tests on the upper hood and fender surfaces. The vehicles were selected based on market share (1989-90), and were intended to represent the distribution of domestic sales by both size classification and manufacturer. Table 5 illustrates how the sample's distribution of vehicle size matches recent domestic sales. The sample's distribution of manufacturers is compared to the domestic market in Table 6.

Table 5: Comparison of Sample and Actual Sales by Vehicle Size

Size Category	Market Share (Top 40 Sales)	Market Share (All Sales)	Sample Distribution
Sub-Compact	22.3%	21.8%	27.3%
Compact	32.3%	27.7%	27.3%
Intermediate	29.1%	33.4%	27.3%
Standard	16.4%	13.0%	18.2%

Table 6: Comparison of Sample and Actual Sales by Manufacturer

Manufacturer	Market Share (1989 Sales)	Number Vehicles in Sample	Sample Distribution
General Motors	34.8%	4	36.4%
Ford	27.3%	3	22.1%
Chrysler	10.3%	1	9.1%
Japan	26.0%	2	18.2%
Korea	1.9%	1	9.1%
Europe	4.9%	0	0.0%

The impact location on a test vehicle was determined by the wrap around distance (WAD) corresponding to the chest height of the typical subject age group. Three subject configurations were selected for this testing: adult, 12-year-old child, and 6-year-old child. The 84 cm (33 inches) WAD for the 6-year-old child places most of these impacts at the extreme front of the upper hood/fender and facia surfaces of contemporary vehicles. The adult surrogate impacts are furthest back on the hood surface with a WAD of 137 cm (54 inches), while the 112 cm (44 inches) WAD for 12-year-old impacts falls nearly halfway between the adult and 6-year-old locations.

The thoracic impact speed for these baseline tests with the upper hood and fender surfaces was 32 km/h (20 mph). Preliminary test results indicated that this impact speed resulted in a range of thoracic injury levels close to the critical threshold values for adult pedestrians. This speed is at the upper end of the estimated thoracic impact speeds derived from the analysis of the high speed film data of pedestrian cadaver impacts at 40.2 km/h (25 mph). The resulting thoracic speed at impact was found to be between 27.4 km/h (17 mph) and 32 km/h (20 mph).

Pedestrian head impact research has shown that the nonsymmetry in under-hood clearance and substructure can significantly affect the impact response characteristics across the hood. To address the possibility of variations in response characteristics across the hood surface, five impact locations were chosen for each age group, for a total of 15 impacts for each of the vehicles tested. At the appropriate WAD for each age group (6, 12, and adult) impacts were made against the right and left hood/fender region, the centerline, and points midway between the fender and centerline impacts (referred to as "midline" in discussions to follow).

2.2.4.1 Results of Adult Impacts

The results of the adult impacts are presented graphically in Figures 20 through 22. In Figures 21 and 22, the family of bars on the right side of the figures are for the driver's side of the vehicle. Vehicles corresponding to the vehicle numbers in these figures are identified in Table 7. Note that some figures include vehicle 8.5 which is a modified Taurus. These modifications and thoracic test results are discussed in Section 2.2.5. For the centerline impacts (Figure 20), only one vehicle (Taurus - Plastic hood) exceeded the "critical" value of 85/90 g, while two others fell within the 85/90 g range. The midline tests (Figure 21) showed a range of TTI values ranging from below 60 g to over 120 g. Most of the vehicles tested gave responses near or below the critical value with only two vehicles giving a response over 100 g. The relative greater stiffness of the hood/fender region has been well documented by the pedestrian head impact research. Although there is a general rise in TTI values for this set of tests, there are still a number of impacts which fall below the critical 85/90 g level. TTI values range from about 70 g to over 115 g.

Table 7: Thorax Impact Tests Vehicle Identification

ID NUMBER	TEST VEHICLE
1	HONDA ACCORD
2	CHEVROLET CAPRICE
3	CADILLAC DeVILLE
4	CHEVROLET CAVALIER (plastic)
5	CHEVROLET CAVALIER (steel)
6	CHRYSLER ACCLAIM
7	FORD ESCORT
8	FORD TAURUS (steel hood)
8.5	FORD TAURUS (steel hood) - modified fender
9	FORD TAURUS (plastic hood)
10	FORD TEMPO
11	HYUNDAI EXCELL
12	NISSAN SENTRA
13	OLDSMOBILE CIERA

The results of the adult testing seem to indicate that the central hood region of most vehicles present a low to moderate threat of thoracic injury to adult pedestrians. The fender and hood/fender seam present a slightly higher threat of injury as indicated by the higher number of tests above the 85/90 g value. Figure 22 presents the results of the hood/fender impacts. The results of the hood/fender impacts show a reasonably even distribution of TTI values ranging between 80 g and 120 g. Several vehicles have results below the critical value of 85/90 g, while only two of the remaining vehicles have TTI values above 100 g at 32 km/h (20 mph).

2.2.4.2 Results of Child Impacts

The child impact uses the threshold value of 60 g as a measure for the onset of serious injury. This value, which is considerably less than the 85/90 g level used for the adult surrogate response, is the best estimate of a comparable "critical value" for the child thoracic surrogates. Results of the 6- and 12-year old tests that are presented graphically in figures 23 through 28 show that none of the vehicle impact responses meet the 60 g threshold value. In Figures 24, 25, 27, and 28 the family of bars on the right side of the figures are for the driver's side of the vehicle.

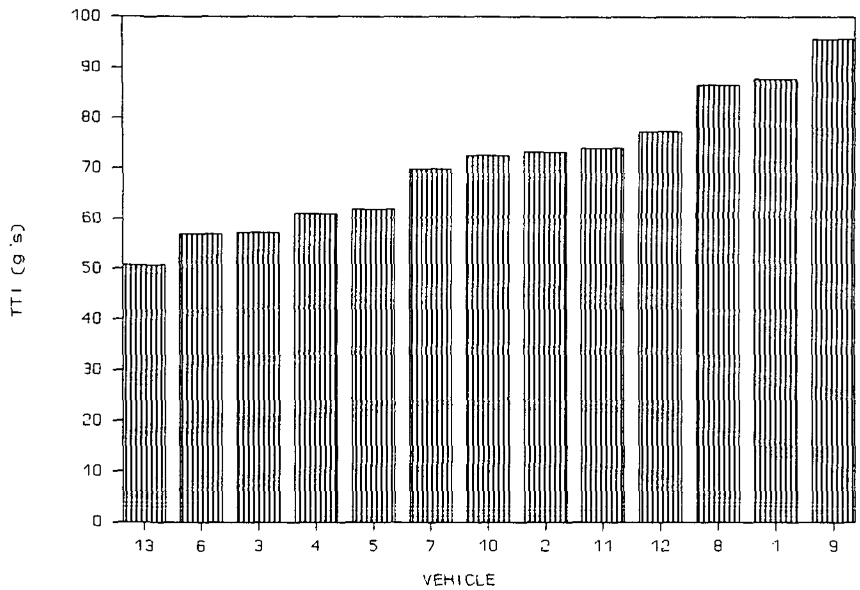

Figure 20: Results of Adult Pedestrian Thorax Impacts - Vehicle Centerline

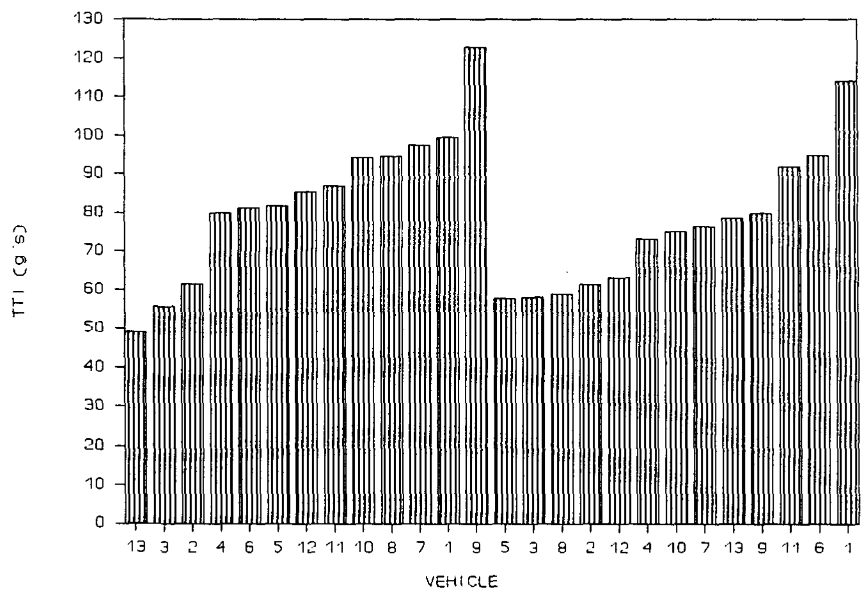

Figure 21: Results of Adult Pedestrian Thorax Impacts - Vehicle Midlines

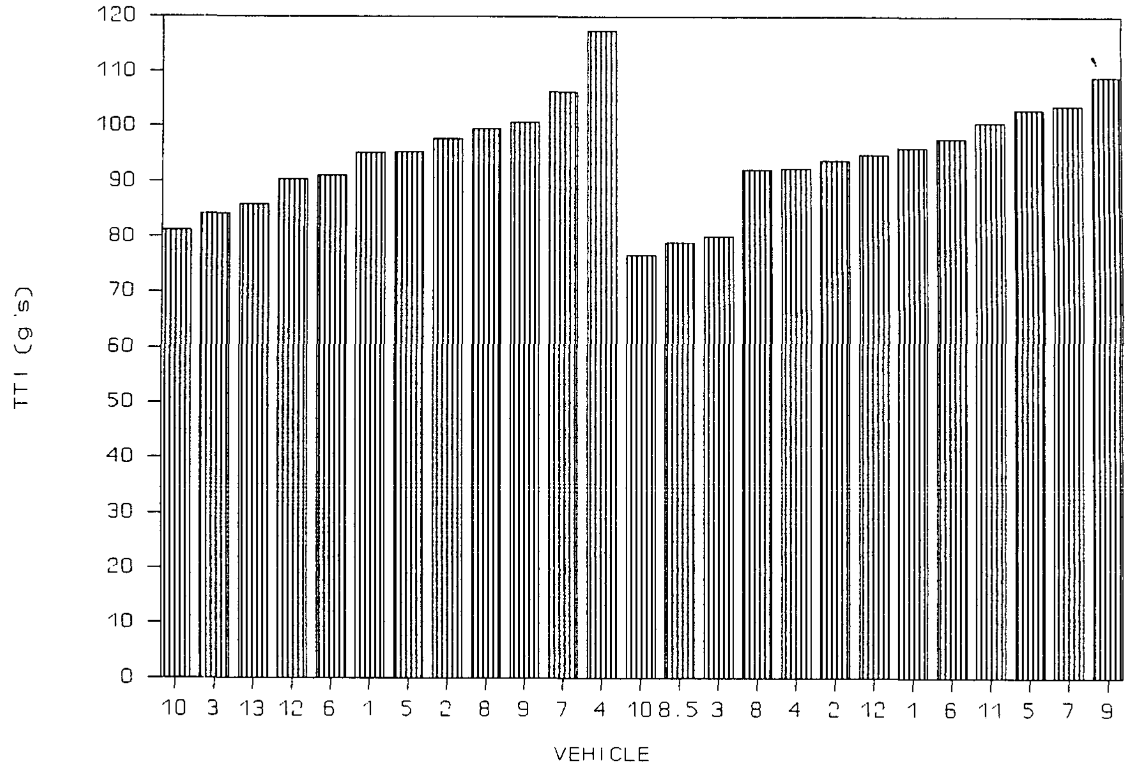

Figure 22: Results of Adult Pedestrian Thorax Impacts - Hood/Fender

The 6-year-old centerline impacts (Figure 23) range from 75 g to 116 g. The midline impacts (Figure 24) show an even greater range of responses ranging from about 70 g to 130 g. This range of response levels is probably due to the stature of the 6-year-old child and the resulting location of impact onto the hood surface. The 33 inch WAD of the six year old child is at or near the transition point from front facia to upper hood surface for most passenger vehicles. The hood latch points, radiator, and headlight structures make the front end of a vehicle a relatively hard impact surface. Also, the direction of impact into the hood surface varied with the hood height of the test vehicle. Vehicles with higher front ends resulted in tests similar to the front facia tests conducted with smaller children while vehicles with lower hood heights resulted in impacts normal to the hood surface such as seen with the 12-year-old and adult simulations. These two conditions combined result in a wide range of impact conditions and impact responses. The fender impacts (Figure 25) show similar results with a range of responses of about 90 g to 150 g. The results of the 12-year-old impacts all exceeded the threshold to serious injury of 60 g TTI. The current impactor is not designed to predict accurate responses for impacts much more severe than the 60 g limit. This is left to future research.

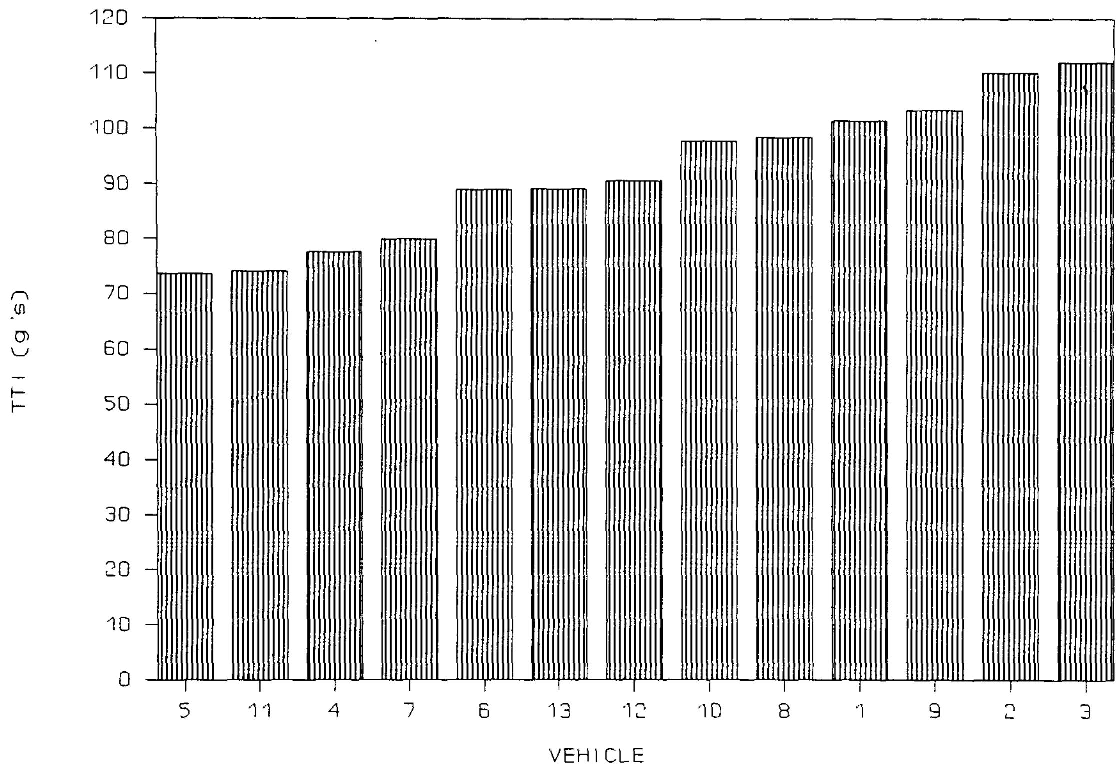

Figure 23: Results of 6-Year Old Pedestrian Thorax Impacts - Vehicle Centerline

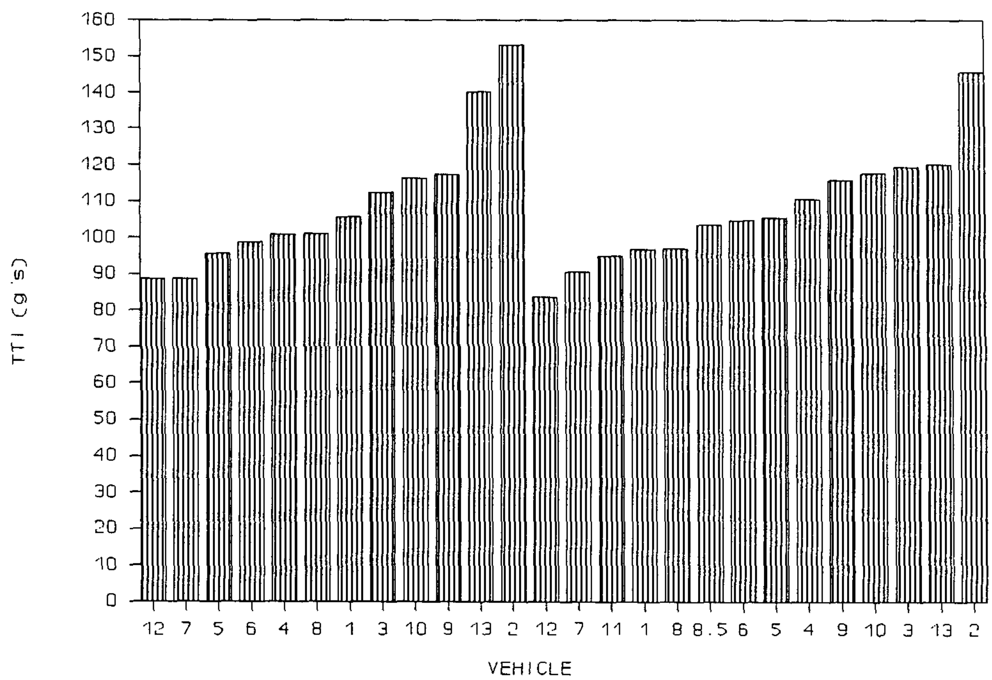

Figure 25: Results of 6-Year Old Pedestrian Thorax Impacts - Hood/Fender

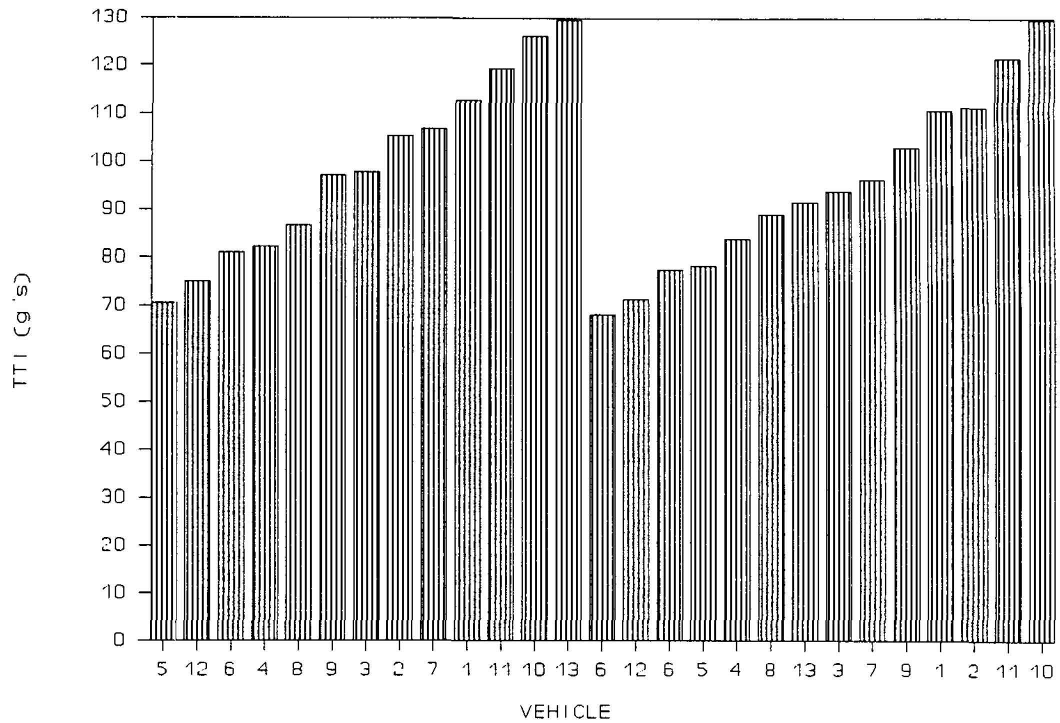

Figure 24: Results of 6-Year Old Pedestrian Thorax Impacts - Vehicle Midlines

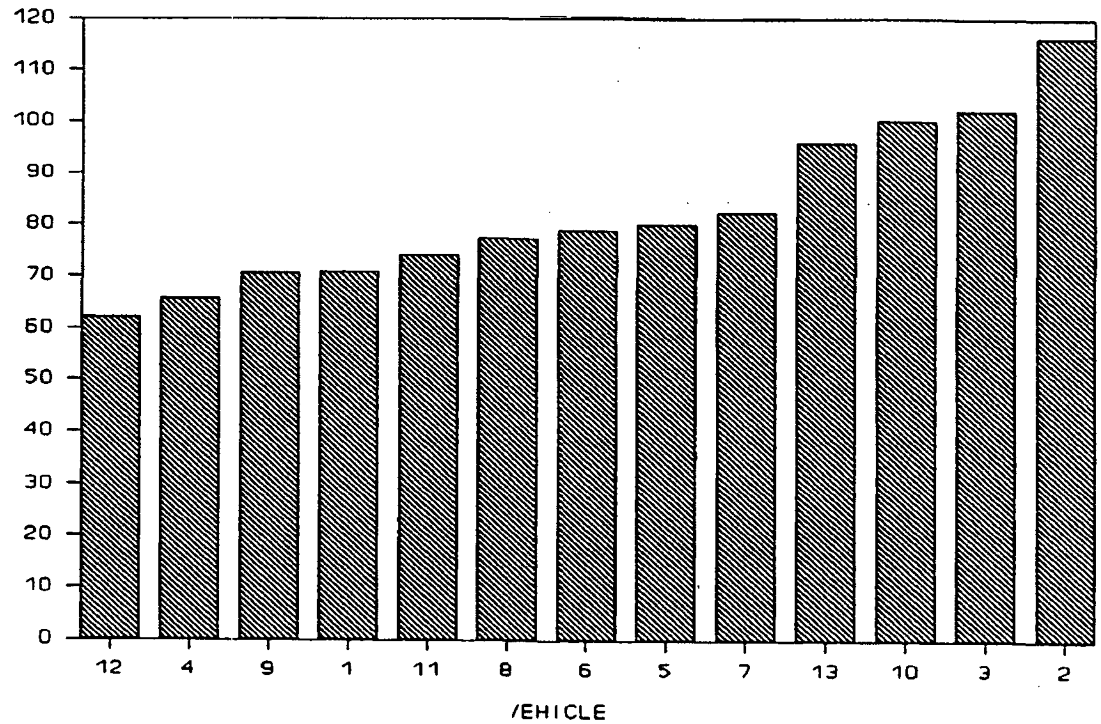

Figure 26: Twelve-year-old Surrogate Test Results - Centerline Impacts

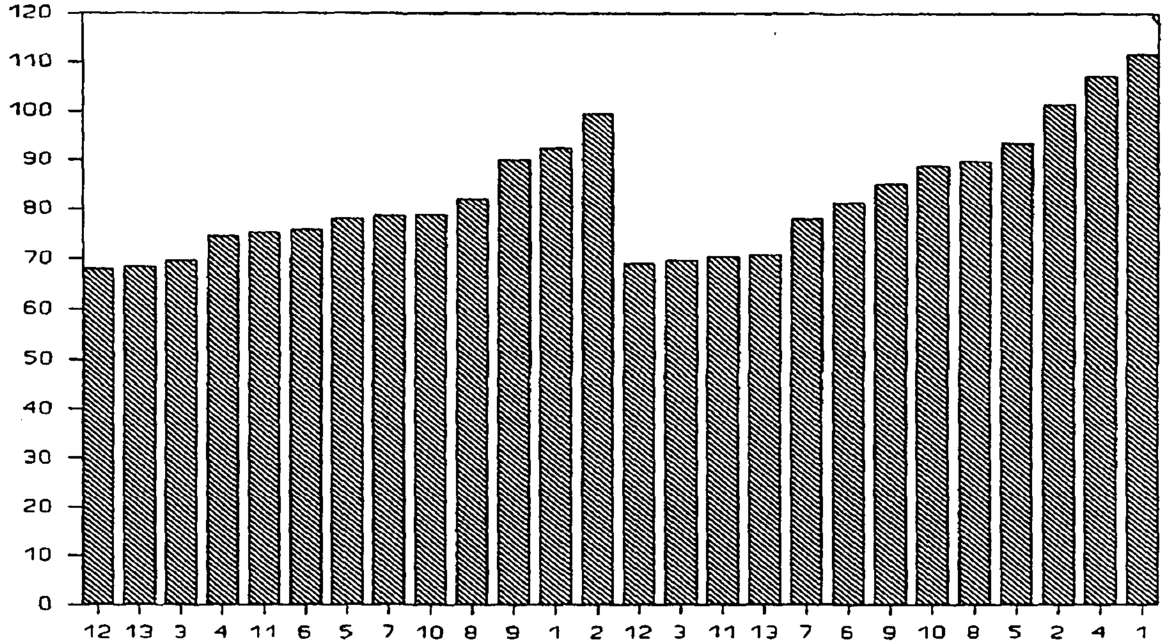

Figure 27: Twelve-year-old Surrogate Test Results - Right/Left Midline impacts

2.2.4.3 Plastic Hood Impacts

A trend in the automotive industry is the increasing amounts of plastics and polymer composites in the structures of automobiles. Early pedestrian head impact testing has indicated that these hoods may present a higher threat to head injury than steel hood designs. Two of the vehicles tested in this thoracic series had composite versions of the standard steel hoods, although only one now has a production version. Reviewing Figures 20 through 28, it is seen that with the Chevrolet Cavalier, although showing significant variations in performance between steel and composite hoods, neither hood is consistently better or worse. For the Ford Taurus, however, there appears to be some increase in overall potential injury severity. However, a number of impact points showed either no significant increase in TTI or a decrease. The conclusion from this limited testing is that there may be some small potential increase in injury severity with composite hoods.

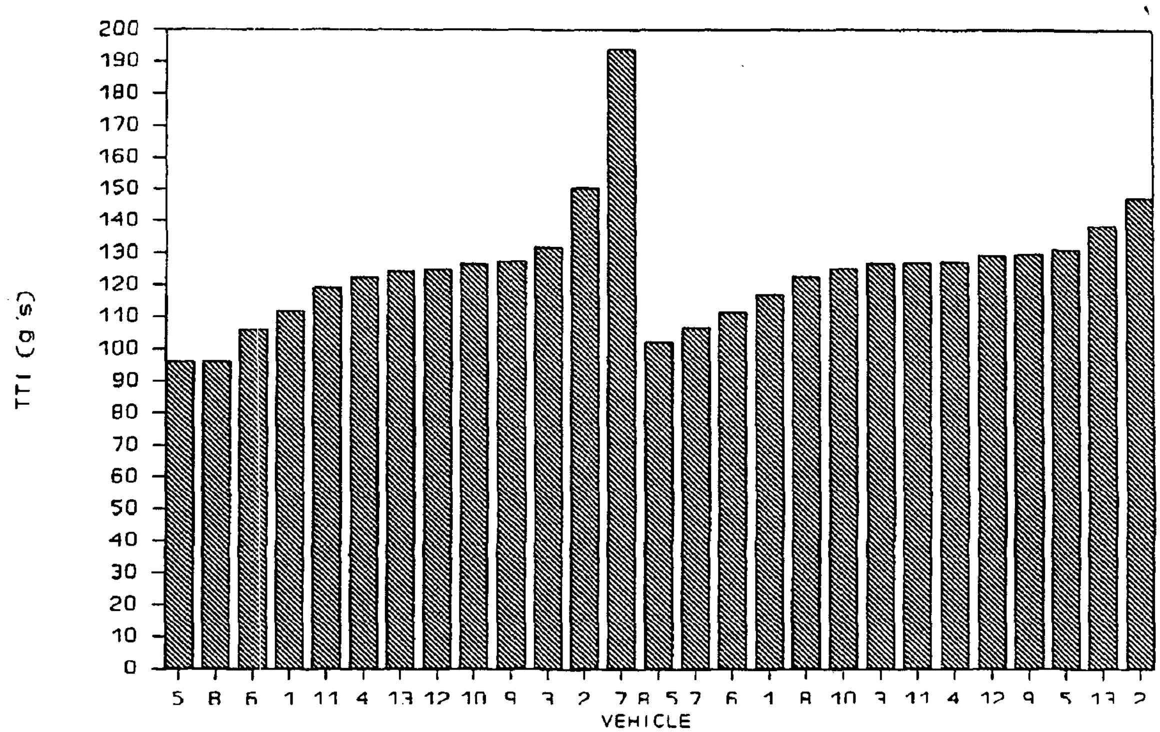

Figure 28: Twelve-year-old Surrogate Test Results - Right/Left Fender Impacts

2.2.4.4 Effects of Impact Speed

One vehicle, the Ford Escort was tested at a lower speed of 24 km/h (15 mph) and at a higher speed of 40.2 km/h (25 mph) using adult, 6-year old, and 12-year old surrogates. For the adult surrogate impacts, reducing the impact speed provided approximately proportional reductions in TTI. However, raising impact speed produced only small increases in TTI in locations where there was lower structural stiffness and clearance to absorb energy. In these cases, it appears that much of the additional energy of impact was absorbed by the vehicle structure rather than producing higher injury measures.

These characteristics were not observed in the 12-year old surrogate results in that increasing the impact speed provided approximately proportional increases in TTI. Reducing the impact speed also provided approximately proportional reductions in TTI, and some TTI scores were reduced to below 60 g, the threshold of serious thoracic injury for children. This suggests that even moderate reductions in impact severity could reduce or eliminate the risk of serious injury for some hood/fender areas.

For 6-year old surrogate impacts, lower and higher impact speeds respectively lowered and raised TTI values approximately proportionally. However, none of the TTI values were below 60 g.

The mass of the 6- and 12-year old surrogates are significantly less than that of the adult surrogate. As a result, hood stiffness levels may be too high for the mass of the lighter thoracic surrogate to deform effectively. A greater proportion of the total energy is absorbed by the thorax rather than deforming the surface of the hood. As a result, these thoraxes may be more sensitive to impact speed, while requiring less underhood clearance to absorb energy.

2.2.5 Experimental Countermeasure Demonstrations

In Section 2.1.5.2, hood/fender modifications to a Ford Taurus were described. The adult and 12-year old child thoracic wrap-around-distances include the area modified for head impact countermeasures, so these modifications were tested at 32 km/h (20 mph) for their influence on TTI using adult and 12-year old surrogates. The results are shown in Table 8. The testing with the 12-year old surrogate showed a decrease in TTI of about 20 percent, but TTI was still significantly above the 60 g thoracic injury threshold. A test at a lower speed of 24 km/h (15 mph) also lowered TTI values significantly, but the resulting values were still well above the 60 g threshold.

Table 8: Summary of Pedestrian Thoracic Impacts with Modified Taurus Hood/Fenders

AGE	IMPACT CONDITION	TTI (g)
12 Year	Steel Hood - Unmodified	122
12 Year	Modified Hood and Fender	102
Adult	Steel Hood - Unmodified	92
Adult	Modified Hood and Fender	79

The adult test show slightly less reduction in TTI, but sufficient to reduce the level below the 85 g-90 g threshold value for adult serious thoracic injury. These hood/fender modifications indicate the possibility of significant benefits for adult thoracic injuries.

In the original front facia testing with child thoracic surrogates, one vehicle showed significantly lower injury values. This vehicle, the 1986 Pontiac Sunbird/Buick Skylark, was selected for testing several potential modifications that could reduce the severity of simulated pedestrian thoracic impact.

The front facia of the Sunbird/Skylark design has several characteristics which made it an ideal choice for initial countermeasure development efforts. The soft polyurethane molding of the facia provides a soft impact surface without the typical grille structures seen in most vehicles. Approximately 10 to 15 cm (4 to 6 inch) clearance exists between the skin of the facia to the rigid structures of the hood edge, latch point, radiator, and other hard structures. The facia and headlight assembly is supported by a relatively light sheet metal substructure which could easily be modified with minimal effects on the performance of nearby vehicle components.

Four modifications were made to the facia area. A sheet metal strip that supports the upper edge of the facia was removed. A decorative metal bezel around the headlight structure was removed. A sheet metal panel that holds the headlight assembly mount was weakened. The last modification was the addition of energy absorbing padding between the facia front and the substructure. These modifications were tested using both the 3-year old and 6-year old surrogates. Test speeds were 24 km/h (15 mph), 32 km/h (20 mph), and 40 km/h (25 mph). The combinations tested were: the unmodified vehicle, the structural modifications, and the structural modifications with padding.

The 3-year old surrogate was used to impact the front facia at the leading hood edge height. Impact locations were the centerline of the vehicle, the headlight region, and a point midway between the first two locations. The 6-year old surrogate was used to test the modifications for an upper hood/fender impact condition. The impact points were the same as those described in Section 2.2.4 for the hood/fender testing.

The results of this testing are shown in Table 9. It is noted that only a few of the tests produced TTI values below the 60 g threshold of serious injury. It also appears that some of the modifications produced no improvements in injury scores. This may be due to the mass of the child thoracic surrogate being too light to cause energy absorption by the vehicle structure. When impact energy levels are higher with the heavier 12-year old surrogate or when the impact speed is raised, the modifications are more effective in lowering TTI, probably because the impact energy is sufficient to cause the vehicle to absorb energy. Also, it is noted that the location across the front of the vehicle is a factor in whether the TTI values were lowered with the modifications. The fact that some tests showed that TTI values were reduced with the modifications indicate that countermeasures can be effective in reducing child pedestrian thoracic injuries.

Table 9 Summary of Impacts with Modified Sunbird/Skylark Facia				
SURROGATE	IMPACT LOCATION	SPEED (km/h)	VEHICLE	TTI (g)
3-year-old	Centerline	32	Baseline	60
		32	Modified	62
		32	Padded	61
		32	Padded	67
		40	Baseline	95
		40	Modified	79
	Midline	32	Baseline	82
		32	Modified	63
		32	Modified	57
		32	Padded	49
		32	Padded	62
	Headlight	24	Baseline	86
		32	Baseline	123
		24	Modified	49
		32	Modified	72
		32	Modified	74
		40	Baseline	188
		40	Modified	102
6-year-old	Centerline	32	Baseline	66
		32	Modified	64
	Fender	32	Baseline	143
		32	Modified	125
	Midline	32	Baseline	139
		32	Modified	107

2.2.6 Countermeasure Effectiveness Model

Similar to the analysis discussed in Section 2.1.5.5, a "harm" model and analysis was utilized to assess the potential benefits of vehicle modifications to reduce thoracic injuries to adults and children in pedestrian-vehicle impacts. As in the previous analysis, a cost index was developed that represents the societal costs incurred from pedestrian thorax impacts. The benefits of modifications are derived from the change in the cost index resulting from lowering thoracic injury severities.

Since little countermeasure demonstration work has been done, the reduction in the cost index was computed for hypothetical across the board TTI reductions of 10 percent and 20 percent for adults and children. For adults, the cost index reductions were between 16 percent and 24 percent for a 10 percent TTI reduction, and between 34 percent and 47 percent for a 20 percent TTI reduction. For children, the cost index reductions were between 19 percent and 26 percent for a 10 percent TTI reduction, and 41 percent for a 20 percent TTI reduction.

2.3 PEDESTRIAN LOWER LIMB INJURIES

Lower limb impacts were once the main focus of pedestrian research in the United States. Early results [32], suggested that lower limb injury among pedestrians could be significantly lessened by reducing the stiffness of vehicle front ends. Based on this research, NHTSA issued a Notice of Proposed Rulemaking (NPRM) in 1981 which would have required the softening of bumpers and other front end structures. More recent studies with modern vehicle styles having lower front profiles showed that simply softening the vehicle fronts would not significantly reduce pedestrian lower limb injuries. For this reason, the proposed rulemaking was terminated in 1991.

Research on pedestrian lower limb injuries has been more active in Europe. In fact lower leg impact simulation is the primary task of a working group organized by the ISO to develop standard test procedures for pedestrian injury investigation. Studies of accident data [33,34,35,36] have continually demonstrated the importance of lower limb injuries in terms of frequency and long term consequence. These studies have shown that the types of leg injuries commonly suffered by pedestrians often result in long periods of disability and affect victims of all ages. Consequently, many researchers have been working to find ways to reduce these injuries. The problem has been approached from several directions. Principal among these are the use of mathematical models and simplified test procedures to examine the effects of modifications to vehicle geometry and compliance.

These studies have produced several important findings. In the area of vehicle front end geometry, bumper height and extension, and the hood edge profile are important factors influencing the type and severity of lower limb injuries in pedestrian impacts. Most researchers have agreed that severe knee injuries occur most often when the bumper strikes the knee region directly. In addition, the outcome of these impacts is worsened when the bumper extension is long or the hood edge profile is exceptionally low. Some researchers have suggested that bumper heights (which are regulated in the U.S.) should be lowered, or perhaps secondary "subbumpers" should be added just below and slightly leading the primary bumpers to reduce the severity of lower limb injuries [37,38].

Another direction of research in pedestrian lower limb protection is investigation of the effects of softening the vehicle fronts. However, as stated earlier, reducing vehicle stiffness alone does not generally reduce the magnitude of lower extremity trauma. Such changes might be more beneficial if combined with vehicle geometry modifications. Again, more research would be required before any conclusions could be drawn.

Two approaches have been followed in the endeavor to develop simplified test methods. First, mathematical models have been developed to study pedestrian impact. While these models reasonably predict trajectories, forces, and accelerations of pedestrian impacts, they are not well-suited to precisely duplicating small parts of the overall impact sequence. This is especially true of the lower extremity impact, because two body segments are often directly involved and the contact models and failure modes are nearly intractable.

The second way, consisting of developing simplified test methods, has been described for the head and thorax investigations. The evolution of subsystem devices has been proceeding in Europe for the last ten years. The latest leg impact simulator developed in Europe is currently being considered as a standard test device by the ISO.

2.3.1 Pedestrian Lower Leg Impactor

A pedestrian lower leg impactor was developed to study lower leg injuries from pedestrian-vehicle impacts. This impactor was derived from the leg of the Hybrid III dummy used extensively by NHTSA and the automotive industry for assessing injury potential in vehicle crashes. This is the dummy used to assess compliance with Federal Motor Vehicle Safety Standard 208, Occupant crash protection.

The primary modification to the Hybrid III leg for use in studying pedestrian leg injuries was to allow the insertion of an aluminum, plastically deforming knee in the form of replaceable knee elements. Considerable design effort was directed toward developing replaceable knee elements that matched the biomechanical data available on knee performance. However, an optimum design was not achieved and remains an objective for further research. To optimize the knee element design also will require more biomechanical data on knee performance to be developed. Nevertheless, the knee elements finally selected are sufficient to begin work in studying pedestrian leg injuries. The lower leg impactor is shown in Figure 29. Instrumentation on the impactor consists of strain gages on the knee to measure shear loads, accelerometers, and angular velocity sensors.

The leg fits onto a carriage which is attached to a hydraulic gun that acts as the acceleration mechanism. The carriage is supported and guided through linear bearings on a system of rails. The carriage simultaneously accelerates the leg and the cart on which the leg rests. The cart coasts along the rails until the leg impacts the vehicle and is knocked free. The cart continues beneath the car until stopped by an arresting mechanism. Instrumentation measures the speed of the cart at the vehicle-to-leg impact.

In order to tune the performance of the leg impactor and optimize the impactor acceleration system, a series of tests was done on a "bumper assembly" that simulates the front of vehicles. This device allows bumper height to be raised or lowered and hood edge angle to be varied. While optimizing the performance of the impactor system, these tests also were the beginning of a vehicle front parameter study. In these tests, bumper height was varied, hood angle varied, bumper padding applied, and a sub-bumper was added below the primary bumper. The results

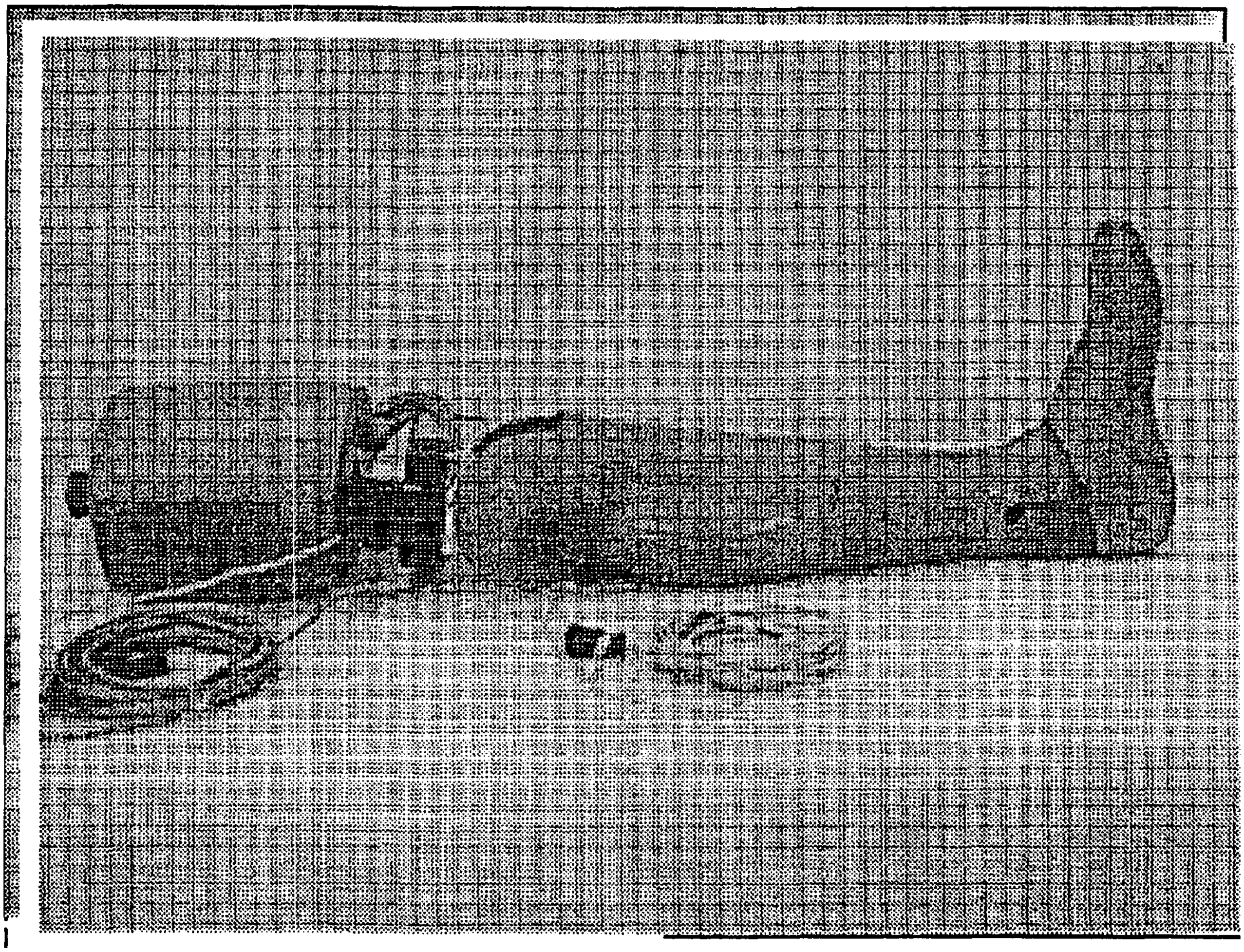

Figure 29: The VRTC Lower Extremity Impactor

of these tests are shown in Table 10. Recognizing that these tests did not represent real vehicle configurations entirely, some conclusions can be drawn. The tests showed that padding the bumper can help to limit the crush type injuries to pedestrian lower extremities. The extent of this help is difficult to determine since the tolerance for such injuries is about 4,000 N (900 lb), while even the lowest load measured was 4,200 N (945 lb). A second conclusion is that the addition of a sub-bumper reduced the knee rotation by 35 percent, although it also raised knee shear significantly. This may indicate that lower leg injury is more likely than knee injury, which is certainly preferable.

Table 10: Summary of Preliminary Pedestrian Leg Impact Simulations

Test #	Impact Speed (m/s)	Bumper Height (mm)	Hood Angle	Bumper Modification	Peak Knee Shear (N)	Peek Knee Angle	Static Knee Angle	Peak Bumper Load (N)
017	11	450	15°	none	3,300	28°	24°	16,960
018	11	450	15°	none	3,800	62°	broke	17,480
019	10	501	15°	none	2,500	27.5°	22.5°	15,900
020	9	552	60°	none	6,560	85°	broke	14,990
021	9	450	15°	none	7,190	35°	33°	10,230
022	8	450	15°	51mm Ethafoam 400 padding on bumper	4,375	65°	72°	4,200
023	10	501	15°	51mm Ethafoam 400 padding on bumper	3,437	110°	105°	5,580
024	10	552	15°	51mm Ethafoam 400 padding on bumper	5,410	101°	79°	7,340
025	10	450	60°	51mm Ethafoam 400 padding on bumper	2,440	80°	80°	4,420
026	9	450/360	60°	51mm Ethafoam 400 padding on bumper & similarly padded sub-bumper	5,125	52°	52°	5,400

2.3.2 Lower Limb Injury Tolerance

The success of research to prevent lower limb injuries depends on understanding the injury mechanisms and tolerances for the different structures of the leg. Two types of loads are considered significant causes of pedestrian leg injuries. First, lateral impact causes shear to occur when the bumper and hood edge strike the leg. Both the femur and the tibia might be affected by this shear, and the knee may be affected depending on the position of the pedestrian relative to the vehicle. The second important mechanism causing lower limb injury is lateral bending. Bending not only contributes to long bone fractures, but also is considered the most important cause of injury to the knee and ankle joints.

There is not universal agreement on the injury tolerances for these injury mechanisms, nor has sufficient biomechanical research been completed to establish the injury tolerance levels. However, at this time, the best estimates of the tolerance levels are 4,000 N (900 lb) for femur lateral impacts, 1,500 N (337 lb) to 4,000 N (900 lb) for tibia lateral impacts, 212 N-m (156 lb-ft) to 320 N-m (236 lb-ft) for tibia and femur bending, and 200 N-m (148 lb-ft) for lateral bending of the knee, which corresponds to about 6 degrees of angular deflection.

2.3.3 Baseline Vehicle Testing

After optimizing the performance of the impactor system and gaining some insight into important vehicle front parameters relative to pedestrian lower extremity injury, the next step was to develop some knowledge about the response of the current vehicle fleet in pedestrian lower extremity impacts. Table 11 gives a list of the vehicles and important test parameters for this series of tests. The models tested ranged from vehicles with low, sloping front ends like the Saturn SC to vehicles with high, square front ends and rigid bumpers like the 1980 Cadillac Fleetwood. In addition, several popular mid-sized models were tested along with the full size 1991 Chevrolet Caprice. The results of the testing are shown in Table 12.

Several observations can be made from the test results. First, vehicles with relatively prominent low leg supporting structures caused less knee bending than most other tests. Second, lower knee accelerations are generally highest for those vehicles which impact the leg with a rigid surface or in a concentrated area just below the knee. Note that the Saturn's flexible bumper which impacts well below the knee causes only 62 g to 150 g lower knee acceleration. Finally, for the most part, those vehicles which minimize knee bending loads tend to cause the most knee shear. In addition, it seems that the vehicle hood edge height and location are not very important to pedestrian lower leg and knee protection, although probably critical for thigh and hip protection. Thus, finding the appropriate bumper and front end design for pedestrian lower extremity protection will require a balance of many considerations including vehicle geometry, front end compliance, and pedestrian head and thorax safety requirements.

The research completed thus far has shown that controlling the primary pedestrian impact so that the leg is struck well below the knee, preferably near the center of gravity of the lower leg, by a reasonably compliant surface and a distributed load can minimize the risk of serious knee injury and disabling fracture of the leg. However, more needs to be done in order to achieve the ability to predict specific injuries in specific tests.

3.0 AVOIDING PEDESTRIAN IMPACTS

The agency's program directed at avoiding pedestrian-vehicle impacts has taken a behavioral approach. Research in this began in 1969 with a pioneering study that was completed in 1971 [39,40]. Previous studies had looked at pedestrian impacts mainly in terms of demographics and road geometry. The 1969 study used these kinds of information, but it concentrated more closely on behavioral factors, the how and why, of pedestrian impacts. The focus was to understand pedestrian-vehicle impact causation and create a knowledge base that could be used to develop behavioral solutions for preventing the impacts.

The 1971 study developed a behavioral model of the impact situation. The model considered the things a pedestrian and driver have to do to avoid hitting each other. These included such functions as: search, detection, evaluation, decision making, action, and vehicle response. Approximately 2,000 urban pedestrian impacts were investigated in 13 large cities across the

Table 11: Baseline Vehicle Test Configurations

Make	Model	Year	Bumper Height [mm]	Hood Height [mm]	Bumper Lead [mm]	Test Speed [m/s]	Test Number
Chevrolet	Cavalier	1988	502	610	86	9.1	0027
Ford	Taurus	1987	508	698	159	9.0	0028
Chevrolet	Berreta	1989	521	594	149	9.8	0029
Plymouth	Acclaim	1990	521	578	140	9.4	0030
Chevrolet	Caprice	1991	454	619	133	9.5	0031
Nissan	Sentra	1988	627	597	140	9.2	0032
Cadillac	Fleetwood	1980	641	908	140	9.5	0033
Honda	Accord	1986	508	648	152	9.2	0034
Saturn	SC	1992	380	460	48	8.2	0035
Saturn	SC	1992	380	460	48	6.5	0036
Chevrolet	Cavalier	1988	502	610	86	6.6	0037
Nissan	Sentra	1988	527	597	140	9.2	0038
Nissan	Sentra	1988	527	597	140	9.8	0039

Table 12: Summary of Results - Baseline Vehicle Tests

Test Number	Vehicle Model	Maximum Knee Shear [N]	Peak Dynamic Angle [°]	Knee Static Angle [°]	Lower Knee Acc. [g's]	Comments
0027	Cavalier	1720	53.2	65.0	361	-----
0028	Taurus	1875	71.0	74.0	239	Elements twisted
0029	Berreta	9000*	58.2	72.0	232	Elements twisted
0030	Acclaim	2100	60.65	80.0	407	Some twisting
0031	Caprice	2200	73.4	79.0	412	Some twisting
0032	Sentra	2000	60.0	59.0	143	Significant twisting
0033	Fleetwood	2500	44.0	74.0	587	-----
0034	Accord	2500	75.0	96.5	191	-----
0035	Saturn SC	2660	58.6	30.0	150	-----
0036	Saturn SC	6000	66.3	36.5	62	-----
0037	Cavalier	2670	53.4	36.0	293	-----
0038	Sentra	2000	62.5	81.5	162	Some twisting
0039	Sentra	2540	55.6	73.0	128	-----

country. About 500 items of information, demographic, behavioral, and environmental, were obtained for each impact through interviews with victims, witnesses, drivers, and police, plus visits to the site.

The behavioral model also guided the analyses. Precipitating factors, such as human errors in terms of selecting a course for the crossing or the search procedures employed, were found to be triggers for impacts. A host of predisposing factors, such as parked cars or other visual screens, use of alcohol, were identified as setting the scene for many impacts. Then, the individual cases were grouped into types based on similarities in these factors. Some of the pedestrian-vehicle impact types are much like "traps" in the real world that snare pedestrians and drivers on a regular basis.

While about 30 different impact types were identified, it was found that **more than half of the total impacts were accounted for by only seven major types**. They are:

> **Dart-Outs** - where the pedestrian appears suddenly, usually from between parked cars.
>
> **Intersection Dash** - where a pedestrian runs across the intersection, is seen too late by the driver, and is struck.
>
> **Turning Vehicles** - where the pedestrian is usually unseen by the driver who is concentrating on turning into or merging with traffic.
>
> **Overtaking** - in which a vehicle stops for a crossing pedestrian and, in so doing, blocks him from the view of a second car overtaking the first one.
>
> **Bus-Stop Related** - where a pedestrian crosses in front of the stopped bus, is screened by the bus from the view of overtaking drivers, and is struck stepping out.
>
> **Ice-Cream Vendor** - a young child is struck by a passing vehicle while going to or from a vending vehicle.
>
> **Backing** - the pedestrian is struck by a vehicle backing up in the street or parking lot. The seven major types became the research targets for the 1970s and 1980s.

Conducted between 1969 and 1983, the research program consisted of nearly thirty projects at a cost of approximately three million dollars.

NHTSA and the Federal Highway Administration (FHWA) share responsibilities for pedestrian safety. NHTSA's program responsibilities in the pedestrian area led it to develop three kinds of countermeasures: training programs, public information and educational materials (PI&E), and model traffic safety regulations. Countermeasures related to the street and highway environment (signals, signs, markings, etc.) were pursued concurrently by FHWA. Both agencies have cooperated extensively by sharing the cost and management of numerous pedestrian projects.

These countermeasure activities can be categorized as education, engineering, and enforcement. Education and engineering are implied by the activities listed above, but enforcement also is an effective means of producing behavioral modification and is an important part of an effective program directed toward reducing the number of pedestrian impacts.

3.1 Countermeasure Research

NHTSA's countermeasure development research focused on correcting or canceling out the effects of the errors leading to the impacts. It followed a three-step cycle. Step one was to conceive of a potential behavioral solution and build it into one of three countermeasure forms (training, PI&E, regulation). The second step involved a limited field test of the countermeasure to see if it changed the specific impact-producing behavior(s). If the behavior-change results were positive, then, in step three, a more complex impact-reduction test was conducted with entire cities often used as "test beds".

Although this three-step process could not be used with all countermeasures, the research program produced several effective countermeasures that reduced particular impact types by 20 to 77 percent. The major accident type for child pedestrian accidents, the dart out, was a particularly effective target. Some of the countermeasures were proven through impact-reduction results, while others are considered effective because they induced desired behavioral changes. In addition, extensive support materials were produced to promote use of the countermeasures.

3.2 Pedestrian Research: 1969-1983

The following are brief descriptions of selected research projects conducted by NHTSA or jointly by NHTSA and FHWA during the 1969-1983 period:

Pedestrian Safety: The Identification of Precipitating Factors and Possible Countermeasures: This 1969 study was the first to develop pedestrian-vehicle impact types and identify relevant countermeasures for urban pedestrian impacts.

Causative Factors and Countermeasures for Rural and Suburban Pedestrian Accidents [41]: The typing methodology developed in the urban pedestrian impact area was extended in this study to cover rural and suburban areas. The major urban types were found to exist elsewhere along with several types specific to the rural/suburban areas.

Development of Model Regulations for Pedestrian Safety [42]: Nine "model" traffic safety regulations were developed to improve pedestrian safety, with each being targeted at one or more specific types of pedestrian crash. Public and official acceptance of the model regulations was assessed. The project provided a set of regulations available for field testing in other projects.

A Comparison of Alcohol Involvement in Pedestrians and Pedestrian Casualties [43]: This landmark study determined that alcohol was heavily involved in adult (age 14 and older) pedestrian fatalities and injuries. Blood Alcohol Concentrations (BACs) were extremely high; approximately 50 percent of those who had been drinking had BACs of 0.20 or higher. A pedestrian relative risk curve was developed, showing an increase in crash risk with increased alcohol use. It was very similar to risk curves for drivers, but the increases in risk occurred at higher BAC levels for the pedestrians since walking is a simpler task than driving and more resistant to alcohol's effects.

Conspicuity for Pedestrians and Bicyclists: Definition of the Problem, Development and Test of Countermeasures [44]: The project reviewed the literature on pedestrian and bicyclist conspicuity, then conducted tests to assess the effectiveness of various materials and strategies for enhancing the nighttime visibility of these road users. Classic advice such as "Wear White at Night" proved to be ineffective, and was replaced with other recommendations. For example, pedestrians should carry a flashlight and wear a vest with two horizontal stripes of bright, retroreflective material. Adding retroreflective trim to the front of footwear was also advised.

Experimental Field Test of Proposed Pedestrian Safety Messages [45,46,47]: The original (1969) urban pedestrian impact data used to develop impact types were reviewed to develop three sets of pedestrian safety messages: one involving an animated character "Willy Whistle" for child pedestrian messages, and two sets of safety messages for adults. The child messages were successful in reducing pedestrian impacts by 20 percent. The adult messages also yielded positive behavioral results.

The Effect of Right-Turn-on-Red on Pedestrian and Bicyclist Accidents [48]: This study assessed the impact of many States in the mid-1970's adopting the "western" version of the Right-Turn-On-Red (RTOR) ordinance. (It allows motorists to turn right on a red signal after stopping <u>unless prohibited by a sign</u>). The frequency of RTOR pedestrian and bicyclist impacts was estimated and the characteristics of these types of impacts determined. The study identified some problems and prompted new research by FHWA into countermeasure solutions.

Experimental Field Test of the Model Ice Cream Truck Ordinance in Detroit [49]: The Model Ice Cream Truck Ordinance (MICTO) is a good example of developing traffic regulations as countermeasures. The problem was young children who are struck going to or from an ice cream truck. This type of impact was analyzed and corrective elements were incorporated into a model ordinance. Key among the ordinance's features was the combined use of flashing lights on the vending vehicle and activation of a STOP swing arm when stopped for vending. The information gathered on swing arm effectiveness in this study later proved useful in recommending this technology for school buses. The ordinance required motorists to stop (then go, if safe) before passing the vending ice cream truck. A field test of the ordinance in the city of Detroit, Michigan, demonstrated a 77 percent reduction in impacts of young children associated with ice cream trucks.

Experimental Field Test of Proposed Anti-Dart-Out Training Programs [50,51]: This project developed and field tested a kindergarten through third grade street crossing training program for use in the elementary schools. It embodied the same behavioral advice as the "Willy Whistle" child safety messages cited earlier, but used in-class and street-side practice, feedback from teachers, and a "hands on" approach. The program produced a 20 percent reduction in dart-out impacts when tested in a major school system in Ohio.

In 1983, in conjunction with FHWA, the agency sponsored a national pedestrian safety conference which showcased all of the countermeasure and support materials, making them available to the highway safety community.

Most recently, agency interest has been stimulated by the need to improve mobility and safety for older pedestrians. Pedestrian and bicycle safety was made a National 402 Priority Program area on November 4, 1991 through the combined efforts of NHTSA and FHWA, thus making it easier for States to use 402 funds for these areas.

3.3 Ongoing Behavioral Research

NHTSA, in conjunction with FHWA, has examined the kinds of impact situations older pedestrians were involved in, and developed safety advice to minimize these risks. This information, contained in the publication, "Walking Through The Years," was made available to several national organizations (American Association of Retired Persons, American Automobile Association, National Safety Council) for dissemination to their large older audiences.

Following that project, NHTSA and FHWA undertook a field study to safeguard older pedestrians. The project deals with the creation of pedestrian safety zones around areas of high impact frequency for older pedestrians. The zones are saturated with an appropriate mix of engineering, enforcement, and educational countermeasures. Phoenix, Arizona, and Chicago, Illinois, are the two test cities for this ongoing project.

Another large-scale research project by NHTSA addresses the problem of alcohol involvement in pedestrian impacts. Approximately 2,500 adult pedestrians killed in crashes each year since 1980 were intoxicated. The purpose of the ongoing research is to devise, develop, and test a set of countermeasures which a community can use to reduce alcohol-related pedestrian impacts. The researchers will work in cooperation with a Community Traffic Safety Program (CTSP) in satisfying the goals of the project which focus on the production of a program manual and countermeasure materials that can serve as a guideline for other communities in designing and implementing a pedestrian alcohol countermeasure program.

FHWA and NHTSA are jointly developing a pedestrian and bicyclist safety training course for all levels of government personnel and public interest groups. The course is designed to increase awareness of these safety problems and provide countermeasure and design information.

Congress has requested a report on how the Department of Transportation can best fulfill its stated policies relating to bicycling and walking. While having several objectives, a major thrust of the Bicycling and Walking Study is to develop plans that promote bicycling and walking as alternate transportation modes while enhancing their safety. Responsibility for the study was assigned to FHWA. NHTSA, however, is cooperating in the study.

3.4 Current Operational Programs

Transferring pedestrian safety technology to the States and communities remains a program priority. Although some success in reducing pedestrian-vehicle impacts can be attributed to past technology transfer activities, more can be done. The following paragraphs describe current pedestrian safety operational programs.

Willy Whistle

"Willy Whistle" pedestrian safety materials have proved to be highly effective in reducing pedestrian traffic injuries and fatalities among children 5-12 years of age. Separate field tests of the materials by NHTSA and by the Insurance Institute for Highway Safety [52] showed impact reductions of approximately 20 percent. The materials consist of a two-part video tape designed for use in school systems. "Stop and Look With Willy Whistle," the first part of the video, teaches basic pedestrian skills to five through eight year olds, with an emphasis on the look-left-right-left sequence of safe street crossing. It is directed specifically at reducing dart-out situations, the most prevalent type for this age group. The second part of the tape, "Walking With Your Eyes," builds on the first program by teaching older children (ages 9-12) advanced pedestrian skills so that they can cross safely in more complex traffic situations. The tape programs are supported by a teacher's guide, information for the parents, and two public service announcements (tapes for television).

Walk Alert

Walk Alert is a national pedestrian safety program developed by FHWA with materials and financial input from NHTSA, and materials contributions from over 100 service organizations and many community groups. It is a comprehensive program addressing pedestrian safety by using the three "E's" of Education, Engineering, and Enforcement. Walk Alert was specifically designed for safety volunteers, concerned citizens, grass roots service organizations, and city and county governments.

Demonstration Community Pedestrian Grants

In 1990, NHTSA and FHWA developed a joint demonstration grant program to address pedestrian safety problems throughout the country. A total of twelve $30,000 grants were competitively awarded in 1990-1991 for the purpose of establishing pedestrian safety demonstrations in various locations across the Nation. These grants were implemented to demonstrate that a community can take preventive action against pedestrian fatalities and injuries by generating community activism to implement law enforcement, education, and engineering countermeasures. These activities represent a balanced approach in preventive measures to address pedestrian safety problems. NHTSA and FHWA believe that with the diversity of the demonstration sites, other localities will be able to identify with at least one of the sites and gain knowledge on how they can address their own pedestrian issues.

Walking in Traffic Safely

A study [53] was undertaken by NHTSA to develop a traffic safety program that could reduce the occurrence of pedestrian impacts for preschoolers (ages 1-4 years). After an analysis of thousands of preschooler impact reports, a set of safety education materials was developed for preschool educators and parents. The Headstart program of the Department of Health and Human Services was the first to use this product and, more recently, the National Association for the Education of Young Children has adopted the curriculum.

Pedestrian Safety Resource Kits

NHTSA and FHWA have developed a pedestrian safety resource kit containing selected printed and audiovisual materials providing information on pedestrian safety issues and problems, and practical solutions. Over 175 kits were distributed to Federal, State and local traffic safety agencies, enabling these personnel to become familiar with key pedestrian safety concepts. Additional kits are planned for distribution on a wider scale.

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