TECHNICAL ASSESSMENT PAPER:

RELATIONSHIP BETWEEN ROLLOVER AND VEHICLE FACTORS

prepared
by

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Table of Contents

List of Tables

List of Figures

1.0 FOREWORD

The activities documented in this report were initiated in response to two petitions for rulemaking requesting the development of a standard for rollover stability. They were submitted to the National Highway Traffic Safety Administration (NHTSA) over the past five years. The first, received by the agency in September 1986, was submitted by Senator (then Congressman) Timothy E. Wirth, and the second, received in June 1988, was submitted by the Consumers Union of United States, Inc. (CU). Although the agency denied the Wirth petition (Reference 1), which asked the agency to propose a specific rollover stability standard, NHTSA in its April 1988 denial (Appendix A) indicated that it intended to conduct additional testing and analysis to investigate the problem of rollover of light duty vehicles and that those efforts might lead to rulemaking. The CU petition (Reference 2), which asked that NHTSA investigate the rollover problem and then propose appropriate rulemaking, was granted in a September 1, 1988 letter (Appendix B), based upon the commitment made in the Wirth denial to investigate the rollover issue.

1.1 INTRODUCTION-GENERAL

Rollover accidents occur for many reasons. As with any accident, all three components of the driver/vehicle/environment system play a part in the development of the situation that results in a crash. However, there are extremes wherein a factor or factors related to one of the parts of the system is predominant in the causation of the accident. In the case of the driver, take the "extreme" example of a driver falling asleep at the wheel; for the environment, consider an unexpected patch of ice on an otherwise clear roadway resulting in a skid; and for the vehicle, a vehicle which has a such a low level of rollover stability that a simple, but severe, steering input by the driver as part of an accident avoidance maneuver results in the vehicle's rolling over.

The vast majority of crashes are caused by the interaction of factors from all three parts of the driver/vehicle/environment system. This rulemaking program attempts to accurately define and measure a vehicle performance factor(s) that is influential in the causation of rollover accidents - to the degree that a regulation based on that factor can significantly reduce the number and/or consequences of rollover crashes.

The goal of this rulemaking program is to determine the feasibility of developing a viable and appropriate standard or standards related to vehicle rollover stability that would reduce the likelihood of rollovers and/or to reduce the casualties associated with vehicle rollover crashes. In order to achieve that goal, a number of research and analysis tasks were planned and conducted. The purpose of these research and analysis tasks was to develop a measure of a vehicle's rollover stability that can be used to predict the vehicle's likelihood of rolling over given involvement in a crash. This document summarizes those efforts and results (which only comprise one aspect of the potential vehicle rulemaking) and discusses the adequacy of the results to accurately predict the rollover accident involvement rate of vehicles. The various alternatives for vehicle stability rulemaking action, and the implications of the research and analysis results on those alternatives, are then discussed. Also addressed are additional testing, analysis and evaluation activities being undertaken by the agency to improve its understanding of rollover accident causation.

1.2 THE ROLLOVER ACCIDENT PROBLEM

This project addresses the crash avoidance aspects of rollover accidents that involve light duty vehicles, which includes passenger cars, and light trucks and vans (LTV's). This latter group includes compact and full-size pickup trucks, mini and full-size passenger and cargo vans, and sport utility vehicles (SUV's). SUV's are passenger vehicles with special features (usually four-wheel-drive) that allow for off-road operation. It should be noted that in the agency's Consumer Information Regulation (49 CFR 575.105) "Utility Vehicles", utility vehicles are defined as "multipurpose passenger vehicles (other than those which are passenger car derivatives) which have a wheelbase of 110 inches or less and special features for occasional off-road operation." Of the SUV's on the market today three, the Toyota Land-Cruiser with a wheelbase of 112.2 inches, the Lamborghini LM002 with a wheelbase of 122.4 inches and the Chevrolet/GMC Suburban with a wheelbase of 129.5 inches, do not fall in both categories.

Rollover crashes are of particular interest since rollover accidents are the most dangerous collision type for all classes of light vehicles, measured by either fatalities or incapacitating injuries per involved occupant. In terms of fatalities per registered vehicle, rollovers are second only to frontal crashes in their level of severity. These results are reported in a 1986 report documenting analyses conducted by NHTSA's National Center for Statistics and Analysis (Reference 3). These high injury/fatality rates are even more alarming given the fact that rollovers are by far the least frequent crash mode, as measured by accident involvements per registered vehicle. The National Accident Sampling System (NASS) datafile for 1989 estimates 137,600 rollover accidents involving passenger cars. Of these, 124,800 are single-vehicle rollovers, and the vast majority of these, 114,800, occur off the roadway. For LTV's, there are 75,600 rollovers, 65,800 single-vehicle rollovers, of which, 57,200 occur off road. Based on NASS data, nearly 90 percent of rollovers occur in single-vehicle accidents. Various accident data studies have indicated that the vehicle is out of control (skidding sideways or spinning) prior to overturning in from 50 percent to 80 percent of all rollovers.

The rollover problem is generally more serious for the LTV, and in particular, the SUV "portion" of the light vehicle group. State accident data (North Carolina for 1984 and 1985) indicate that although the involvement rate (involvements per registered vehicle) for LTV's in all types of collisions is only 68 percent that of passenger cars, their involvement rate in accidents involving rollover is 127 percent that of passenger cars. Rollover accidents are particularly dangerous for the occupants of SUV's, with their incapacitating injury rate being 28 percent higher than that for all light vehicles combined. This occurs even with similar seat belt usage, as shown in an agency regulatory evaluation on "Rear Lap/Shoulder Belts," where seat belt usage rate in accidents of pickups was estimated to be 70 percent of passenger cars, but "on/off road" vehicles were estimated to have usage rates "equivalent" to passenger cars (actual rate was 95 percent).

In terms of rollover fatal accidents, 1989 Fatal Accident Reporting System (FARS) data indicate that LTV's have fatalities per registered vehicle rates 104 [94.5 versus 46.3 fatalities per million RV] percent higher than passenger cars, with small pickup trucks and SUV's having the highest comparative rates- 259 [based on 119.8 fatalities per million RV] percent and 254 [based on 117.5 fatalities per million RV] percent that of passenger cars respectively. However, since there are many more passenger cars the LTV's on our nations highways, approximately two-thirds of all rollovers involve passenger cars. Based on 1989 FARS data, 5682 fatalities occurred in passenger car rollovers and 3862 fatalities occurred in LTV rollovers.

Further discussion of the nature and magnitude of the rollover problem of light duty vehicles and of the prior analyses of accident data is found in the "Technical Evaluation of Rulemaking Petition" (for Senator Wirth's petition on rollover propensity-Reference 4) and in a discussion of the petition in Section 2.1.2.

1.3 PREVIOUS ANALYSIS OF FACTORS RELATED TO ROLLOVER CRASH INVOLVEMENT

The following is a basic review of accident data analyses performed by both the agency and others prior to the efforts reported in this document. This summary presents what has been studied to better quantify the relationship between vehicle, driver and environmental factors and rollover accident involvement.

1.3.1 Analyses Conducted Prior to the Submission of the Wirth Rollover Propensity Petition

Several researchers have reported correlations between certain vehicle parameters and various measures of rollover accident involvement. Some of these are discussed in Reference 4. Two vehicle parameters that were shown to have significant correlations with the rate of rollovers in single vehicle accidents were:

1. rollover stability factor, and

2. critical sliding velocity.

Both the rollover stability factor, which is one-half the vehicle's track width divided by the vehicle's center of gravity height, (h_{cg}), and the critical sliding velocity, which is a measure calculated from various vehicle dimensions and mass and inertial properties, will be discussed later in this section and in Section 4.

Various accident condition variables have been shown to exhibit a relationship with rollover rates. These include pre-crash stability (skidding or spinning), vehicle pre-crash condition (skid sideways or spin) and skid type (rear wheel lateral or four wheel lateral).

Various driver- and environment-related accident variables also seem to influence the likelihood of rollover. These include driver age, alcohol involvement, driver error, rural vs. urban roadway, day vs. night, the roadway speed limit, the rollover's occurring on or off the roadway, and accidents occurring where the roadway was straight or curved.

Of all these factors, the one which exhibited the greatest correlation with rollover accident involvement is rollover stability factor. The rollover stability factor's correlation "makes sense" since it has an obvious physical relationship to the dynamics of a rollover accident (this is discussed in detail in Section 4).

Other factors which are very important in determining a vehicle's rollover stability (measured or calculated) and its rollover propensity are those related to the vehicle type or class. This is particularly true of LTV's. LTV's have functional characteristics that are inherently different from passenger cars and that contribute to an inherently lower level of rollover stability. Since these same characteristics of LTV's are, to some extent, vehicle characteristics basic to the use for which these vehicles are designed, potential for improvement in their fundamental rollover stability may be limited. This view was noted in the agency's denial of the rulemaking petition from Senator Wirth (Appendix A). In responding to that petition the agency stated that a regulatory requirement based on the rollover stability factor alone, given the then limited understanding of the overall rollover accident causation issue, was not reasonable or practicable and might be in conflict with certain statutory considerations.

Before proceeding, one feature of a previous study should be noted. In a 1974 paper (Reference 5), I. S. Jones argued that a vehicle which has a relatively low rate of rollover per single vehicle accident might have a relatively high overall rate of rollover accident involvement, when measured per vehicle mile travelled (VMT), or per registered vehicle, because of a high rate of single vehicle accidents per VMT or registered vehicle. Jones argued that this could be particularly confounding to an analysis of vehicle rollover stability when comparing vehicles with significantly different handling characteristics; the reasoning being that vehicle handling characteristics influence a vehicle's involvement in single vehicle accidents and since most rollovers occur in single vehicle accidents, the influence of those handling differences could confound an analysis that examines the correlation between rollover involvement and vehicle rollover stability measures. Based on this, Jones reasons that by using rollovers per single vehicle accident as the accident rate measure, the confounding influence of other vehicle factors, unrelated to vehicle rollover stability, would be significantly reduced. This is also reasonable noting that the vast majority of rollovers occur in single vehicle accidents and as such, the occurrence of the single vehicle accident can be viewed as the opportunity for, and therefore, an exposure measure of, a rollover accident.

1.3.2 Agency Analyses Conducted Since Submission of the Wirth Rollover Propensity Petition

This section reviews the accident data analyses performed by NHTSA subsequent to the submission of the Wirth petition, but prior to the testing and analyses that have been performed for this program and reported herein.

Beginning in late 1986, the agency conducted several analyses designed to better understand the association between vehicle design factors and performance characteristics, and rollover propensity.

The first significant analysis effort was performed by Harwin and Brewer (Reference 6). It began just prior to the submission of the Wirth petition. Their analysis employed the then recently developed CARDfile (Crash Avoidance Research Data file). The CARDfile database is constructed from information from police accident reports from several states, and is documented in a report by Mark L. Edwards titled "A Database for Crash Avoidance Research" (Reference 7). A portion of the CARDfile database was used in the Harwin and Brewer analysis, and includes data from Maryland and Texas for accident years 1984 and 1985 and from Washington state for accident years 1983 through 1985.

Their database included accident data for a series of forty vehicle make/models (some of which were different "nameplate" versions of the same vehicle model, e.g., Chevrolet Citation and Oldsmobile Omega) which represented nineteen unique passenger car models, including both foreign and domestic models, and eight utility vehicle models. The vehicles in their sample were selected to cover, without major gaps, the range of stability factors from small utility vehicles to large domestic passenger cars. The data base did not include any pickup trucks or vans. Their research examined various vehicle data, including wheelbase (L), center of gravity height (h_{cg}), half track width (TW/2) and the stability factor ($TW/(2*h_{cg})$).

The regression of the CARDfile data between the stability factor and the percent of rollovers in single vehicle accidents shows a strong correlation, with R^2 values ranging between 0.57 and 0.86 for the various State/year combinations. This regression shows a continuous trend of rollovers per single vehicle accident over a broad range of stability factors, as opposed to the two clusters of vehicles that are indicated in a report by L.S. Robertson and A.B. Kelley titled "The Role of Stability In Rollover-Initiated Fatal Motor Vehicle Crashes Under On-Road Driving Conditions," (Robertson/Kelley-Reference 8). That report, which was submitted with and in support of the Wirth petition (Reference 1), shows one group of high stability factor vehicles with low rollover per single vehicle accident rates and another group of low stability factor vehicles with high rollover per single vehicle accident rates, indicating that there is some specific value of stability factor above which vehicles are "safe" and below which they are "unsafe". In the case of the Wirth petition, the petitioner suggested 1.20 as that value. The CARDfile analysis instead shows a generally linear distribution of rollovers per single vehicle accident over a wide range of stability factors with no obvious ranges of "safe" or "unsafe" vehicles.

Harwin and Brewer's research also included a stepwise multivariate regression analysis of the Maryland and Texas data to control for differences in driver and vehicle use. They showed R^2 values for the combination file of Maryland and Texas as well as the Maryland file only. Their final regression equation had an R^2 value of 0.91 for data base combinations with stability factor, percent drivers under 25, percent male drivers, and percent accidents occurring on rural roads included in the regression model.

In summary, Harwin and Brewer indicated that the rollover stability factor statistically explained much of the difference in the rollover rate (computed as the number of rollovers per single-vehicle accident (RO/SVA)) between different vehicle make/models.

Mengert, Salvatore, DiSario, and Walter (Reference 9) re-analyzed the Harwin and Brewer data using logistic regression techniques. This process considers the likelihood of rollover at the accident level rather than at the make/model level as was done in the Harwin/Brewer report. This allows each accident to be treated as a data point (rather than using the summary information from each vehicle make/model as a data point).

This database included over 39,000 single vehicle accidents of which 4,910 were rollover accidents. Several models were developed to relate vehicle metrics and accident conditions. Analysis was conducted at both the accident level and make/model level. At the accident level, the ability of the models to predict rollover versus nonrollover was found to be dependent on stability factor and where the accident occurred, urban or rural. The models were used to predict rollover rates at the make/model level. The index of agreement (R^2) exceeded 0.9 when stability factor was included in the regression, but dropped to approximately 0.5 when stability factor was removed from the analysis. Mengert's plots of the actual versus predicted rollover rate using his 11-factor model showed excellent relationships between rollover rate and stability factor.

These results verified the importance of controlling for confounding differences in vehicle use and driver demographics, and again showed that the stability factor was associated with rollover propensity.

Salvatore, Mengert, DiSario, and Walter expanded the analysis by including pickup trucks and vans in the analysis. Unfortunately, the work was not completed because of the death of the primary author. However, the results they presented suggested that there might be vehicle or driver factors that were inadequately controlled for in the analysis, and that these factors were associated with the particular class to which a vehicle belonged, i.e., passenger car, utility vehicle, pickup truck, or van.

Also, analyses of data from CARDfile and the Fatal Accident Reporting System (FARS) were performed by the agency in response to the Wirth petition. One interesting result is the significant correlations that were found between rollover accident involvement rates and vehicle wheelbase. These are documented in Reference 4, (referred to previously) and in a report by A.C. Malliaris (Reference 10). Malliaris found that reducing wheelbase at a fixed vehicle weight leads to a significant increase in fatal rollover accident involvement, whereas reducing the vehicle weight at a fixed wheelbase leads to a significant reduction in fatal rollover accident involvement.

Unlike the rollover stability factor, whose correlation with rollover accident involvement rate "makes sense", the correlation with wheelbase does not have such an intuitive relationship with the rollover phenomenon. Several possible explanations have been put forth to explain this wheelbase-to-rollover accident involvement correlation. Perhaps this relationship is due to a correlation of wheelbase with vehicle pre-crash stability, pre-crash condition and/or skid type mentioned above.

It has been hypothesized that the wheelbase is acting as a surrogate for the vehicle's yaw stability characteristic. Such a hypothesis is not unreasonable given that vehicles with longer wheelbases have higher yaw moments of inertia and both factors, wheelbase and yaw moment of inertia, influence a vehicle's yaw damping and yaw stability. If the hypothesis of a relationship between wheelbase and directional stability is valid, the connection to an increased likelihood of rollover is supported by results documented in a report by Malliaris, Nicholson, Hedlund and Scheiner (Reference 11) which indicated a relationship between loss of stability and an increased likelihood of rollover. In that report, an analysis of data from NHTSA's National Crash Severity Study found that a vehicle's pre-crash condition in single vehicle accidents was related to the likelihood of that vehicle's rolling over in the accident. The pre-crash condition of "skidding sideways" existed in about 56 percent of passenger car single vehicle rollover crashes, but in only 29 percent of all passenger car single vehicle accidents. For light trucks and vans, the "skidding sideways" pre-crash condition was indicated in about 52 percent of single vehicle rollovers, in only 34 percent of all single vehicle accidents, and the "spin" pre-crash condition was indicated in about 9 percent of single vehicle rollovers, but in only 3.4 percent of all single vehicle crashes. For passenger cars, the lighter cars (less than 3500 pounds curb weight), which would also tend to have shorter wheelbases, were 2.2 times more likely to have a pre-crash condition of skidding sideways than were the heavier cars.

Another explanation of the relationship between rollover propensity and wheelbase is that wheelbase is related to a vehicle's roll stability measurement, because of the general geometric relationship between track width and wheelbase with respect to vehicle size. Also, a causal relationship may exist between rollover accident involvement and critical sliding velocity, and the correlation between a vehicle's wheelbase and its roll moment of inertia, which is a primary factor in the critical sliding velocity, may result in the wheelbase to rollover accident involvement correlation. However, more analyses and testing are needed to verify these hypotheses. Reference 4 includes additional discussion of the level of understanding and the unanswered questions that existed at the initiation of this program.

The effort by Salvatore et al. and those by agency staff motivated the work reported here. A larger number of explanatory factors were considered, a larger number of vehicle models were included, additional accident data from states were used, and additional vehicle design factors were measured and evaluated in statistical analyses for their association with rollover propensity.

Again, vehicle design measures (the stability factor and other stability measures) were found to be statistically useful in estimating the rollover propensity that remained, after controlling for driver and vehicle use factors.

There is remarkable consistency in the results of all of these analyses done over the past three years. Each study shows that confounding non-vehicle factors are important in understanding rollover propensity, but that there is a large portion of the remaining problem that is associated with vehicle factors related to vehicle rollover stability. This association is not surprising since it is consistent with engineering studies of what happens during a rollover. Where the statistical analysis is especially useful is in verifying that the relationship exists, even after confounding factors have been controlled for, quantifying the effect of rollover propensity on safety. Also, such analyses assist in projecting the likely benefits of any changes that manufacturers might make.

1.4 CURRENT AGENCY ACTIVITIES

The agency's recent activities have been directed at improving its understanding of rollover accident causation by expanding the number of parameters that are examined for possible correlation with a vehicle's rollover propensity, and increasing the number and diversity of the vehicles for which vehicle parameters are examined.

The remainder of the report is organized as follows:

> Section 2 discusses the background and history of the agency's past rulemaking and defect investigation actions related to rollover of light duty vehicles.
>
> Section 3 discusses the vehicles that were selected for inclusion in these analyses and the process used in their selection.
>
> Section 4 discusses the vehicle rollover stability metrics that were included in these analyses, the procedures used in their measurement, and the errors associated with their measurement or the measurement of parameters involved in their calculation.
>
> Section 5 discusses the generation of the accident databases used in the RO/SVA rate analyses, the various statistical analysis techniques used and the results of those analyses.

Section 6 discusses the vehicle registration data that was used to estimate vehicle exposure based on vehicle population, the method used to calculate vehicle population estimates from that data and results of analyses of accident data using registered vehicle years as the exposure measure.

Section 7 discusses the dynamic directional control and stability data, the method used in calculating that data and analyses that are planned using that data.

Section 8 discusses the various rulemaking alternatives that are available to the agency to address the rollover safety issue, and discusses the implications of the results of the accident data analyses on those rulemaking alternatives. Also discussed are additional accident data gathering, vehicle testing and data analyses that are planned to further support the agency's rulemaking activities.

2.0 PREVIOUS AGENCY ACTIVITIES RELATED TO ROLLOVER

The following discussion reviews the history and background of previous rulemaking and defect investigation actions taken by NHTSA concerning the rollover safety of light duty vehicles.

2.1 PREVIOUS RULEMAKING ACTIVITIES

2.1.1 Advance Notice of Proposed Rulemaking

In 1973, the agency issued an Advance Notice of Proposed Rulemaking (ANPRM) on Rollover Resistance, Docket 73-10; Notice 1. This ANPRM was primarily directed toward obtaining comments on the development of a test procedure, test conditions and performance requirements to evaluate "vehicle rollover tendencies on smooth, dry pavement." After reviewing the comments to that notice and after conducting several research studies related to vehicle control and stability, the agency decided to discontinue activity in this area. One study titled "Development of Vehicle Rollover Maneuver", concluded that although a vehicle's rollover resistance is dependent on its stability factor "to the first order", that resistance to rollover "can, however, be degraded by other design and operational features under real-life performance conditions." At that time, the agency decided that until the influence of those other factors on real world accidents was better understood, agency action could not be justified.

2.1.2 Petitions for Rollover Prevention Rulemaking

In September 1986, the National Highway Traffic Safety Administration (NHTSA) received a petition (Reference 1) from Congressman Timothy E. Wirth (now Senator Wirth) to issue a Federal Motor Vehicle Safety Standard (FMVSS) to "limit the rollover propensity of passenger automobiles, utility vehicles, and pickup trucks."

That petition requested that the agency take the following actions:

1. Propose an FMVSS to require that the rollover propensity of light duty vehicles, including passenger cars, light trucks and multipurpose passenger vehicles (MPV), be limited by requiring that they have a minimum stability factor, defined as the vehicle's half-track width divided by the vehicle's center of gravity height, of a specified value. The petitioner recommended that the agency consider a value of 1.2 for that minimum stability factor.

2. Conduct a defect investigation of those existing light duty vehicles whose stability factor does not meet the minimum required by the above FMVSS.

3. Obtain and publish stability factor information for vehicles being manufactured for sale in the U.S. and make it available to the public.

4. Immediately warn the owners of those vehicles with the greatest propensity to rollover of the limits of these vehicles and give them information as to steps that they can take to prevent death and injury.

The petitioner alleged that the rollover propensity of vehicles whose stability factor is less than 1.2 is so great and that the relative numbers of deaths and injuries are so high that their manufacture should be prohibited. This conclusion is based on an analysis contained in the Robertson/Kelley report (Reference 8) which was submitted with the Wirth petition. That petition was denied in April 1988.

In June, 1988, the Consumers Union of United States, Inc. (CU), submitted a petition for rulemaking (Reference 2) to the agency that requested the establishment of "a minimum stability standard to protect against unreasonable risk of rollover." That petition was granted in September 1988, and it is that action which the current rulemaking activity addresses.

2.2 DEFECT INVESTIGATION PETITIONS

In October 1979, and in July 1981, the Office of Defects Investigation received two petitions to conduct investigations concerning the stability of Jeep CJ-5 vehicles. Both of these petitions were denied in part due to a lack of specific information indicating that there is a distinct vehicular defect that causes rollover accidents.

In February 1988, the Office of Defects Investigation received a petition to conduct investigations concerning the stability of Suzuki Samurai vehicles. After a review of accident data, that petition was denied. That denial was based in part on the results of an analysis of accident data which indicated that the involvement of Suzuki Samurai vehicles in fatal rollover accidents was no greater than other similar vehicles. However, those same results indicated that Ford Bronco II vehicles seemed to have a significantly higher rate of involvement in fatal rollover accidents. As a result, a defect investigation petition regarding Ford Bronco II vehicles, that was received in August 1988, was granted in February 1989. Another petition for defect investigation concerning Jeep CJ vehicles was received in 1990 and, after an accident data analysis which was more exhaustive than any that had previously been conducted, the Jeep CJ petition was denied in October 1990 (petition denial- Reference 12, Technical Report supporting denial- Reference 13). The Ford Bronco II case was closed in November 1990 (Engineering Analysis Closing Report- Reference 14). Both investigations were closed in part due to the lack of data to support action against any vehicle. Based on analysis of accident data, these vehicles were statistically no different than many other vehicles in the utility vehicle population. Refer to references 12, 13, and 14 for additional details.

3.0 VEHICLE SELECTION

This section discusses the first step in the testing, data gathering and analysis activities performed during this rulemaking program. For the vehicles selected, accident data and vehicle parameters and performance characteristics were gathered to be used in various statistical analyses of the relationship between vehicle factors and rollover accident involvement.

3.1 INTRODUCTION

The selection of the vehicle sample to be used in the accident data versus vehicle metrics analysis was performed prior to the efforts to generate the accident data base and before the testing program to determine the vehicle metrics. The vehicle sample was selected to encompass all classes of light vehicles, i.e., all ranges of passenger cars; small and large pickup trucks; mini and full size vans; and open, small, and large utility vehicles. They were selected to encompass the entire range of market class designations, usage classifications, and size classes. For each of these classifications, an attempt was made to obtain 1) a set representative of the full spectrum of rollover rates, and 2) a set representative of the full spectrum of vehicle parameters. The vehicles selected encompassed the lowest to the highest rollover to single vehicle accident rates. With regard to vehicle parameters, the selections were made to include the complete range of vehicles from the low slung sports cars and full size sedans to the tall narrow utility vehicles with short, medium and long wheelbases.

3.2 VEHICLE SELECTION CRITERIA AND PROCEDURE

A summary of single vehicle accident and single vehicle rollover accident counts was prepared using the Maryland portion of the CARDfile accident data base for 1986 through 1988. This list was then reviewed using the following criteria (each of the criteria is followed by a short description of the basis for it).

1. MODEL YEARS 1981 OR LATER: Model years previous to 1981 did not have a standardized VIN (Vehicle Identification Number) scheme.

2. ADEQUATE DATA AVAILABLE: Data from the Maryland 1986-1988 CARDfile was used to determine the exposure of different vehicles. The minimum number of observations was set at 20.

3. VEHICLES WITH HIGH ROLLOVER PROPENSITY: Evaluate the rollover rates of these vehicles relative to the rest of the sample population.

4. HIGH CURRENT SALES VOLUMES: Vehicles which represent a growing segment of the current vehicle fleet.