IMPLICATIONS OF INCREASED LIGHT TRUCK USAGE ON ROADSIDE SAFETY

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INTRODUCTION

Prior to the 1990s the basic design vehicles for most of the widely used roadside safety hardware were a small and a large passenger car. As recommended in NCHRP Report 230 *(1)*, standard test vehicles were a subcompact 820 kg car and a 2,040 kg full-size sedan. A limited number of barriers were designed to accommodate large trucks and busses.

Since 1980, sales of light trucks has been on a steady and rather dramatic increase. As shown in Figure 1, the market share of light trucks in relation to total passenger vehicle sales, both domestic and import, has increased from approximately 20% in 1980 to almost 40 percent in 1994. Light trucks are defined herein in terms of eight subclasses:

- Passenger vans (minivans);
- Large vans [1/2 ton (450 kg) and 3/4 ton (680 kg) vans];
- Small pickups (such as the Chevrolet S-10);
- Large pickups [1/2 ton (450 kg)];
- Large pickups [3/4 ton (680 kg)];
- Small sport/utility vehicles (such as a Geo Tracker);
- Mid-size sport/utility vehicles (such as a Ford Explorer); and
- Large sport/utility vehicles (such as a Chevrolet Suburban).

Of the 5,700,000+ light trucks sold in 1994, approximately 40% were large pickups (primarily 1/2-ton (450 kg)). Passenger vans were the next highest in sales, with about 23%, followed by small and mid-size sport/utility vehicles at about 20%. The balance of sales were roughly equally divided among the remaining subclasses.

In recognition of the increasing size of the light truck population, the U.S. Congress enacted legislation within the Intermodal Surface Transportation Efficiency Act of 1991 which requires that the Secretary of Transportation shall

> issue a final rule regarding the implementation of revised guidelines and standards for acceptable roadside barriers and other safety appurtenances, including longitudinal barriers, end terminals, and crash cushions. Such revised standards shall accommodate vans, mini-vans, pickup trucks, and 4-wheel drive vehicles and shall be applicable to the refurbishment and replacement of existing roadside barriers and safety appurtenances as well as to the installation of new roadside barriers and safety appurtenances. (Section 1073, Public Law 102-240, 12/18/91)

This ISTEA requirement creates the need to: (1) determine if vans, mini-vans, pick-up trucks, and 4-wheel drive vehicles (hereafter referred to as light trucks) have impact behaviors different from the previously tested passenger vehicles, and (2) assess the adequacy of current design guidelines and standards for roadside barriers, safety appurtenances, and geometric features. Roadside features include permanent and temporary traffic barriers, crash cushions, terminals, truck-mounted attenuators, breakaway supports, cross-sectional elements, and terrain.

NCHRP Report 350 *(2)* published in 1993, superseded NCHRP Report 230 and contains recommended procedures for the safety performance evaluation of highway features. Among other things, Report 350 recommends that the 3/4-ton (680 kg) pickup be used as one of the basic design/test vehicles. This was done in recognition of the increased use of light trucks as passenger vehicles and in response to the 1991 ISTEA requirements. The degree to which the 3/4-ton (680 kg) pickup typifies the light truck fleet, or is a good surrogate for the fleet, has yet to be determined. The Federal Highway Administration (FHWA) adopted Report 350 through rule making as the procedures by which safety features are to be qualified for use on federal-aid highway projects.

There has only been limited research on the safety performance of light trucks for several reasons. One reason is that until recently, crash testing for roadside features only required the use of passenger cars. Another reason is the relatively recent emergence of many types of light trucks for use primarily as passenger vehicles. A final reason is that only in the last few years has accident data become available to permit the study of vehicles in this class.

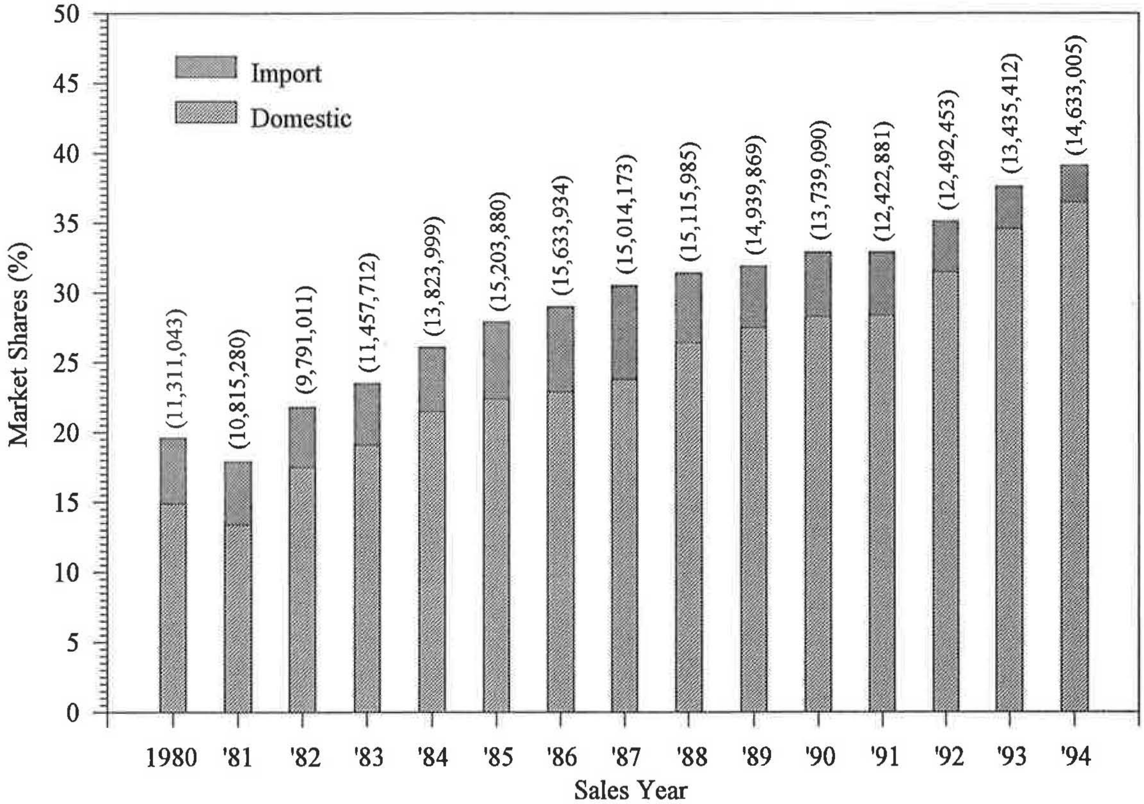

FIGURE 1 Market shares of light trucks, domestic and imported, of total passenger vehicle sales (total passenger vehicle units sold given in parentheses).

To address these concerns, NCHRP Project 22-11 was initiated. Objective of this project are to: (1) evaluate current information on the safety performance of roadside features for each subclass of light trucks, (2) assess the significance of gaps in safety performance information, and (3) recommend priorities for future research, testing, and development needed to ensure that roadside features accommodate light trucks.

Also, although not specifically stated in the objective, the Project Statement states that "In NCHRP Report 350, a 2000 kg pick-up truck is designated as the standard 2000P test vehicle. It has been proposed as the surrogate for all light trucks. It is desired that this project be structured to aid in determining if the 2000P test vehicle is an appropriate or sufficient surrogate for evaluating the safety performance of roadside features with light trucks." Project 22-11 is being conducted by the Texas Transportation Institute. It began June 1994 and is scheduled for completion in June 1996.

This paper presents preliminary findings from this study. Specifically, information is presented on a) projected trends in light truck sales and design, b) light truck properties thought to have an influence on the impact performance of safety features, c) crash test experience with light trucks impacting roadside safety features, and d) field performance of safety features as determined from accident studies. Possible implications of increased light truck usage on roadside safety are offered. It is noted that various accident data bases will also be examined in Project 22-11 for information relative to safety feature performance for light trucks. Information from this phase of the study is not currently available.

The interested reader can find complete details, including sources of un-referenced information, of data summarized in this paper in references 7, 8, and 9.

PROJECTED TRENDS IN LIGHT TRUCK SALES AND DESIGN CHARACTERISTICS

The sales of light trucks, i.e., vans, mini-vans, pickup trucks, and 4-wheel drive vehicles, have been one of the few bright spots for the U.S. automotive industry in recent years. According to the Ward's Automotive Reports, the sales of light trucks in 1963 numbered approximately 1 million vehicles and accounted for 13.9 percent of total new vehicle purchases. The percentage

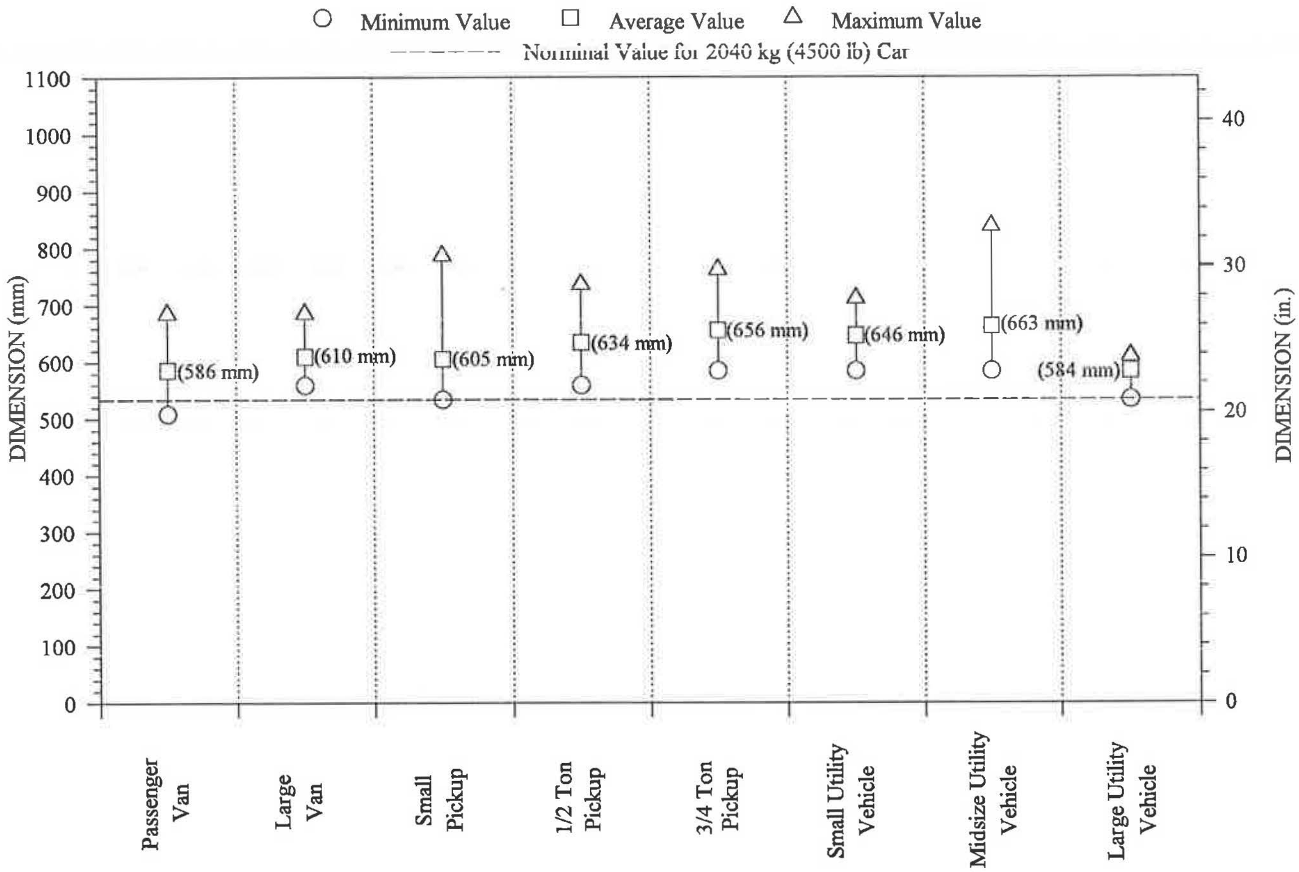

FIGURE 2 Bumper height (top of bumper), 1989–1995 models.

increased to 21.1 percent in 1981 and to a record 38.3 percent and 5.3 million units in 1993. Light trucks are no longer used principally by farmers and construction workers, but are becoming increasingly popular with families for use as passenger vehicles.

Due to the intensely competitive nature of the automobile industry and the unpredictable nature of factors that influence vehicle design, it is extremely difficult to project or predict even short term trends in the vehicle fleet. However, these uncertainties notwithstanding, the automotive industry is predicting continued increases in the market share of light trucks in new vehicle purchases. Perhaps the best source for projected trends in automotive design and marketing is a report entitled "Delphi VII - Forecast and Analysis of the North American Automotive Industry," published in February 1994 *(3)*. It was conducted by the Office for the Study of Automotive Transportation, University of Michigan, Transportation Research Institute, Ann Arbor, Michigan. It was the seventh report in a series of delphi surveys of high-level automotive industry leaders.

Key projections from the Delphi VII report are as follows:

1. Development cycles for new vehicular platforms are projected to continue to decrease, from 48 months now to 36 months in 2003. This means that the highway community will probably have to deal with new design vehicles more frequently.

2. Sales of cars and light trucks are projected to continue to increase at a modest rate, and the ratio of light truck to total passenger vehicle sales is projected to continue to increase slightly up to 2003. The study projects sales of light trucks to reach approximately 38% of total passenger vehicle sales by 2003. However, as shown in Figure 1, these projections are suspect since 1994 sales indicate approximately 40% of total passenger vehicle sales were light trucks, and the trend over the past few years points to an even greater percentage.

3. With regard to passenger car sales by segment (size/model), modest growth is projected for the upper/specialty segment.

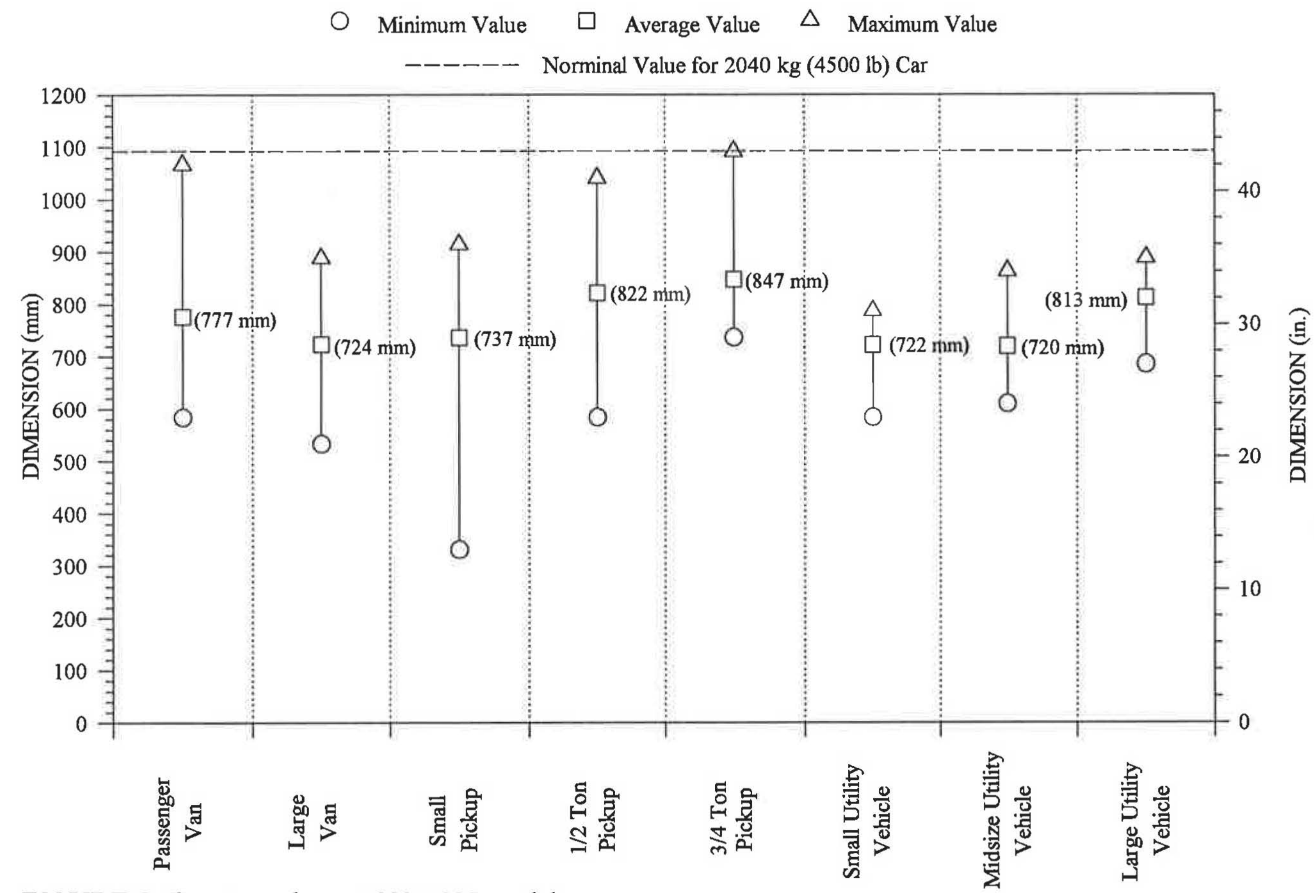

FIGURE 3 Front overhang, 1989–1995 models.

4. With regard to light-truck sales by segment (size/model), no major changes are predicted in the light truck market overall segmentation.

5. By the year 2003, it is predicted that almost all light trucks will have driver's side airbags and 50% will have passenger side airbags. If this happens, adjustments in occupant risk criteria used is assessing crash test results may be warranted, i.e., higher occupant impact velocities and ridedown accelerations may be acceptable.

6. Car and light truck weight is projected to decrease by 7% to 8% by 2003.

7. There will be little change in frame designs for cars and light trucks by 2003.

8. Cars and most mini-vans will continue to have integral body/frame or uni-body construction, while the remainder of light truck subclasses will continue to have separate body/frame construction.

Others in the automotive industry are also predicting continued increases in the market share of light trucks in new vehicle purchases. As stated in a recent newspaper article by Edward W. Hagenlocker, Executive Vice President of Ford Motor Company, "There's no reason we can't see trucks go above 40 percent of total vehicle sales by the year 2002....Fifty percent is a ways out there, but not unattainable."

LIGHT TRUCK PROPERTIES

As part of Project 22-11, a large data base of light truck sales information and dimensional and inertial properties has been assembled. These data have been derived from various sources, including:

1. Gasoline Truck Index, Diesel Truck Index, and Import Truck Index - These documents provide the following parameters: front overhang, overall length, overall height, overall width, wheel base, curb weight on front tires, curb weight on rear tires, tire and rim size, and track width.

2. Automotive News, Wards Automotive yearbooks, and Oak Ridge National Laboratory series on "Light-

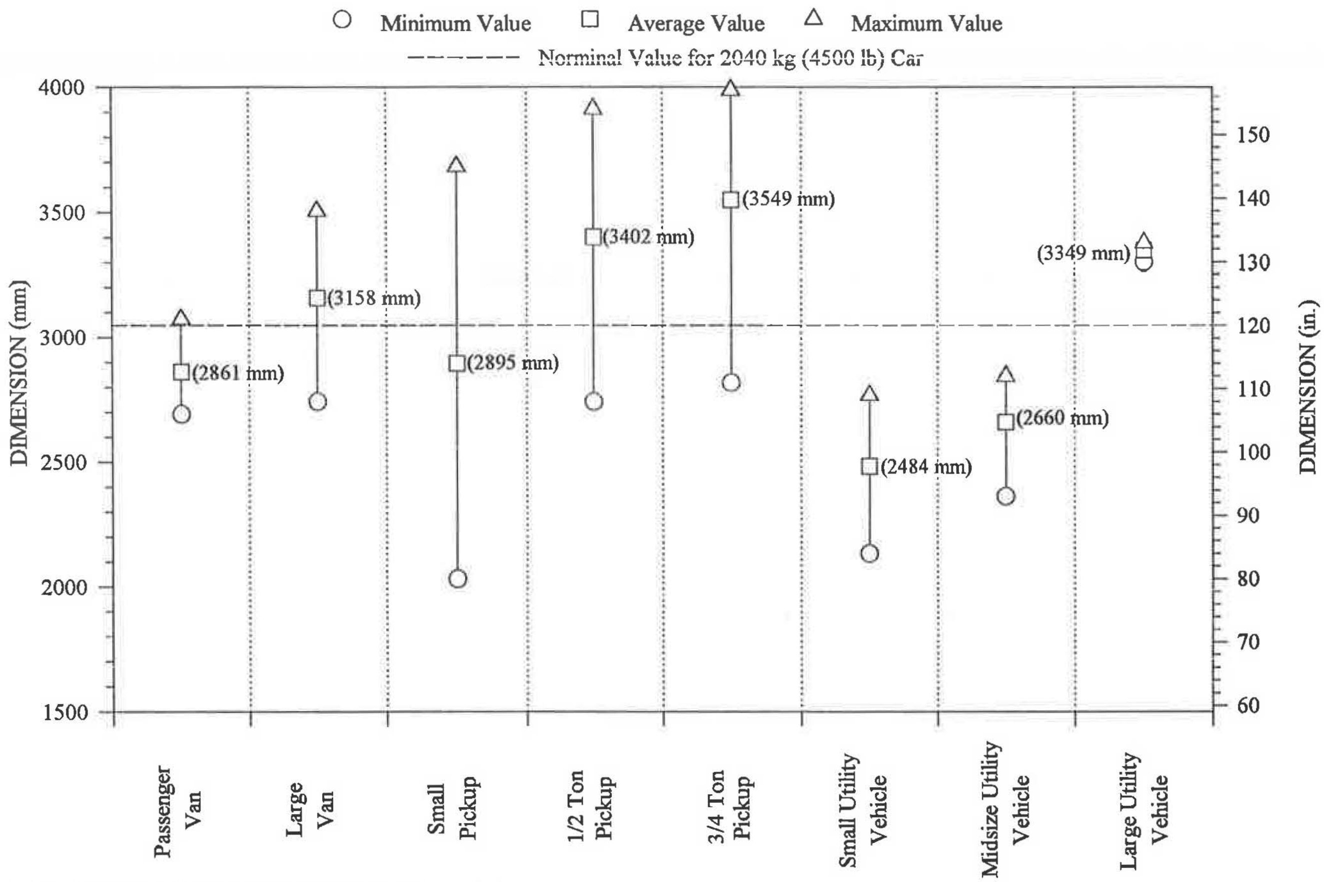

FIGURE 4 Wheel base, 1989–1995 models.

Duty Vehicle MPG and Market Shares Report" - These publications have provided sales data.

3. National Highway Traffic Safety Administration's (NHTSA) Light Vehicle Inertial Parameter Data Base — This is the most comprehensive source for c.g. height and moments of inertia data. It contains measured vehicular inertial parameters for 356 tests performed with NHTSA's Inertial Parameter Measurement Device (IPMD). This data was recently reported in a Society of Automotive Engineers (SAE) paper *(4)*.

4. Other sources for inertial properties — Another report by NHTSA *(5)* contains Inertial properties, including c.g. height and roll and yaw moments of inertia, for 51 vehicles, including 21 passenger cars, 13 pickup trucks, 10 utility vehicles, and 7 vans. An SAE Technical Paper *(6)* presents measured inertial properties of sport utility vehicles, pickup trucks, and vans and describes analytical estimation techniques for moments of inertia applicable to light trucks. Several rollover studies have also reported some inertial properties for light trucks. A paper titled "Engineering Parameters Related to Rollover Frequency," by Jones presents data for 11 models of pickups and 16 models of utility vehicles. Others include "Vehicle Dynamics and Rollover Propensity Research" by Garrott et al., and "An Evaluation of Static Rollover Propensity Measures," by Chrstos. Center-of-gravity heights for a Chrysler mini-van, a full-sized Ford pickup truck, and a GM sport/utility vehicle were published in a University of Michigan report entitled "Center of Gravity Height: A Round-Robin Measurement Program" by Walker et al. In addition, many test agencies have reported c.g. height and, in a few instances moments of inertia, for various light trucks which were used as test vehicles in full-scale crash tests or in computer simulation studies. It should be noted that much of these data are for vehicles produced prior to 1990.

5. Parking lot surveys - Significant parking lot and dealers' lot data have been gathered, primarily dimensional properties such as overall length, overall length, wheelbase, front overhang, bumper height, etc. Software program "VINAssist," version 1.06LE, was used

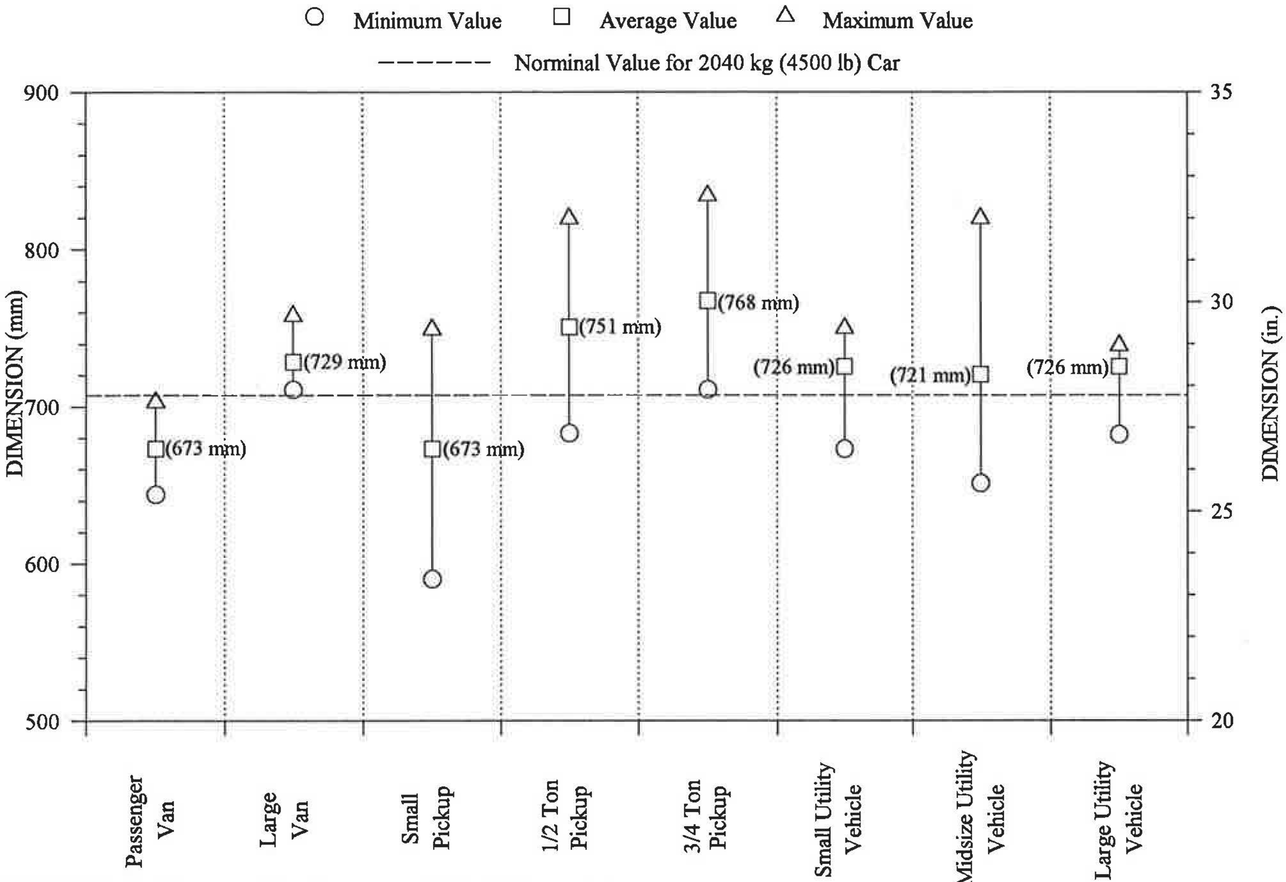

FIGURE 5 Tire outside diameter, 1989–1995 models.

to identify specifics of each vehicle surveyed (model year, type of cab (if applicable), 2 or 4 door, type of engine (diesel or gasoline), 2 or 4 wheel drive, etc.).

Shown in Figures 2 through 8 are dimensional and inertial data for light trucks for model years 1990 through 1994. Figures 2 through 5 contain bumper height, front overhang, wheel base, and un-deflected tire diameter for 1989-95 model years. These data were acquired via parking lot surveys, and included 4-wheel drive vehicles. Vehicles with special "jacked-up" suspension systems were omitted. As previously stated, with the exception of bumper height, data on the same parameters have also been collected from published sources and were correlated with parking lot data.

Shown in Figures 6 through 8 are selected inertial data for light trucks, including curb weight, c.g. location above ground, and c.g. location aft of the front axle.

Based on initial and preliminary examination of these data, one may conclude that the 3/4-ton (680 kg) pickup truck is reasonably representative of the light truck population. In terms of some of the more sensitive parameters such as bumper height, front overhang, mass, and c.g. location above ground, there are some subclasses with parametric values that are believed to be more critical than those of the 3/4-ton (680 kg) pickup and some with values less critical. By more critical is meant that an impact will be more demanding on a safety feature, i.e., more difficult for the impact performance of the features to meet recommended criteria, all other parameters being equal. For example, it is conjectured that demands on a longitudinal barrier will generally increase as the bumper height increases, as the front overhang decreases, as the c.g. height increases, as the tire diameter increases, etc.

Nominal values of the parameters for the 2,040 kg full-size car previously used as a design vehicle are also shown on the figures. It can be seen that the light truck parameters are typically more critical than those of the 2,040 kg car, i.e., for the 2,040 kg car bumper heights are lower, front overhang in larger, and c.g. height is lower.

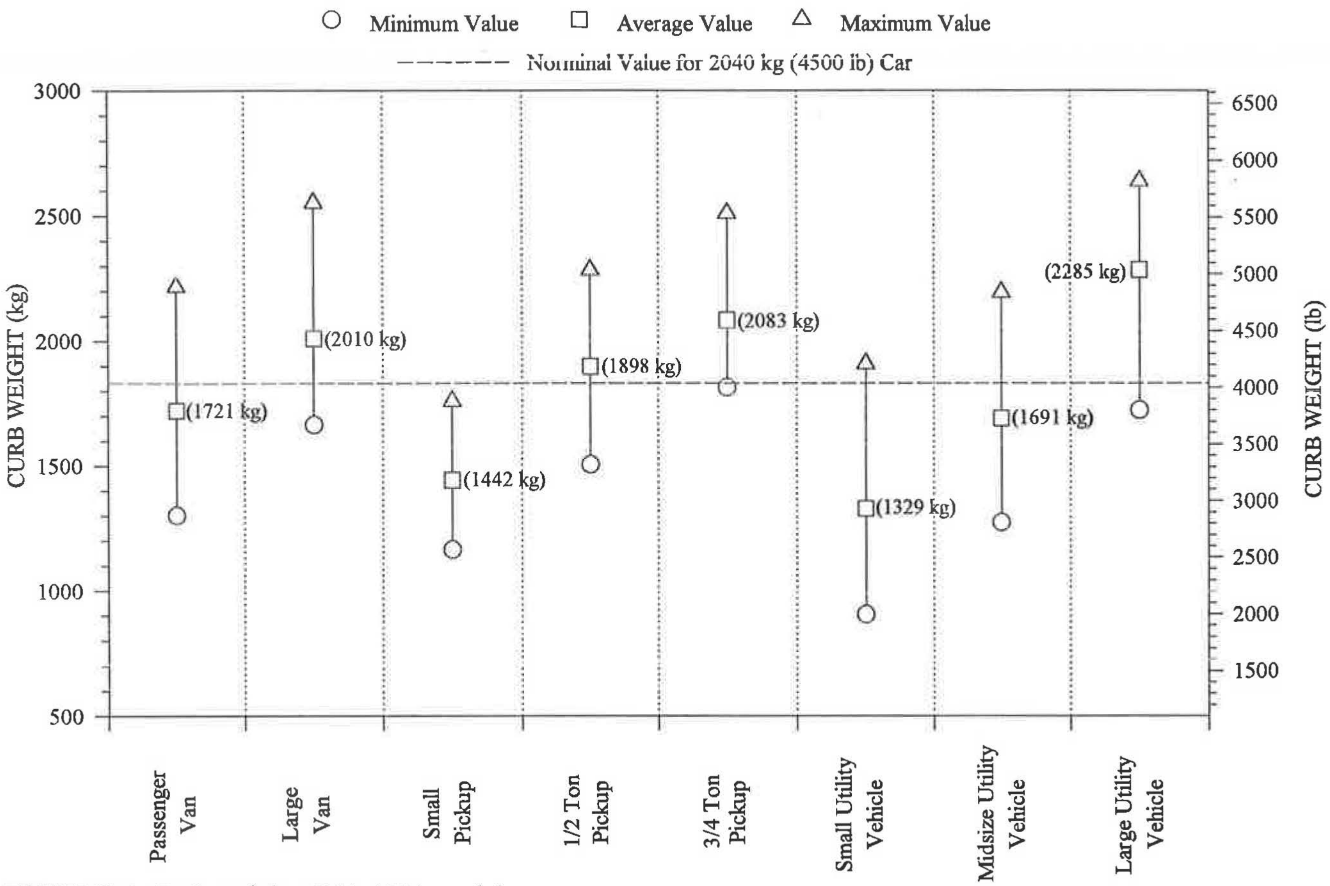

FIGURE 6 Curb weight, 1990–1994 models.

CRASH TEST EXPERIENCE WITH LIGHT TRUCKS

Most of the crash testing with light trucks conducted to date has involved either a 1/2-ton (450 kg) or 3/4-ton (680 kg) pickup truck. Only a very limited amount of testing has been conducted with light truck vehicles such as sport/utility vehicles and vans, respectively.

A vast majority of crash tests with pickup trucks have involved a full-size pickup ballasted to 2,450 kg. Since some of these tests involved a 1/2-ton (450 kg) vehicle, and since the impact conditions typically used in conjunction with the 2,450 kg test vehicle have a smaller impact angle and result in a significantly lower impact severity than those required by test level 3 of Report 350, it is difficult to make conclusive assessments regarding the ability of some of these systems to meet Report 350 criteria. However, in general, these tests do provide considerable insight into the safety performance of current hardware with pickup trucks from which some general observations can be made.

Generally speaking, it appears that most of the common rigid barriers and bridge rails such as the New Jersey safety shape, F-shape, vertical wall, and constant-slope barrier perform satisfactorily with pickup trucks when tested to PL-2 of the AASHTO Guide Specification or TL-3 of NCHRP Report 350. In addition to several pickup truck tests, two tests of a CMB were successfully conducted with a Ford Bronco. However, the results of these tests must be qualified by the model year of the test vehicle (1966) and the impact angles (7 and 15 deg). Clearly, further investigation of these barriers for other light truck vehicles, particularly full-size vans and sport/utility vehicles, is warranted. These vehicles may have greater c.g. heights than the pickup trucks, which increases the propensity for rollover.

The most critical area of concern appears to be the performance of widely used flexible guardrail systems. The short front overhang and increased c.g. and bumper heights of the light truck class significantly increase the

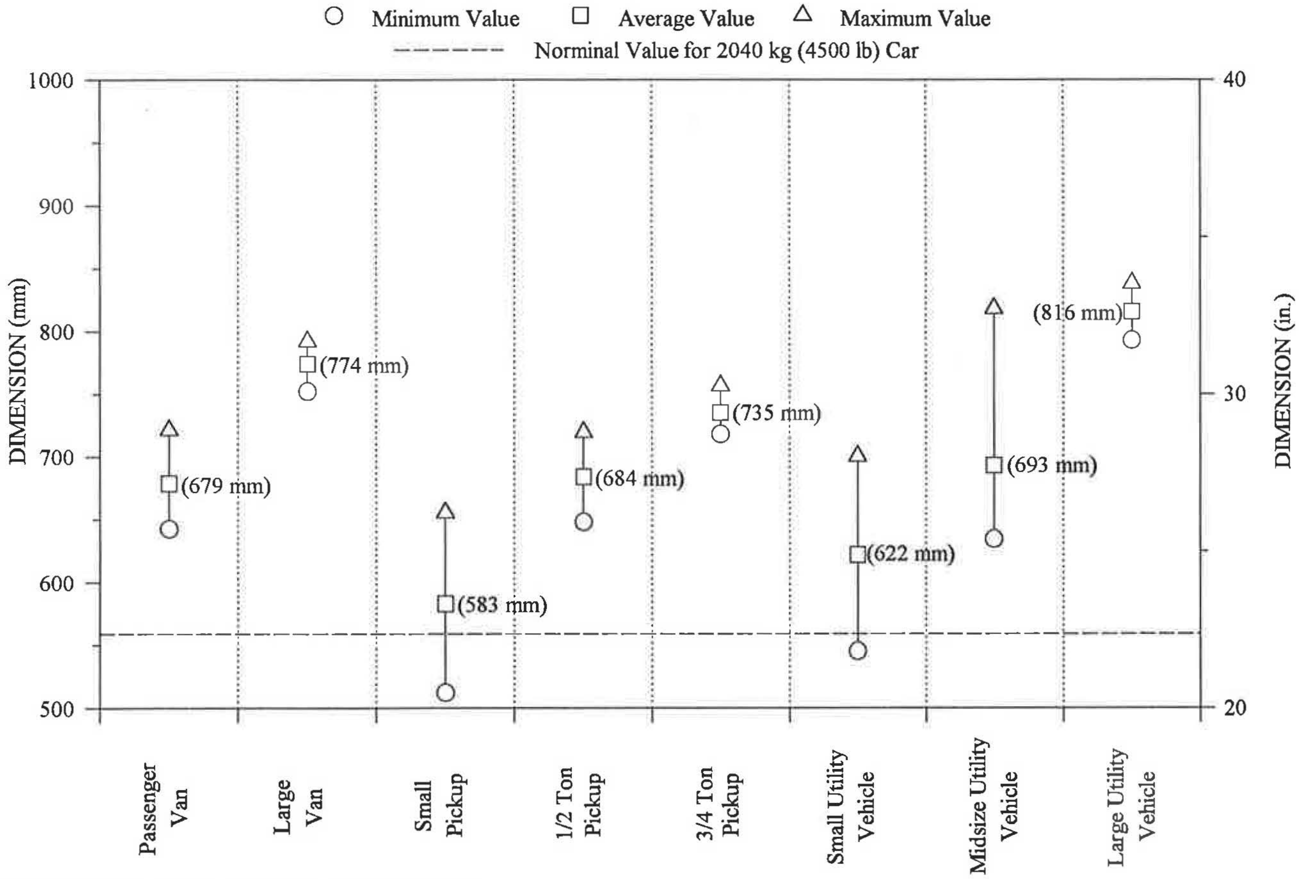

FIGURE 7 C. G. location above ground.

potential for vaulting and rollover during impacts with these systems. Results of recently conducted tests indicate that the performance of the commonly used G4 strong-post W-beam guardrail systems appears marginal when evaluated under NCHRP Report 350 Test Level 3 conditions. During a test of a G4(2W) guardrail system, the front wheel assembly of the vehicle became detached and the vehicle achieved a maximum roll angle of 39 degrees before being redirected. A similar test with a G4(1S) steel post guardrail system under the same nominal impact conditions resulted in a rollover. In another series of tests conducted on the G4(1S), an increasing propensity for rollover with an increase in c.g. height was demonstrated. In these tests, a small 1/2-ton (450 kg) pickup was redirected in a very stable manner, while a full-size 1/2-ton (450 kg) pickup achieved a roll angle of 35 deg, and a 3/4-ton (680 kg) van rolled over.

In other tests, a G2 weak post W-beam guardrail was found to be deficient as a TL-3 barrier, but was found to have satisfactory performance when evaluated as a TL-2 barrier. A G1 cable guardrail system was found to exhibit good impact performance when impacted by a 2000P vehicle under test level 3 conditions.

Most surprising of all, evaluation of the standard G9 three beam system for TL-3 of Report 350 resulted in a failure. Upon impact the 2000P vehicle was redirected but large pitch and roll rates were induced, resulting in a violent rollover. It had been surmised that the G9 system could be the solution to the W-beam problem.

Tests of guardrail-to-bridge rail transitions have been successful in containing and redirecting 3/4-ton (680 kg) pickup trucks. However, during tests of transitions to rigid barriers, a high occurrence of floorpan deformation has been observed that was not evident in previous testing with large passenger sedans. This floorpan deformation has occurred in instances when no evidence of wheel snagging on the end of the parapet was reported. This may be attributed to the reduced front overhang dimension of the pickup truck resulting in more vehicle-barrier interaction, or it may

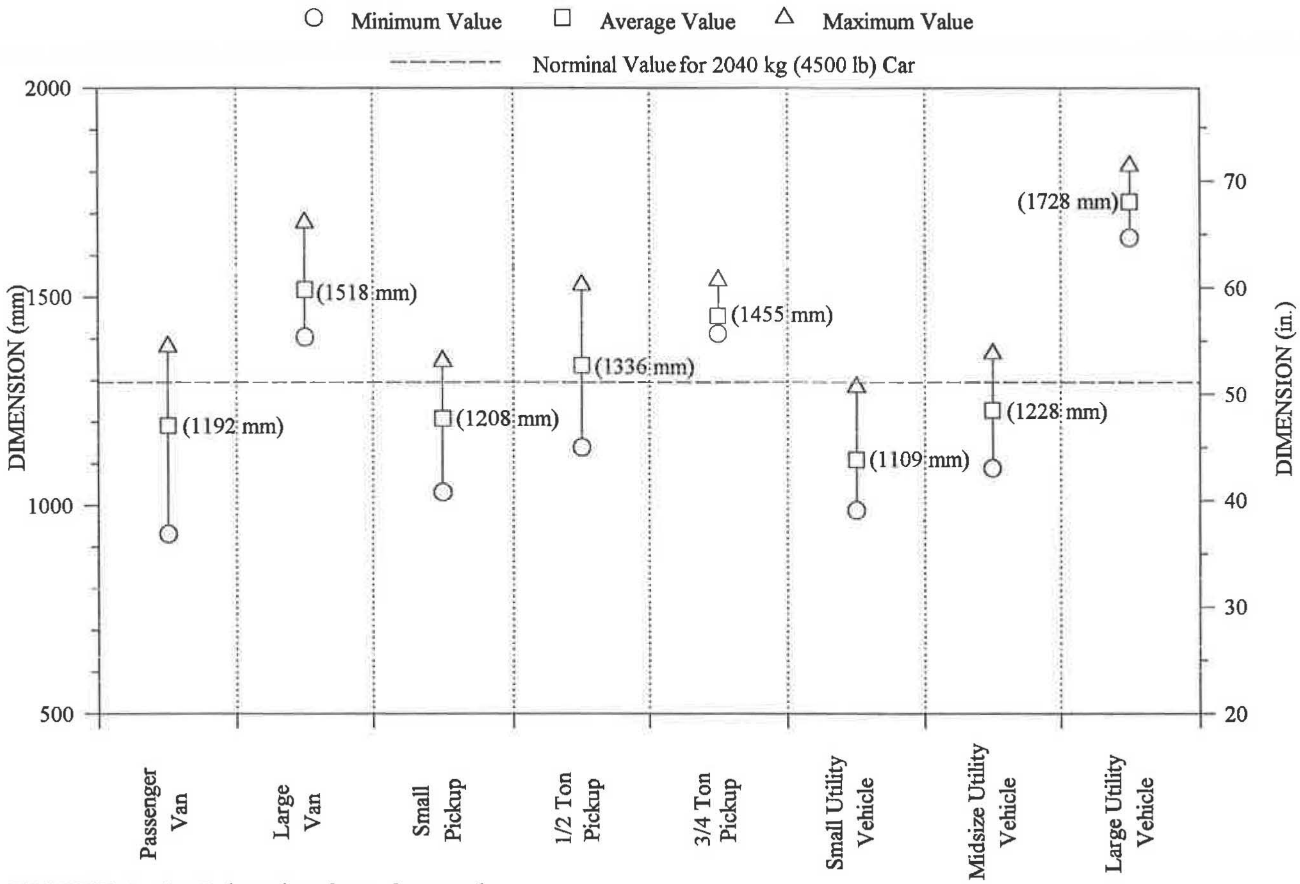

FIGURE 8 C. G. location from front axle.

be due to some other inherent characteristic of these vehicles.

Results of tests on crash cushions and energy-attenuating devices appear to indicate a strong potential for good impact performance. The React 350 crash cushion developed by Roadway Safety Services (RSS), Inc., has been fully qualified according to Report 350 requirements. The Fitch Inertial Barrier System, marketed by RSS, and the Energite Inertial Barrier System, marketed by Energy Absorption Systems (EAS), Inc., have also been qualified for Report 350 requirements. Work was underway at the time of this writing to qualify the ADIEM crash cushion.

At the time of this writing, the Modified Eccentric Loading Terminal (MELT), the ET-2000, and the Slotted Rail Terminal (SRT) were being evaluated in accordance with Report 350 requirements. Details of these test programs were not available for this paper.

Some concern exists regarding the potential for vehicular override or overturn during end-on impacts with some common end treatments due to the geometrics of the light truck class of vehicles and the potential for the accumulation of debris in front of the impacting vehicle. A test with an eccentric loader terminal (ELT) was judged as marginally passing when a 1/2-ton (450 kg) pickup ballasted to 2,450 kg and impacting at a speed of 51 mph achieved a roll angle of 43 degrees. Concern also exists in regard to the potential for vehicular vaulting and overturn during impacts into the side of the terminal at the beginning of length of need.

Testing of roadside geometric features with light trucks has been very limited. In two full-scale embankment traversal tests, a 1/2-ton (450 kg) pickup truck and 3/4-ton (680 kg) van successfully negotiated a 3:1 side-slope with an embankment height of 15 ft. In a similar test with a small passenger car, the vehicle slid down the embankment and rolled over when the tires plowed into the ground. This would appear to indicate that, in terms of roadside encroachments, a small passenger car is more critical than a high c.g. van. However, the rollover of the small car was not a function of the geometry of the side-slope as it was the conditions of the soil. The van, on the other hand, experienced a 23 deg roll angle before stabilizing, and would likely be more sensitive to the actual geometry of the side-slope. Clearly, much more study is required before any conclusions in this regard can be substantiated.

Testing of temporary barriers with light trucks has been very limited. A standard New Jersey concrete safety-shaped barrier connected to a bridge deck with 1 1/4 in. steel pins was successfully tested for TL-3. Although the barrier was neither completely rigid nor free standing, the results of this test are encouraging. However, further testing is needed to more fully define the capabilities of a precast CMB in containing light trucks.

The low-profile portable concrete barrier was developed and tested according to TL-2. This barrier is 508 mm in height and has a negative slope on the traffic face. It is of particular interest to note that almost immediately after impact, the bumper of the pickup truck overrode the top of the barrier, yet the vehicle was still smoothly redirected. This may be at least partially attributed to the negative slope on the face of the barrier.

The TRITON water-filled barrier, developed by EAS, has also passed TL-2 requirements. In addition, suitable end treatments and transitions have also been developed for use with this barrier system and successfully tested to TL-2.

A test of temporary concrete safety-shaped half barrier was not successful. To accommodate space restrictions at some work sites, the Iowa Department of Transportation evaluated the concept of using a half-barrier, which is similar in cross section to a safety-shaped bridge rail, as an alternative to a full-width concrete median barrier. When impacted by a 2,450 kg pickup truck at 60 mph and 20 deg, the barrier segments began to rotate, and the vehicle vaulted the installation.

FIELD EXPERIENCE

A review of literature on field performance data did not result in much useful information for the purpose of Project 22-11, which is to determine the effects of light trucks on the impact performance of various roadside features. There is considerable information in the literature on the accident experience of light trucks, but not specific to crashes involving roadside features. The literature indicates that light trucks are over-represented in fatal crashes and have significantly higher rollover rates than passenger cars. Side-slopes and ditches are identified as the primary tripping mechanism in rollover crashes. The severity of accidents involving light trucks is similar to that of passenger cars overall and for a number of roadside features studied. There are numerous studies to evaluate the impact performance of specific roadside features, but the accident data were not categorized by vehicle type and the findings are thus of little use for the present study.

Further studies of light truck involvement with safety features are being pursued in Project 22-11 through analysis of various accident data bases. These data bases include

- Fatal Accident Reporting System (FARS),
- National Accident Sampling System (NASS) - General Estimate System (GES),
- NASS — Crashworthy Data System (CDS),
- Highway Safety Information System (HSIS), and
- NASS Longitudinal Barrier Special Study (LBSS).

FINDINGS AND IMPLICATIONS

1. Light truck sales have continued to climb over the past 20 years. In 1994 light truck sales were approximately 40% of all passenger vehicle sales. The large pickups (1/2-ton (450 kg) and 3/4-ton (680 kg)) have the largest market share of all the light truck subclasses. Attention must be given to the light truck fleet in the design of roadside safety features.

2. In general, light trucks create greater demands on roadside features than did the heretofore 2,040 kg passenger car design vehicle, all other factors being the same. This is due to higher bumper heights, shorter front overhangs, stiffer crush properties, and higher c.g. locations, among other things.

3. Based on findings to date, the 2000P test vehicle (3/4-ton (680 kg) pickup) appears to be reasonably representative of the larger light truck subclasses (large vans, mid-size and large utility vehicles) with regard to key parameters that influence impact performance.

4. The standard W-beam guardrail systems, which are widely used in the USA, and the standard thrie-beam guardrail system, whose use is fairly widespread and increasing, are marginal at best when subjected to the "basic" Test Level-3 requirements of NCHRP Report 350. In this test the 2000P vehicle impacts the barrier at 100 km/h at an impact angle of 25 degrees. Implications of these results could be enormous.

5. Impact performance of the 2000P vehicle with rigid barriers such as the New Jersey concrete safety shape barrier or the single slope concrete barrier appears to be acceptable.

6. Impact performance of inertial crash cushions are acceptable for Report 350 TL-3 requirements.

7. Test and evaluation of widely used guardrail end treatments such and the MELT and the ET-2000, and the newer slotted rail terminal (SRT) were underway at the time of this writing, and results were not available for inclusion in the paper.

8. Light trucks are more prone to overturn on embankments, ditches, and other roadside geometric features than are cars. Guardrail warrants for embankments and side-slopes may have to be reevaluated.

RECOMMENDATIONS FOR FURTHER RESEARCH

1. Test 3-11 of Report 350 should be conducted with the standard W-beam guardrail system using a representative vehicle from the "large van" and the "large utility" subclass. Note that test 3-11 with the 2000P vehicle with the G4(1S) system has been conducted. Also, similar tests have been conducted with the 1/2-ton (450 kg) pickup with the G4(1S). The purpose of these tests would be to compare performance of the "heavier" light truck subclasses for the "strength" test of Report 350. Test 3-11 would never be conducted with any of the "lighter" light truck subclasses (since it is a strength test), and therefore test 3-11 should not be the basis on which to compare light truck performance. The G4(1S) system is recommended since 1) it is known to have poor performance for the large pickup subclass for test 3-11, and 2) it is the most widely used guardrail system in the USA. These tests would provide valuable insight and data from which the efficacy and relevance of the 2000P vehicle could be evaluated, at least for test 3-11.

2. Test 3-10 of Report 350 should be conducted with the G4(1S) system with a representative vehicle from each of the seven light truck subclasses. The purpose of these tests would be 1) to provide data from which to evaluate and compare the performance of the "heavier" light trucks at impact angles of 20 and 25 degrees, and 2) to evaluate and compare the performance of a representative vehicle from each of the light truck subclasses for the "severity" test of Report 350.

Summarizing, it is anticipated that results from parts a) and b) would be used for several purposes, as follows.

First, results of part a) would aid in determining the efficacy of the 2000P vehicle as a representative/ suitable vehicle from the "heavier" light truck subclasses for the strength tests of Report 350 (tests 1-11, 2-11, 3-11, 4-11, 5-11, and 6-11). It is possible, for example, that a 3/4-ton (680 kg) Suburban vehicle would accomplish the desired goal of testing the strength capabilities of a barrier, without the instability now seen in the 2000P vehicle. Based on instrumented wall tests, the Suburban is known to produce greater loads on a barrier than the pickup, all other factors being the same. Replacing the 2000P vehicle with another vehicle would require/imply acceptance of the premise that a 25 deg/100 km/h impact is such a rarity that longitudinal barriers should not be expected to keep all light trucks upright for such conditions.

Second, results of parts a) and b) may point to the desire/need to abandon test 3-11 altogether as it is now defined if tests in part "a" are failures and tests with the same vehicles in part b) are successes, and if the highway safety community agrees that it should no longer require longitudinal barriers to be designed for test 3-11 conditions. These tests may point to the desire/need to change test 3-11 to a higher speed and lower impact angle, or to the same speed but a 20 degree impact angle, etc.

Third, results of part b) would allow for the direct comparison of the performance of a representative vehicle from each light truck subclass for a widely used safety feature for the "severity" test. Results of part b) may also point to the need for an additional "severity" test involving a vehicle from one of the light truck subclasses. For example, whereas the 820C vehicle's performance with the G4(1S) system is satisfactory, the same may not be true for one or more vehicles from the light truck subclasses.

3. Depending on results and conclusions drawn from parts a) and b), other tests that may be considered include; 1) tests to evaluate alternate impact conditions for test 3-11, e.g., a higher speed and a lower impact angle - tests would be conducted with the G4(1S) system, 2) tests of the concrete safety shaped barrier with vehicles from selected light truck subclasses (FHWA is planning to conduct test 3-11 on the concrete safety shaped barrier in the near future), or 3) tests of other longitudinal barriers (cable barrier for example) with vehicles from selected light truck subclasses.

4. Tests to determine inertia properties, and limited suspension properties, of a representative vehicle from each of the seven light truck subclasses should be conducted. These data are needed for future computer simulation studies.

5. Additional vehicular finite element models should be developed for use with DYNA 3D to better simulate the full range of light truck subclasses. At a minimum, a model of a representative passenger van and a mid-size utility vehicle are needed. These models could be calibrated/validated with previously recommended crash tests (see item b).

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