Initiatives to Address the Mitigation of Vehicle Rollover

National Highway Traffic Safety Administration

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I. Introduction

The mission of the National Highway Traffic Safety Administration (NHTSA) is to save lives, prevent injuries and reduce traffic-related health care and other economic costs. The agency develops, promotes and implements effective educational, engineering, and enforcement programs aimed at ending preventable tragedies and reducing the economic costs associated with motor vehicle use and highway travel.

As an integral part of the U.S. Department of Transportation (DOT), the agency improves public health and enhances the quality of transportation by helping to make highway travel safer. A multi-disciplinary approach is used that draws upon diverse fields such as epidemiology, engineering, biomechanics, the social sciences, human factors, economics, education, law enforcement and communication science to address one of the most complex and challenging public health problems facing our society.

NHTSA is the national and international leader in collecting and analyzing motor vehicle crash data, and in developing countermeasures relevant to preventing and mitigating vehicle crashes, thereby reducing and preventing resulting fatalities and traumatic injury. The agency regulates motor vehicle and original equipment manufacturers through its safety standards program; provides national and international leadership in understanding and assessing the safety impact of advanced technologies; sponsors critical research; spurs progress in harmonizing international safety standards; and conducts innovative projects to improve traffic and motor vehicle safety. All aspects of engineering, education, enforcement and evaluation are incorporated into programs to address the challenges of crash and injury prevention involving people, vehicles, and the roadway environment.

The following report presents an in-depth look at one of the most significant safety issues impacting highway safety and the success of NHTSA's mission – vehicle rollover. This document describes the safety problem represented by vehicle rollover and provides strategies the agency plans to pursue to reduce the likelihood of rollover crash events and to improve crashworthiness in such crashes, thereby saving lives and reducing serious injuries. In addition to the full agenda of highway safety issues, impaired driving, vehicle compatibility and safety belt use are the other priority issues set by NHTSA to reduce the occurrence and consequences of motor vehicle fatalities and injuries. The agency is offering the public the opportunity to comment on each of the four documents, which can be found at future dates on NHTSA's Web site at http://www.nhtsa.dot.gov/people/iptreports.html and also in DOT's docket management system (DMS) at http://dms.dot.gov/. The docket numbers for each of the respective reports are as follows:

- Safety Belt Use NHTSA-2003-14620;
- Impaired Driving NHTSA-2003-14621;
- Rollover Mitigation NHTSA-2003-14622; and,
- Vehicle Compatibility NHTSA-2003-14623.

II. Highway Safety Overview

Despite significant gains since the enactment of Federal motor vehicle and highway safety legislation in the mid 1960's, the annual toll of traffic crashes remains tragically high. In 2001, 42,116 people were killed on the Nation's highways and an additional 3.03 million people suffered serious injuries. Motor vehicle crashes are the leading cause of death and disability for Americans between the ages of 2 and 33.

Traffic crashes are not only a grave public health problem for our Nation, but also a significant economic burden. Traffic crashes cost our economy approximately $230 billion in 2000, or 2.3 percent of the U.S. Gross Domestic Product. This translates to an annual average of $820 for every person living in the United States. Included in this figure is $81 billion in lost productivity, $32.6 billion in medical expenses, and $59 billion in property damage. The average cost for a critically injured survivor of a motor vehicle crash is estimated at $1.1 million over a lifetime. This figure does not even begin to reflect the physical and psychological suffering of the victims and their families.

III. Integrated Project Team Formation

In September 2002, NHTSA formed four integrated project teams (IPTs) to conduct an in-depth review of four priority areas:

- Safety Belt Use,
- Impaired Driving,
- Rollover Mitigation; and
- Vehicle Compatibility.

These teams were chartered to support the agency's strategic planning work by using comprehensive, science and evidence-based analyses to identify innovative solutions and recommend effective strategies in their respective issue areas. The Federal Highway Administration (FHWA), another DOT agency, who has lead responsibility along with State highway agencies for initiatives relating to roadway and roadside hardware improvements, had representatives on the rollover mitigation and vehicle compatibility teams.

Teams were encouraged to be innovative in their thinking and novel in their approaches. The resulting proposals covered a wide range of possible solutions, from what could be accomplished through changing driver behavior, to vehicle modifications and roadway improvements. Recommended strategies were based on science, data and other available evidence. The teams also attempted to estimate the possible benefits and costs associated with implementing various strategies.

Each team began by conducting a problem identification analysis – researching and analyzing crash data in the problem area (e.g., number of injuries and fatalities associated with each issue). The purpose of the problem identification was to accurately describe the safety problem in enough depth to provide structure and underpinning to various potential strategies.

The teams then organized and linked the array of possible strategies to their potential safety impacts. This included estimating the benefits and timeframe for implementation, discussing risks and uncertainties, and identifying constraints.

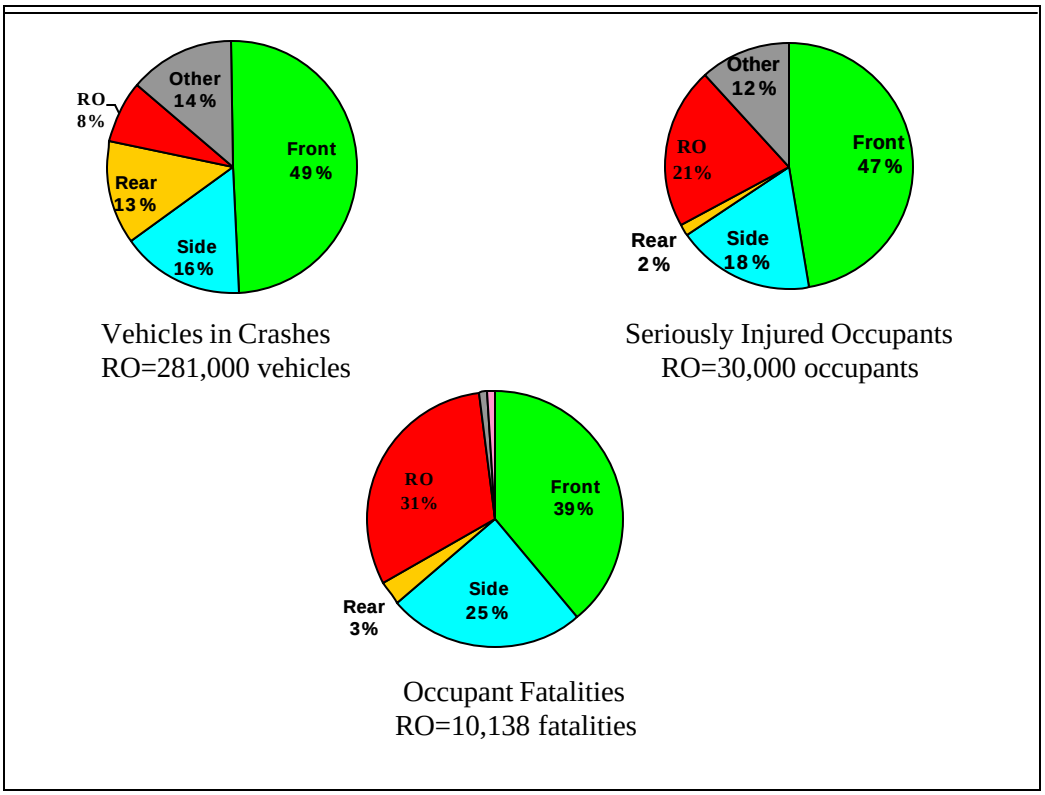
In February 2003, NHTSA senior management officials evaluated the IPT strategies to determine which strategies the agency should pursue. The recommended strategies presented here are not simply a list of activities but relate in a strategic and interdependent manner and, if implemented effectively, will lead to improved safety performance. Each of the four priorities – safety belt use, impaired driving, rollover mitigation and vehicle compatibility – is addressed in a separate document. This document reflects the agency's plan for rollover mitigation strategies.

IV. General Problem Identification for Rollover Mitigation

Rollover crashes are complex events that reflect the interaction of driver, road, vehicle, and environmental factors. A rollover is a crash in which a vehicle revolves at least one-quarter turn (which would be onto its side), regardless of whether the vehicle ends up laying on its side, roof, or even returning upright on all four wheels. Rollovers occur in a multitude of ways. Most rollovers are "tripped," that is the vehicle rolls over after leaving the roadway striking a curb, soft shoulder, guard rail or other object that "trips" it. A small percentage of rollover events are "untripped" (e.g., tire and/or road interface friction).

Rollover crashes are dangerous events. Eight percent of light vehicles (passenger cars, pickups, vans, and sport utility vehicles (SUVs)) in crashes roll over, yet 21 percent of seriously injured occupants and 31 percent of occupant fatalities occur in rollovers **(see Figure 1)**. According to the 2001 Fatality Analysis Reporting System (FARS), a census of all crashes involving a motor vehicle on a public roadway that resulted in at least one fatality within 30 days of the incident, 10,138 people were killed as occupants of light vehicles in rollover crashes. Of those, 8,407 were killed in single-vehicle rollover crashes. Seventy-eight percent of the people who died in single-vehicle rollover crashes were not wearing the vehicle safety belt, and 64 percent were partially or completely ejected from the vehicle (including 53 percent who were completely ejected).

FIGURE 1: All Crashes (RO=Rollover)

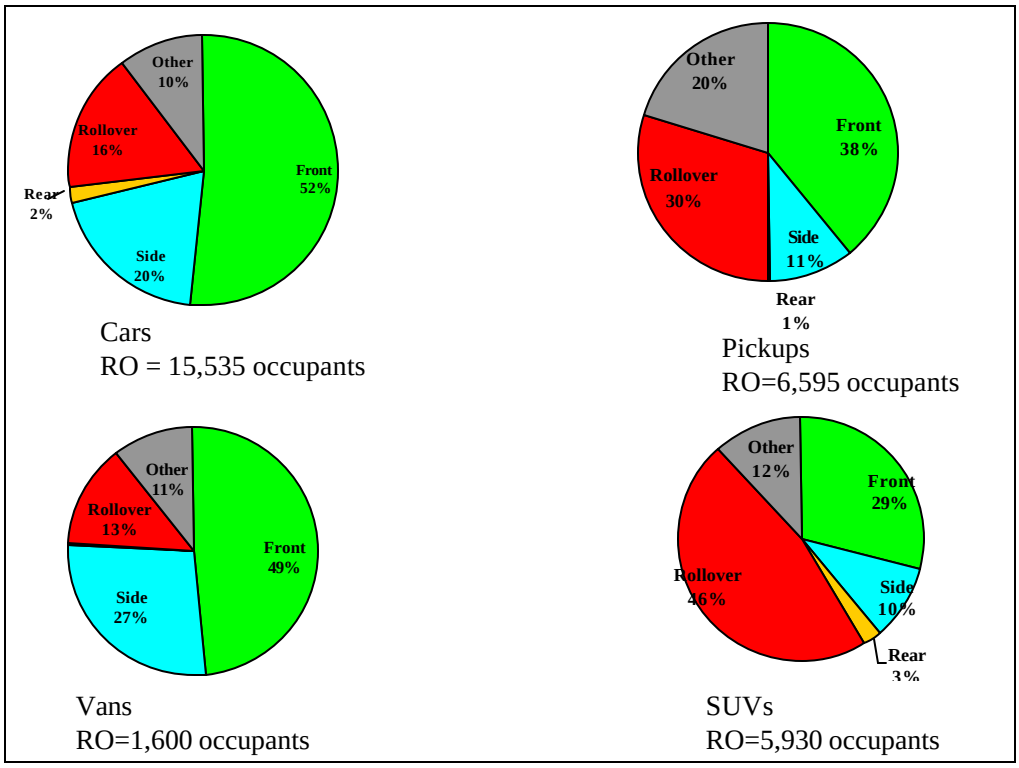


Source: 1997-2001 NASS-CDS, 2001 FARS

Using data from the 1997-2001 National Automotive Sampling System (NASS) Crashworthiness Data System (CDS), an automated, comprehensive national traffic crash database, NHTSA estimates that 281,000 light vehicles are towed from police-reported rollover crashes each year (on average), and that 30,000 occupants of these vehicles are seriously injured, defined as an Abbreviated Injury Scale (AIS) rating of at least AIS 3. AIS is a scale (from 1 to 6) used to rate the severity of injuries based on their threat to life. AIS 1 are minor injuries (e.g., a simple cut or bruise), while AIS 6 injuries almost always result in death. Estimates from NASS CDS indicate that 80 percent of towaway rollovers were single-vehicle crashes, and that 83 percent (168,000) of the single-vehicle rollover crashes occurred after the vehicle left the roadway. An audit of NASS CDS data showed that about 95 percent of rollovers in single-vehicle crashes were tripped by mechanisms such as curbs, soft soil, pot holes, guard rails, and wheel rims digging into the pavement, rather than an "untripped" rollover event (e.g., tire and/or road interface friction).

Figure 2 shows the number of seriously injured, non-fatal occupants (AIS of 3 or greater) in rollover crashes, broken down by vehicle type. Passenger car injuries make up slightly more than half of all serious injuries in light vehicles involved in a rollover, primarily because they are the most prevalent type of light vehicle. The figure also shows the distribution of injuries by type of impact. Rollovers account for 13 to 16 percent of the occupant injuries in vans and cars, but account for a much higher proportion in pickup trucks (30 percent) and SUVs (46 percent).

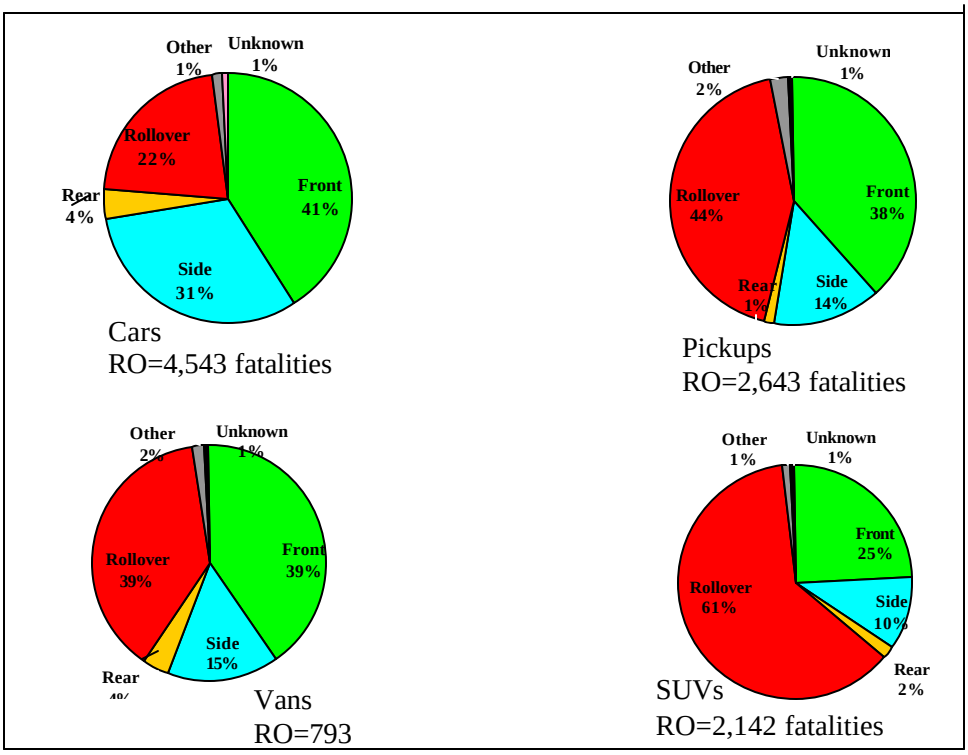
FIGURE 2: Seriously Injured Non-Fatal Rollover Occupants by Vehicle Type



Source: Average Annual Estimate NASS-CDS 1997-2001

The risk of rollover is greater for vehicles with a high center of gravity in relation to the track width. **Figure 3** shows the number of fatally injured occupants in rollover crashes broken down by vehicle type. Passenger car fatalities account for 45 percent of all light vehicle occupant fatalities involved in a rollover. The figure also shows the distribution of fatalities by type of impact. Rollovers account for 22 percent of passenger car fatalities, 39 percent of van fatalities, 44 percent of pickup fatalities, and 61 percent of SUV fatalities. As shown in **Figures 2 and 3**, rollovers in SUVs are the leading cause of severe injury and death to their occupants. Likewise, rollovers are the leading cause of death to pickup truck occupants.

FIGURE 3: Rollover Occupant Fatalities by Vehicle Type



Source: FARS 2001

Estimates from the NASS General Estimates System (GES), 1997-2001, a nationally representative sample of police reported motor vehicle crashes of all types, from minor to fatal, indicate that 1.7 percent of cars, 2.0 percent of vans, 3.8 percent of pickup trucks and 5.5 percent of SUVs were involved in crashes where the vehicle rolled over. Pickup trucks and SUVs have the highest frequency of rollover among the four major classes of light motor vehicles.

Factors that strongly relate to rollover fatalities are: a single vehicle crash (83%), a rural crash location (60%), a high-speed (55 mph or higher) road (72%), nighttime (66%), off-road tripping/tipping mechanism (60%), young (under 30 years old) driver (46%), male driver (73%), alcohol-related (40%), speed-related (40%), unbelted (72%), and/or ejected (64%).

Safety belts are the most effective crashworthiness countermeasure in reducing fatalities resulting from rollovers due to the mitigation of ejection. Based on a NHTSA study of 1986-99 FARS data[1], safety belts reduce fatalities in rollovers by 74 percent in passenger cars and 80 percent for light trucks. A separate IPT was formed to address the issue of increasing safety belt use.[2]

V. PROPOSED INITIATIVES

The initiatives that NHTSA plans to pursue in addressing vehicle rollover are described in this section. The proposed initiatives fall into four main categories: vehicle strategies (crash avoidance and crashworthiness), roadway strategies, behavioral strategies and other initiatives. Under each, the agency has identified a number of approaches of what vehicle and roadway designs as well as driver actions lead to rollover, and what countermeasures would be appropriate to assist in the mitigation of the rollover problem.

A) VEHICLE STRATEGIES

CRASH AVOIDANCE

Improved handling and stability and reform of the Corporate Average Fuel Economy (CAFE) program are the crash avoidance vehicle initiatives the agency is pursuing. They are described in this section.

1) HANDLING AND STABILITY

Handling and stability refers to how well a vehicle stays in contact with the road and remains in the travel lane during ordinary driving maneuvers. Good handling and yaw stability (the vehicle's ability to stay pointed in the direction the driver intended) can reduce the number of "loss of control" crashes that often lead to rollover by assisting the driver in maintaining control of the vehicle. Most rollovers occur when a vehicle runs-off-the-road (ROR) and strikes a curb, soft shoulder, guardrail or other object that "trips" it.

In 2003, NHTSA will implement a combined rating system for rollover resistance using both static and dynamic test data beginning with model year (MY) 2004 vehicles. Static test data refers to the Static Stability Factor (SSF). This is a measurement of the height of the center of gravity divided by one-half of the track width of the vehicle. Static test data are measured while the vehicle is standing still (statically). Dynamic test data is a test of the vehicle in motion, e.g., how well the vehicle does in a particular driving maneuver. The rollover resistance ratings estimate the risk of rollover in the event of a single vehicle crash.

Electronic Stability Control (ESC) (which is offered by several manufacturers under various trade names) is a technology designed to assist drivers in maintaining control of their vehicles during extreme steering maneuvers. ESC senses when a vehicle is starting to spin out (oversteer) or plow out (understeer), and it helps to turn the vehicle to the appropriate heading by automatically applying the brake at one or more wheels (ESC takes over the brakes and may affect the throttle, but not the steering). Some systems also automatically slow the vehicle with further brake and throttle intervention. Slowing the vehicle not only directly reduces the likelihood of a rollover, but also improves the controllability of the vehicle, thereby reducing the likelihood of having a single vehicle crash in the first place.

However, ESC cannot keep a vehicle on the road if its speed is simply too great for the available traction, during some attempted driver maneuvers, or if road departure is a result of driver inattention. In these cases, the installation of roadway departure crash warning systems could assist. A roadway departure crash warning system can consist of two

subsystems. One subsystem (lateral road departure crash warning system) gathers information about road geometry and vehicle position and warns the driver if the vehicle's path is leading to a ROR crash. The second subsystem (longitudinal road departure crash warning system) gathers information about the curvature of the road ahead and current vehicle speed and warns the driver if the vehicle's speed is excessive for upcoming curves. (The warning for the driver could be visual, audible, or a combination of both. It could even be more invasive; e.g., the steering rim could shake or the brakes could be applied for a short time.)

a) Highlights of Current Program

The agency is currently developing a dynamic rollover test to meet the Transportation Recall Enhancement, Accountability, and Documentation (TREAD) Act requirements. A request for comment was issued in the October 7, 2002, rollover rating Notice of Proposed Rulemaking (NPRM). NHTSA is currently evaluating the comments to determine if the proposed concept has merit.

As part of its Dynamic Rollover Test Development research, NHTSA has performed a very limited amount of research on ESC systems. These efforts found substantial system-to-system differences in the performance of various ESC systems.

Agency efforts on roadway departure warning systems consist of research to provide a better understanding of the conditions that lead to ROR crashes. Past and present efforts include:

- University of Michigan Transportation Research Institute, Road-Departure Countermeasures Field Operational Test, to be completed in 2005;
- National Institute of Science and Technology, Objective Tests for Road-Departure Crash Countermeasures, to be completed in 2004; and,
- Carnegie-Mellon University, ROR Collision Avoidance Countermeasures using Intelligent Vehicle Highway System (IVHS) Countermeasures, completed in 1999.

b) Proposed Initiatives

NHTSA will complete the necessary research to evaluate the feasibility of a test protocol and proposed rating system for a consumer information program on handling. After the research is completed, NHTSA will decide whether it is appropriate and reasonable to proceed with a handling rating system.

NHTSA will continue its research and development work on ESC systems to:

- Determine which current ESC systems achieve the highest safety benefits and are most effective. As noted above, there are substantial differences in the performance of existing ESC systems.

- Perform human factors studies, both on test tracks and with the National Advanced Driving Simulator (NADS), to determine how drivers interact and respond to vehicles equipped with ESC systems.

- Perform a real world evaluation study into the effectiveness of current ESC systems in the prevention of roadway departure and rollover crashes.

Following successful completion of the above research and development, NHTSA will decide on the appropriate next steps, including possible rulemaking actions.

In addition, NHTSA's development of performance specifications and objective tests for systems that warn drivers of impending roadway departure will facilitate the development of effective roadway departure warning systems, which will, in turn, determine whether or not there is a sufficient basis to initiate a rulemaking effort in this area.

c) Expected Program Outcomes

The main goal of NHTSA's handling and stability initiatives is to help prevent roadway departure. Improved handling could potentially reduce the magnitude of tripped rollover crashes in which the vehicle leaves the roadway. Publishing handling ratings based on vehicle handling tests could encourage vehicle manufacturers to offer yaw stability control/ESC systems, and other advanced technologies to improve handling and reduce the number of roadway departure crashes.

2) Reform CAFE

In addition to implementing programs in support of its critical safety mission, NHTSA also has responsibility for the Corporate Average Fuel Economy (CAFE) program. The current structure of the CAFE system can provide an incentive to manufacturers to downweight vehicles, increase production of vehicle classes that are more susceptible to rollover crashes, and produce a less homogenous fleet mix. As a result, CAFE is critical to the vehicle compatibility and rollover problems.

a) Highlights of Current Program

In its final rule setting new CAFE standards for MY 2005-2007 light trucks,[3] NHTSA stated that it intends to examine possible reforms to the CAFE system, including those recommended in the National Academy of Sciences' CAFE report.[4]

b) Proposed Initiatives

Consistent with its statutory authority, the agency plans to address issues relating to the structure, operation and effects of potential changes to the CAFE system and CAFE standards. In taking this broad view, the agency recognizes that the regulation of the fuel economy can have substantial effects on vehicle safety, the composition of the light vehicle fleet, the economic well-being of the automobile industry and, of course, our nation's energy security.

c) Expected Program Outcomes

It is NHTSA's goal to identify and implement reforms to the CAFE system that will facilitate improvements in fuel economy without compromising motor vehicle safety or American jobs. In 2003, NHTSA will issue an Advance Notice of Proposed Rulemaking (ANPRM) seeking comment on alternative approaches for reforming the structure of the CAFE program.

As NHTSA is, first and foremost, a safety agency, one of its core priorities will be to closely examine the safety consequences arising from the present composition of the light vehicle fleet. Armed with that information, NHTSA intends to examine the safety impacts, both positive and negative, that may result from any modifications to CAFE as it now exists. Regardless of the root causes, it is clear that the downsizing of vehicles that occurred during the first decade of the CAFE program had serious safety consequences. Changes to the existing system are likely to have equally significant impacts. NHTSA is determined to ensure that these impacts are positive.

CRASHWORTHINESS

Ejection mitigation and roof crush are two major rollover crashworthiness vehicle initiatives that the agency is pursuing, and are described in this section.

1) EJECTION MITIGATION

Studies have shown that the fatality rate for an ejected vehicle occupant is three times as great as that for an occupant who remains inside of the vehicle. Consequently, reducing ejections offers the potential for significant safety gains. The best way to reduce ejection is for occupants to wear their safety belts. However, of the 5,400 ejected fatalities through front side windows, 2,200 are from partial ejections. Fatal injuries from partial ejection can occur even to belted occupants, when their head protrudes outside the window and strikes the ground in a rollover or even the striking vehicle prior to the rollover.

Door latch integrity is also a significant contributor to vehicle occupant ejection in rollover crashes. Every year, 1,660 fatalities and 1,970 seriously injured occupants are ejected through a door and 535 fatalities and 1,200 serious injuries occur in rollover crashes. About two-thirds of all door openings in these crashes involved structural damage to the latch and/or striker (the metal plate attached to the door pillar where the latch enters, securing the door). Faced with these circumstances, safety belt use is the best defense, when a crash occurs.

All vehicles manufactured after 1968 have safety belts as standard equipment. Safety belt use cuts the risk of death in a crash (including rollover crashes) – 60 percent for occupants of light trucks and vans and by 45 percent for occupants of passenger cars. In 2002, the 25 percent of vehicle occupants who failed to buckle up amounted to 6,800 preventable deaths and 170,000 preventable injuries, resulting in $18 billion in medical costs, lost productivity, and other injury-related expenses. Increasing safety belt use is one of NHTSA's highest priorities.

The Motor Vehicle Occupant Safety Survey (MVOSS), a national telephone survey conducted every two years to monitor the public's attitudes about safety belts, child restraints, reasons for their use or non-use, knowledge of safety belt laws, experience with law enforcement, and attitudes about risk perception, indicates that 20-25 percent of nonusers are part-time users. Twenty-six percent of part-time users and 11 percent of hard-core nonusers cite "forgot to put it on" as the most common reason for nonuse; and just over 50 percent of part-time belt users and a third of rear seat occupants and "hard-core" nonusers cite "forgetting" as one of several reasons they do not wear their safety belts.

Safety belt reminders are continuous or intermittent electronic visual and/or audible signals that are tied into a safety belt buckle or safety belt extraction detection system that activate unless the safety belt is buckled. Enhanced safety belt reminder systems signal beyond the eight-second period when the driver's safety belt remains unbuckled (e.g., the Ford BeltMinder™ system is intermittent, illuminating a warning light and sound for 6 seconds, and repeats itself every 30 seconds for 5 minutes or until the driver's safety belt is fastened).

a) Highlights of Current Program

In mitigating ejection, the agency has worked for several years on advanced glazing (an automotive industry term for transparent glass or plastic areas of vehicle bodies), and is currently working on a side impact pole test to evaluate window curtains (side air bag curtains that drop down from the roof line above the door frame to protect occupants from intrusion, splintering glass and window ejection). Motor vehicles with a side window curtain could reduce ejection through the front and rear side windows. Window curtains can provide a double benefit by reducing upper interior head injuries, as well as ejection.

The agency has conducted considerable research to improve door latch integrity, but the primary challenge has been demonstrating a link between performance in the laboratory tests and performance in the real world. Latches fail for several different reasons (e.g., structural failure – broken parts, latch activation (door opens after lock releases during a crash event), or disengagement of the latch), but the crash data are not broken down in a manner that allows an analysis of exactly how a latch failure occurred. Currently, FMVSS No. 206, Door Locks and Door Retention Components, requires latches and strikers to sustain a longitudinal tension load of 11,100 N (force) and a lateral tension load of 8,900 N.

In addition to research, the agency is working with its international partners under the United Nations World Forum for Harmonization Vehicle Regulations 1998 Agreement to develop a harmonized global technical regulation on door lock and door retention systems. This work will provide an opportunity to consider door latch and door retention safety concerns as well as the best available worldwide technological development and regulatory approaches.

Another vehicle solution that could reduce ejection, whether through a vehicle's window or a door, would be the installation of enhanced safety belt reminders.

Currently, Federal Motor Vehicle Safety Standard (FMVSS) No. 208, Occupant Crash Protection, requires installation of a four-to-eight second long signal immediately following the key being turned to the ignition position or the start of the engine if the driver's safety belt is not buckled. In 2002 and again in 2003, NHTSA sent a letter to all the major vehicle manufacturers encouraging the installation of enhanced safety belt reminder systems, which repeat beyond the eight-second requirement. NHTSA also requested information on their intentions to install such systems, what type of technologies they intended to use, the approximate time frame for installation and any customer feedback on their systems that they would be willing to share with the agency. The agency also recently took steps to ensure that companies could use the same safety belt reminder systems used for the European markets in the United States.

Additionally, NHTSA has prepared a detailed report from focus groups and one-on-one in-depth interviews as part of the National Academy of Science's (NAS) study on determining consumer acceptance of different safety belt reminder technologies. NHTSA's report has been delivered to NAS, which is currently preparing its final report.

NHTSA has also been examining ejection potential by using a Dynamic Rollover Fixture, which can simulate rollover conditions and evaluate occupant kinematics, injury mechanisms, and evaluate the performance of restraint systems and ejection countermeasures.

b) Proposed Initiatives

The agency will soon complete its research on ejection mitigation. This will include evaluations of the linear impactor test to ensure it is repeatable and accurately discriminates ejection potential. A linear impactor is a device that has an instrumented test metal head form at the end of it. This device is propelled linearly at a potential countermeasure such as an inflatable window curtain and/or an advanced glazed window. The impactor can measure how far the head form traveled and it can measure acceleration. The agency will also evaluate different approaches for assessing rollover sensor performance for window curtains. Upon completion of this research, NHTSA will decide on the appropriate next steps, including possible rulemaking actions.

On the issue of door latch integrity, the agency is working on an NPRM to upgrade FMVSS No. 206.

In addition, NHTSA will continue to encourage automobile manufacturers to voluntarily install enhanced safety belt reminder systems on all vehicles. NHTSA will add a safety belt reminder element to the New Car Assessment Program (NCAP) so that consumers can easily identify which vehicles are equipped with these devices.

The agency is working on an NPRM for FMVSS 214, Side Impact Protection that would introduce a pole test. One of the leading countermeasures to meet a pole test is an air bag window curtain. While the pole test would have no ejection mitigation

requirements, the window curtain can be further developed to provide for ejection mitigation.

c) Expected Program Outcomes

NHTSA hopes to significantly reduce the potential for partial and complete ejection fatalities and injuries. By having window curtains and/or advanced glazing requirements the potential for ejection through windows could be reduced, and better door locks/latches could also effectively reduce ejection through vehicle doors.

The agency believes increased safety belt use alone would have a significant impact on the nation's fatality and injury numbers. Safety belt use reduces the opportunity for ejection, which many times is the main harmful event following a crash. Automobile manufacturers have responded positively to the agency's encouragement by increasingly incorporating safety belt reminder systems in their new vehicle models, principally in concert with their implementation of the advanced air bag rule. Preliminary data on public acceptance of such systems has also been positive. Based on a study conducted by the Insurance Institute for Highway Safety and Ford Motor Company in 2001, safety belt use increased 5 percentage points (equal to a 17 percent conversion rate) among drivers in vehicles equipped with the Ford BeltMinder™ system.

2) ROOF CRUSH

During rollover crashes, all occupants, even those who are belted, can sustain head or neck injuries when their upside down body weight places forces on the neck when their head hits the roof, particularly when the roof is in contact with the ground. This is true even in the absence of a significant amount of roof crush. On average, 6,500 persons annually have at least one serious injury due to roof contact where some amount of roof intrusion is present. Over half (3,450) of these injured persons were belted. When an occupant receives a significant injury from contact with roof structures, it is generally not clear if the crash forces propelled the occupant out of the seat and upwards to contact the roof, or if the roof contacted the occupant who remained restrained and did not move very much in the seat.

a) Highlights of Current Program

Currently, FMVSS No. 216, Roof Crush Resistance, requires that a passenger car roof withstand a load of 1.5 times the vehicle's unloaded weight, up to a maximum of 22,240 N (force), or 5,000 pounds, whichever is less, to either side of the forward edge of the vehicle's roof with no more than 125 mm (5 inches) of crush. The same standard applies to light trucks and vans with a gross vehicle weight rating (GVWR) of 2,722 kg or less (6,000 lbs) without the 22,240 N force limit. A request for comment on possible changes to FMVSS No. 216 was published in the *Federal Register* on October 22, 2001.

NHTSA has also looked to the improvement of vehicle safety belts in contributing to the issue of injuries due to contact with the roof. Current safety belts have the potential to allow significant body motion during some rollovers. The agency has conducted one

test on a pretensioner with an inflatable tubular belt in a rollover fixture to determine how well the belt holds the anthropomorphic test dummy in its seat. (A pretensioner uses the air bag sensors to determine when to deploy. It is designed to pull the slack out of a safety belt before the occupant "loads" it. Upon impact, a lock-up retractor would be designed to lock up the belt and not let it release from its locked position until some time after the crash sequence is over, thereby reducing head excursion.)

b) Proposed Initiatives

NHTSA plans to propose an upgrade of its roof crush standard to require roofs to allow less crush during a rollover event. One possible upgrade is to increase the load used during its testing. The agency is evaluating different angles of the loading plate for the FMVSS No. 216 test to determine whether they may make a difference in roof crush pattern. The load plate test involves loading the roof structure of a vehicle with a flat plate and measuring force-deflection characteristics of the roof. The agency will also consider whether to apply the standard to light vehicles above 6,000 pounds GVWR.

In addition, NHTSA will conduct testing to examine countermeasures to keep occupants better secured to the seat in the event of a rollover. NHTSA will investigate the effectiveness of integrated belts (standard three-point shoulder and lap belts), pretensioners, four-point belts (integrated safety belt with secondary straps sewn close to the front buckle to act as a tether which keeps the safety belt from riding up or twisting) and inflatable tubular belts.

c) Expected Program Outcomes

The main objective of NHTSA's roof crush and safety belt effectiveness initiatives is to make vehicles safer during rollover crashes. The agency's efforts will work to make more effective safety belts and stronger vehicle roofs to better protect vehicle occupants during a rollover event.

B) ROADWAY STRATEGIES

FHWA has lead responsibility along with State highway agencies for rollover initiatives relating to roadside improvements. According to the FHWA's *1998 National Strategic Plan*, roadside crashes cost society $80 billion each year. This is more than three times the annual amount spent by Federal, state, and local government agencies to maintain and operate our Nation's roads.

1) ROADWAY AND ROADSIDE IMPROVEMENTS

Estimates from NASS CDS indicate 83 percent of the single-vehicle rollovers occurred after the vehicle left the roadway. Roadway/roadside features tripped 95 percent of rollovers in single-vehicle crashes. Vehicles that leave the roadway may encounter objects or terrain features that will influence whether a rollover occurs or not. There are two approaches that FHWA and highway agencies use in reducing the consequences of rollover crashes. They are a) keeping a vehicle on the roadway and b) minimizing the harm to a vehicle/driver if it/they leave the road.

Overall, the best way to reduce rollover crashes is to keep vehicles on the roadway and in the intended lane, where drivers will have the best chance to control their vehicles. Several studies have shown that the installation of shoulder rumble strips significantly reduce ROR crashes caused by driver inattention. By alerting a drowsy or inattentive driver that he or she is drifting from the travel lane, corrective action can often be taken before the vehicle leaves the paved portion of the road. Centerline rumble strips are also being studied that warn drivers when they are drifting into an opposing traffic lane. This type of rumble strip will reduce vehicle-to-vehicle impacts. Rumble strips are inexpensive and detectable by all types of vehicles. Currently, it is estimated that rumble strips have been installed on at least 30 percent of U.S. rural freeways.

On two-lane rural highways, the total roadway width (lanes and shoulders) influences crash frequency. Studies have shown that ROR crash rates decrease as the shoulder width is increased (with the safety effectiveness related to the accompanying lane width).

In addition to preventive measures, such as those mentioned above, an effective strategy dictates provisions to minimize the consequences when a driver runs off the road. For instance, the quality of the roadside (slope, clear zone) in combination with the roadway influences both severity and frequency of crashes. Mitigation measures for narrow lanes on rural roads may thus include wider shoulders and improved roadsides. Additionally, fixed objects located on the roadside such as turned-down guardrail ends, trees, or utility poles may cause rollover.

Regardless of roadway width, shoulders should be flush with the roadway surface and sufficiently stable to support vehicular use in all kinds of weather without rutting (a roadway rut deep enough to trip a vehicle, usually on the shoulder of the road). Research is beginning to suggest that pavement edge drop-offs are a significant contributor to loss of control and ROR rollover crashes on rural highways. A safety edge, a sloping end to the pavement, can eliminate many over-correction and scrubbing crashes. Scrubbing may occur when there is a lip (3 or more inches high if the edge is vertical) between the edge of the road and the shoulder of the road. This high pavement edge creates a "scrubbing condition" that must be overcome through oversteering. As drivers oversteer to reenter the roadway, they are prone to lose control of the vehicle. Compounding the danger, the rear wheel may catch the edge of the shoulder, swinging the car around. These actions may cause the car to veer into the adjacent lane, where it may overturn or ROR and rollover.

a) Highlights of Current Program

FHWA is engaged in a "Vital Few Goals" program in which reducing road departure fatalities and injuries by 10% is one of the three safety goals. Since the most frequent "most harmful event" in ROR crashes is a rollover, FHWA is also dedicated to reducing the number of rollover crashes.

FHWA has been involved with the State Departments of Transportation in their development and implementation of the American Association of State Highway and Transportation Officials (AASHTO) Strategic Highway Safety Plan. The Plan identified 22 goals to be pursued to achieve a significant reduction in highway crash

fatalities. Two of the goals, 15 and 16 align with the approach that FHWA is engaged in to reduce rollover fatalities through infrastructure (roadway and roadside) improvements. These are "Keeping Vehicles on the Roadway "and "Minimizing the Consequences of Leaving the Road." These also align with NHTSA's focus on crash avoidance and crashworthiness.

In reducing roadway departure crashes, FHWA issued a Technical Advisory containing improved information on shoulder rumble strip design and installation for rural National Highway System segments. Mississippi installed and tested different rumble strip designs combined with pavement marking overlays on rural roads. Initial evaluations from this test indicated improved safety results on rainy nights from the more-visible markings and audible rumble strip warnings.

FHWA released the Interactive Highway Safety Design Model (IHSDM), a suite of software analysis tools for explicit, quantitative evaluation of safety and operational effects of geometric design on two-lane rural highways. IHSDM provides estimates of the effect of lane and shoulder width, as well as other roadway geometry, on expected crash frequency. IHSDM results support decision-making throughout the highway geometric design process. The goal is to yield safer roads through better design.

b) Proposed Initiatives

Keeping Vehicles on the Roadway

FHWA plans to develop guidance/requirements to ensure adequate retroreflectivity for pavement markings and signs. It will foster the development and implementation of different rumble strip designs combined with pavement marking overlays on rural roads. Initial evaluations from tests indicate improved safety results on rainy nights from the more-visible markings and audible rumble strip warnings.

In addition, FHWA hopes to increase the number of States using the IHSDM for two-lane road safety assessments.

Minimizing the Consequences of Leaving the Road

State highway offices will provide traversable roadsides to reduce tripping mechanisms. FHWA will continue to urge highway agencies to upgrade obsolete roadside hardware that may cause a rollover. In addition, FHWA along with the highway agencies will investigate the need to update guidelines for slopes and ditches that will safely and cost-effectively accommodate light trucks. Likewise, both will work to develop and implement programs to provide /pavement/shoulder treatments such as the "safety edge" during pavement resurfacing projects and maintenance.

c) Expected Program Outcomes

FHWA hopes to successfully urge highway agencies to identify changes in roadside and roadway infrastructure to: 1) enhance the ability of drivers to remain on the roadway, 2) minimize the consequences of leaving the road by providing a recoverable zone, relocating or making breakaway fixed objects, or shielding the obstacle with a barrier.

These actions will help to reduce rollover occurrences and subsequent vehicle occupant harm.

C) BEHAVIORAL STRATEGIES

1) CONSUMER INFORMATION PROGRAM

Preliminary evidence[5] suggests that consumers are misinformed about the safety of SUVs. While SUVs offer superior protection to their occupants in some multi-vehicle crash scenarios, they also have a rollover rate that is greater than any other vehicle type.

a) Highlights of Current Program

NHTSA's NCAP brochures include a rating for rollover resistance based on a vehicle's SSF. The Rollover Resistance Rating essentially measures vehicle characteristics of center of gravity and track width. The lowest rated vehicles (1 star) are at least four times more likely to roll over than the highest rated vehicles (5 stars). The Rollover Resistance Ratings of vehicles were compared to 220,000 actual single vehicle crashes, and the ratings were found to relate very closely to the real-world rollover experience of vehicles. Based on these studies, NHTSA determined that taller, narrower vehicles, such as SUVs, are more likely than lower, wider vehicles, such as passenger cars, to trip and roll over once they leave the roadway. Accordingly, NHTSA awards more stars to wider and/or lower vehicles. Additionally, utility vehicles (under Part 575.105) are currently required to have a warning label on their sunvisors alerting of the vehicle's higher rollover propensity.

b) Proposed Initiatives

The agency will carry out consumer research to determine the most effective communications approaches and messages to increase public awareness of the rollover propensity of certain vehicle classes, inform drivers of ways to reduce their risk, and encourage change in driving behaviors that contribute to rollovers. The agency will also implement a marketing plan to increase consumer knowledge on the rollover ratings provided in the NCAP information.

In addition, NHTSA will investigate whether it is feasible to amend the Rollover NCAP test procedure and rating to reflect the existence of electronic height control systems offered by certain automobile manufacturers. NHTSA's current SSF rollover rating system predicts that for any vehicle, a reduction in center of gravity height in relation to track width will lead to reduced rollover risk. Electronic height control systems can be linked to speed of vehicle and terrain and are presently available on a limited number of premium passenger cars (e.g. Mercedes E-Class) and sport utility vehicles (e.g. Lexus LX470). These systems allow the vehicle, dependent upon sensed driving conditions, to raise or lower the ride height while in motion. Electronic height control systems can have an effect on a vehicle's rollover propensity. For example, the Lexus LX470 Active Height Control (AHC) suspension can change the vehicle's SSF from approximately 1.05 (rated two-stars **) to 1.16 (rated three-stars ***).

c) *Expected Program Outcomes*
Consumer information will be targeted to audiences to affect their vehicle buying habits and change their driving habits. For example, vehicle safety belt use is the most effective countermeasure during rollovers, and increasing belt use in pickup trucks alone would provide significant benefits. Demonstrating which vehicles come equipped with electronic height control systems can also affect consumer choice.

VI. OTHER INITIATIVES

There has been no recent, in-depth, on-scene, multi-case crash investigation study completed on rollover crashes. NHTSA is seeking funds to conduct a National Motor Vehicle Crash Injury Causation Study. A Rollover Causation Study would be a subset of this broader effort. The rollover study would include the investigation of the use of handheld Global Positioning Satellite (GPS) technology to pinpoint the exact road location of the crash as well as all vehicle, driver and roadside features that influenced the rollover event. GPS technology will allow researchers to identify trends in rollover crashes. The project would investigate the cause of rollover crashes, including vehicle, highway, environment and driver-related problems in developing effective countermeasures.

In addition, NHTSA and FHWA are intrinsically involved with the Safety Research Plan of the TRB Future Strategic Highway Research Plan (F-SHRP). That plan represents a major data collection effort associated with operation over two lane rural roads – the location for a significant percentage of the ROR rollover crashes.

VII. CONCLUSION

The agency has long been concerned with the safety consequences of vehicle rollover. Many factors contribute to the occurrence of rollover crashes. Rollover correlates closely with unsafe and reckless driving behaviors, poor road design, and vehicle type. Certain categories of vehicles, such as SUVs and small pickup trucks are more prone to rollover than other classes of light motor vehicles. In recognition of the increasing rollover problem, NHTSA has made finding solutions one of its highest priorities and believes the initiatives included in this report will lead to both near-term and longer-term solutions to reduce rollovers and to mitigate their consequences.

REFERENCES

"Fatality Reduction by Safety Belts for Front-Seat Occupants of Cars and Light Trucks" NHTSA, December 2000, DOT HS 809 199, page 28, Table 2.

[2] See NHTSA's Safety Belt Use IPT strategy document. The report can be found on NHTSA's Web site at http://www.nhtsa.dot.gov/people/iptreports.html and also on DOT's docket management system (DMS) at http://dms.dot.gov/, docket number NHTSA-2003-14620.

[3] 68 FR 16867, April 7, 2003.

[4] National Research Council, (January 2002). Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards. Washington, DC; National Academy Press.

[5] "An Analysis of the Impact of Sport Utility Vehicles in the United States," Oak Ridge National Laboratory, August 2000. Washington, D.C.; Office of Transportation Technologies, U.S. Department of Energy.