FTA RESEARCH

FEDERAL TRANSIT ADMINISTRATION

FTA Standards Development Program: Crashworthiness/Crash Energy Management Follow-up for Less than 30 Ft Bus

JULY 2019
Revised DECEMBER 2020

FTA Report No. 0141
Federal Transit Administration

PREPARED BY

Center for Urban Transportation Research
University of South Florida

U.S. Department of Transportation
Federal Transit Administration

COVER PHOTO

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Metric Conversion Table

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liter	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: volumes greater than 1000 L shall be shown in m^3				
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or “metric ton”)	Mg (or “t”)
TEMPERATURE (exact degrees)				
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C

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14. ABSTRACT
FTA directed this comprehensive study that includes background research and analysis on needs and gaps for voluntary standards or recommended practices for crashworthiness and crash energy management (CEM) for less than 30-ft paratransit body-on-chassis buses (cutaways). It includes case study evaluations for four states—Florida, California, New York, and Pennsylvania—and a supplemental examination of NTSB investigation reports and recommendations associated with similar vehicles. Findings are presented related to voluntary standards, guidelines, or recommended practices related to crashworthiness, crash energy management, data needs, and future research.

15. SUBJECT TERMS Crashworthiness, crash energy management, safety standards, transit vehicle standards, vehicle crash testing and analysis

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ABSTRACT

FTA directed this comprehensive study that includes background research and analysis on needs and gaps for voluntary standards or recommended practices for crashworthiness and crash energy management (CEM) for less than 30-ft paratransit body-on-chassis buses (cutaways). It includes case study evaluations for four states—Florida, California, New York, and Pennsylvania—and a supplemental examination of NTSB investigation reports and recommendations associated with similar vehicles. Findings are presented related to voluntary standards, guidelines, or recommended practices related to crashworthiness, crash energy management, data needs, and future research.

EXECUTIVE SUMMARY

The Federal Transit Administration (FTA) entered into a Cooperative Agreement with the Center for Urban Transportation Research (CUTR) at the University of South Florida to research areas of transit safety risk, identify associated existing standards and recommended practices, and perform a gap analyses to establish the need for additional standards, guidance, or recommended practices to support and further the safe operation of the nation's public transportation industry. Public transit agencies may use the findings of the reports generated through these efforts and any subsequent guidance to leveraged agency decision-making. The research team performed this research to further examine the crashworthiness of "cutaway" or body-on-chassis medium-duty transit buses that are less than 30 ft long, building upon the FTA research report *Crashworthiness/ Crash Energy Management for Bus* (CUTR, 2017), which identified existing public transportation bus crashworthiness standards, including crash energy management (CEM) applications body-on-chassis (cutaway) buses and serves as a foundational resource for this research report. This source included the identification of gaps that exist related to cutaway bus structural and crashworthiness standards and findings that included a recognition that cutaway vehicle design, crashworthiness, and structural integrity standards are necessary.

The operating environments and the general characteristics of paratransit passengers further highlight the need for crashworthiness standards for cutaway vehicles. They often are operated in rural areas characterized by higher operating speeds on undivided and/or unpaved roadways and longer emergency response times. The need for crashworthiness standards is compounded by the type of public transportation used by passengers for services provided by these vehicles, including older adults and persons with disabilities. Both the operating environments and passenger profiles lead to a greater likelihood of increased severity when collisions occur.

Although public transportation is one of the safest modes of travel, collisions are a major challenge, resulting in high costs associated with property damage or bodily harm and damaging the perception of the entire public transportation industry. The data analysis performed as part of this evaluation and the review of relevant research demonstrated that there is room for improvement in the bus crashworthiness standards in use today.

Existing Standards

Although current State, U.S., and international (United National Economic Commission for Europe [UNECE] and Australian Design Regulations [ADR]) standards exist, many applicability restrictions exclude cutaway transit buses. Additionally, many occupant protection standards are limited to drivers of the vehicles, thus leaving passengers vulnerable. Federal Motor Vehicle Safety Standards (FMVSS) that exist and are currently applicable to cutaway transit buses are § 571.204, "Steering control rearward displacement," § 571.205, "Glazing materials," § 571.213, "Child restraint systems," § 571.217, "Bus emergency exits and window retention and release," and § 571.302, "Flammability of interior materials."

Although FMVSS 220 is related to school bus rollover protection, a quasi-static load test can be used to determine the strength and integrity of a cutaway vehicle in the event of a rollover. Additionally, the UNECE-R66 standard can be used to determine the rollover strength of the cutaway. Similarly, FMVSS 214 is related to side-impact testing standards, which are not statutorily required for cutaways but can be used to calculate vehicle strength in a side-impact scenario.

Crash and Safety Testing Standard for Paratransit Buses Acquired by the State of Florida (Florida Standard) requires crashworthiness and safety assessments of paratransit body-on-chassis buses and specifies "single-deck vehicles designed and constructed for more than 8 but less than 22 passengers, whether seated or standing, in addition to the driver and crew."[1] Paratransit body-on-chassis buses are required to pass either an experimental full-scale crash test or a numerical analysis test using a finite element (FE) method for two impact scenarios—side impact and rollovers, which are identified as critical and dangerous by bus manufacturers and operators in the U.S.[2]

Data Limitations

For the purposes of FTA statistical summaries, paratransit cutaway buses are categorized as "less than 30 ft buses," which account for approximately 34% of the total non-rail vehicles purchased with FTA grant funds.[3] It is important to note that not all cutaway buses are less than 30 ft in length and not all less-than-30-ft buses are cutaways. However, without distinct vehicle descriptions or classifications beyond general size categories included in National Transit Database (NTD), the best analytical option for identifying potential vehicles is using the less-than-30 ft classification.

Paratransit trips often are longer than city trips, occurring in rural environments on two-lane highways with higher travel speeds, which contributes to the need to include cutaway vehicles in the national safety standards discussion.

The limitations of NTD data are discussed in this report and in FTA Report No. 0103, *Review and Evaluation of Public Transportation Safety Standards*. The ability to research collision events for rural public transportation agencies and the paratransit buses used to provide that service is significantly influenced by these

[1] http://www.tripsflorida.org/docs/Crash%20and%20Safety%20Testing%20Standard%20full%20 document%20v.%203.01%202009%201.pdf.
[2] Bojanowski, C., et al., "Florida Standard for Crashworthiness and Safety Evaluation of Paratransit Buses," 21st International Technical Conference on the Enhanced Safety of Vehicles, US DOT NHTSA, Paper No. 09-0299-O, Stuttgart, Germany, June 15–18, 2009.
[3] Analysis of FTA 2015 Statistical Summary, "Vehicle Purchases by Type of Vehicle, Program, Population," 2011–2015, https://www.transit.dot.gov/funding/grants/fy-2015-statistical-summary.

limitations. The current safety reporting for FTA Section 5311 Formula Grants for Rural Areas requires only aggregated reporting by the funding recipients behalf of their subrecipients, unless the recipient allows self-reporting for its subrecipients. Rural reporters must report total reportable events and the total number of fatalities and injuries associated with those events.[4] No additional information, such as bus type or details of the event is required from rural reporters; therefore, identifying causal or contributing factors in these collision events is even more challenging than performing the same evaluation for urban system reporters.

There is no method available to identify injuries and fatalities that could have been due to lack of crashworthiness standards.

To determine if the absence of vehicle crashworthiness standards (or limited standards) contribute to injuries or fatalities, the research team conducted case studies to evaluate collisions on a case-by-case basis, focusing on collisions that resulted in injuries or fatalities.

Case Study Evaluations

To gain a comprehensive understanding of the impacts that crashworthiness and CEM applications can have on the overall safety of passengers and operators of cutaway transit vehicles, the research team first examined state data from those that purchased the most vehicles under 30 ft using FTA Section 5310 funds. Florida, California, New York, and Pennsylvania accounted for more than half (54%) of new vehicles. After corresponding with representatives from these states, it was determined that a new approach was necessary, as no pertinent data were gathered from correspondence. Re-evaluation of the approach led to further examination using rural NTD data. States were ranked by reportable incidents, total injuries, and total fatalities over the decade of available data. Several states—California, Kentucky, North Carolina, Tennessee, and Texas— stood out as ranking in the top 10 for number of incidents, fatalities, and injuries sustained over the 10-year period 2007–2016. South Carolina's Section 5311 agencies also ranked in the top 10 for injuries and fatalities, but ranked 14th in total reportable incidents. Conversely, Florida ranked 7th for the number of reportable incidents, but ranked 25th and 28th for fatalities and injuries, respectively.

Four case study states were initially selected for further examination—California, Florida, North Carolina, and Tennessee. Florida was the only state with stringent procurement guidelines that require all cutaway vehicles to have crashworthiness considerations. In total, 140 subrecipient agencies were included in the research. Between October 2017 and July 2018, subrecipient agencies with at least one injury or fatality in the past decade were contacted to determine if the injury/ fatality information found in the rural NTD data

[4] FTA, 2017 NTD Policy Manual, https://www.transit.dot.gov/ntd/2017-ntd-policy-manual.

occurred on a cutaway. If the response was positive, more information regarding the event was requested, including internal agency reports, police reports, and photos, if available. Agencies were assured that all responses would be summarized without specific agency/individual identification.

Table ES-1 shows the subrecipient responses. As of July 2018 (the date the survey was closed), 84 of the 140 subrecipient agencies responded, yielding a 60% response rate.

Table ES-1

Responses Received from 140 Agencies Contacted

Confirmed Collision Involving Cutaway	Not a Cutaway	Not a Collision	No Data / Did Not Wish to Participate	No Response
4	31	7	41	56

Of the 84 agencies responding, 41 indicated that they either did not have the necessary data or did not wish to be a part of the study. In many cases, the NTD data were not consistent with what agency representatives shared with the research team, which included a few agencies that had no record of the events referenced in the NTD. A total of 31respondents indicated that the bus or other public transit vehicle involved was not a cutaway, and 7 said the injury or fatality was sustained on a cutaway but was not the result of a collision; 4 of the 7 non-collision responses were lift incidents that resulted in either passenger or operator injuries, 2 agencies reported non-collision operator injuries with no other data released, and 1 non-collision injury was sustained on a cutaway due to a fall that occurred because of hard braking.

Four agencies—one from each case study state—responded with data related to cutaway collisions that resulted in at least one injury or fatality, providing information on 7 cutaway collisions that resulted in 13 injuries and 3 fatalities. The research team examined each of these collisions to identify and extract all pertinent information as it relates to contributing factors of injuries and fatalities. Of the seven crashes that resulted in injuries or fatalities, four were the result of a traffic control device violation, such as a signal or stop sign violation, and the others included sideswipe, rear-end, and a single-vehicle embankment encroachment crash.

Of the 13 injuries, 7 were sustained by occupants of personal vehicles involved in collisions with cutaway vehicles, 3 were to operators of cutaway vehicles, and 3 cutaway passengers sustained injuries. No cutaway passenger injuries were due to loss of survivable space within the vehicle but were due to injuries sustained by the force of the seatbelt restraining him/her. One operator of a cutaway vehicle was injured injury due to a medical emergency determined to be a contributing factor to the collision; there was no loss of or intrusion into survivable space in the cutaway. All other operator injuries were relatively minor and the result of airbag deployment or seatbelt restraining force for incidents with available data.

Additional data were obtained about one collision that resulted in fatal injuries in both vehicles involved. A personal vehicle was traveling at a high rate of speed (105 mph, according to black box data) when it failed to obey a traffic control device, resulting in a side-impact collision with a cutaway vehicle. Both vehicles rolled over, and there were no survivors in either vehicle. The fatality of the operator of the cutaway was determined to be caused by burns to 80% of his body and a fractured neck. There was no way to verify seat belt usage because a thermal event occurred because of the collision. The research team was not provided with sufficient information to determine if loss of survivable space contributed to the fatal injury of the cutaway operator.

With the limited data available, the case study process did not demonstrate that the lack of crashworthiness standards led to any injuries or fatalities from these events. However, to supplement this effort, the research team examined National Transportation Safety Board (NTSB) reports of events involving similar vehicles.

NTSB Investigations

Based on the results of NTSB investigations and corresponding recommendations to NHTSA, there remains work to be done to improve the crashworthiness of cutaway vehicles, including removing the weight applicability restrictions for several standards; developing standards for frontal, side, rear, and rollover collisions; requiring manufacturers to comply with newly-developed occupant crash protection standards; and increasing roof strength standards.[5] A number of accident investigation reports issued by the NTSB (see summaries in *Crashworthiness/Crash Energy Management for Bus*) identified the loss of survivable space and intrusions into the passenger cabins of over-the-road buses as contributing to injuries and fatalities sustained. Several, including a Dolan Springs, Arizona, accident that occurred in 2009, involved a cutaway vehicle like those currently used in paratransit and rural public transportation services across the U.S. Following an investigation of a Davis, Oklahoma, truck-tractor semitrailer/medium-size bus collision investigation, the NTSB stated that "medium-size buses, regardless of weight, operate in a manner similar to motorcoaches and, as such, should be held to similarly stringent standards."[6] NTSB established that motorcoach occupant protection standards could improve the crashworthiness of medium-size buses.

[5] "NHTSA's Approach to Motorcoach Safety" (2007), https://www.nhtsa.gov/DOT/NHTSA/Vehicle%20Safety/Articles/Associated%20Files/481217.pdf.
[6] https://www.ntsb.gov/investigations/AccidentReports/Reports/HAR1503.pdf.

Findings

Finding 1 – Inclusion of vehicle type in NTD event descriptive data will allow analyses by vehicle types to be comprehensive and comparable across geographies.

Finding 2 – Expanded applicability of FMVSS or other standards in cutaway vehicle procurement specifications may improve crashworthiness.

Finding 3 – Additional research to support industry standards or guidance designed to mitigate injuries and fatalities associated with secondary impact collisions, such as industry specifications for interior fittings, may help improve safety outcomes.

SECTION 1

Introduction

The Federal Transit Administration (FTA) entered into a Cooperative Agreement with the Center for Urban Transportation Research (CUTR) at the University of South Florida to research areas of transit safety risk, identify existing standards and recommended practices to address those areas of risk, and perform a gap analyses to establish the need for additional standards, guidance, or recommended practices to support and further the safe operation of the nation's public transportation industry. At the direction of FTA, CUTR and its research partner, the Transportation Technology Center, Inc. (TTCI), are performing research and background studies on various topics to collect the information necessary for FTA to issue recommendations to the industry on voluntary standards or to publish guidance documents or resource reports to assist the industry in mitigating areas of risk. The findings of the reports generated through these efforts and subsequent guidance can be leveraged to guide public transit agency decision-making. This research was conducted to further examine the crashworthiness of buses less than 30 ft in length.

Although transit agencies put forth great effort to avoid collisions, they continue to occur. For the public transportation industry, it is imperative that agencies train their employees and continue to invest in proven technologies and improve training and other practices to make the transportation network safer. However, collisions will continue to occur, and improved crashworthiness of transit vehicles is an important element in the safe operation of these systems. Crashworthiness, achieved through various crash energy management (CEM) techniques and applications, may increase the likelihood of survivability for operators, passengers, and, when applicable, occupants of other vehicles involved in a collision.

Crashworthiness/Crash Energy Management for Buses (CUTR, 2017) identified existing public transportation bus crashworthiness standards, including CEM body-on-chassis (cutaway) buses, and serves as a foundational resource for this research report. It includes the identification of gaps that exist related to cutaway bus structural and crashworthiness standards and findings that included a recognition that cutaway vehicle design, crashworthiness, and structural integrity standards are necessary. The team identified additional crashworthiness performance documentation that could be used to support the development of voluntary standards, recommended practices, or guidance documents and expanded previous efforts by evaluating transit-specific body-on-chassis vehicle incidents.

This report provides a needs assessment, gap analysis, and findings, including identification of relevant standards within the U.S. that the industry could adopt, non-transit-specific standards that could be modified for transit applicability, and existing standards that can be adapted for this specific vehicle type.

SECTION

2

Background

Collisions are a major challenge faced by the public transportation bus sector. They result in high costs associated with property damage, bodily harm, litigation, and claims and damage the perception of the entire public transportation industry. An analysis of the National Transit Database (NTD) Safety and Security 40 (S&S 40)[7] time series database indicates that more than 42,400 major bus collisions occurred between January 2008 and February 2018. Bus safety and security events during that period resulted in nearly 164,850 injuries, 83,660 of which were passenger injuries, and 1,036 fatalities, the majority of which were pedestrians or occupants of other vehicles. There were also 6,307 collisions reported in the category of Demand Response[8] services on the S&S 40 between 2008 and February 2018, with 78 demand response-related fatalities, including 24 passengers and 3 operators. Additionally, there were 17,760 injuries associated with demand response safety and security events, 48% of which were to passengers or operators on the demand response vehicle. As noted, these data are related to collisions, injuries, and fatalities associated with and reported as occurring in demand response services.

Although the data indicate that demand response bus collisions do not constitute the majority of all collision-related injuries and fatalities reported in the bus mode, improving the CEM of demand response cutaway vehicles has the potential to reduce the 8,400+ injuries and 27 fatalities that were sustained by transit passengers or operators between January 2008 and February 2018.[9]

In addition to S&S 40 data reported by urban systems, rural NTD data are collected for FTA Section 5311 agencies on NTD's RU-20 form. RU-20 data 2007–2016 reveal that 5,610 reportable incidents resulted in 110 fatalities and 3,394 non-fatal injuries. As the rural data reporting format does not allow for distinction between types of persons involved in incidents that led to a fatality or injury, those totals include all person types.[10] Further analysis of the rural data was completed for specific case study states and is reflected in subsequent data analysis sections of this report. Although it is notable that some Section 5311 subrecipient agencies operate buses larger than 30-ft cutaways, examining rural data is a way to gain insight into the challenges associated with the

[7] NTD S&S 40 forms are completed monthly by urbanized area formula recipients and do not include transit safety and security data for rural public transportation providers (FTA Section 5311) or agencies providing services to persons with disabilities and older adults (FTA Section 5310).
[8] NTD defines "Demand Response" as a transit mode comprising passenger cars, vans, or small buses operating in response to calls from passengers or their agents to the transit operator, who then dispatches a vehicle to pick up the passengers and transport them to their destinations.
[9] Calculated using the sum of passenger and operator injuries and fatalities for only Demand Response mode reported to NTD for the 2008 reporting year through February 2018.
[10] Person type reflects those reported in NTD and includes transit users, transit workers, roadway users, or others injured or fatally injured in transit collision events.

crashworthiness of cutaway vehicles even though the bus type/size is specifically noted in the NTD system.

These injury and fatality statistics are sobering, further validating the need for cutaway transit bus CEM standards. A key aspect to consider is that crashworthiness of a bus is determined not only by the structural integrity of the bus but also by the interior design and safety features that reduce secondary impact injuries to occupants due to contact with interior objects such as seat backs, windscreens and stanchions, and other bus occupants.

Currently, there are few structural or secondary impact physical testing results for cutaway buses. CEM and crashworthiness safety standards applicable to these medium-size transit buses are limited, in part due to a gross vehicle weight rating (GVWR) that exceeds the 10,000-lb passenger vehicle weight threshold for many Federal Motor Vehicle Safety Standards (FMVSS) related to crashworthiness and occupant protection. Additionally, the two-part assembly of a cutaway vehicle creates construction inconsistencies and, subsequently, vulnerability in the cutaway crashworthiness bus structural integrity.[11] Research sponsored by the Florida Department of Transportation (FDOT) indicates that the structural strength of various paratransit buses is unpredictable and scattered due to different construction techniques.[12]

The following section discusses the relevant crashworthiness standards for body-on-chassis transit buses and includes an examination of standards, guidelines, and existing regulations. (For more information regarding existing full-size transit bus standards, refer to Crashworthiness/Crash Energy Management for Bus). Encompassed within this review are existing U.S. standards, including FMVSS, State standards, and standards developed and adopted by entities outside the U.S., including the United Nations Economic Commission for Europe (UNECE) and Australian Design Regulations (ADR). In addition, this examination includes standards and recommended practices issued by Standards Development Organizations (SDOs) such as the American Public Transit Association (APTA). Where data were available, the literature review also presents recommendations from previous studies and reports that establish the efficacy of any established standards.

[11] Kwasniewski, K, C. Bojanowski, J. Siervogel, J. Wekezer, and K. Cichocki (2009), "Crash and Safety Assessment Program for Paratransit Buses," International Journal of Impact Engineering, 36(2), 235-242, http://sciencedirect.com/science/article/abs/pii, S0734743X0800119X

[12] Bojanowski et al., “Florida Standard for Crashworthiness and Safety Evaluation of Paratransit Buses.”

SECTION

3

Existing Bus Crashworthiness Standards for Paratransit Body-on-Chassis Buses (Cutaways)

FTA Report No. 0103, *Review and Evaluation of Public Transportation Safety Standards*, prepared pursuant to Section 3020 of the Fixing American's Surface Transportation (FAST) Act, and the associated *Compendium of Transit Safety Standards*, issued to the industry through a *Federal Register* request for comments (81 FR 30605, May 2016), identified several crashworthiness-related standards by transit mode, including bus and all rail modes, as defined by the NTD. This literature review focuses on identified crashworthiness standards related to cutaway body-on-chassis buses. The research team conducted separate previous analyses on rail and general transit bus crashworthiness/CEM standards. *Crash Energy Management for Heavy, Light, and Streetcar Rail Modes* (publication pending) and *Crashworthiness/Crash Energy Management for Transit Buses* (publication pending) are part of FTA's Standards Development Program.

Bus crashworthiness standards exist at both the Federal and State levels in the U.S. Additionally, countries and organizations outside the U.S., such as ADR and UNECE, mandate the use of bus crashworthiness standards. The Society of Automotive Engineers (SAE) International and other SDOs have developed crashworthiness standards for buses. Industry organizations and their corresponding bus crashworthiness standards, regulations, or rules are presented in this section.

Florida Safety Testing Standard for Paratransit Buses

Cutaway vehicles are a distinct type of transit bus because of their two-stage construction—a reputable auto manufacturer constructs a driver cab and chassis, and a second-stage manufacturer retrofits the cab and chassis with a passenger compartment and other necessary equipment.[13] The backside of the driver cab is removed to allow for operator access to the passenger compartment of

[13] Kwasniewski et al., "Crash and Safety Assessment Program for Paratransit."

the vehicle. There is evidence of structural weaknesses associated with a two-stage-constructed vehicle, and FDOT continues to support extensive research efforts regarding the crashworthiness and safety assessments of these vehicles. Florida enacted Chapter 14-90, Florida Administrative Code (FAC) for bus transit systems that operate or purchase vehicles or equipment with State funding. Detailed descriptions of the rules established by Chapter 14-90, FAC, documents that guide the testing and evaluation of these vehicles by FDOT, and associated research findings are presented throughout this report.

In addition, FDOT developed the *Transit Research Inspection Procurement Services* (TRIPS) program, which provides agencies with a means of procuring quality vehicles at the lowest possible price. The *Rollover Crashworthiness Assessment for Cutaway Buses Acquired by the State of Florida* and the *Pre-Qualification Structural Testing for Cutaway Buses Acquired by the State of Florida* combined comprise the Florida Standard, which requires crashworthiness and safety assessments of paratransit body-on-chassis buses. The standard applies to all cutaway type vehicles procured through FDOT.[14] Paratransit body-on-chassis buses are required to pass either an experimental full-scale crash test or a numerical analysis test using a finite element (FE) method for rollover scenarios, identified as critical and dangerous, by bus manufacturers and operators in the U.S.[15] The Florida Standard recognizes the importance of verification and validation of any FE models; as such, all new vehicle types and updated models must undergo one full-scale rollover test. Inputs to the FE model validation for the Florida Standard include the following:

- One full-scale rollover test to validate a completely new vehicle type (partial FE model validations used when minor structural modifications introduced in new bus models)
- Material characterization tests for major structural parts of the body
- Quasi-static connection tests for two vulnerable connections of each bus—roof-to-wall and wall-to-floor
- Impact hammer test of a bus wall panel
- Verification of center of gravity, mass, and wheel reactions
- Verification of energy

Rollover Crashworthiness Assessment for Cutaway Buses Acquired by the State of Florida provides detailed testing, simulation, and validation methods used by FDOT to confirm compliance with the Florida Standard.[16] These methods are described briefly in the section below.

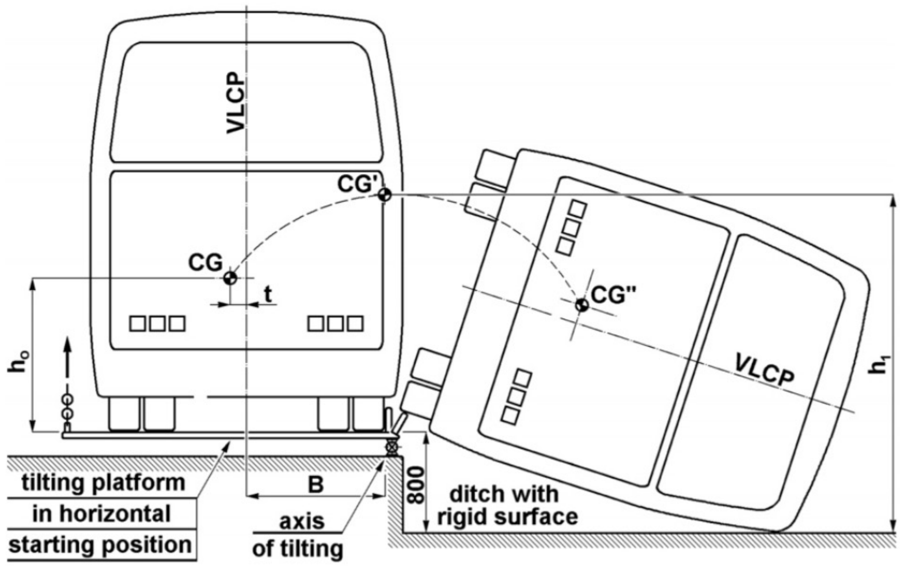
The rollover assessment is a test used to validate the FE model. Florida Standard rollover assessment criteria were adopted from the UNECE R66 standard, which requires the first article vehicle testing on a tilt table that starts at a horizontal

[14] http://www.tripsflorida.org/docs/FDOT%20prequal%20std%203-18-15.pdf; http://www.tripsflorida.org/docs/FDOT%20rollover%20std%203-18-15.pdf.
[15] Bojanowski et al., "Florida Standard for Crashworthiness and Safety Evaluation of Paratransit Buses."
[16] http://www.tripsflorida.org/docs/FDOT%20rollover%20std%203-18-15.pdf.

angle. The tilt table is then quasi-statically rotated toward the weaker passenger door side of the vehicle until the critical center of gravity roll-over point is reached. At that critical point, the table is no longer tilted and the vehicle rolls off the table onto the rigid-surfaced ditch located 800 mm beneath the tilt table horizontal position (measured from the point the vehicle wheel contacts the platform to the bottom of the rigid surface ditch, as shown in Figure 3-1).[17]

Figure 3-1

Specifications of Florida Standard Rollover Test



Pre-qualification structural testing is the second method used to validate FE model estimates of side panel plastic deformation and structural displacement into the passenger compartment. The test includes a drawing review followed by a series of evaluations conducted on a representative paratransit side panel section and wall frame connections. The panel test initiates with the panel rested horizontally on raised tubular supports. A rotational pendula device then impacts the panel with a square tube hammer (mass determined from expected plastic yield point) from a specified height to determine the elastic deformation zone. Wall-to-roof and wall-to-floor connections are tested through an applied load to specified deformations to determine threshold values. The deformation characteristics and deflection are recorded and used for comparison of numerical results.[18] Penetration of the survival space is used as a failure criterion in both tests. The cutaway side structure is deemed to be crashworthy and safe if its survival space is neither compromised by intrusion nor projection throughout the tests. In this standard, survival space is defined as space to be preserved in the passenger, crew, and driver compartment(s) to provide a safe environment for occupants during accidents. The term "crew" refers to any employee on board the bus who is not an operator.[19]

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[17] *Ibid.*

[18] http://www.tripsflorida.org/docs/FDOT%20prequal%20std%203-18-15.pdf.

[19] http://www.tripsflorida.org/docs/FDOT%20rollover%20std%203-18-15.pdf.

Vehicles procured through the TRIPS program must pass these required tests and corresponding performance-based standards, and all transit vehicles purchased in Florida using 49 USC Chapter 5310 funds must be purchased through Florida's TRIPS Program.

Other Relevant Standards for Paratransit Buses

FMVSS 220 is related to school bus rollover protection; although not statutorily required, the quasi-static load test can be used to determine the strength and integrity of a cutaway vehicle in the event of a rollover. Additionally, the UNECE-R66 standard can be used to determine the rollover strength of a cutaway. Similarly, FMVSS 214 is related to side-impact testing standards, which are not statutorily required for cutaways but can be used to calculate vehicle strength in a side-impact scenario. Several studies and associated reports have evaluated current testing standards for cutaway vehicles, the resulting conclusions and subsequent findings are presented in the evaluation section of this report.

SECTION

4

Data Presentation and Gap Analysis

Paratransit buses comprise a significant share of the total national bus fleet, and crashworthiness research should consider these vehicles. For the purposes of FTA statistical summaries, paratransit cutaway buses are categorized as "Less than 30 ft Bus," which accounted for 34% of the total vehicles purchased with FTA grant funds in 2011–2015.[20] It is important to note that not all cutaway buses are less than 30 ft in length and not all less-than-30-ft buses are cutaways. However, without distinct vehicle descriptions or classifications beyond general size categories included in the NTD, the best analytical option to identify potential vehicles is using the less than 30-ft classification.

Paratransit trips often are longer trips, occurring in rural environments on two-lane highways with higher traveling speeds, which contributes to the need for the inclusion of cutaway vehicles in the national safety standards discussion. Although these vehicles comprise a significant portion of the transit bus vehicles purchased with FTA funding, there are challenges associated with establishing the need for crashworthiness standards.

The limitations of NTD data have been discussed in this report and in FTA Report No. 0103, Review and Evaluation of Public Transportation Safety Standards. The ability to research collision events for rural public transportation agencies and the paratransit buses used to provide that service is significantly influenced by these limitations. The current safety reporting for FTA Section 5311 Formula Grants for Rural Areas requires only aggregated reporting by the funding recipients (state DOTs) on behalf of their subrecipients, unless the recipient allows self-reporting for its subrecipients. Rural reporters must report total reportable events and the total number of fatalities and injuries associated with those events.[21] No additional information, such as bus type or details of the event, is required from rural reporters; therefore, identifying causal or contributing factors in paratransit and demand response collision events is more challenging than performing the same evaluation for urban system reporters. There is no way to identify injuries and fatalities that could have been due to the lack of crashworthiness standards.

Crashworthiness of a vehicle as a contributor to injuries or fatalities cannot be determined or inferred directly from available data. To determine if vehicle crashworthiness contributed to injuries or fatalities, the research team evaluated

[20] Analysis of FTA 2015 Statistical Summary, "Vehicle Purchases by Type of Vehicle, Program, Population, 2011–2015," https://www.transit.dot.gov/funding/grants/fy-2015-statistical-summary.
[21] FTA, *2017 NTD Policy Manual.*

collisions on a case-by-case basis, focusing on collisions that resulted in injuries or fatalities. That evaluation required individual contact with each agency; an analysis of rural NTD data was performed to identify those agencies.

Analysis of the NTD rural data from the RU-20 forms for 2007–2016 (most recent data available at the time of this report) reveals the annual trends of rural reportable incidents, injuries, and fatalities. Although the linear trend indicates decreases in major reportable incidents (Figure 4-1) and fatalities (Figure 4-2), there were notable spikes in 2015 and 2016 that may be attributed to a single significant event (or series of events). Additionally, there is a corresponding increase of injuries (Figure 4-3) for those years.

Figure 4-1

Reportable Incident Trend for Section 5311 Transit Agencies, 2007–2016

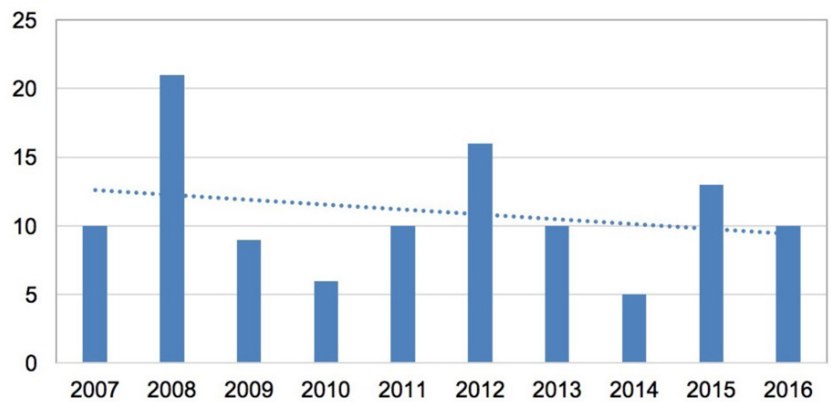


Figure 4-2

Fatality Trend for Section 5311 Transit Agencies, 2007–2016

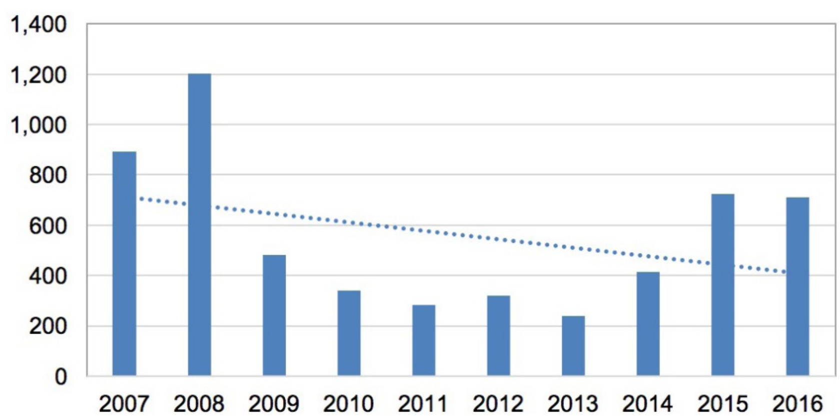
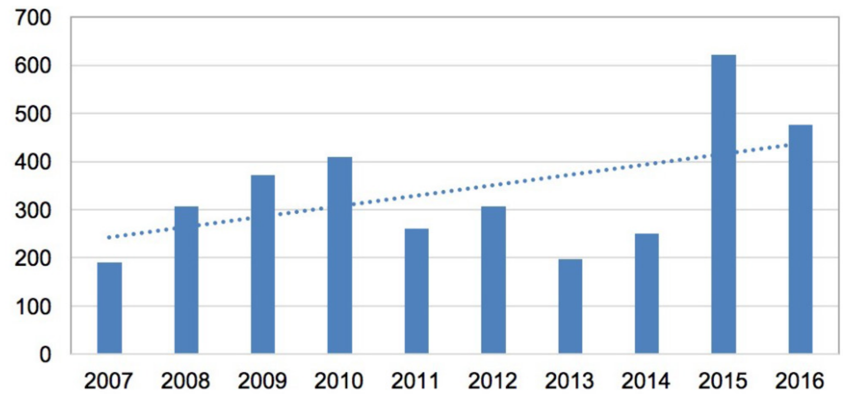


Figure 4-3

Injury Trend for Section 5311 Transit Agencies, 2007–2016



A significant challenge in proving the need for increased cutaway vehicle safety standards is the inadequacy of existing data collection methods. Paratransit cutaway vehicles often are categorized into other general bus categories in overall crash statistics, leading to scarce data availability for the analysis of cutaway collisions.[22] For example, per FMVSS, a bus classification is either a school bus or "other type of bus," with no exception for paratransit body-on- chassis.[23]

FMVSS is not the only data source that fails to classify paratransit or cutaway vehicles as a distinct type. The fact that cutaway specific data are not available is not reason enough to preclude that type of vehicle from the safety standards discussion. The Federal Highway Administration (FHWA) produces an annual Highway Statistics Series, in which vehicle miles of travel (VMT) are estimated by vehicle type and urban or rural classification using State-reported highway performance and monitoring system data. The Series lists vehicle type as "bus" without distinguishing bus type.

Nationally, approximately 35% of all bus miles traveled between 2011 and 2016 were on rural roads.[24] Often, the type of bus that operates in small urban or rural areas is a cutaway vehicle.[25] The share of travel on rural roads is important when considering safety factors associated with travel. According to the National Highway Traffic Safety Administration (NHTSA), rural roads consistently have more annual vehicular fatalities than urban roads (18,590 rural compared to 17,656 urban in 2016), and rural roads have 2.5 times higher fatality rates per 100 million VMT compared to urban roads (1.96 rural fatalities per 100 million miles traveled compared to 0.79 urban fatalities per 100 million miles traveled in 2016).[26] Rural roadway characteristics that lead to the increased danger are

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[22] *Ibid.*

[23] "Crash and Safety Testing Standard for Paratransit Buses Acquired by the State of Florida", https://www.fdot.gov/docs/default-source/transit/pages/CrashSafetyTestingStandardsFullDocument.pdf.

[24] Analysis of FHWA Statistics Series data 2011–2016. Data obtained from https://www.fhwa.dot.gov/policyinformation/statistics.cfm

[25] Texas Transportation Institute (2007), "White Paper: Transit Vehicles for Small Urban and Rural Public Transportation Systems in Texas," Texas Department of Transportation, http://www.regionalserviceplanning.org/coordination/documents/white_papers/transit_vehicles_02-2007.pdf.

[26] https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812521.

increased speed limits and two-lane undivided roadway design. Although only 19% of the U.S. population lives in rural areas, 30% of all VMT occurs on rural roadways and, as of 2016, 50% of all motor vehicle fatalities occurred on rural roadways.

The disproportionate share of fatalities correlates to the likelihood of increased severity in collisions coupled with the increased emergency response time associated with rural areas.[27] Rural accidents require increased response times due to notification time, response travel time, and transport time.[28] Rural crashes were reported an average of 2.3 minutes later than urban crashes, the average response time was 5.4 minutes longer, and the transport time was an average of 13 minutes longer for the patient to reach the hospital.[29] Many characteristics of driving in rural environments contribute to a likelihood of increased injury severity. NHTSA reports that 67% of drivers that perished in rural areas died at the scene, compared to 50% of drivers in urban geographies. The distances that emergency response vehicles must travel add to the decreased likelihood of survival, as drivers in rural areas represented 62% of those who died en route to the hospital compared to 38% for drivers in urban areas.[30] Additionally, the share of vehicle occupants fatally injured due to rollovers accounted for 37% of all rural vehicle occupants killed, whereas rollovers in urban areas accounted for only 24% of urban occupants killed.[31] Although these statistics are associated with all vehicular fatalities, the use of paratransit or body-on-chassis vehicles in rural areas and the risks associated with operating in these environments are important to consider.

Cutaways often are used as shuttles for assisted living facilities in addition to their use for demand response and paratransit public transit services.[32] As populations age, driving cessation may be necessary due to declining health or physical abilities and many will rely on others to transport them or will move to communities in which public transit is available.[33] This is an important aspect to consider, as the U.S. Census Bureau recently announced that people age 65 or older will outnumber children for the first time in U.S. history by 2030.[34] The aging of the populous that uses public transit is important to consider because of the associated increased fragility of older adults. As human bone structures

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[27] Zwerling, C., C. Peek-Asa, P. S. Whitten, S-W. Choi, N. L. Sprince, M. P. Jones (2005), "Fatal Motor Vehicle Crashes in Rural and Urban Areas: Decomposing Rates into Contributing Factors," *Injury Prevention,* 11 24-28, http://injuryprevention.bmj.com/content/11/1/24.

[28] http://docs.trb.org/prp/17-01660.pdf.

[29] *Ibid.*

[30] 2016 Rural/Urban Comparison of Traffic Fatalities, Traffic Safety Fact Sheet, NHTSA, DOT HS# 812521, https://crashstats.nhtsa.dot.gov/#/.

[31] *Ibid.*

[32] Souders, D. J., B. Gepner, N. Charness, and J. Wekezer, "Older Adults as Cutaway Bus Passengers. User-Centered Literature Review," *Transportation Research Record*, https://doi.org/10.3141/2516-05.

[33] Persson, D., "The Elderly Driver: Deciding When to Stop," *The Gerontologist*, 33(1), 1993, 88-91.

[34] U.S. Census Bureau, "Older People Projected to Outnumber Children for First Time in U.S. History," March 13, 2018, https://www.census.gov/newsroom/press-releases/2018/cb18-41-population-projections.html.

age, the material properties of bone change, causing them to become frail.[35,36,37] Seat belt use can improve injury outcomes in most collisions by preventing full or partial ejection,[38] but many vehicles do not have seat belts. If seat belts were available, especially for older adults, three-point shoulder belts would be preferred to allow collision forces to be distributed more evenly across the torso to prevent injury. Additionally, making seat backs from softer materials would allow the absorption and distribution of collision forces to reduce the likelihood of passenger injury.[39] Currently, there are no minimum standards for seat belts in these vehicles nor are there standards that address the material and design of vehicle seats.

FTA Report No. 0078, *State of Transit Bus Safety in the U.S.* (2014) evaluated the safety of public transit bus services in both rural and urban environments between 2008 and 2012. The report emphasizes that consideration should be given to the size and capacity of the vehicle types in operation when evaluating the safety of rural transit operations and reiterated NHTSA data on increased emergency medical response times, revealing that it may take up to an hour for medical assistance to arrive in some rural areas.

As paratransit cutaway vehicles account for a significant share—more than one of every three buses purchased with FTA 5310 grant funds—coupled with nearly one in every four bus miles operated in a rural environment, the crashworthiness of cutaway buses must be considered to ensure a holistic approach to address public transit safety concerns. National safety statistics highlight the additional challenges associated with rural operating environments, such as higher operating speeds on undivided and/or unpaved roadways combined with longer response times for emergency personnel, and lead to a greater likelihood of increased severity when collisions occur. The characteristics of driving paratransit vehicles in a rural environment can be mitigated with increased cutaway bus crashworthiness standards.

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[35]Kemper, A. R., C. McNally, E.A. Kennedy, S. J. Manoogian, A. L. Rath, T. P. Ng, J. D. Stitzel, E.P. Simit, S. M. Duma, and F. Matsuoka, "Material Properties of Human Rib Cortical Bone from Dynamic Tension Coupon Testing," *Stapp Car Crash Journal*, 49, 2005, 199-230.
[36]Gayzik, F., M. Yu, K. Danelson, D. Slice, and J. Stitzel, "Quantification of Age-Related Shape Change of the Human Rib Cage through Geometric Morphometrics," *Journal of Biomechanics,* 41, 2008, 1545-1554.
[37] Lau, A., M. Oyen, R. Kent, D. Murakami, and T. Torigaki, "Indentation Stiffness of Aging Human Costal Cartilage," *Acta Biomaterialia*, 4, 2008, 97-103.
[38] Souders et al., "Older Adults as Cutaway Bus Passengers."
[39] *Ibid.*

SECTION

5

Case Study Evaluations

To gain a comprehensive understanding of the impacts that crashworthiness and CEM applications can have on the overall safety of passengers and operators of cutaway transit vehicles, the research team identified states that have purchased the most vehicles under 30 ft using FTA Section 5310 funds. Florida, California, New York, and Pennsylvania accounted for more than half (54%) of new vehicles. After corresponding with representatives from each state, it was determined that a new approach was necessary, as no pertinent data were gathered from the correspondence. The re-evaluation of the approach led to further examinations using Section 5311 safety data available through the NTD. States were ranked by reportable incidents, total injuries, and total fatalities over the decade of available data. Several states—California, Kentucky, North Carolina, Tennessee, and Texas—stood out as ranking in the top 10 for number of incidents, fatalities, and injuries sustained over the 10-year period of 2007–2016. South Carolina's Section 5311 agencies also ranked in the top 10 for injuries and fatalities but ranked 14th in total reportable incidents. Conversely, Florida ranked 7th for the number of reportable incidents, but ranked 25th and 28th for fatalities and injuries, respectively. The research team further examined each of these states, as discussed below.

Revenue miles between incidents were calculated to ensure that any uptick in incidents was not solely due to concurrent increases in service provided. Rural rate data were available only through 2014 at the time of the data analysis, so all rates reference 2007–2014. Figures 5-1, 5-2, and 5-3 display the findings from the revenue mile analysis. It should be noted that smaller numbers indicate increased safety concerns by state, normalized by statewide rural revenue miles. Additionally, the null data presented for Florida in Figure 5-3 are due to the lack of fatalities in Florida in the timeframe examined.

Figure 5-1

Revenue Miles between Major Reportable Incidents by State for Section 5311 Agencies, 2007–2014

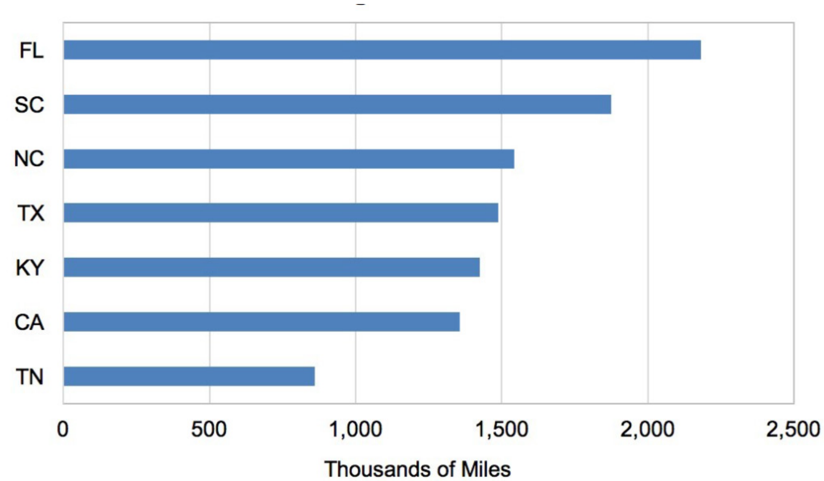


Figure 5-2

Revenue Miles between Injuries by State for Section 5311 Agencies, 2007–2014

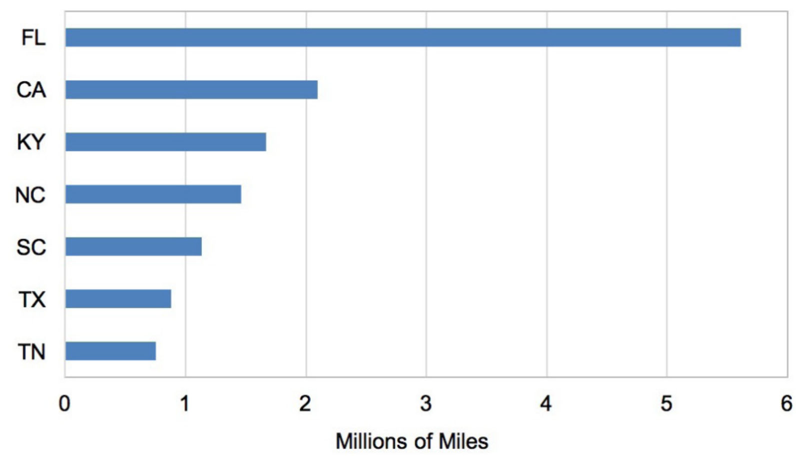
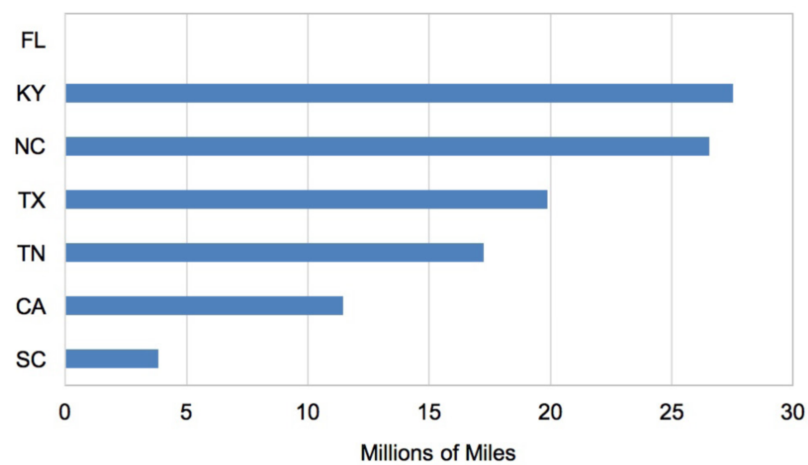


Figure 5-3

Revenue Miles between Fatalities by State for Section 5311 Agencies, 2007–2014



The rate data analysis reinforced the initial findings, and four case study states were selected for further examination. With more than 600 subrecipient agencies, an analysis of all top-ranked states was not achievable in the study timeframe. Therefore, the states contacted were California, Florida, North Carolina, and Tennessee. Florida remained in the case study analysis as the only state with stringent procurement guidelines that require all cutaway vehicles have crashworthiness considerations.

Limiting the case study examination to California, Florida, North Carolina, and Tennessee reduced the number of individual Section 5311 subrecipient agencies to be reached to 140. Outreach to those states was conducted between October 2017 and July 2018. Once a subrecipient agency was identified as having at least one injury or fatality in the past decade, contact information was obtained for collision information, including internal agency reports, police reports, and photos, if available. Each was asked if the injury/fatality information found in the rural NTD occurred on a cutaway. If the response was positive, more information regarding the event was requested. All agencies were assured that their responses would be summarized without specific agency or individual identification.

Each agency was contacted until a response was received, up to four times. Responses are displayed in Table 5-1. As of July 2018 (the date the survey was closed), 84 of the 140 agencies responded, yielding a 60% response rate.

Table 5-1

Responses Received from 140 Agencies Contacted

Confirmed Collision Involving Cutaway	Not a Cutaway	Not a Collision	No Data / Did Not Wish to Participate	No Response
4	31	7	41	56

Of the received responses, 41 agencies indicated that they either did not have the data necessary or did not wish to be a part of the study. In many cases, the NTD data were not consistent with what agency representatives shared with the research team, which included a few agencies that had no record of the events referenced in the NTD. In total, 31 responses revealed that the bus or other public transit vehicle involved was not a cutaway, 7 responded that the injury or fatality was sustained on a cutaway but was not the result of a collision, 4 of the non-collision responses were identified as lift incidents that resulted in either the passenger or the operator sustaining injuries, 2 agencies reported non-collision operator injuries with no other data released, and the non-collision injury sustained on a cutaway was due to a fall that occurred because of hard braking. Four agencies, one from each case study state, responded with data related to cutaway collisions that resulted in at least one injury or fatality and provided information on 7 cutaway collisions that resulted in 13 injuries and 3 fatalities. The research team examined each collision to identify and extract all pertinent information as it related to contributing factors of injuries and fatalities.

Given the small number of responses, the summary of collisions is not grouped by case study state. Seven crashes that resulted in injuries or fatalities were reported, four of which were the result of a traffic control device violation such as a signal or stop sign violation. The other types of collisions include sideswipe, rear-end, and a single-vehicle embankment encroachment crash.

There were 13 injuries, 7 of which were sustained by occupants of personal vehicles that were involved in collisions with cutaway vehicles, 3 were to operators of cutaway vehicles, and 3 were to passengers. The cutaway passenger injuries were not due to any loss of survivable space within the cutaway vehicle but rather to the force of the seat belt restraining them. For occupants of cutaway vehicles, one operator injury was sustained due to a medical emergency that was determined to be a contributing factor to the collision; there was no loss of or intrusion into survivable space in the cutaway. All other operator injuries were relatively minor and the result of airbag deployment or seat belt restraining force for the incidents with available data.

Additional data were obtained about one collision that resulted in fatal injuries in both vehicles involved. A personal vehicle was traveling at a high rate of speed (105 mph, according to black box data) when the driver failed to obey a traffic control device, resulting in a side-impact collision with a cutaway vehicle. Both vehicles rolled over, and there were no survivors in either vehicle. The fatality of the cutaway operator was determined to be caused by burns to 80% of his body and a fractured neck. There was no way to verify seat belt usage because a thermal event occurred because of the collision. The research team was not provided with sufficient information to determine if loss of survivable space contributed to the fatal injury of the cutaway operator.

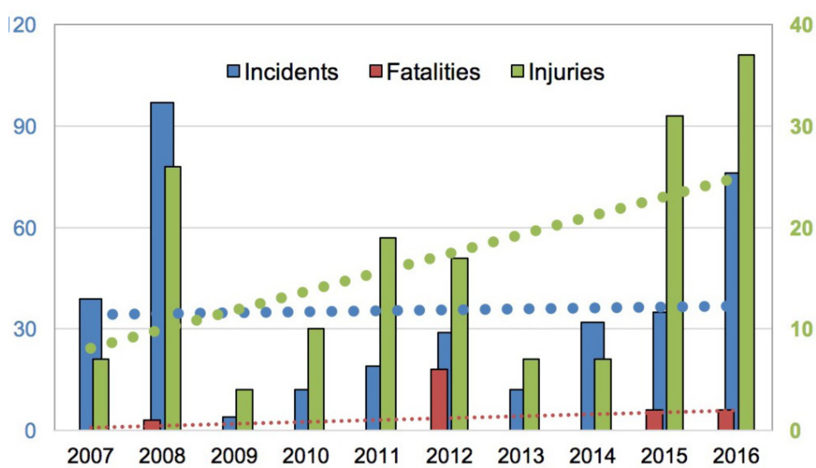
General trends of major incidents, injuries, and fatalities for Section 5311 agencies by case study state are provided in the following sections. These data provide a visual representation of the increasing or decreasing nature of the trends of incidents, injuries, and fatalities. The injuries and fatalities presented in the following figures are inclusive of all person types, including occupants of personal vehicles, bicyclists, and pedestrians. Although cutaway vehicles are more susceptible to structural weaknesses in rollover and side-impact collisions, they are still larger than most personal vehicles, and the physics of mass often lead to more severe damage sustained by the personal vehicle. Therefore, it is important to clarify that the efforts of increasing the crashworthiness of cutaways vehicles will not decrease the likelihood of all injuries and fatalities displayed in the following figures.

California

Figure 5-4 illustrates the trend of Section 5311 agency-reportable major incidents, injuries, and fatalities in California for 2007–2016. The left axis refers to the number of incidents reported, and the right axis refers to reported injuries and fatalities. The dotted lines indicate the 10-year trends that reflect an increasing trend for injuries, minimal increases and fatalities, and no increase in the number of incidents reported. The most notable increase is for the injuries sustained in California, with spikes in 2015 and 2016.

Figure 5-4

Trend in Major Reportable Incidents, Injuries, and Fatalities, California Section 5311 Agencies, 2007–2016

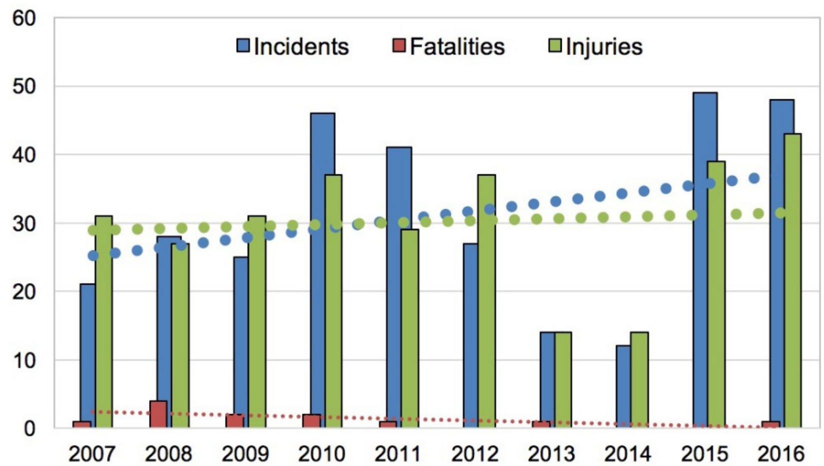


North Carolina

Figure 5-5 shows the trend in major reportable incidents, injuries, and fatalities in North Carolina for 2007–2016. The most notable increases are incidents and injuries sustained, with spikes in 2015 and 2016. North Carolina has a decreasing linear trend in fatalities over the past decade.

Figure 5-5

Trend in Major Reportable Incidents, Injuries, and Fatalities, North Carolina Section 5311 Agencies, 2007–2016

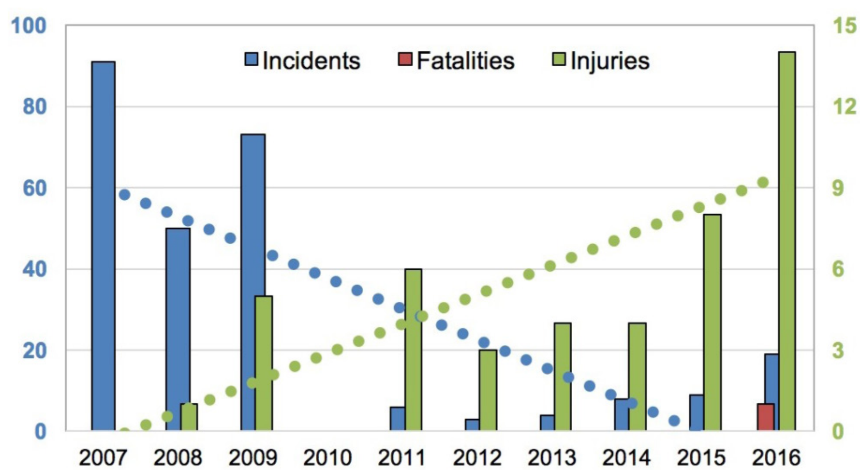


Florida

Figure 5-6 illustrates the trend in major reportable incidents, injuries, and fatalities in Florida for 2007–2016. The left axis refers to the number of incidents reported, and the right axis refers to the injuries and fatalities reported. The most notable increase is in the injuries sustained with spikes in 2015 and 2016. The reportable incident trend line shows a decreasing linear trend over the past decade. The only rural fatality that occurred in Florida in the past decade was in 2016, and the agency revealed that it occurred on a 40-ft transit coach, not a cutaway. It is important to emphasize that the injuries and fatalities in the figures are to all person types, not just occupants or operators of cutaway vehicles.

Figure 5-6

Trend in Major Reportable Incidents, Injuries, and Fatalities, Florida Section 5311 Agencies, 2007–2016

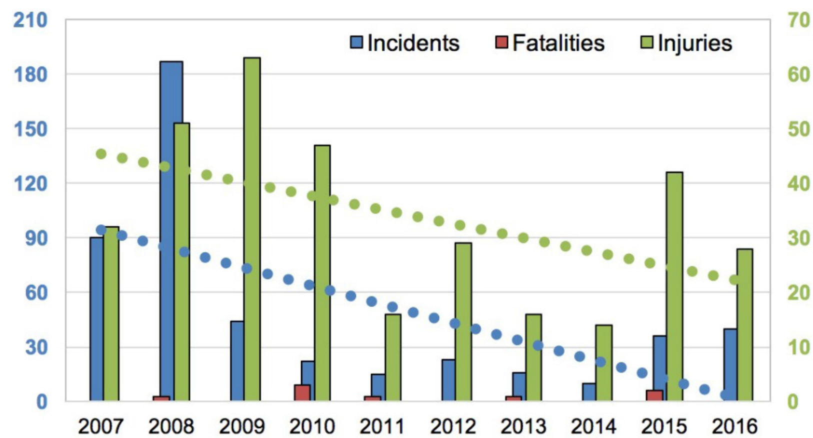


Tennessee

Figure 5-7 displays the trend in major reportable incidents, injuries, and fatalities in Tennessee for 2007–2016. The most notable trends are decreases in incidents and injuries sustained in Tennessee, with spikes in injuries in 2015 and 2016.

Figure 5-7

Trend in Major Reportable Incidents, Injuries, and Fatalities, Tennessee Section 5311 Agencies, 2007–2016



Comparison of state date requires consideration of total vehicle miles in relation to incident and injury/fatality data. Millions of miles between incidents and injuries are depicted in Figures 5-8 and 5-9.

Figure 5-8

Millions of Vehicle Miles between Incidents by State, Section 5311 Agencies, 2007–2014

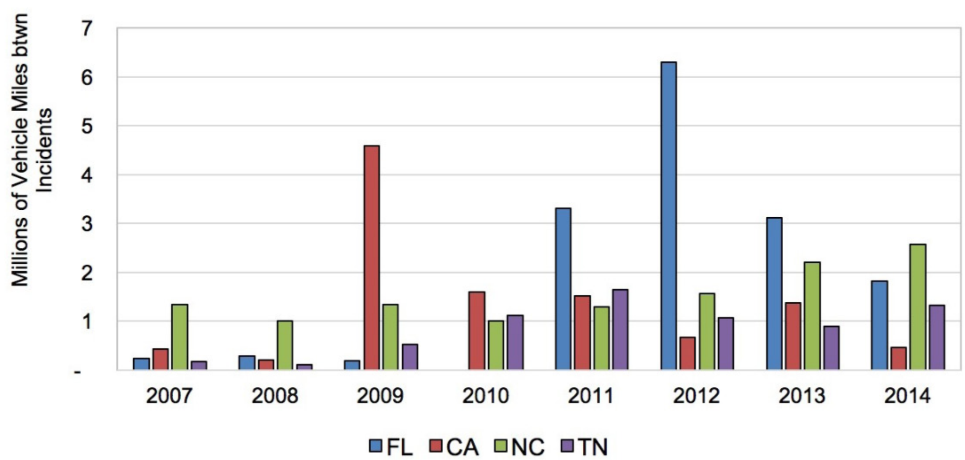
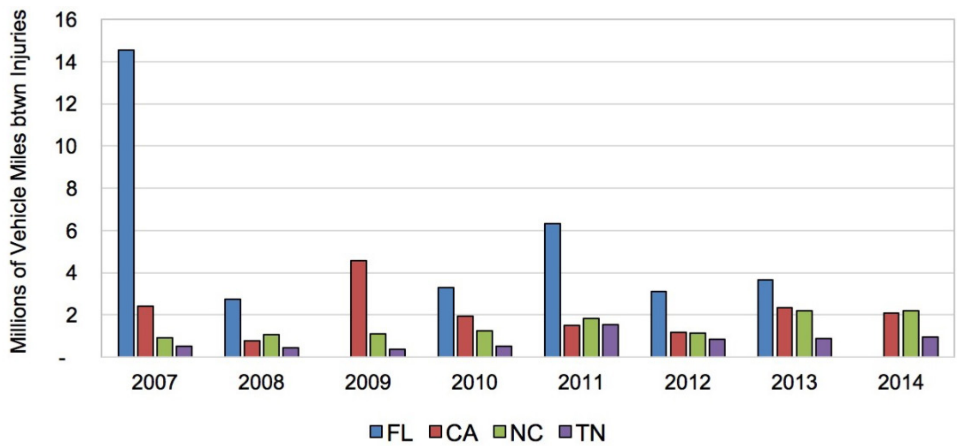


Figure 5-9

Millions of Vehicle Miles between Injuries by State, Section 5311 Agencies, 2007–2014



Additional Outreach

Through networking opportunities and status updates, the research team contacted other transit professionals with similar safety interests, including the Washington State Transit Insurance Pool (WSTIP), which classifies all events by type of vehicle. However, WSTIP only recently began collecting vehicle type information and had not yet collected any collision information specifically related to cutaway buses. Additionally, WSTIP indicated that all claims in cutaways in the past were related to securement issues, primarily due to improper or ineffective use of the securement system. WSTIP provided contact information for a Washington State DOT representative who provided information about cutaway statewide procurement specifications. Cutaway vehicles bought through the WSDOT statewide contract must meet FMVSS standards for rollover (§ 571.220), seat belts (§ 571.209, §5 71.210), seat materials (§ 571.302), passenger seats (§ 571.207), ADA lift/ramps (§ 571.403, §571.404), and Federal escape standards (§ 571.217). Expanded applicability of the FMVSS is included for:

- § 571.207 – Seating systems
- § 571.209 – Seat belt assemblies
- § 571.210 – Seat belt assembly anchorages

Outreach to the New Mexico DOT revealed that no fatalities had occurred since 2001 and that less than a half a dozen incidents with injuries occurred in the past decade. The agency forwarded a request for data to all rural subrecipient agencies in the state, but no responses were received.

SECTION

6

Conclusions

Structural Vehicle Performance Evaluation of Cutaway Buses

Two types of bus collisions likely to cause residual occupant space intrusion[40] are roof crush or rollover and side-impact.[41] Aside from residual space, it is also important to consider the secondary impacts that contribute to the likelihood of injury or fatality of paratransit occupants if the vehicle is involved in a collision. *Crashworthiness/Crash Energy Management for Bus* summarizes the most likely contributors to injuries and fatalities when a cutaway vehicle is involved in a collision and focuses on rollover events, side impact collisions, and secondary impacts. The literature review also presents some NTSB and NHTSA recommendations in response to fatal events involving over-the-road coaches.

Transit Cutaway Bus Crashworthiness/CEM Standards

Although public transportation is one of the safest modes of travel, the industry should consider crashworthiness standards for cutaway transit buses to ensure the safety of occupants, including drivers, in collisions. Collisions are a major challenge faced by the public transportation bus sector that result in high costs associated with property damage or bodily harm and damage the perception of the entire public transportation industry. The data analysis performed as part of this evaluation and the review of relevant research demonstrate that there is room for improvement in the bus crashworthiness standards in use today.

Although current state, U.S., and international (UNECE and ADR) standards exist, many applicability restrictions exclude cutaway transit buses. Additionally, many occupant protection standards are limited only to the vehicle driver, thus leaving the passengers vulnerable. The FMVSS 200 Series focuses on several aspects of crashworthiness, but 49 CFR 571.201, "Occupant protection in interior impact," is applicable only to vehicles that weigh less than 10,000 lb GVWR. Unfortunately, nearly every transit bus, including smaller cutaway style paratransit vehicles, exceeds 10,000 lb. GVWR. Other FMVSS standards applicable only to drivers include § 571.207, "Seating systems," § 571.208, "Occupant crash protection," § 571.209, "Seat belt assemblies," and § 571.210, "Seat belt assembly anchorages." The FMVSS safety standards that do exist

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[40] Per UNECE R-66, residual space is the space to be preserved in the passenger, crew, and driver compartment(s) to provide better survival possibility for passengers, drivers, and crew in case of a rollover accident.
[41] Bojanowski et al., "Florida Standard for Crashworthiness and Safety Evaluation of Paratransit Buses."

and are currently applicable to cutaway transit buses are § 571.204, "Steering control rearward displacement," § 571.205, "Glazing materials," § 571.213, "Child restraint systems," § 571.217, "Bus emergency exits and window retention and release," and § 571.302, "Flammability of interior materials."

In addition to U.S. FMVSS standards, some U.S. states call for the Federal standards to apply to additional vehicle types, thus removing the weight applicability restrictions present at the Federal level. States with additional procurement guidelines include Florida, Wisconsin, Washington, and Minnesota. Those standards and guidelines are noted throughout the report and are presented in the table of current standards in Appendix A.

UNECE has issued several bus crashworthiness standards applicable to transit cutaway buses, including several standards for safety belts and their anchorages, child restraint systems, seat and seat anchorage strength, head restraints, prevention of fire risk, glazing materials, and superstructure strength. ADR's crashworthiness standards applicable to transit buses include seats, seat anchorages, child restraints, seatbelts, glazing materials, and rollover protection. UNECE and ADR standards are highlighted in Appendix A.

When determining the crashworthiness of a bus, it is important to consider both the structural integrity of the vehicle and contributing factors that lead to secondary impacts in a collision. It is imperative that standards consider not only residual space that remains following a collision, but also the design of seats, seat belts, headrests, and window glazing to reduce the likelihood of secondary impacts to passengers and drivers.

Challenges with Cutaway Crashworthiness Standards

Cutaways often have a GVWR that exceeds the 10,000-lb. limiting weight for many 49 CFR Part 571 Section 200 FMVSS standards. Additionally, the two-part assembly of cutaway vehicles creates construction inconsistencies and subsequent crashworthiness and structural integrity vulnerabilities.[42] Additionally, these body-on-chassis cutaway vehicles often operate in rural environments that are more dangerous due to increased speeds and rural roadway designs.

Florida is leading the way in stringent cutaway standards, requiring the testing of all paratransit buses to withstand side-impact and rollover scenarios. Details of the required test results can be found in the evaluation of standards section for paratransit body-on-chassis.

[42] Kwasniewski et al., "Crash and Safety Assessment Program for Paratransit."

When crashworthiness standards do not agree across regulating geography, several studies have been performed to determine the most appropriate. The rollover/superstructure strength tests that conflict are the 49 CFR 571.216 and 571.220 (FMVSS roof crush resistance/school bus rollover protection) standards and the UNECE R-66 (superstructure strength) standard. The FMVSS standard is based on a quasi-static test, and the UNECE R-66 is based on a dynamic test. Most researchers who performed comparative analyses determined that the UNECE test is more stringent and should be the deciding standard for rollover strength.

Another standard that is inconsistent across regulating geography is the side-impact standard. The main discrepancy is the height and weight of the sled test deformable barrier. Although the FMVSS personal motor vehicle standard is based on a passenger car bumper height, the Florida Standard and the IIHS testing protocols use a deformable barrier that is more representative of a truck or SUV (addressing both the bumper height and mass of these vehicles), given the increased proportion of personal vehicles on the roadway that are larger vehicles.

Investigation Reports and Supporting Research

Following several NTSB recommendations, there is still work to be done to improve the crashworthiness of cutaway vehicles, including removing the weight applicability restrictions for several standards; developing standards for frontal, side, rear, and rollover collisions; requiring manufacturers to comply with newly-developed occupant crash protection standards; and increasing roof strength standards.[43] The NTSB recognizes that medium-size buses, regardless of weight, operate in a manner similar to motorcoaches and, as such, should be held to similarly stringent standards.[44] Several accident investigation reports issued by the NTSB (see summaries in *Crashworthiness/Crash Energy Management for Bus)* have identified the loss of survivable space and intrusions into the passenger cabins of over-the-road buses as contributing to injuries and fatalities sustained. A number of these, including a Dolan Springs, Arizona, accident that occurred in 2009, involved a cutaway vehicle such as those currently used in paratransit and rural public transportation services across the U.S. Following an investigation of a Davis, Oklahoma, truck-tractor semitrailer/medium-size bus collision investigation that NTSB noted, "medium-size buses, regardless of weight, operate in a manner similar to motorcoaches." NTSB established that motorcoach occupant protection standards could improve the crashworthiness of medium-size buses.

[43] "NHTSA's Approach to Motorcoach Safety."
[44] https://www.ntsb.gov/investigations/AccidentReports/Reports/HAR1503.pdf.

Data and Gap Analysis Summary

The research team examined NTD data to determine if the need for national crashworthiness standards for body-on-chassis cutaway buses is warranted. Although the literature review findings support the development of crashworthy standards for cutaway vehicles, the data evaluation and outreach responses provided insufficient evidence that crashworthiness standards should be mandatory for transit cutaway buses. There are no NTD data to support the need for crashworthiness standards for these vehicles, but there is supplemental evidentiary support for standards that exists within NTSB investigation reports and other research.

Nationally, buses operated approximately 37% of all bus miles traveled on rural roads between 2011 and 2016.[45] Often, the type of bus that operates in small urban or rural areas is a cutaway vehicle.[46] The share of travel on rural roads is important when considering safety factors associated with travel. According to NHTSA, rural roads consistently have more annual fatalities than urban roads (18,590 rural compared to 17,656 urban in 2016), and rural roads have 2.5 times higher fatality rates per 100 million VMT compared to urban roads (1.96 rural fatalities per 100 million miles traveled compared to 0.79 urban fatalities per 100 million miles traveled in 2016).[47] Some rural roadway characteristics that lead to the increased danger are increased speed limits, limited lighting, and two-lane undivided roadway design. Although only 19% of the U.S. population lives in rural areas, 30% of all VMT occur on rural roadways and, as of 2016, 50% of all motor vehicle fatalities occurred on rural roadways. The disproportionate share of fatalities correlates to the likelihood of increased severity in collisions that occur, coupled with the increased emergency response time associated with rural areas.[48]

Crashes that occur in rural areas have increased response times due to notification time, response travel time,[49] and transport time. Not only are rural crashes reported an average of 2.3 minutes later than urban crashes, but the average response time is 5.4 minutes longer and the transport time is an average of 13 minutes longer for the patient to reach the hospital.[50] Many characteristics of driving in rural environments contribute to a likelihood of increased injury severity. NHTSA reports that 67% of drivers that perished in rural areas died at

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[45] Analysis of FHWA's Highway Statistics Series data for 2011 through 2016. Data obtained from https://www.fhwa.dot.gov/policyinformation/statistics.cfm.
[46] Texas Transportation Institute, "White Paper."
[47] https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812521.
[48] Zwerling et al. (2005).
[49] http://docs.trb.org/prp/17-01660.pdf.
[50] *Ibid.*
[51] https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812521.
[52] *Ibid.*

the scene compared to 50% in urban geographies. The distances that emergency response vehicles must travel add to the decreased likelihood of survival, as drivers in rural areas represent 62% of drivers who died en route to the hospital compared to 38% for drivers in urban areas.53 Additionally, the share of vehicle occupants fatally injured due to rollovers accounted for 37% of all rural vehicle occupants killed, whereas rollovers in urban areas accounted for only 24% of urban occupants killed.54

Collision and event data on paratransit vehicles operating in rural areas are scarce. The support of standards for these vehicles rests in the percentage these vehicles represent of all non-rail transit vehicles purchased with FTA funds coupled with the increased risk associated with rural highway travel and trips of longer duration.

An examination of the standards that exist, whether contained within the FMVSS, State regulations and laws, or internationally, establishes that the adoption of these may lead to improved overall safety for occupants of these vehicles.

SECTION

7

Findings

Based on the research and analysis conducted, several findings were developed:

- **Finding 1** – Inclusion of vehicle type in NTD event descriptive data will allow analyses by vehicle types to be comprehensive and comparable across geographies.

- **Finding 2** – Expanded applicability of FMVSS or other standards in cutaway vehicle procurement specifications may improve crashworthiness.

- **Finding 3** – Additional research to support industry standards or guidance designed to mitigate the injuries and fatalities associated with secondary impact collisions, such as industry specifications for interior fittings, may help improve safety outcomes.

APPENDIX

A Current Bus Crashworthiness Standards

Table A-1

Current Bus Crashworthiness Standards

Geography	Type of Rule	Document	Title	Applicability	Target (Crashworthiness-related)	Link
US (FMVSS)	Regulation	49 CFR 571.204	Steering control rearward displacement	Transit bus	Operator safety	http://www.ecfr.gov/cgi-bin/retrieveECFR?gp=&SID=bc402070bf156ce6b5d4b2bd7c375da7&mc=true&n=pt49.6.571&r=PART&ty=HTML#se49.6.571_1204
US	Regulation	49 CFR 571.205	Glazing materials	Transit bus	Occupant ejection	
US	Regulation	49 CFR 571.213	Child restraint systems	Transit bus	Built-in restraints	
US	Regulation	49 CFR 571.217	Bus emergency exits and window retention and release	Transit bus	Occupant ejection	
US	Regulation	49 CFR 571.302	Flammability of interior materials	Transit bus	Vehicle fires	
US	Regulation	49 CFR 571.207	Seating systems	Transit bus – operator only	Seat failure	
US	Regulation	49 CFR 571.208	Occupant crash protection	Transit bus – operator only	Forces on crash dummies	
US	Regulation	49 CFR 571.209	Seat belt assemblies	Transit bus – operator only	Operator safety	

Table A-1 (cont.)

Current Bus Crashworthiness Standards

Geography	Type of Rule	Document	Title	Applicability	Target (Crashworthiness-related)	Link
US	Regulation	49 CFR 571.210	Seat belt assembly anchorages	Transit bus – operator only	Operator safety	
US	Regulation	49 CFR 571.216	Roof crush resistance	Bus with GVWR <10,000 lb	Rollover	
US	Regulation	49 CFR 571.220	School bus rollover protection	School bus	Rollover	
UNECE	Regulation	R-14	Safety-belt anchorages, ISOFIX anchorages systems, ISOFIX top tether anchorages	M3 – vehicles with more than 8 passenger seats and mass exceeding 5 metric tons (11,023 lb)	Seat belts	http://www.unece. org/ fileadmin/DAM/ trans/main/ wp29/ wp29resolutions/ ECE- TRANS-WP29-78- r4e.pdf
UNECE	Regulation	R-16	Safety-belts, restraint systems, child restraint systems, ISOFIX child restraint systems	M3	Seat belts	https://www.unece. org/ fileadmin/DAM/ trans/main/ wp29/ wp29regs/2015/ R016r8. pdf
UNECE	Regulation	R-17	Seats, their anchorages and any head restraints; prohibits side- facing seats.	M3 – vehicles not covered in UNECE R-80	Seat failure	https://www.unece. org/ fileadmin/DAM/ trans/main/ wp29/ wp29regs/2015/ R017r5e. pdf
UNECE	Regulation	R-25	Head restraints (headrests)	M3	Secondary injury	https://www.unece.org/ fileadmin/DAM/trans/ main/wp29/wp29regs/ r025r1e.pdf
UNECE	Regulation	R-34	Prevention of fire risks	M3	Collision-related testing	https://www.unece. org/ fileadmin/DAM/ trans/main/ wp29/ wp29regs/2015/ R034r3e.pdf
UNECE	Regulation	R-36	General construction of large passenger vehicles	M3	Load distribution requirements, minimum area available for passengers, maximum passenger capacity	https://www.unece.org/ fileadmin/DAM/trans/ main/wp29/wp29regs/ r036r3e.pdf

Table A-1 (cont.)

Current Bus Crashworthiness Standards

Geography	Type of Rule	Document	Title	Applicability	Target (Crashworthiness-related)	Link
UNECE	Regulation	R-43	Glazing materials	M3	Occupant ejection	https://www.unece.org/fileadmin/DAM/trans/main/wp29/wp29regs/R043r3e.pdf
UNECE	Regulation	R-66	Superstructure Strength	M3	Rollover	https://www.unece.org/fileadmin/DAM/trans/main/wp29/wp29regs/r066r1e.pdf
UNECE	Regulation	R-80	Strength of seats and their anchorages	M3	Seat failure	https://www.unece.org/fileadmin/DAM/trans/main/wp29/wp29regs/R080r1e.pdf
UNECE	Regulation	R-114	Airbag replacement	M3	Operator safety	https://www.unece.org/fileadmin/DAM/trans/main/wp29/wp29regs/r114e.pdf
UNECE	Regulation	R-135	Pole side impact performance	M2 – vehicles with more than 8 passenger seats and max. mass not exceeding 5 metric tons (11,023 lb)	Forces on crash dummies	https://www.unece. org/fileadmin/DAM/ trans/main/wp29/ wp29regs/2016/R135r1e. pdf
ADR	Standards	3/03	Seats and seat anchorages	ME – Heavy Omnibus with Gross Vehicle Mass exceeding 5.0 tonnes	Seat failure	https://infrastructure. gov.au/roads/motor/ design/files/ADR_ Applicability Summary- M-Group.pdf
ADR	Standards	4/05	Seatbelts	ME	Seat belts	https://www.legislation.gov.au/Details/F2014C00230
ADR	Standards	5/05	Anchorages for seatbelts	ME	restraint failure	https://www.legislation.gov.au/Details/F2009C00157

Table A-1 (cont.)

Current Bus Crashworthiness Standards

Geography	Type of Rule	Document	Title	Applicability	Target (Crashworthiness-related)	Link
ADR	Standards	8/01	Safety glazing material	ME	Occupant ejection	https://www.legislation.gov.au/Details/F2015C00542
ADR	Standards	34/02	Child restraint anchorages, child restraint anchor fittings	ME	restraint failure	https://www.legislation.gov.au/Details/F2012L00703
ADR	Standards	42/04	General safety requirements	ME	External or internal protrusions	https://www.legislation.gov.au/Details/F2016C00153
ADR	Standards	59/00	Standards for omnibus rollover strength	ME	Rollover	https://www.legislation.gov.au/Details/F2012C00535
ADR	Standards	68/00	Occupant protection in buses	ME	Seat performance	https://www.legislation.gov.au/Details/F2006L01454
FL	Rule	Section 14-90.007(1)(b) F.A.C.	Structural integrity	Bus procured through Florida's Transit Research Inspection Procurement Services (TRIPS)	CEM	http://www.flrules. org/gateway/ ruleno.asp?id=14-90.007&Section=0
FL	Rule	Section 14-90.007(1)(c) F.A.C.	Compliance with FMVSS 49 CFR: 571 secs 207, 209, 210, 217, 302 are at least partially-related to vehicle crashworthiness (shown above)	Bus procured through TRIPS Program	Seating systems, seat belt assembly, seat belt anchorages, emergency exits and window retention release, and flammability of interior materials	
FL	Rule	Section 14-90.007(8) F.A.C.	Emergency exits	Bus procured through TRIPS Program	Emergency evacuation	

Table A-1 (cont.)

Current Bus Crashworthiness Standards

Geography	Type of Rule	Document	Title	Applicability	Target (Crashworthiness-related)	Link
FL	Rule	Section 14-90.007(12) F.A.C.	Seat belts	Bus procured through TRIPS Program	Operator safety	
MN	Rule	Minnesota Administrative Rules Chapter 8840.5940 Section (1)	Rollover protection	All vans and buses	Rollover	https://www.revisor.mn.gov/rules?id=8840.5940&keyword_type=all&keyword=bus
WI	Rule	Wisconsin Administrative Code Chapter Trans 330.10 (12)	Equipment requirements and standards (Frame)	Motor bus	The frame shall conform to the requirements under 49 CFR 393.201	https://docs.legis.wisconsin. gov/code/admin_code/ trans/330
WI	Rule	Wisconsin Administrative Code Chapter Trans 330.10 (20)	Equipment requirements and standards (Seating)	Motor bus	Seat performance	
WI	Rule	Wisconsin Administrative Code Chapter Trans 330.10 (30)	Equipment requirements and standards (Windows and windshields)	Motor bus	Compliance with 49 CFR 571.217	
APTA	Guidelines	Procurement Guidelines Section 6: TS 23.2	Crashworthiness	Transit Coach	Performance guidelines	http://www.apta.com/resources/reportsandpublications/Documents/ APTA%20Bus%20Procurement%20Guidelines%20(June%202013).docx

Table A-1 (cont.)

Current Bus Crashworthiness Standards

Geography	Type of Rule	Document	Title	Applicability	Target (Crashworthiness-related)	Link
FTA	Guidelines	Vehicle Design - Low-floor Vehicles	Crashworthiness	Low floor buses	Vehicle design guidelines	https://www.transit. dot. gov/research- innovation/ vehicle- design
SAE	Recommended Practice	J2249_199901	Wheelchair tie- down and occupant restraint systems for use in motor vehicle	Automotive including bus	Places emphasis on design requirements, test procedures, and performance requirements for dynamic performance of WTORS in a 48-km/h, 20-g frontal impact	http://www.sae. org/search/?sort= date&content- type=(%22STD%22)&root- code= (%22J2249%22)

ACRONYMS AND ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
ADR	Australian Design Rules
ANSI	American National Standards Institute
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ATD	Anthropomorphic Test Devices
BEA	Bureau of Economic Analysis
BTS	Bureau of Transportation Statistics
BTW	Behind the Wheel
CDC	Centers for Disease Control and Prevention
CEM	Crash Energy Management
CFR	Code of Federal Regulations
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
CUTR	Center for Urban Transportation Research
DOT	Department of Transportation
ERT	Equivalent Rollover Testing
FAC	Florida Administrative Code
FAST Act	Fixing America's Surface Transportation Act
FDOT	Florida Department of Transportation
FE	Finite Element
FMCSA	Federal Motor Carrier Safety Administration
FMVSS	Federal Motor Vehicle Safety Standards
FTA	Federal Transit Administration
GAO	Government Accountability Office
GES	General Estimates System
GVWR	Gross Vehicle Weight Rating
HOS	Hours of Service
IIHS	Insurance Institute for Highway Safety
ISO	International Standards Organization
MAP–21	Moving Ahead for Progress in the 21st Century
MCI	Motor Coach Industries
NASS	National Automotive Sampling System
NCTR	National Center for Transit Research

NFPA	National Fire Protection Association
NHTSA	National Highway Traffic Safety Administration
NHTS	National Household Travel Survey
NIOSH	National Institute for Occupational Safety and Health
NMDOT	New Mexico Department of Transportation
NTD	National Transit Database
NTSB	National Transportation Safety Board
OCC	Operations Control Center
OSHA	Occupational Health and Safety Administration
PTASP	Public Transportation Agency Safety Plan
ROW	Right of Way
SAE	Society of Automotive Engineering
SGR	State of Good Repair
SINCAP	Side Impact New Car Assessment Program
SMS	Safety Management Systems
SUV	Sport Utility Vehicle
TCRP	Transit Cooperative Research Program
TRACS	Transit Advisory Committee for Safety
TRB	Transportation Research Board
TRI	FTA Office of Research, Demonstration, and Innovation
TRID	Transport Research International Documentation
TSO	FTA Office of Transit Safety and Oversight
UNECE	United National Economic Commission for Europe
USC	United States Code
USDOT	United States Department of Transportation
USF	University of South Florida
VRTC	Vehicle Research and Testing Center
WSDOT	Washington State Department of Transportation
WSTIP	Washington State Transit Insurance Pool

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