AN ANALYSIS OF TRANSIT BUS AXLE WEIGHT ISSUES

Prepared for:

American Public Transportation Association

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Disclaimer

FINAL REPORT

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Executive Summary

This report analyzes transit bus axle weight issues that have evolved over the past few decades with changes in regulations, bus design and construction, and operations. These changes have resulted in certain transit buses exceeding applicable axle weight limits. This report provides information to help decision-makers identify options to reduce bus weight, mitigate the negative impacts of transit buses exceeding weight limits, and address competing regulations in this area. These options, which can be implemented individually or in combination, include various changes to (1) transit bus design and manufacturing, (2) transit operations, (3) pavement design and engineering, and (4) regulations.

This research reviewed findings from literature and other documentation published over the past decade and gathered current knowledge from relevant stakeholders regarding:

1) Relevant national and state laws and regulations pertaining to transit bus weight,
2) The weight of transit buses while in service,
3) The impacts of transit buses on pavement, and
4) Options to mitigate negative impacts on pavement, transit systems, and communities.

Transit Buses and Regulations

Commercial motor vehicles—including transit buses—are subject to regulations established by federal, state, and municipal authorities to support safe, efficient, and equitable transit service while controlling infrastructure and environmental impacts. Regulations are dynamic and respond to changes in industry characteristics, technological advancements, user requirements, and a host of societal norms. Consequently, regulations occasionally have requirements that compete with one another and create an impractical or unenforceable regulatory environment, as is currently the situation for the transit industry.

Both federal and state regulations limit axle weights for transit buses (and other commercial motor vehicles) to help protect highway infrastructure, among other objectives. In 1974, federal weight limits for single and tandem axles for all commercial motor vehicles, including transit buses, were set at 20,000 and 34,000 pounds, respectively.

In addition to weight limits, transit buses, are affected by federal and state policies, programs, and regulations concerning energy use, emissions, passenger accessibility, and vehicle testing standards, all of which have resulted in design modifications that alter the curb weight of transit buses. Specifically, environmental and accessibility regulations have been enacted that require additional transit bus components (such as lower polluting fuel systems and wheelchair lifts) without corresponding transit bus weight limit increases. Additionally, federal stipulations mandating a minimum 12-year service life necessitates the use of certain heavy-duty transit bus components.

Consequently, it has become increasingly difficult for in-service transit buses to comply with federal and state axle weight regulations. In response, federal law exempted transit buses from prescribed axle weight limits in the early 1990s, and these exemptions were extended indefinitely with the Moving Ahead for Progress in the 21st Century (MAP-21) transportation reauthorization bill in 2012. Additionally, 14 states have enacted limits specifically for transit buses to address this issue.

Transit Bus Fleet and Operating Characteristics

The physical and operational characteristics of transit buses impact the weight of transit bus axles and the magnitude of pavement deterioration they cause. While a variety of bus configurations exist, currently, transit systems in the United States consist predominantly of the following types of buses:

- **Two-axle 40-ft buses** comprise approximately two-thirds of the transit bus fleet in the United States. The curb weights for these transit buses currently range between approximately 20,000 and 33,000 pounds, and fully-loaded weights range from approximately 30,000 to 44,000 pounds. As such, passengers comprise roughly one-third of the gross vehicle weight (GVW) of a fully-loaded 40-ft transit bus.
- **Three-axle 60-ft** articulated buses are the next most common transit bus in service, comprising about 10% of the fleet. The curb weights for these buses currently range between approximately 38,000 and 50,000 pounds, and fully-loaded weights range from approximately 56,000 to 65,000 pounds.

Based on available transit bus test data, fewer than half of all transit bus models comply with a 20,000 pound single axle weight limit when empty (i.e., at curb weight) and nearly all rear axles on transit buses longer than 35 feet exceed 24,000 pounds.

The transit bus manufacturing industry has undertaken significant research and development activities directed at decreasing the curb weight of transit buses. Future opportunities to reduce transit bus curb weight include the use of lighter weight materials and alternative manufacturing techniques, but any weight reductions are expected to be costly for the manufacturing industry. Alternative axle arrangements (such as adding a tag axle) may reduce the pavement deterioration caused by transit buses by redistributing the weight of the bus in a more favorable manner.

Simultaneous with efforts to reduce bus weights, some transit operators have seen increasing passenger loading and demand for better on-board service amenities (such as air conditioning, bike racks, information systems, and surveillance equipment). These developments increase the curb and operating weight of transit buses—sometimes beyond axle weight limits—and offset weight reduction efforts.

Transit Bus Weight Impacts on Pavements

Transit buses that operate above legal weight limits may pose problems associated with pavement design and road maintenance. These problems are particularly relevant for low functional road classes (e.g., collectors, local streets), which are less able to withstand transit bus axle loads than high functional road classes (e.g., Interstate highways, major arterials).

All axle loads contribute to pavement deterioration. However, the literature review revealed sparse and disparate results on the proportion of pavement deterioration and maintenance expenditures attributable to transit buses. Ultimately, deterioration depends on the number of transit buses operating on a route, the intensity of axle loads of those buses (which varies spatially and temporally), the structure of pavement on the route, and numerous environmental factors. While there is evidence from information about the physical characteristics of transit buses that certain buses exceed axle weight limits (indeed, certain bus models exceed these limits without any passengers on board) and mostly anecdotal indications of the concomitant impacts on pavement, there is relatively little empirical substantiation of these impacts. A lack of in-service transit bus weight data precludes definitive quantification of the impacts transit buses have on pavements, and also poses future challenges in appropriately accommodating them in pavement design practices.

Despite a lack of recorded empirical evidence, experience in some jurisdictions has led to the use of higher quality pavement materials and adjustments to mixture designs to improve the ability of pavements to withstand transit axle loads. These strategies are most commonly implemented on transit routes, transit facilities, and locations expected to experience aggressive wear from transit buses (e.g., bus stops).

Options to Address Transit Bus Axle Weight Issues

Clarifying issues concerning transit bus axle weight necessitates a systems approach. While this is well-recognized, the numerous inter-relationships between various types of impacts and the entities being impacted remain complex and difficult to fully understand. Hence, any option to address the issues has tradeoffs, and the course of action is not readily-apparent.

Twenty-three options were developed to address transit bus axle weight issues based on the literature review, survey, and interview findings. These issues may affect roadway infrastructure (principally pavement), transit systems and the communities they serve, transit bus manufacturers, and public transportation agencies. Table ES-1 summarizes these options within five categories, along with key outcomes and tradeoffs associated with each option:

1) Transit bus weight data
2) Transit bus design
3) Transit bus operations
4) Pavement design and engineering
5) Regulations and enforcement

The options were developed with the goal of achieving at least one of two main outcomes. First, there are opportunities to mitigate pavement deterioration caused by transit buses if axle weights are lowered (e.g., through bus design or operational changes) or if pavements are designed to better withstand transit bus axle loads. These outcomes can occur without changing regulatory limits. Second, there are opportunities to revise weight regulations (e.g., by increasing limits or introducing exemptions) and the enforcement of these regulations to reduce the likelihood that transit bus axles will violate regulations. While these opportunities may help resolve regulatory issues, they may not mitigate pavement deterioration.

Whatever the outcome, however, addressing issues associated with transit buses exceeding prescribed axle weight limits requires tradeoffs. There is no single operational, design, technological or regulatory solution that resolves these issues without some undesirable consequence.

Table ES-1: Summary of Options to Address Transit Bus Weight Issues

Options by Category	Key Outcomes and Tradeoffs
Category 1: Options Related to Transit Bus Weight Data	
1. Install weigh-in-motion devices at selected locations	• Does not directly mitigate pavement impacts • Does not address regulatory issues • Additional operational costs • Requires appropriate analysis capability
2. Combine transit schedules, bus inventory, ridership, and GPS data	• Does not directly mitigate pavement impacts • Does not address regulatory issues • Additional operational costs • Requires appropriate analysis capability • On-board equipment adds weight
3. Install on-board weight sensors	• Does not directly mitigate pavement impacts • Does not address regulatory issues • Additional operational costs • Requires appropriate analysis capability • On-board equipment adds weight
Category 2: Options Related to Transit Bus Design	
1. Increase steer axle weight capacity	• Mitigates pavement deterioration • Addresses regulatory issues • May increase curb weight • Increases manufacturing and procurement costs • Worsens vehicle handling
2. Provide tandem steer axles	• Mitigates pavement deterioration • Addresses regulatory issues • Increases curb weight • Increases manufacturing and procurement costs • Increases maintenance costs • Decreases fuel efficiency • Reduces passenger capacity • May diminish bus maneuverability
3. Provide tandem drive axles	• Mitigates pavement deterioration • Addresses regulatory issues • Increases curb weight • Increases manufacturing and procurement costs • Increases maintenance costs • Decreases fuel efficiency • Reduces passenger capacity

Options by Category	Key Outcomes and Tradeoffs
	• May diminish bus maneuverability
4. Use wide-base single tires	• Mitigation of pavement deterioration uncertain • May address regulatory issues • Decreases curb weight • Increases fuel efficiency
5. Manufacture transit buses with alternative materials	• Mitigates pavement deterioration • Addresses regulatory issues • Decreases curb weight • Increases manufacturing and procurement costs • Increases maintenance costs
6. Apply additive manufacturing methods	• Mitigates pavement deterioration • Addresses regulatory issues • Decreases curb weight • Increases manufacturing and procurement costs
7. Provide lower performance transit bus components	• Mitigates pavement deterioration • Addresses regulatory issues • Decreases curb weight • Imposes logistical challenges • Increases manufacturing and procurement costs
8. Reduce auxiliary features on transit buses	• Mitigates pavement deterioration • Addresses regulatory issues • Decreases operating weight • Degrades service provision
Category 3: Options related to transit bus operations	
1. Operate more low capacity buses	• Mitigation of pavement deterioration uncertain • May address regulatory issues • May necessitate more buses and drivers to meet demand • May degrade service provision • Increases transit bus emissions • Increases transit agency costs • Increases transit bus pavement impact per passenger
2. Restrict the number of passengers on existing transit buses	• Mitigation of pavement deterioration uncertain • May address regulatory issues • May necessitate more buses and drivers to meet demand • May degrade service provision • Increases transit agency costs • Increases transit bus pavement impact per passenger
3. Increase bus frequency during peak periods	• Mitigation of pavement deterioration uncertain • May address regulatory issues • May necessitate more buses and drivers to meet demand • May degrade service provision • Increases transit agency costs • Increases transit bus pavement impact per passenger

Options by Category	Key Outcomes and Tradeoffs
4. Restrict transit buses from certain routes	• Mitigates pavement deterioration on certain routes • May address regulatory issues • May degrade service provision
5. Match transit bus models to passenger demand	• Mitigates pavement deterioration • May addresses regulatory issues • Introduces logistical and management challenges • Increases transit agency costs
Category 4: Options related to pavement design and engineering	
1. Design and implement pavements to better withstand transit bus axle loads	• Mitigates pavement deterioration • Does not address regulatory issues • Requires revisions to design and construction specifications • Requires development of programs to monitor and manage pavement assets • Increases pavement construction and maintenance costs
2. Adjust pavement design loads to more accurately reflect transit bus axle weights	• Mitigates pavement deterioration • Does not address regulatory issues • Requires appropriate data collection and analysis capability
Category 5: Options related to transit bus weight regulations and enforcement	
1. Maintain current regulatory environment (*status quo*)	• Does not mitigate pavement impacts • Perpetuates current regulatory environment • No incremental costs
2. Decrease axle weight limits to match limits for other CMVs	• Mitigates pavement deterioration • Does not address regulatory issues • Increases operating costs • Decreases compliance without rigorous enforcement
3. Increase or eliminate axle weight	• Does not mitigate pavement deterioration • Addresses regulatory issues • Reduces incentives to pursue manufacturing alternatives that decrease curb weight • Raises concerns about special allowances for transit industry
4. Require annual permits	• Does not mitigate pavement deterioration • Addresses regulatory issues • Increases administrative costs
5. Improve enforcement practices	• Mitigates pavement deterioration • Does not address underlying cause of regulatory issues • May increase operational delays and costs • Additional equipment operational costs

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1 Introduction

Commercial motor vehicles—including transit buses—are subject to complex regulatory requirements established by federal, state, and municipal authorities. These regulations support safe, efficient, and equitable transit service while limiting infrastructure and environmental impacts. Regulations are dynamic and respond to changes in industry characteristics, technological advancements, user requirements, and a host of societal norms. Consequently, regulations occasionally compete with one another and create an impractical or unenforceable regulatory environment. The transit industry currently operates within a competing set of regulatory requirements regarding bus axle weight. Periodically evaluating regulations and their implications can help mitigate these situations.

The competing regulatory environment pertaining to transit bus axle weight is primarily attributable to the existence of weight limits that predate changes in other areas of regulation and have not been reconsidered in light of these changes. In particular, environmental and accessibility regulations require bus manufacturers to include additional equipment and technologies on transit buses that address environmental concerns (e.g., pursuant to the Clean Air Act and Energy Policy Act) and accommodate passengers with disabilities (e.g., pursuant to the Americans with Disabilities Act). Federal regulations also mandate a minimum 12-year service life for most transit bus models, which necessitates the use of heavy-duty bus components. In addition to regulatory requirements, increases in passenger weight and changing customer expectations regarding comfort, safety, and security have contributed to increases in transit bus weight. These developments increase both the curb and operating weight of transit buses beyond what was expected when transit bus axle weight regulations were initially established.

Consequently, transit buses sometimes operate above legal weight limits and may pose problems associated with pavement design and road maintenance. These problems are particularly relevant for low functional road classes (e.g., collectors, local streets), which are less able to withstand transit bus axle loads than high functional road classes (e.g., Interstate highways, major arterials).

Transit bus operating weights, like any vehicle type, can be conceptualized as a cumulative distribution function that characterizes the likelihood that weights occur within specified weight ranges. Figure 1 conceptualizes a cumulative distribution function for transit bus single axle weights that could be observed at a certain location over a certain time period (note: this figure is a conceptual illustration only). This report is principally concerned with transit buses exceeding specified axle weight limits, represented in Figure 1 by the portion of the distribution curve to the right of the vertical axle weight limit line. The size of this portion of the distribution depends on (1) the shape and position of the axle weight distribution (i.e., various factors might cause decreases or increases in bus axle weights which shift the distribution to the left or right, respectively), and (2) the magnitude of the axle weight limit.

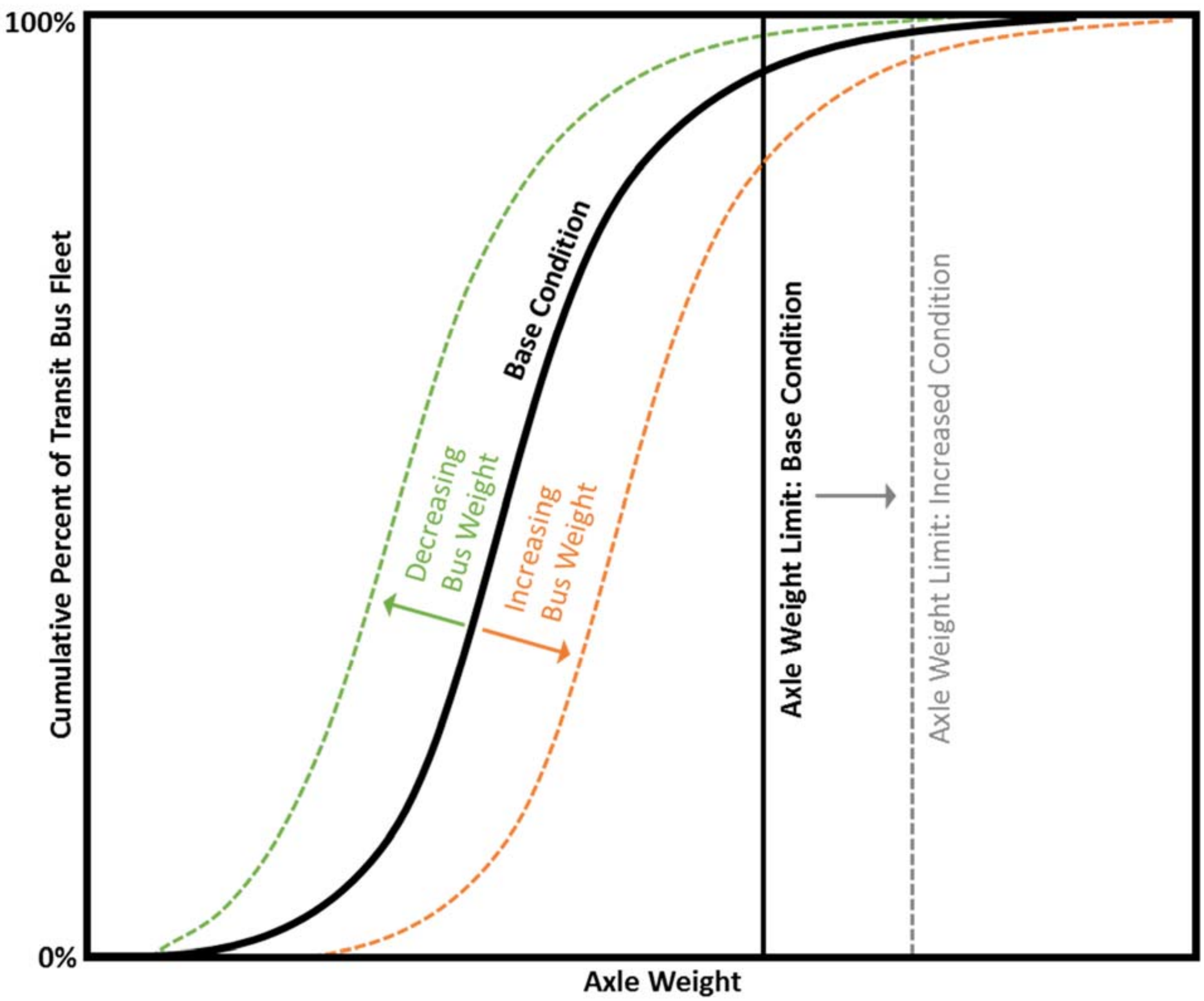


Figure 1: Conceptual Representation of a Transit Bus Single Axle Weight Distribution

Operating commercial motor vehicles—including transit buses—with axle weights in excess of the prescribed axle weight limit constitutes a regulatory violation and contributes disproportionately to pavement deterioration. Reducing or eliminating regulatory violations may be achieved by (1) lowering axle weights or (2) increasing the axle weight limit (provided that this does not encourage increases in in-service axle weights). Mitigating pavement deterioration may similarly be achieved by lowering axle weights, but may also be addressed through changes in pavement design and management practices.

Simply lowering the proportion of transit bus axle weight observations exceeding the axle weight limit does not necessarily mitigate pavement deterioration by transit buses. This is true for two main reasons. First, the extent to which an axle weight exceeds the weight limit is as important (or more) as the proportion of observations that exceed the limit. It is well-established that one highly overloaded axle may cause more pavement deterioration than several moderately overloaded axles. Second, certain options that lower transit bus axle weights may necessitate higher transit bus volumes. Thus, these options should consider the pavement deterioration tradeoff between lower axle weights and higher transit bus volumes.

There are positive and negative aspects of operating transit buses above the legal weight limit.

- **Negative aspects** of operating a transit bus that exceeds axle weight limits can generally include additional pavement deterioration, weight regulation violation, structural failure risks, additional fuel consumption, and higher bus maintenance costs.
- **Positive aspects** of operating a fleet with transit buses that exceed axle weight limits can include improved operational efficiencies (e.g., increased utilization of bus passenger capacities), better service, reduced emissions per passenger-mile, potentially less overall pavement damage (i.e., it is possible for fewer, heavier buses to damage pavement less than more, lighter buses), simpler fleet management, longer transit bus lifespan (if higher weights are associated with heavy-duty construction), and overall lower capital, operating, and maintenance costs.

While negative aspects are generally measured on a per bus basis, positive aspects generally occur at a system-wide level. Therefore, mitigating negative transit bus axle weight issues may provide positive effects on a per bus basis but negative system-wide effects.

This report analyzes bus axle weight issues that have evolved over the past few decades and provides information to help decision-makers identify options to reduce bus weight, mitigate the negative impacts of transit buses exceeding weight limits, and address competing regulations in this area. These options, which can be implemented individually or in combination, include various changes to (1) transit bus design and manufacturing, (2) transit operations, (3) pavement design and engineering, and (4) regulations.

1.1 Purpose and Objective

The purpose of this report is to clarify issues surrounding transit bus weight. The objective is to examine and present information regarding:

1) Relevant national and state laws and regulations pertaining to transit bus weight,
2) The weight of transit buses while in service,
3) The impacts of transit buses on pavement, and
4) Options to mitigate negative impacts on pavement, transit systems, and communities.

The Federal Transit Administration (FTA) addressed these four issues in their 2003 report titled *Study and Report to Congress: Applicability of Maximum Axle Weight Limitations to Over-the-Road and Public Transit Buses* (Federal Transit Administration, 2003). The FTA (2003) report identified 23 distinct policy options categorized into six broad areas:

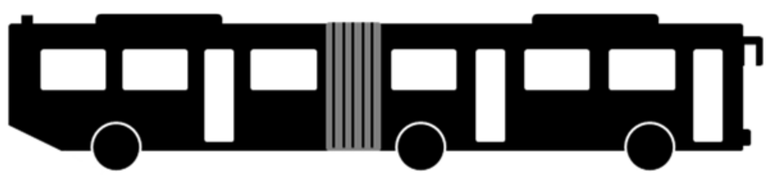
1) adjustments to axle weight limits,
2) transit bus design and operational requirements,
3) subsidies to produce, buy, and operate lighter-weight buses,
4) federal procedural changes,
5) changes to highways used by buses, and
6) measures to internalize costs.

This report re-examines the issues identified in the FTA report within the context of new regulations impacting transit bus operating weights, new manufacturing strategies, and new infrastructure design approaches.

1.2 Scope, Definitions, and Terminology

This report focuses on the six transit bus types shown in Table 1, herein referred by their nominal lengths.

Table 1: Scope of Transit Buses

Transit Bus Type (Nominal Length)	Actual Length[1] (ft)	Conceptual Representation[2]
2-axle 35-foot buses	32.5 – 37.4	
2-axle 40-foot buses	37.5 – 42.4	
2-axle 45-foot buses	42.5 – 47.5	
3-axle 45-foot buses	42.5 – 47.5	
3-axle 45-foot double-deck buses	42.5 – 47.5	
3-axle 60-foot articulated buses	55.0 – 65.0	

Notes:
[1]Length is measured from bumper to bumper
[2]Lengths of the conceptual representations are to scale

The following are important definitions used in this report. These terms are used consistently throughout the report. The literature uses various, and sometimes contradictory, definitions and terminology to describe transit bus weight. Consequently, interpretation and contextual awareness was required during the literature review to correctly determine the appropriate definition and intention of the authors for these terms.

- **Axle weight:** The load applied to a roadway by an individual axle or axle group.
- **Axle weight limit:** The maximum total weight that can be carried on an individual axle or group of axles, as defined by law. This limit varies by jurisdiction and road type. The axle weight limit is not necessarily equivalent to the gross axle weight rating (see below), nor is it the weight of the axle itself.
- **Commercial motor vehicle (CMV):** The transit buses considered in this report are CMVs and are subject to corresponding laws and regulations. A CMV is legally defined in the US Code of Federal Regulations (49 CFR 383.5) as "a motor vehicle or combination of motor vehicles used in commerce to transport passengers or property if the motor vehicle—
    1. Has a gross combination weight rating or gross combination weight of 11,794 kilograms or more (26,001 pounds or more), whichever is greater, inclusive of a towed unit(s) with a gross vehicle weight rating or gross vehicle weight of more than 4,536 kilograms (10,000 pounds), whichever is greater;
    2. Has a gross vehicle weight rating or gross vehicle weight of 11,794 or more kilograms (26,001 pounds or more), whichever is greater;
    3. Is designed to transport 16 or more passengers, including the driver; or
    4. Is of any size and is used in the transportation of hazardous materials as defined in this section."
- **Crush load:** The maximum passenger capacity of a transit bus, in which there is little or no space between passengers and one more passenger cannot enter without causing serious discomfort to the others. At crush load, the number of passengers exceeds the number of designed passenger positions. The number of passengers representing the crush load is not necessarily equivalent to the number of passengers of an overloaded bus.
- **Curb weight:** The total weight of a transit bus without passengers or a driver. Curb weight includes fuel and is sometimes referred to as tare weight.
- **Fully-loaded transit bus:** A transit bus that is carrying the maximum number of passengers for which it was designed. This includes seated and standing passengers. A fully-loaded transit bus' gross vehicle weight (GVW) is not necessarily the same as the

GVW limit or the gross vehicle weight rating (GVWR); in fact, it is expected to be different. Current design assumptions for passenger weight and standing area are 150 pounds and 1.5 ft^2, respectively.

- **Gross axle weight rating (GAWR):** The maximum operating weight allowed on a particular axle or axle group for safe and reliable operation of the vehicle as determined by the axle and/or vehicle manufacturer. Exceeding the GAWR can result in decreased dynamic performance and potentially structural failure of the axle.
- **Gross vehicle weight (GVW):** The weight of a fully-loaded transit bus (i.e., curb weight plus the design passenger load). This definition applies in the context of design specifications and is thus considered a constant value. However, in other contexts, including some of the documents and regulations cited in this report, GVW refers to the operating weight of a vehicle including curb weight and payload weight. Thus, in this contexts, transit bus GVW is expected to fluctuate continually as variable weight aspects of the bus change, such as the number of passengers. This latter definition is more useful when comparing the weight of a bus to its prescribed weight limit.
- **Gross vehicle weight limit:** The maximum total weight that a vehicle is legally allowed to operate as defined by law. This limit varies by jurisdiction and road type.
- **Gross vehicle weight rating (GVWR):** The maximum weight of a vehicle plus its load for safe and reliable operation of the vehicle as determined by the manufacturer.
- **Overloaded transit bus:** A transit bus that is carrying more than the maximum number of passengers for which it was designed. The GVW of an overloaded transit bus is not necessarily the same as the GVW limit or the GVWR, nor is it necessarily higher than these weights.

1.3 Methodology

This report is based on a literature and regulatory review, state surveys and follow-up interviews, city and county surveys and follow-up interviews, transit bus industry representative interviews, and transit bus industry expert interviews (e.g., researchers).

1.3.1 Literature and Regulatory Review

The literature review was directed at updating and supplementing the information from the 2003 FTA report. As such, the literature review mostly included documents published post-2002 including:

- national-level reports from the Transportation Research Board (TRB), the American Public Transit Association (APTA), and the Federal Transit Administration (FTA);
- studies performed by or for government agencies, academic institutions, and private industry;
- transit bus manufacturing design specifications;
- journal articles; and
- conference proceedings.

The regulatory review summarized legislation and regulations impacting transit bus weight at the federal level and for each of the 50 states. This review primarily involved searching the US Code of Federal Regulations and individual state laws and was supplemented by the state, county, and city surveys and follow-up interviews. Vehicle size and weight laws and regulations are complex; they usually vary by jurisdiction, sometimes contain organizational, vehicle-, spatial-, or temporal-specific exemptions and grandfather clauses, and are often interpreted differently between agencies. Further, the documented laws and regulations are not always reflective of the vehicle types and weights operating on the roadway.

This report interprets these laws and regulations as best as possible based on the consultant's existing knowledge and experience concerning vehicle weights and dimensions and feedback obtained from public agencies. Consequently, the regulatory review serves to inform issues concerning transit bus weight governance; readers seeking to apply these laws and regulations are advised to consult specific legislation as originally published by the respective government bodies.

1.3.2 State Surveys and Follow-Up Interviews

The state survey and follow-up interviews focused on issues concerning transit bus axle weight limits, the enforcement of these limits, and pavement impacts that may be attributable to transit buses. A web-based survey consisting of 12 questions was developed and distributed to representatives from all 50 states in mid-2014. Survey recipients included state members of two Commercial Vehicle Safety Alliance (CVSA) committees related to transit bus weight: the Size and Weight Committee and the Passenger Carrier Committee. Survey recipients were asked to supply the appropriate contact if they were not the most qualified individual to complete the survey. Some states submitted responses that may have been completed with input from multiple individuals or departments, whereas others submitted responses from a single person. A total of 16 survey responses were received. Appendix A contains a complete list of survey respondents, the full text of the survey, and a summary of survey responses.

Six states were selected for follow-up interviews: Colorado, Nevada, New Jersey, Ohio, Texas, and Utah. These states were selected with project panel committee input based on their responsiveness to the state surveys and in some cases on their distinctive regulatory environment (e.g., states that have laws exempting transit buses from commercial motor vehicle axle weight limits). The purpose of these interviews was to obtain clarification for certain survey questions, ask additional questions, and obtain information that was otherwise unavailable through the literature or original survey. Four of the six states (Nevada, Texas, Colorado, and Utah) were able to provide additional information while two states (Ohio and New Jersey) did not have personnel available that could add to the survey responses.

1.3.3 City and County Surveys and Follow-Up Interviews

The city and county survey and follow-up interviews focused on issues concerning transit bus axle weight limits, transit bus operations, and pavement impacts that may be attributable to transit buses. A web-based survey was developed and distributed to representatives from 432 metropolitan planning organizations (MPOs), counties, and cities in mid-2014 (this represented nearly all MPOs in the country). Survey recipients were asked to supply the appropriate agency contact if they were not the most qualified individual to complete the survey. Some agencies submitted responses that may have been completed with input from multiple individuals or departments, whereas others submitted responses from a single person. A total of 50 responses were received. Overall, there was not a significant degree of awareness regarding issues with transit bus axle weights, weight limits, enforcement, exemptions, and mitigation strategies for pavement deterioration. Appendix A contains a complete list of survey respondents, the full text of the survey, and a summary of survey responses.

Eight individuals were contacted for follow-up interviews based on their responsiveness to the surveys and in some cases because of their distinctive operating environment. The purpose of these interviews was to obtain clarification for certain survey questions, ask additional questions, and obtain information that was otherwise unavailable through the literature or original survey.

1.3.4 Transit Bus Industry Representative Interviews

A total of nine telephone interviews were conducted with major bus manufacturers, the American Public Transportation Association, and the California Transit Association. These interviews consisted of 14 semi-structured questions to guide the discussion; however, interviewees were encouraged to discuss any issues they thought were relevant. This broadened the range of discussion topics and revealed issues that may not have been apparent otherwise. Interviews provided information concerning the factors influencing transit bus weight and weight changes, options to reduce transit bus weight and address competing regulations, and insight regarding future transit bus technologies and costs.

1.3.5 Transit Bus Industry Expert Interviews

Five transit bus industry experts were interviewed through email correspondence, telephone conversations, or in-person meetings. These interviews consisted of semi-structured questions to guide the discussion; however, interviewees were encouraged to discuss any issues they thought were relevant. This approach helped establish the tone of the interview, provide the interviewee with the scope of the discussion, and allowed for a broad range of topics to be discussed, some of which would not have been apparent otherwise. Interviewees included representatives from a transit operating agency, a representative from a transit bus testing facility, a private bus manufacturing consultant, a private commercial motor vehicle regulations and vehicle performance consultant, and a public sector regulator.

1.4 Report Organization

This report contains eight chapters. The remainder of the report is organized as follows:

- Chapter 2 summarizes the legal and regulatory environment, including federal and state transit bus axle weight limits. It also identifies several federal and state policies and programs that impact transit bus weight.
- Chapter 3 discusses physical characteristics of transit buses that affect their weight based on literature review, survey, and interview findings. This chapter characterizes different bus models and their compliance with weight laws, identifies factors that affect transit bus weight, and describes various transit bus materials and designs.
- Chapter 4 discusses operational characteristics of transit buses that affect their weight and pavement impact based on literature review, survey, and interview findings. This

chapter provides information about transit bus routing, passenger loading, and various operational measures that may impact transit bus axle weights.

- Chapter 5 discusses pavement design and engineering issues related to transit bus axles based on literature review, survey, and interview findings. This chapter provides a high-level overview of pavement design approaches, describes the pavement impact of transit buses, and identifies methods for designing and maintaining pavements for transit buses.
- Chapter 6 provides options and tradeoffs to help mitigate the negative impacts of transit buses exceeding axle weight limits and address competition among regulations. These options are based on information from Chapters 2 through 5. Options relate to transit bus axle weight data, transit bus design, operations, pavement design and engineering, and weight regulations and enforcement.
- Chapter 7 provides a summary of the main findings of this research.
- Chapter 8 provides the bibliography.

2 Legal and Regulatory Environment

This chapter describes the legal and regulatory environment related to transit bus weight, including regulatory changes that have occurred in the past that have impacted transit bus weights. It summarizes federal and state transit bus weight limits and identifies policies and programs at various government levels that have impacted transit bus weight.

2.1 Transit Bus Axle Weight Limits

2.1.1 Federal Transit Bus Axle Weight Limits

Prior to 1914, U.S. commercial motor vehicle (CMV) axle weight regulations existed on a state-to-state basis. The first federal regulations were enacted by the federal-aid highway program in 1956 (Transportation Research Board, 2002). The initial single and tandem axle weight limits for CMVs were 18,000 pounds and 32,000 pounds, respectively (Transportation Research Board, 1990). These limits were based on the American Association of State Highway and Transportation Officials (AASHTO) recommended practices at the time. States that established their own CMV regulations prior to the introduction of federal CMV weight limits in 1956 were granted temporary grandfather exemptions (Transportation Research Board, 2002). In 1974, the CMV axle weight limits were raised to 20,000 pounds for single axles and 34,000 pounds for tandem axles. These same limits still exist today; however, over the past few decades transit buses have been granted several temporary and indefinite exemptions to these limits. Table 2 displays a timeline of key dates and events between 1956 and 2014 regarding legal and regulatory changes concerning federal transit bus axle weight limits.

Table 2: Timeline of important federal regulations governing transit bus axle weight limits

Policy	Year Enacted	End Date	Effect
Federal Aid Highway Act of 1956	1956	None	Single axle weight limit set to 18,000 pounds and tandem axle weight limit set to 32,000 pounds[1] on federal roads
Amendment to the Federal Aid Highway Act of 1956	1974	None	Single axle weight limit and tandem axle weight limit for federal roads increased to 20,000 pounds and 34,000 pounds, respectively[1]
Surface Transportation Assistance Act (STAA) of 1982	1982	None	States with more restrictive limits required to conform with the federal standards[2]
Intermodal Surface Transportation Efficiency Act (ISTEA)	1992	1994	Transit buses temporarily exempted from 20,000 pounds single axle weight limit on Interstate Highways. States are not allowed to enforce a single axle weight limit of less than 24,000 pounds
National Highway System Designation Act of 1995	1995	1997	ISTEA exemption extended
Transportation Equity Act for the 21st Century (TEA-21)	1998	2003	ISTEA exemption extended
Consolidated Appropriations Act of 2005	2004	2005	ISTEA exemption extended
Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU)	2005	2009	ISTEA exemption extended
Transportation, Treasury, Housing and Urban Development, the Judiciary, the District of Columbia, and Independent Agencies Appropriations Act	2005	2009	Amended the ISTEA exemption to include "covered states[a]"
Moving Ahead for Progress in the 21st Century Act (MAP-21)	2012	Indefinite	Exemption extended indefinitely[3]

Notes:

[a] As stated by the *Transportation, Treasury, Housing and Urban Development, the Judiciary, the District Of Columbia, and Independent Agencies Appropriations Act, a* covered State is "a State that has enforced, in the period beginning on October 6, 1992, and ending on the date of enactment of this subparagraph [2005], a single axle weight limitation of 20,000 pounds or greater but less than 24,000 pounds, including enforcement tolerances".

Sources:

[1] Transportation Research Board (1990)
[2] Transportation Research Board (2002)
[3] American Public Transportation Association (2012)

2.1.2 State Transit Bus Axle Weight Limits

Federal weight regulations for CMVs are applicable to Interstate highways and 160,000 miles of other major roads (Transportation Research Board, 2002). State- and locally-controlled roads often have separate regulations that differ from federal regulations. Table 3 displays the transit bus single and tandem axle weight limits for each state. This table shows that most states govern transit bus weights under CMV regulations; however, 14 states have separate transit bus weight limits as described in Table 4. Both Table 3 and Table 4 are based on interpretations of various state codes and statutes and should not serve as a legal reference. Readers are advised to consult current applicable statutes for exact legal phrasing.

Table 3: State-specific transit bus axle weight limits

State	Single Wheel	Steering Axle[1]	Single Axle	Tandem Axle[2]	Bus Specific[3]
Alabama	-	-	20,000	-	No
Alaska	-	-	20,000	38,000	No
Arizona	Exempt	Exempt	Exempt	Exempt	Yes
Arkansas	-	20,000	20,000	34,000	No
California	Exempt	Exempt	Exempt	Exempt	Yes
Colorado	Exempt	Exempt	Exempt	Exempt	Yes
Connecticut	Exempt	Exempt	Exempt	Exempt	Yes
Delaware	-	-	22,400	40,000	No
D.C.	-	18,000	22,000	38,000	No
Florida	-	-	22,000	-	No
Georgia	9,040 HP 11,700 LP	- -	18,080 20,340	36,160 40,680	No
Hawaii	-	-	22,500	34,000	No
Idaho	10,000	-	20,000	34,000	No
Illinois	-	-	20,000	34,000	No
Indiana	-	-	20,000	34,000	No
Iowa	-	-	20,000	34,000	No
Kansas	10,000	-	20,000	34,000	No
Kentucky	-	-	20,000	35,700	No
Louisiana	-	-	18,000 HP 20,000 LP	32,000 HP 34,000 LP	No
Maine	-	-	22,400	38,000	No
Maryland	-	-	24,000	Exempt	Yes
Massachusetts	-	-	22,400	36,000	No
Michigan	-	-	18,000 HP 20,000 LP	26,000 HP 34,000 LP	No
Minnesota	10,000	-	20,000	34,000	No
Mississippi	-	-	20,500	34,500	No
Missouri	-	-	20,000	34,000	Yes
Montana	-	-	20,000	34,000	Yes
Nebraska	10,000	-	21,000	35,700	No

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State	Single Wheel	Steering Axle[1]	Single Axle	Tandem Axle[2]	Bus Specific[3]
Nevada	-	-	20,000 ST 25,000 DT	-	Yes
New Hampshire	-	-	23,520	35,700	No
New Jersey	-	-	22,400	34,000	No
New Mexico	11,000	-	21,600	34,320	No
New York	11,200	-	22,400	36,000	No
North Carolina	-	-	20,000	38,000	No
North Dakota	10,000	-	20,000	34,000	No
Ohio	Exempt	Exempt	Exempt	Exempt	Yes
Oklahoma	-	-	20,000	34,000	No
Oregon	Exempt	Exempt	Exempt	Exempt	Yes
Pennsylvania	-	-	23,520	-	Yes
Rhode Island	-	-	22,400	36,000	Yes
South Carolina[4]	8,000 HP 10,000 LP	-	16,000 HP 20,000 LP	36,000	No
South Dakota	-	-	20,000	34,000	No
Tennessee	Exempt	Exempt	Exempt	Exempt	Yes
Texas	-	-	20,000	34,000	No
Utah	10,500	-	20,000	34,000	No
Vermont	-	-	24,640	39,600	No
Virginia	-	-	20,000	34,000	Yes
Washington	-	-	20,000	34,000	No
West Virginia	-	-	22,000	-	No
Wisconsin	11,000 A 6,600 B	-	20,000 A 13,200 B	34,000 A 20,400 B	No
Wyoming	10,000	-	20,000	36,000	No

General Notes:
- No entry indicates that the limit was not specified by state law
- All limits include enforcement tolerances
- In some cases a state's gross vehicle limits (e.g., Bridge Formula B) may restrict axle weights to less than the axle weight limit

Numbered Notes:
[1] The single axle limit is assumed to apply to steering axles unless otherwise specified
[2] No entry indicates that the tandem axle limit is assumed to be double the single axle limit
[3] Bus specific weight laws are described in Table 4
[4] South Carolina specifies high pressure tires as greater than 100 psi inflation pressure (this distinction could not be found for other states)

Definitions:
ST = Axles with single tires
DT = Axles with dual tires
HP = High pressure tires
LP = Low pressure tires
A = Class A Highways
B = Class B Highways

Source:
State codes, statutes, laws, and municipal regulations

Table 4 summarizes bus-specific vehicle weight statutes from 14 states. These statutes often apply one of the following five regulatory approaches to transit bus weight limits (in order of least restrictive to most restrictive):

- **Vehicle weight exemption:** This approach exempts buses from all state vehicle weight limits, including wheel loads, axle loads, and gross vehicle loads. It eliminates transit bus weight violations, increases transit agency flexibility for transit bus procurements, and can reduce transit agency costs by enabling operation of high capacity buses. However, it may increase the likelihood of heavy transit bus axles, increase pavement maintenance costs, and possibly necessitate designing higher strength pavements and bridges.

- **Axle weight exemption:** This approach exempts buses from single axle and/or tandem axle CMV weight limits but not gross vehicle weight limits. The effects of this approach are similar to vehicle weight exemptions. This type of exemption eliminates transit bus axle weight violations while allowing transit buses to legally operate near or at their gross vehicle weight limit, increases transit agency flexibility for transit bus procurements, and reduces transit agency costs by operating high capacity buses. However, the approach may increase the likelihood of heavy transit bus axles, increase pavement maintenance costs, and possibly necessitate designing higher strength pavements.
- **Increased axle weight limit:** This approach accommodates transit buses with high rear axle weights. MAP-21 legislation has compelled some states to adopt 24,000 pounds as the single axle weight limit (the maximum CMV single axle weight limit is 20,000 pounds in most states). Despite this increase, certain current bus models exceed this limit when fully-loaded. Similar to vehicle and axle weight exemptions, this statute benefits transit agencies and bus manufacturers but may increase infrastructure costs.
- **Increased axle weight limit for specific bus types:** Some states have increased the single axle weight limit for 60-ft articulated buses due to their operational benefits. This approach reduces or eliminates axle weight violations for these buses and may lower transit agency operational costs. If these buses replace 2-axle transit buses (especially 40-ft models) or decrease their frequency while maintaining service levels, they may reduce overall pavement deterioration.
- **Bus-specific weight limits that match CMV weight limits:** Although most bus-specific weight legislation involves increasing allowable axle weights for buses, some states specifically set weight limits for buses that match their general CMV laws. These types of limits are the most restrictive bus-specific weight limits and, relative to the foregoing approaches, are most likely to mitigate pavement deterioration. However, restrictive weight limits also increase non-compliance, as certain bus models are heavier than these limits even when no passengers are on board.

Table 4: States with transit bus specific weight legislation[1]

State	Transit Bus Specific Legislation
Arizona	Arizona Revised Statues (Section 28-1091) exempt transit buses from Arizona's size, weight, and load provisions. Further, Arizona Administrative Code (R17-6-108) exempts equipment operated by the Arizona DOT, another state agency, an Arizona county, an Arizona city, or an Arizona municipality from obtaining an overweight permit.
California	All transit buses purchased before 2013 are exempt from California's 20,500 pound single axle weight limit (California Transit Association, 2014). However, in 2013, 2014, and 2015, all transit agencies must adhere to specific requirements for purchasing new transit buses, including those that might exceed 20,500 pounds. In 2016, these procurement provisions expire and previous bus axle weight state law (i.e., limiting axle weight to 20,500 pounds) will be reinstated (unless state law is changed again before then).
Colorado	Colorado Revised Statutes (Section 42-4-510) exempts public transportation vehicles operated by any political subdivision of the state from vehicle size and weight provisions and from requiring overweight permits.
Connecticut	Connecticut state law (Section 14-267b) exempts transit buses from CMV axle weight limits subject to compliance with US Code CMV weight limits.
Maryland	Effective October 1, 2014 (when Senate Bill 72 comes into effect), intrastate transit buses in Maryland will be subject to a 24,000 pound single axle weight limit and be exempt from tandem axle weight limits (Walker, 2014). Gross vehicle weight limits set by Bridge Formula B will still apply.
Missouri	According to the Missouri Revised Statutes (Section 304.181), "no bus having a greater weight than 20,000 pounds on one axle or 34,000 pounds on any tandem axle shall be moved on or operated on any highway in this state [Missouri]".
Montana	The Montana Annotated Code (Section 61-10-107) exempts transit buses from one of Montana's provisions which requires all non-steering axles weighing more than 11,000 pounds to be equipped with at least four tires or wide based tires and a 500 pound/inch of tire width load capacity. Transit buses must comply with 20,000 pound and 34,000 pound limits for single and tandem axles, respectively.
Nevada	The Nevada Revised Statutes (Section 484D.645) exempts transit buses from all vehicle weight limits on non-federal roads, subject to compliance with 20,000 pound limits on single axles with single tires or 25,000 pound limits on single axles with dual tires. The Nevada Department of Transportation may permit transit buses that are part of a demonstration project to carry up to 29,000 pounds on a single axle with single tires, subject to minimum tire widths of 20 inches.
Ohio	Ohio Revised Code (Section 5577.04) exempts transit buses using pneumatic tires (i.e., rubber and fabric tires inflated with air) from state axle load, wheel load, and gross vehicle weight limits.
Oregon	Oregon Vehicle Code (Section 818.030) exempts transit buses from weight limits, subject to approval by the corresponding road authority.
Pennsylvania	Pennsylvania Consolidated Statutes (Title 75 - § 4948) requires transit buses to comply with 73,280 pound gross vehicle weight limits, 22,400 pound single axle weight limits (plus an enforcement tolerance of 5%), or 800 pounds/inch of tire width on non-Interstate highways.

State	Transit Bus Specific Legislation
Rhode Island	State of Rhode Island General Laws (Section 31-25-3) exempt articulated transit buses from the state's size, weight, and load limits.
Tennessee	Tennessee Motor Vehicle Laws (Section 55-7-207) require transit buses to comply with federal weight regulations on all public roads in any county in which there is regularly scheduled public mass transportation service.
Virginia	Virginia's size, weight, and equipment requirements (Section 4 – Permits) state that articulated buses may operate under permit on non-Interstate highways subject to 60,000 pound gross vehicle weight limits or 25,000 pound single axle weight limits.

Notes:
[1] This table is based on interpretations of various state codes and statutes and should not serve as a legal reference. Readers are advised to consult current applicable statutes for exact legal phrasing.

2.2 Policies and Programs Impacting Transit Bus Weight

2.2.1 Federal Policies

The Clean Air Act, Surface Transportation and Uniform Relocation Assistance Act, Americans with Disabilities Act, Energy Policy Act, and Moving Ahead for Progress in the 21st Century Act are the five key federal laws that impact transit bus weight. Following is a short description of the transit bus weight aspects of these laws. Although there are other federal laws that include language concerning transit bus weight policies and regulation, these five are considered the most influential on transit bus axle weights. It is difficult to directly link these policies to specific components that cause increases in transit bus weight. However, examples of technologies which have been implemented in response to these policies include emissions-related components, engine and propulsion-related components to enable use of alternative fuels (e.g., compressed natural gas, hydrogen), and components such as wheelchair lifts to improve accessibility.

- **Clean Air Act:** The Clean Air Act was passed in 1970 and amended in 1977 and 1990. The 1990 amendment promoted conformity to the Environmental Protection Agency's (EPA's) National Ambient Air Quality Standards (42 USC Part 7554) by preventing projects that are inconsistent with state air quality goals from accessing federal funding.
- **Surface Transportation and Uniform Relocation Assistance Act (STURAA):** STURAA was signed in 1987 and required new model buses to be tested before being purchased with federal funds. This requirement was modified by the Intermodal Surface Transportation Efficiency Act (ISTEA) in 1991 and Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) in 2005. According to STURAA, the Federal

Transit Administration (FTA) must cover 80% of the bus testing costs. Testing is performed by the Bus Testing Program of the FTA at the Altoona Bus Research and Testing Center in Pennsylvania and includes the tests shown in Table 5. Although these tests do not have pass/fail standards, they encourage bus manufacturers to incorporate more robust, and subsequently heavier, components in their designs to improve test results.

Table 5: Bus Testing Requirements[1]

Test Category	Testing Components
Maintainability	- accessibility of components and subsystems - servicing, preventative maintenance, and repair and maintenance during testing - replacement and/or repair of selected subsystems
Reliability	- documentation of breakdown and repair times during testing
Safety	- double-lane change (obstacle avoidance)
Performance	- acceleration, gradeability, and top speed test
Structural integrity	- structural shakedown test - structural distortion - static towing test - dynamic towing test - jacking test - hoisting test - structural durability
Fuel economy	- fuel consumption test using an appropriate operating cycle
Noise	- interior noise and vibration tests - exterior noise tests
Emissions	- gas and particulate matter tests (this is not the same procedure as is used to meet EPA requirements)

Notes:
[1]Although buses are required to complete each of the listed tests, currently there are no "pass/fail" requirements

Source:
Altoona Bus Research and Testing Center (2014)

- **Americans with Disabilities Act:** This act was created in 1990 and required that all current and future bus systems across the United States be fully accessible. Consequently, transit buses include wheelchair lifts, mobility aids, and special provisions for door openings, step heights, seating, lighting, information and fare-box systems (49 CFR Part 38, Subpart B).
- **Energy Policy Act:** The Energy Policy Act of 2005 helped establish the National Fuel Cell Bus Technology Development Program. This program promotes the development of

commercially viable fuel cell electric bus propulsion technologies and infrastructure under the authorization of SAFETEA-LU (Chandler & Eudy, 2012).

- **Moving Ahead for Progress in the 21st Century Act (MAP-21):** This act was established in 2012 and specified the need to develop bus testing pass/fail standards (Federal Transit Administration, 2012). Currently, transit buses undergo testing at the Altoona Bus Research and Testing Center but are not subject to minimum performance standards. Pass/fail standards could necessitate bus design alterations which could affect transit bus weights. These standards were scheduled for implementation by September 30, 2014; however, the FTA has granted an extension for their development.

2.2.2 Federal Programs

Changing practices in bus design and operations to increase safety and improve rider experience are contributing to higher transit bus curb weights. Although these changes are not necessarily mandated by law they are becoming a common means of meeting public expectations. Examples of federal programs and regulations encouraging these changing practices are as follows:

- **Clean Fuels Grant Program:** This program originated as a formula-based grant program, but was amended by SAFETEA-LU in 2005 to be a discretionary grant program. The purpose is to help meet National Ambient Air Quality Standards and support "emerging clean fuel and advanced propulsion technologies for transit buses and markets for those technologies" (Federal Transit Administration, n.d. a).
- **Fuel Cell Bus Program:** This program was a product of SAFETEA-LU in 2005 and has since awarded over $60 million toward fuel cell bus technology development and promotion. The goal is to develop fuel cell buses into a commercially-viable bus technology (Federal Transit Administration, n.d. b).
- **Electric Drive Strategic Plan:** The US federal government, along with industry input, developed this plan to coordinate research for transit bus electric drive technologies. The goal is "to advance electric drive and related technologies to enable commercially-viable transit vehicles with significantly higher efficiencies, lower emissions, and superior performance" (Kulyk, 2011, p. 8).
- **Executive Order (EO) 13514 and the proposed "HD National Program":** Enacted in 2009, this program is designed to "establish an integrated strategy towards sustainability in the Federal Government and to make the reduction of greenhouse gas

(GHG) emissions a priority for Federal agencies" (FedCenter, 2012). The HD National Program, which was proposed in 2010, helps achieve EO 13514 by setting stricter emission and fuel efficiency standards for medium- and heavy-duty trucks and buses (Chandler & Eudy, 2012).

- **American Recovery and Reinvestment Act of 2009 (ARRA):** Enacted in 2009, the ARRA was designed to promote investment in clean transit technologies by providing funding for new transit purchases and projects (American Public Transportation Association, 2012). The Transit Investments for Greenhouse Gas and Energy Reduction (TIGGER) Program stemmed from the ARRA and has allotted more than $360 million in grants to public transportation agencies to reduce energy consumption and GHG emissions.
- **Federal Transit Administration (FTA) Notice of Funding Availability (NOFA).** In 2013, the FTA announced the availability of $29,000,000 in Research, Development, Demonstration, and Deployment Program funds for research demonstration projects of national significance. Funding is available to demonstrate innovative technologies, methods, practices, and techniques in three areas: (1) operational safety, (2) infrastructure or equipment resiliency, and (3) all-hazards emergency response and recovery methods. The impact on transit bus axle weights is uncertain; it could increase weight through the development and incorporation of additional transit bus components or decrease weight by innovating current designs.

2.2.3 State Policies and Programs

Certain state governments have implemented policies and programs that impact transit bus weight. Following are some examples.

- **California Air Resources Board (CARB) Urban Transit Fleet Rule:** This regulation, enacted in 2000, requires 15% of new transit bus purchases for all Californian transit agencies with 200 or more transit buses to be zero-emission buses (ZBuses) (Eudy & Post, 2014).
- **New York State Energy Research and Development Authority (NYSERDA) Clean Fueled Bus Program:** Established in 1997, this program aided local and state transit agencies purchase over 500 alternatively fueled (non-diesel) buses (Drake, 2014). It also assists local and state transit agencies purchase infrastructure to support alternative fuel bus technologies (US Department of Energy, 2012).

- **New Jersey Low Emission or Alternative Fuel Bus Acquisition Requirement:** This legislation requires all transit buses purchased by New Jersey transit agencies to meet specific particulate and emissions standards or be powered by fuel other than conventional diesel (US Department of Energy, 2013).

3 Axle Weight Issues Associated with Transit Bus Design

This chapter characterizes the current US transit bus fleet, estimates transit bus compliance with axle weight limits for different bus models, approximates individual transit bus components' contribution to axle weight, and describes the impact of various technologies on transit bus weight.

3.1 Literature Review Findings

3.1.1 Transit Bus Types and Weight Characteristics

The transit bus fleet is continuously evolving, with over 5,000 new transit bus purchases every year in the US (Lowe, Aytekin, & Gereffi, 2009). In the US, federal regulations require transit buses to have a minimum 12-year service life (Clark, Zhen, & Wayne, 2009). The average transit bus age of the current US fleet is approximately 7.8 years (American Public Transportation Association, 2013a). Figure 2 shows the approximate distribution of active buses (including, but not limited to, transit buses) in the US by their model year.

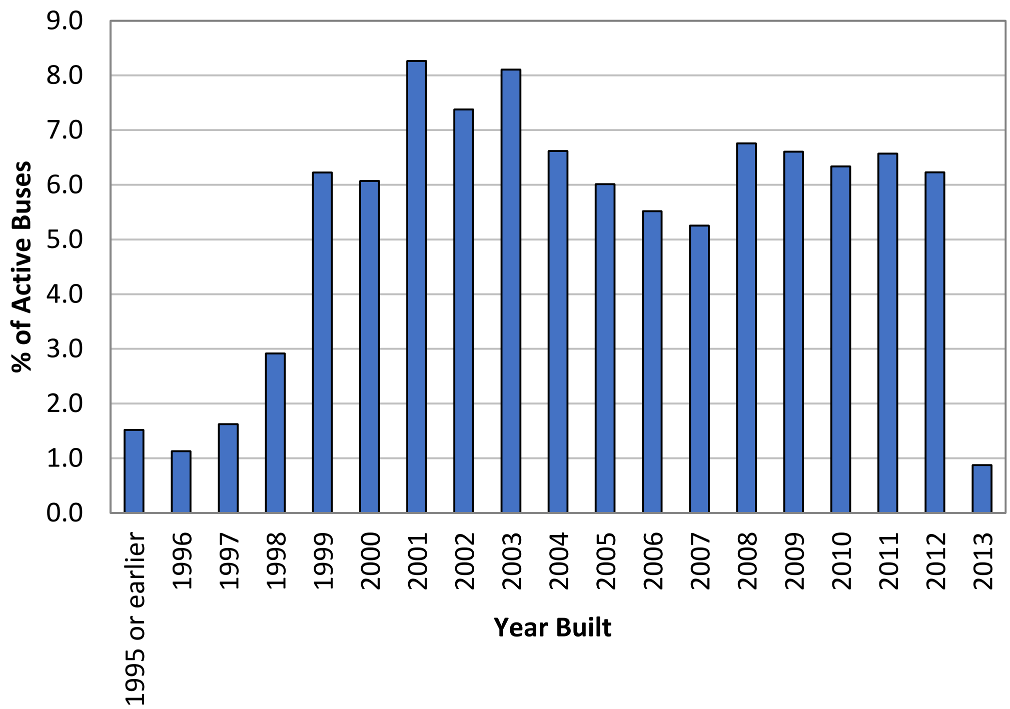


Figure 2: Manufacturing year of active US buses (American Public Transportation Association, 2013b)

In 2011 there were approximately 1,078 transit agencies operating 69,175 buses in the US (American Public Transportation Association, 2013a). Table 6 indicates that most transit agencies are operating 2-axle 40-ft transit buses; many of these are rear-engine diesel buses with automatic transmissions (Clark, Zhen, & Wayne, 2009). Gillig, New Flyer, and Nova Bus (Volvo) are the primary transit bus manufacturers in the US. As of 2009, these companies manufactured over 95% of US transit buses (Lowe, Aytekin, & Gereffi, 2009).

Table 6: US bus fleet purchases and active fleet by bus type

Bus Type	Length[a] (ft)[1]	Number Purchased[b1] (2000-2005)	% of Total Purchased[1] (2000-2005)	% of Total Ordered[c2] (2013)	% of Total Active Buses[c] (2013)
40' Transit	37.5 - 42.5	19,291	69.1	71.1	63.8
Articulated	55 - 61	3,128	11.2	15.7	9.3
Intercity	35-45	903	3.2	0.6	7.6
35' Transit	32.5 - 37.4	1,307	4.7	4.2	6.0
Suburban	27.5 - 45	357	1.3	1.4	4.9
30' Transit	27.5 - 32.4	1,579	5.7	5.5	3.8
45' Transit	45	650	2.3	1.1	2.2
Small vehicle	< 27.5	636	2.3	0.4	2.0
Trolley replica	all	52	0.2	0.0	0.4
Double Deck	all	N/A[d]	N/A[d]	0.0	0.1
Total		27,903	100.0	100.0	100.0

Notes:
[a] Length is measured from bumper to bumper
[b] No data available for bus purchases from 2003
[c] Values are based on the 2013 APTA survey which includes responses from 130 transit agencies and account for a combined total of 35,991 buses in the US bus fleet
[d] No data available on double deck bus purchases from 2000-2005

Sources:
[1] APTA (2006)
[2] APTA (2013b)

There is little information about in-service transit bus weights. However, as per STURAA bus testing requirements, all transit bus models are weighed at the Altoona Bus Research and Testing Center. The resulting bus test reports include weight data disaggregated by wheel, axle, and gross vehicle weight under various loading conditions. The subsequent discussion and analysis are based on this data, which represents tests completed after 2001 (data was unavailable for 3-axle 45-ft models and excludes auxiliary components such as information technology equipment and destination signs). This discussion addresses passenger capacity and weight, transit bus design features and their contribution to weight, axle loads and distributions, and the comparison of axle loads with prescribed axle load limits.

Table 7 provides passenger capacities and the curb and fully-loaded weights of different transit buses. As shown in the table, the most common type of transit bus, the 2-axle 40-ft model, has a maximum capacity ranging from 61 to 92 passengers and a range of fully-loaded weights between approximately 30,000 and 44,000 pounds. This range decreases for shorter buses and increases for longer buses. Articulated 60-ft buses have the highest fully-loaded weight range, from approximately 56,000 to 65,000 pounds, and also accommodate up to 123 passengers.

Table 7: Altoona Bus Test Report Transit Bus Models Passenger Capacity and Weight Summary

Transit Bus Type	Passengers		Curb Weight (lb)	Fully-Loaded Weight (lb)
	Max Seated	Max Total		
2-axle 35-foot	27 – 40	46 – 72	15,450 – 28,510	23,360 – 39,020
2-axle 40-foot	35 – 44	61 – 92	20,520 – 32,520	30,600 – 44,100
2-axle 45-foot	44 – 46	80 – 86	30,130 – 30,450	41,480 – 42,530
3-axle 45-foot[1]	–	–	–	–
3-axle 45-foot Double-deck	79 – 82	116 – 122	36,560 – 37,930	54,670 – 55,850
3-axle 60-foot Articulated	41 – 61	89 – 123	37,920 – 49,520	55,975 – 64,690

Notes:

[1] No data available on this type of transit bus except for over-the-road coaches

[2] Only includes data from Altoona bus test reports available online completed after 2001

Figure 3 illustrates some of the design features of transit buses, all of which contribute to transit bus weight. There are also many internal components not shown in this figure that significantly contribute to transit bus weight. Eliminating any of these components to reduce transit bus weight is unlikely; however, reducing the weight of these components may be feasible.

Figure 4 shows the proportional weight contribution of various components for a fully-loaded 2-axle 40-ft transit bus. This figure reveals that passengers (seated passengers plus standees) contribute nearly one-third of the operational weight. Manufacturers can only control this weight component by reducing passenger capacity which contradicts many transit agency demands. This figure also identifies components that offer the highest potential for reducing transit bus weight. For example, decreasing structure weight by half has a significant effect on overall weight whereas decreasing floor weight by half does not.

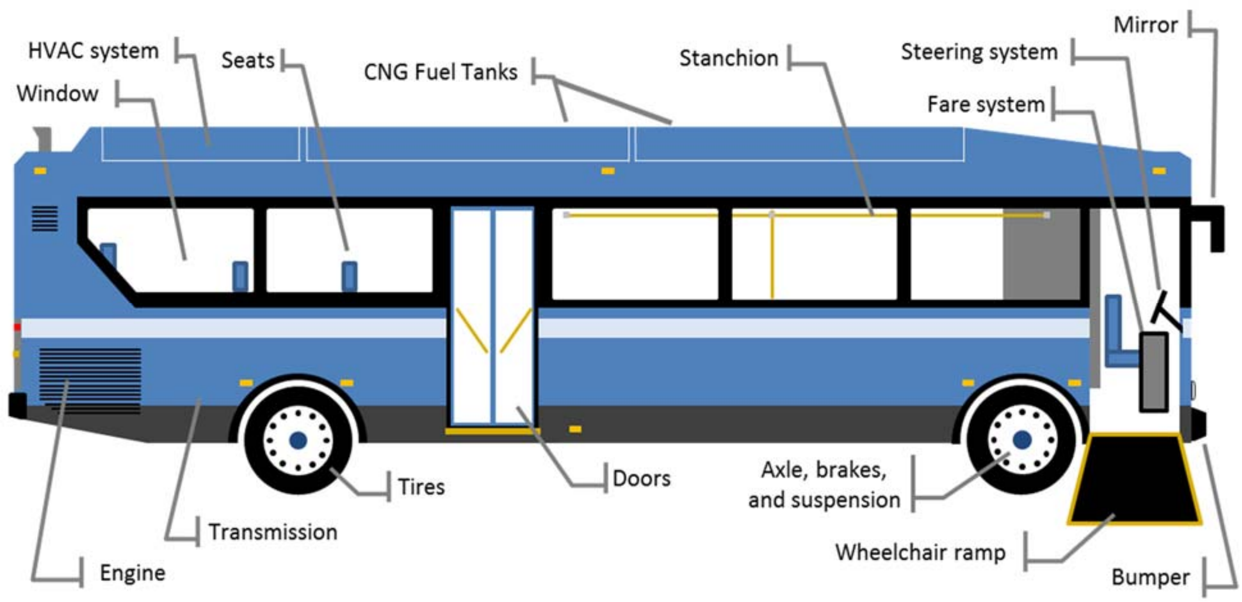


Figure 3: Examples of Transit Bus Components

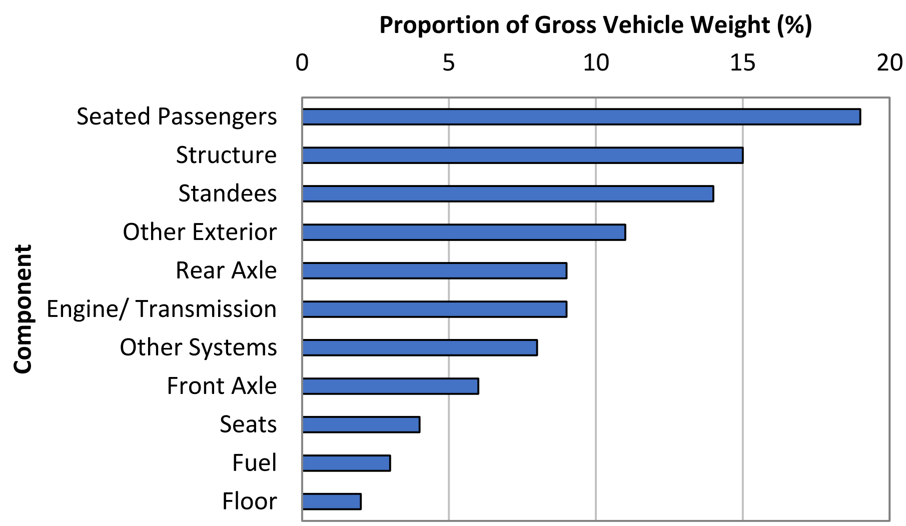


Figure 4: Typical weight breakdown for fully-loaded 40-ft transit buses as of 2003 (Federal Transit Administration, 2003)

Many transit agencies are requesting auxiliary features (e.g., rear and side cameras, vehicle detection units, advisory signage, narrative stop displays, HVAC systems) to improve passenger experiences, comfort, and safety. Figure 5 shows the proportion of US transit buses equipped with certain auxiliary features. These features commonly require additional components such as mounting brackets, wiring systems, and computers which can be overlooked when estimating the additional weight associated with auxiliary features.

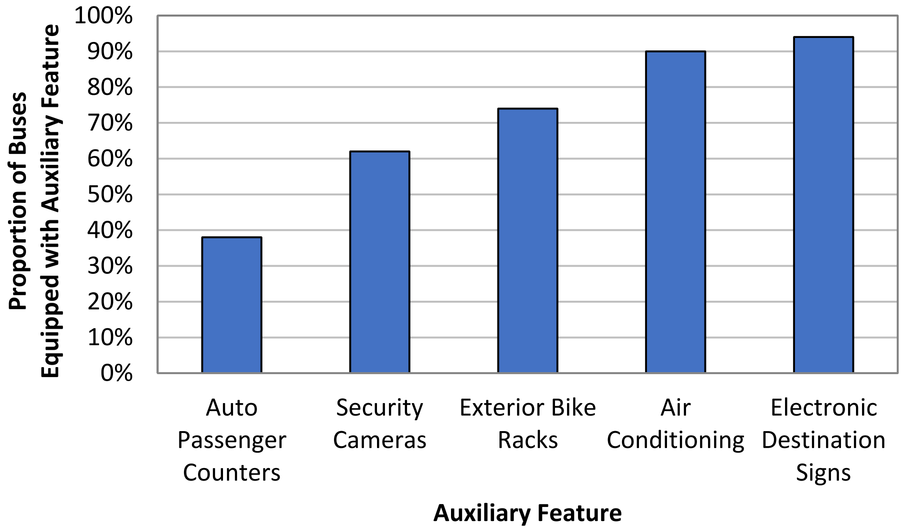


Figure 5: Transit Bus Auxiliary Features

Figure 6 plots the axle weights of 67 Altoona tested bus models while fully-loaded and illustrates how they compare to the 24,000 pound single axle weight limit. Figure 7 uses this data to estimate the average axle weight distribution of each transit bus type (note: the width and location of the weight distributions are conceptual representations and may not accurately reflect the actual axle tributary areas). These figures show the following:

- All transit buses had front axle weights less than 20,000 pounds and most were less than 15,000 pounds.
- Nearly all rear axles for transit buses longer than 35 feet (and all 35 of the 40-ft models) exceed 24,000 pounds.
- On average, front and rear axle weights of 2-axle 35-ft transit buses are approximately 3,000 and 6,000 pounds lower than other bus models, respectively, and are nearly always compliant with the 24,000 pound axle weight limit.
- On average, rear axles carry nearly double the weight of front axles (i.e., approximately 67% on the rear axle compared to 33% on the front axle). According to the 4th power rule (which is discussed in Section 5), a 2-axle vehicle with evenly distributed weight between its axles will cause approximately 60% of the pavement damage compared to the same vehicle with 33% of its weight on one axle and 67% on the other (assuming that both axles are otherwise the same).

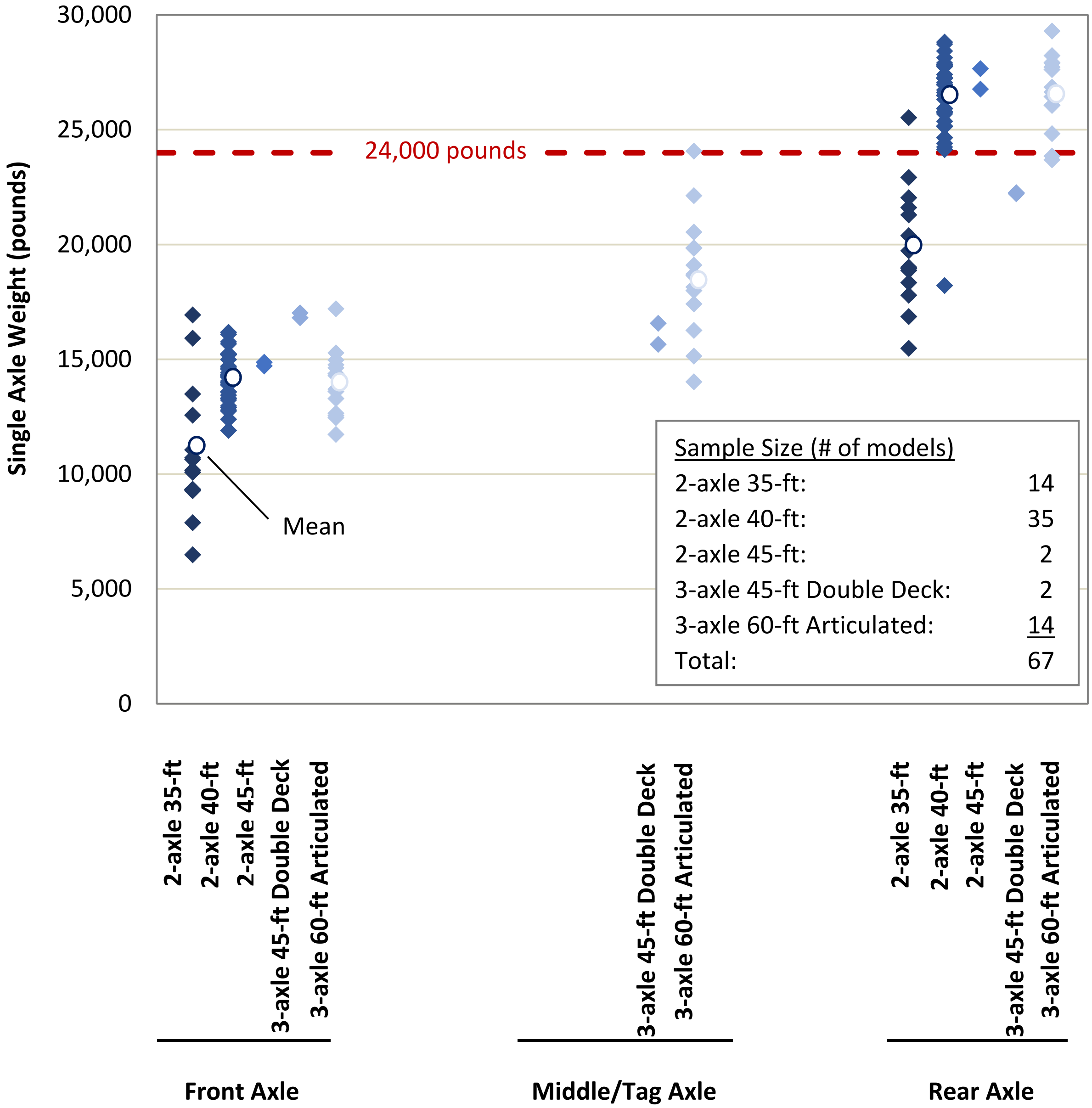
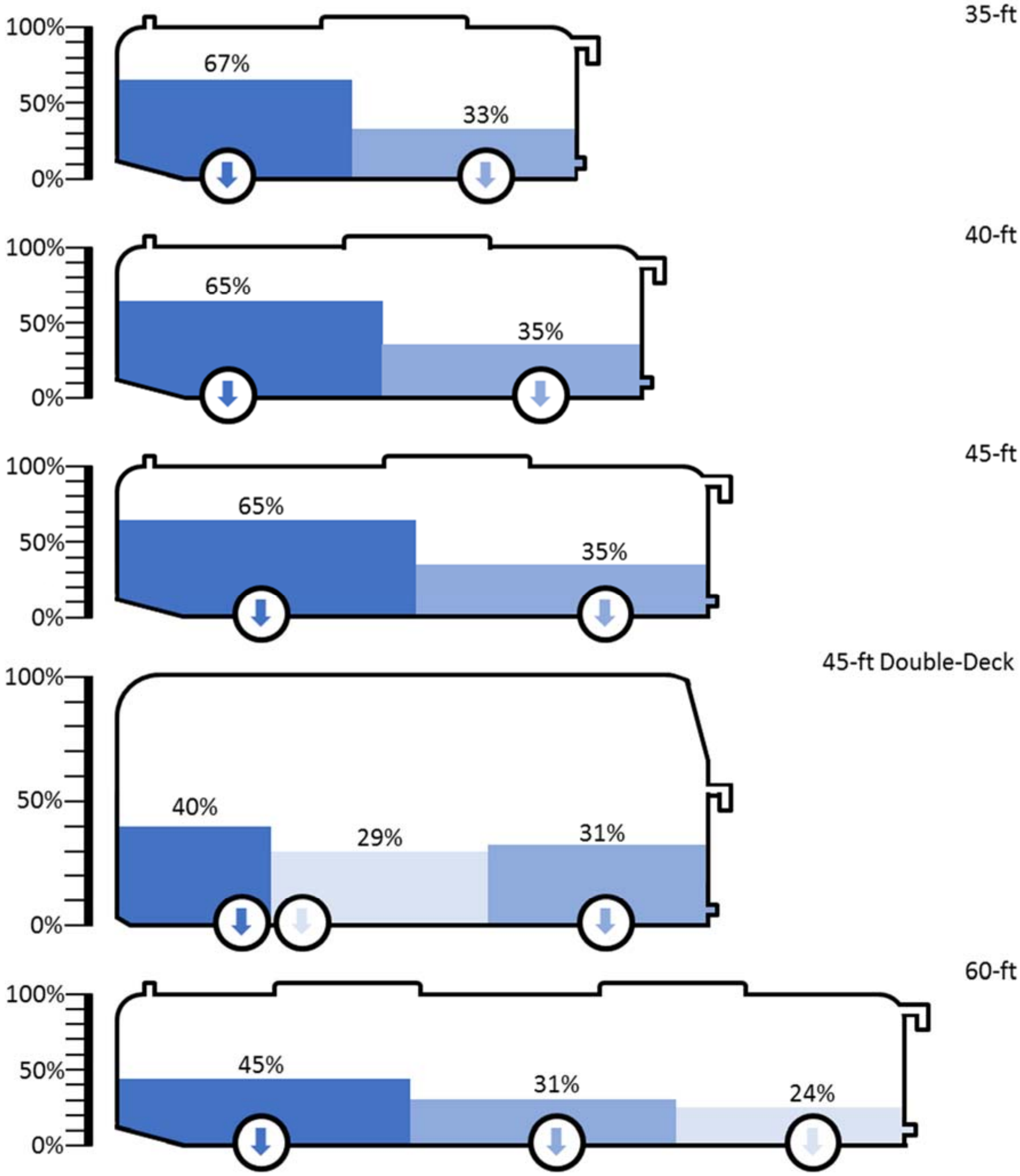


Figure 6: Range of Single Axle Weights by Transit Bus Type when Fully-Loaded



Note: The width and location of the weight distribution bars are conceptual representations of the axle tributary areas and may not accurately reflect the actual axle tributary areas of a transit bus

Figure 7: Average Axle Weight Distributions for Fully-loaded Transit Bus Models

A basic estimate of transit bus compliance with weight regulations can be derived by comparing single axle weight data to axle weight limits as shown in Figure 8. This figure compares 67 transit axle weights from the Altoona database to common single axle weight limits (20,000 pounds, 22,400 pounds, 24,000 pounds, and the GAWR) under various loading conditions (note:

these weights exclude auxiliary components commonly found on transit buses). This comparison reveals several key points:

- Fewer than half of the transit bus models comply with a 20,000 pound single axle weight limit when empty (i.e., curb weight) and one model exceeds the 24,000 pound single axle weight limit when empty.
- Only nine out of the 67 (13%) bus models comply with a 20,000 pound single axle weight limit when fully-loaded. Of these nine buses, only three comply with the manufacturer's GAWR (all three are 2-axle 35-ft buses).
- Only seven out of the 67 (10%) bus models are compliant with both the 24,000 pound weight limit and the manufacturer's GAWR when fully-loaded.

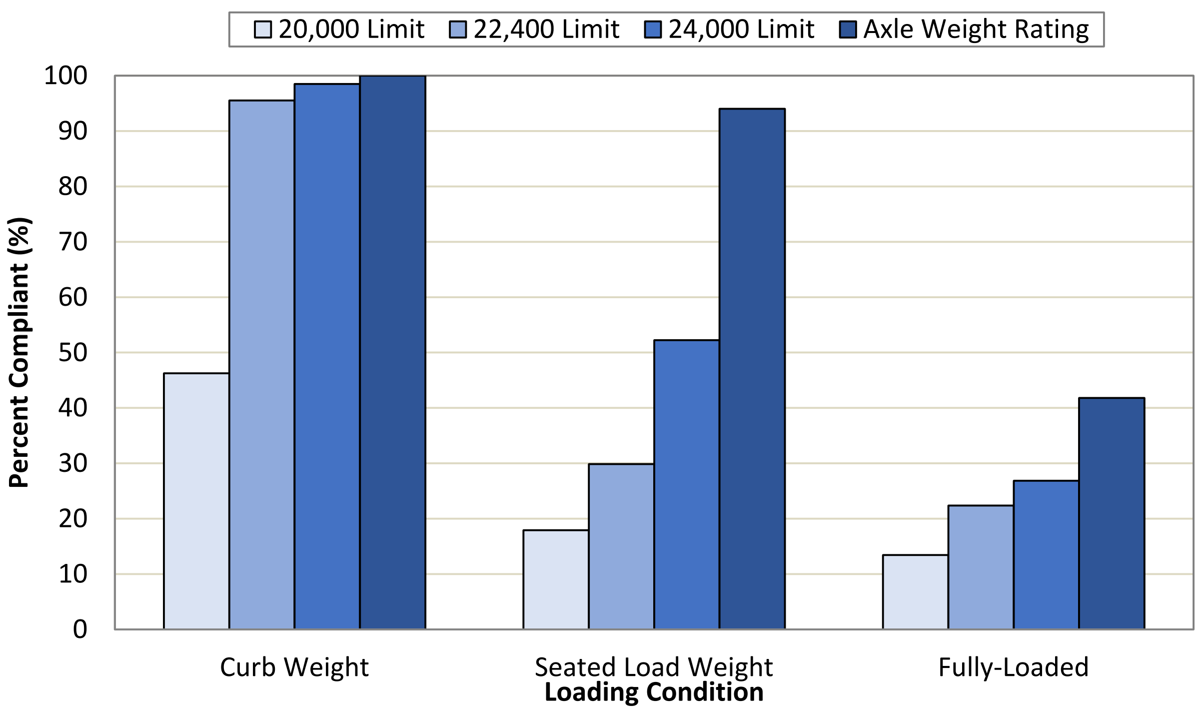


Figure 8: Transit Bus Model Compliance with Selected Single Axle Weight Limits (Altoona Bus Test Report Database, 2014)

3.1.2 Transit Bus Materials and Manufacturing Methods

Most transit buses are currently manufactured with steel. Manufacturing transit buses with alternative and lightweight materials is an effective method for reducing bus weight. However, these materials can significantly increase manufacturing costs, may have few domestic suppliers, and have a limited track record of performance (Battelle, 2007). Current lightweight alternatives to steel in transit bus manufacturing are:

- ultrahigh strength steel,
- carbon fiber,
- aluminum,
- wrought magnesium alloys,
- polymer-matrix composites,
- fiberglass, and
- lightweight structural foams.

Replacing conventional steel transit bus components with aluminum and magnesium has the potential to reduce total vehicle weights by up to 30% and 40%, respectively (Klinikowski, Muthiah, & Kulakowski, 2004). Using composite materials, such as fiberglass and carbon fibers, instead of conventional steel can lower transit bus axle weights by 1,000 to 3,000 pounds per axle (Federal Transit Administration, 2003). However, magnesium is highly susceptible to corrosion and transit buses manufactured with aluminum and composite materials are currently too costly to competitively penetrate the market.

The transit industry (including manufacturers and research institutions) have conducted considerable research to test and develop lightweight transit buses. Four examples of these efforts, the Advanced Technology Transit Bus (ATTB), the CompoBus, an ultra-lightweight steel prototype, and the BUSolutions Low-Cost of Ownership-1st 40-foot Hybrid (LCO-140H), are described in the following paragraphs.

The ATTB program was among the first programs to design a transit bus using lightweight composite materials for structural components. The goal was to design a transit bus that was 10,000 pounds lighter than an equivalent steel bus and met emissions and accessibility requirements for the same cost as a conventional transit bus. To achieve this goal, the ATTB had the following features (Arieli Associates Management, Operations and Engineering Consulting, N.D.):

- a monocoque body (which eliminated the need for a chassis);
- extensive use of lightweight composites (fiberglass and foam);
- a wheelchair ramp instead of a lift; and

- individually powered wheels (which eliminated the need for axles).

ATTB program details were shared with bus manufacturers and many resulting technologies have since been integrated into modern transit bus designs (Canadian Public Transit Discussion Board, 2013).

The CompoBus incorporated lightweight composite materials into its design using composite resin infused molding. The goal of the CompoBus was to reduce the weight of a 40-ft transit bus by 7,000 pounds compared to conventional steel buses; however, the final design only achieved a 2,000 pound reduction. The first 40-ft prototype was subjected to STURAA (Surface Transportation and Uniform Relocation Assistance Act) testing in 2000 and had a curb weight of 24,950 pounds (The Pennsylvania Transportation Institute, 2000). A 45-ft model was also built which increased seating capacity by 15% while maintaining the same curb weight as a conventional 40-ft transit bus (Henke, 2005). High production costs caused the termination of the CompoBus program in 2005. Despite the purchase of approximately 260 CompoBuses by the Los Angeles County Metropolitan Transportation Authority (LACMTA) in 2008, insufficient demand for these buses resulted in their discontinuation (Canadian Public Transit Discussion Board, 2013).

Through a public-private partnership a 40-foot prototype bus was developed and constructed using an ultra-lightweight steel that reduces transit bus weight by 50% compared with standard 40-foot buses. Although state funding for a second prototype was suspended in 2010 (Shea, 2010), this prototype confirmed the feasibility of certain concepts and components to reduce transit bus weight. These included:

- using resistance welding (i.e., spot welds placed along the seam between 8-foot long panel segments),
- adjusting the assembly sequencing of primary structure (floor panel components, side pillars, door frames, and roof segments),
- utilizing front and rear end sheet metal with reduced noise, vibration, and harshness characteristics,
- designing cantilevered seats,
- incorporating a crash energy management system, and
- altering the suspension and driveline design (Emmons & Diamond, 2004).

The BUSolutions Low-Cost of Ownership-1st 40-foot Hybrid (LCO-140H) is a relatively new lightweight transit bus design. The goal of the BUSolutions project was to “develop an extremely lightweight, heavy-duty bus design that yields superior fuel efficiency [to] conventional buses at a lower lifecycle cost while requiring no infrastructure upgrades to operate” (Heskitt, Smith, & Hopkins, 2012, p. 3). The LCO-140H incorporates many innovative features that reduce the overall weight of the bus including (Green Car Congress, 2012) (Heskitt, Smith, & Hopkins, 2012):

- enhanced rear engine compartment layout;
- cool air corridor with roof air intake;
- intelligent decentralized multiplex system;
- super single tires;
- single piece balsa composite floor and roof;
- spray-on interior; and
- aluminum structural components (instead of steel).

The LCO-140H has a curb weight of 25,800 pounds and maximum payload of 14,700 pounds (97 passengers plus driver), resulting in a gross vehicle weight of 40,500 pounds when fully loaded. Referencing Figure 6, these weights are comparable to standard 40-ft diesel buses. This bus’ technical specifications indicate that the proportional weight on the front and rear axles is 29% and 71%, respectively. Therefore, when fully loaded, the weight on the front and rear axle is 11,745 and 28,755 pounds, respectively. The LCO-140H also has the option to use wide-base tires (455/45R22.5) on the rear axle; however, this lowers the rear axle GAWR by 4,660 pounds.

3.1.3 Transit Bus Propulsion Systems

Emissions policies introduced in the past few decades have resulted in new transit bus diesel systems that incorporate emissions reduction components (e.g., particulate filters and traps) and utilize low-sulfur diesel fuels (Klinikowski, Muthiah, & Kulakowski, 2004). Although these systems initially increased engine weight, innovations to diesel engine design have offset these increases (Klinikowski, Muthiah, & Kulakowski, 2004). Extensive research is also being conducted to develop alternatively powered systems using fuels other than conventional diesel or gasoline to help comply with increasingly stricter emissions standards. Transit buses that utilize alternative fuels or propulsion systems are on average heavier than their traditional diesel counterparts (Klinikowski, Muthiah, & Kulakowski, 2004).

Diesel buses comprised 60% of the transit bus fleet in 2013, a decrease from 95% in 1995 owing largely to increased utilization of natural gas and hybrid buses (American Public Transportation Association, 2013a; American Public Transportation Association, 2013b). Many transit agencies are using alternatively-powered transit buses exclusively, such as the Los Angeles County Metropolitan Transportation Authority (2,224 transit buses) and the Tri-County Metro Transportation Authority in Portland (594 transit buses) (American Public Transportation Association, 2013b). Figure 9 shows the distribution of bus fuel propulsion systems in the US as of 2013 (data in this figure is not specific to transit buses).

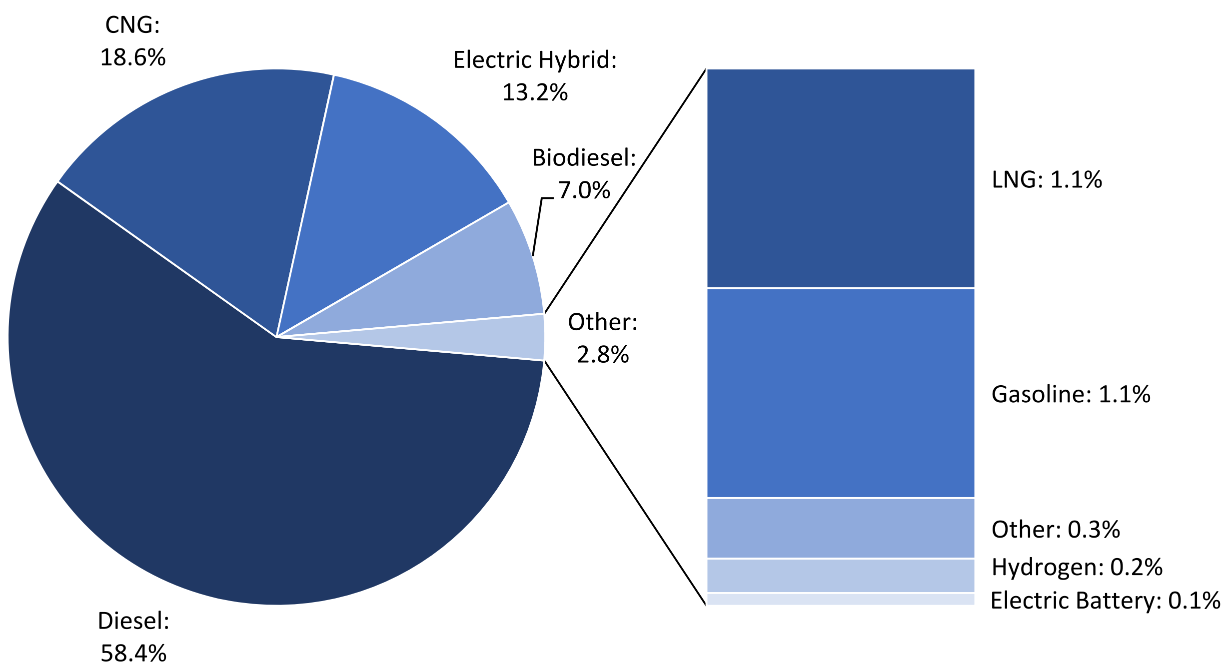


Figure 9: Proportion of different fuels used in the US bus fleet (American Public Transportation Association, 2013a)

Compressed natural gas (CNG) and liquefied natural gas (LNG) transit buses are alternative fuels to diesel, and CNG transit buses in particular are becoming increasingly common. These fuel types require special gas cylinders for storage which are often located on the bus roof. These cylinders are partially responsible for CNG and LNG bus weights being up to 2,500 pounds (11%) heavier than diesel buses (Klinikowski, Muthiah, & Kulakowski, 2004). Further, one study found that over 90% of CNG buses operating in Texas have rear axle weights that exceed 20,000 pounds (Battelle, 2007).

Hybrid electric buses utilize an electric drive system in tandem with a small combustion engine system. These buses are on average 2,400 pounds (9.5%) heavier than the corresponding diesel models (Klinikowski, Muthiah, & Kulakowski, 2004). Unlike other alternative propulsion systems, hybrid electric buses can reduce emissions while still using diesel-specific infrastructure. These buses are becoming increasingly popular; the New York Metropolitan Transportation Authority (New York City, NY), Washington Metrobus (Washington, D.C.), and King County DOT (Seattle, WA) operate more than 2,800 hybrid buses combined (American Public Transportation Association, 2013c). Figure 10 compares the curb weights for diesel, CNG, and hybrid electric versions of one transit bus model that is currently in production. This figure illustrates that unloaded CNG and hybrid electric transit buses are around 2,000 to 3,000 pounds heavier than unloaded diesel buses.

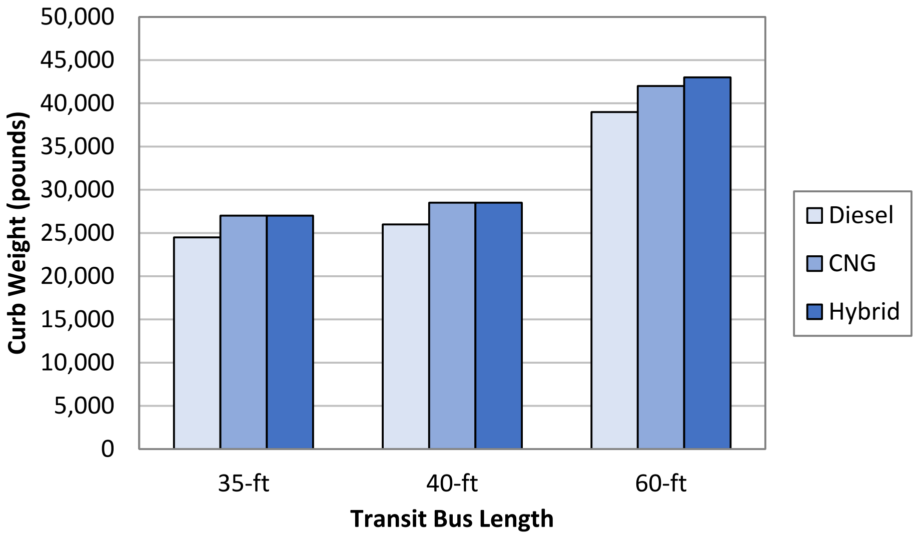


Figure 10: Curb weight comparison between New Flyer Xcelsior diesel, CNG, and hybrid electric transit buses (New Flyer, 2014)

Electric flywheels are a recent hybrid technology advancement for transit buses. Although electric flywheels have been used in uninterruptable power supply (UPS) systems and regenerative braking systems for high performance racecars for many years, they are an emerging transit bus technology (Davies, 2014). Electric flywheel systems are similar to most regenerative braking technologies insofar as they convert and store rotational energy into electricity during braking and supply this energy to the drive axle when it is needed. However, instead of storing energy in batteries, electric flywheels store the energy as momentum.

Electric flywheel systems weigh around 130 pounds, are similar in size to a passenger car wheel, and can increase fuel efficiency by approximately 20% compared to conventional diesel buses (Davies, 2014). They can be used to hybridize existing diesel buses and are well suited for stopping and starting operations. Electric flywheels have higher costs compared to batteries although there is potential to recover these costs through reduced maintenance and operating costs (Federal Energy Management Program, 2003). Currently there is one public transit provider in the United Kingdom that is installing flywheel systems on 500 buses over the next two years (Davies, 2014).

Hydrogen fuel cell (HFC) buses are a well-researched zero-emission bus (ZBus) technology which can eliminate tailpipe emissions by converting hydrogen directly into electricity (Chandler & Eudy, 2012). Although HFC buses are still in the prototyping and testing phase of development, they are gradually progressing towards becoming a commercially-available technology and have already been operated through various pilot programs. Figure 11 shows that the number of in-service HFC buses in the US has steadily increased from fewer than 10 prior to 2010 to about 25 in 2014 (Eudy & Gikakis, 2013). The retirement of several prototype designs is largely responsible for the decrease observed in 2008 and 2009. This table differentiates between “first generation” and “second generation” buses, where the generation refers to the degree of “commercial readiness” of a bus, not necessarily the manufacturers’ designations. New piloting programs of both second generation and new first generation HFC buses contributed to their growth from 2010 to 2014. For example, BC Transit introduced 20 second generation HFC buses for regular service in 2010. On-board hydrogen storage presents a challenge for HFC buses to become a practical option. Current storage options require heavy components that can increase transit bus weight by 25% compared to conventional diesel buses (Chandler & Eudy, 2006).

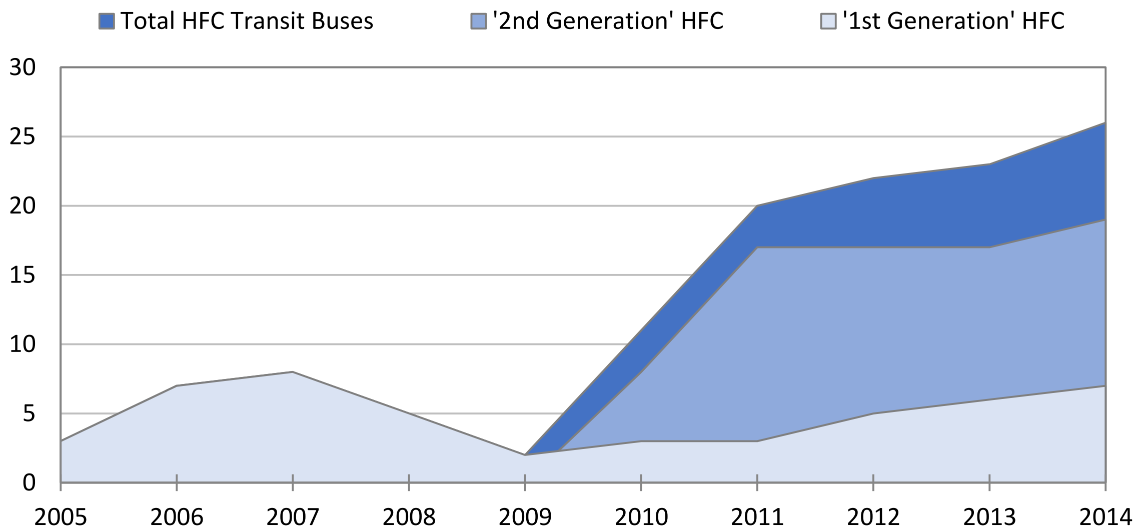


Figure 11: In-service Hydrogen Fuel Cell (HFC) Transit Buses in the US (Eudy & Gikakis, 2013)

3.1.4 Transit Bus Accessibility Requirements and Safety-Related Features

Policies such as the Americans with Disabilities Act (ADA) require all current and future US transit buses to be fully-accessible. Specifically, buses longer than 22 feet must have space to accommodate two wheelchairs. Between 1995 and 2011, the "percentage of buses that are accessible increased from 60 percent to 99 percent" (American Public Transportation Association, 2013c, p. 17). Initial responses to ADA requirements involved retrofitting many high floor buses with wheelchair lifts; however, these lifts were costly, unreliable, and weighed approximately 1,000 pounds (King, 1994). Consequently low floor buses equipped with lower weight wheelchair ramps are now used to meet the ADA requirements. Specific impacts of ADA requirements on transit bus axle weights include the following:

- **The transition from high floor to low floor buses** has changed transit bus axle weight distribution. Low floor transit buses eliminate equipment storage space beneath the bus, thus requiring certain components to be relocated elsewhere, often to the rear. Subsequently, low floor transit buses have a higher proportion of the gross vehicle weight resting on the rear axle compared to high floor buses (Federal Transit Administration, 2003).
- **Mobility assistance components** such as wheelchair ramps and hydraulic systems have contributed to higher transit bus axle weights. Wheelchair ramps weigh approximately

100-200 pounds; this excludes any weight caused by additional reinforcement (Federal Transit Administration, 2003).

- **Low floor bus passenger capacity** is up to 16% lower compared to high floor buses due to the relocation of components (Kulakowski, Muthiah, Yu, & Klinikowski, 2004). Reducing passenger capacity can lower transit bus GVW (which could positively impact pavement deterioration) but could also necessitate additional buses to adequately serve a route (which could negatively impact pavement deterioration).

Technological advancements have increased wheelchair weight by more than 200 pounds and have subsequently affected transit bus weights. A 2005 study analyzed 1,000 people using mobility devices (i.e., self-propelled wheelchairs, attendant-propelled wheelchairs, electric wheelchairs, and electric scooters) in the United Kingdom and found that the average combined weight of the device and occupant was 290 pounds and the maximum weight was 750 pounds (Hitchcock, Hussey, Burchill, & Magdalen, 2006). Electric wheelchairs exhibited the highest average combined weight of 400 pounds. This study also found that the average combined weight of a mobility device and its occupant increased by more than 20 pounds from 1999 to 2005.

3.1.5 Transit Bus Axle and Tire Weight Distribution

The distribution of a transit bus' weight, its axle configuration, and the types of axles, tires, and suspension systems used on the bus affect the weight limit relevant to the bus and influence pavement deterioration. This section discusses the use of tandem axles (on the rear or front) and wide-base radial tires on transit buses.

Two-axle transit buses most frequently exceed axle weight limits on the rear axle. Adding a tag axle converts the rear axle into a tandem axle group, thereby reducing the individual axle loads but also increasing curb weight. Notably, tag axles used on buses normally have only two tires, rather than two sets of dual tires. Tag axles can be raised or lowered based on weight capacity requirements. While this can mitigate pavement deterioration, transit buses with rear tandem axle groups have larger turning radii and reduced maneuverability compared to those with a single rear axle; this can be critical for operating in urban areas with restricted road geometry. Steer tag axles (i.e., axles with pivoting wheels to assist turning movements) can improve turning radii and maneuverability and are currently being evaluated (Sleath, Kalasih, & Hutchinson, 2006). Tandem tag axles can also reduce passenger capacity, increase manufacturing costs and maintenance costs, and increase pavement deterioration through wheel scrub (i.e., dragging the tag axle across the pavement during turning movements).

Tandem steer axles can be used on the front of transit buses. This can reduce rear axle weights by facilitating the relocation of transit bus components in the rear to the front without exceeding single axle GAWR and tire capacities. Most current 2-axle transit buses have approximately one-third of the bus weight on the front axle and two-thirds on the rear axle (Federal Transit Administration, 2003). According to the 4th power rule (which is discussed in Section 5), a 2-axle vehicle with evenly distributed weight between its axles will cause approximately 60% of the pavement damage compared to the same vehicle with 33% of its weight on one axle and 67% on the other (assuming that both axles are otherwise the same). Tandem steer axles on transit buses is not a new concept; during the 1960s over 900 buses with tandem steer axles and single rear axles were built in the United Kingdom (Wikia, N.D.). Further, one double-deck Japanese transit bus model currently utilizes a tandem steer axle and a tandem rear axle (Wikia, N.D.).

Wide-base radial tires can be used on either axle to replace dual tires. They may offer an opportunity to mitigate certain types of negative pavement impacts while marginally reducing transit bus weight (a wide-base tire is approximately 100 pounds lighter than dual tires). Wide-base tires emerged in the 1980s as an alternative to dual tire assemblies, primarily in the trucking industry (Al-Qadi & Wang, 2009). Initially wide-base tires caused significantly more pavement damage compared to dual tires, so road authorities discouraged their use. Recent technological advancements have produced certain new generation wide-base (NGWB) tires that cause comparable pavement damage as dual tire assemblies, but are less detrimental to pavements than initial wide-base tire models (Greene, Toros, Kim, Byron, & Choubane, 2009). Research has also found that NGWB tires cause more pavement damage on local and primary roads compared to Interstate highways. Since most transit buses operate on local and primary roads, replacing dual tires with NGWB tires may accelerate overall pavement deterioration.

Replacing current steer axle tires with wide-base tires may be an option to mitigate pavement impacts from the front axle. Some construction, mining, and logging vehicles currently use wide-base tires on steering axles (Al-Qadi & Wang, 2009), though these are typically early generation wide-base tire models. While this could help shift transit bus weight from the rear to the front axle, it is unclear if the experience of using wide-base tires on steer axles in the trucking industry is transferable to transit buses.

NGWB tires offer several emissions, rider comfort, and safety benefits, in part due to their reduced rolling resistance. Fuel economy at highway speeds (i.e., 55-65 mph) and in suburban "stop and go" conditions was improved by up to 12% and 10%, respectively, for trucks equipped with NGWB tires instead of dual tires. Further, NOx emissions at highway speeds and in suburban "stop and go" conditions were reduced by up to 37% and 14%, respectively, for trucks equipped with NGWB tires instead of dual tires (Greene, Toros, Kim, Byron, & Choubane, 2009).

3.2 Interview Findings

Interviews with major bus manufacturers, the American Public Transportation Association, and the California Transit Association provided information concerning the factors influencing transit bus weight and weight changes, options to reduce transit bus weight and address regulatory matters, and insight regarding future transit bus technologies and costs. This section summarizes these interviews.

3.2.1 Factors Influencing Transit Bus Weight and Weight Changes

Interviewees cited regulatory and customer demands as the primary factors influencing transit bus weight. The most significant regulatory factors in the past few decades are the Americans with Disabilities Act and the Clean Air Act. The most significant customer demand factors are increasing technology requirements, additional comfort items, providing hybrid cages and upgraded seats, placing equipment on transit bus roofs which requires sturdier roof design, using alternative fuels, and requiring transit buses to have a 12-year lifespan which necessitates heavy-duty components. Manufacturers indicated that public agencies are introducing penalties for transit buses exceeding specified weights in bid evaluations. According to one interviewee, California and New Jersey are exerting the most pressure on manufacturers to lower transit bus weights.

Transit bus manufacturing changes have contributed to both increases and decreases in weight. Advanced air conditioning, electronic fareboxes, wheelchair lifts, fire suppression systems, and compressed natural gas and hybrid technologies have each significantly increased transit bus weight. Other elements that have contributed less significantly to higher transit bus weights are thicker windows, on-board electronics, heavier engines and more complex transmissions, larger alternators, cameras and video cameras, passenger counters, passenger seats, bike racks, and appearance packages (e.g., bus rapid transit marketing materials). Manufacturing transit buses with composite materials consisting of glass filament and carbon fiber, installing wheelchair ramps instead of lifts, plastic fuel tanks and coolant coils, PVC piping, composite flooring, and constructing structures with aluminum instead of steel have each decreased transit bus weight.

3.2.2 Options to Reduce Transit Bus Weight and Address Competing Regulations

Most manufacturers consider replacing steel with lighter materials, such as aluminum and composite materials, as the most feasible option to lower transit bus weight. Examples include composite floors, plastic fuel tanks, aluminum skirt panels, and plastic radiator hold tanks, and generally using more plastic throughout the transit bus. Other suggestions from manufacturers were using a centralized computer system to operate all on-board electronics instead of requiring each on-board technology to use a separate operating system, which is the current practice; gearing transmissions for lower speeds to right-size engines and fuel tanks; and adapting rail air conditioning technology to transit buses which can decrease weight by creating a self-contained, roof-mounted system. Bus manufacturers also identified low resistance tires and Frequency Selective Dampening (FSD) shocks as current transit bus components that could reduce transit bus pavement impacts. Some non-manufacturing interviewees suggested issuing transit buses temporary oversize/overweight vehicle permits to allow them to operate above axle weight limits, permanently exempting transit buses from weight limit regulations, increasing transit bus weight limits, and purchasing smaller transit buses as options to address regulatory matters.

Only some manufacturers indicated they are conducting research and development to lower transit bus weights. Most manufacturers are content maintaining current transit bus weights and using composite materials when possible. Manufacturers conducting research and development find that future transit bus design changes may increase maintenance and tooling costs. Most interviewees identified difficulties for shifting weight to front axles due to steering axle maximum weight and tire capacity limits. One interviewee examined the possibility of moving the engine from the rear to the center of the bus; however, this proved impractical. Some interviewees considered CNG and hybrid roof-mount air conditioning as feasible options to shift weight to front axles.

3.2.3 Insight Regarding Future Transit Bus Technologies and Costs

Bus manufacturers cite the minimum 12-year transit bus service life required by transit agencies (following federal regulations) as the largest obstacle for reducing transit bus weight.

To achieve this lifespan transit buses must be constructed with heavy-duty components. Most interviewees estimated that design and manufacturing changes required to reduce transit bus weights by 2,000 to 3,000 pounds while maintaining a 12-year lifespan would increase manufacturing costs by $30,000 to $40,000 per bus.

One interviewee indicated that constructing transit buses with composite materials instead of aluminum and steel (which is the current practice) would increase manufacturing costs by $50,000 to $75,000 per bus. To put this in perspective, the average new transit bus cost for a transit agency in 2012 and 2013 was $486,653 for a two door bus greater than 27.5 feet in length (American Public Transportation Association, 2013).

Certain transit bus types, such as the 2-axle 40-ft model, require weight reductions up to 8,000 pounds to become compliant with current weight limits. Bus manufacturers indicate that they have explored nearly all cost-feasible design and manufacturing options currently available to reduce transit bus weight. These findings reveal the limited ability current manufacturing innovations have for lowering transit bus weights and the significant costs associated with relatively small weight reductions.

4 Axle Weight Issues Associated with Transit Bus Operations

This chapter identifies transit bus operations that impact bus weights and pavement deterioration (e.g., bus routing and passenger loading) and how operational changes can address transit bus weight issues. Transit bus operations such as routing, vehicle maneuvers (e.g., turning, frequent starting and stopping), and passenger loading impact pavement performance. Operational changes can affect transit bus loading characteristics (e.g., axle weight and bus frequencies), the pavement types experiencing high transit bus weights, and service quality. Specifically, these changes can result in transit buses operating on stronger or weaker pavements or operating at lower gross vehicle weights (which typically results in lower axle weights). Generally transit agencies can adapt bus operations to meet market demands and public policy but cannot easily modify transit bus maneuvers to mitigate pavement impacts.

4.1 Literature Review Findings

4.1.1 Transit Bus Routing

Unlike most road users, transit buses operate on specified routes at specified times with specified vehicles and often in specified lanes (e.g., the curb lane or exclusive bus lanes). Transit buses are one of the few commercial motor vehicles to regularly use minor arterials and collector roads and their frequent starting and stopping differentiate them from most other vehicles. Although transit bus operational characteristics uniquely impact pavement performance, estimating the magnitude of these impacts is difficult due to insufficient in-service weight data. Moreover, actions to mitigate pavement deterioration may negatively impact service.

Flex routing, an emerging practice that combines fixed route service and on-demand service for transit (Alshalalfah & Shalaby, 2009), may introduce pavement loadings on roads that were not considered during road design. Flex routing is often accomplished by diverting transit buses from major arterials or collector streets to local roads. While flex routes typically involve smaller bus equipment there are many examples of flex routes in the US that use full-size buses (Higgins & Cherrington, 2005).

4.1.2 Transit Bus Passenger Loading

Passenger loading is the single largest contributor to transit bus weight, as shown in Section 3.1.1. Annual national ridership trends have fluctuated in recent years but have generally remained around 5.5 billion passenger-trips since 2007 (American Public Transportation Association, 2014). However, some transit agencies are reporting increases in the average proportion of transit bus axle weight attributable to passengers (Federal Transit Administration, 2014). This could be partially due to strategies and campaigns to increase ridership (e.g., marketing bus rapid transit (BRT) services) and increases in average passenger weight.

During peak travel periods, transit buses often accept as many passengers as possible without regard for maximum ridership capacity (Australia National Transport Commision, 2014). This practice can increase ridership, reduce the number of buses required to service a route, and generally improve a transit agency's operational efficiency. However, this practice can lead to transit bus ridership exceeding bus capacity and violation of axle weight limits. Fully- and overloaded transit buses that typically exceed axle weight limits are higher capacity buses with 40 foot lengths or greater (as shown in Section 3.1.1).

Increases in average US adult weight is another contributor to rising transit bus weights. According to the Centers for Disease Control and Prevention (CDC) the mean weight for an American adult increased by more than 24 pounds from 1960 to 2002 (Ogden, Fryar, Carroll, & Flegal, 2004). Recent studies state that the average American adult weight is approximately 180 pounds (Quilty-Harper, 2012). Bus manufacturers and bus testing facilities currently assume the average transit bus passenger weighs 150 pounds and occupies 1.5 ft^2 of floor space (Federal Transit Administration, 2003). These assumptions are based on "calculations carried out by the National Highway Traffic Safety Administration in 1971, which in turn was based on data gathered by the CDC between 1960 and 1962" (Twilley, 2011). The Federal Aviation Administration (FAA) currently uses an average adult passenger weight of 190-195 pounds, which is based on more recent CDC data and includes a 5-10 pound allowance for clothing and a 16 pound allowance for personal items (Federal Aviation Administration, 2005). The rise in average adult weight and the apparently low passenger weight assumption used by the transit industry is potentially causing transit buses to operate at higher weights than predicted and exceeding axle weight limits with fewer passengers than expected.

In 2011, the FTA proposed increasing the average passenger weight design standard from 150 to 175 pounds and average occupied floor space from 1.50 ft^2 to 1.75 ft^2 to reflect increases in the average weight of Americans. This proposal was withdrawn after Congress passed MAP-21 due to the amendment to 49 U.S.C. 5318, which required the development of pass/fail standards for the FTA's bus testing program (Federal Transit Administration, 2012). The proposed rulemaking could have substantially impacted transit bus manufacturers and operators (Schlosser, 2011) by necessitating changes in bus designs to maintain structural requirements and reducing total passenger capacity by up to ten passengers per bus.

4.1.3 Transit Bus Operational Measures to Reduce Axle Weight

Table 8 provides several transit bus operational measures to reduce axle weights. These measures are increasing bus frequency, restricting passengers from loading when weight limits are reached, changing transit bus purchasing criteria, and adjusting transit bus routing.

Table 8: Operational measures to mitigate increased transit bus axle weights

Potential Mitigation Measure	Effect
Increase transit bus frequency	This measure could reduce the number of passengers per bus, thus reducing the axle weights. However, it is possible that operating higher volumes of lighter buses will cause more pavement damage than fewer heavier buses. Further this measure may not reduce the number of fully-loaded buses during peak times since transit users may not wait for a later bus that has more available capacity (Australia National Transport Commision, 2014). Increasing transit bus frequency could also improve service and attract more riders which could increase passenger loading.
Restrict passengers from boarding when weight limits are reached	Bus operators could restrict passengers from boarding when weight limits are reached. Enforcing this measure would be difficult, particularly if the bus' weight capacity is reached before the passenger capacity (Australia National Transport Commision, 2014).
Change transit bus purchasing criteria	Some states, such as California and New Jersey, have purchasing criteria that stipulate how transit agencies can spend state-provided funds (US Department of Energy, 2013). These stipulations often require transit buses to comply with emissions standards, but could include curb weight or axle weight provisions for transit buses in the future.
Adjust transit bus routing	Transit bus routes could be adjusted to restrict transit buses on certain roadways based on their pavement strength (Federal Transit Administration, 2003). Although this measure could address pavement impact issues it could also decrease service below an acceptable level.

4.2 Survey Findings

This section summarizes the findings from the 432 surveys that were distributed to city and county transportation officials, including MPOs and public transit agencies. These surveys were designed to identify operational issues associated with transit buses exceeding axle weight limits and options to address these issues. Fifty surveys were completed but respondents did not always answer each question. Follow-up interviews were requested from eight individuals; however, no new information was obtained from this effort as the potential interviewees did not respond to interview requests. This lack of response appears to align with the scarcity of comprehensive resources available on operational issues related to transit bus axle weight. Appendix A contains survey details.

Most survey respondents were not knowledgeable about transit bus weight issues, as a detailed understanding of these issues is not required for most aspects of their job responsibilities. Generally local governments consider transit bus axle weight limits, exemptions, and enforcement as a state or federal issue.

Vehicle weight issues sometimes arise during the preparation and execution of Unified Planning Work Programs (UPWPs) when dealing with freight and logistics planning; however, transit bus axle weights are not specifically addressed by these programs. Only 25 percent of the survey respondents had conducted a UPWP and only one respondent indicated that their organization had studied transit bus axle weight impacts on pavement performance. This respondent indicated that these studies are used for curb and gutter rehabilitation and installing Portland cement concrete landing pads.

Few survey respondents (4 out of 42) maintained or had access to an inventory of transit bus weights, exemptions, and enforcement policies. Moreover, most respondents (26 out of 27 responses) were unaware of specific transit bus axle weight limits in their jurisdiction while one respondent indicated that transit bus axle weights were not enforced. Most respondents (24 out of 38 responses) were unsure if transit bus axle weight limit exemptions existed in their jurisdiction and others (13 out of 38 responses) indicated that exemptions in their jurisdiction did not exist. One respondent indicated that their jurisdiction had a local and state weight exemption for an individual dedicated BRT corridor.

Most survey respondents (22 out of 39 responses) were unsure which of the six types of transit buses (described in Section 1.2) had the most pavement impacts in their jurisdiction. Of those that did know (22 out of 39 responses), 17 indicated it was 2-axle 40-ft transit buses, 3 indicated that it was 3-axle 60-ft articulated transit buses, and 2 indicated it was 3-axle 45-ft transit buses. Most respondents (34 out of 37) were either unsure if their jurisdiction responded to pavement damage attributable to transit buses or did not have a significant response to this damage. Those that did address pavement damage attributed to transit buses responded by changing pavement design practices, pavement materials, construction methods, pavement maintenance practices, transit bus design specifications, and transit bus operations.

5 Pavement Design and Engineering Issues Associated with Transit Bus Axle Weights

This chapter begins with a brief overview of pavement design and engineering practices to provide context to the summary of findings from the literature and surveys concerning transit bus impacts on pavement performance. Readers are encouraged to refer to the *Mechanistic-Empirical Pavement Design Guide: A Manual of Practice* (American Association of State Highway and Transportation Officials, 2008) for a detailed description of these practices.

Pavements are usually designed to meet performance criteria based on the expected axle loading and environmental conditions over the desired pavement life. The design process requires multiple inputs pertaining to:

- **traffic loads** - axle loads, volume, axle configuration, speed, others;
- **pavement structure** - layer thicknesses, materials properties, sub-base characteristics, others;
- **climate** - temperature and precipitation patterns, freeze-thaw cycles, others; and
- **construction and maintenance** - methods, tolerances, treatment, timing, others.

The pavement design process incorporates these inputs into a set of deterioration models to predict performance outcomes such as serviceability (often expressed as a functional relationship between pavement roughness and accumulated traffic loads over time) and common failure modes (e.g., fatigue cracking, rutting).

This design process has evolved considerably over the last few decades. Most notably, in recent years, some jurisdictions have replaced conventional empirical methods with a mechanistic-empirical approach. Empirical methods are based on the experimental results of road tests conducted in the 1950s and use equivalent single axle loads (ESALs) to represent the cumulative effects of axle loads on pavement. The mechanistic-empirical method incorporates mechanistic theory (i.e., knowledge about how a layered structure like pavement responds to applied loads) with empirical findings concerning pavement performance and uses axle load spectra (ALS) to represent variations of axle loads.

By convention, one ESAL is equivalent to the load effect of one 18,000-pound single axle with two sets of dual tires. Since not all vehicle axles exhibit these characteristics (i.e., axle weights can be lower or higher than 18,000 pounds and some axles are configured in groups), pavement designers convert expected axle loads into ESALs by applying appropriate load equivalency factors. These factors are selected as a function of:

- whether the wearing surface is flexible (bituminous) or rigid (Portland cement concrete);
- axle grouping (e.g., single, tandem, tridem);
- the minimum level of serviceability accepted before repairs are required (the terminal serviceability index);
- the structural number (SN), which varies by layer thickness and material properties; and
- axle load, which may vary by vehicle class.

The relationship between axle weights and ESALs is nonlinear. Specifically, it is commonly understood that doubling an axle load does not simply double the pavement damage, but rather increases pavement damage by a factor of 16. This is sometimes referred to as the “fourth power relationship.”

Despite the evolution toward mechanistic-empirical design approaches, the concept of ESALs is still commonly used to describe pavement design and performance, including in literature pertaining to the impact of transit bus axles on pavements. To aid in understanding, the literature commonly compares transit bus ESALs with passenger car ESALs. A passenger car weighing 4,000 pounds (approximately 2,000 pounds per axle) is equivalent to 0.0004 ESALs. Assuming an empty transit bus is 1.25 ESALs, a fully-loaded transit bus is 3.49 ESALs, and an overloaded transit bus is 5.55 ESALs, these buses would cause the equivalent amount of pavement damage as 3,100, 8,700, and 13,900 passenger cars, respectively (Raymond, 2004). Figure 12 extends this relationship (based on the fourth power relationship and assuming a passenger car ESAL of 0.0004) across a continuous spectrum of single axle weights. For example, this figure shows that nearly 15,000 passenger cars would cause the same pavement damage as a single, 28,000-pound axle.

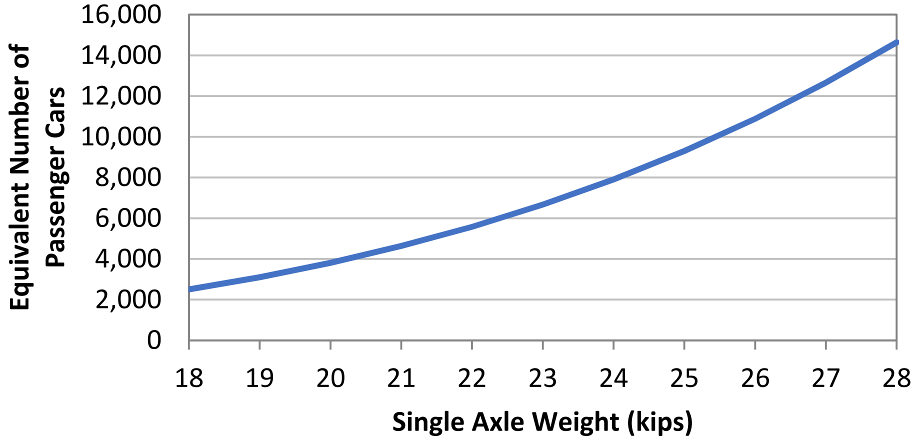


Figure 12: Relationship between passenger car ESALs and single axle weight

The primary traffic-related data inputs for the mechanistic-empirical pavement design method are ALS (as opposed to ESALs) and traffic volume by vehicle class. Pavement designers use these traffic loading inputs (and the other inputs described above such as climate factors) to estimate pavement stress-strain responses using mechanistic-based (i.e., theoretical) models. Empirical data collected using field observations and measurements are used to calibrate the models which can then relate the stress-strain responses to pavement performance and damage.

ALS are essentially axle load distributions by axle grouping (single, tandem, tridem) which are disaggregated temporally (e.g., by month) and by vehicle class. Buses (including transit buses and over-the-road buses) are one distinct vehicle class[1]. Bus ALS data may be sourced locally or from regional or national default tables. Pavement designers must often estimate appropriate urban bus ALS values (or use default values) since this data is usually unavailable locally. Given the lack of in-service transit bus weight data, these estimates and default data may not accurately reflect transit bus weights to use for pavement design.

Regardless of the design approach, selection of pavement materials and mixtures are critical design decisions because they have different responses to applied axle loads. For example, flexible pavements, such as asphalt concrete, exhibit relatively large deflections when subject

[1] Buses are considered class 4 in the Federal Highway Administration 13-vehicle classification scheme. Vehicles in classes 4 through 13 are considered for pavement design purposes. These vehicles include buses and all types of commercial trucks.

to heavy axles, but recover to their original state upon removing the load. Under repeated loading, flexible pavement may deteriorate, which can result in cracking or rutting. Rigid pavements, such as Portland cement concrete, are stiffer and exhibit smaller deflections compared to flexible pavements. Under repeated heavy axle loading, rigid pavements tend to fail due to fatigue. Fatigue damage increases exponentially with increasing load level (i.e., axle load) for both flexible and rigid pavements. Ultimately, the pavement designer aims to select those materials and mixtures that will best withstand local loading and environmental conditions.

5.1 Literature Review Findings

5.1.1 Transit Bus Pavement Impacts

Accurately determining the extent of pavement damage by vehicle type requires data that is currently not readily-available in most jurisdictions. Pavement damage estimates attributed to transit buses are often inconclusive and inaccurate. One study found that 2.4% of the total pavement maintenance cost in New Jersey is attributable to buses (Boile et al. 2004). Other studies have estimated that “heavy buses are responsible for 70 to 90 percent of the damage to the streets on the bus routes” (Battelle, 2007, p. 3). In a 2003 report, pavement deterioration attributable to transit buses was estimated to be $0.72 per mile of travel, resulting in approximately $1.6 billion in pavement damage that year (Federal Transit Administration, 2003). Although these studies are not comparing the same road networks and transit systems, their disparities exemplify the complexity of estimating pavement damage due to transit buses and suggests that more research about transit bus pavement impacts may be necessary.

Literature consistently reports that passenger loading conditions affect transit bus impacts on pavements as illustrated in Table 9 (Federal Transit Administration, 2003). A moderately loaded transit bus typically imposes between 1.5 and 2.0 ESALs on pavement, whereas a fully-loaded transit bus can have comparable ESALs to a fully-loaded tractor-semitrailer (i.e., four to five ESALs). Studies have also found that transit bus ESALs tend to marginally increase with speed (Kulakowski, Xiao, Yu, & Klinikowski, 2002) and on pavements with rougher pavement surfaces (Fekpe, 2006).

Table 9: Effect of Passenger Loads on Axle Weights and ESALs

Passenger Load	Axle Weight (lb)		Road Type	Total ESALs	Front Axle ESAL Contribution[1]	Rear Axle ESAL Contribution[1]
	Front Axle	Rear Axle				
13 passengers	10,303	19,647	Interstate	1.40	0.10	1.30
			Other	1.56	0.11	1.45
Fully-loaded	13,152	25,059	Interstate	4.08	0.29	3.79
			Other	4.50	0.32	4.18

Notes:
[1] Front/rear ESAL contributions are based on the 4th power rule (using the provided axle weights) and calibrated to match the provided total ESAL value

Source:
FTA (2003)

According to the FTA (2003), of the $1.65 billion in pavement damage costs attributed to transit buses:

- minor arterials and collectors accounted for 80% of these costs with 37% of the total transit bus vehicle-miles traveled (VMT),
- non-Interstate principal arterials accounted for 20% of these costs with 55% of the total transit VMT, and
- urban Interstate highways accounted for less than 1% of these costs with 9% of the total transit bus VMT.

Therefore, the pavement damage cost per transit bus VMT for minor arterials and collectors is approximately six times greater than for non-Interstate principal arterials and 26 times greater than for Interstate highways.

The different pavement damage costs associated with each road class is likely due to the difference in average pavement strengths of these facilities. Figure 13 shows the average strength of US pavements (in terms of structural number) disaggregated by roadway functional class, relative to the heavy/medium/light strength designations established by the Highway Economic Requirements System (HERS)[2]. Based on this classification scheme, Interstate highways on average have "heavy" pavements (SN≈5.3), other principal arterials on average have "medium" strength pavements (SN≈4.2), and minor arterials and collectors have

[2] HERS is an engineering and economic analysis tool designed to identify highway deficiencies and the most cost-effective system-wide improvement options.

"medium-light" strength pavements (SN≈3.3). Increasing minor arterial and collector street pavement strength (i.e., increasing the SN by increasing layer thicknesses and/or changing materials or mixture designs) could reduce the relatively high proportion of pavement damage costs attributable to transit buses on these functional classes.

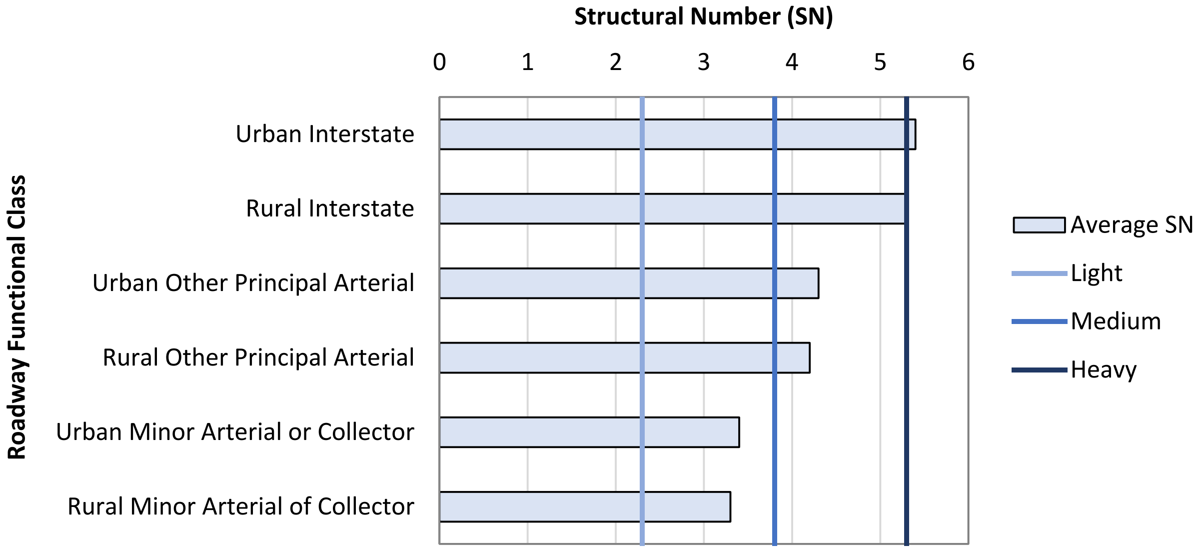


Figure 13: US roadway pavement strength by functional class (Federal Transit Administration, 2003)

Evaluating the incremental cost of increasing pavement strength on minor arterials and collectors versus the savings of reduced pavement maintenance and rehabilitation costs can be used to determine if increasing pavement strength is feasible from an economic perspective. However, from a public sector perspective, pavement costs are one of many costs to consider concerning transit service. Other costs include infrastructure lifecycle costs, transit bus operational costs, and various externalities such as environmental effects and safety. Minimizing one cost element may increase total costs. For example, higher passenger capacity transit buses may have lower operational costs per passenger but their higher operating weights could increase infrastructure costs (Federal Transit Administration, 2003).

5.1.2 Methods for Designing and Maintaining Pavements for Transit Buses

One way local and state departments of transportation can respond to transit bus weight increases is by altering their pavement design practices. Pavement designs are sensitive to estimates of transit bus volumes and axle loads due to the exponential relationship between axle weight and pavement damage. Since transit bus axle weights are not regularly or systematically measured, it can be difficult to select accurate axle weight estimates for pavement design. Most sources indicate that transit buses typically impose 1 to 2 ESALs, some jurisdictions use 6 ESALs (Alberta Transportation, 2013), and some data sources using weigh-in-motion (WIM) data find that FHWA class 4 vehicles (i.e., transit and over-the-road buses) typically impose 0.57 ESALs (Bell, 2014).

Researchers and departments of transportation have developed pavement design guides and best practices to help increase pavement life on bus exclusive facilities and other roadways that are expected to have high transit bus volumes. These guides and practices are continually being updated as ongoing research identifies methods and materials to further improve pavement performance. The following are some examples of pavement design approaches specifically applied to accommodate transit buses:

- **Increased design axle loads:** Although many states limit transit buses to 20,000 pounds per axle, the Riverside Transit Agency (2004) in California recommends designing pavements that are expected to experience transit bus traffic to withstand repetitive axle loads of at least 25,000 pounds. Increasing the design axle load could entail the use of thicker pavement layers and/or changes in material properties, mixture designs, and reinforcement (for rigid pavements).
- **Adequate design life:** The BRT Standard developed by the Institute for Transportation and Development Policy (2014) recommends a minimum 30-year design life for BRT facilities to prevent unnecessary delays due to maintenance and rehabilitation. A 30-year design life can be achieved with many different pavement types, including asphalt pavements with surface replacements every 10 to 12 years, jointed plain concrete pavement (JPCP), or continuously reinforced concrete pavement (CRCP).
- **Improved asphalt mix quality:** Using rut resistant asphalt mixes, such as "large stone binder course (LSBC), high stability surface course HL 1 (with PG 64-28), and stone mastic asphalt (SMA), show enhanced performance and favorable life-cycle costing" for urban asphalt concrete pavements subject to bus traffic (Burlie, Uzarowski, & Emery, 2000, p. 145).
- **Stiffer asphalt:** For roadways where transit buses are expected to frequently stop and start, flexible pavements using "Superpave performance graded asphalt cement (PGAC) that is two grades stiffer than that based on the design high temperature for the project location" (Burlie, Uzarowski, & Emery, 2000, p. 157) can mitigate pavement damage.

- **Strategic use of Portland cement concrete pavements:** Constructing 10- to 12-ft wide, 8-inch thick (minimum) reinforced Portland cement concrete pavement pads at locations where transit buses frequently stop, start, or perform turning maneuvers has been effective in reducing premature pavement failures that are common with asphalt (Riverside Transit Agency, 2004).

One transit agency in California examined the cost-effectiveness of three alternative pavement structures (each with 10-ft wide lanes) designed specifically for dedicated BRT routes (Monismith, Weissman, Popescu, & Santero, 2008). The three designs had the following characteristics:

- **Flexible pavement:** This design included four layers of asphalt (various binders) with a total thickness of 14 inches, a 6-inch aggregate sub-base, and compacted subgrade.
- **Composite pavement:** This design included a two inch asphalt surface layer, a 10-inch Portland cement concrete layer with dowels at transverse joints (the main structural element), a six-inch asphalt concrete base, a six-inch aggregate sub-base, and a compacted sub-grade.
- **Precast composite pavement system:** This system included a two-inch asphalt surface layer, two precast concrete beams in the wheel paths measuring 50 inches wide and 11 inches thick with two layers of asphalt concrete between the precast concrete beams, a six-inch asphalt concrete base, a six-inch aggregate sub-base, and subgrade.

The design vehicle was a 3-axle, 60-ft low-floor articulated bus and the design period was 50 years. The designers assumed a front axle weight of 15,600 pounds, middle axle weight of 26,500 pounds, and a rear axle weight of 15,600 pounds (gross vehicle weight of 57,000 pounds). The design also assumed nearly 175,000 repetitions of 15,600-pound axles and 87,000 repetitions of 26,500-pound axles over the 50-year period. Using these parameters, the total cost estimates for the composite and precast pavement systems were similar to each other, but approximately 40% higher than the flexible pavement system.

Methods to address transit bus axle loads during pavement rehabilitation are also available. One study found that unbonded Portland cement concrete overlays and conventional jointed plain concrete pavement (JPCP) inlays are effective rehabilitation treatments for urban roadways subject to frequent transit bus axle loads. The roadway in the study, located in Toronto, Canada, was originally paved with asphalt pavement and required maintenance every two to three years due to severe rutting. More than 10 years after being rehabilitated with JPCP the roadway has not required any maintenance, although some joint faulting has been observed. The researchers in this study expect that this pavement will reach or exceed the design service life of 25 years and recommend the use of dowel bars at transverse joints in future projects to mitigate potential joint faulting (Kivi, Tighe, Fung, & Grajek, 2013).

5.2 Survey Findings

This section summarizes the findings from state surveys. Fifty surveys were distributed to state transportation officials to identify pavement design, regulatory, and enforcement issues associated with transit buses exceeding axle weight limits and options to address these issues. Sixteen surveys were completed, but respondents did not always answer each question and some questions allowed respondents to provide more than one answer. Six interviews were conducted to obtain additional information or clarify survey responses. Findings from these interviews directly contributed to the development of the options presented in Chapter 6. Appendix A contains survey details.

Overall, state respondents seem unconcerned about transit bus axle weight issues. In particular, states operate weigh scales in locations with low transit bus traffic volumes and do not have responsibility for designing and maintaining the roads that experience the most transit bus traffic or managing a transit bus fleet. Therefore state surveys and interviews provided limited information concerning transit bus axle weight issues and options to address these issues.

Few respondents (5 out of 16 responses) had special transit bus weight limits on state roads; three of these had higher tandem axle weight limits and the same single axle weight limits as other commercial motor vehicles while the other two had higher single axle weight limits (up to 24,000 pounds) with 34,000-pound tandem axle weight limits. Interview responses revealed that states were uncertain about the rationale for current transit bus weight limits; however, all interviewees agreed that weight limit regulations were unlikely to change in the near future.

Most respondents (13 out of 16 responses) indicated that their state enforced transit bus weights using weigh scales (both portable and fixed) and occasional audits. However, interviewees indicated that they have limited or no transit bus weight data. One interviewee indicated their state allows transit buses to exceed Bridge Formula B weight limits subject to compliance with single axle weight and GAWR limits. Respondents indicated that virtual weigh stations (13 out of 16 responses) and on-board weight sensors (5 out of 16 responses) could better facilitate transit bus weight enforcement; however, none of the respondents have tested enforcement methods besides weigh scales and audits.

Most respondents (15 out of 16 responses) were either unsure if their state responded to pavement damage attributable to transit buses (11 out of 16 responses) or did not have a significant response to this damage (4 out of 16 responses). Interviewees indicated that transit bus axle weight has an insignificant impact on pavement design for most state highways, largely due to low transit bus volumes. The only respondent that addressed pavement damage attributed to transit buses did so by changing pavement materials. Interviewees generally indicated that operational costs for transit agencies are a more significant issue than pavement costs and increasing operating efficiencies (e.g., using larger buses or maximizing passenger capacity) would be more important than decreasing pavement damage from transit buses exceeding single axle weight limits. Two interviewees indicate their state uses Portland cement concrete pads at bus stops to mitigate transit bus pavement damage, particularly rutting. This state estimates additional state road construction costs of tens of thousands of dollars per lane-mile to accommodate repeated 24,000-pound single axle loads attributed to transit buses.

6 Options to Mitigate Negative Impacts of Transit Bus Axle Weights

This chapter presents options to address issues associated with transit buses exceeding prescribed axle weight limits. These issues may affect roadway infrastructure (principally pavement), transit systems and the communities they serve, transit bus manufacturers, and public transportation agencies.

The options have been developed with the goal of achieving at least one of two main outcomes. First, there are opportunities to mitigate pavement deterioration caused by transit buses if axle weights are lowered (e.g., through bus design or operational changes) or if pavements are designed to better withstand transit bus axle loads. These outcomes can occur without changing regulatory limits. Second, there are opportunities to revise weight regulations (e.g., by increasing limits or introducing exemptions) and the enforcement of these regulations to reduce the likelihood that transit bus axles will violate regulations. While these opportunities may help resolve regulatory issues, they may not mitigate pavement deterioration.

Whatever the outcome, however, addressing issues associated with transit buses exceeding prescribed axle weight limits requires tradeoffs. There is no single operational, design, technological or regulatory solution that resolves these issues without some undesirable consequence. This chapter describes each option and presents its associated advantages and risks for various stakeholders. These options pertain to in-service transit bus axle weight data, transit bus design, transit bus operations, pavement design and engineering, and regulations and enforcement.

6.1 Options Related to Transit Bus Axle Weight Data

Comprehensive understanding about the pavement impacts of transit buses exceeding weight limits is currently lacking. This is partially due to insufficient data to accurately quantify transit bus axle weights and their variation in space and time. This section provides three options to acquire better evidence of transit bus axle weight. Initially, these options may only be practical as part of a pilot program. Nevertheless, if applied, each option can help improve understanding about the weight distribution of transit buses in operation, the impacts of transit buses exceeding weight limits, and the implications of changing bus design, operations, and regulations or pavement design. Further, these options can inform pavement design at high transit bus volume locations and also support other activities, such as transit route planning and bus design. However, these options do not directly mitigate transit bus axle weight impacts or resolve competing regulations associated with transit bus weight.

6.1.1 Install Weigh-in-Motion (WIM) Devices at Selected Locations

Weigh-in-motion devices are routinely used on rural highways to measure the axle weights of vehicles travelling at highway speeds. Various technologies ranging in accuracy and costs (capital and operational) are available. Strategically installing WIM devices at urban locations with sufficient transit bus volumes and appropriate traffic conditions (e.g., free-flow speed and relatively long vehicle headways) could provide a continuous, reliable record of transit bus axle weight data at those locations.

Installing and operating WIM devices would require additional costs (e.g., ongoing maintenance and calibration) and would only provide data at specific locations (although this data could be used to infer weight distributions elsewhere). Further, vehicle classification algorithms used by WIM devices are not always able to reliably distinguish transit buses from other vehicles; this could be mitigated by installing WIM devices on exclusive bus facilities.

6.1.2 Combine Transit Schedules, Bus Inventory, Ridership, and GPS Data

Many transit agencies have data that could be used to estimate in-service transit bus axle weights. In combination, transit schedules, bus inventories, real-time ridership data, and GPS technologies could help determine the magnitude and variation of transit bus axle weight throughout the network. This option requires an ongoing resource commitment by the transit agency to store, process, and analyze the data. Transit agencies may incur additional costs to install GPS and passenger counting technologies on transit buses which would cause a marginal weight increase.

6.1.3 Install On-board Axle Weight Sensors

On-board axle weight sensors are an emerging technology for monitoring axle weights in the trucking industry and could be applicable for transit buses. These sensors provide a continuous measurement of axle weight which can be stored for further processing and analysis. This option requires an ongoing resource commitment by the transit agency to store, process, and analyze the data. Transit agencies may incur additional costs to install sensors on transit buses which would cause a marginal weight increase. Further, these sensors would require ongoing maintenance and calibration.

6.2 Options Related to Transit Bus Design

Altering transit bus design has the potential to both mitigate the impacts of transit buses on pavements and address regulatory issues. The options described in this section may achieve these goals by:

- Increasing steer axle weight capacity, thereby enabling weight to be shifted off the rear axle (which normally carries a higher proportion of the bus load);
- Adding a second axle to either the front or rear of the transit bus to reduce the load per axle;
- Using new generation wide-base tires to redistribute tire loads; or
- Reducing the curb weight of the bus through the use of lighter weight materials, application of innovative manufacturing processes, lowering the bus performance standards, or reducing auxiliary features on the bus.

Arguably, reducing transit bus curb weight is the single-most effective option for meaningfully mitigating the impacts of buses on pavements and addressing regulatory issues. An important tradeoff, however, is that bus manufacturers indicate that reducing transit bus curb weight by 2,000 to 3,000 pounds could cost an additional $30,000 to $40,000 per transit bus. Moreover, reducing the curb weight by several thousand pounds may not result in compliance with existing weight limits for some transit bus models.

While substantial efforts have been made to lower transit bus curb weights, the weight reductions achieved have been negated by service-related pressures to raise passenger capacity and add auxiliary features to the bus, and various regulatory requirements concerning minimum service life, accessibility, and emissions control.

6.2.1 Increase Steer Axle Weight Capacity

Steer axles have a lower gross axle weight limit compared to drive axles since they have two tires instead of four. Steer axle tire pressure requirements further limit the weight capacity. Designing and manufacturing a stronger steer axle and inflating tire pressure could increase its gross axle weight limit. This would allow rear bus components to be placed towards the front of the bus, redistributing weight from the drive axle to the steer axle.

Increasing steer axle weight capacity could improve drive axle compliance with axle weight limits. Distributing weight more equally between axles could also reduce the ESAL loading of a bus, and hence the pavement damage caused by the bus, without decreasing its gross vehicle weight. However, strengthening the steer axle could result in a higher curb weight and inflated tire pressures could increase pavement damage; both of these could offset the ESAL reduction benefits. There is also uncertainty about the feasibility of inflating steer axle tire pressure. Strengthening the steer axle could entail redesigning the steer axle and related components (a potential weight increase), relocating bus components, and redesigning bus components around the steer axle to be compatible with the space provided. These bus design changes would be costly and may be reflected in the procurement cost for transit agencies. Finally, a shift of weight towards the front of the bus may be detrimental to vehicle handling and cause increases in vehicle operational costs (e.g., higher tire and brake wear).

6.2.2 Provide Tandem Steer Axles

Tandem steer axles are uncommon, particularly on transit buses. Examples of vehicles with tandem steer axles are certain construction vehicles and some double-decker touring coaches in Japan. Tandem steer axle weight limits are higher than single axle weight limits and provide an opportunity to shift bus weight from the drive axle to the front axles.

Tandem steer axles have the potential to increase transit bus compliance with axle weight limits and potentially reduce pavement damage from these buses. Providing a tandem steer axle would raise the bus’ curb weight, complicate the front axle group which could increase maintenance costs, decrease fuel efficiency, reduce passenger capacity, and potentially diminish bus maneuverability. Tandem steer axles on transit buses have not been tested and could require significant costs to redesign and manufacture transit buses appropriately.

6.2.3 Provide Tandem Drive Axles

Commercial motor vehicles including over-the-road coaches commonly use tandem drive axles; however, they are rarely found on public transit buses except for some double-decker transit buses. The tandem drive axle on these buses typically comprises one axle with four tires (e.g., two sets of dual tires) and a second axle with two tires which can be lifted when additional weight capacity is not needed (e.g., when the transit bus is empty). This lift axle is commonly referred to as a tag axle.

The benefits and risks of tandem drive axles are similar to tandem steer axles. Tandem drive axles have the potential to increase transit bus compliance with axle weight limits and potentially reduce pavement damage from these buses. Providing a tandem drive axle would raise the bus' curb weight, complicate the rear axle group which could increase maintenance costs, decrease fuel efficiency, reduce passenger capacity, and potentially diminish bus maneuverability. Although the design and operation of tandem drive axles is common on other commercial motor vehicles, implementing them on transit buses could require significant costs to redesign and manufacture transit buses appropriately.

6.2.4 Use New Generation Wide-Base Tires

New generation wide-base (NGWB) tires could be used in place of the dual-tire single axle assembly common on most transit buses. Primary interest in the use of NGWB tires originated from the trucking industry to reduce fuel consumption and emissions. Compared to an axle equipped with dual tires, the use of two NGWB tires on the drive axle could provide a 200-pound weight saving. Tire manufacturers have conducted extensive research and testing concerning the safety, fuel consumption, durability, and pavement impacts of these tires, with somewhat disparate results concerning pavement deterioration. Nevertheless, technological advancements continue to occur that could make these tires a feasible option for transit buses.

The use of wide-base tires on the steer axle offers an opportunity to transfer weight to the front of the bus. However, there is insufficient research and experience to understand the impacts these tires might have on maneuverability and pavement damage in urban areas.

6.2.5 Manufacture Transit Buses with Alternative Materials

Alternative materials for transit bus design include alternative metals to steel and composite materials. Ultrahigh strength steel, aluminum, and magnesium are examples of alternative metals for manufacturing transit buses. Researchers and manufacturers have manufactured several prototype transit buses using alternative metals. These prototypes demonstrate the feasibility of this option and also reveal important risks to consider.

Transit buses manufactured with alternative metals can substantially reduce curb weights compared to a conventional steel transit bus, making these buses more likely to comply with axle weight limits. Alternative metals are significantly more expensive than conventional steel and often require changes in transit bus design and manufacturing methods. Due to prohibitively high costs, the production of most transit bus prototypes using alternative metals have been suspended. Further, certain alternative metals such as magnesium are highly susceptible to corrosion which can lead to higher maintenance costs and shorter bus life. Despite the current limitations, bus manufacturers indicate that aluminum may be a feasible option in the future.

Carbon fiber and fiberglass are examples of composite materials for manufacturing transit buses. Manufacturing transit bus components with composite materials can reduce axle weights by up to 3,000 pounds per axle compared to conventional steel. Although transit buses manufactured with composite materials are not yet commercially operated, manufacturers continue to explore options for making them commercially feasible. According to bus manufacturers, composite transit buses currently cost between $50,000 and $75,000 more than buses with steel and aluminum construction.

Composite materials are corrosion-resistant and stronger than steel. Transit buses manufactured with composite materials could reduce curb weight enough to lower gross vehicle weight below weight limits for certain bus models. Risks associated with composite materials include higher manufacturing costs and few composite transit bus manufacturers in North America. Composite transit bus costs are currently prohibitively high for commercial use. Further, composite materials tend to fail catastrophically and are typically non-recyclable which raises safety and environmental concerns, respectively. Despite the current limitations, bus manufacturers indicate that composites may be a feasible option in the future.

6.2.6 Apply Additive Manufacturing Methods

Additive manufacturing is a relatively new concept in the commercial manufacturing industry (although this technology has been around since the 1980s). This technology allows objects to be created in a series of layers using many different types of materials including plastics and metals. Additive manufacturing offers the ability to create mechanical and structural parts using innovative designs that traditional manufacturing methods cannot accomplish. These innovative designs often require substantially less material for construction while achieving the same, or better, performance characteristics. This technology is gaining momentum commercially and is already used in the aerospace industry.

Additive manufacturing is a feasible option for designing and manufacturing transit buses more efficiently. This technology can decrease transit bus weight through manufacturing lighter parts and consolidating complex parts with many individual components connected with fasteners into a solid part. Experience using additive manufacturing in other industries indicates that it could decrease transit bus curb weight enough for most buses to operate below axle weight limits. This option would require bus manufacturers to significantly change their operations and would likely require manufacturing prototypes for testing and research prior to commercial application. Appropriate design, testing, and implementation of such prototypes would be costly and time consuming.

6.2.7 Provide Lower Performance Transit Bus Components

Transit buses are designed to meeting certain performance specifications (e.g., regarding speed, acceleration capability) to enable operation in many different conditions. Sometimes transit buses have unnecessarily high performing components. For example, some transit buses do not require a large engine or high capacity fuel tank. Gearing transit bus transmissions for lower speeds is one way to better match engine and fuel tank size with performance requirements. This option would encourage transit agencies to procure transit buses with smaller mechanical components that more appropriately correspond to their operating environment.

Designing transit buses with lower performance components could contribute to decreases in curb weight. Consequently, the weight of the bus structure required to support lighter mechanical components could also be decreased, provided that it would still be sufficient to meet bus lifespan and utilization expectations. Implementing this option in isolation would be unlikely to reduce weights below the weight limit. This option may be infeasible in areas with variable topography (e.g., high performance components may be required to traverse steep grades) and difficult to implement from a logistical perspective (e.g., transit agencies may be required to operate a mixed fleet of low and high performance buses and match these buses to appropriate routes). There is a risk that these design changes could increase transit bus capital costs and that lower performance transit buses may have inferior acceleration and braking abilities that could lead to difficulties maintaining a schedule and meeting market demand. Current EPA regulations are an obstacle for changing engine performance; transit bus manufacturers are required to use a single engine type certified by EPA. This requirement would need to be modified before smaller engines could be used on transit buses.

6.2.8 Reduce Auxiliary Features on Transit Buses

Transit bus auxiliary features are usually included to improve passenger comfort, convenience, and safety. Examples include rear and side cameras, vehicle detection units, electronic destination signage, narrative stop displays, HVAC systems, exterior bike racks, security cameras, and passenger counters. Some transit agencies are installing electronic displays on buses for advertising. Transit agencies sometimes provide auxiliary features to increase ridership, improve safety, and generate additional revenue. Many individual features are lightweight and the incremental weight increases from multiple features often only marginally increases overall bus weight. Further, curb weights measured at Altoona typically do not include auxiliary features. Therefore, this option will not help transit buses reduce their curb weight but can help control curb weight increases for operational transit buses. Currently most on-board technologies require their own operating system and hardware. Providing a centralized computer system to operate all electronics is an option to reduce weight from auxiliary features.

Removing auxiliary features can contribute to lower transit bus weight; however, implementing this option in isolation would unlikely reduce weights below the weight limit. Fewer auxiliary components would also reduce capital, operating, and maintenance costs. As a service provider, transit agencies are compelled to meet rising passenger expectations. Increasing ridership and generating additional revenue through advertising are also important issues for transit agencies and which are supported in part by providing auxiliary features. This option provides limited effectiveness concerning weight reduction.

6.3 Options Related to Transit Bus Operations

This section outlines operational options that can reduce transit bus axle weights or mitigate pavement impacts produced by transit buses that exceed weight limits. Transit bus operations can be modified to decrease bus weights without changing routing, maintain current bus weights with route restrictions, or select bus types based on route characteristics. Although these options may help address regulatory issues, they typically do so by decreasing operational efficiency and increasing transit agency costs. Their ability to mitigate system-wide pavement deterioration is uncertain.

6.3.1 Operate More Low Capacity Buses

Low capacity transit buses, defined as 2-axle 35-ft buses in this report, typically comply with axle weight limits, even when fully loaded. Therefore, replacing 2-axle 40-ft transit buses with 2-axle 35-ft transit buses may resolve regulatory concerns associated with bus weights. This may require additional transit buses to meet demand which could potentially improve transit service by reducing bus headways but also increase transit agency costs (e.g., higher capital costs to purchase more buses and higher operating and maintenance costs). Operating more buses requires additional drivers, increases the potential for transit buses to be fully loaded before servicing all stops along a route, increases transit bus emissions, negatively impacts traffic flow and congestion, and also increases the transit bus ESAL per passenger.

6.3.2 Restrict the Number of Passengers on Existing Transit Buses

Reducing the maximum number of passengers allowed on a transit bus will reduce bus axle weights and may partially or completely resolve regulatory issues (depending on the maximum number of passengers and the bus model). The maximum number of passengers could be pre-determined by assuming an average weight per passenger and calculating the number of passengers that would result in the transit bus operating at the weight limit. This approach would require automatic passenger count technologies or the use of on-board axle weight sensors to inform the driver when the maximum was reached.

This option could increase transit agency costs due to additional equipment costs or requiring additional transit buses to compensate for decreased service, increase the potential for transit buses to be fully loaded before servicing all stops along a route, create transit user dissatisfaction for those denied entry to a bus with capacity for additional passengers, increase the transit bus ESAL per passenger, and underutilize the manufacturer's rated passenger capacity. The success of this option requires bus drivers to comply with the passenger loading restriction.

6.3.3 Increase Bus Frequency During Peak Periods

Most transit buses reach passenger capacity during peak times or special events. During these times bus drivers tend to accept new passengers until the physical capacity has been reached. Most transit buses exceed axle weight limits under these loading conditions. Increasing transit bus frequency during these times can reduce the probability of transit buses being fully-loaded or overloaded. This option could increase transit agency costs (e.g., higher capital costs for additional buses to meet frequency demands and corresponding increases in operating and maintenance costs), require additional bus drivers, result in similar pavement impacts as operating fewer and heavier transit buses, and increase the transit bus ESAL per passenger. This option also does not guarantee that transit buses will not be fully-loaded or overloaded since transit users tend to board the first bus available regardless of how many passengers are on board.

6.3.4 Restrict Transit Buses from Certain Routes

Weaker pavements, such as those on local, collector, and certain minor arterial roads, are more susceptible to damage from transit buses exceeding weight limits than pavements used on higher class roadways such as Interstate highways and major arterials. Therefore pavement damage from transit buses exceeding weight limits can be mitigated by restricting them to roads designed to better withstand their axle weights. Some cities already follow a similar practice by restricting transit buses on certain roadway functional classes; however, these restrictions are typically established to help transit buses avoid streets with insufficient lane widths and small turning radii. This option may divert transit buses away from routes that warrant transit service, is unlikely to mitigate pavement damage on all transit routes, and may be difficult to implement since roads with the same roadway classification may be designed with different standards. This option partially resolves regulatory issues, particularly on those routes where restrictions would apply.

6.3.5 Match Transit Bus Models to Passenger Demand

Transit agencies already analyze passenger demand to identify bus routes, select appropriately sized buses, and determine service frequency. These decisions are usually made to maintain a desired level of service and often do not explicitly consider pavement damage. The versatility of medium-capacity transit buses, such as 2-axle 40-ft models, to serve various passenger demands and operate on most urban roadways can significantly decrease logistical challenges. However, fully-loaded 2-axle 40-ft transit buses exceed weight limits and generally cause more pavement damage than fully-loaded 35-ft and 60-ft models.

This option encourages transit agencies to add another dimension to their decision process that considers various bus models to minimize ESALs per passenger. Overall this option aims to replace 2-axle 40-ft transit buses with 2-axle 35-ft and 3-axle 60-ft articulated transit buses. Since 2-axle 40-ft transit buses comprise the majority of the transit fleet, this option would likely require significant investment or time to implement. It also introduces additional logistical difficulties and fleet management challenges to ensure adequate supply of appropriately sized transit buses at all times. This option may partially address regulatory issues and helps mitigate the pavement impact of these buses.

Fully-loaded high capacity transit buses, defined as 3-axle 60-ft articulated buses, have similar axle weights as 2-axle 40-ft transit buses and exceed single axle weight limits. However, from a systems perspective, replacing 2-axle 40-ft transit buses with high capacity transit buses can reduce overall pavement impacts since fewer high capacity buses may be required. This effectively lowers transit bus ESALs per passenger. This option could increase capital costs since high capacity transit buses are more expensive than 2-axle 40-ft transit buses (although fewer buses may be required). Transit agencies may find that high capacity transit buses are infeasible to efficiently operate in their system, particularly in small cities or on low demand routes. Additionally, this option's effectiveness requires a significant number of high capacity transit buses to replace 40-ft transit buses.

High capacity transit buses are usually inappropriate for low demand routes or operations on lower class roadways. In these situations there may be opportunities to operate 2-axle 35-ft transit buses instead of 2-axle 40-ft transit buses. Transit buses on these routes are rarely fully-loaded and could be serviced by 2-axle 35-ft transit buses operating at the same frequency as 2-axle 40-ft transit buses.

6.4 Options Related to Pavement Design and Engineering

This section outlines two pavement design and engineering options that could mitigate transit bus pavement impacts. Neither of these options would address current regulatory issues.

6.4.1 Design and Implement Pavements to Better Withstand Transit Bus Axle Loads

Designing and implementing pavements that better withstand transit axle loads is a direct way of mitigating pavement deterioration caused by transit buses. Many approaches may be applied to achieve this, including:

- increasing layer thicknesses (including the thickness of underlying supporting layers);
- changing the types and quality of materials used;
- adjusting mixture designs;

- enhancing reinforcement (for rigid pavements); and
- improving construction methods and maintenance scheduling.

Of these approaches, changes to materials and mixture designs may be the most feasible. Systematic implementation of this option may require revisions to existing pavement design and construction specifications applied to the urban network (and particularly to transit routes) and the development of programs to collect pavement condition data and better manage pavement assets.

Naturally, implementing pavement design and engineering changes system-wide is costly, and in certain cases may not be warranted. A more strategic and cost-effective approach involves implementation of pavements specifically designed to withstand transit bus axle loads at targeted locations where transit buses frequently stop, start, or turn—maneuvers that tend to accelerate pavement deterioration. For example, implementing more Portland cement concrete pads at bus stops may mitigate pavement deterioration caused by buses at these locations, minimize costs associated with frequent maintenance and associated delays, and avoid costs of unnecessarily upgrading pavements at other locations.

6.4.2 Adjust Pavement Design Loads to More Accurately Reflect Transit Bus Axle Weights

Designing pavements to accommodate loads induced by transit bus axles requires more accurate and comprehensive data about in-service transit bus axle weights. This requirement becomes particularly apparent as pavement design practices evolve to integrate a more mechanistic understanding of the relationship between axle loads and pavement deterioration over time. Given this evolution, there will be an increasing need to estimate and forecast the distribution of transit bus axle loads as part of the pavement design process. Better representation of these loads helps reduce the risk of over- or under-designing pavements, but requires investment in data collection and analysis.

6.5 Options Related to Transit Bus Weight Regulations and Enforcement

The regulations governing transit bus axle weight are complex and dynamic, and generally have not been subject to rigorous on-road enforcement practices. Without effective enforcement, the objectives of regulating axle weights—including the objective of preserving infrastructure—

are undermined. Because of this relationship, this section includes options pertaining to both the weight regulations themselves and the enforcement of these regulations. Some of these options have the potential to both mitigate negative impacts of transit buses on infrastructure and address current regulatory issues.

6.5.1 Maintain Current Regulations (*Status Quo*)

Maintaining current regulations does not mitigate negative impacts of transit buses or address the competition among regulations. Arguably, this option also perpetuates the current confusing regulatory environment within which transit buses operate. However, as no regulatory or administrative changes would be required, no incremental costs associated with such changes would be incurred.

6.5.2 Decrease Axle Weight Limits to Match Limits for Other CMVs

Current federal and certain state regulations allow transit bus axle weights in excess of limits applicable to other CMVs. Given this situation, an option to help mitigate negative infrastructure impacts is to decrease axle weight limits for transit buses so that they match limits in place for other CMVs—provided that transit buses are able to comply with the limits. This decrease could occur either by lowering the weight limit directly or removing current axle weight exemptions. Current trends in bus manufacturing indicate that compliance with reduced weight limits would currently be impractical, though this option could promote further research and development activities regarding lightweight materials for bus manufacturing and alternative manufacturing processes. Implementing these alternatives imposes costs for manufacturers. For transit bus operators, operational costs would increase if compliance with axle weight limits were rigorously enforced. Without enforcement, compliance within such a regulatory environment would likely decrease. A potential variation of this option involves applying reduced axle weight limits only to routes that are most susceptible to pavement deterioration (e.g., routes with pavements that are less able to withstand transit bus axle weights).

6.5.3 Increase or Eliminate Axle Weight Limits

Increasing or eliminating axle weight limits has the potential to improve transit bus axle weight compliance, thus addressing competing regulations at least for certain bus models. However, relative to the current situation, increasing or eliminating axle weight limits could incrementally increase pavement deterioration and reduce incentives for bus manufacturers to pursue research and development activities concerning lightweight materials and alternative manufacturing techniques to reduce transit bus curb weights. Additionally, other industries subject to weight regulations may raise concerns about special allowances extended to the transit industry. A potential variation of this option involves applying an increased axle weight limit or exemption on routes most capable of withstanding higher axle loads.

Axle weight limit increases or exemptions might also be considered as a way of incentivizing the application of other beneficial features. For example, some states currently allow increases to the GVW limit for vehicles equipped with idle reduction technologies, though these allowances do not always translate into axle weight increases thus limiting the ability for operators to take full advantage of the allowance. Nevertheless, this type of option could also be used for technologies or features other than idle reduction technologies, such as buses that use alternative fuels or advanced safety features.

6.5.4 Require Annual Permits

Accommodating vehicles that exceed prescribed axle weight limits is commonplace in the trucking industry, particularly when trucks carry indivisible loads. There is potential to implement a similar permit system for transit buses in situations where they are expected to routinely exceed axle weight limits. In most circumstances, a permit is issued because accommodating a particular movement is deemed desirable despite the fact that it cannot be made in compliance with the normal weight limits and may cause infrastructure deterioration.

Operating a transit bus or a fleet of transit buses under permit would not mitigate pavement deterioration, but could address the regulatory issues through essentially administrative processes. That is, a transit bus could exceed normal axle load limits but would do so legally if operated in compliance with the permit conditions. Administratively, issuing an annual permit to a transit bus fleet may be more efficient than issuing trip-based permits, and would be easier to implement and amend than a regulatory change. Conceptually, the permitting approach differs from exemptions (as some jurisdictions currently use) because permits provide the possibility of transparently stipulating specific operating conditions (e.g., the spatial and temporal scope of operations that can be made pursuant to the permit) and potentially recovering costs through permit fees if deemed necessary and appropriate.

6.5.5 Improve Enforcement Practices

Improved enforcement of transit axle weight limits—whether these limits are specified through basic regulations, exemptions, or permits—could mitigate the incrementally negative infrastructure impacts of axle loads that exceed prescribed limits. Without an expectation of compliance and the ability to deter axle weight limit violations through effective enforcement, there is no purpose in setting such limits. Increasing the number of times transit buses are checked for weight compliance while in-service may deter non-compliant operations, particularly if these checks occur randomly in time and space. However, these stops would impose operational delays and costs.

Alternatively, there may be opportunities to utilize enforcement technologies such as WIM sensors, cameras, and communication systems to remotely monitor transit bus axle weights without requiring the bus to stop. These types of systems, referred to as virtual weigh stations, are increasingly deployed by highway agencies to help enforce truck axle weights.

Another approach that could be considered involves placing the onus of weight compliance on the transit operating authority and requiring the authority to implement technologies and systems that enable continual demonstration of axle weight compliance. Such systems could be subject to occasional audits.

If more effective enforcement of transit bus axle weight is envisaged, it is not readily-apparent what an appropriate sanction for non-compliance might entail. Since transit operations are primarily overseen by public sector agencies, a punitive fee for exceeding axle weight limits may be inappropriate as it will only result in the exchange of funds from one public agency to another.

6.6 Summary of Options

Table 10 summarizes options to address issues associated with transit buses exceeding axle weight limits, along with key outcomes and tradeoffs associated with each option. The options involved transit bus weight data, transit bus design, transit bus operations, pavement design and engineering, and transit weight regulations and enforcement practices.

Table 10: Summary of Options to Address Transit Bus Weight Issues

Options by Category	Key Outcomes and Tradeoffs
Category 1: Options Related to Transit Bus Weight Data	
1. Install weigh-in-motion devices at selected locations	• Does not directly mitigate pavement impacts • Does not address regulatory issues • Additional operational costs • Requires appropriate analysis capability
2. Combine transit schedules, bus inventory, ridership, and GPS data	• Does not directly mitigate pavement impacts • Does not address regulatory issues • Additional operational costs • Requires appropriate analysis capability • On-board equipment adds weight
3. Install on-board weight sensors	• Does not directly mitigate pavement impacts • Does not address regulatory issues • Additional operational costs • Requires appropriate analysis capability • On-board equipment adds weight
Category 2: Options Related to Transit Bus Design	
1. Increase steer axle weight capacity	• Mitigates pavement deterioration • Addresses regulatory issues • May increase curb weight • Increases manufacturing and procurement costs • Worsens vehicle handling
2. Provide tandem steer axles	• Mitigates pavement deterioration • Addresses regulatory issues • Increases curb weight • Increases manufacturing and procurement costs • Increases maintenance costs • Decreases fuel efficiency • Reduces passenger capacity • May diminish bus maneuverability
3. Provide tandem drive axles	• Mitigates pavement deterioration • Addresses regulatory issues • Increases curb weight • Increases manufacturing and procurement costs • Increases maintenance costs • Decreases fuel efficiency • Reduces passenger capacity • May diminish bus maneuverability
4. Use wide-base single tires	• Mitigation of pavement deterioration uncertain • May address regulatory issues • Decreases curb weight • Increases fuel efficiency
5. Manufacture transit buses with	• Mitigates pavement deterioration

Options by Category	Key Outcomes and Tradeoffs
alternative materials	• Addresses regulatory issues • Decreases curb weight • Increases manufacturing and procurement costs • Increases maintenance costs
6. Apply additive manufacturing methods	• Mitigates pavement deterioration • Addresses regulatory issues • Decreases curb weight • Increases manufacturing and procurement costs
7. Provide lower performance transit bus components	• Mitigates pavement deterioration • Addresses regulatory issues • Decreases curb weight • Imposes logistical challenges • Increases manufacturing and procurement costs
8. Reduce auxiliary features on transit buses	• Mitigates pavement deterioration • Addresses regulatory issues • Decreases operating weight • Degrades service provision
Category 3: Options related to transit bus operations	
1. Operate more low capacity buses	• Mitigation of pavement deterioration uncertain • May address regulatory issues • May necessitate more buses and drivers to meet demand • May degrade service provision • Increases transit bus emissions • Increases transit agency costs • Increases transit bus pavement impact per passenger
2. Restrict the number of passengers on existing transit buses	• Mitigation of pavement deterioration uncertain • May address regulatory issues • May necessitate more buses and drivers to meet demand • May degrade service provision • Increases transit agency costs • Increases transit bus pavement impact per passenger
3. Increase bus frequency during peak periods	• Mitigation of pavement deterioration uncertain • May address regulatory issues • May necessitate more buses and drivers to meet demand • May degrade service provision • Increases transit agency costs • Increases transit bus pavement impact per passenger
4. Restrict transit buses from certain routes	• Mitigates pavement deterioration on certain routes • May address regulatory issues • May degrade service provision
5. Match transit bus models to passenger demand	• Mitigates pavement deterioration • May addresses regulatory issues • Introduces logistical and management challenges

Options by Category	Key Outcomes and Tradeoffs
	• Increases transit agency costs
Category 4: Options related to pavement design and engineering	
1. Design and implement pavements to better withstand transit bus axle loads	• Mitigates pavement deterioration • Does not address regulatory issues • Requires revisions to design and construction specifications • Requires development of programs to monitor and manage pavement assets • Increases pavement construction and maintenance costs
2. Adjust pavement design loads to more accurately reflect transit bus axle weights	• Mitigates pavement deterioration • Does not address regulatory issues • Requires appropriate data collection and analysis capability
Category 5: Options related to transit bus weight regulations and enforcement	
1. Maintain current regulatory environment (*status quo*)	• Does not mitigate pavement impacts • Perpetuates current regulatory environment • No incremental costs
2. Decrease axle weight limits to match limits for other CMVs	• Mitigates pavement deterioration • Does not address regulatory issues • Increases operating costs • Decreases compliance without rigorous enforcement
3. Increase or eliminate axle weight	• Does not mitigate pavement deterioration • Addresses regulatory issues • Reduces incentives to pursue manufacturing alternatives that decrease curb weight • Raises concerns about special allowances for transit industry
4. Require annual permits	• Does not mitigate pavement deterioration • Addresses regulatory issues • Increases administrative costs
5. Improve enforcement practices	• Mitigates pavement deterioration • Does not address underlying cause of regulatory issues • May increase operational delays and costs • Additional equipment operational costs

7 Summary and Conclusions

Clarifying issues concerning transit bus axle weight necessitates a systems approach. While this is well-recognized, the numerous inter-relationships between various types of impacts and the entities being impacted remain complex and difficult to fully understand. Hence, any option to address the issues has tradeoffs, and the course of action is not readily-apparent.

To help clarify the issues, this research reviewed findings from literature and other documentation published over the past decade and gathered current knowledge from relevant stakeholders regarding:

1) Relevant national and state laws and regulations pertaining to transit bus weight (see Chapter 2),
2) The weight of transit buses while in service (see Chapters 3 and 4),
3) The impacts of transit buses on pavement (see Chapter 5), and
4) Options to mitigate negative impacts on pavement, transit systems, and communities (see Chapter 6).

Perhaps owing to the systems nature of this topic, the literature review drew from traditional (e.g., academic research) and non-traditional sources (e.g., policies, industry websites). The review revealed relatively few comprehensive documents on this subject. Similarly, it was uncommon for stakeholders to be knowledgeable on the wide range of issues relevant to the topic—particularly stakeholders from municipal and state departments of transportation). Therefore, there were numerous instances where stakeholders did not provide responses to survey and interview questions. This underscores the value and need for research on this topic.

Both federal and state regulations limit axle weights for transit buses (and other commercial motor vehicles) to help protect highway infrastructure, among other objectives. In 1974, federal weight limits for single and tandem axles for all commercial motor vehicles, including transit buses, were set at 20,000 and 34,000 pounds, respectively.

In addition to weight limits, transit buses, are affected by federal and state policies, programs, and regulations concerning energy use, emissions, passenger accessibility, and vehicle testing standards, all of which have resulted in design modifications that alter the curb weight of transit buses. Specifically, environmental and accessibility regulations have been enacted that require additional transit bus components (such as lower polluting fuel systems and wheelchair lifts) without corresponding transit bus weight limit increases. Additionally, federal stipulations mandating a minimum 12-year service life necessitates the use of certain heavy-duty transit bus components.

Consequently, it has become increasingly difficult for in-service transit buses to comply with federal and state axle weight regulations. In response, federal law exempted transit buses from prescribed axle weight limits in the early 1990s, and these exemptions were extended indefinitely with the Moving Ahead for Progress in the 21st Century (MAP-21) transportation reauthorization bill in 2012. Additionally, 14 states have enacted limits specifically for transit buses to address this issue.

The physical and operational characteristics of transit buses impact the weight of transit bus axles and the magnitude of pavement deterioration they cause. While a variety of bus configurations exist, currently, transit systems in the United States consist predominantly of the following types of buses:

- **Two-axle 40-ft buses** comprise approximately two-thirds of the transit bus fleet in the United States. The curb weights for these transit buses currently range between approximately 20,000 and 33,000 pounds, and fully-loaded weights range from approximately 30,000 to 44,000 pounds. As such, passengers comprise roughly one-third of the GVW of a fully-loaded 40-ft transit bus.
- **Three-axle 60-ft** articulated buses are the next most common transit bus in service, comprising about 10% of the fleet. The curb weights for these buses currently range between approximately 38,000 and 50,000 pounds, and fully-loaded weights range from approximately 56,000 to 65,000 pounds.

Based on available transit bus test data, fewer than half of all transit bus models comply with a 20,000 pound single axle weight limit when empty (i.e., at curb weight) and nearly all rear axles on transit buses longer than 35 feet exceed 24,000 pounds.

The transit bus manufacturing industry has undertaken significant research and development activities directed at decreasing the curb weight of transit buses. Future opportunities to reduce transit bus curb weight include the use of lighter weight materials and alternative manufacturing techniques, but any weight reductions are expected to be costly for the manufacturing industry. Alternative axle arrangements (such as adding a tag axle) may reduce the pavement deterioration caused by transit buses by redistributing the weight of the bus in a more favorable manner.

Simultaneous with efforts to reduce bus weights, some transit operators have seen increasing passenger loading and demand for better on-board service amenities (such as air conditioning, bike racks, information systems, and surveillance equipment). These developments increase the curb and operating weight of transit buses—sometimes beyond axle weight limits—and offset weight reduction efforts.

Transit buses that operate above legal weight limits may pose problems associated with pavement design and road maintenance. These problems are particularly relevant for low functional road classes (e.g., collectors, local streets), which are less able to withstand transit bus axle loads than high functional road classes (e.g., Interstate highways, major arterials).

All axle loads contribute to pavement deterioration. However, the literature review revealed sparse and disparate results on the proportion of pavement deterioration and maintenance expenditures attributable to transit buses. Ultimately, deterioration depends on the number of transit buses operating on a route, the intensity of axle loads of those buses (which varies spatially and temporally), the structure of pavement on the route, and numerous environmental factors. While there is evidence from information about the physical characteristics of transit buses that certain buses exceed axle weight limits (indeed, certain bus models exceed these limits without any passengers on board) and mostly anecdotal indications of the concomitant impacts on pavement, there is relatively little empirical substantiation of these impacts. A lack of in-service transit bus weight data precludes definitive quantification of the impacts transit buses have on pavements, and also poses future challenges in appropriately accommodating them in pavement design practices.

Despite a lack of recorded empirical evidence, experience in some jurisdictions has led to the use of higher quality pavement materials and adjustments to mixture designs to improve the ability of pavements to withstand transit axle loads. These strategies are most commonly implemented on transit routes, transit facilities, and locations expected to experience aggressive wear from transit buses (e.g., bus stops).

The twenty-three options presented in this report were developed with the goal of achieving at least one of two main outcomes: mitigating pavement deterioration caused by transit buses or addressing regulatory issues concerning transit bus axle weight. Whatever the outcome, however, addressing issues associated with transit buses exceeding prescribed axle weight limits requires tradeoffs. There is no single operational, design, technological or regulatory solution that resolves these issues without some undesirable consequence.

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APPENDIX A – SURVEY RESULTS SUMMARY

This study distributed surveys to state government representatives and city and county government representatives. This appendix provides the survey questions, responses, and lists survey respondents.

8.1 State Surveys

Online surveys were distributed to all 50 states. Table 11 lists the agencies of the 16 respondents.

Table 11: State survey respondents

Agency	
North Carolina State Highway Patrol	Florida DOT, Motor Carrier Size and Weight
Ohio State Highway Patrol	Massachusetts State Police
Wisconsin Department of Transportation Div of State Patrol	Vermont Department of Motor Vehicles
North Carolina State Highway Patrol	Colorado DOT
Texas Department of Public Safety	Arkansas Highway Police
Montana Motor Carrier Services	Tennessee Highway Patrol
Michigan State Police CVED	Nebraska State Patrol
Indiana State Police	New Jersey State Police

The survey consisted of 12 questions as follows:

1. In case we need to follow up with you once you have completed the survey, would you please provide your name, title, agency, email address, and phone number?

Name: ______________________________

Title: ______________________________

Agency: ______________________________

Email Address: ______________________________

Phone Number: ______________________________

2. Does your state specify axle weight limits for transit buses operating on state roads differently from those limits specified by federal requirements?

○ Yes
○ No
○ Don't know

3. If you answered "yes" to Question 2, please provide the axle weight limits in pounds for the following axles:

Steering axle: ______________________________

Single axle: ______________________________

Tandem axle group: ______________________________

4. Are there any exemptions in place in your state for transit buses that exceed specified vehicle axle weight limits?

- ○ Yes
- ○ No
- ○ Don't know

If so, please briefly describe: ________________________

5. How are transit bus axle weight limits enforced in your state? (Select all that apply)

- ○ Transit buses are weighed at fixed weigh stations
- ○ Transit buses are weighed using portable weigh scales
- ○ Transit agencies are subject to occasional weight enforcement audits
- ○ Transit bus axle weights are not enforced
- ○ Don't know
- ○ Other (please specify)

6. What types of enforcement technologies could facilitate enforcement of transit bus axle weights in your state? (Select all that apply)

- ○ On-board axle weight sensors
- ○ Virtual weigh stations (i.e., integrating weigh-in-motion devices, image capture, communications technologies)
- ○ Don't know
- ○ Other (please specify)

7. Have any of the following alternatives to traditional on-road enforcement approaches been considered to enforce transit bus axle weights in your state? (Select all that apply)

- ○ Compliance accreditation program with occasional audits
- ○ Special sanctions for transit bus weight violations
- ○ Weight compliance audits based on ridership data
- ○ No alternative approaches have been considered
- ○ Don't know
- ○ Other (please specify)

8. Has your state ever conducted analyses to address pavement deterioration that may be attributable to transit buses?

- ○ Yes
- ○ No
- ○ Don't know

If so, please briefly describe: ______________________________

9. In your experience, which types of transit buses may impact pavement in your state? (Select all that apply)

- ○ 2-axle 35- to 45-foot buses
- ○ 3-axle 60-foot articulated buses
- ○ 3-axle 45-foot buses
- ○ 3-axle 45-foot double-deck buses
- ○ Don't know

10. How has your state responded to pavement deterioration that may be attributable to transit buses in your state? (Select all that apply)

- ○ Changed pavement design practices
- ○ Changed pavement materials used
- ○ Changed methods of pavement construction
- ○ Changed pavement maintenance practices
- ○ Changed transit bus design specifications (e.g., require tandem rear axles)
- ○ Changed transit bus operations (e.g., altered routing, assigned transit buses to certain routes, limited the number of passengers per transit bus, etc.)
- ○ Changed transit bus size and weight regulations
- ○ No significant response
- ○ Don't know
- ○ Other (please describe)

11. Is there an individual within your organization knowledgeable about the impact of transit bus axle weights on pavement design and maintenance?

- ○ Yes
- ○ No
- ○ Don't know

12. If yes, please provide name and contact information.

Name: ____________________________________

Company: ____________________________________

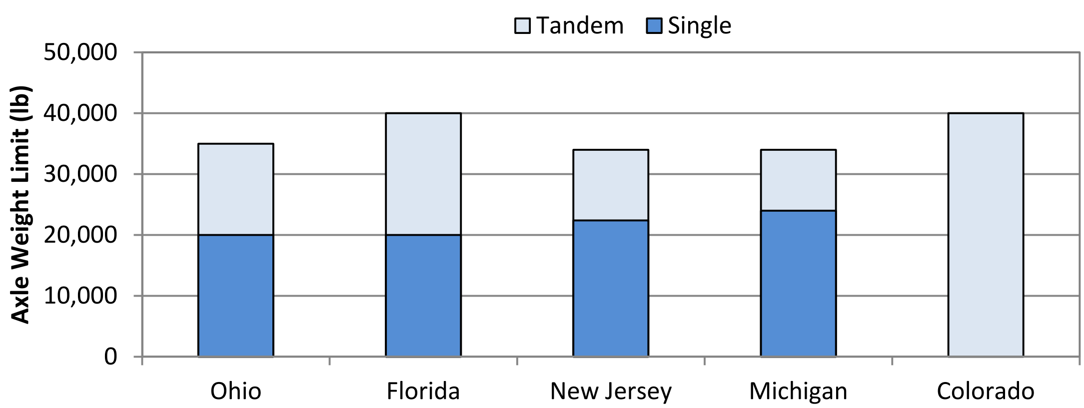
Email Address: ____________________________________

Phone Number: ____________________________________

The following summarizes the technical survey responses; therefore not all 12 questions are shown. For certain questions respondents were allowed to select more than one answer. Consequently, some response counts will exceed the total number of respondents (i.e., 16).

2. Does your state specify axle weight limits for transit buses operating on state roads differently from those limits specified by federal requirements?	Response Percent	Response Count
Yes	31%	5
No	69%	11
Don't know	0%	0
Answered question		16
Skipped question		0

3. If you answered "yes" to Question 2, please provide the axle weight limits in pounds for steering, single, and tandem axle groups.



4. Are there any exemptions in place in your state for transit buses that exceed specified vehicle axle weight limits?	Response Percent	Response Count
Yes	19%	3
No	81%	13
Don't know	0%	0
Answered question		16
Skipped question		0

5. How are transit bus axle weight limits enforced in your state?

	Response Percent	Response Count
Transit buses are weighed at fixed weigh stations	14%	3
Transit buses are weighed using portable weigh scales	43%	9
Transit agencies are subject to occasional weight enforcement audits	5%	1
Transit bus axle weights are not enforced	29%	6
Don't know	0%	0
Other (please specify)	10%	2
Answered question		16
Skipped question		0

6. What types of enforcement technologies could facilitate enforcement of transit bus axle weights in your state? (Select all that apply)

	Response Percent	Response Count
On-board axle weight sensors	27%	6
Virtual weigh stations	59%	13
Don't know	0%	0
Other (please specify)	14%	3
Answered question		16
Skipped question		0

7. Have any of the following alternatives to traditional on-road enforcement approaches been considered to enforce transit bus axle weights in your state? (Select all that apply)

	Response Percent	Response Count
Compliance accreditation program with occasional audits	0%	0
Special sanctions for transit bus weight violations	0%	0
Weight compliance audits based on ridership data	0%	0
No alternative approaches have been considered	94%	15
Don't know	6%	1
Other (please specify)	0%	0
Answered question		16
Skipped question		0

8. Has your state ever conducted analyses to address pavement deterioration that may be attributable to transit buses?

	Response Percent	Response Count
Yes	0%	0
No	19%	3
Don't know	81%	13
Answered question		16
Skipped question		0

9. In your experience, which types of transit buses may impact pavement in your state? (Select all that apply)		
	Response Percent	Response Count
2-axle 35- to 45-foot buses	31%	8
3-axle 60-foot articulated buses	8%	2
3-axle 45-foot buses	15%	4
3-axle 45-foot double-deck buses	15%	4
Don't know	31%	8
Answered question		16
Skipped question		0

10. How has your state responded to pavement deterioration that may be attributable to transit buses in your state? (Select all that apply)		
	Response Percent	Response Count
Changed pavement design practices	0%	0
Changed pavement materials used	6%	1
Changed methods of pavement construction	0%	0
Changed pavement maintenance practices	0%	0
Changed transit bus design specifications	0%	0
Changed transit bus operations	0%	0
Changed transit bus size and weight regulations	0%	0
No significant response	24%	4
Don't know	59%	10
Other (please describe)	12%	2
Answered question		16
Skipped question		0

11. Is there an individual within your organization knowledgeable about the impact of transit bus axle weights on pavement design and maintenance?	Response Percent	Response Count
Yes	6%	1
No	56%	9
Don’t know	38%	6
Answered question		16
Skipped question		0

8.2 City and County Surveys and Findings

Online surveys were distributed to 432 MPOs, counties, and cities. Table 12 lists the responding agencies. Although 50 responses were received, only 45 respondents provided their agency name.

Table 12: City and County Survey Respondents

Agency		
Altoona MPO	Fresno COG	Ouachita COG
Amarillo MPO	Greater Attleboro Taunton Regional Transit Authority	Pinellas County Metropolitan Planning Organization
Bangor Area Comprehensive Transportation System	Gulf Regional Planning Commission	Pueblo Area Council of Governments MPO
Cache MPO	Herkimer-Oneida Counties Transportation Study MPO	Rapid City Area MPO
Chattanooga-Hamilton County/N. GA Transportation Planning Organization	Hillsborough MPO	Region 2000 Local Government Council
Charlotte County-Punta Gorda MPO	Lawton Area Transit System	Regional Transportation Commission of Washoe County
Chippewa-Eau Claire MPO	Lubbock Metropolitan Planning Organization	River to Sea TPO
City of Lincoln-StarTran	Manchester Transit Authority	River Valley Transit
City of Missoula/Missoula MPO	Maricopa Association of Governments	Southeastern Regional Planning and Economic Development District
City of Winchester	Merrimack Valley Planning Commission	Springfield Area Transit Study
Cumberland Area MPO	Mid-America Regional Council	Stateline Area Transportation Study
DeKalb Sycamore Area Transportation Study	Midland Area Transportation Study	Strafford Regional Planning and MPO
Farmington Metropolitan	Montgomery Area Transit	Tri-county RPC Lansing Michigan

Planning Organization	System	
FIVCO ADD/KYOVA	Morgantown Monongalia MPO	Valley Council of Governments
Flint Hills MPO	Northern Shenandoah Valley Regional Commission	

The survey consisted of 16 questions as follows:

1. In case we need to follow up with you once you have completed the survey, would you please provide your name, title, agency, email address, and phone number?

Name: ____________________________________

Title: ____________________________________

Agency: ____________________________________

Email Address: ____________________________________

Phone Number: ____________________________________

2. Does your jurisdiction conduct planning activities for freight and logistics that may have relevance to issues associated with transit bus axle weight?

○ Yes
○ No
○ Don't know

3. If you answered "yes" to Question 2, what types of activities have been identified in the Unified Planning Work Program (UPWP) for freight? (Select all that apply)

○ General Freight Movement Logistics
○ Special Freight Corridor Studies
○ Regional Freight Movement and Logistics
○ Statewide Freight Movement and Logistics
○ Other (please describe)

4. Have any of your studies or activities addressed axle weight of vehicles and impacts on pavement deterioration?

○ Yes
○ No
○ Don't know

5. Do axle weight limits for transit buses exist within your service planning area that are different from those limits specified by state and federal requirements?

- ○ Yes
- ○ No
- ○ Don’t know

If so, please provide details of limits that depart from state and federal requirements in the space below. (Please describe).

6. If transit bus axle weight limits exist within your service planning area, do they vary by type of road facility or geographical location (e.g., urban core, suburban, rural, certain corridors)? (Select all that apply)

- ○ Roadway functional class (e.g., Interstate, arterial, collector)
- ○ Land use (e.g., urban core, suburban)
- ○ Corridor-based
- ○ Don't know
- ○ Other (please describe)

7. If transit bus axle weight limits exist within your service planning area, how are they enforced? (Select all that apply)

- ○ Transit buses are weighed at fixed weigh stations
- ○ Transit buses are weighed using portable weigh scales
- ○ Transit agencies are subject to occasional weight enforcement audits
- ○ Transit bus axle weights are not enforced
- ○ Don't know
- ○ Other (please describe)

8. Are there any exemptions in place among your local governments for transit buses that exceed specified vehicle axle weight limits?

- ○ Yes
- ○ No
- ○ Don’t know

If so, please briefly describe.

9. Do you maintain or have access to an inventory of transit bus weight limits, exemptions, and enforcement policies?

- ○ Yes
- ○ No
- ○ Don’t know

If so, please briefly describe.

10. Has your jurisdiction(s) ever conducted analyses to address pavement deterioration that may be attributable to transit buses?

- ○ Yes
- ○ No
- ○ Don’t know

If so, please briefly describe.

11. In your experience, which types of transit buses may impact pavement based on being in service in your area? (Select all that apply)

- ○ 2-axle 35- to 45-foot buses
- ○ 3-axle 60-foot articulated buses
- ○ 3-axle 45-foot buses
- ○ 3-axle 45-foot double deck buses
- ○ Don't know

12. How has your state responded to pavement deterioration that may be attributable to transit buses in your state? (Select all that apply)

- ○ Changed pavement design practices
- ○ Changed pavement materials used
- ○ Changed methods of pavement construction
- ○ Changed pavement maintenance practices
- ○ Changed transit bus design specifications (e.g., require tandem rear axles)
- ○ Changed transit bus operations (e.g., altered routing, assigned transit buses to certain routes, limited the number of passengers per transit bus, etc.)
- ○ Changed transit bus size and weight regulations
- ○ No significant response
- ○ Don’t know
- ○ Other (please describe)

13. Is there a Public Transportation Representative on your Technical Advisory Committee?

- ○ Yes
- ○ No
- ○ Don't know

14. If yes, please provide name and contact information.

Name: ________________________________

Company: ________________________________

Email Address: ________________________________

Phone Number: ________________________________

15. Is there an Engineer Representative on your Technical Advisory Committee knowledgeable of pavement engineering and design?

- ○ Yes
- ○ No
- ○ Don't know

16. If yes, please provide name and contact information.

Name: ________________________________

Company: ________________________________

Email Address: ________________________________

Phone Number: ________________________________

The following summarizes the technical survey responses; therefore not all 16 questions are shown. For certain questions respondents were allowed to select more than one answer. Consequently, some response counts will exceed the total number of respondents (i.e., 50).

2. Does your jurisdiction conduct planning activities for freight and logistics that may have relevance to issues associated with transit bus axle weight?	Response Percent	Response Count
Yes	25%	12
No	63%	30
Don't know	13%	6
Answered question		48
Skipped question		2

3. If you answered “yes” to Question 2, what types of activities have been identified in the Unified Planning Work Program (UPWP) for freight? (Select all that apply)	Response Percent	Response Count
General Freight Movement Logistics	25%	5
Special Freight Corridor Studies	15%	3
Regional Freight Movement and Logistics	35%	7
Statewide Freight Movement and Logistics	10%	2
Other (please describe)	15%	3
Answered question		15
Skipped question		35

4. Have any of your studies or activities addressed axle weight of vehicles and impacts on pavement deterioration?	Response Percent	Response Count
Yes	2%	1
No	89%	40
Don’t know	9%	4
Answered question		45
Skipped question		5

5. Do axle weight limits for transit buses exist within your service planning area that are different from those limits specified by state and federal requirements?	Response Percent	Response Count
Yes	2%	1
No	50%	22
Don't know	48%	21
Answered question		44
Skipped question		6

6. If transit bus axle weight limits exist within your service planning area, do they vary by type of road facility or geographical location (e.g., urban core, suburban, rural, certain corridors)? (Select all that apply)	Response Percent	Response Count
Roadway functional class (e.g., interstate, arterial, collector)	4%	1
Land use (e.g., urban core, suburban)	0%	0
Corridor-based	0%	0
Don't know	79%	22
Other (please describe)	18%	5
Answered question		28
Skipped question		22

7. If transit bus axle weight limits exist within your service planning area, how are they enforced? (Select all that apply)	Response Percent	Response Count
Transit buses are weighed at fixed weigh stations	0%	0
Transit buses are weighed using portable weigh scales	0%	0
Transit agencies are subject to occasional weight enforcement audits	0%	0
Transit bus axle weights are not enforced	4%	1
Don't know	78%	21
Other (please describe)	19%	5
Answered question		27
Skipped question		23

8. Are there any exemptions in place among your local governments for transit buses that exceed specified vehicle axle weight limits?	Response Percent	Response Count
Yes	3%	1
No	34%	13
Don't know	63%	24
Answered question		38
Skipped question		12

9. Do you maintain or have access to an inventory of transit bus weight limits, exemptions, and enforcement policies?	Response Percent	Response Count
Yes	10%	4
No	64%	27
Don't know	26%	11
Answered question		42
Skipped question		8

10. Has your jurisdiction(s) ever conducted analyses to address pavement deterioration that may be attributable to transit buses?	Response Percent	Response Count
Yes	2%	1
No	83%	34
Don’t know	15%	6
Answered question		41
Skipped question		9

11. In your experience, which types of transit buses may impact pavement based on being in service in your area? (Select all that apply)	Response Percent	Response Count
2-axle 35- to 45-foot buses	44%	17
3-axle 60-foot articulated buses	8%	3
3-axle 45-foot buses	5%	2
3-axle 45-foot double deck buses	0%	0
Don't know	56%	22
Answered question		39
Skipped question		11

12. How has your state responded to pavement deterioration that may be attributable to transit buses in your state? (Select all that apply)	Response Percent	Response Count
Changed pavement design practices	5%	2
Changed pavement materials used	5%	2
Changed methods of pavement construction	5%	2
Changed pavement maintenance practices	5%	2
Changed transit bus design specifications	3%	1
Changed transit bus operations	3%	1
Changed transit bus size and weight regulations	0%	0
No significant response	49%	18
Don't know	38%	14
Other (please describe)	5%	2
Answered question		37
Skipped question		13

15. Is there an Engineer Representative on your Technical Advisory Committee knowledgeable of pavement engineering and design?	Response Percent	Response Count
Yes	48%	19
No	30%	12
Don't know	23%	9
Answered question		40
Skipped question		10