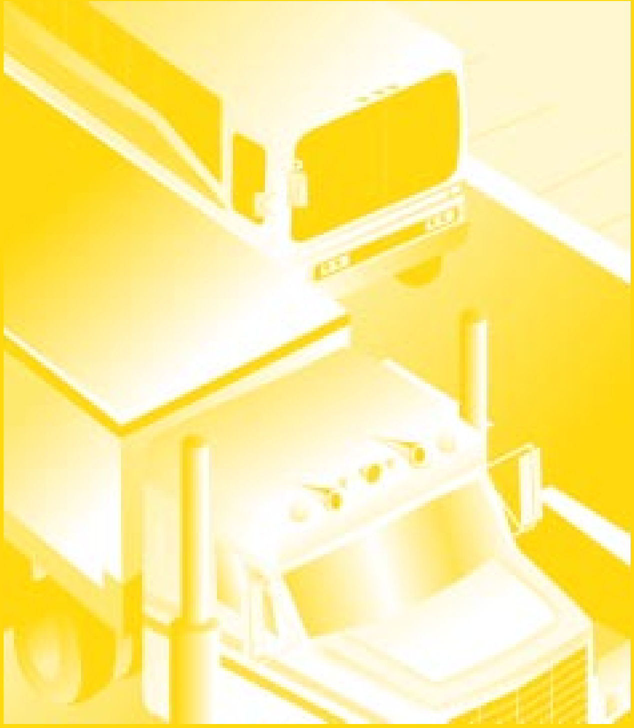
NTSB/SR-02/03
PB2002-917005

Safety Report

Evaluation of the Rollover Propensity of 15-passenger Vans



National Transportation Safety Board
Washington, D.C.

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NTSB/SR-02/03
PB2002-917005
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National Transportation Safety Board
490 L'Enfant Plaza, S.W.
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National Transportation Safety Board. 2002. *Evaluation of the Rollover Propensity of 15-passenger Vans*. Safety Report NTSB/SR-02/03. Safety Study NTSB/SR-02/03. Washington, DC.

Abstract: Fifteen-passenger vans, which make up about 0.25 percent of the passenger vehicle fleet in the United States, are frequently used to transport school sports teams, van pools, church groups, and other groups. Although they are involved in a proportionate number of fatal accidents compared to their percentage in the fleet, they are involved in a higher number of single-vehicle accidents involving rollovers than are other passenger vehicles. Various factors have been associated with 15-passenger van rollover, particularly occupancy level and vehicle speed. Fully loading or nearly loading a 15-passenger van causes the center of gravity to move rearward and upward, which increases its rollover propensity and could increase the potential for driver loss of control in emergency maneuvers. The National Highway Traffic Safety Administration has been evaluating vehicle rollover for several years. The agency has initiated rulemaking activities concerning vehicle rollovers, established a rollover resistance rating system, and is currently examining dynamic testing procedures; however, these programs have not been extended to 15-passenger vans. As a result of this safety report, the National Transportation Safety Board issued safety recommendations to the National Highway Traffic Safety Administration and to the manufacturers of 15-passenger vans.

Contents

Conversion Factors for the International System of Units (SI)

To convert from	***into***	***multiply by***
feet (ft)	meters (m)	0.3048
inches (in)	centimeters (cm)	2.54
miles (U.S. statute)	kilometers (km)	1.609344
pounds (lb)	kilograms (kg)	0.4535924

Acronyms and Abbreviations

ANPRM	advance notice of proposed rulemaking
CFR	*Code of Federal Regulations*
CG	center of gravity
ESC	electronic stability control
FARS	Fatal Analysis Reporting System
FMVSS	*Federal Motor Vehicle Safety Standards*
FR	*Federal Register*
GVWR	gross vehicle weight rating
NAS	National Academy of Sciences
NCAP	New Car Assessment Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
SSF	static stability factor
TREAD	Transportation, Recall Enhancement, Accountability, and Documentation Act of 2000
VIN	vehicle identification number

Executive Summary

Fifteen-passenger vans, which make up about 0.25 percent of the passenger vehicle fleet in the United States, are frequently used to transport school sports teams, van pools, church groups, and other groups. Although they are involved in a proportionate number of fatal accidents compared to their percentage in the fleet, they are involved in a higher number of single-vehicle accidents involving rollovers than are other passenger vehicles. Various factors have been associated with 15-passenger van rollover, particularly occupancy level and vehicle speed. Because these vans are designed to carry 15 passengers, the Safety Board is particularly concerned about the relationship between occupancy level and vehicle rollover. Fully loading or nearly loading a 15-passenger van causes the center of gravity to move rearward and upward, which increases its rollover propensity and could increase the potential for driver loss of control in emergency maneuvers.

The National Highway Traffic Safety Administration (NHTSA) has been evaluating vehicle rollover for several years. NHTSA has initiated rulemaking activities concerning vehicle rollovers, established a rollover resistance rating system, and is currently examining dynamic testing procedures; however, these programs have not been extended to 15-passenger vans. The Safety Board is concerned that NHTSA has not included 15-passenger vans in the dynamic testing or proposed rollover resistance ratings for this class of vehicle, given their high rate of rollover involvement in single-vehicle accidents, particularly under fully or nearly loaded conditions.

As a result of this safety report, the National Transportation Safety Board issued new safety recommendations to the National Highway Traffic Safety Administration and the manufacturers of 15-passenger vans.

Background

About 2:30 p.m. on February 10, 2000, a Ford 1999 E-350 XLT 15-passenger van carrying a track coach, an athletic trainer, and eight student athletes, departed Prairie View A&M University near Hempstead, Texas. A 21-year-old student athlete was driving, and the van was traveling northbound on a two-lane highway near Karnack, Texas. About 6:50 p.m., the van was traveling about 82 mph as it approached a northbound Jeep Cherokee that was signaling to turn left near the first entrance to a convenience store parking lot. A van occupant stated that the Jeep slowed while signaling to turn left, did not complete its left turn into the first entrance, and continued traveling forward. When the van driver attempted to pass the Jeep on the left, the Jeep began its left turn into the second entrance of the convenience store. The van driver tried to reverse the passing action by swerving the van sharply to the right, and the van went out of control. No contact between the van and the Jeep occurred. The van yawed right, then left, dropped off the pavement edge, and began overturning. The van traveled a total of about 490 feet from where it began its yaw to where it came to its final resting position; the distance traveled from where it hit the pavement edge to where it came to rest was about 265 feet. Evidence on the roadway indicated that the van overturned three full turns before coming to rest inverted. The accident resulted in fatal injuries to the van driver and three of five ejected occupants. The remaining six passengers, including two other ejected occupants, sustained serious injuries.[1]

In recent years, the Safety Board has investigated other highly visible accidents involving 15-passenger vans, such as the one near Karnack, Texas.[2] Although there are many factors involved in such accidents, the Safety Board is currently concerned about the propensity of 15-passenger vans to roll over.[3]

Although the Safety Board has previously addressed the safety of large vans,[4] it has not addressed the rollover propensity of the vehicles. Throughout the 1970s and

[1] National Transportation Safety Board, *Single-Vehicle Rollover, Texas State Highway 43, Near Karnack, Texas, February 10, 2000*, Highway Accident Brief NTSB/HAB-02/03 (Washington, DC: NTSB, 2002).

[2] For example, Henrietta, Texas, May 8, 2001 (NTSB Accident No. HWY-01-FH-022); and Randleman, North Carolina, July 1, 2001 (NTSB Accident No. HWY-01-FH-027).

[3] In this report, the Safety Board limits discussion to the rollover propensity of 15-passenger vans. Other safety factors such as driver qualifications, occupant protection, and tire blowout will be addressed in its accident investigations.

[4] For example, (a) *Pattison Head Start Center School Van Run Off Bridge and Fire Near Hermanville, Mississippi, December 17, 1981*, Highway Accident Report NTSB/HAR-82/05 (Washington, DC: NTSB, 1982). (b) *Crashworthiness of Large Poststandard School Buses*, Safety Study NTSB/SS-87/01 (Washington, DC: NTSB, 1987). (c) *Performance of Lap/Shoulder Belts in 167 Motor Vehicle Crashes*, Safety Study NTSB/SS-88/02 and NTSB/SS-88/03 (Washington, DC: NTSB, 1988), 2 Vols. (d) *Crashworthiness of Small Poststandard School Buses*, Safety Study NTSB/SS-89/02 (Washington, DC: NTSB, 1989). (e) *Pupil Transportation in Vehicles Not Meeting Federal School Bus Standards*, Special Investigation Report NTSB/SIR-99/02 (Washington, DC: NTSB, 1999).

1980s, the Safety Board issued recommendations to the National Highway Traffic Safety Administration (NHTSA) and other organizations on occupant protection, emergency egress, and crashworthiness of vans. More recently, the Safety Board issued recommendations directed at the use of large vans for school transportation and recommended that children should be transported in vehicles that meet Federal school bus standards or the equivalent. (Appendix A lists previously issued Safety Board recommendations and their current status.)

The Fleet and Accidents

Fifteen-passenger vans represent about 0.25 percent of the passenger fleet in the United States.[5] Historically, Dodge and Ford have manufactured the majority of 15-passenger vans, with Chevrolet and GMC making up the remainder of the fleet. The following model year 2002 makes and models are available with seating for 15 passengers: Chevrolet Express G3500 Extended; Ford Econoline Wagon E-350 XL Extended; Ford Econoline Wagon E-350 XLT Extended; Dodge Ram Wagon 3500 Maxi; and GMC Savana G3500 Extended (appendix B contains more detailed vehicle information). Dodge, however, ceased production of 15-passenger vans in June 2002.

Analysis of Fatal Analysis Reporting System (FARS) data for 1991–2000 shows that 15-passenger vans are involved in about 0.22 percent of the fatal accidents (1,204 vans of 557,786 vehicles) and 0.24 percent of the single-vehicle fatal accidents (499 vans of 209,447 vehicles).[6] This is proportionate to the percent of 15-passenger vans in the passenger vehicle fleet (0.25 percent); however, 15-passenger van accidents are involved in a higher percentage of rollover accidents than are passenger cars and smaller vans. About 52 percent of the 15-passenger vans involved in single-vehicle, fatal accidents experience a rollover (as a primary or subsequent event) compared to 33 percent of the passenger automobiles involved in such accidents (figure 1). Additionally, 81 percent of the 15-passenger van occupant fatalities occur in single-vehicle rollover accidents (figure 2).

[5] U.S. Department of Transportation, National Highway Traffic Safety Administration, "15-Passenger Vans Involved in Fatal Crashes: Statistical Fact Sheet," Item in press release packet (Washington, DC: NHTSA, April 15, 2002). In contrast, the Bureau of Transportation Statistics reports that in 1998 there were 215,496,003 registered vehicles: 131,838,538 registered passenger vehicles; 3,879,450 motorcycles; 71,330,205 other 2-axle 4-tire vehicles; 5,734,925 single-unit trucks; 1,997,345 combination trucks, and 715,540 buses (U.S. Department of Transportation, Bureau of Transportation Statistics, *National Transportation Statistics 2000*, BTS01-01 (Washington, DC: BTS, April 2001)).

[6] FARS is maintained by the National Highway Traffic Safety Administration (NHTSA) of the U.S. Department of Transportation. The database is a census of all fatal crashes involving a motor vehicle traveling on a trafficway customarily open to the public and results in the death of a person (occupant of a vehicle or a nonmotorist) within 30 days of the crash.

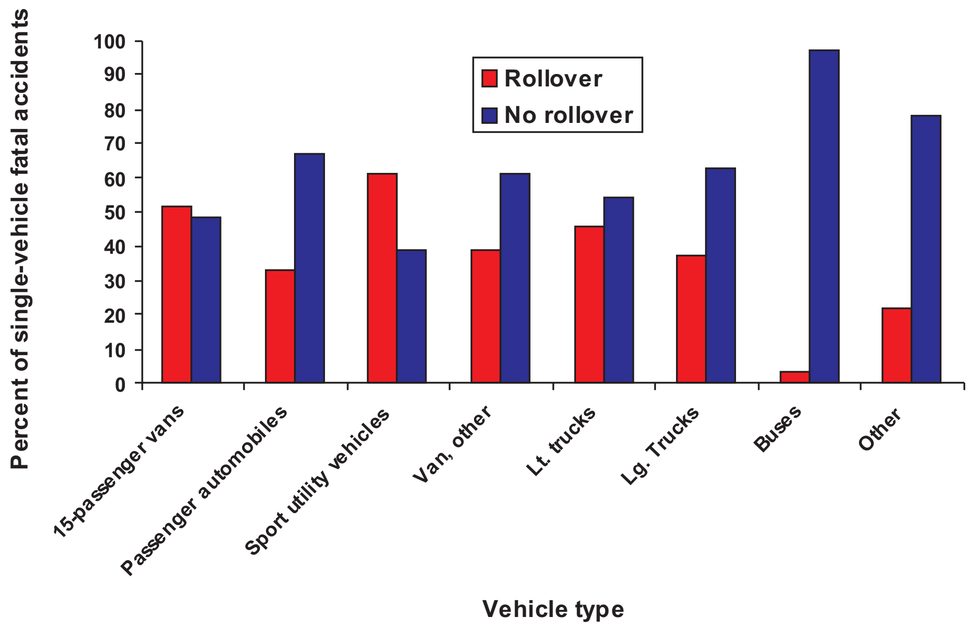

Figure 1. Percent of single-vehicle fatal accidents by vehicle type and rollover involvement, 1991–2000. (Data source: Fatality Analysis Reporting System of the National Highway Traffic Safety Administration.)

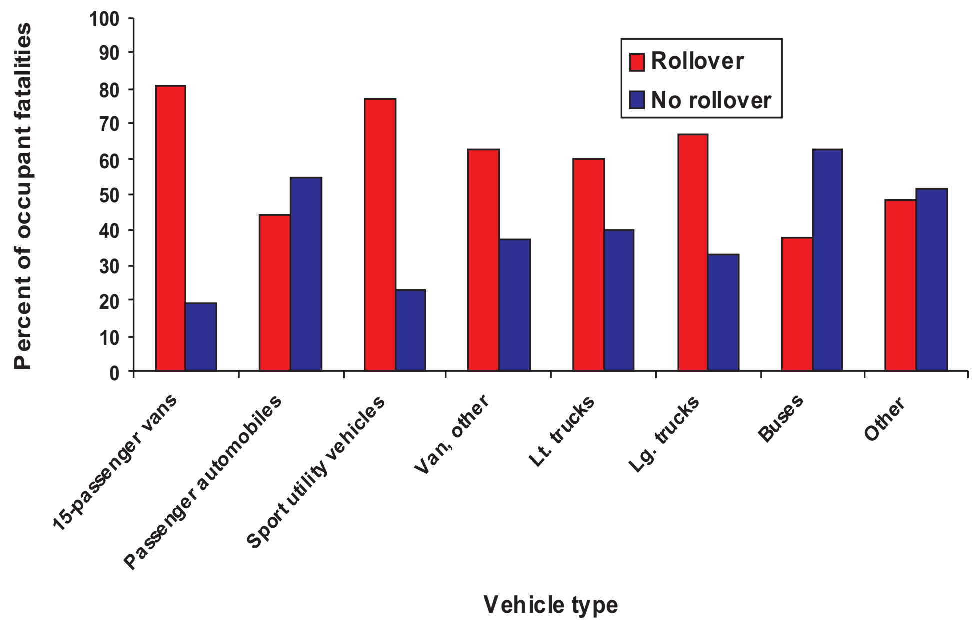

Figure 2. Percent of occupant fatalities by vehicle type and rollover involvement, 1991–2000. (Data source: Fatality Analysis Reporting System of the National Highway Traffic Safety Administration.)

Rollover Propensity

Research has shown that among other factors, accidents in rural areas, vehicles with higher occupancy levels, vehicle speed, driver alcohol/drug involvement, and younger driver age are associated with rollover propensity.[7] However, much of the previous work was done on passenger vehicles and excluded 15-passenger vans.[8] The Safety Board thus conducted analyses on the FARS data for single-vehicle, fatal 15-passenger van accidents that occurred from 1991 through 2000 and found similar results, suggesting that occupancy level and vehicle speed are consistently associated with van rollover (figures 3 and 4).[9] The analyses are described and discussed in appendix C.

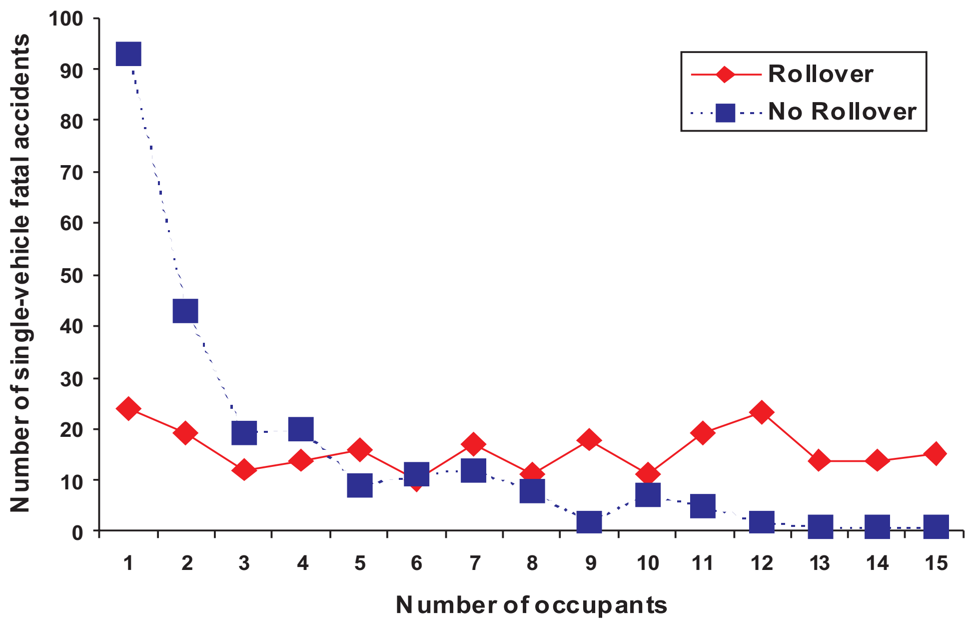

Figure 3. Number of single-vehicle fatal accidents by number of occupants and rollover involvement, 1991–2000. (Data source: Fatality Analysis Reporting System of the National Highway Traffic Safety Administration.)

[7] (a) W. Riley Garrott, Barbara Rhea, Rajesh Subramanian, and Gary J. Heydinger, *The Rollover Propensity of Fifteen-Passenger Vans*, Research Note (Washington, DC: NHTSA, April 2001). (b) T.M. Klein, *A Statistical Analysis of Vehicle Rollover Propensity and Vehicle Stability*, SAE Tech. Pap. 920584 (Warrendale, PA: Society of Automotive Engineers, 1992) 135-150. (c) "Consumer Information Regulations; Federal Motor Vehicle Safety Standards; Rollover Resistance; Final Rule [49 CFR Part 575]," *Federal Register* Vol. 66, No. 9, dated January 12, 2001: 3388-3437.

[8] NHTSA informed Safety Board staff on June 4, 2002, that the agency is currently preparing a technical report that examines single-vehicle, fatal 15-passenger van rollover accidents. According to NHTSA, the FARS data analysis has been extensive and evaluates the effect of several factors such as speed, number of vehicle occupants, vehicle maneuvers, age of the driver, and alcohol involvement on vehicle rollover. NHTSA expects to publish this report in 2002.

[9] The Safety Board notes that the validity of data for vehicle speed is often questioned.

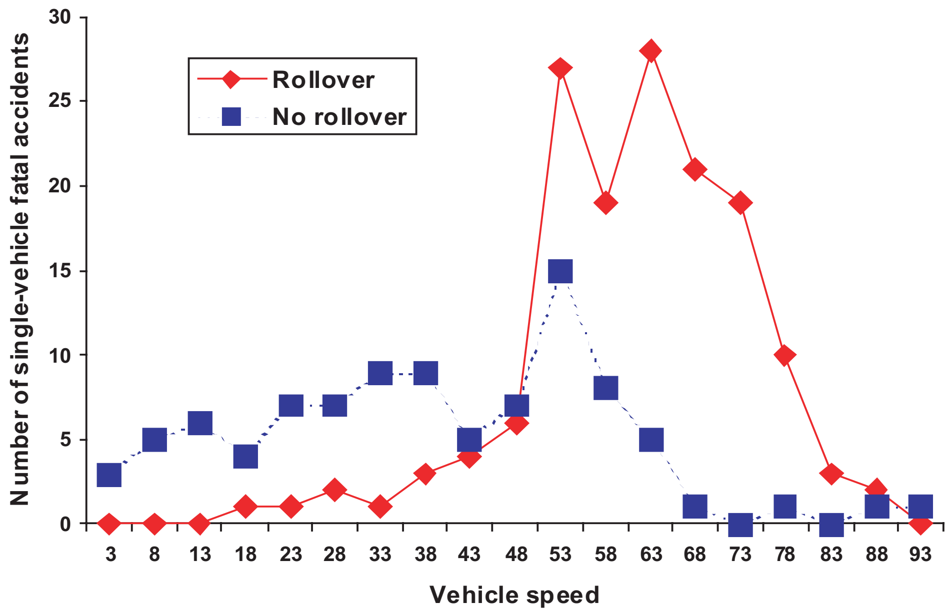

Figure 4. Number of single-vehicle fatal accidents by vehicle speed and rollover involvement, 1991–2000. (Data source: Fatality Analysis Reporting System of the National Highway Traffic Safety Administration.)

Because these vans are designed to carry 15 passengers, the results relating occupancy level to rollover are particularly disturbing. NHTSA research reported in 2001 that 15-passenger vans with 10 or more occupants had three times the rollover ratio than did those with fewer than 10 occupants.[10] The same analyses conducted by the Safety Board on the FARS data yielded higher rollover ratios for all levels of occupancy levels but similar magnitudes of increase in the rollover ratio when comparing lightly loaded to fully loaded vans (table 1).[11] Fifteen-passenger vans with 10–15 occupants had a rollover ratio of 85.0 percent compared with a ratio of 28.3 percent for vans with fewer than 5 occupants.

[10] (a) Rollover ratio is the number of all single-vehicle rollover accidents divided by the number of all single-vehicle accidents. (b) Garrott and others (2001) conducted their analyses using a subset of NHTSA's State Data System. The State Data System is a census of crashes (fatal, injury, and property-damage) that occur in 17 States (California, Florida, Georgia, Illinois, Indiana, Kansas, Maryland, Michigan, Missouri, North Carolina, New Mexico, Ohio, Pennsylvania, Texas, Utah, Virginia, and Washington).

[11] FARS data for 1991–2000.

Table 1. Number of accidents, rollovers, and rollover ratio by occupancy level of 15-passenger vans in single-vehicle accidents.

Occupancy level	All single-vehicle accidents	All rollovers	Rollover ratio[a] (percent)	Combined rollover ratios for 1 to 9 occupants and for 10 or more occupants (percent)
Results from the 2001 NHTSA analysis[b] (Data source: Subset of NHTSA's State Data System, 1994–1997):				
Fewer than 5	1,815	224	12.3	12.7
5–9	77	16	20.8	
10–15	55	16	29.1	35.4
More than 15	10	7	70.0	
Results from the 2002 NTSB analysis (Data source: FARS data, 1991–2000):				
Fewer than 5	244	69	28.3	39.4
5–9	114	72	63.2	
10–15	113	96	85.0	85.8
More than 15	21	19	90.0	

FARS = Fatality Analysis Reporting System (FARS); NHTSA = National Highway Traffic Safety Administration; NTSB = National Transportation Safety Board.

[a] The number of all single-vehicle rollover accidents divided by the number of all single-vehicle accidents.

[b] W. Riley Garrott, Barbara Rhea, Rajesh Subramanian, and Gary J. Heydinger, *The Rollover Propensity of Fifteen-Passenger Vans*, Research Note (Washington, DC: NHTSA, April 2001).

A simulation study conducted by the NHTSA illustrates some of the adverse effects that loading can have on the handling of 15-passenger vans.[12] The simulations showed that the fully loaded 15-passenger van made a transition from understeer to oversteer as the lateral acceleration increased.[13] Further, under one simulated driving maneuver, the fully loaded van rolled over whereas the lightly loaded (driver only) van did not. NHTSA concluded that the computer simulations illustrated the adverse effects that a fully loaded passenger van can have on its handling properties (sudden transition from understeer to oversteer) and rollover propensity. Adding passengers and cargo to a 15-

[12] Garrott and others, 2001.

[13] A simple test illustrates the concepts of understeer and oversteer. A vehicle is driven around a circle at a constant speed, then the speed is slowly increased. If the vehicle tends to go off the outside of the circle so that the driver must increase steering to maintain the circle, then the vehicle is considered to be an understeer vehicle. If the vehicle tends to go off the inside of the circle so that the driver must reduce steering to maintain the circle, then the vehicle is considered to be an oversteer vehicle. Understeer and oversteer can affect the stability of a vehicle; however, just because a vehicle is an oversteer vehicle does not mean that it is uncontrollable. A more detailed discussion of understeer and oversteer and their impact on stability and control is contained in (a) William F. Milliken and Douglas L. Milliken, "Simplified Steady State Stability and Control," Chapter 5, and "Simplified Transient Stability and Control," Chapter 6 in *Race Car Vehicle Dynamics* (Warrendale, PA: Society of Automotive Engineers, 1995) 123-229 and 231-277; and (b) Thomas D. Gillespie, "Rollover," Chapter 9 in *Fundamentals of Vehicle Dynamics* (Warrendale, PA: Society of Automotive Engineers, 1992) 309-333. The Society of Automotive Engineers' definitions of understeer and oversteer are given in Milliken and Milliken (1995), p. 164.

passenger van causes the center of gravity to move rearward and upward, which increases the vehicle's rollover propensity and could increase the potential for driver loss of control in emergency maneuvers.[14] Details of the NHTSA simulations, and information about vehicle dynamics and the effects of moving the center of gravity rearward and upward, are provided in appendix D.

[14] (a) NHTSA simulations, reported in Garrott and others, 2001. (b) NHTSA press release packet, April 15, 2002. (c) Gillespie (1992) discusses general vehicle dynamics of how increasing the center of gravity height affects rollover.

Activities Pertaining to Vehicle Rollover

Technology

Technology has been developed to assist drivers in maintaining control of the vehicle; for example, antilock brakes, traction control, lane departure systems, and electronic stability control (ESC) systems. Antilock brakes use speed sensors, valves, pumps, and controllers to stop the vehicle in a safe manner. Traction control systems sense when a tire is slipping or losing traction and automatically activate the brakes or slow down engine speed. Lane departure systems typically alert the driver when the vehicle has departed from the driving lane. ESC systems are computer-controlled systems that attempt to stabilize the vehicle by monitoring a vehicle's movement and the direction the driver is steering. If the driver inputs and the vehicle response do not correspond, computer controls intervene to enhance the driver's ability to maintain control of the vehicle by selectively braking individual wheel(s), or changing power applied to the wheels. Future ESC systems will likely include inputs to steering and differential power control to the wheels.

Some of these technologies are currently available on certain motor vehicles, including some sport utility vehicles and minivans. Antilock brakes are currently available on 15-passenger vans, but traction control systems, lane departure systems, and ESC systems are not. Given the rollover propensity of 15-passenger vans, such technological systems may have potential to assist drivers in maintaining control of these vehicles.

Rulemaking Activities

NHTSA Rulemaking Activities

NHTSA originally proposed rulemaking concerning vehicle rollovers in 1973 when it issued an advance notice of proposed rulemaking on minimum performance rollover resistance and periodically has taken rulemaking action since then (table 2); however, there are no rollover standards at present for any highway vehicle. In 2001, NHTSA issued a final rule pertaining to the development of a consumer information rollover resistance rating system based on a static measure of stability (discussed further in the "Consumer Information" section of this report). NHTSA proposed additional rulemaking related to vehicle rollover on October 7, 2002 (*Federal Register* (FR), Vol. 67, No. 194). The notice is a follow-on to NHTSA's request for comments published on July 3, 2001, which announced the agency's plans to evaluate driving maneuver tests for rollover resistance and to develop a dynamic test for the consumer information program. The proposed rule contains information on a dynamic testing protocol, but it does not extend to 15-passenger vans because the *Federal Motor Vehicle Safety Standards* (FMVSS) define a motor vehicle designed to carry more than 10 persons as a bus (Title 49 *Code of Federal Regulations* (49 CFR) Part 571.3).

Table 2. Rulemaking activities of the National Highway Traffic Safety Administration concerning vehicle rollovers.

Year	Activity	Outcome
April 1973	NHTSA published an advance notice of proposed rulemaking (ANPRM) on resistance to rollover.	Terminated.
September 1986	Congressman Wirth petitioned NHTSA to establish a safety standard for rollover resistance by setting a minimum allowable static stability factor (SSF).	Denied.
June 1988	Consumers Union petitioned NHTSA to establish a safety standard to protect occupants against “unreasonable risk of rollover.”	NHTSA embarked on research program but did not proceed with rulemaking.
January 1992	NHTSA issued an ANPRM on various regulatory actions to reduce the frequency of vehicle rollovers and/or the number and severity of injuries resulting from vehicle rollovers.	NHTSA terminated rulemaking in June 1994 to establish a standard and proposed to require manufacturers to label vehicles with information on their rollover stability using either tilt table angle or critical sliding velocity.
September 1994	Congress prohibited NHTSA from requiring vehicle labeling until completion of National Academy of Sciences (NAS) study.	NAS study recommended that NHTSA expand scope of consumer information it provides to the public.
June 1996	NHTSA reopened comment period on proposed labeling rule.	
August 1996	NHTSA was petitioned by the Consumers Union to develop a test of vehicle emergency handling capability and to provide test results on new vehicles to the public as consumer information.	Petition granted. NHTSA began new research program.
June 2000	NHTSA published request for comments on consumer information program that will use the SSF to indicate overall rollover risk in single-vehicle crash.	
November 1, 2000	Congress enacted the Transportation Recall Enhancement, Accountability, and Documentation (TREAD) Act.	NHTSA expands dynamic testing program.
January 12, 2001	Final rule published on Consumer Information Regulations adding rollover resistance.	Rollover resistance ratings available beginning with model year 2001 vehicles.
July 3, 2001	NHTSA published request for comments on developing dynamic test to add to consumer information program.	
October 7, 2002	NHTSA published an NPRM on its dynamic testing protocol and proposed alternatives for using the dynamic test results in consumer information on the rollover resistance of new vehicles.	

Congressional Activity

The Transportation Recall Enhancement, Accountability, and Documentation (TREAD) Act was enacted on November 1, 2000. Among other requirements, it mandated NHTSA to develop dynamic tests of vehicle rollover by November 1, 2002, and to conduct rulemaking to determine how best to disseminate test results to the public.[15] This requirement applies to motor vehicles, including passenger cars, multipurpose passenger vehicles, and trucks with a gross vehicle weight rating of 10,000 pounds or less; the requirement does not apply to 15-passenger vans because the FMVSS define such vehicles as buses.

Consumer Information From NHTSA

Rollover Risk Rating System

In 2001, NHTSA's New Car Assessment Program (NCAP) was expanded to include consumer information on the rollover risk of passenger cars, and of light, multipurpose passenger vehicles and trucks.[16] The expansion does not extend to vehicles that carry more than 10 passengers. The rollover resistance rating system, available beginning with model year 2001 vehicles, is shown in table 3. The ratings estimate the risk of rolling over in a single-vehicle crash; the system does not predict the likelihood of such a crash.

Table 3. Rollover resistance ratings for vehicles in a single-vehicle crash, available beginning with model year 2001 vehicles.

Vehicle rating	Crash rollover risk
Five stars	Less than 10 percent
Four stars	10–20 percent
Three stars	20–30 percent
Two stars	30–40 percent
One star	Greater than 40 percent

Source: National Highway Traffic Safety Administration, New Car Assessment Program.

[15] The NPRM published by NHTSA on October 7, 2002 (*Federal Register*, Vol. 67, No. 194) was in response to the TREAD Act.

[16] The NCAP program was established in 1978 with the purpose of providing consumers with a measure of the relative safety potential of vehicles in frontal crashes. NCAP information includes results from frontal and side crash tests as well as rollover resistance ratings. The ultimate goal of the program is to improve occupant safety by providing market incentives for vehicle manufacturers to voluntarily design their vehicles to better protect occupants in a crash rather than by regulatory devices.

The rollover resistance rating is based on the static stability factor (SSF). The SSF is generated by dividing a vehicle's track width (distance between the wheels from side to side, denoted by t) by twice the vehicle's center of gravity height (SSF=t/2h).[17] The SSF used for the NCAP rollover resistance rating is based on measurements for a driver-only load condition.

Static measures of stability (that is, SSF, tilt table ratio, and critical sliding velocity[18]) have been shown to be important factors in understanding vehicle rollover.[19] NHTSA, in its 2001 research, compared static stability factors of two 7-passenger vans and a 15-passenger van under lightly loaded and fully loaded conditions. Although the SSF decreased for all three vans from the lightly loaded condition to the fully loaded condition, the change was the greatest for the 15-passenger van: the SSF decreased 3 percent for one 7-passenger van, 5 percent for the other 7-passenger van, and 11 percent for the 15-passenger van.

In response to a 2001 congressional mandate,[20] the National Research Council of the National Academy of Sciences (NAS) completed a review of NHTSA's rollover resistance rating system.[21] It concluded that the SSF captures important vehicle characteristics related to rollover propensity and is strongly correlated with the outcome of actual crashes (rollover or no rollover). However, it also concluded that the NCAP rollover resistance rating system, which uses numbers of stars to indicate rollover risk, is likely to be of limited use in presenting practical information to the public because (1) there were shortcomings in the statistical methodology used to derive the average rollover curve; (2) the approximation of the rollover curve by five discrete categories is coarse and does not adequately convey the degree of resolution among vehicles provided by available crash data; and (3) limited procedures used by NHTSA to evaluate the rating system raise questions about the system's effectiveness. The NAS report recommended that

> 1. NHTSA should vigorously pursue its ongoing research on driving maneuver tests for rollover resistance, mandated under the TREAD Act, with the objective of developing one or more dynamic tests that can be used to assess transient vehicle behavior leading to rollover.
>
> 2. In the longer term, NHTSA should develop revised consumer information on rollover that incorporates the results of one or more dynamic tests on transient vehicle behavior to complement the information from static measures, such as SSF.

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[17] Typical SSF values for passenger cars range from 1.25 to 1.45 or more. Typical SSF values for SUVs range from 1.04 to 1.24.

[18] The tilt table angle is the angle at which a vehicle will begin to tip off a gradually tilted platform. The critical sliding velocity is the minimum velocity needed to trip a vehicle that is sliding forward.

[19] (a) Garrott and others, 2001. (b) Klein, 1992. (c) NHTSA's final rule on rollover resistance (*Federal Register* Vol. 66, No. 9, dated January 12, 2001: 3388-3437).

[20] Department of Transportation and Related Agencies Appropriations Act of 2001 (Public Law 106–346).

[21] Transportation Research Board, National Research Council, *An Assessment of the National Highway Traffic Safety Administration's Rating System for Rollover Resistance*. (Prepublication copy).

3. NHTSA should investigate alternative options for communicating information to the public on SSF and its relationship to rollover. In developing revised consumer information, NHTSA should:

- Use a logit model as a starting point for analysis of the relationship between rollover risk and SSF.[22]
- Consider a higher-resolution representation of the relationship between rollover risk and SSF than is provided by the current five-star rating system.
- Continue to investigate presentation metrics other than stars.
- Provide consumers with more information, placing rollover risk in a broader context of motor vehicle safety.

NHTSA launched a vehicle dynamic rollover propensity research program in the late 1990s. Phases I, II, and III evaluated a broad range of dynamic testing maneuvers that might induce on-road, untripped rollovers. The program tested 12 vehicles (3 passenger cars, 3 light trucks, 3 sport utility vehicles, and 3 vans[23] but no 15-passenger vans) using candidate test maneuvers designed to determine fundamental vehicle handling properties and untripped rollover propensity measured by two-wheel lift. The program also studied pulse brake automation in rollover maneuvers.[24]

As a result of the TREAD Act of 2000, NHTSA is conducting phases IV, V, and VI of its dynamic rollover propensity program. These phases of research will continue to look at additional testing maneuvers and examine various influences on rollover testing (for example, the effect of outriggers, cold and hot weather testing, and surface effects). The October 2002 NPRM describes NHTSA's proposed test maneuvers and two load conditions. NHTSA has informed the Safety Board that 15-passenger vans will not be included in this testing because the FMVSS define these vehicles as buses.

[22] A logit model is a binary response model where the probability of an event occurring (that is, rollover) is estimated.

[23] The vans were an 8-passenger 1998 Ford E-150 Club Wagon, an 8-passenger 1998 Chevrolet Astro, and a 7-passenger 1998 Dodge Caravan. Each vehicle was tested with a driver, instrumentation, and outriggers.

[24] (a) W. Riley Garrott, J. Gavin Howe, and Garrick Forkenbrock, *An Experimental Examination of Selected Maneuvers That May Induce On-road Untripped, Light Vehicle Rollover: Phase II of NHTSA's 1997–1998 Vehicle Rollover Research Program*, Report No. TBD (Washington, DC: NHTSA, July 1999). (b) W. Riley Garrott, "NHTSA Research on Dynamic Rollover Tests," presented at the session "Crash Avoidance II: Rollover, Tires, Handling, and Stability," SAE/Government/Industry Meeting, May 13–15, 2002; Washington, DC.

Consumer Advisories

Following several high publicity 15-passenger van accidents, NHTSA published a consumer advisory in April 2001. The advisory contained a cautionary warning to users of 15-passenger vans because of an increased rollover risk under certain conditions. NHTSA issued a second consumer advisory in April 2002, making the following safety tips:

- Protect passengers with a seat belt policy;
- Select an experienced driver;
- Make sure the driver is not fatigued or driving too fast;
- Properly maintain your tires; and
- Avoid placing any load on the roof—that increases the chance of rollover.

Summary

Fifteen-passenger vans, which make up about 0.25 percent of the passenger vehicle fleet, are frequently used to transport school sports teams, vanpools, church groups, and other groups. Although they are involved in a proportionate number of fatal accidents compared to their percentage in the fleet, they are involved in a higher rate of single-vehicle accidents involving rollovers than are other passenger vehicles.

Various factors have been associated with vehicle rollover, particularly occupancy level and vehicle speed. Both the FARS data and a subset of State census data show that the rollover rate for fully loaded or nearly loaded 15-passenger vans is about three times the rollover ratio of vans with fewer than 5 passengers. Further, statistical analyses have shown that increased occupancy level and vehicle speed (measured by either travel speed or posted speed limit) consistently predict the increased likelihood of 15-passenger van rollover. Other accident characteristics have also been shown to be related to vehicle rollover but with less reliability.

Because these vans are designed to carry 15 passengers and frequently are used by various organizations to transport many passengers to activities, the Safety Board is particularly concerned about the relationship between occupancy level and vehicle rollover. Fully loading or nearly loading a 15-passenger van causes the center of gravity to move rearward and upward, which increases the vehicle's rollover propensity and could increase the potential for driver loss of control in emergency maneuvers. Simulations conducted by NHTSA illustrate how fully loading a 15-passenger van could adversely affect the vehicle's handling properties in extreme maneuvers.

NHTSA has been evaluating vehicle rollover for several years. At the direction of the TREAD Act of 2000, NHTSA expanded its dynamic testing on several vehicles, but it does not include 15-passenger vans. Further, although NHTSA has initiated rulemaking activities concerning vehicle rollovers, established a vehicle rollover resistance rating system, and is currently examining dynamic testing procedures, these programs do not extend to 15-passenger vans. Given their high rate of rollover involvement in single-vehicle accidents, particularly under fully loaded conditions for which they are designed and are being used, the Board believes that 15-passenger vans should be included in dynamic testing and proposed rollover resistance ratings for this class of vehicle. Information from the dynamic testing also has the potential to develop a dynamic testing protocol that could supplement the NCAP rollover resistance rating system. Therefore, the Safety Board recommends that the National Highway Traffic Safety Administration include 15-passenger vans in its dynamic testing program. The dynamic testing should test the performance of 15-passenger vans under various load conditions.

The Safety Board recognizes that NHTSA has issued two consumer advisories regarding the propensity of 15-passenger vans to roll over. The NCAP program also serves as an available source of consumer information about the safety potential of vehicles in crashes; however, the NCAP rollover resistance rating system does not currently include 15-passenger vans. The Safety Board believes that, at a minimum, the rollover resistance rating system should be extended to include 15-passenger vans. Therefore, the Safety Board recommends that NHTSA extend the NCAP rollover resistance program to 15-passenger vans, especially for various load conditions. The inclusion of 15-passenger vans in NHTSA's dynamic testing program, as described and recommended earlier in this report, would provide valuable information by which to supplement the rollover resistance rating system. Thus, the Board also recommends that in extending the rollover resistance program to 15-passenger vans, NHTSA also use the dynamic testing results of 15-passenger vans to supplement the static measures of stability in the NCAP rollover resistance program.

Various technological systems have been developed to assist drivers in maintaining control of the vehicle. Although some of these systems are currently available on some vehicle types, most of them are not currently available on 15-passenger vans. Given the rollover propensity of these vehicles, technological systems such as traction control, lane departure systems, and particularly electronic stability control systems may have potential to assist drivers in maintaining control of 15-passenger vans. The Safety Board therefore recommends that NHTSA, in conjunction with the manufacturers of 15-passenger vans, evaluate, and test as appropriate, the potential of technological systems, particularly electronic stability control systems, to assist drivers in maintaining control of 15-passenger vans.

Findings

1. Although 15-passenger vans are involved in a proportionate number of accidents compared to their percentage in the fleet, they are involved in a higher rate of single-vehicle accidents involving a rollover than are other passenger vehicles.

2. Statistical analyses have shown that increased occupancy level and vehicle speed (measured by either travel speed or posted speed limit) consistently predict the increased likelihood of 15-passenger van rollover.

3. Although the National Highway Traffic Safety Administration has initiated rulemaking activities concerning vehicle rollovers, established a vehicle rollover resistance rating system, and is currently examining dynamic testing procedures, these programs do not extend to 15-passenger vans.

4. Given the rollover propensity of 15-passenger vans, technological systems such as traction control, lane departure systems, and particularly electronic stability control systems may have potential to assist drivers in maintaining control of these vehicles.

Recommendations

As a result of this safety report, the National Transportation Safety Board made the following safety recommendations:

To the National Highway Traffic Safety Administration

Include 15-passenger vans in the National Highway Traffic Safety Administration dynamic testing program. The dynamic testing should test the performance of 15-passenger vans under various load conditions. (H-02-26)

Extend the National Car Assessment Program (NCAP) rollover resistance program to 15-passenger vans, especially for various load conditions, and use the dynamic testing results of 15-passenger vans, as described in Safety Recommendation H-02-26, to supplement the static measures of stability in the NCAP rollover resistance program. (H-02-27)

Evaluate, in conjunction with the manufacturers of 15-passenger vans, and test as appropriate, the potential of technological systems, particularly electronic stability control systems, to assist drivers in maintaining control of 15-passenger vans. (H-02-28)

To the manufacturers of 15-passenger vans

Evaluate, in conjunction with the National Highway Traffic Safety Administration, and test as appropriate, the potential of technological systems, particularly electronic stability control systems, to assist drivers in maintaining control of 15-passenger vans. (H-02-29)

By the National Transportation Safety Board

Carol J. Carmody
Acting Chairman

John A. Hammerschmidt
Member

John Goglia
Member

George W. Black, Jr.
Member

Adopted October 15, 2002

Appendix A

Previously Issued Safety Recommendations Pertaining to Large Vans

Safety Recommendation No.: H-79-14
Date Issued: April 4, 1979
Recommendation:

In its on-going and planned investigation of van accidents: (1) study the failures of custom highback bucket seats and anchorage systems to determine if they pose a significant injury of safety problem; (2) study the failures of custom steering wheels which do not meet FMVSS 203 to determine whether they pose a significant injury or safety problem; (3) study the extent to which doors jam in collisions to determine if corrective action is needed to prevent ejection and to enhance escape; (4) determine if FMVSS 203 and 204 (steering wheel and steering column) should be extended to all classes of vans or if new requirements are needed for vans; (5) determine the feasibility of extending FMVSS 212 to all classes of vans.

Recipient(s):	**Status:**
National Highway Traffic Safety Administration	Closed—Acceptable Action

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Safety Recommendation No.: H-79-15
Date Issued: April 4, 1979
Recommendation:

Intensify its study to explore the feasibility of extending the passive restraint requirements of FMVSS-208 to all classes of vans.

Recipient(s):	**Status:**
National Highway Traffic Safety Administration	Closed—Acceptable Action

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Safety Recommendation No.: H-79-17
Date Issued: April 4, 1979
Recommendation:
Include in its exploratory rulemaking and research activity control of crash aggressiveness of vans in relation to other vehicles.

Recipient(s):	**Status:**
National Highway Traffic Safety Administration	Closed—Acceptable Action

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Safety Recommendation No.: H-82-38
Date Issued: October 6, 1982
Recommendation:

Examine the crash performance of vans in rollovers and all accident types, through its crash testing and accident investigation programs, to determine if there is any tendency for doors and other escape areas to unnecessarily jam or be blocked in low-speed crashes. If necessary, establish additional crash performance standards for van escape areas, especially those used for public transportation.

Recipient(s):	**Status:**
National Highway Traffic Safety Adminstration	Closed—Acceptable Action

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Safety Recommendation No.: H-89-3
Date Issued: May 25, 1989
Recommendation:

Purchase only school bus type vehicles which meet the Federal Motor Vehicle Safety Standards set for school buses in April 1977.

Recipient(s):	**Status:**
Church Associations and other special activity groups	Closed—No Longer Applicable

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Safety Recommendation No.: H-83-39
Date Issued: September, 28, 1983
Recommendation:

Review State laws and regulations, and take any necessary legislative action, to ensure that passengers in small (more than 10 passengers and less than 10,000 GVWR) school buses and school vans are required to use available restraint systems whenever the vehicle is in motion; ensure that all users of such vehicles are aware of and comply with these provisions.

Recipient(s):	**Status:**
States and the District of Columbia	Closed—Acceptable Action

Safety Recommendation No.: H-89-40
Date Issued: September 28, 1983
Recommendation:

Review State laws and regulations, and take any necessary legislative action, to ensure that vehicles designed to carry more than 10 passengers and weighing less than 10,000 pounds GVWR, used to transport children to and from school, school-related events, camp, daycare center, or similar purposes meet all Federal Motor Vehicle Safety Standards applicable to small school buses.

Recipient(s):	**Status:**
States and the District of Columbia	Various

Safety Recommendation No.: H-89-47
Date Issued: March 19, 1990
Recommendation:

Conduct research, including computer simulation and sled crash tests using hybrid III dummies if needed, to determine the relationship between restraining barrier design and injuries to unrestrained and lapbelted passengers of different sizes on small school buses (gross vehicle weight rating of 10,000 pounds or less). Research should focus on the height, width, padding, location, and anchorage strength of the barrier, and the spacing between the barrier and front seats. Amend Federal Motor Vehicle Safety Standard 222 "School Bus Passenger Seating and Crash Protection" as needed.

Recipient(s):	**Status:**
National Highway Traffic Safety Adminstration	Closed—Acceptable Alternate Action

Safety Recommendation No.: H-89-49
Date Issued: March 19, 1990
Recommendation:

Collect and evaluate accident data on the crash performance of the roof and emergency exits on small school buses (gross vehicle weight rating of 10,000 pounds or less) in rollovers. Data should not be limited to van based buses. Based on analysis, ascertain whether it is appropriate to amend Federal Motor Vehicle Safety Standard 220, "School Bus Rollover Protection," to make roof performance tests for small school buses (gross vehicle weight of 10,000 pounds or less) to be identical in all aspects to those now required of large school buses (gross vehicle weight rating of more than 10,000 pounds). If such tests are not appropriate, modify the test for small school buses to stress the roof more than the present force application plate test does.

Recipient(s): **Status:**

National Highway Traffic
Safety Administration — Closed—Acceptable Action

Safety Recommendation No.: H-89-50
Date Issued: March 19, 1990
Recommendation:

Collect and evaluate accident data involving small school buses to ascertain whether school buses with a gross vehicle weight rating of 10,000 pounds or less should be required to meet joint strength requirements Federal Motor Vehicle Safety Standard 221, "School Bus Body Joint Strength."

Recipient(s): **Status:**

National Highway Traffic
Safety Administration — Closed—Acceptable Action

Safety Recommendation No.: H-89-51
Date Issued: March 19, 1990
Recommendation:

Specify in new rulemaking or in an amendment to Federal Motor Vehicle Safety Standard 206, "Door Locks and Door Retention Components," a requirement for a positive latch locking mechanism on the passenger loading doors of small school buses (gross vehicle weight rating of 10,000 pounds or less) to eliminate the possibility of inadvertent door opening during a frontal crash or roll over. Work with school bus and school van manufacturers to develop the performance standards.

Recipient(s): **Status:**

National Highway Traffic
Safety Administratiin — Closed—Acceptable Alternate Action

Safety Recommendation No.: H-89-53
Date Issued: March 19, 1990
Recommendation:

Work with the National Highway Traffic Safety Administration to develop performance standards for a locking mechanism for the boarding doors of school buses with a gross vehicle weight rating of 10,000 pounds or less to eliminate the possibility of inadvertent door opening during frontal or rollover crash.

Recipient(s):	**Status:**
Members of the School Bus Manufacturers Institutute and Manufacturers of Van Conversion School Buses	Various

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Safety Recommendation No.: H-89-54
Date Issued: March 19, 1990
Recommendation:

Provide retrofit kits for small school buses (gross vehicle weight rating of 10,000 pounds or less) currently without positive latch door control locking mechanisms.

Recipient(s):	**Status:**
Members of the School Bus Manufacturers Institute and Manufacturers of Van Conversion School Buses	Closed—Acceptable Action

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Safety Recommendation No.: H-91-13
Date Issued: April 10, 1991
Recommendation:

Enact legislation that requires occupants of all passenger automobiles, vans, and light trucks to use lap/ shoulder belt systems at seating positions equipped with such belt systems.

Recipient(s):	**Status:**
The 12 States Without Mandatory Seatbelt Use Laws	Closed—Acceptable Action

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Safety Recommendation No.: H-99-20
Date Issued: July 6, 1999
Recommendation:

Require that head start children be transported in vehicles built to Federal school bus structural standards or the equivalent.

Recipient(s):	**Status:**
U.S. Department of Health and Human Services	Closed—Acceptable Action

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Safety Recommendation No.: H-99-21
Date Issued: July 6, 1999
Recommendation:

Incorporate and mandate the use of the guidelines from the National Highway Traffic Safety Administration's guideline for the safe transportation of pre-school age children in school buses into the rules for the transportation of Head Start children.

Recipient(s):	**Status:**
U.S. Department of Health and Human Services	Closed—Acceptable Action

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Safety Recommendation No.: H-99-22
Date Issued: July 6, 1999
Recommendation:

Require that all vehicles carrying more than 10 passengers (buses) and transporting children to and from school and school-related activities, including, but not limited to, Head Start programs and day care centers, meet the school bus structural standards or the equivalent as set forth in 49 *Code of Federal Regulations* Part 571. Enact regulatory measures to enforce compliance with the revised statutes.

Recipient(s):	**Status:**
States, U.S. territories, and the District of Columbia	Various

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Safety Recommendation No.: H-99-23
Date Issued: July 6, 1999
Recommendation:

Review your State and local laws and, if applicable, revise to eliminate any exclusions or exemptions pertaining to the use of age-appropriate restraints in all seat belt equipped vehicles carrying more than 10 passengers (buses) and transporting school children.

Recipient(s):	**Status:**
States, U.S. territories, and the District of Columbia	Various

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Safety Recommendation No.: H-99-24
Date Issued: July 6, 1999
Recommendation:

Adopt the National Highway Traffic Safety Administration's guideline for the safe transportation of pre-school age children in school buses, distribute the guideline to all school bus operators transporting preschool-age children to and from school or school-related activities, and encourage those operators to implement the guideline.

Recipient(s):	**Status:**
States, U.S. territories, and the District of Columbia	Various

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Safety Recommendation No.: H-99-25
Date Issued: July 6, 1999
Recommendation:

Inform their members about the circumstances of the accidents discussed in this special investigation report and urge that they use school buses or buses having equivalent occupant protection to school buses to transport children.

Recipient(s):	**Status:**
Church Associations	Various

Safety Recommendation No.: H-99-26
Date Issued: July 6, 1999
Recommendation:

Inform your members of the circumstances of the East Dublin, Georgia, accident and of the added safety benefits of transporting children by school bus, and encourage them to use buses built to Federal school bus structural standards or equivalent to transport children.

Recipient(s):	**Status:**
The Community Transportation Association of America	Open—Acceptable Response

Appendix B

Vehicle Specifications, Model Year 2002

Table B–1. Specifications of 15-passenger vans, model year 2002.

Vehicle specifications	Ford Econoline Wagon E-350 XL Extended	Ford Econoline Wagon E-350 XLT Extended	Dodge Ram Wagon 3500 Maxi	Chevrolet Express G3500 Extended	GMC Savana G3500 Extended
Exterior dimensions:					
Curb weight, automatic (lb.)	6,425	6,500	5,570	5,957	5,962
Wheelbase (in.)	138	138	127.6	155	155
Length (in.)	231.9	231.9	231.2	238.8	238.8
Width (in.)	79.3	79.3	79.8	79.4	79.4
Height (in.)	84.1	84.1	79.9	82.8	82.8
Ground clearance (in.)	7	7	8.4	8.5	8.5
Interior dimensions:					
Standard seating	15	15	15	12	12
Optional seating	12	12	12	15	15
Payload and towing:					
Maximum towing (lb.)	10,000	10,000	7,750	10,000	10,000
Maximum payload (lb.)	3,194	3,151	3,560	3,543	3,538
Maximum GVWR	9,400	9,400	9,200	9,500	9,500
Steering and suspension:					
Turning diameter (left)	48	48	52.4	53.5	53.5
Turning diameter (right)	48	48	52.4	53.5	53.5
Safety features:					
Antilock brakes	Std	Std	Std	Std	Std
Four-wheel antilock brakes	Std	Std	Opt	Std	Std
Depowered air bag	Std	Std	Std	Std	Std
Passenger air bag	Std	Std	Std	Std	Std
Head air bag	NA	NA	NA	NA	NA
Side air bag	NA	NA	NA	NA	NA
Child safety seats	NA	NA	NA	NA	NA
Traction control	NA	NA	NA	NA	NA
Stability control	NA	NA	NA	NA	NA
Rollover test results	Not tested	Not tested	Not tested	Not tested	Not tested

GVWR = gross vehicle weight rating; NA = not available; Opt = optional equipment; Std = standard equipment.

Source: <http://carpoint.msn.com> and <http://www.edmunds.com> accessed April 29,2002.

Appendix C

Predicting 15-passenger Van Rollover Accidents

Method

Data for years 1991–2000 from the Fatality Analysis Reporting System (FARS) were used for the Safety Board's analyses to predict 15-passenger van rollover accidents. The FARS, maintained by the National Highway Traffic Safety Administration (NHTSA), is a census of all fatal crashes involving a motor vehicle traveling on a trafficway customarily open to the public and results in the death of a person (occupant of a vehicle or a nonmotorist) within 30 days of the crash.

Accidents selected for analysis involved single-vehicle, fatal 15-passenger van accidents (n=499). Single-vehicle accidents were examined to eliminate accidents involving rollovers caused by collision of vehicles. Fifteen-passenger van body types were identified through the vehicle identification number (VIN).[1]

The dependent variable, rollover involvement, is defined in FARS as a three-level variable: no rollover (n=240), rollover as a first event (n=168), and rollover as a subsequent event (n=91). The dependent variable was recoded into a dichotomous variable indicating that the vehicle was not involved in a rollover (code=0) or was involved in a rollover (code=1) as a primary or subsequent event. Independent variables in the analysis included occupancy level, travel speed, driver age, driver drinking, roadway profile, pavement type, roadway surface condition, roadway function, driver sex, driving maneuver, and roadway alignment.[2] Vehicle information (wheelbase and vehicle length, width, and height) was also used in the analysis.[3]

For each variable, missing data values were recoded to system missing values.[4] Although the number of occupants ranged from 1 to 26, values greater than 15 were considered missing data (n=21). The Safety Board considered these vans to be loaded with occupants beyond the number for which the vehicles were intended. Because it is inappropriate to model nominal scaled variables as interval scaled variables, the multilevel categorical variables were recoded into dichotomous variables.[5] Vehicle length, width, and height were treated as continuous variables, although it is noted that the variability was

[1] The VIN codes for 15-passenger vans were provided by NHTSA. The VINs do not identify whether a van is used as a cargo van or a passenger van.

[2] These variables were used directly from FARS.

[3] Information on wheelbase and vehicle length, width, and height, was obtained from the World Wide Web sites <http://carpoint.msn.com> and <http://www.edmunds.com>.

[4] FARS assigns a value to missing data (that is, '9' or '99'), which skews the continuous data and creates a new category with categorical data.

limited. Wheelbase was recoded into a dichotomous variable (wheelbase = 127 inches; wheelbase > 127 inches) to assess whether a shorter wheelbase was indicative of rollover.

Logistic regression was used to predict the probability of vehicle rollover. Logistic regression allows for the examination of the effect of several independent variables simultaneously on the dichotomous variable of rollover involvement. Initially, stepwise logistic procedures were used to identify significant predictors of 15-passenger van rollover.[6] Based on the stepwise regression results, hierarchical logistic regressions were performed.

Four basic models, described below, were developed and tested using both stepwise and hierarchical logistic regression.

Model 1. The predictor variables were travel speed, occupancy level, wheelbase, vehicle length, vehicle width, vehicle height, driver drinking, driver sex, driver age, roadway function, driving maneuver, relation to the roadway, roadway profile, roadway surface condition, and roadway alignment.[7]

Model 2. The predictor variables were the same as in model 1 except posted travel speed was substituted for travel speed. The substitution was made because the validity of travel speed is often questioned. Use of posted speed limit, however, also raises questions, including whether or not the vehicle was traveling at, above, or below the speed limit.

Models 3 and 4. The vehicle variables (wheelbase and vehicle length, weight, and height) were excluded because these variables (a) were obtained from sources other than FARS, (b) were not shown to be significantly related to rollover based on the bivariate correlations, (c) had limited variance, and (d) limited the sample size. Model 3 used the variable travel speed; model 4 used the variable posted speed limit.

Results

Tables C–1 and C–2 provide distribution and descriptive information. The correlation matrix (table C–3) shows several significant relationships with rollover. Specifically, rollovers are associated with accidents on graded or hillcrest roadways, rural roadways, female drivers, straight driving maneuvers, curved roadways, increased occupancy level, increased travel speed, and off-roadway occurrences. Additionally, several of the variables are correlated with one another.

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[5] An alternative procedure would be to create design variables (dummy variables); however, because some values of the multilevel variables contained few or no cases, it was decided to dichotomize the variables.

[6] The stepwise procedure either includes or excludes variables in the model based on a fixed statistical algorithm.

[7] Pavement type was excluded because of small cell size.

Table C–1. Distribution of the categorical independent variables, by rollover involvement, in the National Transportation Safety Board analysis of FARS data on single-vehicle, fatal 15-passenger van rollover accidents for years 1991–2000 (n=499).

Variable	Number of nonrollover accidents (code=0)	Number of rollover accidents (code=1)
Roadway profile (n=494):		
Level (0)	203	175
Grade, hillcrest (1)	35	81
Pavement type (n=486):		
Concrete, blacktop (0)	227	250
Slag, gravel (1)	2	7
Roadway surface condition (n=498):		
Wet, snow, ice (0)	49	70
Dry (1)	190	189
Roadway function (n=498):		
Rural (0)	83	207
Urban (1)	157	51
Driver sex (n=497):		
Female (0)	38	66
Male (1)	202	191
Driving maneuver (n=417):		
Curve (0)	181	180
Straight (1)	15	41
Roadway alignment (n=499):		
Curve (0)	26	68
Straight (1)	214	191
Driver drinking (n=499):		
No (0)	224	236
Yes (1)	16	23
Wheelbase 127" (n=499):		
No (0)	126	152
Yes (1)	114	107
Relation to roadway (n=493):		
Off roadway (0)	71	193
On roadway (1)	167	62

FARS = Fatality Analysis Reporting System, maintained by the National Highway Traffic Safety Administration.

Table C–2. Descriptive statistics of the continuous independent variables, by rollover involvement, in the National Transportation Safety Board analysis of FARS data on single-vehicle, fatal 15-passenger van rollover accidents for years 1991–2000 (n=499).

Variable	n	Minimum	Maximum	Mean	Standard deviation
Occupancy level:	471	1	15	5.61	4.46
Nonrollover accidents	234	1	15	3.35	3.07
Rollover accidents	237	1	15	7.85	4.50
Travel speed:	242	3	95	54.08	18.79
Nonrollover accidents	94	20	95	40.36	19.36
Rollover accidents	148	3	90	62.79	12.03
Vehicle length:	278	222.9	238.8	229.24	3.99
Nonrollover accidents	120	222.9	238.8	229.71	3.92
Rollover accidents	158	222.9	238.8	229.51	3.95
Vehicle width:	291	78.8	79.9	79.52	0.30
Nonrollover accidents	125	78.8	79.9	79.55	0.30
Rollover accidents	166	78.8	79.9	79.50	0.30
Vehicle height:	264	79.9	84.1	81.71	1.79
Nonrollover accidents	114	79.9	84.1	81.54	1.70
Rollover accidents	150	79.9	84.1	81.83	1.86
Driver age:	498	15	86	38.96	14.13
Nonrollover accidents	240	17	77	40.06	14.23
Rollover accidents	258	15	86	37.93	13.99

FARS = Fatality Analysis Reporting System, maintained by the National Highway Traffic Safety Administration.

The initial stepwise logistic model based on 15 predictor variables, including travel speed, was based on 107 cases.[8] The stepwise regression concluded in three steps: travel speed was entered in step one, occupancy level was included in step two, and roadway function was included in the third step. Thus, the final stepwise regression model included three significant predictor variables: travel speed, occupancy level, and roadway function, as shown in table C–4.[9] The probability of rollover involvement is defined as $1/1\text{-}e^{-z}$, where z = -4.643-1.410 (roadway function) + 0.081(travel speed) + 0.184 (occupancy level).

[8] Cases with missing data are deleted on a listwise basis.

[9] (a) The Wald statistic was used to determine significance of the coefficients. The Wald statistic is based on a chi-square distribution; it is the square of the ratio of the coefficient to its standard error. (b) The odds ratio indicates the change in odds for a case when the value of that variable increases by 1; thus, when occupancy increases by one, the odds of a rollover are increased by a factor of 1.202.

Table C–3. Correlation matrix (* $\underline{p} < 0.05$).

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Roadway profile (1)	1.00 494	.67 483	-.17* 493	-.12* 493	-.04 492	.21* 413	-.26* 494	.02 494	-.03 494	.09 466	.11 242	-.01 276	-.03 289	.11 262	.00 493	-.17* 488	.20* 494
Pavement type (2)		1.00 486	.08 485	-.05 485	-.05 484	.10* 406	-.05 486	-.04 486	-.06 486	.03 458	-.21* 237	.08 274	-.02 287	.06 262	.01 485	-.00 480	.07 486
Roadway surface condition (3)			1.00 498	.06 497	.06 496	-.12* 416	.16* 498	-.02 498	.16* 498	.03 470	.10 242	-.01 278	.07 291	-.06 264	-.08 497	.19* 492	-.08 498
Roadway function (4)				1.00 498	.07 496	-.10* 416	.13* 498	-.02 498	.08 498	-.35* 470	-.37* 241	-.14* 277	.13* 290	-.10 263	.01 497	.36* 492	-.46* 498
Driver sex (5)					1.00 497	0.05 415	-.01 497	0.09* 497	-.02 497	-.18* 470	-.01 241	.01 277	-.03 290	.04 263	.03 497	.07 491	-.12* 497
Driving manuever (6)						1.00 417	-.76* 417	15* 417	-.04 417	.04 391	.05 209	.07 235	-.03 243	.15* 223	.04 416	-.19* 412	.16* 417
Roadway alignment (7)							1.00 499	-.15* 499	.09* 499	-.05 471	-.04 242	-.08 278	.04 291	-.17* 264	.00 498	.20* 493	-.20* 499
Driver drinking (8)								1.00 499	.10* 499	-.16* 471	.14* 242	-.09 278	.01 291	-.08 264	-.02 498	-.11* 493	.04 499
Wheelbase 127" (9)									1.00 499	.00 471	-.04 242	-.49* 278	.12* 291	-.78* 264	.11* 498	.01 493	-.06 499
Occupancy level (10)										1.00 471	.39* 223	.11 268	-.06 280	.07 255	-.11* 470	-.23* 465	.51* 471
Travel speed (11)											1.00 242	.14 139	-.14 143	.09 129	-.10 242	-.43* 240	.58* 242
Vehicle length (12)												1.00 278	-.26* 278	.56* 264	-.06 277	.02 274	.06 278
Vehicle width (13)													1.00 291	-.48* 264	-.02 290	.00 287	-.09 291
Vehicle height (14)														1.00 264	-.16* 263	-.03 260	.08 264
Driver age (15)															1.00 498	-.01 492	-.08 498
Relation to roadway (16)																1.00 493	-.46* 493
Rollover (17)																	1.00 499

Table C–4. Logistic regression model 1 (n=107).

Variables in the equation	Estimated coefficient	Standard error	Wald statistic	Significance	Odds ratio
Step 1:					
Travel speed	0.098	0.020	24.373	0.000	1.103
Constant	-4.780	1.124	18.070	0.000	0.008
Step 2:					
Travel speed	0.082	0.020	16.956	0.000	1.085
Occupancy level	0.211	0.072	8.652	0.003	1.234
Constant	-5.140	1.143	20.240	0.000	0.006
Step 3:					
Travel speed	0.081	0.021	14.986	0.000	1.085
Occupancy level	0.184	0.072	6.554	0.010	1.202
Roadway function	-1.410	0.687	4.209	0.040	0.244
Constant	-4.643	1.186	15.321	0.000	0.010

Overall, 83 percent of the 15-passenger van accidents were correctly classified. As shown in the classification table (table C–5), 64 van accidents were correctly classified as involving a rollover, and 25 vans were correctly classified as not being involved in a rollover accident. A total of 18 accidents were incorrectly classified: 12 accidents that were not involved in a rollover but were predicted to involve a rollover; and 6 accidents that were involved in rollovers but rollover was not predicted.

Table C–5. Classification table for model 1.

Event observed	Event predicted		Percent correctly classified
	No rollover	Rollover	
No rollover (n=37)	25	12	67.6
Rollover (n=70)	6	64	91.4
Overall percent			83.2

The Nagelkerke R^2 for the last step of model 1 is 0.58.[10] The model -2LL is 57.907, $\underline{p} < 0.05$, indicating that the logistic regression with the three coefficients (travel speed, occupancy level, and roadway function) is significantly different from the model containing only the constant ($X^2 = 137.988$).

[10] The -2 times the log of the likelihood (-2LL) values and the Nagelkerke R^2 are other measures of fit. Similar to the R^2 in linear regression, the Nagelkerke R^2 attempts to quantify the proportion of explained variation in the logistic regression model.

The second logistic regression (model 2) was conducted substituting posted speed limit for travel speed, and the n increased to 203 cases. The correlation between posted speed limit and travel speed is 0.69, $p < 0.05$, and similar results were expected between the two analyses. As such, posted speed limit and occupancy level were significantly related to rollover. Relation to the roadway and roadway profile were also significant predictors of vehicle rollover (table C–6). Overall, 85.2 percent of the cases were correctly classified. About 60 percent of the variation in 15-passenger van rollover is explained by the logistic regression model (Nagelkerke R^2=0.596). The -2LL is 119.531, $p < 0.05$, showing that the logistic equation is significantly different from the model containing only the constant.

Table C–6. Logistic regression results for model 2 (n=203).

Variables in the equation	Estimated coefficient	Standard error	Wald statistic	Significance	Odds ratio
Step 1:					
Speed limit	0.099	0.015	45.394	0.000	1.104
Constant	-5.211	0.840	38.460	0.000	0.005
Step 2:					
Speed limit	0.069	0.015	20.042	0.000	1.072
Occupancy level	0.235	0.051	20.913	0.000	1.265
Constant	-4.870	0.852	32.641	0.000	0.008
Step 3:					
Relation to roadway	-1.711	0.412	17.244	0.000	0.181
Speed limit	0.053	0.017	9.917	0.002	1.054
Occupancy level	0.247	0.054	20.998	0.000	1.281
Constant	-3.329	0.951	12.265	0.000	0.036
Step 4:					
Speed limit	0.057	0.017	10.596	0.001	1.058
Occupancy level	0.244	0.055	19.37	0.000	1.276
Relation to roadway	-1.495	0.431	12.040	0.001	0.224
Roadway profile	1.078	0.477	5.117	0.240	2.940
Constant	-3.902	1.028	14.406	0.000	0.020

Models 3 and 4 were conducted using a smaller set of predictor variables, excluding the vehicle variables. In model 3, travel speed was used (n=188); in model 4, posted speed limit was substituted (n=364). Four significant predictors were in model 3: travel speed, occupancy level, roadway alignment, and relation to the roadway (table C–7). About 80 percent of the cases were correctly classified. The Nagelkerke R^2 is 0.544.

Model 4 resulted in a five-variable model (table C–8) with about 82 percent of the cases correctly classified. The five significant variables are posted speed limit, relation to the road, occupancy level, roadway alignment, and roadway profile. The Nagelkerke R^2 is 0.596.

Table C–7. Logistic regression results for model 3 (n=188).

Variables in the equation	Estimated coefficient	Standard error	Wald statistic	Significance	Odds ratio
Step 1:					
Travel speed	0.090	0.014	40.301	0.000	1.094
Constant	-4.524	0.797	32.205	0.000	0.011
Step 2:					
Occupancy level	0.189	0.047	16.198	0.000	1.208
Travel speed	0.077	0.014	29.382	0.000	1.080
Constant	-4.941	0.825	35.845	0.000	0.007
Step 3:					
Occupany level	0.197	0.048	16.582	0.000	1.218
Roadway alignment	-1.313	0.510	6.634	0.010	0.269
Travel speed	0.080	0.015	29.300	0.000	1.083
Constant	-4.134	0.889	21.614	0.000	0.016
Step 4:					
Relation to roadway	-0.861	0.424	4.123	0.042	0.423
Occupancy level	0.200	0.049	16.481	0.000	1.222
Roadway alignment	-1.232	0.508	5.887	0.015	0.292
Travel speed	0.072	0.015	21.474	0.000	1.074
Constant	-3.426	0.948	13.072	0.000	0.033

Table C–8. Logistic regression results for model 4 (n=364).

Variables in the equation	Estimated coefficient	Standard error	Wald statistic	Significance	Odds ratio
Step 1:					
Speed limit	0.112	0.012	87.718	0.000	1.118
Constant	-5.920	0.668	78.534	0.000	0.003
Step 2:					
Relation to roadway	-1.485	0.279	28.398	0.000	0.226
Speed limit	0.102	0.013	64.904	0.000	1.108
Constant	-4.781	0.723	43.757	0.000	0.008
Step 3:					
Relation to roadway	-1.587	0.299	28.247	0.000	0.205
Speed limit	0.078	0.013	34.822	0.000	1.081
Occupancy level	0.177	0.037	22.569	0.000	1.193
Constant	-4.406	0.726	36.860	0.000	0.012
Step 4:					
Relation to roadway	-1.453	0.308	22.313	0.000	0.234
Speed limit	0.085	0.014	36.785	0.000	1.089
Occupancy level	0.176	0.038	21.745	0.000	1.193
Roadway alignment	-1.074	0.367	8.551	0.003	0.342
Constant	-4.024	0.755	28.409	0.000	0.018
Step 5:					
Relation to roadway	-1.365	0.314	18.922	0.000	0.255
Roadway profile	0.840	0.352	5.689	0.017	2.317
Speed limit	0.088	0.014	37.560	0.000	1.092
Occupancy level	0.175	0.038	21.280	0.000	1.191
Roadway alignment	-0.929	0.378	6.047	0.014	0.395
Constant	-4.538	0.807	31.958	0.000	0.011

In each of the stepwise logistic regression models, the speed-related variable (travel speed or posted speed limit) and occupancy level were consistently identified as predictors of 15-passenger van rollover. Depending on the model, other variables were also shown to be significant predictors of van rollovers. Because the speed-related variables and occupancy level were consistently predictive of rollover, a set of hierarchical logistical regressions were conducted where the speed-related variables and occupancy level were entered on the first block and the remaining variables were entered on the second block.

Table C–9 shows the results for the hierarchical logistic regressions. Again, the difference between the first two models is the speed-related variable. Model 1, using travel speed and occupancy level at block 1, resulted in a Nagelkerke R^2 of 0.543, and 82.2 percent of the cases were correctly classified. Travel speed and occupancy level significantly predicted vehicle rollover. The addition of the remaining predictor variables in the second block did not significantly improve prediction, $X^2(13, n=107) = 16.483$, $p > 0.05$. Model 2, which used speed limit as a proxy for travel speed, had an increased sample size of 207. The Nagelkerke R^2 is 0.452, and 79.7 percent of the cases are correctly classified. The entry of the additional variables significantly improves prediction, $X^2(13, n=207)=41.447$, $p < 0.05$. The Nagelkerke R^2 increases to 0.613, and 85.5 percent of the cases are correctly classified. Occupancy level remains a significant predictor of van rollover; relation to the roadway (off roadway) is added as a significant predictor of rollover. Posted speed limit is not a significant predictor.

Table C–9. Hierarchical logistic regression results.

Model, step, and variables in the equation	Estimated coefficient	Standard error	Wald statistic	Significance	Odds ratio
Model 1 (n=107)					
Step 1: Nagelkerke R^2 = 0.543; percent cases correctly classified = 82.2					
Step 2: Nagelkerke R^2 = 0.663; percent cases correctly classified = 89.7					
Variables in the equation:					
Travel speed	.095	.030	10.109	.001	1.100
Occupancy level	.185	.092	4.027	.045	1.203
Wheelbase	1.028	1.177	.764	.382	2.797
Vehicle length	-.032	.099	.102	.749	.969
Vehicle width	-.041	1.296	.001	.975	.960
Vehicle height	.427	.385	1.226	.268	1.532
Driver drinking	-.579	1.123	.266	.606	.560
Roadway function	-1.265	.853	2.196	.138	.282
Driver sex	-1.509	1.048	2.074	.150	.221
Driving maneuver	-.691	1.673	.171	.680	.501
Relation to roadway	-.723	.767	.888	.346	.485
Roadway profile	-.282	.794	.126	.723	.754
Roadway surface condition	.388	.879	.195	.659	1.474
Driver age	.051	.025	4.321	.038	1.053
Roadway alignment	-1.565	1.461	1.148	.248	.209
Constant	-29.748	125.826	.056	.813	.000
Model 2 (n=207)					
Step 1:Nagelkerke R^2 = 0.452; percent cases correctly classified = 79.7					
Step 2: Nagelkerke R^2 = 0.613; percent cases correctly classified = 85.5					
Variables in the equation:					
Speed limit	.030	.016	3.516	.061	1.031
Occupancy level	.285	.060	22.470	.000	1.330
Wheelbase	-.584	.743	.619	.431	.557
Length	-.007	.064	.013	.911	.993
Width	-.627	.833	.566	.452	.534
Height	-.082	.235	.121	.728	.921
Driver drinking	.901	.734	1.510	.219	2.463
Roadway function	-.763	.456	2.808	.094	.466
Driver sex	.040	.495	.006	.936	1.041
Driving maneuver	.230	.862	.071	.790	1.258
Relation to roadway	-1.545	.452	11.664	.001	.213
Roadway profile	.933	.506	3.397	.065	2.542
Roadway surface condition	.092	.514	.032	.858	1.097
Driver age	.015	.013	1.266	.260	1.015
Roadway alignment	-.583	.658	.785	.376	.558
Constant	55.733	78.565	.503	.478	1.60E+24

Table C–9. Hierarchical logistic regression results. *(Continued)*

Model 3 (n=188)					
Step 1: Nagelkerke R^2 = 0.493; percent cases correctly classified = 78.2					
Step 2: Nagelkerke R^2 = 0.569; percent cases correctly classified = 80.3					
Variables in the equation:					
Travel speed	.080	.017	21.244	.000	1.083
Occupancy level	.184	.052	12.348	.000	1.202
Driver drinking	-.435	.695	.391	.532	.647
Roadway function	-.501	.499	1.006	.316	.606
Driver sex	-.611	.548	1.246	.264	.543
Driving maneuver	-1.415	1.062	1.777	.183	.243
Relation to roadway	-.674	.469	2.067	.151	.510
Roadway profile	.135	.457	.088	.767	1.145
Roadway surface condition	-.151	.503	.090	.764	.860
Driver age	.011	.015	.568	.451	1.011
Roadway alignment	-2.279	.964	5.588	.018	.102
Constant	-2.559	1.447	3.125	.077	.077
Model 4 (n=379)					
Step 1: Nagelkerke R^2 = 0.371; percent cases correctly classified 74.9					
Step 2: Nagelkerke R^2 = 0.549; percent cases correctly classified 82.1					
Variables in the equation:					
Speed limit	.028	.010	8.064	.005	1.028
Occupancy level	.205	.037	31.302	.000	1.227
Driver drinking	.294	.497	.350	.554	1.342
Roadway function	-1.135	.304	13.980	.000	.321
Driver sex	-.265	.352	.566	.452	.767
Driving maneuver	.110	.596	.034	.853	1.117
Relation to roadway	-1.402	.303	21.469	.000	.246
Roadway profile	.749	.337	4.946	.026	2.115
Roadway surface condition	-.142	.331	.183	.669	.868
Driver age	-.004	.009	.185	.667	.996
Roadway alignment	-.594	.500	1.410	.235	.552
Constant	-.915	.911	1.008	.315	.401

As in the stepwise regressions, models 3 and 4 were conducted using a smaller set of predictor variables, which excluded the vehicle-related variables, and used either travel speed (model 3) or speed limit (model 4) to indicate speed of vehicle. The results of model 3 indicate that travel speed and occupancy level significantly predict vehicle rollover. The addition of roadway alignment significantly improves prediction ($X^2(9, n=188)=17.498$, $p < 0.05$). The Nagelkerke R^2 increases to 0.569 (from 0.493), and the number of correctly classified cases increases from 78.2 to 80.3. Block 1 of model 4, where posted speed limit and occupancy level are entered, has a Nagelkerke R^2 of 0.371 and correctly classified 74.9 percent of the cases. Variables added in block 2 improve prediction ($X^2(9, n=379)=77.711$, $p < 0.05$), the Nagelkerke R^2 increases to 0.549, and 82.1 percent of the cases are correctly classified. Significant predictors include occupancy level, posted speed limit, roadway function (rural accidents increase odds of being involved in a rollover), relation to the roadway (off-road accidents increase odds of being involved in a rollover), and roadway profile (accidents on a grade or hillcrest increase odds of being involved in a rollover).

Discussion

Four logistic regression models were developed and tested using stepwise logistic regression and hierarchical logistic regression. The primary difference among the logistic models was the selection of the speed-related variable, which was defined either as travel speed (models 1 and 3) or posted speed limit (models 2 and 4), and the exclusion of the vehicle-related variables (models 3 and 4).

The use of posted speed limit rather than travel speed does not make the results more reliable. Although the sample size increases when using the posted speed limit, the Nagelkerke R^2 and the number of correctly classified cases are generally lower than when using travel speed. The validity of travel speed data is often questioned because the posted speed limit is cited as the travel speed and self reports of travel speed are not reliable. The posted speed limit does not indicate the actual speed of the vehicle, which may be at, lower, or above the posted speed limit.

The vehicle variables (length, width, height, and wheelbase) were originally included in the model because it was expected that they may have an effect (or a combined effect) on 15-passenger van rollover. However, the vehicle variables were not significantly predictive of rollover. It is noted that these variables had limited variance and small sample size.

In each of the stepwise regression equations, the speed-related variables and the occupancy level were significant predictors of 15-passenger van rollover. Additional variables were also shown to be significant depending on the model (table C–10 summarizes the regression results). Because occupancy level and the speed-related variables were shown to be related to rollover in all of the models, hierarchical logistic regression procedures were used to determine how much additional variance the other variables accounted for in rollover, after occupancy level and the speed-related variables were entered into the equation. The results indicate that in models 2, 3, and 4, (a) the addition of other variables significantly improves prediction, and (b) the percentage of correctly classified cases increases; however, the improvements are not necessarily substantial.

Table C–10. Summary of stepwise and hierarchical logistic results of significant predictors of 15-passenger van rollover.

Item	Model 1	Model 2	Model 3	Model 4
Variables entered into model	Travel speed Occupancy level Wheelbase Vehicle length Vehicle width Vehicle height Roadway function Driving maneuver Relation to roadway Roadway profile Roadway surface condition Roadway alignment Driver drinking Driver sex Driver age	Posted speed limit Occupancy level Wheelbase Vehicle length Vehicle width Vehicle height Roadway function Driving maneuver Relation to roadway Roadway profile Roadway surface condition Roadway alignment Driver drinking Driver sex Driver age	Travel speed Occupancy level Roadway function Driving maneuver Relation to roadway Roadway profile Roadway surface condition Roadway alignment Driver drinking Driver sex Driver age	Posted speed limit Occupancy level Roadway function Driving maneuver Relation to roadway Roadway profile Roadway surface condition Roadway alignment Driver drinking Driver sex Driver age
Significant predictors in stepwise logistic regression	Travel speed Occupancy level Roadway function	Posted speed limit Occupancy level Relation to roadway Roadway profile	Travel speed Occupancy level Relation to roadway Roadway alignment	Posted speed limit Occupancy level Relation to roadway Roadway profile Roadway alignment
Significant predictors in hierarchical logistic regression	Travel speed Occupancy level	Occupancy level Relation to roadway	Travel speed Occupancy level Roadway alignment	Posted speed limit Occupancy level Roadway function Relation to roadway Roadway profile

The Safety Board acknowledges potential confounding with the findings. The analyses were conducted on fatal accidents, which frequently include higher speed accidents. The Board also recognizes the limitations of the vehicle speed variables (travel speed and posted speed limit). The VIN does not indicate whether the van is a cargo van or a passenger van because the final configuration of the van is usually completed at the vehicle dealer. However, in summary, the results indicate that increased vehicle speed and occupancy level consistently predict the increased likelihood of 15-passenger van rollover and that other factors may improve prediction of van rollover.

Appendix D

Vehicle Dynamics of 15-passenger Vans

The National Highway Traffic Safety Administration (NHTSA) conducted a simulation study to show the effects of occupant loading on the handling of 15-passenger vans.[11] NHTSA included two steering maneuvers in its simulation study: one was designed to measure the understeer/oversteer characteristics of the vehicle, and the other was a steering reversal maneuver.[12] To show the effects of occupant loading, simulation runs were performed at a driver-only load condition and also when the van was fully loaded to its gross vehicle weight (GVW).[13] Tire and suspension properties for the simulations were not measured but were based on existing parametric data to roughly approximate those of a 15-passenger van. Measured values from a 2000 Ford E-350 were used for center of gravity (CG) location and inertia properties. According to these measurements for the Ford E-350, loading the van to its GVW increased the CG height of the van about 4 inches and moved the CG rearward about 18 inches, placing 65 percent of the weight on the rear tires of the van (table D–1). The increase in CG height and rearward movement of the CG could result if any 15-passenger van were loaded to the GVW because other 15-passenger vans have similar seating configurations to the Ford E-350.

[11] W. Riley Garrott, Barbara Rhea, Rajesh Subramanian, and Gary J. Heydinger, *The Rollover Propensity of Fifteen-Passenger Vans*, Research Note (Washington, DC: NHTSA, April 2001).

[12] A simple test illustrates the concepts of understeer and oversteer. A vehicle is driven around a circle at a constant speed, then the speed is slowly increased. If the vehicle tends to go off the outside of the circle so that the driver must increase steering to maintain the circle, then the vehicle is considered to be an understeer vehicle. If the vehicle tends to go off the inside of the circle so that the driver must reduce steering to maintain the circle, then the vehicle is considered to be an oversteer vehicle. Understeer and oversteer can affect the stability of a vehicle; however, just because a vehicle is an oversteer vehicle does not mean that it is uncontrollable. A more detailed discussion of understeer and oversteer and their impact on stability and control is contained in (a) William F. Milliken and Douglas L. Milliken, "Simplified Steady State Stability and Control," Chapter 5, and "Simplified Transient Stability and Control," Chapter 6 in *Race Car Vehicle Dynamics* (Warrendale, PA: Society of Automotive Engineers, 1995) 123-229 and 231-277; and (b) Thomas D. Gillespie, "Rollover," Chapter 9 in *Fundamentals of Vehicle Dynamics* (Warrendale, PA: Society of Automotive Engineers, 1992) 309-333. The Society of Automotive Engineers' definitions of understeer and oversteer are given in Milliken and Milliken (1995), p. 164.

[13] The driver-only load condition was the weight of the van with a weight equivalent to a 50th percentile male dummy in the driver's seat and no cargo. The fully loaded condition was the weight of the van with weights equivalent to a 50th percentile male dummy in every seating position, plus ballast (simulated luggage) in the rear cargo space.

Table D–1. Measured parameters of the 2000 Ford E-350 XLT Super Duty 15-passenger van.

Load condition	Center of gravity height (inches)	Longitudinal distance from front axle to vehicle center of gravity	Percent weight on rear axle
Driver only[a]	31.9	72.4	52.4
Fully loaded to GVW[b]	35.9	90.3	65.3

GVW = gross vehicle weight.

[a] The weight of the van with a weight equivalent to a 50th percentile male dummy in the driver's seat and no cargo.

[b] The weight of the van with weights equivalent to a 50th percentile male dummy in every seating position, plus ballast (simulated luggage) in the rear cargo space.

Source: W. Riley Garrott, Barbara Rhea, Rajesh Subramanian, and Gary J. Heydinger, *The Rollover Propensity of Fifteen-Passenger Vans*, Research Note (Washington, DC: U.S. Department of Transportation, National Highway Traffic Safety Administration, April 2001).

In the first simulated maneuver, the understeer/oversteer characteristics of a lightly loaded 15-passenger van and a fully loaded 15-passenger van were calculated using a slowly increasing steer rate of 5º per second and a constant vehicle speed of 30 mph. The simulation showed that the fully loaded 15-passenger van made a transition from understeer to oversteer as the lateral acceleration increased. This result is important because an oversteer vehicle requires different driver inputs than does an understeer vehicle in order to stabilize it in a steady-state cornering maneuver. NHTSA's report also noted the safety concern:

> The fact that a heavily laden vehicle's understeer characteristics are similar to its lightly loaded condition at low lateral accelerations but different at higher lateral accelerations is a topic of concern. This sort of transition is known to cause safety problems, particularly for drivers who normally only drive smaller passenger vehicles and who are unfamiliar with a loaded fifteen passenger van's responsiveness and limits.

In the second set of simulations, the vans were placed through a steering reversal maneuver. In the maneuver, the vans were driven at a steady speed of 30 mph, and a steering input of about 180º of right steer was followed abruptly by 180º of steer input to the left. In the simulations, the fully loaded van rolled whereas the lightly loaded (driver only) van did not. NHTSA's examination of the results found that rollover was preceded by a high sideslip angle, indicating a reduction in the rear axle's cornering capability.

The NHTSA report concluded that the computer simulations illustrated the adverse effects that a fully loaded passenger van can have on the vehicle's handling properties (sudden transition from understeer to oversteer) and rollover propensity. However, the simulation results should be viewed with caution because the suspension and tire properties used by NHTSA were default values and not specific to any particular van. The default measures of the suspension and tire properties may not replicate true measures; therefore, simulated test results may vary from actual results.

Analyses of data on occupancy level and rollover conducted by NHTSA and the Safety Board show that 15-passenger vans with 10 or more occupants have much higher rollover ratios than do those with fewer occupants.[14] NHTSA's measurements of the Ford E-350 indicate that adding passengers and cargo to a 15-passenger van causes the CG to move rearward and upward. Increasing the CG height increases the rollover propensity, measured using the static stability factor (SSF).[15] In its simulation study, NHTSA measured the inertial properties of a fully loaded 15-passenger van versus a lightly loaded van. These measurements found that a decrease in stability under the fully loaded condition correlated to an increase in the rollover risk of about 40 percent.[16] Basic vehicle dynamics also indicate that increasing the CG height can make the vehicle more prone to rollover.[17] Moving the CG rearward and upward and adding weight to the rear tires can cause the vehicle to handle differently and make it more prone to sideslip.[18] It could also decrease lateral stability in extreme maneuvers, as the NHTSA steering reversal simulations indicate. These changes in handling may make it more difficult for the driver to control the vehicle in some emergency situations. The magnitude of the change in handling and rollover potential depends on a number of factors including the amount of change in the CG location, weight, suspension properties, tire properties, type of maneuver, and driver response.

NHTSA's simulations illustrate how fully loading a 15-passenger van could adversely affect handling in extreme maneuvers and increase the van's rollover propensity. Given the general vehicle dynamics, NHTSA's measurements of CG locations and SSF of a lightly loaded and a fully loaded 15-passenger van, and NHTSA's simulation results, the Safety Board is concerned that fully loading or nearly loading a 15-passenger van causes the center of gravity to move rearward and upward, which increases the vehicle's rollover propensity and could increase the potential for driver loss of control in emergency maneuvers.

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[14] (a) Rollover ratio is the number of all single-vehicle rollover accidents divided by the number of all single-vehicle accidents. (b) NHTSA's analysis, conducted on data for 1994–1997, is reported in Garrott and others, 2001. The Safety Board's analysis, conducted on FARS data for 1991–2000, is discussed in the "Background" section and appendix C of this report (*Evaluation of the Rollover Propensity of 15-passenger Vans*, NTSB/SR-02/03).

[15] The SSF is generated by dividing a vehicle's track width (distance between the wheels from side to side, denoted by t) by twice the vehicle's center of gravity height (SSF=t/2h).

[16] This figure is based on NHTSA's Rollover Ratio versus Static Stability Factor regression trend line. NHTSA uses this trend line to provide consumers information on the rollover risk of passenger cars, and of light, multipurpose passenger vehicles and trucks. This trend line is based solely on SSFs measured for a driver-only load condition because this is the most common load condition in which private consumer vehicles are driven.

[17] Gillespie, 1992.

[18] Milliken and Milliken, 1995.