U.S. Department
of Transportation
**Federal Transit
Administration**

Study & Report to Congress: Applicability of Maximum Axle Weight Limitations to Over-the-Road and Public Transit Buses

Pursuant to Senate Report No. 107-38

December 2003

Acknowledgements

This project benefited from the information, insights and comments provided by the following people at the Federal Transit Administration and Federal Highway Administration: Marcel Belanger, Donald Durkee, Paul Marx, Jeffrey Mora, Michael O'Connor, Terry Rosapep, and James Saklas. Special thanks go to Quon Y. Kwan, FTA Project Manager. We also thank the following people for their insights: John Maddox and William Coryell of North American Bus Industries, Paul Murphy of Motor Coach Industries, Mark Braeger of Orion Bus, George Husman of the Southern Research Institute, Tony Mascarin of IBIS Associates, Steve Misencik of TPI Composites, and David Klinikowski and Mustafa El-Gindy of the Altoona Bus Research and Testing Center. Volpe Center authors of the report include Scott Smith (Project Manager), John Brewer and Douglass Lee. Other contributions were made by William Chernicoff, Scott Lian, Matthew Rabkin, and Edward Ramsdell. Although these people and others contributed to the results of this study, the authors are solely responsible for any errors and omissions contained in this report.

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Acronyms

AASHTO	American Association of State Highway and Transportation Officials
ABA	American Bus Association
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ATTB	Advanced Technology Transit Bus
BTS	Bureau of Transportation Statistics
CAA	Clean Air Act
CNG	Compressed Natural Gas
D	Pavement Depth
DAWR	Drive Axle Weight Rating
DOT	United States Department of Transportation
ESAL	Equivalent Single Axle Load
FAWR	Front Axle Weight Rating
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FMVSS	Federal Motor Vehicle Safety Standards
FTA	Federal Transit Administration
GMC	General Motors Corporation
GVWR	Gross Vehicle Weight Rating
HERS	Highway Economic Requirements System
HPMS	Highway Performance Monitoring System
ISTEA	Intermodal Surface Transportation Efficiency Act (1991)
LFT	Long Fiber Thermoplastic
LNG	Liquefied Natural Gas
MAC	Minor Arterial and Collector
MCI	Motor Coach Industries
NABI	North American Bus Industries
NHTSA	National Highway Traffic Safety Administration
NTD	National Transit Database
OEM	Original Equipment Manufacturer
OPA	Other Principal Arterial
OTR	Over-the-road
PSI	Present Serviceability Index
PSR	Pavement Serviceability Rating
SN	Structural Number
TAWR	Tag Axle Weight Rating
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
U.S.C.	United States Code
VMT	Vehicle Miles Traveled

Executive Summary

The Senate Report on the Fiscal Year (FY) 2002 U.S. Department of Transportation (DOT) appropriations bill requested that the Department conduct a study and submit to Congress a report on the applicability of Federal maximum weight limitations to over-the-road (OTR) buses (also called motorcoaches) and public transit vehicles.

Since the passage of the Surface Transportation Assistance Act of 1982, Federal weight limits on the Interstate Highway System have been 20,000 lbs for a single axle and 34,000 lbs for a tandem axle (unless the State had higher limits in effect prior to July 1, 1956). Since 1992, there has been a permissive arrangement whereby States are not required to enforce axle weight limits for intrastate transit buses. A similar arrangement for over-the-road buses was enacted in February 2003. Both are due to expire in October 2003.

This study is intended to

- Assess current status and trends in bus axle weight
- Estimate the cost of pavement damage caused by buses
- Assess both the technical and economic feasibility of lighter-weight buses
- Evaluate within a benefit-cost framework selected policies that could address over-limit bus axle weights
- Given the above assessments, make recommendations to Congress about the applicability of axle weight limits to transit and over-the-road buses.

The benefit-cost evaluation considers operating costs for bus travel, externalities of bus travel, and the externalities of induced automobile travel resulting from a change in the price of bus travel. Externalities are those identified in the 1997 Federal Highway Cost Allocation Study *(1)*, namely, pavement damage, congestion, crash, air pollution and noise. The evaluation also assumes that all States are currently allowing overweight buses to operate.

Bus Weight Trends

Over the past 20 years, an increasing number of transit and over-the-road buses have been operating in excess of the 20,000 lb single axle limit. When loaded with passengers, transit bus rear axles routinely exceed the 20,000 lb axle weight limitation. Although the overall weight of a large motorcoach is higher than that of a transit bus, axle weight tends to be lower, because the motorcoach has a tandem rear axle (two rear axles close to each other). Nonetheless, a substantial number of motorcoaches also exceed the 20,000 lb axle weight limit with a full passenger and baggage load.

Unlike a truck, the payload (passengers plus baggage) on a bus is only about 1/3 of the total vehicle weight; 2/3 is the empty weight of the vehicle. The weight of a fully loaded (seated plus standees) 40-foot transit bus may be about 36,000 lbs, while its empty weight is about 28,000 lbs. This weight is distributed to a front and rear axle, with the rear axle carrying about 2/3 of the load. The weight of a fully loaded 45-foot motorcoach (all seats taken plus baggage) may be about 47,000 lbs, while its empty weight is about 36,000 lbs. This weight is distributed between the front and two rear axles. The first of the rear axles, called the drive axle, may carry almost 1/2 of the total weight.

For both the transit bus and motorcoach, major components of the fully loaded weight include the bus structure (about 1/6 of the total weight), the drive train (about 1/4) and the passengers (about 1/3).

Since the 1970s, the weights of both transit buses and motorcoaches have increased by several thousand pounds. Major sources of increased transit bus weight include equipment required to meet the Americans with Disabilities Act (ADA) accessibility requirements and the use of some alternative fuels. Major sources of increased over-the-road motorcoach weight include increased length and passenger capacity, passenger amenities, safety improvements, emissions controls, and accommodation of passengers with disabilities.

Pavement Damage

The stress of a heavy-vehicle axle on pavement is often measured in Equivalent Single Axle Loads (ESALs).[1] An ESAL is defined as the equivalent of a single 18,000-pound axle. A heavy vehicle, such as a truck or a bus, will typically impose between 1 and 4 ESALs on a pavement. The relative stress on the pavement is approximately proportional to the fourth power of axle weight.[2] For example, an axle with 20,000 pounds on it will impose approximately 1.52 ESALs. This is $(20,000 / 18,000)^4$, or 1.52 times that of an 18,000-pound axle. As a result, the actual ESAL loading of a bus depends heavily on the number of passengers on board. A fully loaded bus may impose three to five times the stress of an empty bus.

A pavement has associated with it an ESAL-lifetime and a reconstruction cost. Heavy-duty pavements have somewhat higher reconstruction costs and much longer ESAL-lifetimes than light-duty pavements. For example, an urban Interstate highway may have an ESAL-lifetime of some 38 million ESALs (equivalent to 17 million passes of a

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[1] American Association of State Highway and Transportation Officials (AASHTO) Road Test.

[2] In 1989, Small, Winston and Evans *(2)* refitted the AASHTO data using different economic methods, and found that the relationship between axle weight and pavement damage may be closer to the 3rd power, rather than the 4th power. This study also concluded that the traditional AASHTO equations overstate the ESAL life of heavy-duty pavements. Unfortunately, there is no clear consensus as to what the revised equations should be. Accordingly, this study uses the traditional AASHTO 4th power relationships, as presented in the 1993 *AASHTO Guide for Design of Pavement Structures (3),* and used in the Highway Economic Requirements System.

vehicle that has two axles loaded to 18,000 lbs each) and a reconstruction cost of about $1.6 million per lane mile.[3] On the other hand, a medium-duty street (such as an urban minor arterial or collector) may have an ESAL-lifetime of only 800,000 ESALs, with a reconstruction cost of about $800,000 per lane mile. Accordingly, the cost per ESAL-mile is much higher on the medium-duty street ($1.05 / ESAL-mile) than for an urban Interstate highway ($0.04 / ESAL-mile). Although Congress intended that the study focus on Interstate highways, the high cost of pavement damage by both transit and OTR buses on other roads cannot be ignored.

Given a weighted average of actual passenger loads, Table ES-1 gives the estimated pavement damage cost per vehicle mile for transit and over-the-road buses. The functional classes for roadways considered in this table are Interstates, Other Principal Arterials (OPA), and Minor Arterials/Collectors (MAC).

Table ES-1 Estimated Pavement Damage Cost per Vehicle Mile

		Transit		OTR	
Functional Class	$/ESAL-mi	ESAL	$/VMT	ESAL	$/VMT
Rural Interstate	$ 0.016	1.40	$ 0.022	1.66	$ 0.026
Rural OPA	$ 0.12	1.56	$ 0.18	1.86	$ 0.22
Rural MAC	$ 0.77	1.56	$ 1.20	1.86	$ 1.44
Urban Interstate	$ 0.042	1.40	$ 0.058	1.66	$ 0.069
Urban OPA	$ 0.17	1.56	$ 0.27	1.86	$ 0.32
Urban MAC	$ 1.05	1.56	$ 1.65	1.86	$ 1.96

To assess the total pavement damage caused by the transit and over-the-road buses, it is necessary to assess annual mileage traveled by roadway functional class. Based on various government and industry data sources *(5,6,7)*, the following vehicle-miles traveled (VMT) were estimated. They are multiplied by the pavement damage costs (from Table ES-1) to estimate total pavement damage cost. There may be some slight discrepancies in the total costs due to rounding.

Table ES-2 Estimated Annual VMT and Pavement Damage Cost

	VMT (millions)		Cost (millions $)		
Functional Class	Transit	OTR	Transit	OTR	TOTAL
Rural Interstate	0	700	$ 0	$ 18	$18
Rural OPA	240	600	$ 44	$ 132	$176
Rural MAC	160	400	$ 193	$ 574	$767
Urban Interstate	200	500	$ 12	$ 35	$47
Urban OPA	1,020	60	$ 276	$ 19	$295
Urban MAC	680	40	$ 1,120	$ 79	$1,199
Total Rural	**400**	**1,700**	**$ 237**	**$ 724**	**$961**
Total Urban	**1,900**	**600**	**$ 1,408**	**$ 133**	**$1,541**
Overall Total	**2,300**	**2,300**	**$1,645**	**$ 857**	**$2,502**

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[3] Reconstruction costs are taken from Table 7-11 of reference *(4)*.

Since buses travel many fewer vehicle-miles per year than trucks (4.6 billion VMT for transit and over-the-road buses versus 206 billion VMT for trucks), the pavement damage cost attributable to buses is at least an order of magnitude lower than that attributable to trucks.

The total annual pavement damage to Interstate highways from transit buses is estimated to cost $12 million, from over-the-road buses $53 million, for a total of $65 million from both kinds of buses. The total pavement damage cost to all other roads is much higher - $1,633 million from transit buses, $804 million from over-the-road buses, for a total of $2,437 million from both kinds of buses.

Lightweight Materials for Manufacturing Buses

The weight of a bus can be reduced in several ways. Lower weight non-structural components (e.g., smaller engines and multiplexed wire systems) will always help. However, major weight savings are frequently dependent on the material chosen for the bus structure. The savings can be implemented in the form of more efficient structural design (e.g., integrally formed seats), the use of less material (e.g., thinner gauge panels), or the use of lower density material (e.g., replacing stainless steel with aluminum). Many of the more sophisticated innovations in recent years have focused on advanced composite materials.

Axle-weight reduction can be approached as either incremental or revolutionary. The incremental approach involves substituting individual components to reduce weight. Many manufacturers use composites as direct replacement materials for non-structural components. Some buses use composite skins on steel frames. Composite seats have also been developed, and composite floor panels are being marketed. Such applications are low risk and provide a modest weight savings. The major payback to the bus fleet manager is in reduced operating costs. Risks with such an approach are low, but the maximum total weight savings that may be realized is unlikely to reach 3,000 to 5,000 lbs, with axle-weight savings of at most 1,000 to 3,000 lbs per axle.

The revolutionary approach involves major changes in the bus structure (in materials and design) or bus components. For example, adding a second rear axle to transit buses would increase the total weight of the bus but reduce the maximum axle load. Potential weight savings may be 10,000 lbs for the bus, or in the case of a single rear axle, over 5,000 lbs for that axle.

Two examples of buses that have attained major weight savings with changes in bus structure are the Advanced Technology Transit Bus (ATTB) and North American Bus Industries (NABI) CompoBus™. The Federal Transit Administration (FTA) funded the development of a prototype Advanced Technology Transit Bus (ATTB) in the 1990s. The ATTB demonstrated the utility of composite structures and had a curb weight some 9,000 lbs below that of contemporary buses. More recently, NABI has introduced the CompoBus, a composite bus that is approximately 3,000 lbs lighter than a comparably equipped steel bus.

Market Penetration of Lighter Weight Buses

Corbeil et al. (1995) estimated the cost and weight savings for various weight reduction projects *(8)*. It appears that the modest weight reductions (up to about 4000 lbs) were fairly inexpensive to attain, costing perhaps $10 / lb. A bus with a 4,000 lb weight reduction might carry a price premium of $40,000. After that, the marginal cost for each pound of weight reduction increases to approximately $30 / lb, so that a bus with a 7,000 lb weight reduction might carry a price premium of $130,000.

Given that lighter-weight buses may cost substantially more to build than conventional buses, but enable operating cost and social benefits, two questions arise:

1) When one considers only the costs internal to the bus fleet manager (capital costs, fuel costs, and other operating costs), is the investment in lighter-weight buses worthwhile?

2) When one considers all costs (including external costs, such as pavement damage), is the investment in lighter-weight buses worthwhile?

For this analysis, it is assumed that lighter-weight buses are available for $10 / lb for the first 4,000 lbs of weight reduction, and $30 / lb for further weight reduction.

These added capital costs far exceed what the bus fleet managers are likely to gain in fuel savings or reduced maintenance costs. Therefore, the answer to question (1), above, is no. That is, if social costs are disregarded and we assume the above price premiums, the investment in lighter-weight buses is not worthwhile.

However, if pavement damage costs are considered, then some investment in lighter-weight buses is worthwhile. Figures ES-1 and ES-2 show the tradeoffs for transit and OTR buses for various empty weights. They plot pavement damage cost, the operating cost, and the sum of the two costs. Since the primary external cost of bus operation is pavement damage, this sum is close to the total social cost.

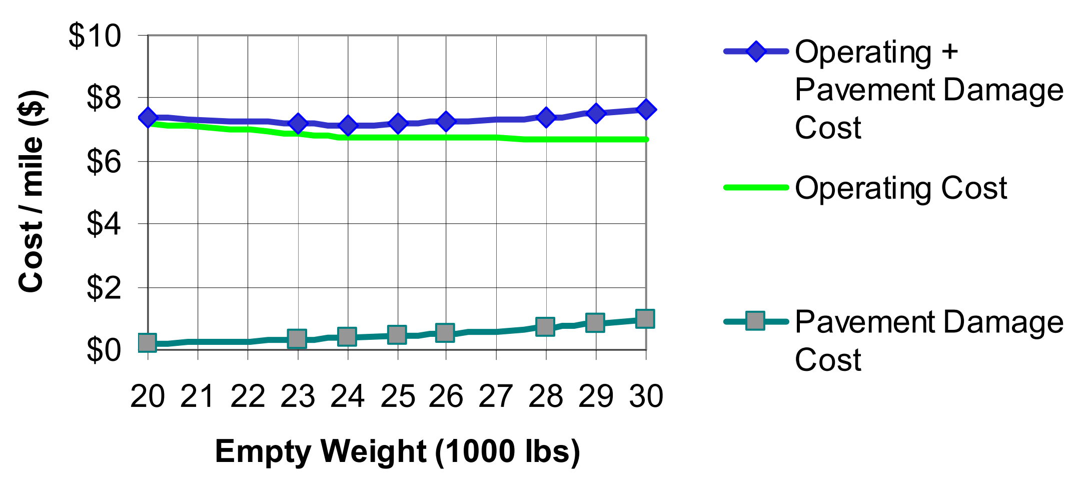

Figure ES-1 Transit Bus Per Mile Cost as a Function of Empty Weight

For the transit bus, total (operating plus pavement damage) cost is minimized with an empty weight of 24,000 to 25,000 lbs. This represents a 3,000 – 4,000 lb weight reduction from the current typical weight of 28,000 lbs.

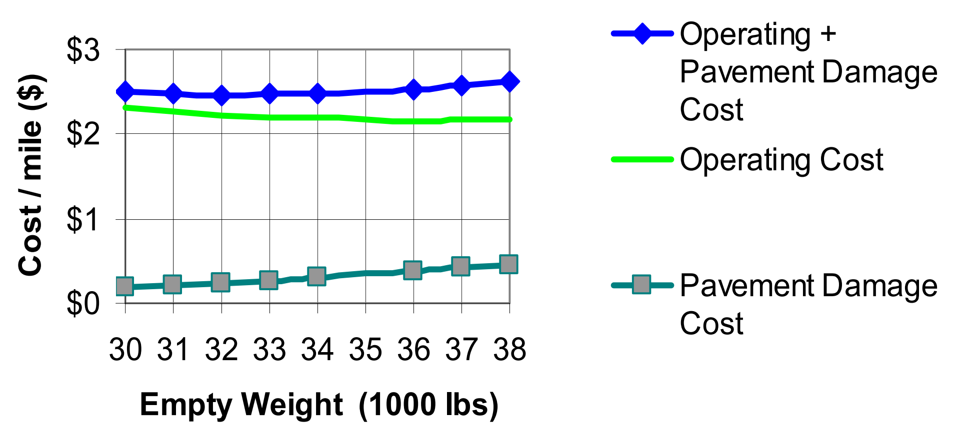

Figure ES-2 Over-the-Road Bus Per Mile Cost as a Function of Empty Weight

For the over-the-road bus, the total (operating plus pavement damage) cost is minimized with an empty weight of 32,000 to 33,000 lbs. This represents a 3,000 – 4,000 lb weight reduction from the current typical weight of 36,000 lbs.

The exact weight reduction that is socially desirable depends on the cost to attain a particular weight savings. This analysis assumed that the cost per pound of weight savings would increase significantly after 4,000 lbs were saved. Therefore, it is not surprising that this model indicated an optimal weight savings of about 4,000 lbs. If the cost to attain a weight savings should turn out to be higher than what is modeled here, the optimal weight savings will be less. If the cost is lower, the optimal weight savings will be higher.

To summarize, lighter-weight buses can have a small positive benefit for transit and over-the-road fleet managers in terms of reduced operating and maintenance costs, but in many cases, this benefit is not enough to outweigh the difference in capital cost. Direct replacement of standard parts with lightweight composite parts (e.g. transit bus seats, OTR motorcoach baggage doors) is an incremental technology that is enjoying some market penetration. Unfortunately, the more revolutionary approaches of major structural redesign and all-composite structures are making slower progress, primarily because of the larger up-front capital costs, commitments to new maintenance facilities, and a limited track record for safety and durability.

The CompoBus and other lighter-weight transit buses are making headway in areas such as California where axle weight limits are forcing the implementation of more innovative alternatives. In contrast, the total market for over-the-road motorcoaches may be so small that no niche market for lighter-weight buses can realistically develop. Preliminary cost-benefit analysis shows that weight savings are unlikely to be justified on the basis of fuel savings alone. Unless external costs such as pavement damage are made visible to bus fleet managers (i.e. are internalized), there will be little incentive to acquire lighter-weight buses.

Policy Options

The study considered 23 distinct policies that can be grouped into six broad areas:

- Policies that adjust axle weight limits in Federal regulations.
- Policies that impose design requirements on vehicles or their operation.
- Policies that offer subsidies to fleet managers or manufacturers.
- Policies that affect the roads used by buses.
- Policies that alter the rulemaking process to take account of external costs.
- Policies that utilize market-like mechanisms to internalize costs.

Adjustments to Axle Weight Limits

Examples include allowing States to provide an exemption for *inter*state transit buses, restoring the 1992-2003 policy (no exemption for motorcoaches), re-imposing Federal weight limits on buses, and various across-the-board weight limits.

Design and Operational Requirements

Examples include requiring transit buses to have tag axles, and adding or rearranging transit service to avoid overcrowded buses. This second idea was inspired by the concept of a divisible load, which is simply a load that can be divided among two or more vehicles. One finding from this study was that while dividing a heavy load between two trucks can often reduce overall pavement damage, dividing a large load of passengers between two buses is generally not effective. This is because the empty/loaded weight ratio is higher on a bus than on a truck. Therefore, the detrimental effect of the added bus (with its relatively high empty weight) is usually more than enough to offset the beneficial effect of spreading the load among more axles.

Subsidies to Produce, Buy and Operate Lighter-Weight Buses

Examples include research and development grants, a lighter-weight bus development program, and measures to facilitate adoption of new technology by bus fleet managers.

Federal Procedural Changes

The example evaluated was a requirement that Federal rulemakings consider weight impacts.

Changes to Highways Used by Buses

Examples include upgrading roads used by buses, and restricting buses to strong roads.

Measures to Internalize Costs

Examples include financial incentives for the purchase and use of lighter weight buses, an axle-weight distance pavement charge, and congestion pricing applied to all vehicles.

Benefit-Cost Analysis

A number of the above policies will not produce significant benefits, either because they are ineffective or because they are impractical to implement at this time. Chapter VII contains an evaluation of both re-imposed weight limits and of incentive programs that are designed to make pavement damage costs visible to bus fleet managers. Since the immediate need is to determine the applicability of Federal weight limits to over-the-road (OTR) buses and public transit vehicles, an evaluation of re-imposed weight limits is presented below for both transit and OTR buses.

For each policy, there is a set of impact linkages that trace a path from the imposition of the policy to its resulting benefits. Figure ES-3 depicts a set of impact linkages resulting from the imposition of a lower axle weight limit.

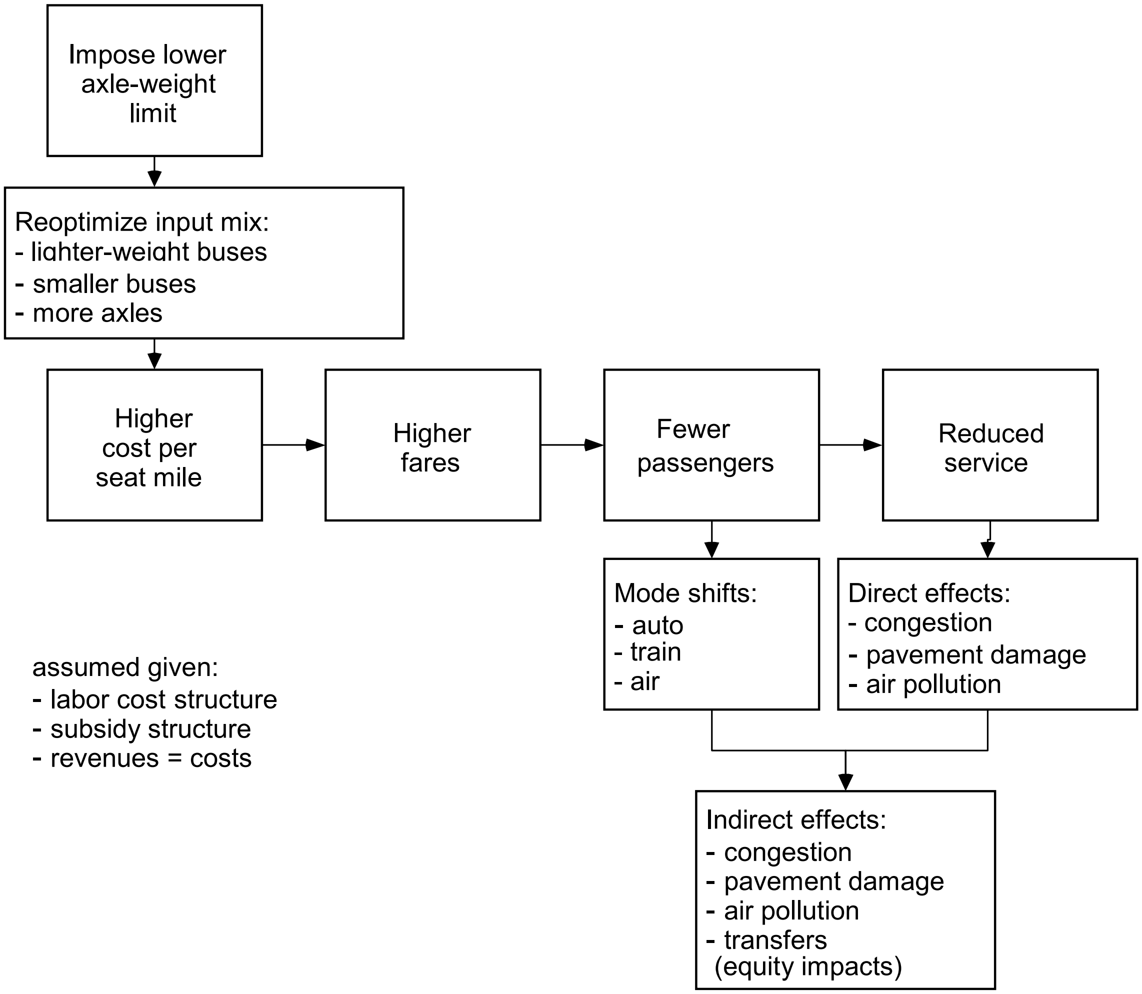

Figure ES-3 Impact Linkages

Each policy was evaluated, using the following steps:

- Enumerate likely responses to the policy.
- For each response, evaluate the change in operating cost for the bus fleet manager. Major components of operating cost include capital, labor, fuel and other costs, such as maintenance and insurance.
- Based on the change in operating cost, identify the responses that will be chosen.
- Quantify the response in passenger demand, under the assumption that any change in operating cost is passed on in the form of changed fares.

- Quantify the change in bus externalities, such as pavement damage.
- Quantify passenger mode shifts.
- Quantify the change in automobile externalities that occur as a result of some passengers shifting to private automobile.

The global cost and benefit numbers presented in Table ES-3 represent an upper bound on the magnitude of benefit that may be obtained if there is 100% compliance with the re-imposed weight limits. Given potentially lax enforcement of bus weight limits, and the particular difficulties of enforcement in urban areas, compliance, in reality, may be less than 100%.

Re-impose the Requirement that States Enforce Weight Limits on Transit Buses

For this policy, the following transit fleet manager responses were considered:

- Using smaller buses
- Adding a second rear axle
- Reducing the weight of the bus while keeping the same size. In areas with a 20,000 lb axle weight limit, an 8,000 lb reduction would be required. In areas with a 22,400 lb axle weight limit, a 4,000 lb reduction would suffice.

The only response that produced a reduction in pavement damage cost greater than the increase in operating cost was that of reducing the weight of the bus while keeping its size the same.

Re-impose the Requirement that States Enforce Weight Limits on OTR Motorcoaches

Responses included using smaller buses (for example, using a 40-foot motorcoach instead of a 45-foot motorcoach) and reducing the weight of the bus while keeping its size the same. Similar to transit, the only response that produced a reduction in pavement damage cost larger than the increase in operating cost was that of reducing the weight of the bus while keeping the same size.

Conclusions

The impacts of re-imposed weight limits are summarized below:

Table ES-3 Summary of Policy Impacts

Policy Option	Net Annual Benefit (Millions $)	Comment
Re-impose the Requirement that States Enforce Weight Limits on Transit Buses	$268	Positive benefit only if lighter-weight transit buses are available at reasonable cost. Otherwise, the benefit is negative. Furthermore, the stated benefit represents an upper bound on what can realistically be achieved, because it assumes that States will enforce the weight limits and that bus fleet managers will obey them.
Re-impose the Requirement that States Enforce Weight Limits on OTR Buses	$123	Positive benefit only if lighter-weight OTR buses are available at reasonable cost. Otherwise, the benefit is negative. Furthermore, the stated benefit represents an upper bound on what can realistically be achieved, because it assumes that States will enforce the weight limits and that bus fleet managers will obey them.

The re-imposition of weight limits provides a positive benefit only if lighter-weight buses are available at a reasonable cost. Since the market for lighter-weight buses is not well developed, the re-imposition of weight limits at this time would likely produce a negative benefit. As discussed earlier, a market for lighter-weight buses is not likely to develop unless pavement damage costs are made visible to bus fleet managers.

Recommendations

1. Continue the Current Permissive Arrangement for Intrastate Transit Buses

In the absence of a well-developed market for lighter-weight buses, the options for meeting any re-imposed weight limits include the following:

- Shifting transit service from Interstate highways to arterials. This would increase operating costs, and would also increase overall pavement damage costs, since arterials are generally less able to withstand heavy axle loads than Interstate highways.

- Spreading the passenger load among many lightly loaded buses. For many fleet managers, the equipment is not available. Even if equipment were available, there would be no reduction in pavement damage because the many lightly loaded buses would cause as much or more damage as the few heavily loaded buses.

- Acquiring smaller buses. The added cost would outweigh the savings in pavement damage.

- Using tag axles. Due to maneuverability issues, this may not be practical on some streets. The added cost would likely outweigh the savings in pavement damage.

All the above options have costs in excess of the expected reduction in pavement damage. Accordingly, the existing permissive arrangement for transit buses should be continued until cost-effective responses to its removal are available.

2. Continue the Current Permissive Arrangement for Over-the-Road Buses

Similar to transit, there is no well-developed market for lighter-weight motorcoaches. None of the other options (such as using smaller buses) for meeting weight requirements are particularly attractive, for the same reasons that they are not attractive in transit. Accordingly, the existing permissive arrangement for over-the-road buses should be continued until cost-effective responses to its removal are available.

3. Consider Vehicle Weight Impacts in Federal Rulemakings

Any regulation that leads to a significant change in vehicle weights will have far-reaching impacts, not only on pavement damage, but also on fuel consumption, emissions, and possibly safety. A major change in vehicle weight may have impacts that are both economically and environmentally significant. Since these impacts may not be obvious to the agency making the rule, some consideration of vehicle weight in rulemaking seems appropriate.

Current rules (Executive Order 12866 of 1993, amended by Executive Order 13258 in 2002) call for a regulatory impact analysis of any regulation with significant economic impact, defined as at least $100,000,000. Each of the following actions would, in the absence of other changes, lead to approximately $100,000,000 more in pavement damage each year:

- Add 800 lb per bus to 1/2 of the transit bus fleet
- Add 400 lb per bus to the entire transit bus fleet
- Add 2000 lb per bus to 1/2 of the motorcoach fleet
- Add 1000 lb per bus to the entire motorcoach fleet.

Therefore, in future rulemakings, Federal rule makers should be required to take into account the effect of weight on those actions where the expected pavement damage impact (considering both the weight added and number of vehicles affected) exceeds $100,000,000.

Chapter I: Background and Purpose

The Senate Report on the Fiscal Year (FY) 2002 U.S. Department of Transportation (DOT) appropriations requested that the Department conduct a study and submit to Congress a report on the maximum axle weight limitations applicable to vehicles using Interstate highways, or under State law, as the limitations apply to over-the-road (OTR) buses (also called motorcoaches) and public transit vehicles.

Section 339 of S.1178, the Senate version of the DOT and Related Agencies Appropriations Bill, 2002, proposed to amend section 1023(h) of the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA), Pub. L. 102-240, to allow all OTR buses to be exempted from Federal axle weight restrictions that are presently applicable only to public buses. Section 339 of the Senate bill also called for this study and report to include the following:

1) Determination of the applicability of vehicle weight limitations

   - Applicability of the requirements of 23 U.S.C. 127 to over-the-road (OTR) buses and public transit vehicles

2) Short and long term recommendations concerning the applicability of those requirements. Items to consider in making this determination include

   - Vehicle design standards

   - Statutory and regulatory requirements including the Clean Air Act (42 U.S.C. 7401 et seq), the Americans with Disabilities Act of 1990 (42 U.S.C. 12101 et seq) and motor vehicle safety standards prescribed under chapter 301 of Title 49, U.S.C.

   - The availability of lightweight materials suitable for use in the manufacture of OTR buses, the cost of those lightweight materials relative to the cost of heavier materials in use as of the date of determination, and any safety or design considerations relating to the use of those materials.

3) Analysis of means of encouraging development and manufacture of lighter-weight buses

   - Potential procurement incentives for public transit authorities to encourage the purchase of lighter-weight public transit vehicles using Federal Transit Administration (FTA) grants

- Potential tax incentives for manufacturers and private fleet managers to encourage the purchase of lighter-weight OTR buses.

4) Analysis of consideration in rulemakings of additional vehicle weight. Should Congress require that each rulemaking by an agency of the Federal Government that affects the design or manufacture of motor vehicles consider

    - The weight that would be added to the vehicle by the implementation of the proposed rule
    - The effect that the added weight would have on pavement wear
    - The resulting cost to Federal, State and local governments?

5) Cost-benefit analysis relating to the axle weight of OTR buses that considers

    - Cost of pavement wear caused by OTR buses
    - Benefits of the OTR bus industry to the environment, economy and transportation system of the United States.

Federal Law

Since the passage of the Surface Transportation Assistance Act of 1982, Federal weight limits on the Interstate Highway System have been 20,000 lbs for a single axle and 34,000 lbs for a tandem axle (unless the State had higher limits in effect prior to July 1, 1956). Since 1992, there has been a permissive arrangement whereby states are not required to enforce axle weight limits for intrastate transit buses. A similar arrangement for over-the-road buses was enacted in February 2003. Both are due to expire in October 2003.

As amended by Sec. 347 of the Department of Transportation and Related Agencies Appropriations Act, 2003 [Pub. L. 108-7, Division I, 117 Stat. 11, 419, February 20, 2003], Sec. 1023(h)(1) of the Intermodal Surface Transportation Efficiency Act of 1991 reads as follows:

> "(h) OVER-THE-ROAD BUSES AND PUBLIC TRANSIT VEHICLES. –
>
> "(1) TEMPORARY EXEMPTION. – The second sentence of section 127 of title 23, United States Code, relating to axle weight limitations for vehicles using the Dwight D. Eisenhower System of Interstate and Defense Highways, shall not apply, for the period beginning on October 6, 1992, and ending on October 1, 2003, to—
>
> "(A) any over-the-road bus (as defined in section 301 of the Americans with Disabilities Act of 1990 (42 U.S.C. 12181); or
>
> "(B) any vehicle that is regularly and exclusively used as an intrastate public agency transit passenger bus."

Section 12181(5) of title 42, United States Code, reads as follows:

> "(5) Over-the-road bus. The term 'over-the-road bus' means a bus characterized by an elevated passenger deck located over a baggage compartment."

Section 127 of title 23, United States Code, does not apply to trucks and buses – only to States. As a condition of accepting Federal-aid highway funds, the States must adopt and enforce the axle, bridge formula, and maximum gross weight standards of § 127(a). If a State fails to adopt laws consistent with that provision, the Federal Highway Administration (FHWA), with the approval of the Secretary, is required to withhold the National Highway System (NHS) funds that would otherwise be apportioned to that State under 23 U.S.C. 104(b)(1).

Section 1023(h)(1) allows States to exempt intrastate transit buses and OTR buses from the 20,000-pound single-axle or the 34,000- pound tandem axle limit of "S" 127 without risking loss of NHS funds. However, unless a State exercises its option to exempt them, transit and OTR buses remain subject to the normal Interstate axle-weight limits.

Current Bus Operations

Over the past 20 years, an increasing number of transit and over-the-road buses have been operating in excess of the 20,000 lb limit.

For transit buses, rear axles routinely exceed the 20,000 lb axle weight limitation when loaded with passengers. Approaches used for dealing with overweight transit buses include the following:

- Some States, particularly in the northeast, have higher axle-weight limits that preempt the Federal limits due to grandfather rights. In these States, transit buses with a seated load often remain legal.
- A number of years ago, bus operators for the Los Angeles County Metropolitan Transportation Authority (LACMTA) received traffic citations for driving overweight transit buses on Interstate highways. As a result, the authority bought over 90 tandem-axle Neoplan transit buses for freeway operation (Figure I-1).
- Federal law currently allows States to exempt intrastate transit buses from the weight limit.

Figure I-1 Transit Bus with Tandem Rear Axle (Neoplan AN440/3)

Challenges faced by the transit industry in reducing bus axle weight include the following:

- High labor costs lead to purchases of high-capacity buses, in order to ensure reasonable driver productivity.
- Wheelchair lifts and alternative fuels add to bus weight.
- There is little ability to shift passengers around in a bus to better distribute the weight of the passengers among the axles.
- The need to maneuver on city streets limits the use of tandem axles.
- Lighter-weight buses currently carry a substantial price premium, and are not yet being purchased in large numbers. An example of a lighter-weight bus is the North American Bus Industries (NABI) CompoBus™ (Figure I-2).

Figure I-2 NABI CompoBus (Photo Courtesy: NABI)

Although the overall weight of an over-the-road motorcoach tends to be higher than that of a transit bus, axle weight tends to be lower, because a large motorcoach has two rear axles. Nonetheless, a 1999 survey of Canadian motorcoach operations *(9)* found that some 18% of buses had a drive axle weight exceeding 9,100 kg (20,000 lbs). Similar to LACMTA, Greyhound bus operators have received citations in California. Challenges faced by the commercial motorcoach industry in reducing axle weight are similar to those for the transit industry, and include the following:

- High labor costs lead to purchases of high-capacity buses, in order to ensure reasonable driver productivity. In the past 10 years, there has been a shift from 40' buses to 45' buses.
- Wheelchair lifts, 4-stroke engines, and passenger amenities have added to bus weight.
- Little flexibility exists to shift the payload (passengers and baggage) around to meet axle weight requirements.

Prior to the passage of the over-the-road bus axle weight limit exemption in 2003, the commercial motorcoach industry *(10)* believed there was a substantial inequity in providing a weight exemption only to transit fleets, since in the case of commuter express services both transit agencies and private bus fleet managers provide a similar service using similar equipment.

Purpose and Organization of this Report

The issues raised by the Congressional request for the current study have existed for more than ten years, as evidenced by a request in 1992 for a similar study, that was completed in 1994 *(11)*. The purpose of this report is to provide information to Congress to clarify the choices and offer quantitative as well as qualitative insight into the tradeoffs and consequences of policy alternatives.

A difference between the 1994 study *(11)* and this report is that the scope in 1994 included only "public transit vehicles." It included 2-axle transit buses and 3-axle articulated buses, but did not include 3-axle non-articulated buses (such as those used for suburban express service and over-the-road buses).

This report is organized in the following chapters:

Chapter II presents current fleet size and weight trends.

Chapter III assesses the impact of overweight buses.

Chapter IV discusses the technical issues in making lighter-weight buses.

Chapter V presents an assessment of potential market penetration for lighter-weight buses, in both the transit and OTR sectors.

Chapter VI presents a number of policy alternatives.

Chapter VII presents a cost-benefit analysis of selected policy alternatives.

Chapter VIII presents recommendations.

Appendix 1 addresses Equivalent Single Axle Load (ESAL) factors for transit and over-the-road buses.

Appendix 2 addresses pavement damage as a function of empty weight.

Appendix 3 addresses OTR bus benefits versus pavement damage.

Appendix 4 provides a glossary of terms.

Appendix 5 lists references.

Chapter II: Current Situation and Trends

This chapter presents background material that is needed to develop effective policies with respect to bus axle weight. It includes information on the following topics:

- Bus fleet size and vehicle miles traveled. To the extent feasible, this is broken out by market segment (over-the-road motorcoach and transit bus) and roadway type (Interstate and non-Interstate).

- Bus weight analysis. This section presents axle weights and weight ratings for various bus models, weight by vehicle components, and trends in axle weights.

Since the Congressional request was for a study of transit buses and over-the-road motorcoaches, this study does not investigate school buses in depth. School buses are mentioned only because they are needed to reconcile data sources that include all buses (such as FHWA *(1)*), and data sources that are specific to one market segment (such as the American Bus Association and the American Public Transportation Association).

II.1 Fleet Composition and Size

The three major market segments for buses in the U.S. are school buses, transit buses and over-the-road motorcoaches. A school bus is defined (49 U.S.C. 30125) as a "passenger motor vehicle designed to carry a driver and more than 10 passengers, that the Secretary of Transportation decides is likely to be used significantly to transport preprimary, primary, and secondary school students to or from school or an event related to school." School buses have a wide range in sizes, from passenger vans to the 40' yellow school buses often seen on the road. School buses differ from other bus types in that they often have the engine in the front.

Transit buses are those used for public transit service. They also have a wide range in sizes. Two-axle transit buses (Figure II-1) are 30 to 45 feet long, while 3-axle 60-foot articulated buses (Figure II-2) are sometimes used on high volume routes. Both have the engine in the rear.

Figure II-1 A Typical Transit Bus

Figure II-2 Articulated Transit Bus

An over-the-road (OTR) bus is defined (42 U.S.C. 12181) as "a bus characterized by an elevated passenger deck located over a baggage compartment." Over-the-road buses generally have an engine in the rear. Typical lengths range from 30 to 45 feet.

Figure II-3 Over-the-Road Motorcoach

According to the 1997 Federal Highway Cost Allocation Study *(1)*, total bus fleet size was 654,000 vehicles in 1994, split roughly as 71% (464,000) school buses, 24% (157,000) transit buses and 5% (33,000) over-the-road buses. Since 1994, the total fleet size has increased, to 729,000 in 1999 and 746,000 in 2000 *(5)*.

Although the number of school buses is high, their impact is lower than one might expect because the miles traveled per school bus per year is substantially lower than for the other two bus types.

II.2 Vehicle Miles Traveled

To understand the pavement damage caused by transit and OTR buses on Interstate highways, it is first necessary to assess the number of vehicle miles traveled by transit and OTR buses. It is then necessary to assess the number of vehicle miles traveled on Interstate highways, for each type of bus.

In 2000, buses traveled a total of 7,601 million miles *(5)*. The number of vehicle miles, by roadway class, is shown in Table II-1.

Table II-1 VMT (millions) by Highway Class *(5)*

		Bus	Truck	Other, including auto	Total
Rural	Interstate	981	52,637	215,342	268,960
	Arterial	1,270	41,646	377,653	420,569
	Other	2,247	26,348	366,837	395,432
Urban	Interstate	791	32,191	360,598	393,580
	Other	2,312	52,969	1,215,981	1,271,262
TOTAL		7,601	205,791	2,536,411	2,749,803

Bus Vehicle Miles by Bus Market Segment

As stated earlier, the three major bus market segments are school buses, transit buses, and over-the-road motorcoaches. Reference *(1)* indirectly gives an estimate of vehicle-miles traveled by market segment, by stating "Of the total bus population of 654,000 vehicles in 1994, 71 percent were school buses, 24 percent were transit buses, and 5 percent were intercity buses … School buses average about 11,000 miles of travel each year, transit buses 22,000 miles, and intercity buses 66,000 miles per year." This statement implies the following vehicle miles traveled per year:

Table II-2 1994 Vehicle Miles (millions) by Market Segment

1994	Fleet Percent	Vehicles	Miles/vehicle/year	Vehicle-miles/year (millions)
School bus	71	464,000	11,000	5,100
Transit bus	24	157,000	22,000	3,450
Intercity bus	5	33,000	66,000	2,180

Industry sources give different estimates. APTA presents the following numbers for transit buses in 1990, 1994 and 2000:

Table II-3 Public Transit Vehicle Miles (millions) *(6)*

	1990	1994	2000 (Preliminary)
Bus	2,130	2,162	2,315
Demand Responsive	306	464	759
Total	2,436	2,626	3,074

R.L. Banks and Associates (2000) gives 2,600 million vehicle miles in 1999 for intercity motorcoaches in the U.S. and Canada, divided as 50% on scheduled intercity, 33% on charter, 6.7% tour, 4.3% private commuter, 1.6% airport shuttle, 1.3% sightseeing, 1% contract commuter, 2.4% other *(7)*. Transport Canada *(9)* estimated approximately 375 million vehicle-km (or 234 million vehicle-miles) of motorcoach travel in Canada each year, leaving 2,366 million motorcoach vehicle miles in the U.S.

Finally, the National Highway Traffic Safety Administration (2002) indicates 4,300 million annual vehicle miles for school buses *(12)*.

Combining these sources, we can derive ranges of annual vehicle miles for the transit and OTR bus market segment, as indicated in Table II-4 below:

Table II-4 Vehicle Miles (millions) by Market Segment

	Lowest estimate			Highest estimate		
	VMT	Year	Source	VMT	Year	Source
Transit	2,626	1994	APTA *(6)*	3,450	1994	Computed from *(1)*
OTR	2,180	1994	Computed from *(1)*	2,366	1999	*(7)* and *(6)*

Note that small vehicles (vans, automobiles) are often used for school bus and demand response transit services. These vehicles may be counted in the mode-specific totals, but not in the overall total for buses.

For the purpose of this study, we will use the following estimates of annual vehicle miles for transit and motorcoach in 2000 in the U.S.:

- 2,300 million for transit. This is based on APTA figures, but does not include demand-response transit. Demand-response transit vehicles are generally vans, and are much smaller than transit buses. It is rounded down to allow for some overlap between transit and motorcoach.

- 2,300 million for OTR motorcoach. This is partway between the two estimates presented in Table II-4.

If the total of 7,600 million bus vehicle miles in *(5)* is correct, this provides a split of 2,300 million for transit, 2,300 million for OTR motorcoach, and the remaining 3,000 million vehicle miles for other buses, including school buses.

Bus Vehicle Miles by Bus Market Segment and Highway Class

The vast majority of roads that urban transit and intercity coach buses travel on are part of the Federal aid highway system and receive Federal funds. Many of these roads are not Interstate highways. Interstates are an important functional class of highway, but not the only important functional class.

The following paragraphs present an approximate estimate of OTR and transit bus vehicle miles by highway class. Recall that Table II-1 gave VMT by highway class. Table II-5 gives the percentage breakdown for all buses by highway class.

Table II-5 Bus Annual VMT by Highway Class *(5)*

		Bus VMT (millions)	Percent
Rural	Interstate	981	13
	Arterial	1,270	17
	Other	2,247	30
Urban	Interstate	791	10
	Other	2,312	30
TOTAL		7,601	100

For the three market segments (OTR motorcoach, transit bus and school bus) the mileage distribution by highway class differs considerably from the averages given above. For example, urban transit buses seldom travel on Interstate highways, whereas OTR buses travel mostly on Interstates. In the 1994 FHWA study *(11)* transit fleet managers were asked, “How many miles do public transit buses with overweight single, middle and/or rear axles operate on the Interstate System in each jurisdiction or State each year?” There were a variety of responses. Those agencies that responded with total miles gave low numbers, such as 3.8%, 8%, or 1000 miles/bus/year.

This study uses the following assumptions to develop percentages of bus travel on Interstate highways for transit and OTR buses:

- Transit bus usage is primarily in urban areas, with 9% assumed on urban Interstates.
- OTR bus usage is split between rural and urban areas. Given the generally longer trip lengths for OTR trips, a high percentage of VMT is on Interstates.

The above two assumptions lead to the conclusion that school bus usage is primarily in rural areas, and accounts for the bulk of non-Interstate rural VMT. This is reasonable because in urban areas, schoolchildren are more likely to live within walking distance of the school, and, if they do travel by school bus, have shorter trips. Given the generally short trips of school buses (when compared to OTR buses) most school bus travel is assumed not to occur on Interstates.

With the above assumptions, VMT of transit, OTR and school bus travel were fitted so that the total VMT by road type would be close to those given in Table II-5. The results appear in Table II-6. Given the approximate nature of these estimates, VMT are rounded to the nearest 100 million.

Table II-6 Estimated annual VMT by Highway Class and Market Segment

	VMT (millions)			
	OTR	Transit	School	TOTAL
Rural Interstate	700	0	300	1,000
Other Rural	1,000	400	2,100	3,500
Urban Interstate	500	200	100	800
Other Urban	100	1,700	500	2,300
TOTAL	2,300	2,300	3,000	7,600

II.3 Weight Components and Trends

This section reviews axle weights for transit and over-the-road buses. After first presenting a breakdown of overall registered and operating weights, this section addresses current axle weights, the impact of vehicle components on bus weight, and historical trends in bus weight.

Reference *(1)* gives a breakdown of VMT for buses by both registered and operating weight, presented below:

Table II-7 VMT by Registered and Operating Weight

			Registered Weight		Operating Weight	
Weight range (1000 lb)	1994 Vehicles	2000 Vehicles	1994 VMT Millions	2000 VMT Millions	1994 VMT Millions	2000 VMT Millions
0 – 20	150,519	173,536	1,476	1,701	1,355	1,562
20 – 30	340,305	392,345	3,336	3,847	2,400	2,767
30 – 40	104,709	120,721	1,027	1,184	2,255	2,600
40 – 50	58,899	67,905	577	666	354	408
50 – 60					52	60
Bus Total	654,432	754,509	6,416	7,397	6,416	7,397

The high number of vehicles under 30,000 pounds presumably include most school buses and demand-response transit vehicles. The 30,000 to 40,000 pound class may include some school buses, most transit and most mid-size over-the-road buses. The over 40,000 pound categories include some transit and most of the larger over-the-road buses.

II.3.1 Axle Weights by Bus Configuration

Transit Buses

Transit buses typically have one of two configurations: 2-axle and 3-axle articulated[4]. Most (80%) of the 2-axle transit buses listed in the 2002 APTA Vehicle Survey *(13)* have a length of 40 feet. The 3-axle articulated design is typically used on high volume transit routes. This bus has a two-axle front section attached to a one-axle rear section, and a typical total length of 60 feet.

Forty-foot low floor models are the most popular among new two-axle transit buses, although the majority of buses now in use are high floor models. The overall Gross Vehicle Weight Rating (GVWR) is a maximum weight established by the manufacturer for the vehicle. It includes passengers and baggage. For standard 2-axle transit buses the GVWR ranges from 29,000 lbs to about 40,000 lbs. It is larger (66,000 lbs) for three-axle articulated buses. Each axle on the bus also carries a specific weight rating. The weight rating gives an upper bound on the weight that should be carried on the axle, and may be much higher than the actual axle weight. For the front (steering) axle this ranges from 12,000 lbs to 16,500 lbs, although current tire and wheel technology limits the front axle weight to approximately 14,600 lbs. The rear drive axle holds the higher weight rating, ranging from 19,000 to 28,600 lbs. For articulated transit buses, the third axle supports the aft section of the vehicle, and it may have a rating as high as 26,000 lbs.

The 1994 FHWA study *(11)* gave axle weights for several popular 40-foot transit bus models. The weights for the Neoplan AN-440-A are from *(14)* while the other weights are from the Altoona Bus Testing and Research Center (the study did not give axle weights for the North American Bus Industries buses):

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[4] The tandem-axle transit bus (such as the Los Angeles County Metropolitan Transportation Authority Neoplan bus discussed in Chapter 1) is not a typical transit bus.

Table II-8 Loaded Axle Weights (lbs) for 40-foot Transit Buses

Manufacturer	Model	Total Empty Weight	Gross (Seated)		Gross (Seated + Standing)	
			Front	Rear	Front	Rear
NOVA Bus	RTS T80 206	27,600	12,700	21,500	14,250	25,200
Gillig	Phantom	28,650	12,950	22,700	14,500	25,600
Orion	V	25,880	11,424	21,356	14,499	25,040
New Flyer	D40LFS	25,550	8,800	21,050	10,800	22,600
Neoplan	AN-440-A	27,830	11,650	22,480	12,900	24,780

Over-the-Road Buses

Over-the-road buses are widely used in intercity commercial bus service and in some suburban commuter express transit service. They typically have a 3-axle non-articulated design. This bus has a raised deck over a baggage compartment, with engine in the rear. Bus length is normally between 35 and 45 feet. The first rear axle (called the drive axle) has a weight rating similar to that for a transit bus (up to 26,000 lbs) and has a pair of tires on each side. The second rear axle often has only one tire on each side. It is called a trailing axle or tag axle and typically has a weight rating of about 14,000 lbs, or about 60% of the load rating of the drive axle.

The Prevost H series motorcoach curb weight is 36,860 lbs, with a seating capacity of 56 to 58 passengers. Measurements from the Altoona Bus Research and Testing Center indicate the Motor Coach Industries (MCI) D4500 has an empty weight of 36,680 lbs, almost identical to that for the Prevost bus.

Kulakowski et al. (2002) used the following weights (including passengers) for the prototypical transit bus and motorcoach *(15)*:

Table II-9 Axle Weights used in Kulakowski *(15)*

Bus type	Gross weight (lb)	Front-axle (lb)	Drive-axle (lb)	Tag-axle (lb)
40' transit	38,210	13,152	25,059	N/a
45' motorcoach	44,396	13,377	21,393	9,626

II.3.2 Weight by Vehicle Component

Transit Buses

No recent information is available on the detailed weight breakdown for a transit bus. Reference *(8)* presents a weight breakdown for a General Motors Corporation (GMC) transit bus. With a full passenger load (45 seated, 34 standees at 150 lb each) Figure II-4 shows the breakdown.[5]

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[5] Since this study used an older model bus, the total weight for their bus is several thousand pounds lighter than is typical for buses today. However, the rough percentage breakdown by component is still valid.

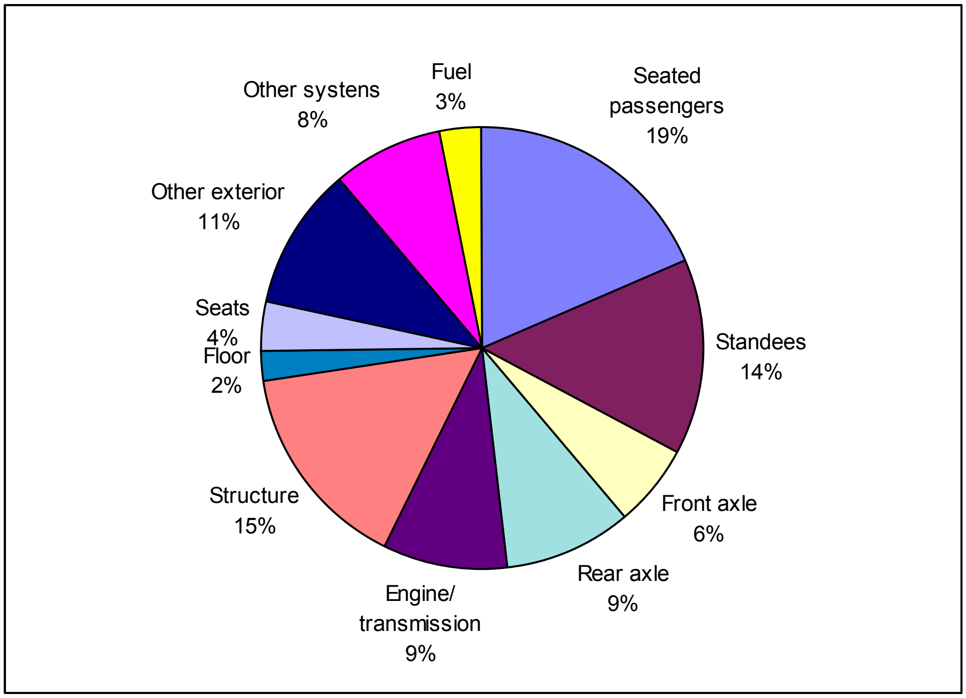

Figure II-4 Weight Breakdown for Transit Bus (from GMC, total weight 36,050 lb)

Over-the-Road Buses

Similar to a transit bus, components of OTR bus weight include the frame, body, drive train (engine, differential, axles), and passengers. Detailed information reported for the Prevost Car XLII intercity bus shown is in Figure II-5 *(9)*:

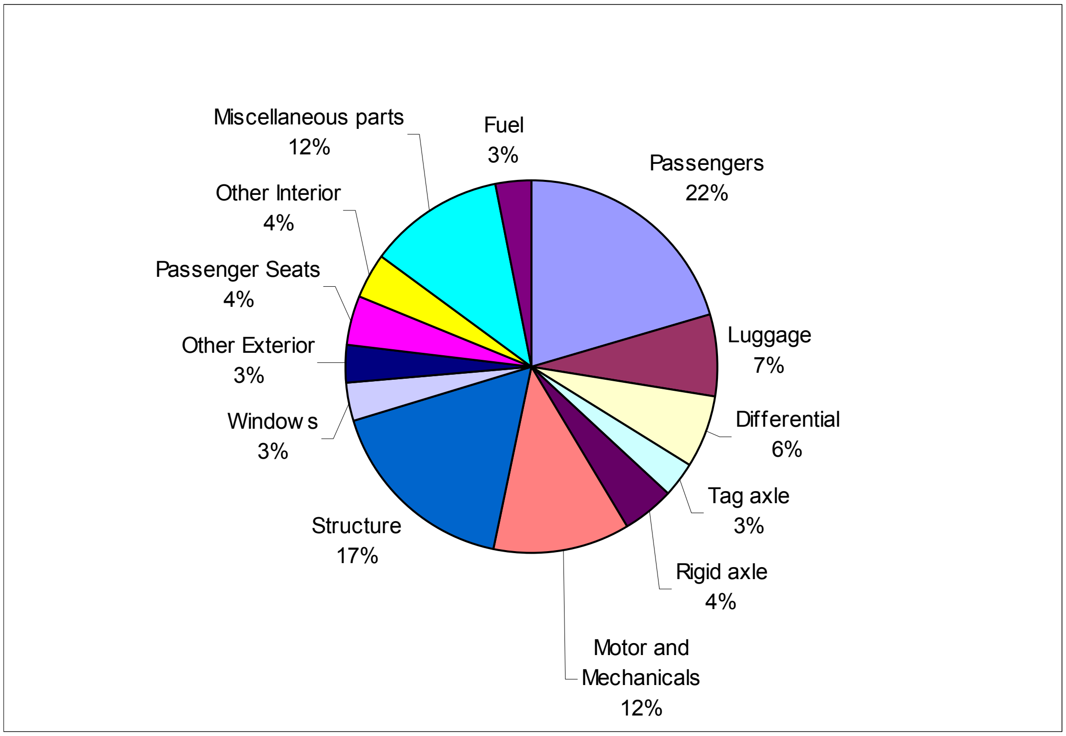

Figure II-5 - Weight Breakdown for Intercity Motorcoach (from Prevost, total weight 47,000 lb)

Industry sources [Meritor, 3/21/03] indicate axle weights between 1000 and 1800 lbs, with the higher weights for the drive axles. Engines are approximately 2000 – 2500 lbs [Detroit Diesel], and transmissions are about 1000 lbs [Allison].

II.3.3 Trends in Vehicle Weights

Excessive weight concerns manufacturers because it affects

- Fuel economy
- Vehicle cost operating and capital cost by requiring more robust suspension, propulsion and braking
- Vehicle capital cost by requiring stronger structural components.

Manufacturers continually look for ways to reduce weight. Recent examples include the use of composites for non-structural parts and an estimated savings of over 300 lbs by using multiplexing for wiring systems *(16)*.

At the same time, a number of factors are leading to increased vehicle weights. Since larger vehicles carry more passengers, they tend to have lower per-passenger driver and maintenance costs, thus improving productivity. Other considerations leading to increased vehicle weight include a desire for a greater number of passenger amenities on over-the-road buses, safety improvements, environmental concerns (such as new fuels and emissions control equipment), and the need to accommodate passengers with disabilities. The estimates of increased weight due to these items vary widely. It is important to note that the short-term impact of a requirement (e.g. for wheelchair access or reduced emissions) may be considerably larger in both weight and cost than the long-term impact of the requirement. In the short term, the requirement is generally met via a modification to an existing design (e.g. a wheelchair lift added to the existing design for a high-floor bus) while in the long term, the new vehicle can be designed with the requirement in mind (e.g. a wheelchair ramp on a low-floor bus).

Over the years, the weights of both transit buses and motorcoaches have increased (Figure II-6). Transit bus curb weights (defined as the weight of the empty vehicle with a full fuel tank) were taken from *(8)*.[6]

Motorcoach information is for a Prevost intercity OTR motorcoach *(9)*. This study noted that 45-foot buses were introduced in 1993.

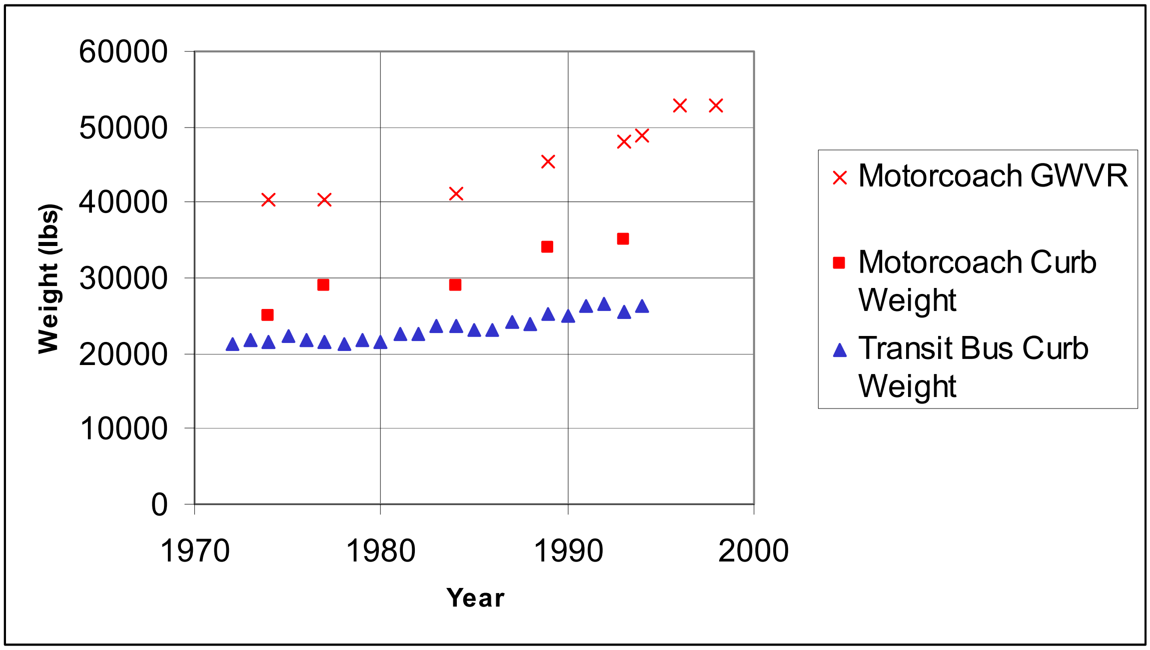

Figure II-6 Historical Development of Bus Weight

II.3.4 Factors Leading to Increased Vehicle Weight

The major factors leading to increased vehicle weight are discussed in more detail below, first for transit buses, and then for over-the-road buses.

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[6] The data in this study represent an average for transit buses in Canada. In the U.S., the curb weights for 31 40-foot diesel transit buses tested in Altoona during the 1990s were reviewed. The median weight was approximately 28,000 lbs, which is consistent with the most recent Canadian data. This is not surprising, since the Canadian and U.S. bus industries share many of the same manufacturers, and operate under similar constraints. It is interesting to note that even though accommodation of passengers with disabilities is often given as a reason for the weight increase, much of the weight increase occurred before such accommodations were required at the Federal level (Americans with Disabilities Act of 1990 and the Canada Transportation Act of 1996).

Transit

Major sources of increased transit bus weight in recent years include Americans with Disabilities Act (ADA) accessibility requirements and the use of some alternative fuels.

Passengers with Disabilities

Accommodation of passengers with disabilities, particularly persons in wheelchairs, impacts bus weight in two ways. The direct impact comes from the actual weight of the devices used for such accommodation, such as wheelchair lifts and tiedowns. There is also an indirect impact in that these accommodations may reduce passenger capacity.

On a high floor transit bus, respondents in the 1994 FHWA study indicated that wheelchair lifts and tiedowns add approximately 1,100 lbs to the weight *(11)*. In contrast, the marginal weight of a ramp on a low-floor bus is considerably less, perhaps 100 lbs. There may be some additional weight due to the need for reinforcement around the installation [reference Lift-U/Hogan Mfr 209-838-2400].

Figure II-7 Wheelchair Ramp

Recent National Highway Traffic Safety Administration (NHTSA) rules (Federal Motor Vehicle Safety Standards (FMVSS) 403 and 404 /NHTSA docket 2002-13917, effective 12/27/2004) might increase the weight impact of wheelchair lifts significantly. The rules require 600 lb capacity lifts on all public/private vehicles over 10,000 lbs that carry passengers. They require that the proof test load of three times the operational capacity (1,800 lb) be done in an actual bus rather than on a test stand and the lift must remain operational after the test. An ultimate load test of four times the operational capacity (2,400 lb) must also be performed, although it may be performed on a test stand.

In addition to the direct weight of the devices, reinforcements and accessories, the accommodations impact vehicle passenger capacity. NABI has stated because of difficulty in placing seats over the wheel wells, a low floor bus has a somewhat lower seating capacity than its high floor counterpart *(17)*.

Alternative Fuels

With the concern about the impact of diesel exhaust on air quality in urban areas, there is continuing interest in alternative fuels for transit vehicles. Given the weight of batteries (for electric or hybrid electric buses) and the fuel tanks (for compressed natural gas buses), alternative fuel systems can add significantly to vehicle weight. One reason is that the use of CNG involves the use of large fuel tanks, generally placed on top of the bus (see Figure II-7 above). NABI [Coryell] noted that given infrastructure and emissions concerns with CNG, and improvements in diesel emissions control, CNG buses might be less popular in the future. Table II-10 illustrates estimated and measured weight impacts of alternative fuels:

Table II-10 Alternate Fuel Impacts

Fuel	Added Weight (lbs)	Source
Diesel-electric hybrid	several thousand	Coryell
	3,000 – 3,500	Braeger
	< 3,000 lbs	Alison, BAE
	1,025 lbs	Curb weight difference between Orion VI diesel and Orion VI hybrid-electric, from Altoona data
CNG	3,000	Coryell
	2,500 – 2,800	Braeger
	2,700 – 3,500 lbs	Respondent in *(11)*
	2,270 lbs	Curb weight difference between Orion VII with diesel and CNG, from Altoona data
	2,600 lbs	Curb weight difference between Neoplan AN440 with diesel and CNG, from Altoona data
LNG	1,755 lbs	Difference between Ikarus 416 with and without LNG, from 1994 study

Other issues

Transit managers have indicated that other sources of increased weight included crashworthiness requirements, air conditioning and emissions controls *(11)*. Finally, since the 1970s, the allowable width of vehicles has increased from 96 to 102 inches.

Summary

To summarize, the major factors leading to increased transit bus weight are listed below:

Table II-11 Major Contributors to Increased Transit Bus Weight

Item	Approximate weight added
Wheelchair lift or ramp	100 – 1,100 lbs
Added structure to accommodate lift	Not well quantified, but probably minimal
Alternative fuels	2,000 – 3,000 lbs
Crashworthiness improvements	500 lbs
Other factors (emissions controls, width increase, air conditioning, long service life requirements)	Not well quantified
TOTAL	3,000 lbs or more

Motorcoach

Major sources of increased weight for over-the-road buses include increased length and passenger capacity, passenger amenities, safety improvements, emissions, and accommodation of passengers with disabilities.

Length and Passenger Capacity

Prior to 1991, most states limited motorcoach lengths to 40 feet. However, with the passage of the Motor Carrier Act of that year, Congress prohibited states from imposing a maximum length of less than 45 feet. Part of the rationale for this length change was to maintain passenger capacity in the face of ADA wheelchair accommodation requirements *(10)*. This has some impact on weight. For example, the 41-foot version of the Prevost H Series motorcoach has a seating capacity of 48, and an empty weight of 35,535 lbs, while the 45-foot version has a seating capacity of 56-58 and an empty weight of 36,860 lbs. This is a difference of 1,325 lbs in empty weight, while the gross weight (including the extra passengers) is about 3,000 lbs higher *(18)*.

Passenger Amenities

The ABA reports *(10)* that passenger amenities have added several hundred pounds. Examples include

- Video/sound systems: 250 to 300 lbs
- Noise and vibration abatement: 500 to 800 lbs
- Seating comfort: 50 to 200 lbs.

While the government does not mandate these amenities, they may be necessary to maintain the competitiveness of buses in the marketplace.

Safety Improvements

In the motorcoach industry, improved braking systems may add perhaps 400 to 500 lbs *(10)*. There is also concern that the indiscriminate extension of automotive requirements (for example, the specifications for seatbelts) could add substantially to the weight of a bus [Murphy].

Emissions

Although the consensus is that added weight from emission control equipment is minimal, the American Bus Association claims an increase of more than 1400 lbs due to the change from 2-stroke to 4-stroke engines, and environmentally friendly refrigerant systems.

As diesel systems become cleaner (via the use of particulate filters), interest is waning in alternative fuels for over-the-road buses.

Passengers with Disabilities

Accommodation of passengers with disabilities, particularly wheelchairs, impacts motorcoach weight in the same ways as on a transit bus. The direct impact comes from the actual weight of the devices used for such accommodation, such as wheelchair lifts and tiedowns. There is also an indirect impact in that these accommodations may reduce passenger capacity.

An OTR bus lift weighs about 700 lb. It requires less automation than the transit version, although an OTR bus manufacturer estimates it adds up to 2,000 lbs to curb weight. Components of the added weight include the wheelchair lift, moveable seats, added structure to accommodate the lift and boarding door, wider entrance doors, securement devices, and ingress/egress assists *(10)*.

Recent NHTSA rules (NHTSA FMVSS 403 and 404) regarding weight capacity requirements for wheelchair lifts would impact motorcoaches just as they do transit buses.

In addition to the weight of the lifts, tiedowns and other devices, the accommodations impact vehicle passenger capacity. Part of the rationale for increasing the length of OTR motorcoaches from 40 to 45 feet was to restore the space taken by wheelchair accommodation *(10)*.

Summary

To summarize, factors leading to increased weight on motorcoaches are listed below:

Table II-12 Major Contributors to Increased OTR Bus Weight

Item	Approximate weight added
2-stroke to 4-stroke engines	1,200 lbs
Freon replacement AC systems	200 lbs
Wheelchair lift	700 lbs
Added structure to accommodate lift	1,000 lbs
Entertainment systems	250 – 300 lbs
Noise and vibration abatement	600 – 800 lbs
Seat comfort	50 – 200 lbs
Increased bus length	1,000 – 2,000 lbs
Increased passenger capacity (8 passengers and baggage)	1,500 lbs
More durable power train	200 lbs
More durable anti-lock brakes	400 – 500 lbs
TOTAL	6,000 – 9,000 lbs

Chapter III: Impacts of Overweight Buses

The 1997 Federal Highway Cost Allocation Study *(1)* gives five areas of social cost for vehicle operation: pavement damage, congestion, crash, air pollution and noise. For heavy vehicles on Interstate highways, this study indicates that the largest costs are for pavement damage, air pollution, and (in urban areas) congestion.

III.1 Pavement Damage

As the tires of a heavy axle roll across a stretch of pavement, the pavement deflects, i.e., it bends downward, as shown in Figure III-1. For flexible (asphalt) pavement, the deflection is relatively large (often visible to the naked eye), but the pavement essentially springs back to its previous state. The repeated flexing, however, gradually weakens the binder (tar or asphalt), and eventually the aggregate (crushed rock) separates from the binder. The pavement cracks, shows other signs of distress (e.g., rutting, which amounts to two parallel longitudinal depressions) and ultimately breaks up into chunks of detached aggregate and binder.

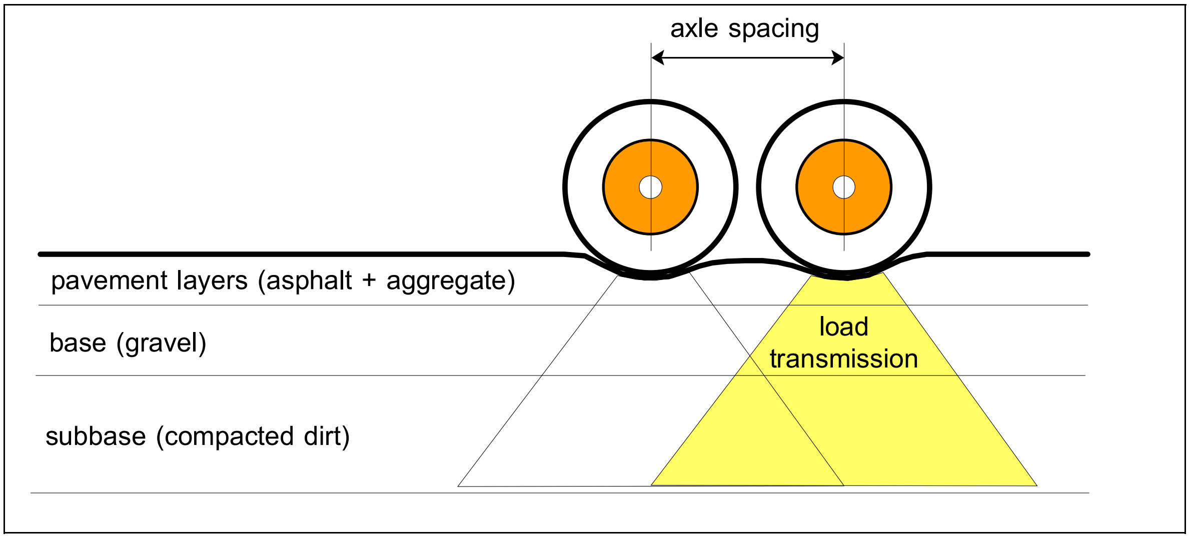

Figure III-1 Pavement Deflection from Tandem Axle

Rigid pavements made with Portland cement concrete are stiffer due to the greater stiffness of the concrete and the structural effect of steel reinforcing bars imbedded in the concrete. Rigid pavements do not deflect as much as flexible pavements, but heavy loads affect them in other ways. Tires on heavy axles damage the surface of the concrete, causing it to crack or spall (flake) off, eventually exposing the steel to corrosion from water and road salts. Heavy axles also cause expansion joints to separate. Undamaged steel-reinforced concrete can withstand many heavy axle loads, but if the load exceeds the elastic limit of the steel, the pavement does not recover from the deflection and is said to have failed; in effect, a single pass by an overloaded vehicle can destroy a concrete pavement.

An arbitrary scale has been established to measure the stress of an axle on a pavement, and the units are ESALs.[7] An ESAL (Equivalent Single Axle Load) is defined as the equivalent of a single 18,000-pound axle. The stress on the pavement depends on the axle weight, axle configuration, and the strength of the pavement. A commonly used measure of flexible pavement strength is Structural Number (SN). An SN of 5 represents a heavy-duty pavement while an SN of 2 represents a light-duty pavement. The structural number itself is a function of the depth of the various pavement layers. Thicker layers result in a higher structural number. For rigid pavements, the measure used is pavement depth (D).

The relationship between axle weight and pavement damage has traditionally been viewed as a 4th power relationship, as shown in Figure III-2. This means that doubling the axle weight (say, from 18,000 to 36,000 lbs) will result in an approximately 16-fold increase in pavement damage.

In 1989, Small, Winston and Evans refitted the American Association of State Highway Officials (AASHO, predecessor to AASHTO) data using different economic methods, and found that the relationship between axle weight and pavement damage may be closer to the 3rd power, rather than the 4th power *(2)*. The authors also developed a revised ESAL lifetime equation, and concluded that the AASHTO equation overestimates the ESAL lifetime for heavy-duty pavements.

There is no clear consensus as to what the revised equations should be. Accordingly, this study uses the traditional AASHTO relationships, as presented in the 1993 *AASHTO Guide for Design of Pavement Structures (3),* which form the basis for the equations that are used in the Highway Economic Requirements System. Use of the revised equations would lead to the higher pavement damage costs on heavy-duty pavements, though they would still be an order of magnitude less than the pavement damage costs on lighter-duty pavements. The conclusions of this study would not change.

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[7] American Association of State Highway and Transportation Officials (AASHTO) Road Test.

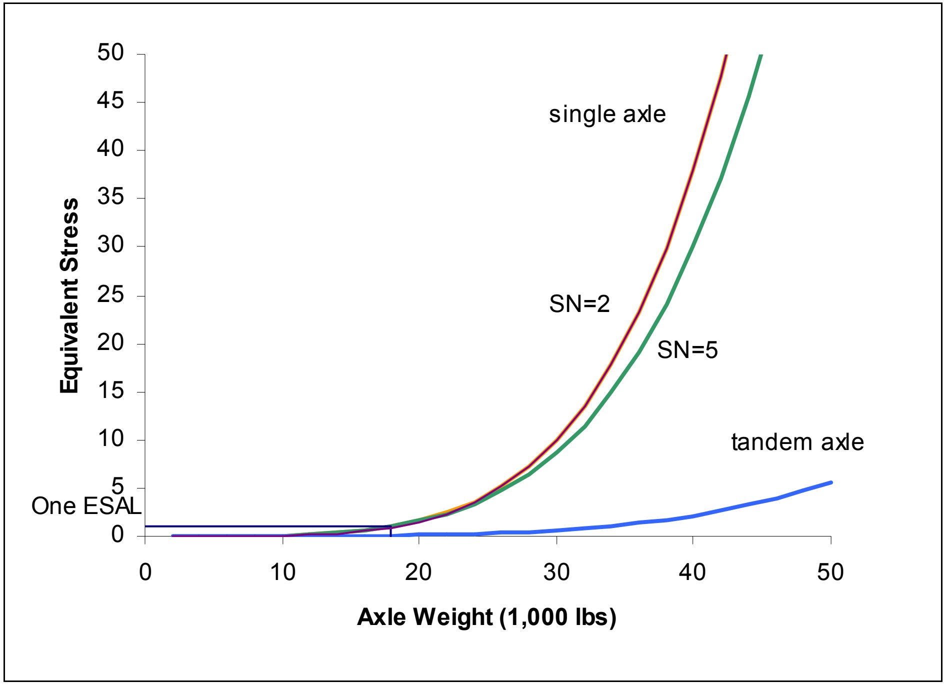

Figure III-2 Axle load Equivalence Factors for Flexible Pavement ***(3)***

Because of the geometric relationship between axle weight and stress, the pavement damage caused by a heavy vehicle is less if the vehicle has more axles for the same gross weight. The weight-spreading value of more axles is somewhat altered if they are close together, as is the case with tandem axles. For example, on rigid pavement, a tandem axle carrying 36,000 lbs (18,000 lbs on each of the individual axles) would impose approximately 2.5 ESALs, and not the 2 ESALs that would be imposed if the axles were spaced further apart.

ESAL equivalency factors show the relative impact of different axle weights, holding pavement type and strength constant. They do not indicate an absolute amount of damage or stress, nor even a relative magnitude of cost of the damage.

Pavement Strength

A thicker pavement is better able to withstand stress from heavy axles. For flexible pavements, the pavement structure is composed of several layers, each transmitting the load to the next lower layer (which include gravel and compacted earth at the bottom) and also spreading the load out, as in Figure III-1. Table III-1 presents average structural numbers for various functional classes for urban and rural roads. Averages were obtained from the Highway Performance Monitoring System (HPMS) sample database, which is expanded to represent all non-local roads in the US.

Table III-1 Average Structural Number (SN) by Pavement Type

Pavement Type	Flexible Pavement, average SN (from HPMS)
Rural Interstate	5.33
Rural Other Principal Arterial	4.15
Rural Minor Arterial or Collector	3.26
Urban Interstate	5.40
Urban Other Principal Arterial	4.29
Urban Minor Arterial or Collector	3.35

Making a rigid pavement deeper provides greater strength in the same way a deeper beam is stronger. The commonly used measure of strength for a rigid pavement is depth D (in inches). A larger depth indicates a stronger pavement. The default values in the Highway Economic Requirements System (HERS) for light, medium and heavy-duty pavements are given below *(4)*:

Table III-2 HERS Default Values for SN and D

Pavement Class	Structural Number (SN)	Depth (D)
Heavy	5.3	10
Medium	3.8	8
Light	2.3	6.5

The relationship between the structural number (SN, for flexible pavement) and depth (D, for rigid pavement) is similar to the relationship between axle weight and stress: a small amount of additional depth provides a proportionately higher amount of strength (Figure III-3). In this figure, the ESAL lifetime is the number of ESALs that will pass over a section of pavement to reduce its Present Serviceability Rating (PSR) from 5.0 (better than new) to 1.5 (badly broken up).[8] Although the curve appears flat for structural numbers below 3.0, the curve rises steeply at all levels and would look the same if the vertical scale were expanded; the knee of the curve would simply shift leftward. What this implies is that a small amount of additional depth or a higher structural number increases the ability of the pavement to withstand ESALs much more than proportionately. If the cost of the pavement is roughly proportional to its thickness, this means that there are economies of scale in building stronger pavement.

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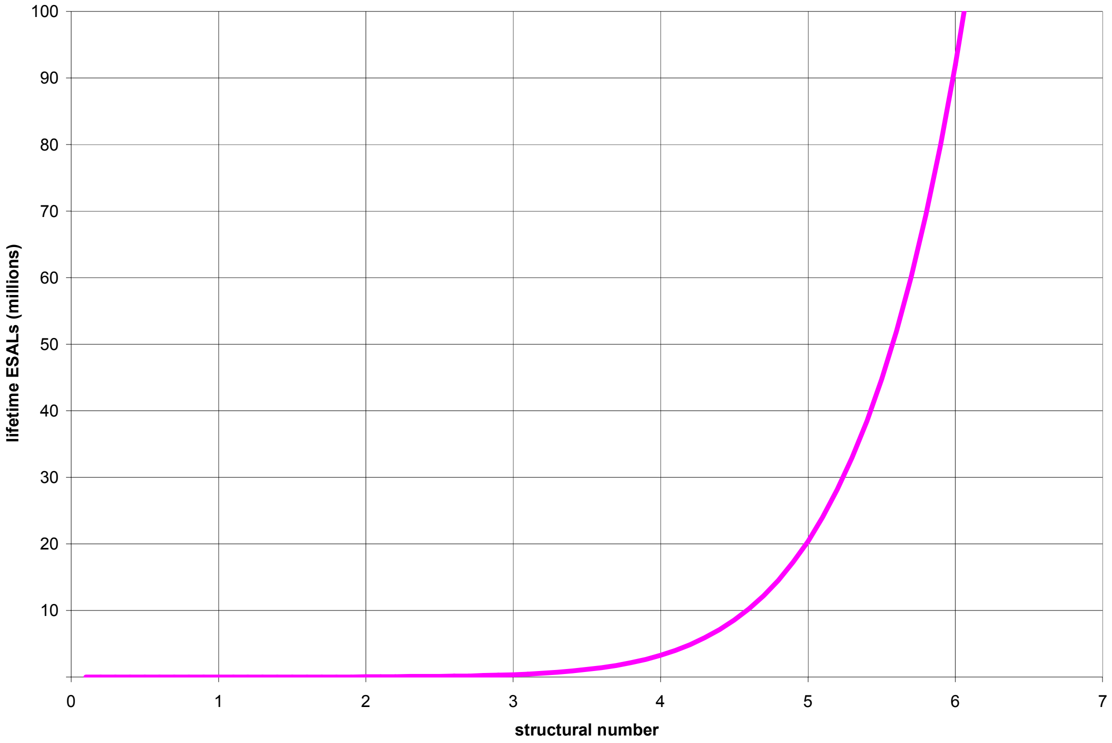
[8] The Present Serviceability Rating is a subjective system based on a 0 to 5 scale. A rating of 5 is better than new, while ratings of 2 or below indicate enough deterioration to significantly affect the speed of free flow traffic *(19)*.



source: Flexible pavement design equation from *(3)*.

Figure III-3 Relationship Between Lifetime ESALs and Structural Number

It also means that the cost of an ESAL (discussed in the next section) depends greatly on the structural number or depth of the pavement. Even though their initial cost is higher, high-strength pavements generally have a lower cost per ESAL.

Cost of Pavement Damage

Pavement wear is a variable cost in that each time a heavy axle passes over a pavement, it causes some damage. Pavement restoration, however, is a capital cost, in that it occurs less often than once a year. Imputing a cost to the ESAL application from the restoration expenditure requires some leaps of logic.

Vehicle wear is similar: driving at high speeds on rough roads will cause screws to loosen, welds to break, and metal to fatigue. Over time, temperature and moisture also cause deterioration. Eventually the vehicle has to be scrapped or rebuilt. Smoother roads and slower speeds will slow the process, but wearing out of the capital asset still occurs.

For pavement, there are good models of the independent effects of axle applications on pavement condition, as described above. But because the damage is not corrected immediately, there is a problem in matching the restoration cost to the damage. One perspective is to say the passage of a heavy axle advances the time of restoration by some number of days, and the present value of advancing the restoration schedule is the cost of the damage. This assumes the pavement already exists, and future ESAL traffic is predictable. But pavements are being designed and constructed now to serve expected future traffic; there is no justification in assuming there are no costs until the system wears out and has to be replaced. There is no market for middle-aged pavements, whereas vehicles can be readily sold to recover their capital costs.

A reasonable assumption is to treat the damage and the restoration cost as simultaneous, for discounting purposes. All ESALs are regarded as identical, without respect to whether they occur early or late in the lifetime of the pavement. The cost per ESAL, then, is a matter of matching the ESAL life of the pavement to the cost of constructing it.[9] The results are shown in Table III-3. Structural numbers were obtained from Table III-1. In Table III-3, the reconstruction cost does not include added congestion delay during reconstruction, nor added user cost (such as vehicle wear and fuel) during the time before reconstruction when the road is in poor condition. The ESAL lifetimes are estimated from the American Association of State Highway and Transportation Officials (AASHTO) design equation for a number of characteristics that are taken as average, except for the structural number. Since the cost used is that for full reconstruction (and not merely resurfacing), the PSR (present serviceability rating of the pavement) is assumed to start at 5.0 (better than new) and deteriorate to 1.5 (badly broken up).[10] Maintenance costs are ignored, but normal maintenance is assumed.

Table III-3 Flexible Pavement Restoration Costs per ESAL

Functional Class	SN[11]	Reconstruction Cost ($1000 $/lane-mi)	ESAL Lifetime (PSR 5.0 to 1.5)	$ / ESAL-mi
Rural Interstate	5.33	540	34,510,000	$ 0.016
Rural Other Principal Arterial	4.15	520	4,404,000	$ 0.118
Rural Minor Arterial, Collector	3.26	491	638,000	$ 0.770
Urban Interstate	5.40	1,595	38,438,000	$ 0.042
Urban Other Principal Arterial	4.29	1,000	5,777,000	$ 0.173
Urban Minor Arterial, Collector	3.35	831	789,000	$ 1.053

Using costs per lane mile assumes that the AASHTO design equation applies to each lane of a facility, not to all lanes collectively.

Heavy-duty pavements, such as on Interstates and other expressways, are built to withstand heavy axles, and the cost per application is modest. For lighter pavements, however, heavy axles can be very destructive.

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[9] The methodology used here follows that of Appendix E of the 1982 Federal Highway Cost Allocation Study *(20)*. Economists prominent in the transportation field reviewed this method at the time, and it conforms to accepted economic concepts. The method avoids the allocation of fixed costs to vehicle classes, and is based directly on ESAL impacts rather than other attributes of the vehicle.

[10] Unit costs are taken from the HERS (Highway Economic Requirements System) model *(4),* in 1997 dollars.

[11] Because of the sensitivity of the strength of the pavement to its SN, a small error in the estimation of SN results in high variability in the cost per ESAL.

User Costs

Between the time when a heavy axle damages the pavement and the restoration of that pavement, the roughness of the pavement is increased for other users. The vehicles most affected by the roughness are passenger cars. Such vehicles incur greater fuel consumption, tire and vehicle wear, and slower speeds as a result of the roughness. Without the heavy axles, the passenger vehicles would not suffer these effects.

Because it makes it "cheaper" for the heavy vehicles to restore the pavement periodically at intervals of ten or twenty years, rather than each time the damage is done, the lower cost of restoration should be offset by the added costs to owners and operators of passenger vehicles as a result of "batching" the road repair.

Congestion

Congestion costs directly associated with pavement damage include added congestion that might occur due to rough roads and during pavement restoration.

Environmental Costs

By and large there are no significant environmental costs directly associated with pavement damage. It is possible that there might be some indirect effects if passengers were shifted from one mode to another or deterred from traveling or encouraged to travel.

Damage Cost Rates for Buses

With ESAL factors for single and tandem axles, on flexible and rigid pavement, for a range of pavement strengths, the ESAL stress placed on the pavement by a given vehicle can be calculated from the distribution of weights on each axle. Using the prototypical transit bus and motorcoach from *(15)* (see Table II-9), as well as some prototypical lightly loaded vehicles, the damage costs can be estimated under various configurations. Table III-4 presents the ESALs for various vehicle configurations.

Table III-4 ESALs for Transit Buses and Motorcoaches

Type of Bus	Axle Weight (lbs) Front	Rear	Tag	ESALs
40' Transit (seated plus standees)				
Interstate	13,152	25,059		4.08
Other	13,152	25,059		4.50
40' Transit (13 passenger load)[12]				
Interstate	10,303	19,647		1.40
Other	10,303	19,647		1.56
45' Motorcoach (full seated load)				
Interstate	13,377	21,393	9,626	2.06
Other	13,377	21,393	9,626	2.16
45' Motorcoach (37 passenger load)				
Interstate	12,729	20,383	9,177	1.66
Other	12,729	20,383	9,177	1.86

Applying ESAL factors specific to the road type (Interstate, other) and the actual weights by axle, summing the ESALs for each axle of the vehicle, and then multiplying by the cost factor specific to the road type gives the dollars per vehicle mile for the vehicle (Table III-5).

This table gives the estimated pavement damage cost per VMT for the functional classes of Interstate, Other Principal Arterial (OPA), and Minor Arterial/Collector (MAC). The cost per ESAL-mile is from Table III-3.

Table III-5 Estimated Pavement Damage Cost per Vehicle Mile

		Transit		OTR	
Functional Class	$/ESAL-mile	ESAL	$/VMT	ESAL	$/VMT
Rural Interstate	$ 0.016	1.40	$ 0.02	1.66	$ 0.03
Rural OPA	$ 0.118	1.56	$ 0.18	1.86	$ 0.22
Rural MAC	$ 0.770	1.56	$ 1.20	1.86	$ 1.44
Urban Interstate	$ 0.042	1.40	$ 0.06	1.66	$ 0.07
Urban OPA	$ 0.173	1.56	$ 0.27	1.86	$ 0.32
Urban MAC	$ 1.053	1.56	$ 1.65	1.86	$ 1.96

Table III-6 gives the estimated vehicle-miles traveled and total pavement damage cost. Vehicle-miles per year are computed from Table II-6, under the assumptions of

- No travel on roads other than Interstate highways, arterials or collectors
- Non-Interstate operations is primarily on Other Principal Arterials (OPA), i.e. OPA / (OPA + MAC) = 60%

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[12] The ESALs of a transit bus varies enormously with the passenger load. Since most transit vehicles operate at far less than their full crush capacity, an ESAL-weighted average transit bus passenger loading of 13 is assumed in Table III-5. Similarly, the ESAL-weighted average motorcoach loading is 37 passengers. Appendix 1 contains a derivation of these assumed loadings, which, because of the fourth power rule, are somewhat higher than the average passenger loads.

Table III-6 Estimated Bus Total Pavement Damage Cost

	VMT (millions)		Cost (millions $)	
Functional Class	Transit	OTR	Transit	OTR
Rural Interstate	0	700	$ 0	$ 18
Rural OPA	240	600	$ 44	$ 132
Rural MAC	160	400	$ 193	$ 574
Urban Interstate	200	500	$ 12	$ 35
Urban OPA	1,020	60	$ 276	$ 19
Urban MAC	680	40	$ 1,120	$ 79
Total Rural	**400**	**1,700**	**$ 237**	**$ 724**
Total Urban	**1,900**	**600**	**$ 1,408**	**$ 133**
Overall Total	**2,300**	**2,300**	**$ 1,645**	**$ 857**

Based on Table III-6, the pavement damage cost (averaged over all roadway types) for a transit bus is $0.72 / vehicle-mile. For an over-the-road bus, the weighted average is $0.37 / vehicle-mile.

ESAL loadings of buses are in the same order of magnitude as those of trucks. A fully loaded 80,000 lb 5-axle tractor-trailer might have an ESAL loading of 4 to 5, similar to that of a fully loaded transit bus *(21)*. However, since the payload / empty weight ratio is higher for a truck than a bus the range of axle weights for trucks is greater than it is for buses. A lightly loaded tractor-trailer may weigh approximately 40,000 lbs *(1)*, and would impose a significantly lower ESAL loading, due to the fourth power rule.

The use of air suspension in many buses means that for a given axle weight, buses may cause somewhat less pavement damage than some trucks.

Conclusions

Four conclusions may be drawn from the above analysis of pavement damage:

1. On Interstate highways, over-the-road buses cause more pavement damage ($53 million / year) than do transit buses ($12 million / year). This is because OTR buses travel more miles on Interstate highways than do transit buses.

2. On roads other than Interstate highways, transit buses cause more damage than OTR buses ($1,633 million versus $804 million). However, this conclusion is highly dependent on the assumptions that are made about the types of roads that these buses operate on. The above conclusion is based on the assumption that non-Interstate operations for both transit and OTR buses are split between Other Principal Arterials and Minor Arterials/Collectors in a 60/40 ratio.

3. The bulk of damage caused by both transit and OTR buses is on non-Interstate roads, particularly those highways that have been built to lower pavement strength.

4. As expected, since transit and over-the-road buses travel 1/27th the vehicle-miles per year of trucks (7.6 billion VMT for buses versus 206 billion VMT for trucks), the

pavement damage cost attributable to buses is at least an order of magnitude lower than that attributable to trucks.

III.2 Other Impacts

Bus operation also affects congestion, safety, air pollution and noise. These impacts are briefly discussed below.

III.2.1 Congestion

The 1997 Highway Cost Allocation study *(1)* presented high, middle and low estimates for congestion costs. The congestion costs for buses are taken from the middle estimates and are given in Table III-7. Total costs are calculated using the VMT given in Table II-6.

Table III-7 Congestion Costs

Cost per vehicle-mile ($) (From *(1)*, table V-23)	Transit	OTR
Rural	0.0237	0.0237
Urban	0.1278	0.1278
Annual Cost (Million $)	Transit	OTR
Rural	9	40
Urban	243	77
Net cost per vehicle-mile ($, weighted average)	0.11	0.05

The middle estimates of congestion cost for *automobile* travel from *(1)* $0.0128 (rural) and $0.0621 (urban) per vehicle-mile. The congestion cost per vehicle-mile of bus travel is approximately twice that of an automobile. However, given the higher occupancy of a bus, the congestion cost per ***passenger***-mile of bus travel is much lower.

If we assume that available engine power is matched to the curb weight of the bus (i.e. heavier buses have more powerful engines, and therefore do not cause increased delay due to slow acceleration or slow hill climbing), there are negligible direct impacts of heavy axle loadings on congestion. Some policies regarding axle weight charges or regulations might have indirect impacts on congestion. Because congestion is currently managed in an inefficient way on most US highways—especially those on which buses might travel—it is necessary to carefully consider congestion impacts when appropriate. Passengers diverted from buses may choose to travel by automobile, thus increasing congestion.

III.2.2 Crash (Safety)

Crash costs for buses are taken from the middle estimates used in the 1997 Highway Cost Allocation study *(1)*, and are given in Table III-8. Total costs are calculated using the VMT given in Table II-6.

Table III-8 External Crash Costs

Cost per vehicle-mile ($) (From *(1)*, table V-24)	Transit	OTR
Rural	0.044	0.044
Urban	0.0189	0.0189
Annual Cost (Million $)	Transit	OTR
Rural	18	75
Urban	36	11
Net cost per vehicle-mile ($, weighted average)	0.02	0.04

Heavier buses may improve safety for their occupants, while creating a greater hazard for other road users in the event of a multi-vehicle crash. Similar to congestion, policies regarding axle weight charges or regulations might have indirect impacts on safety because any passengers diverted from bus may choose a mode with a different crash risk.

III.2.3 Air Pollution

Air pollution costs for buses are taken from the Addendum to the 1997 Highway Cost Allocation Study Final Report *(22),* and are given in Table III-9. Total costs are calculated using the VMT given in Table II-6.

Table III-9 Air Pollution Costs

Cost per vehicle-mile ($) (From *(22)*, Table 12)	Transit	OTR
All Roads	0.039	0.039
Annual Cost (Million $)	Transit	OTR
All Roads	90	90

The use of heavy buses requires the use of more powerful engines, with higher associated emissions. However, since air pollution varies approximately linearly with vehicle weight (a 10% increase in vehicle weight requires a 10% more powerful engine, emitting roughly 10% more air pollution), while pavement damage varies as to the fourth power, the impact of a bus weight change on air pollution is likely to be far less than the impact of a bus weight change on pavement damage. As with congestion, policies regarding axle weight charges or regulations might have indirect impacts on air pollution because any passengers diverted from bus may choose a mode with higher emissions on a passenger mile basis.

III.2.4 Noise

Noise costs for buses are taken from the middle estimates for noise costs in the 1997 Highway Cost Allocation study *(1)*, and are given in Table III-10. Total costs are calculated using the VMT given in Table II-6.

Table III-10 Noise Costs

Cost per vehicle-mile ($) (From *(1)*, table V-22)	Transit	OTR
Rural	0.0013	0.0013
Urban	0.0172	0.0172
Annual Cost (Million $)	Transit	OTR
Rural	1	2
Urban	33	10
Net cost per vehicle-mile ($, weighted average)	0.01	0.01

III.3 Conclusions

Over the past 30 years, both transit and over-the-road buses have seen a substantial increase in empty weight. Reasons for this increase include larger vehicles (shift from 40 to 45 feet for over-the-road buses), use of alternative fuels, and the need to accommodate passengers with disabilities. As a result, when either transit or over-the-road buses have passengers on board, their drive axle weights often substantially exceed the 20,000 lb Federal weight limit.

Given the third or fourth power relationship between axle-weight and pavement damage, the amount of pavement damage caused by a heavy vehicle is highly dependent on both the payload (freight or passengers) being carried by the vehicle and on its axle configuration. Assessing pavement damage on the assumption that all vehicles are loaded to their maximum weight capacity will overstate the amount of pavement damage caused.

Under reasonable assumptions of passenger loads, the ESALs imposed by both transit and over-the-road buses appear to be between 1.5 and 2.0. This is in the same order of magnitude as that imposed by many trucks (which, like buses, are often not loaded to their full weight capacity). Since the total VMT of buses is much lower than that of trucks, the total pavement damage caused by buses is at least an order of magnitude lower than that caused by trucks.

The cost of pavement damage depends on pavement strength. When vehicles operate on heavy-duty roads (such as Interstate highways), the pavement damage costs are modest. These costs are much higher on light-duty roads. Thus, the bulk of damage caused by both transit and OTR buses is on non-Interstate highways.

On Interstate highways, over-the-road buses cause more damage than transit buses because of the greater number of vehicle miles traveled by OTR buses on Interstates. On roads other than Interstate highways, transit buses cause more damage than OTR buses, mainly because of the greater number of vehicle miles traveled by transit buses on such roads.

Five areas of social cost of vehicle operation were presented in the 1997 Highway Cost Allocation Study: pavement damage, congestion, crashes, air pollution and noise. The primary social cost of bus operation appears to be pavement damage. Nonetheless, policies that shift travel away from bus to automobile may result in higher overall social costs, particularly in the areas of congestion, crashes and air pollution.

Chapter IV: Lightweight Materials for Manufacturing Buses

The weight of a bus can be reduced in several ways. Lower weight non-structural components (e.g., smaller engines, multiplexed wire systems) will always help. However, major weight savings are frequently dependent on changes in either the design or materials for the bus structure. The savings can be implemented in the form of more efficient structural design (e.g., integrally formed seats), the use of less material (e.g., thinner gauge panels), or the use of lower density material (e.g., replacing stainless steel with aluminum). For example, Thomas Built Buses constructs its 30-foot SLF200 buses out of aluminum, enabling the use of 19.5 inch instead of 22.5-inch tires, and a B-series instead of L-series Cummins engine. Many of the more sophisticated innovations in recent years have focused on newer engineered materials such as advanced composite materials. Since Congress had requested an investigation of lighter-weight materials, as opposed to advanced forming processes, designs, and use of new alloys, the remainder of this chapter focuses on lighter-weight materials.

This section of the report first discusses various composite material constituents (thermosets, thermoplastic, and fibers), which is followed by a more detailed discussion of composites impact on weight, cost, strength, and fire safety. Finally, there is a discussion of the current and potential use of composites.

IV.1 Composite Materials

Composites consist of two or more materials that remain distinguishable at the microscale. Constituent materials typically include a matrix (or binder) and a reinforcement. In this context, a composite generally consists of a polymeric matrix, along with a fiber (such as glass or carbon) as reinforcement.

Composites can enable thousands of pounds of weight reduction, lower manufacturing cost and may improve durability. Figure IV-1 shows the specific strength (tensile strength divided by density) and specific modulus (modulus divided by density) of metals, plastics and various composites. In this figure, LFT means long-fiber thermoplastic. The modulus is a measure of stiffness, and is defined as the force required to deform the material a set amount.

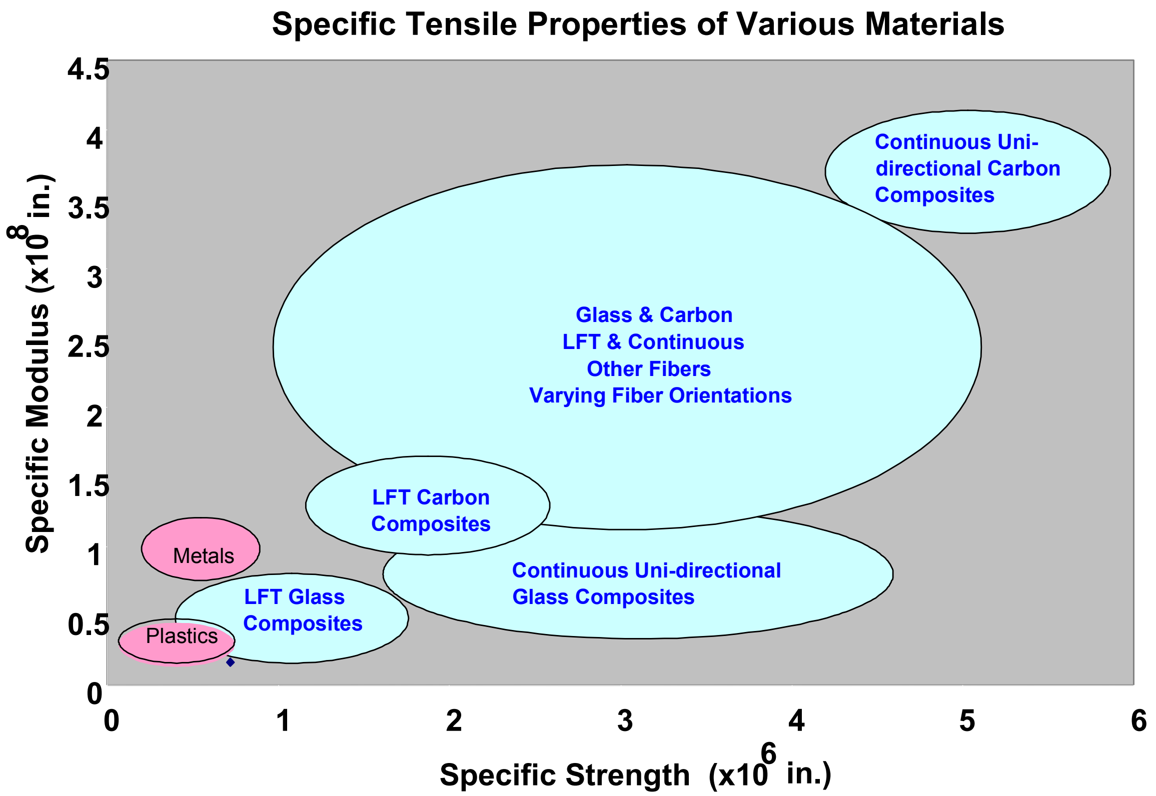

Figure IV-1 Specific Strength and Specific Modulus (stiffness) of Various Materials

According to TPI, the manufacturer of the CompoBus shell, a composite bus body shell is about 30% lighter than one made of steel *(23)*. The bus manufacturing industry has already taken a number of steps to introduce composites into vehicle design.

The next few sections present details on composite materials.

IV.1.1 Polymeric Matrices

A composite matrix serves to protect and stabilize its fibers. It maintains fiber orientation, inhibits fiber buckling and facilitates load sharing through shear transfer. Load transfer around damaged fibers can actually increase material strength above that of the fiber alone.

There are two main types of composite matrices: thermosets and thermoplastics.

Thermosets

Thermoset matrices, such as polyesters, vinyl esters, epoxies and phenolics, are usually two part chemical mixtures that, when mixed, undergo a chemical reaction (curing) that cross-link the monomers into one large polymer. This extensive cross-linking gives the cured matrix tremendous chemical resistance. However, the cross-linking is permanent. Hence, composites that contain thermoset matrices cannot be melted and reformed.

Thus, recycling the material (beyond grinding the composite as a filler) is impractical. Repairs are made by cutting out a bad section and gluing in a new section.

Thermoplastics

A thermoplastic matrix will soften when heated. Thus, a composite with a thermoplastic matrix can be repaired through melting and reforming. Some formulations are resistant to methanol, while many are not. This can be an issue in some situations such as with certain window washing fluids. Thermoplastic-based composites can also be recycled. If fiber lengths can be maintained at over 0.5 inches (fiber aspect ratio approaching 2000) high strength and impact properties can be maintained. [Husman]

IV.1.2 Fibers

Glass fibers have good strength and stiffness. Although the fibers themselves are brittle, load sharing through the matrix around fiber breaks results in significant strength retention. Although denser than carbon and aramid fibers, glass fibers are attractive in many applications because of their low cost.

For larger structures in which weight becomes an issue, carbon fibers may be needed. Carbon is relatively expensive, although it is likely the price will decrease in the near future. It is not needed as the predominant fiber except in special cases, but it is used selectively in current designs to keep laminate volumes down. Fiber sizing depends on the matrix that is used and affects the price.

Aramid fibers, such as Kevlar®, are damage resistant. However, there are few bus applications where their durability is worth the increase in cost. Furthermore, virtually every composite structure - certainly those in bus applications - will experience compression along its fibers in many loading conditions. It is the lateral stability provided by the matrix that allows the fibers in the material to take any compression at all. Nonetheless, the microstructure of aramid fibers is such that the matrix is not as effective in stabilizing the fiber. Hence, aramid composites are poor in compression.

IV.2 Issues with Composites

IV.2.1 Weight

Weight reduction is a major reason for using advanced composites. Some argue that this technology is already sufficient to meet axle weight requirements, as demonstrated by the NABI CompoBus [Misencik]. Others have pointed out that less structural weight requires a smaller engine, smaller axles, and thus additional weight savings [Coryell]. If lightweight components and materials are used everywhere appropriate (engine, axles, windows, seats, floor coverings) it may be possible to save approximately 7000 lbs [Coryell].

IV.2.2 Cost, Durability, Repairability

Although the raw materials for composites are currently more expensive than for conventional materials, finished costs can be competitive. This is because large structures can be formed in a few large pieces, eliminating most assembly costs. However, for a bus, sheet metal on a box metal frame is also a straightforward design with low assembly cost, so the manufacturer's cost advantage of composites alone may be marginal.

The extensive use of composites may present both some operating cost advantages and some added risks for bus fleet managers. Advantages include improved fuel economy (from the reduced weight) and possibly improved durability. Fatigue and rust problems are virtually non-existent with composites. Repair techniques are similar to those for composite boats. The repair costs are not necessarily higher than for contemporary structures, but the techniques are different, thus requiring an initial investment in training and equipment. According to one composite manufacturer [Misencik] it takes 1 to 14 days (depending on the specific geometry of the part) to prepare a replacement part from a factory mold. A risk is that the long-term properties of composites are not as well quantified as for metals.

IV.2.3 Strength

An advantage of composites is their high strength to weight ratio. However, composites are "notch-sensitive". This means that when traditional joining via fasteners is used, composites lose more strength for a given hole size than ductile metals. Fortunately, composite components are usually designed to be bonded, resulting in efficient load transfer. If a traditional fastener (like a screw or rivet) is essential, a metal insert can be molded into the composite to allow for less damaging load distribution.

IV.2.4 Fire Safety

In large passenger vehicle crashes (commercial aircraft, trains, etc.) the fire after the crash has sometimes led to more fatalities than the crash itself. Therefore, fire safety is of significant concern for transit vehicles. In 1993, FTA published *Recommended Fire Safety Practices for Transit Bus and Van Materials Selection,* that were adapted from the 1984 Urban Mass Transit Administration (UMTA) rail transit vehicle recommended practices. The Recommended Practices contain flammability and smoke emission performance criteria for a range of materials and provide a means to screen out those that are particularly hazardous. Research is underway to update the Recommended Practices for both rail transit and transit buses and vans. In addition, the National Highway Traffic Safety Administration's (NHTSA) Federal Motor Vehicle Safety Standard (FMVSS) 302 requires that bus interior materials be resistant to ignition sources, such as matches or cigarettes.

For composites, fire safety can be addressed via the use of additives to the matrix or coatings on the structure. Both have strength and weight penalties. Further research is underway.

IV.3 Current and Potential Use of Composite Materials

The FTA funded the development of the Advanced Technology Transit Bus (ATTB) in the 1990s. The ATTB demonstrated the utility of structures made of a fiberglass and structural foam composite. The ATTB front axle was rated to 13,220 lb and the rear axle rating was 18,740 lb yielding a gross vehicle weight rating of 31,960 lb. Even though the ATTB was powered by compressed natural gas, its curb weight was some 9,000 lbs below that of contemporary buses.

Figure IV-2 Advanced Technology Transit Bus

More recently, North American Bus Industries (NABI) has introduced the CompoBus™, a totally thermosetting plastic composite unitized bus that is several thousand pounds lighter than a comparably equipped steel bus [Coryell] (Illustration in Chapter I, page I-4). New Flyer's Invero® incorporates thermosetting composite materials in flooring, side panels, and ceilings that replace plywood and welded sheet steel with a foam-filled honeycomb sandwich.

In the over-the-road industry, a number of premium buses have fiberglass (rather than stainless steel or aluminum) skins.

Many manufacturers are using composites in a piecemeal way, generally as direct replacement materials for non-structural components. Some buses use composite skins on steel frames. Thermoplastic composite seats have also been developed. According to the Southern Research Institute [Husman], they cost 40% less to produce and save 50% weight. Production seat designs are being developed that are thinner, thus providing more legroom. Composite floor panels are being marketed. Their major selling points are a longer life than the plywood panels currently in use as well as reduced weight. A 20-40% savings may be possible on a 1,600 lb panel floor *(9)*. Such applications have low risk and provide a modest weight savings. The major payback is in reduced operating costs.

The use of composites for major structural components, and the redesign of bus structures to take advantage of new materials, promises significantly greater weight savings, but with higher risk. This involves the manufacturing of large composite shell sections that can handle requirements such as roof crush (avoiding collapse of the roof in a rollover) and auto impact (4,000 lb vehicle at 25 mph). The use of such large sections also promises significantly lower assembly costs. However, given the comparatively small number of transit and OTR buses manufactured each year (fewer than 5,000 and 3,000, respectively), it is unlikely that a current bus manufacturer could afford to retool for a completely composite design. Stainless steel is still the industry standard for OTR bus frames.

Crocker et al (2000), in a study with Prevost Car *(9)*, examined the potential for reducing weight on intercity motorcoaches. They found that by optimizing the bus structure, a savings of 9% (or about 3,000 lbs on a 35,000 lb bus) might be possible. The report also suggests that an optimized bus structure plus reduced weight on other components would yield a total savings of 20% (7,000 lbs).

IV.4 Conclusions

To summarize, axle-weight reduction can be viewed as either incremental or revolutionary. The incremental approach involves substituting individual components (such as seats, side panels, floor panels) to reduce weight. Many buses on the road today have benefited from such incremental improvements. Risks with such an approach are low, but the maximum total weight savings that may be realized is unlikely to reach 3,000 to 5,000 lbs, with axle-weight savings of at most 1,000 to 3,000 lbs per axle.

The revolutionary approach involves major changes in the bus structure (in materials and design) or bus components. For example, adding a second rear axle to transit buses would increase the total weight of the bus but reduce the maximum axle load. Potential weight savings may be 10,000 lbs for the bus, or in the case of a single rear axle, over 5,000 lbs for that axle.

Chapter V: Market Penetration of Lighter Weight Buses

No advanced concept or technology is widely deployed unless its customers are convinced that it will deliver the greatest value for the cost. Sophisticated customers usually make comparisons on the basis of life cycle cost and the associated benefit of each option. At the same time, political or financial considerations (e.g., lack of capital) may make it necessary to place a high value on short-term benefits. For example, some transit bus fleet managers may prefer to demonstrate immediate improvements in performance despite the commitment to increased long-term maintenance expenses.

Much has been written about the market penetration of advanced and innovative technologies *(24).* It is often not enough for a technology to be useful, available, or even cheaper. Evolutionary or "sustaining" technologies are generally introduced piecemeal into a product line, starting out as high-end features and eventually being incorporated into the standard merchandise. Revolutionary or "disruptive" technologies are seldom adopted quickly into a mainstream product line. Large suppliers can be too invested in the status quo production methods to deploy radical technologies. Hence, smaller companies often offer the technology to specialized niche markets and thus hope to gain first mover advantages.

In the context of the bus manufacturing industry, an example of the sustaining technology would be the lightweight bus seat developed by Southern Research Institute. It directly replaces an existing part at a lower weight and a lower long run cost.

Examples of a more disruptive technology include radical redesign of the bus structure and the extensive use of lighter-weight materials such as composites for structural components. While composites offer reduced weight and simplified manufacturing processes, original equipment manufacturers (OEMs) recognize that buses are long-term investments for which many customers may be risk averse. Hence, a moderate improvement in expected life cycle costs may not be worth the investment in new training and infrastructure or the risk that the technology may be insufficiently durable. Nonetheless, once a new technology is demonstrated or mandated, obsolete alternatives will quickly be abandoned.

One manufacturer noted that bus OEMs tend to reduce technical risk by using the truck industry to "vet" new technologies. That is, since truck fleet managers turn over their vehicles more frequently and since they are far more sensitive to small increases in performance and life cycle costs (for example, fuel economy), truck OEMs are more likely to deploy advanced technologies first. Once a generation of trucks has proved that a technology is durable and effective, bus OEMs more readily accept it. In terms of an alternative validation method, the ATTB proved the feasibility of a lighter-weight composite bus.

Approximately 3,000 to 5,000 transit buses (35 feet or longer) are delivered each year, although the number varies significantly from year to year. NABI began delivery of the CompoBus in 2003, and several hundred buses have been delivered or are on order. Hence, the market penetration of lighter-weight transit buses has been limited, but shows promise.

The market for motorcoaches is smaller, with fewer than 3,000 deliveries each year. Whereas large components (e.g., front and rear "end caps") are often made of lightweight structural material such as fiberglass, no radical lighter-weight structural design is currently being manufactured for motorcoaches.

As assessment of the potential market penetration of lighter-weight buses must cover the following topics:

- Life cycle costs of bus operation, and of introducing lighter-weight buses
- Other forces that encourage innovation
- Obstacles to innovation

V.1 Life Cycle Costs

Bus operations have costs and benefits that are both internal and external. The internal costs incurred by bus fleet managers include the capital costs of the bus fleet itself, as well as the recurring costs of labor, maintenance, fuel, insurance, and taxes. They also bear the costs associated with the loss of goodwill resulting from inferior service. The external costs borne by society for the operation of the fleet include air pollution, safety, pavement damage, crashes, and congestion.

Table V-1 compares some typical life cycle costs for transit buses and over-the-road motorcoaches. For the capital cost, a bus lifetime of 12 years is assumed, with a 5% discount rate and an annual mileage of 31,000 and 66,000 for transit and over-the-road buses, respectively. Several things are observed. First, there are generally higher per-mile costs for transit, primarily because most transit buses are in local service; their average speed, and thus vehicle miles traveled per year, is lower than for over-the-road buses. Second, the bus operator is the largest contribution to life cycle cost. In cases where the bus operator's salary does not change with capacity, using vehicles that hold more passengers can increase bus operator productivity.

A third observation is the relative value of the components of operating costs. For example, suppose a 1,000 lb (approximately 3%) savings in bus weight would produce a 2% increase in fuel economy, or about 1/2 cent per mile. To a transit bus fleet manager, this is an even tradeoff with a 1/2 cent per mile increase in capital cost (roughly a 0.5% increase in bus price, or between $1,000 - $2,000 on a bus that costs $300,000).

Therefore, from a fuel economy standpoint, weight savings that cost more than $1 - $2 per pound would not be worthwhile. However, if that same weight savings reduced pavement damage costs by 10 cents per mile[13], then the value of this weight savings to society is a 10 cent per mile increase in capital cost (roughly a 9% increase in bus price, or about $28,000 on a bus that costs $300,000). From the standpoint of pavement damage, this 1000 lb weight savings is worth roughly $28,000, or $28 / lb.

Table V-1 Life Cycle Cost of Buses[14]

	Transit		Over-the-road	
	Bus-mile	Passenger-mile	Bus-Mile	Passenger-mi
Assumed occupancy	.	10		34
Capital cost (the bus)	$ 1.05	$ 0.11	$ 0.62	$ 0.02
Operator	$ 4.36	$ 0.44	$ 0.86	$ 0.03
Fuel	$ 0.25	$ 0.03	$ 0.18	$ 0.01
Other operating	$ 0.99	$ 0.10	$ 0.50	$ 0.01
Total direct cost to fleet manager	$ 6.65	$ 0.67	$ 2.16	$ 0.06
Pavement Damage	$ 0.72	$ 0.07	$ 0.37	$ 0.01
Crash	$ 0.02	$ 0.00	$ 0.04	$ 0.00
Congestion	$ 0.11	$ 0.01	$ 0.05	$ 0.00
Air Pollution	$ 0.04	$ 0.00	$ 0.04	$ 0.00
Noise	$ 0.01	$ 0.00	$ 0.01	$ 0.00
Total social cost of bus operation	$ 0.90	$ 0.09	$ 0.51	$ 0.01
Total direct plus social cost	$ 7.55	$ 0.76	$ 2.77	$ 0.07

(Note: there may be slight discrepancies in the totals due to rounding)

For the bus manufacturer, the marginal cost to save the first pound of weight is not the same as the marginal cost to save the thousandth pound. Three sources are used to estimate the capital cost premium for lighter-weight buses:

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[13] Appendix 2 of this report presents pavement damage cost per mile as a function of bus curb weight.

[14] Data sources for Table V-1 are as follows:

Transit bus occupancy: Average of 9.2 (from reference *(6)*) and 10.8 (from Exhibit 2-20 of reference *(19)*)

Motorcoach occupancy: Estimated based on occupancy distributions in Appendix 1.

Bus capital cost: Estimated based on a bus lifetime of 12 years, 5% discount rate, 31,000 mi / year and 66,000 mi /year for transit and motorcoach respectively. The 31,000 mi / year is derived from APTA *(6)*), and the 66,000 mi / year from the 1997 Federal Highway Cost Allocation Study *(1)*. New vehicle costs of $289,000 (transit) and $364,000 (motorcoach) were taken from APTA reports on new vehicle costs for 2001-2002 *(6)*.

Operator, Fuel and other operating costs: For transit, these are derived from Fiscal Year 2000 APTA data *(6)*. For motorcoach, they are estimated. The total cost per mile of $2.16 is close to the $1.90 reported by the American Bus Association *(25)*.

Pavement damage costs are from the discussion following Table III-6.

Other social costs are also taken from Chapter III.

First is a press release from the Los Angeles County Metropolitan Transportation Authority *(26),* which indicates that their newly introduced CompoBus costs $310,000 and saves 2,100 lbs. This is $21,000 higher than the APTA average bus cost of $289,000, and thus indicates a price premium of $10 / lb.

Second is the opinion expressed in *(11)* indicating a $100,000 premium to meet weight limits. Since the weight reduction required to meet weight limits is in the 4,000 – 8,000 lb range, this indicates a premium of $12 - $25 / lb.

Finally, Corbeil et al. quoted the cost and weight savings for various specific weight reduction projects *(8)*.[15] The costs (converted to US dollars) and weights are shown in Figure V-1.

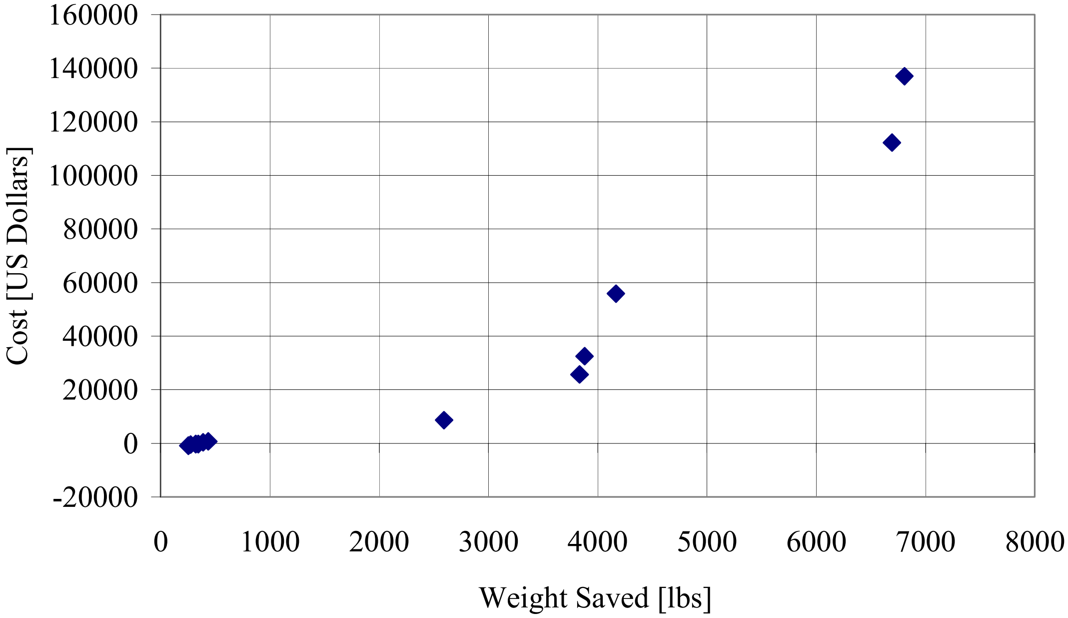

Figure V-1 Cost versus Weight Savings for Various Weight Reduction Projects

The data clearly fall into two groups. The savings from two hundred to five hundred pounds changed the price by less than $1,000. Presumably these were direct applications of sustaining technologies, such as replacing components with lightweight alternatives or a more efficient design. Some of the projects even showed a reduction in cost, as the replacement components were cheaper. A linear regression over this range showed that each additional pound saved added about $8.00 to the cost of the bus.

The larger magnitude savings (over 2,500 lbs) obviously required more radical redesign. Starting with a clean sheet of paper yielded 2,500 pounds of weight savings for a relatively small long-term unit cost. Nonetheless, a linear regression over the region

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[15] Although *(8)* used a specific older bus as its baseline, many of the weight reduction measures considered would be applicable to any bus. Therefore, the marginal costs per unit weight reduction should be relevant to buses other than the specific model that was used in the study. For example, seats, flooring and wiring are shared across multiple bus platforms.

showed that removing additional weight was more expensive, with an average cost of $15 to $20 per pound, and a marginal cost of approximately $30 per pound.

In the years since this study was published, it can be presumed that many of the sustaining technologies that produce a few hundred pounds of savings have been introduced into the transit fleet. The weight savings from these innovations have been used to partially offset the weight gains from other changes, such as wheelchair lifts. Therefore, the rate of increase in bus weight is lower than it might otherwise have been. The lower cost redesign features are probably in more general use. Within the uncertainty of the effects of inflation and technological advances in the interim, it should be expected that major weight savings would come at a cost of between $10 and $30 per pound. For a transit bus that now costs $289,000, a 6,000 lb weight reduction would raise the price between 20 and 60%. Such an increase in capital cost could not be justified on the basis of fuel savings alone. It is unclear whether even the reduction in pavement damage would justify such an increase in capital cost. This tradeoff will be discussed further in Section V.4 and in Chapter VII.

V.2 Forces that Encourage Innovation

There are numerous incentives to adopt new technologies in the bus industry. Fleet managers appreciate the value of reduced operating costs. Customer convenience improvements will increase ridership of both transit and OTR buses. If a technology designed to attract and maintain customers succeeds in enhancing revenue, then it will have value to the bus fleet managers. Such technologies might include more comfortable seats, soundproofing, bus locator displays, and, on OTR buses, in-seat entertainment devices.

Regulatory mandate can also promote innovation. Within the context of emissions standards or ADA requirements, technologies have been developed and deployed which may not have occurred otherwise. The fact that states like California enforce a 20,000-pound axle weight limit is a factor in the local market penetration of the NABI CompoBus.

Some features have been designed to meet one criterion but have had synergistic effects in other areas. For example, low floor buses were popularized as an easier way to meet ADA requirements. Despite a slight decrease in seating capacity, they also have advantages of faster loading and unloading and therefore better service. Similarly, a lighter exterior will save structural weight and increase fuel economy and may enable the use of a lighter engine and axle, further reducing operating costs. Composite structures also decrease maintenance costs by eliminating exterior corrosion.

V.3 Obstacles to Innovation

Virtually any technology that promises improved service and reduced life cycle costs will come with new maintenance requirements, equipment, and methods. Large composite shells might require new repair equipment and infrastructure. Alternative fuels will require new storage facilities. Smaller, more efficient engines might require new parts inventories. All new technologies require training for maintenance personnel.

Some innovations may not be deployed because the capital costs or life cycle costs borne by the bus fleet manager are larger. This is often a chicken-and-egg problem, because the production volume needed to bring acquisition and maintenance costs down is unlikely at the prices the original equipment manufacturers (OEMs) must charge initially to stay in business.

As stated above, some innovations are avoided simply because of high perceived risk - in one sense, a fear of the unknown. This is another chicken-and-egg problem. Many bus fleet managers will not risk embracing a new technology until it is proven in service. There are concerns that lighter-weight buses have no extensive track record in durability and safety. However, until some fleet managers try it, there can be no track record. The risk is smaller for sustaining technologies such as lightweight replacement components; even a widespread problem would only incur the cost of standard replacement parts. Fortunately, as noted above, large-scale applications of composites are gaining experience in service.

V.4 Economic Viability of Lighter-weight Buses

Given that lighter weight buses may cost substantially more to build than conventional buses, but may enable operating cost and social benefits, two questions arise:

1) When one considers only the costs visible to the bus fleet manager (capital costs, fuel costs, and other operating costs), is the investment in lighter-weight buses worthwhile?

2) When one considers all costs (both those visible to the bus fleet manager and social costs, such as pavement damage), is the investment worthwhile?

For this analysis, it is assumed that lighter weight buses are available for \$10 / lb for the first 4,000 lbs of weight reduction, and \$30 / lb for further weight reduction. These assumptions are made to illustrate the point that first few thousand pounds of weight savings will have a lower incremental cost than larger weight savings. The 4,000 lb breakpoint is fairly arbitrary, and may, in reality, be somewhat different. Furthermore, no assumptions have been made about how the weight reduction has been obtained. It might be through the use of composites, or through more efficient vehicle design. Table V-2 presents the price premiums:

Table V-2 Assumed Price Premiums for Lighter-Weight Buses

Weight savings (lb)	Price Premium	Added Transit Capital Cost/Mile	Added OTR Capital Cost /Mile
2,000	$20,000	$0.07	$0.03
3,000	$30,000	$0.11	$0.05
4,000	$40,000	$0.15	$0.07
5,000	$70,000	$0.25	$0.12
6,000	$100,000	$0.36	$0.17
8,000	$160,000	$0.58	$0.27

These added capital costs far exceed what the bus fleet managers are likely to gain in fuel savings (1/2 cent per mile per 1000 lb weight reduction) or reduced maintenance costs. Therefore, the answer to question (1), above, is no. That is, if social costs are disregarded and we assume the above price premiums, the investment in lighter-weight buses is not worthwhile.

However, if pavement damage costs are considered, then some investment in lighter-weight buses is worthwhile. Figures V-2 and V-3 show the tradeoffs for transit and OTR buses for various empty weights. They plot pavement damage cost, operating cost, and the sum of the two costs. Since the primary external cost of bus operation is pavement damage, this sum is close to the total social cost.

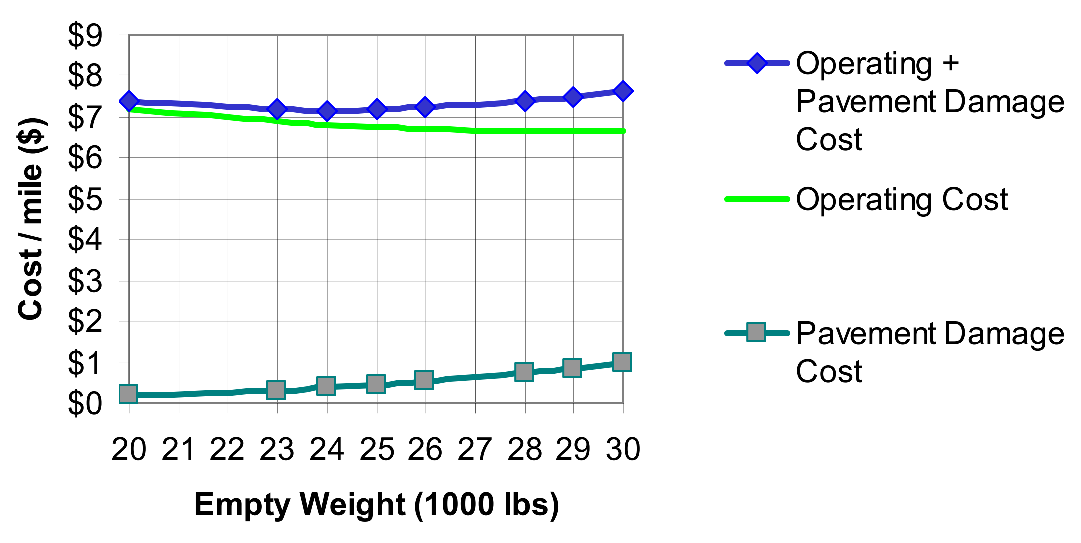

Figure V-2 Two-axle Transit Bus Per Mile Cost as a Function of Empty Weight

For the transit bus, total (operating plus pavement damage) cost is minimized with an empty weight of 24,000 to 25,000 lbs. This represents a 3,000 – 4,000 lb weight reduction from the current typical weight of 28,000 lbs.

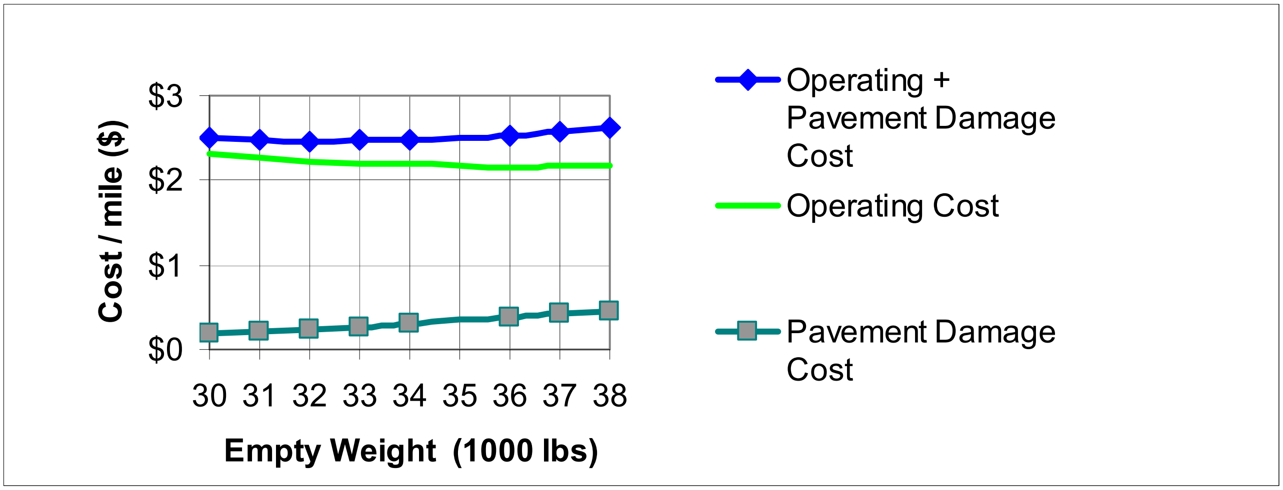

Figure V-3 Over-the-Road Bus Per Mile Cost as a Function of Empty Weight

For the over-the-road bus, the total (operating plus pavement damage) cost is minimized with an empty weight of 32,000 to 33,000 lbs, which represents a 3,000 – 4,000 lb weight reduction from the current typical weight of 36,000 lbs.

The exact weight reduction that is socially desirable is highly dependent on the cost to attain a particular weight savings. In this analysis, it was assumed that the cost per pound of weight savings would increase significantly after 4,000 lbs were saved. Therefore, it is not surprising that this model indicated an ideal weight savings of about 4,000 lbs. If the cost to attain a weight savings should turn out to be higher than what is modeled here, the optimal weight savings will be less. If the cost is lower, the optimal weight savings will be higher.

V.5 Conclusions

To summarize, lighter-weight buses could have a small positive benefit for transit and over-the-road bus fleet managers in terms of reduced operating and maintenance costs, but in many cases, this benefit is not enough to outweigh the difference in capital cost. Direct replacement of standard parts with lightweight composite parts (transit bus seats, OTR motorcoach baggage doors) is an incremental technology that is enjoying some market penetration. Unfortunately, the more revolutionary technology of all-composite structures is making slower progress, primarily because of the larger up-front capital costs, commitments to new maintenance facilities, and a limited track record for safety and durability. The CompoBus and other transit buses are making headway in areas such as California where axle weight limits are forcing the implementation of more innovative alternatives. In contrast, the total market for over-the-road motorcoaches may be so small that no niche market for lighter-weight buses can realistically develop. Preliminary cost-benefit analysis shows that weight savings are unlikely to be justified on the basis of fuel savings alone. Unless external costs such as pavement damage are made visible to bus fleet managers, there will be little incentive for either the transit or over-the-road bus industries to acquire lighter-weight buses.

Chapter VI: Initial Review of Policy Alternatives

Bus axle weights have increased over the past 30 years, and have now bumped up against regulatory constraints on axle weight. The increased weights are partly due to market demand for higher quality service (air conditioning, comfort) and vehicle durability, and partly due to government regulations intended to achieve social goals (clean air, elderly and handicapped accessibility). The constraints vary somewhat by region and level of government, but are intended to protect the investment in highway pavements from excessive damage by heavy vehicles.

Analysis of policy options consists of three steps:

1) Enumeration and description of the policy ***alternatives***, including the status quo or base alternative.

2) Estimation of the ***impacts*** of each policy, relative to the base alternative.

3) ***Evaluation*** of whether and why each policy alternative would be an improvement over the status quo or over other policies.

Candidate policies may be winnowed down at each step, so that only a few of the most promising policies receive a full analysis.

VI.1 Design of Policy Alternatives

Policy changes could include different axle weight limits (perhaps differentiated by vehicle type, purpose, type of road, or other attribute), other regulatory actions, subsidies to bus fleet managers or manufacturers, design or other standards to reduce externalities (pollution, noise, pavement damage), and market-like mechanisms that serve to internalize costs, such as an axle weight charge, congestion toll, or pollution tax.

For the evaluation of a policy to be useful, the evaluation should consider a full range of options for addressing the problem. Some of these may be incremental changes from current policy, perhaps accumulating over a phase-in period of as much as a decade. Other alternatives may call for a substantial change in the direction of government actions. Some policies may not be realistically implemented in the short term, but nonetheless represent ideal strategies to aim for in the long run.

Most important for policy evaluation is that all relevant options be considered within a framework that treats their impacts comprehensively and in a balanced and objective manner.

VI.2 Estimating the Impacts of a Policy

In the transportation sector, there are many consumers and suppliers making decisions on the basis of the costs and benefits to themselves of their own actions. Thus the evaluation of any particular policy requires estimating how the various affected parties will change their behavior in response to the new policy. An exemption from weight limits for some group will cause the members of that group to travel more distance with heavier axle loads than would be the case without the exemption. Conversely, a lower axle-weight limit or a user charge for heavier axle loads will cause some highway users to seek to reduce those charges by adding axles, reducing vehicle weight, and foregoing the travel if the benefits to the user are less than the costs paid by the user.

Responses to policies

In the case of bus axle-weight policies, the major affected parties include bus fleet managers, bus users (primarily passengers), and bus suppliers (primarily bus manufacturers). Other affected parties include other road users, road abutters and other taxpayers.

For example, an evaluation of an axle-weight policy that is applied to bus fleet managers should consider the following areas:

1) How will bus fleet managers respond to the policy? Possible responses include changing the fleet mix, changing the amount of service provided or the service mix or changing fares.

2) Given the bus fleet manager response, what will be the change in the bus share of pavement damage, congestion, crashes, air pollution and noise?

3) If the bus service mix or bus fares are changed, bus users will react by switching modes (presumably to or from private auto). Given the bus user reaction, what will be the change in the auto share of pavement damage, congestion, crashes, air pollution and noise? Will the change in policy result in trips being added or foregone?

Such a policy, although it is only imposed directly on the bus fleet managers, might also be expected to change the behavior of other parties:

- Demand for lighter-weight buses will change, and manufacturers will try to meet that demand.

- Bus fleet managers might reduce service, or seek to pass higher operating costs on to passengers in the form of higher fares.

Passengers, faced with reduced service or increased fares, may seek other modes, or forgo the travel.

Secondary or Indirect Impacts

If there are reductions in bus service or shifts to other modes caused by fare increases or service reductions, then there will be impact on the size and composition of impacted sectors. The bus industry will shrink, reducing operating labor, maintenance expenditures, management costs, fuel consumption, taxes, and other costs. The industry may become more concentrated or more competitive, depending in part on scale economies. Negative externalities in the form of noise, air pollution, and congestion from buses will be reduced. Correspondingly, other modes of travel will expand, by lesser magnitudes. These modes also produce negative externalities, which can be estimated quantitatively. Although such externalities are legitimately included within the scope of benefit cost analysis, the magnitude of inefficiency (from negative externalities) that can be corrected by policies in related markets (the bus travel market, in this instance) is typically small.

Some of the employment lost in the bus sector will be gained in other sectors, not necessarily transportation (trips forgone probably result in some other consumption, whether recreational or business). For example, shedding low volume service on light-duty pavements is likely to mean less service to small rural communities. From the standpoint of benefit cost analysis, this is neither a cost nor a benefit, but a transfer. Any number of equity dimensions may be considered, and to some extent estimated quantitatively, but it is a political choice as to whether transfers justify compensation, e.g., whether residents of small rural communities should receive subsidized transportation.

VI.3 Evaluation of Policy Alternatives

A proposed policy should be evaluated in terms of

- ***Efficiency***: does the change in policy result in actions that maximize net benefits to society?
- ***Equity***: does it treat similar users similarly, and not worsen the distribution of income?

A primary goal of any government action should be to improve economic efficiency by encouraging individual decisions that provide the greatest value to society as a whole. Jobs, income, trade, and productivity are all part of economic efficiency, but a focus on just one or even several of these measures does not provide sufficient information to know whether a given policy action improves or worsens efficiency.

The framework for assessing efficiency in the public sector is benefit-cost analysis. A broad perspective is taken: does the policy generate benefits to society as a whole that exceed the costs to society?

A proposed policy option is compared to a base or do-nothing option that represents the state of the relevant world if the no proposed policy option is implemented. For investment evaluation (e.g., a capital improvement), the base alternative may be referred to as the “do-nothing” alternative or the “no-build” alternative; for regulatory evaluation the base alternative is often called the "counterfactual," a set of facts representing the option not taken. Whether labeled base or counterfactual, the meaning is the same.

If the policy has any consequences, the policy option being evaluated will result in some changes of conditions that will be different from the base alternative. These changes are referred to as the impacts of the policy. The evaluation is then the dollar or other valuation of these differences or impacts. Once valued, the impacts are regarded as "benefits" whether or not they are positive or negative in arithmetic sign, or who bears or receives them. "Costs" are the costs of implementing the policy initially. Benefits, for example, may include the costs to bus fleet managers of complying with the policy. Whether labeled costs or benefits, the purpose of the evaluation is to include all important impacts, valued as accurately as is feasible, and aggregated appropriately to obtain net benefits.

Efficiency

As stated earlier, an efficient policy is one that encourages individual decisions that provide the greatest value to society as a whole. Properly functioning markets perform this task automatically, so, to some degree, policy evaluation can focus particularly on consequences of current policies that lie outside proper markets. Regulations and subsidies create market responses, but the results may or may not be efficient.

It is necessary to pay explicit attention to pavement damage because it is external to the bus fleet manager and therefore not considered in decisions about bus purchase or operation, other than to the extent that regulations impose limits on axle weight. Changes in operating costs may be estimated (e.g., additional fuel from heavier weight), but only for purposes of estimating industry response, not as a measure of cost or benefit. For simplification in analysis, additional costs or cost savings faced by the bus fleet manager are assumed to be passed on to consumers in the form of higher or lower fares. For transit fleet managers, higher costs are more likely to lead to service cutbacks in the short run, but this still can be represented as an increase in the price of (the same) service.

Equity

In addition to a concern for total costs and benefits, policy evaluation should also pay attention to how the costs and benefits are distributed among the affected parties, including owners, workers, and taxpayers. Suppose a policy (such as an axle weight limit) is applied to bus fleet managers. The cost of the policy may be shifted backward, in this case onto bus manufacturers, or forward onto bus passengers. In the case of a subsidized transit operation, the impact may be shifted onto taxpayers. The actual result depends upon supply and demand elasticities, which in turn are affected by market conditions such as competition or monopoly.

For example, if an axle-weight/distance charge were to be imposed, it might be spread among the parties as follows:

1) Suppliers of buses, parts, garages, maintenance and operating labor, etc. having to charge lower prices in the face of diminished demand from bus fleet managers (owner or buyers).

2) Intercity bus fleet managers reducing service, affecting profits and passenger satisfaction.

3) Increased costs are passed on to passengers (likely in a competitive environment).

4) Transit bus fleet managers requiring a higher subsidy, in order to avoid reducing service or increasing fares.

A policy should treat all parties affected by bus service production and consumption in an equitable and even-handed manner. Exempting some group from considering their pavement damage costs solely because the group is small, and therefore, does not do much damage is a flawed rationale. Every user is part of some small group that could potentially be exempted.

VI.3.1 Transfers

In conducting regulatory evaluation, one of the most difficult aspects is distinguishing transfers from real costs or benefits. Transfers are typically an exchange of money that has no social cost or benefit. A subsidy paid to transit bus fleet managers, for example, is money taken out of the taxpayers' pocket and given to transit bus fleet managers. There may be a behavior change associated with the transfer (more transit service is produced) that may have efficiency consequences, but the transfer itself is neither a cost nor a benefit to society as a whole. Examples of transfers include:

1) Subsidies paid to public or private bus fleet managers.

2) Revenues received in taxes or user charges.

3) Loss or gain of revenues by private or public bus fleet managers.

4) Gain or loss of employment in the public or private bus sectors.

Transfers become of interest when estimating the equity impacts of a policy, summarized as "who gains and who loses." Whether a policy is "fair" is not something that can be concluded objectively, although there some kinds of transfers that are generally regarded as undesirable, such as taking from the poor and giving to the rich, and treating entities differently who appear to be similar from the standpoint of society.

VI.4 Review of Proposed Policy Options

For convenience, the array of proposed policy alternatives is grouped according to the type of strategy pursued, e.g., regulatory versus subsidy. The base case for policy evaluation is described, followed by an initial screening review of a broad range of policies.

VI.4.1 Strategies for Policy Instruments

Policy options can be grouped into six types that can be distinguished according to the mechanism by which they affect behavior:

- Policies that adjust axle weight limits in Federal regulations.
- Policies that impose design requirements on vehicles.
- Policies that offer subsidies to bus fleet managers or manufacturers.
- Policies that affect the roads used by buses.
- Policies that alter the rulemaking process to take account of external costs.
- Policies that utilize market-like mechanisms to internalize costs.

The policy options will be described, impacts assessed, and results evaluated on an informal basis to identify those that seem most promising.

Base Alternative: Retain Today's Policy

The baseline policy includes multiple State limits, and an existing temporary Federal exemption from the requirement that States enforce weight limits on over-the-road buses and intrastate transit buses. It is assumed that today's policy has effectively resulted in an exemption from weight limits for these buses. State limits as applied to buses are typically either 20/34 (20,000 lb one axle / 34,000 lbs tandem axle) or 22.4 / 36 (22,400 lbs for one axle / 36,000 lbs for a tandem axle). However, some states have different limits.

If today's policy were made permanent, a probable adaptation would be a reduction in efforts to develop lighter-weight transit and over-the-road buses.

For Interstate highways, some states have lower weight limits than for other roads; this makes little economic sense since it is the Interstates that are built to a higher strength standard, and are generally better able to withstand heavy vehicles.

VI.4.2 Adjustments to Axle Weight Limits

This group of policies changes regulatory constraints under which bus fleet managers must function.

Expand the Current Permissive Arrangement to Interstate Transit Buses

This policy change would allow operation of overweight transit buses on regularly scheduled fixed routes that cross State borders. The impact would likely be small, for the following reasons:

- Many of the jurisdictions where interstate service operates (such as New York, New Jersey, Pennsylvania, Maryland, and the District of Columbia) already have higher weight limits for buses *(27)*.
- Much existing interstate transit service consists of long express routes that use over-the-road vehicles with two rear axles.

- Even in those States where lower weight limits do apply, U.S.DOT believes it is not being enforced.

In those few situations where expanding the current permissive arrangement does have an impact, likely adaptations would include the following:

- Increased transit service to major attractions that are just over a State border. For example, due to current weight rules, a transit route may terminate just before the State border, even though there is a major passenger generator just over the border. Extending such a route could substantially increase ridership.

- In situations where it is more appropriate to use a transit bus than an over-the-road bus (e.g. a local service), increased use of transit buses on services that cross State borders.

Retain the 1992 - 2003 Policy

This policy includes multiple State limits and a Federal exemption from the requirement that States enforce weight limits on intrastate transit buses but no exemption for over-the-road motorcoaches. It was the policy between 1992 and February 2003.

Since this was the policy over most of the last 10 years, we see the response on our roads today. Responses include the appearance of second rear axles on motorcoaches and current efforts by bus manufacturers to reduce (or at least to not increase) bus weight.

Re-impose Weight Limits on Transit and Over-the-Road Buses

Current Federal policy allows States to exempt intrastate transit vehicles and over-the-road buses from weight limits on Interstate highways. The effect of removing this exemption would depend on current State and local weight rules as they are applied to Interstate highways and local roads. Since loaded transit buses routinely exceed these limits, the effect could be disruptive to the transit industry in those states with low weight limits. However, over the long term, it would provide a strong impetus for lighter-weight buses. With the Federal weight limits re-imposed on Interstate highways, adaptations might include

- Acquisition of over-the-road motorcoaches for transit services on Interstates

- Shifting of service from Interstates to arterials

- Use of smaller buses

- Development of lighter-weight buses.

An Across-the-Board 20,000 lb Single Axle / 34,000 lb Tandem Axle Limit

This is the Federal rule as it currently applies to trucks and is the rule in many states. Similar to the re-imposition of weight limits on buses, the effect of such a limit would be disruptive to the transit industry, at least in the short term. The motorcoach industry would also have to adapt in those sections of the country that currently have higher weight limits. Probable adaptations would include

- Acquisition of over-the-road motorcoaches for transit services on Interstates (a dual-rear axle motorcoach is more likely to meet a weight limit than a transit bus)
- Shifting of transit service from Interstates to arterials
- Development of lighter-weight transit buses and motorcoaches.

All of these adaptations have a monetary cost, which will be borne either by the passengers (in the form of fare increases) or by the taxpayers (in the form of increased subsidies).

If fares increase, bus users will react by shifting trips to automobile or foregoing the trips. With the shift in trips to automobile, overall congestion and pollution become somewhat worse.

If subsidies increase so that ridership stays constant, bus users will react by shifting their trips to arterials (because some of the service has shifted to arterials). The shifting of service to arterials will produce little or no positive benefit.[16] Given the generally lower pavement strength of arterials, every dollar of pavement damage avoided on an Interstate highway will add several dollars of pavement damage on the arterial, assuming that buses travel the same number of miles on each type of road (Table III-5, page III-8).

We can see that under the above circumstances, such a policy would not be efficient. Although it reduces pavement damage on Interstate highways, it increases congestion costs, user costs, and pavement damage costs on arterial streets.

An Across-the-Board 22,400 lb Single Axle / 36,000 lb Tandem Axle Limit

This is the rule in several states (primarily in the northeast), and was proposed by the American Bus Association. The 22,400 lb single-axle limit would accommodate most motorcoaches and transit buses with a seated load. A probable consequence of adopting this rule would be a reduction in efforts to develop lighter-weight transit buses and motorcoaches.

Add a 15% Tolerance to the 22,400 lb Single Axle / 36,000 lb Tandem Axle Limit

The American Bus Association also proposed a 15% tolerance over the 22.4/36 limit. This results in a 25,800 lb single axle / 41,000 lb tandem axle limit. Such a limit would accommodate virtually all transit buses and motorcoaches, although it may be slightly exceeded by some transit buses carrying crush loads. A probable consequence of adopting this rule would be a reduction in efforts to develop lighter-weight transit buses and motorcoaches.

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[16] DOT's biennial "Conditions and Performance" Report to Congress discusses the status and investment needs of highways and transit. In this report, conditions and needs are reported for all functional classes of highways and for all levels of government. A policy that merely deflects the traffic from Interstate highways to other functional classes of highway would not yield a net benefit to the Nation. In fact, such diversion would cause more damage on other functional classes because they are not built to the same rigorous load bearing standards as the Interstates. A policy that had the effect of diverting heavy vehicles *to* the Interstates would make more economic sense.

VI.4.3 Design and Operational Requirements

In some circumstances, the ideal outcome can be estimated if social costs and benefits were properly accounted for, but the institutional mechanisms are not in place to allow normal decision processes to arrive at the optimal choice. In such circumstances, the preferred outcome can be specified in terms of design or engineering requirements (such as emissions control devices or air bags) and imposed via regulatory means.

The only such design requirement that has been proposed for heavy bus axle weights is the addition of a second rear axle that carries less weight than a full tandem axle. The only operational requirement that has been proposed is to arrange service to avoid overcrowded transit buses.

Add Tag Axles to All Transit Buses

This is envisioned to be a transit bus requirement, since there is more to be gained by adding a second rear axle to transit buses than a third rear axle to motorcoaches.

Adding axles reduces the ESAL loading for the same gross vehicle weight; because of the geometric relationship between axle load and pavement stress, spreading the vehicle weight over more axles reduces not only the weight on each axle, but the sum of the ESAL loadings for all axles. Strategies for increasing the number of axles include the following:

1) Add a second axle to the single drive (or non-steering) axle that carries an equal (or proportionate) share of the load as the other axle; making the axle self-steering reduces dragging and tire scrubbing on narrow turns, increasing bus maneuverability.

2) Add a variable-load or "tag" axle to single or tandem axles that can be lowered to carry a share of the vehicle weight when the vehicle is heavily loaded or operating on light-duty pavements; the tag axle may have only 2 instead of 4 tires, and has a lower rating than the adjacent drive axle.

The axle itself adds weight to the bus. Its added complexity increases the capital and maintenance costs for the bus. In a low floor transit bus, it reduces seating capacity.

The advantage of a raisable tag axle is that it can be lowered when gross vehicle weight and pavement strength warrant more axles to spread the load, but the axle can be raised for maneuverability. Unfortunately, the axle is most easily deployed on roads where it is needed the least, namely strong roads such as Interstate highways. When maneuverability is required, the pavements are more likely to be light-duty.

Given the need to maneuver on city streets, the added weight and complexity that a steerable tag axle would entail, and the reduction in seating capacity that would be created by the addition of a second rear axle on a transit bus, a requirement that all transit buses have tag axles would not be feasible. However, the use of transit buses with tag axles may be feasible in some situations, such as routes that are confined to major arterials and Interstate highways.

Add or Rearrange Transit Service to Avoid Overcrowded Buses

In trucking, it often makes sense from the standpoint of pavement damage to divide a heavy load. This is because a 30,000 lb tractor-trailer with a 50,000 lb payload (total weight 80,000 lb) can cause more than twice the pavement stress of the same tractor-trailer with a 25,000 lb payload. Therefore, from a pavement damage standpoint, it makes sense to split the 50,000 lb load into two 25,000 lb loads. (Note that such a split may not make sense from an operating cost standpoint.)

To determine whether splitting a payload will reduce pavement stress, one needs to consider the ESALs per unit payload. If p is the payload, and e is the empty weight of the vehicle, the number of ESALs imposed is approximately proportional to $(p+e)^4$. Therefore the number of ESALs per unit payload is proportional to $(p+e)^4 / p$. This is a U-shaped curve with respect to p. Where ESALs per unit payload is decreasing as payload increases, it makes no sense to split the load. However, if ESALs per unit payload is increasing as payload increases, splitting the load will reduce pavement stress.

Review of several truckload carrier websites (J.B.Hunt, Schneider) indicates that a 53-foot tractor-trailer may carry a payload as high as 50,000 lbs. The approximate ESAL per unit payload for such a tractor-trailer is shown in Figure VI-1, assuming ideal distribution of the payload. For this prototypical truck, splitting the load will reduce pavement damage for payloads heavier than about 40,000 lbs.

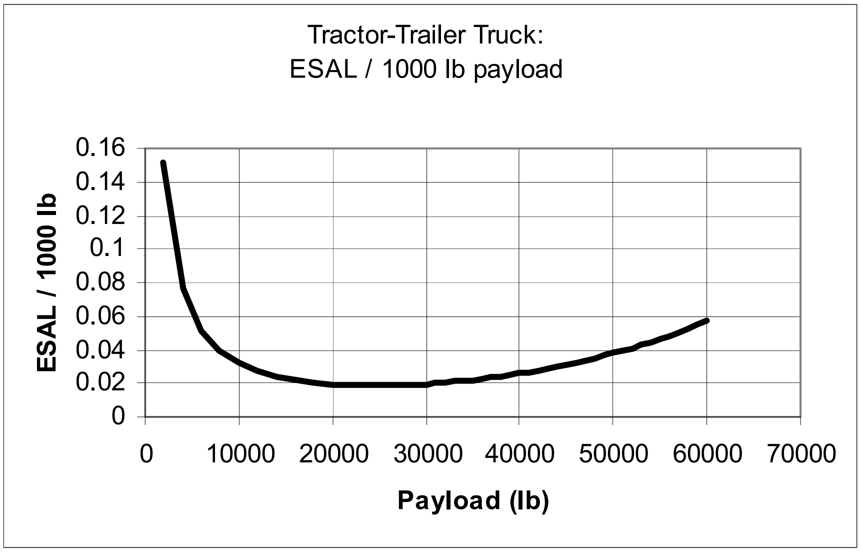

Figure VI-1 Truck ESAL / 1000 lb payload

The ESAL / passenger curve for the 40-foot transit bus, on the other hand, does not begin to curve upward until the number of passengers on-board the bus is well beyond the seated capacity of the bus (Figure VI-2). For the bus, there is no advantage to splitting the load until at least 60 passengers are on board, and even after that, the advantage is slight. Therefore, in the case of transit, running more buses with fewer passengers on each bus makes little sense from a pavement damage standpoint.[17]

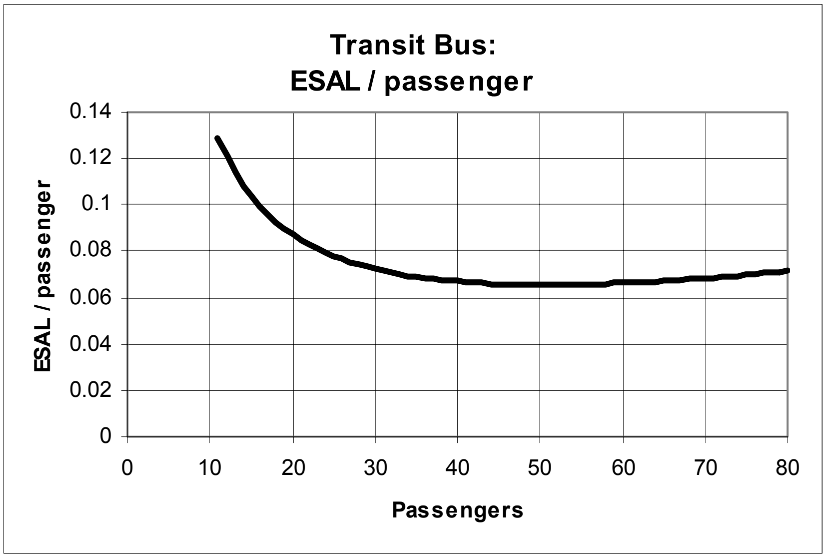

Figure VI-2 Transit Bus ESAL / passenger

Similar to transit buses, there is little advantage to dividing a passenger load among several over-the-road motorcoaches. The ESAL per passenger curve has a similar downward-slope (Figure VI-2) and does not start to slope upward until 60 passengers are on board, a number higher than the number of seats on the bus.

To conclude, the only way that removal of passengers from an overweight bus could be realistically expected to reduce pavement damage is if total bus ridership were also to decline significantly. In this latter case, the increased per-passenger operating cost, loss in incremental consumer surplus, and increases in other-mode externalities would far outweigh any savings in pavement damage.

VI.4.4 Subsidies to Produce, Buy and Operate Lighter-Weight Buses

Such incentives may be applied to either the bus manufacturers or to the bus fleet managers, and may take several forms:

1) Research and development grants to produce lightweight bus materials, or improved weight distribution on a bus

2) A development program to build lighter-weight buses

3) Measures to facilitate the adoption of new technology by bus fleet managers

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[17] Use of a 3rd power relationship (as discussed in Chapter III) instead of a 4th power relationship only strengthens this conclusion. With a 3rd power relationship, the curve does not begin to slope upward until over 90 passengers are on board.

Research and Development Grants for Lighter-Weight Buses

The first of these options is applied directly to bus manufacturers, to encourage them to make lighter-weight buses. The reasoning is that an average bus weight reduction of several thousand pounds could save several hundred million dollars per year in pavement damage. Therefore, a substantial investment may be worthwhile. This investment could be focused either on materials or on a new bus. Even if the new bus is, on the whole, unsuccessful, manufacturers can apply concepts from it to reduce weight on other bus models.

Another option is to encourage a bus design that improves the weight distribution. Recall that on a transit bus, it is generally only the rear axle that is overweight. An uneven weight distribution may result in an overloaded axle even though the gross vehicle weight could be legally accommodated on the number of axles used. One cause for this is the cantilevering of the engine behind the rear axle. The ideal weight for a steering axle is less than that for a load-bearing axle, although perhaps steering axles can be enhanced to carry a heavier load without sacrificing maneuverability and control.[18] However, because placing the engine at the back of the bus optimizes seating capacity, it is not likely that the engine will be placed elsewhere.

Given the fourth power relationship between weight and ESAL loading, improving the weight distribution among existing axles will reduce the overall ESAL loading for the bus. For example, the transit bus used in *(15)* had front and rear axle loadings of 13,152 and 25,059 lbs respectively. This front axle loading is well under the typical maximum front axle loading of 14,600 lbs (Section II.3.1). Under certain assumptions (flexible pavement with SN=5), this yields ESAL loadings of 0.225 (front) and 3.824 (rear) for a total ESAL loading of 4.049. Suppose 1,500 lbs were shifted from the rear to front axle. This would yield ESAL loadings of 0.362 and 2.913, for a total ESAL loading of 3.275. Even though the total weight of the bus has not changed, the total ESAL loading is almost 20% lower, because the rear axle loading has been reduced by 1,500 lbs.

Conduct a Development Program to Build Lighter Weight Buses

A number of years ago, the FTA sponsored development of the Advanced Technology Transit Bus (ATTB) program with Los Angeles County Metropolitan Transportation Authority (LACMTA) aimed to develop a lighter-weight, low floor, low emissions transit bus. Although the ATTB itself did not go beyond the prototype stage, concepts from it found their way into industry. For example, NABI introduced a lighter-weight CompoBus, using similar technology to the composite material vehicle structure of ATTB. Since at least one lighter-weight bus has been developed by private industry, a new lighter-weight bus development program is not needed.

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[18] The ABA claims that steering axle tires on motorcoaches are larger than “comparable” truck tires, and can therefore carry a larger share of the load.

Measures to Facilitate the Adoption of New Technology by Bus Fleet Managers

Adoption of new technology often involves substantial upfront expense or increased risk. Even though bus fleet managers may believe the technology to be beneficial over the long term, shortages of capital and risk aversion may prevent them from adopting them. Examples of such measures include the following:

- Funds to develop specialized maintenance facilities for lighter-weight buses. For body maintenance, a composite shell requires different tools and techniques than a metal shell. This would include both the facilities and the training for maintenance personnel.
- Development of standards or guidelines for repairs.

VI.4.5 Federal Procedural Changes

A change in the process by which decisions are made can often lead to a more balanced consideration of factors and result in more optimal decisions. The only candidate here is the proposal that Federal rulemaking explicitly take into account the effects of regulations on pavement damage and the bus industry.

Require that Federal Rulemakings Consider Weight Impacts

Any regulation that leads to a significant change in vehicle weights will have far-reaching impacts, not only on pavement damage, but also on fuel consumption, emissions, and possibly safety. A 1000 lb change in vehicle weight may have impacts that are both economically and environmentally significant. Since these impacts may not be obvious to the agency making the rule, some consideration of vehicle weight in rulemaking seems appropriate.

VI.4.6 Changes to Highways Used by Buses

This group of options includes those that strengthen or smooth the highways already used by buses, without attempting to change their routes, and policies that directly seek to restrict the roads that may be used by buses to avoid light-duty pavements.

Just as there are diseconomies of scale in adding weight to an axle (the stress goes up geometrically), there are economies of scale in building thicker pavements (greater depth results in more than proportionate increase in the ability to withstand ESAL loads). The thicker a pavement is, the more it can spread the load applied at its surface over its base and subbase. For example, an urban road with structural number (SN) of 3.4 has an ESAL lifetime of approximately 900,000. With heavy bus and truck traffic, this lifetime can be consumed in a few years. An urban road with SN of 5.3 costs about twice as much to reconstruct as the weaker urban road, but its ESAL lifetime is almost 33,000,000, or 37 times as long. Therefore, the cost per ESAL-mile is much less on a stronger road than on a weaker road, and a policy that shifts travel to stronger pavements would reduce the total cost of pavement damage.

Conversely, a policy that shifts travel to weaker pavements would increase the total cost of pavement damage. An example of such a policy would be one that has the effect of shifting buses from Interstate highways to roads of lower pavement strength.

Travel can be shifted to stronger pavements by rerouting trips to utilize pavements with a higher structural number or pavement depth, usually by traveling on higher functional classes of highways. Presumably such rerouting adds to circuitry and total VMT.

Upgrade Roads Used by Buses to Higher Strength

The majority of Interstate highways already are built to high strength, so this is primarily an issue for other roads. There are substantial economies of scale in building roads to higher strength if the volume of heavy vehicles warrants such an investment. Because greater pavement depth results in more than a proportionate increase in the ability of the road to withstand loads from heavy vehicles, the pavement damage cost of a bus or truck operating on a heavy-duty road is much less than that of the same bus or truck operating on a light-duty road.

Therefore, strengthening the roads that buses (and trucks) run on may well be more cost-effective than making a major investment in lightening the vehicles. This is particularly true in the case of urban roads, where

- Some roads may carry very high bus volumes
- The roads that are used by transit buses do not change much from year-to-year, or (in our older cities) even from decade-to-decade.

However, predicting where over-the-road buses will run, particularly charter buses, may be more difficult.

Restrict Buses to Strong Roads

Interstate highways and most major arterials are strong enough to handle either 2- or 3-axle buses; minor arterials and collectors often are not as strong and may be easily damaged by axles above certain limits. Pavement damage from buses could be greatly reduced by setting standards for each road (or type of road) that restrict the maximum axle weight permissible on that road. Lighter-duty pavements would require lighter and presumably smaller buses if used by transit vehicles or tour buses.

Thus heavy vehicles would have to stay on stronger pavements, while lighter vehicles could travel more widely.

VI.4.7 Measures to Internalize Costs

Analogous to changes in government procedures, another strategy seeks to improve decisions by ensuring that the parties creating certain costs fully recognize their consequences. If bus fleet managers are not charged for pavement damage or congestion, they will tend to create more of these costs than they would otherwise. Market-like mechanisms attempt to determine what the costs are so that bus fleet managers will face them directly and make appropriate choices. Such external costs include pavement damage, congestion, and air pollution.

Credits to Buy or Use Lighter Weight Buses

This option applies to bus fleet managers, and is a financial incentive to encourage the purchase and use of lighter-weight buses. By stimulating demand for lighter-weight buses, this policy will induce manufacturers to build them. This policy would be some combination of a credit for lighter-weight buses and a tax on heavy buses, paid at the time of bus purchase.

To set the amount of such a credit or tax, the government would first set a baseline axle loading, for which the credit or tax would be zero. If the new bus has a lower axle loading than the baseline, a credit would be set based on the expected difference in pavement damage (over the lifetime of the bus) between the new bus and the baseline bus. Alternatively, such a credit or tax could be imposed on an annual basis, possibly also based on mileage. Finally, it could be imposed based on the mileage and pavements that are used, in which case it becomes the axle-weight distance pavement charge that will be discussed next.

Axle-Weight Distance Pavement Charge

If the fundamental problem is that some buses at some times are causing pavement damage at a significantly higher rate than is desirable, then the most direct response is to charge each bus for the pavement damage it causes. The cost of the damage depends upon the axle weights the bus is applying to the pavement, the strength of the pavement at the time the bus passes over it, the volume of light vehicles that use the road after the bus passes and before the pavement is restored, and the cost of pavement restoration. The policy would consist of

- Imposing a charge per ESAL mile on all heavy vehicles, reflecting the number of axles, gross weight, and weight distribution of the vehicle.
- The magnitude of the charge per ESAL would reflect the costs of damage to the pavement, depending upon the strength of the particular pavement being traveled.

A pavement charge tied to the type of pavement and condition as well as the actual weight of the bus would be the most equitable and consistent policy that could be designed and implemented. Responses to an axle-weight distance pavement charge would all reduce pavement damage, and include the following:

- Reduce the weight of the vehicle, by buying lighter-weight buses
- Reduce the axle loadings by buying tandem axle buses
- Buy buses with an improved weight distribution among the existing axles.
- Shift travel to stronger roads.
- Reduce the amount of travel by bus.

With the ability to inexpensively locate vehicles on a real-time basis, an axle-weight distance pavement charge is becoming practical. Assessing the weight might be an issue (weigh in motion sensors are not yet in widespread use), but would be less of an issue for bus than for truck, because in a bus:

- The payload (passengers and baggage) is a smaller proportion of the gross weight, and
- There are fewer opportunities to redistribute the payload in a bus.

Therefore, an axle weight that is measured once for a particular bus model and assumed passenger loading would likely be closer to the real axle weight than a similar one-time measurement would be on a truck.

Congestion Tolls (peak pricing or value pricing)

Buses reduce congestion by serving passenger trips that would otherwise be taken by automobile. The share of auto trips that is removed, however, by additional subsidy to transit is generally estimated to be small. This is due to the combined effect of automobile travel that is not expensive relative to typical incomes and bus service that is less convenient and suffers the same congestion as autos.

Instead of attempting to make bus travel more attractive by exempting transit from weight limits, a more effective strategy would be to raise the price to highway travel in congested locations at congested times. This strategy is referred to as congestion tolls or peak pricing or “value” pricing. Several highways in Southern California differentiate tolls according to levels of demand, and in Great Britain, the City of London has recently instituted a central area vehicle toll that has been successful at largely eliminating congestion.

Thus a congestion toll combined with higher axle weight limits on light and moderate duty roads would provide transit with enough of a market advantage so that higher fares and/or higher ridership would easily offset the additional cost of reducing axle weights. In the absence of congestion pricing, imposition of bus axle-weight limits or weight-distance pavement charges would have a downside in urban areas, due to shifting some passengers to autos. If a congestion toll is not imposed, then an offsetting credit might be provided to bus fleet managers that approximates the improvement in congestion resulting from having passengers travel by bus rather than auto.

VI.5 Selection of Policy Options for Further Evaluation

The policy options are numerous, and they could be combined in myriad ways. However, many of the policies are extremely unlikely to be implemented, and do not warrant a detailed cost evaluation at this time. In some cases, implementation of the policy is not practical. In other cases, it appears from a preliminary analysis that the responses to a policy will cause more harm than good. Finally, policies whose impacts closely duplicate those of another policy will also not receive a separate evaluation.

Policies that are eliminated on account of practicality include the following:

- Add Tag Axles to All Transit Buses
- Upgrade Roads Used by Buses to Higher Strength
- Restrict Buses to Strong Roads
- Axle-Weight Distance Pavement Charge
- Congestion Tolls (peak pricing or value pricing)
- Add or Rearrange Transit Service to Avoid Overcrowded Buses
- Conduct a Development Program to Build Lighter Weight Buses

The remaining policy options fall into four areas.

First are those policies that seek to tighten current weight restrictions:

- Re-impose Weight Limits on Transit and Over-the-Road Buses
- Retain the 1992 - 2003 Policy, which would represent a tightening of current policy for over-the-road buses
- An Across-the-Board 20,000 lb Single Axle / 34,000 lb Tandem Axle Limit
- An Across-the-Board 22,400 lb Single Axle / 36,000 lb Tandem Axle Limit, which would effectively represent a tightening of current policy for transit

Second are those policies that seek to relax current weight restrictions (that, at this point, only apply to interstate transit buses and school buses):

- Expand the Current Permissive Arrangement to Interstate Transit Buses
- Add a 15% Tolerance to the 22,400 lb Single Axle / 36,000 lb Tandem Axle Limit, which would make virtually all buses legal.

Third are those policies that encourage development and use of lighter-weight buses, either through direct subsidies or market mechanisms:

- Credits to Buy or Use Lighter Weight Buses
- Research and Development Grants for Lighter-Weight Buses
- Measures to Facilitate the Adoption of New Technology by Bus Fleet Managers

Fourth is the policy that aims at government rulemaking:

- Require that Federal Rulemakings Consider Weight Impacts

One policy is chosen for evaluation in each of the four areas.

Where appropriate, each of these policies would contain a phase-in transition period, and the Federal government would provide some assistance in facilitating the transition. Further evaluation of selected policies is accomplished via benefit-cost analysis in the next chapter.

Chapter VII: Benefit-Cost Evaluation of Selected Policies

A limited number of policy options have been chosen for more thorough evaluation. These are the policies among those reviewed in the previous chapter that appear to offer the greatest potential for generating positive net benefits compared to the status quo. Evaluation of each policy is accomplished via benefit-cost analysis. Each policy option is compared to a base case (or counterfactual), the equivalent of the "do nothing" alternative for capital improvement evaluation.

VII.1 Policies to be Evaluated

Table VII-1 lists the policies to be evaluated. Because the transit and motorcoach sectors may have different responses to one policy, separate evaluations are performed for each sector.

Table VII-1 Policies to be Evaluated

Policy
Re-impose Weight Limits on Transit Buses (VII.2)
Re-impose Weight Limits on Over-the-Road Motorcoaches (VII.3)
Expand the Current Permissive Arrangement to Interstate Transit Buses (VII.4)
Financial Incentives to Use Lighter Weight Transit Buses (VII.5)
Financial Incentives to Use Lighter Weight OTR Buses (VII.6)

VII.1.1 Benefit Categories

The cost side is taken to consist of only the direct costs (to the government) of policy implementation. All other relevant impacts are classified as benefits, whether they have a positive or negative sign. The list of benefits is shown in Table VII-2.

Table VII-2 Benefit Categories

Type of Benefit	Benefit Component	Directness of Impact
Internal to the Bus Fleet Manager	Operating cost savings (capital, labor, fuel, maintenance, vehicle wear, tires)	1st Order Direct
	Incremental consumer surplus	2nd Order
External to the Bus Fleet Manager	Pavement damage	1st Order Direct
	Congestion (partial)	1st Order Direct
	Air Pollution and Noise	1st Order Direct
	Accidents (partial)	1st Order Direct
Externalities in Related Markets	Automobile externalities	3rd Order

For simplification in analysis, additional costs or cost savings faced by the bus fleet manager are assumed to be passed on to consumers in the form of higher or lower fares. For transit fleet managers, higher costs are more likely to lead to service cutbacks in the short run, but this still can be represented as an increase in the price of (the same) service.

VII.1.2 Impact Linkages

Impact linkages show the connection from the policy action to the resulting benefits. Figure VII-1 depicts a set of impact linkages to the imposition of a lower axle weight limit.

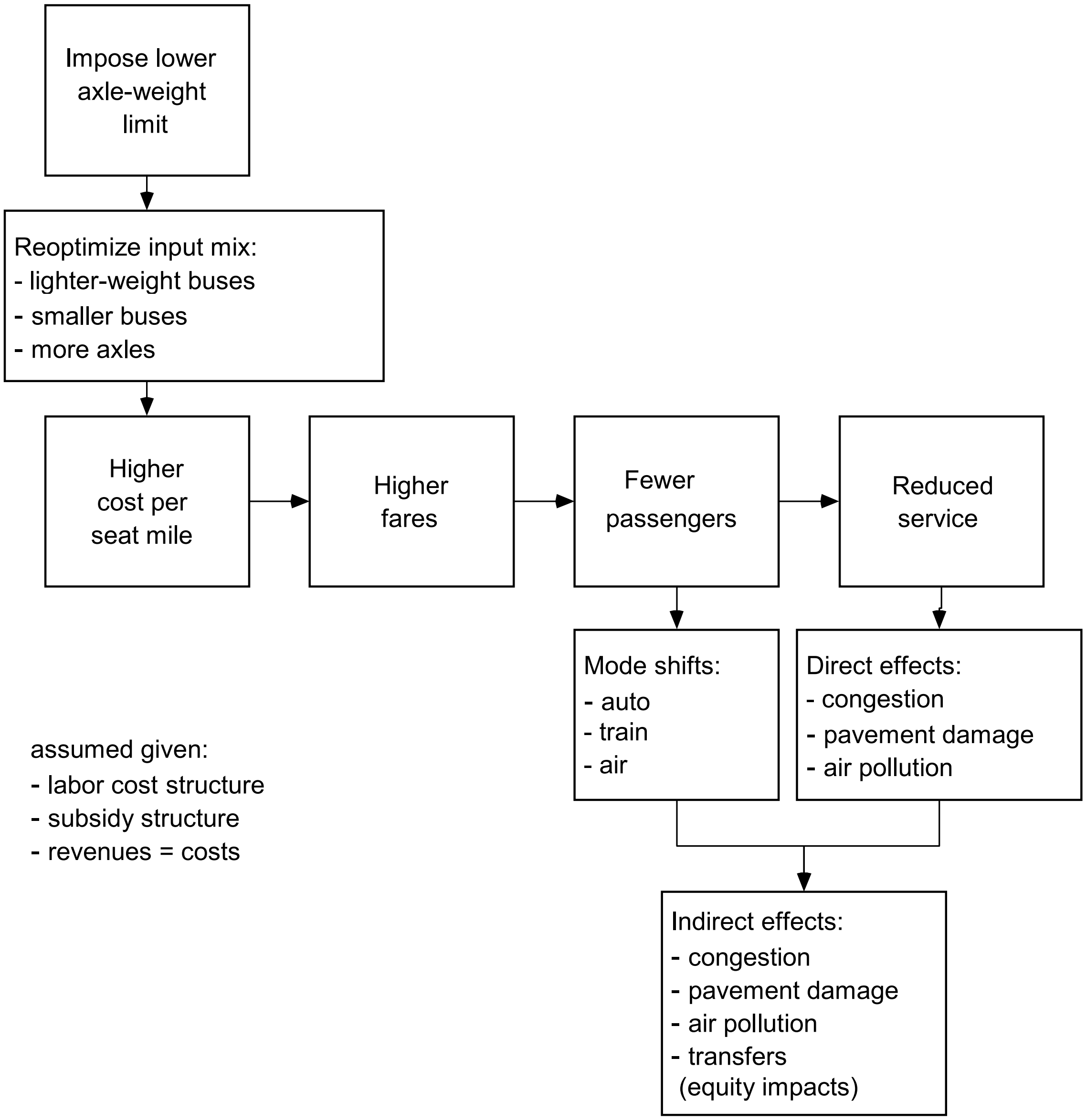

Figure VII-1 Impact Linkages for Bus Axle-weight Policy Evaluation

A spreadsheet model was set up which follows this structure. With this model, the evaluation includes the following actions:

- Enumerate likely responses to the policy.

- For each response, evaluate the change in operating cost. Major components of operating cost include capital, labor, fuel and other costs, such as maintenance and insurance.

- Based on the change in operating cost, identify the responses that will be chosen.

- Quantify the response in passenger demand, under the assumption that any change in operating cost is passed on in the form of changed fares.

- Quantify the change in bus externalities, such as pavement damage.

- Quantify passenger mode shifts.

- Quantify the change in automobile externalities that occur as a result of some passengers shifting to private automobile.

If a response has no positive impact (e.g., it raises operating cost while failing to reduce pavement damage) it will not be evaluated in detail. Each response is evaluated as though it was the only response to the policy. In reality, however, fleet managers will choose from a variety of responses, and may choose responses that are different in the long term than those in the short term. We also assume that all States have taken advantage of the current permissive arrangement on bus axle weights. Therefore, it currently acts as an exemption.

The first policy to be evaluated is the re-imposition of Federal axle weight limits on transit buses.

VII.2 Re-impose Weight Limits on Transit Buses

Current Federal policy allows States to exempt intrastate transit vehicles and over-the-road buses from axle weight limits on Interstate highways. The effect of changing this policy would depend on current State and local weight rules as they are applied to Interstate highways and local roads. Since loaded transit buses routinely exceed these limits, the effect could be disruptive to the transit industry in those states with low weight limits. Long-term, it could provide an impetus for lighter-weight buses.

The global cost and benefit numbers presented below (Table VII-18) represent an upper bound on the magnitude of benefit that may be obtained if there is 100% compliance with the re-imposed weight limits. Given potentially lax enforcement of transit bus weight limits, and the particular difficulties of enforcement in urban areas, compliance, in reality, may be less than 100%.

Since many states either impose the 20,000 lb Federal limit or use a 22,400 lb axle weight limit, responses are considered that meet these limits.

For a transit bus, some approximate combinations that would meet a 20,000 lb rear-axle weight limit are listed below:

- Empty weight of 28,000 lbs (typical for 40-foot bus) with 16 passengers
- Empty weight of 26,000 lbs, with 30 passengers
- Empty weight of 24,500 lbs, with 40 passengers (seated capacity)
- Empty weight of 20,000 lbs, with 70 passengers

Combinations that would meet a 22,400 lb rear-axle weight limit include the following:

- Empty weight of 28,000 lbs, with 40 passengers
- Empty weight of 26,000 lbs, with 55 passengers
- Empty weight of 23,500 lbs, with 70 passengers

An immediate re-imposition of weight limits would force transit bus fleet managers to either shift service from Interstate highways to arterials or to remove passengers from existing buses. Since neither of these responses effectively reduces pavement damage while maintaining ridership (see Chapter VI), it is assumed that re-imposition of weight limits would be phased in so that transit bus fleet managers can acquire new equipment. For example, existing transit buses would continue to be exempt (grandfathered).

VII.2.1 Transit Bus Fleet Manager Responses to the Re-imposition of Weight Limits

Responses to the re-imposition of weight limits on Interstate highways include

- Using smaller buses
- Adding a second rear axle (tag axle), and
- Reducing the weight of the bus while keeping its size the same.

These responses can be expected to lead to an increase in operating cost.

Smaller Transit Buses

Under such a response, transit fleet managers might switch from 40-foot to 35-foot buses. This saves weight in terms of both the number of passengers and the empty weight of the bus. The smaller bus is assumed to have the following characteristics, compared to the base case:

Table VII-3 Smaller Transit Bus

	Base	New	Difference
Length (ft)	40	35	(5)
Empty Weight (lb)	28,000	26,000	(2,000)
Seats	40	34	(6)
Cost	$289,000	$274,000	($15,000)

With the smaller bus, other operating costs such a labor and fuel may also decrease. Wage rates in related sectors suggest there is some relationship between vehicle size and driver wage. For example, according to 2001 data from the Bureau of Labor Statistics, drivers of large tractor-trailers earn $16.21 / hour and drivers of smaller trucks earn

$12.32 / hour. Although adjustments in labor rates are unlikely in the short run[19], they may occur in the long run as fleet managers seek ways to reduce the cost per passenger-mile of operating smaller buses. For this analysis, we assume that the 15% reduction in seating capacity eventually results in a 7% reduction in driver cost per mile. We also assume a 10% reduction in other operating costs. These assumptions are used only in those responses that involve use of smaller buses.

Data from the trucking industry show there is some relationship between vehicle weight and fuel economy. It appears that a 3% reduction in weight will result in approximately a 2 % decrease in fuel consumption, all other things being equal.

With these reductions in operating costs, the smaller bus has a lower cost per vehicle mile, but a higher cost per passenger mile (Table VII-4). (Note that if it were possible to use smaller buses with a lower operating cost per passenger mile, the fleet manager would have most likely adopted the smaller vehicles already.)

Table VII-4 Impact of Smaller Buses on Operating Cost

	Base	New	Difference	New/Base
Operating Cost ($ / vehicle-mile)	$6.66	$6.17	($0.49)	93%
Operating Cost ($ / seat-mile)	$0.167	$0.181	$0.014	109%
Operating Cost ($ / passenger-mile)	$0.666	$0.725	$0.059	109%

Transit Buses with Tag Axles

Although use of tag axles may not be feasible for all routes, there are some situations where transit fleet managers may choose to respond to a weight policy by acquiring buses with tag axles for use on some routes. Acquisition of buses with tag axles, while it will effectively reduce ESAL loads on the roads where those buses operate, will increase the per vehicle-mile cost for the following reasons:

- The second axle adds weight to the bus, thus increasing fuel consumption
- It adds capital and maintenance expense for the bus fleet manager, and
- The introduction of a new bus type adds to maintenance expense.

It will also increase the seat-mile cost because in a transit bus, the second axle will most likely reduce seating capacity. Furthermore, the roads that are best suited for these buses (roads with few sharp turns, such as Interstate highways) have the least need for them, because these roads tend to be built to the greatest strength.

Currently, tag-axles are used in motorcoaches. A standard motorcoach design is not well suited for most transit routes for the following reasons:

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[19] Collective bargaining agreements at most transit agencies protect operators from losing their jobs and incurring payroll reductions due to changeover in equipment.

- The single door will greatly increase dwell times at stops
- Wheelchair access is cumbersome
- The second rear axle presents challenges on sharp turns.

The tag axle is assumed to add 5,000 lbs to the overall weight of the bus and $5,000 to the capital cost of the bus *(11)*. It is also assumed to reduce seating capacity by 2 passengers and to increase maintenance cost by 1%. The impact on operating cost is as follows:

Table VII-5 Tag Axle Impact on Operating Cost

	Base	New	Difference	New/Base
Operating Cost ($ / vehicle-mile)	$6.66	$6.72	$0.06	101%
Operating Cost ($ / seat-mi)	$0.167	$0.177	$0.010	106%
Operating Cost ($ / passenger-mile)	$0.666	$0.707	$0.041	106%

Lighter-Weight Transit Buses

In locations with axle weight limits of 20,000 lbs, a 40-foot transit bus with a full seated load is overweight by approximately 3,500 lbs on the rear axle, while a transit bus with a crush load of 70 passengers is overweight by about 8,000 lbs on the rear axle. Where the axle weight limit is 22,400 lbs, the transit bus with a crush load is overweight by about 4,500 lbs. Accordingly, two scenarios were tested. Scenario A represents a bus that would be legal in areas with a 22,400 lb limit under virtually all passenger loadings, while scenario B represents a bus that would be legal on roads with a 20,000 lb axle weight limit. The capital cost premiums (Table VII-6) are drawn from the analysis in Chapter V.

Table VII-6 Lighter-Weight Transit Bus Scenarios

Scenario	Weight savings	Capital cost premium
A	4,000 lb	$40,000 (average $10 / lb)
B	8,000 lb	$160,000 ($10 / lb first 4000 lb, then $30 /lb thereafter. Average premium is $20 / lb.)

Table VII-7 presents empty weights, bus costs, and operating costs for these scenarios. The changed capital costs were incorporated into the per-mile operating costs using a 12-year bus lifetime, 31,000 miles / year, and a amortization rate of 5%. The 31,000 miles per year is derived from APTA data, as Total Bus Vehicle Miles divided by Active Vehicles.

Table VII-7 Lighter-Weight Transit Bus Scenario Operating Costs

	Base	A	B
Empty Weight (lb)	28,000	24,000	20,000
Cost	$ 289,000	$ 329,000	$ 449,000
Operating Cost ($ / vehicle-mile)	$6.66	$ 6.78	$ 7.20
Operating Cost ($ / seat-mile)	$0.167	$ 0.170	$ 0.180
Operating Cost ($ / passenger-mile)	$0.666	$ 0.678	$ 0.720

Summary of Transit Bus Fleet Manager Responses to the Re-imposition of Weight Limits

Table VII-8 summarizes the operating cost impacts of the various responses.

Table VII-8 Summary of Transit Bus Fleet Manager Responses to Re-imposed Weight Limits

Response	Cost / passenger-mile	Comment
Smaller Buses	up 9%	
Tag Axles	up 6%	May not be practical on many roads
Reduce 4000 lb at $10 / lb	up 2%	Scenario A: Will meet a 22,400 lb weight limit
Reduce 8000 lb at $20 / lb	up 8%	Scenario B: Will meet a 20,000 lb weight limit

The best responses appear to be the two weight reductions and tag axles. Unfortunately, since the market for lighter-weight buses is not well developed, it would not be feasible for all transit fleet managers to start buying lighter-weight buses at this time. The market for transit buses with tag axles is also limited; furthermore, tag axles may not be practical on many roads.

VII.2.2 Evaluation of Transit Fleet Manager Responses to the Re-imposition of Weight Limits

Since the actual responses that transit bus fleet managers choose will depend on the (uncertain) development of the lighter-weight bus market, each response is evaluated separately, as though it were the only response. The likely responses to removal of the weight exemption include use of smaller buses, increased use of tag axles, and the two weight reduction responses.

For each fleet manager response that increases the cost per passenger-mile, and therefore the price charged to passengers, passengers will also respond, by forgoing trips or switching to other modes. Assumptions used for modeling the passenger response are as follows:

Table VII-9 Passenger Response Assumptions

Parameter	Value
Base annual transit VMT	2,300 million
Base annual transit passenger-miles traveled	23,000 million
Price Elasticity (long term)[20]	-0.8
Fraction of lost passengers who switch to transport modes other than automobile	0.2
Fraction of lost passengers who switch to automobile	0.2
Automobile occupancy	1.59

External costs for automobile usage are taken from the 1997 Federal Highway Cost Allocation Study.

Impact of Smaller Transit Buses

With the 9% increase in cost, passenger-miles decrease, due to reduced demand. This leads some trips to be diverted to automobile and to other modes. Bus vehicle miles, however, increase, because the buses are smaller (Table VII-10). This is because even though average load factors of a transit bus are low, there are portions of many routes where the bus is running at capacity. More buses will be needed to serve the demand. Hence, average bus occupancy will decrease.

Table VII-10 Smaller Buses Impact on Vehicle and Passenger Miles

	All Roads Base	New	Difference	New/Base
Bus vehicle-miles (millions)	2,300	2,494	194	108%
Bus passenger miles (millions)	23,000	21,203	(1,797)	92%
Induced auto passenger-miles (millions)			359	
Induced auto vehicle-miles (millions)			226	

Table VII-11 shows the net benefit from smaller buses both for Interstate highways and for all roads. The benefit categories shown in this table are as follows:

- Bus Operating Cost Savings. This is the decrease (or increase) in bus operating cost, and is assumed passed on to passengers in the form of changed fares. It includes bus capital cost, operator wages, fuel and other operating costs. A negative number (noted in parentheses) indicates a higher operating cost, and therefore a higher fare.
- Bus Pavement Damage Cost Savings. This is the decrease (or increase) in pavement damage cost, and is a function of bus vehicle-miles and pavement damage per bus.
- Bus Other External Cost Savings. This is the decrease (or increase) in crash, congestion, air pollution and noise costs imposed by buses.
- Incremental Consumer Surplus. This is the gain (or loss) in consumer surplus from induced (or forgone) bus passenger trips.

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[20] A 1992 study by Goodwin*(28)* indicates that in the long-term, price elasticities may be somewhat larger in magnitude than is commonly assumed. Therefore, a value of –0.8 was used in this study. For those actions that increase bus fares, use of a smaller elasticity would result in less loss of ridership, and less shifting to other modes, such as automobile.

- Auto External Cost Savings. This is the decrease (or increase) in automobile external costs that result from reduced (or induced) automobile trips.
- Other Mode External Cost Savings. This is the decrease (or increase) in other mode external costs that result from reduced (or induced) other mode trips. For convenience, the other mode is assumed to have the same external cost as a bus on a per passenger-mile basis.

Table VII-11 Smaller Buses Net Benefit

Millions $ / year	Interstate	All Roads
Bus Operating Cost Savings	$ (110)	$ (1,260)
Bus Pavement Damage Cost Savings	$ 3	$ 384
Bus Other External Costs Savings	$ (3)	$ (31)
Incremental Consumer Surplus	$ (2)	$ (20)
Auto External Cost Savings	$ (2)	$ (19)
Other Mode External Cost Savings	$ (1)	$ (32)
Net Benefit	$ (114)	$ (979)

Table VII-11 shows that even though there is an improvement in pavement damage, it is more than offset by the increased operating cost. Overall, the net benefit of going from standard transit buses to smaller transit buses is negative.

Impact of Transit Buses with Tag Axles

With a 6% increase in operating cost, fares increase, and demand decreases. Bus capacity decreases slightly, so vehicle miles remain essentially unchanged:

Table VII-12 Tag Axle Impact on Vehicle and Passenger Miles

	All Roads			
	Base	New	Difference	New/Base
Bus vehicle-miles (millions)	2,300	2,289	(11)	100%
Bus passenger miles (millions)	23,000	21,741	(1,259)	95%
Induced auto passenger-miles (millions)			252	
Induced auto vehicle-miles (millions)			158	

The projected savings in pavement damage is significant, but may not be fully realizable due to the maneuverability issues with tag axles on minor roads. In any event, it is not enough to outweigh the increase in operating cost (Table VII-13).

Table VII-13 Tag Axle Net Benefits

Millions $ / year	Interstate	All Roads
Bus Operating Cost Savings	$ (77)	$ (891)
Bus Pavement Damage Cost Savings	$ 6	$ 825
Bus Other External Costs Savings	$ (1)	$ (8)
Incremental Consumer Surplus	$ (1)	$ (10)
Auto External Cost Savings	$ (1)	$ (13)
Other Mode External Cost Savings	$ (1)	$ (23)
Net Benefit	$ (75)	$ (120)

Impact of Lighter Transit Buses

Recall from Table VII-6 that Scenario A represented a 4,000 lb weight reduction, while Scenario B represented an 8,000 lb weight reduction at much higher capital cost. Because the cost per passenger mile increases under both scenarios, fares increase, and demand decreases (Table VII-14).

Table VII-14 Lighter-Weight Transit Bus Scenario Impacts on Vehicle and Passenger Miles

	All Roads Base	Scenario A	Scenario B
Bus vehicle-miles (millions)	2,300	2,261	2,137
Bus passenger miles (millions)	23,000	22,614	21,370
Induced auto passenger-miles (millions)		77	326
Induced auto vehicle-miles (millions)		49	205

When Interstate highways alone are considered, the pavement damage benefits do not warrant the increased operating cost (Table VII-15). However, when all road types are considered, the pavement damage benefits do outweigh the increased capital costs for both Scenarios A and B. Unlike the other responses reviewed, this response does provide a net benefit (Table VII-16).

Recall from Chapter III that the pavement damage cost-per-mile is much lower on Interstate highways than on other types of roads (Table III-5, page III-8). Therefore, when Interstate highways alone are considered, a major investment in lower axle weights is usually not worthwhile. On the other hand, when all roads are considered, such an investment in lower axle weights is worthwhile.

Table VII-15 Lighter-Weight Transit Bus Net Benefits on Interstate Highways

	Interstate Highways	
Millions $ / year	Scenario A	Scenario B
Bus Operating Cost Savings	$ (24)	$ (100)
Bus Pavement Damage Cost Savings	$ 6	$ 9
Bus Other External Costs Savings	$ 1	$ 4
Incremental Consumer Surplus	$ (0)	$ (1)
Auto External Cost Savings	$ (0)	$ (2)
Other Mode External Cost Savings	$ (0)	$ (1)
Net Benefit	$ (17)	$ (91)

Table VII-16 Lighter-Weight Transit Bus Net Benefits on All Roads

Millions $ / year	All Roads Scenario A	Scenario B
Bus Operating Cost Savings	$ (277)	$ (1,146)
Bus Pavement Damage Cost Savings	$ 796	$ 1,267
Bus Other External Costs Savings	$ 15	$ 45
Incremental Consumer Surplus	$ (1)	$ (17)
Auto External Cost Savings	$ (4)	$ (17)
Other Mode External Cost Savings	$ (7)	$ (29)
Net Benefit	$ 522	$ 103

Under the price premiums modeled here, the use of lighter-weight buses provides a net benefit. Where the average price premium reaches $20 / pound saved (scenario B), however, the increased cost to the transit bus fleet manager (due to the increased capital cost of the bus) approximately equals the savings in pavement damage.

Given that bus lifetimes are longer than 10 years, and that the current market for lighter-weight buses is extremely limited, an immediate shift to lighter-weight buses is extremely unlikely.

Overall Evaluation of Re-imposing Weight Limits on Transit Buses

When Interstate highways alone are considered, none of the responses to removal of the transit bus exemption produces a net benefit. When all roads are considered, there is a net benefit from the use of lighter-weight buses. This benefit depends on the price premium for the lighter-weight bus, dropping close to zero as the price premium exceeds $20 / lb. Table VII-17 summarizes the results:

Table VII-17 Summary of Transit Impacts from Re-Imposed Weight Limits

Response	Cost / pass-mi	Net Benefit (millions $ / yr) assuming this response is the sole response Interstate	All Roads
Smaller Buses	up 9%	(114)	(979)
Tag Axles	up 6%	(75)	(120)
Reduce 4000 lb at $10 / lb	up 2%	(18)	522
Reduce 8000 lb at $20 / lb	up 8%	(90)	103

The best response from both the standpoint of the cost to the bus fleet manager cost and of social benefit appears to be the 4,000 lb weight reduction. Unfortunately, a 4,000 lb weight reduction would be insufficient to meet a 20,000 lb axle weight limit under crush load conditions. Therefore, some fleet managers would be forced to choose either tag axles or the larger weight reduction.

The actual net benefit of the policy will depend upon how the policy is implemented. Since Table VII-17 indicates that implementation of this policy will not provide a net benefit unless lighter-weight buses are available at reasonable cost, it is assumed that the policy is implemented gradually, so that fleet managers can respond by purchasing lighter-weight buses. In areas with a 22,400 lb weight limit, fleet managers choose the reduction of 4,000 lbs. In areas with a 20,000 lb weight limit, fleet managers choose either the 8,000 lb weight reduction or tag axles. Table VII-18 shows a possible distribution of responses, along with a total net benefit. As noted earlier, these numbers represent an upper bound on the magnitude of the benefit. Some transit bus fleet managers may not comply with any re-imposed weight limits, and given the difficulty of enforcing weight limits in urban areas, States may not direct large efforts at enforcement.

Table VII-18 Evaluation of Transit Bus Fleet Manager Responses to Re-imposed Weight Limits

Response	Fraction adopting	Interstate	All Road
Smaller Buses	0	$ -	$ -
Tag Axles	0.2	$ (15)	$ (24)
Reduce 4000 lb at $10 / lb	0.5	$ (9)	$ 261
Reduce 8000 lb at $20 / lb	0.3	$ (27)	$ 31
TOTAL NET BENEFIT	1	$ (51)	$ 268

VII.3 Re-impose Weight Limits on Over-the-Road Motorcoaches

Current Federal law allows States to exempt over-the-road motorcoaches from weight limits on Interstate highways. Similar to transit, the effect of a policy change would depend on current State and local weight rules as they are applied to Interstate highways and local roads. This analysis assumes that if weight limits are re-imposed, they will be obeyed. In practice, current and future levels of fleet compliance and State enforcement are unknown. Therefore, the global cost and benefit numbers presented below (Table VII-27) represent an upper bound on the magnitude of benefit that may be obtained, assuming 100% compliance.

Although the prototypical motorcoach used in this study already meets a 22,400 lb limit with a full passenger load, it does not comply with a 20,000 lb limit. Combinations that would meet a 20,000 lb weight limit include the following:

- Empty weight of 36,000 lbs (typical for a 45-foot motorcoach), with 33 passengers
- Empty weight of 32,000 lbs with 56 passengers.

VII.3.1 OTR Fleet Manager Responses to Re-imposition of Weight Limits

Possible responses to enforcement of weight limits include the following:

- Confining existing vehicles to States with higher weight limits,
- Using smaller buses, and
- Reducing the weight of the bus while keeping its size the same.

Similar to transit, these responses can be expected to lead to an increase in operating cost per passenger.

Confine Existing Vehicles to States with Higher Weight Limits

For some regional operations, it may be possible to confine use of existing 45-foot motorcoaches to those states that have at least a 22,400 lb axle weight limit. This is, essentially, a "do nothing" response. It would not be feasible for most bus fleet managers.

Smaller Motorcoaches

Under such a response, over-the-road fleet managers might switch from 45-foot to 40-foot buses. This saves weight in terms of both the number of passengers and the weight of the bus. However, it results in increased operating cost per passenger, because the buses carry fewer passengers. For this study, the load factor is assumed to stay constant, so that with fewer seats, the average number of passengers on board also decreases. The smaller bus is assumed to have the following characteristics, compared with the base case.

Table VII-19 Smaller OTR Bus

	Base	New	Difference
Length (ft)	45	40	(5)
Empty Weight (lb)	36,000	34,000	(2,000)
Seats	56	48	(8)
Cost	$364,000	$349,000	($15,000)

In the long run, labor, fuel and other operating costs may also decrease, similar to the case with the smaller transit bus. Thus, the smaller bus has a lower cost per vehicle mile, but a higher cost per passenger mile (Table VII-20):

Table VII-20 Smaller OTR Bus Operating Cost

	Base	New	Difference	New/Base
Operating Cost ($ / vehicle-mile)	$2.16	$2.02	($0.14)	93%
Operating Cost ($ / seat-mile)	$0.0386	$0.0421	$0.0035	109%
Operating Cost ($ / passenger-mile)	$0.0636	$0.0693	$0.0057	109%

Lighter-weight Motorcoaches

As noted earlier, a 4,000 lb weight reduction would be required to ensure that the drive axle does not exceed 20,000 lb for a fully loaded 45-foot over-the-road bus. For this weight reduction, a $40,000 price premium ($10 / lb) is assumed. Table VII-21 presents empty weights, bus costs, and operating costs:

Table VII-21 Lighter-weight OTR Bus Operating Cost

	Base	New	Difference	New/Base
Empty Weight (lb)	36000	32000	(4000)	89%
Cost	$ 364,000	$ 404,000	$40,000	111%
Operating Cost ($ / vehicle-mile)	$2.16	$ 2.22	$0.06	103%
Operating Cost ($ / seat-mile)	$0.0386	$ 0.0396	$0.0010	103%
Operating Cost ($ / passenger-mile)	$0.0636	$ 0.0652	$0.0020	103%

Summary of OTR Bus Fleet Manager Responses to Re-imposition of Weight Limits

Table VII-22 summarizes the operating cost impacts of the three responses.

Table VII-22 Summary of OTR Impacts from Re-imposed Weight Limits

Response	Cost / pass-mi	Comment
No change	0	Current motorcoaches are legal in many states
Smaller Buses	up 9%	
Reduce 4000 lb at $10 / lb	up 3%	Will meet a 20,000 lb weight limit

Motorcoach fleet managers in States with high weight limits may not have to change their operations at all in those States. For fleet managers in other regions and those who wish to operate nationally, the best response is a lighter-weight bus. Unfortunately, 45-foot lighter-weight buses are not currently available.

VII.3.2 Evaluation of OTR Fleet Manager Responses to the Re-imposition of Weight Limits

Since the actual responses that bus fleet managers choose will depend on the (uncertain) development of the lighter-weight bus market, each response is evaluated separately, as though it were the only response. The likely responses to removal of the weight exemption include use of smaller buses and the use of lighter-weight buses. Some bus fleet managers may confine operation of heavy buses to States with higher weight limits.

For each fleet manager response that increases the cost per passenger-mile, and therefore the price charged to passengers, passengers will respond, by forgoing trips or switching to other modes. Assumptions used for modeling the passenger response are the same as those used for transit (Table VII-9, page VII-8), except that with an average loading of 34 passengers per motorcoach, annual OTR passenger-miles traveled is 78,200 million.

Impact of Smaller Motorcoaches

For the evaluation, the 9% increase in operating cost per passenger-mile is passed on to passengers. As a result, passenger-miles decrease 7%, and some auto trips are induced. The vehicles are smaller, so vehicle miles increase by 8% (Table VII-23).

Table VII-23 Smaller OTR Bus Vehicle and Passenger Miles

	All Roads			
	Base	New	Difference	New/Base
Bus vehicle-miles	2,300	2,491	191	108%
Bus passenger miles	78,200	72,594	(5,606)	93%
Induced auto passenger-miles			1,121	
Induced auto vehicle-miles			705	

Although there is an overall decrease in pavement damage, the cost savings in pavement damage due to going from 45-foot to smaller motorcoaches is more than offset by the increased operating cost (Table VII-24) for the fleet.

Table VII-24 Smaller OTR Bus Net Benefit

Millions $ / year	Interstate	All Roads
Bus Operating Cost Savings	$ (216)	$ (414)
Bus Pavement Damage Cost Savings	$ 11	$ 177
Bus Other External Costs Savings	$ (12)	$ (21)
Incremental Consumer Surplus	$ (8)	$ (16)
Auto External Cost Savings	$ (26)	$ (46)
Other Mode External Cost Savings	$ (3)	$ (17)
Net Benefit	$ (255)	$ (336)

Impact of Lighter-weight Motorcoaches

The increased operating cost is passed on in the form of higher fares. Thus ridership declines slightly, and there is some diversion to automobile (Table VII-25).

Table VII-25 Lighter-weight OTR Bus Vehicle and Passenger Miles

	All Roads			
	Base	New	Difference	New/Base
Bus vehicle-miles	2,300	2,251	(48)	98%
Bus passenger miles	78,200	76,558	(1,642)	98%
Induced auto passenger-miles			329	
Induced auto vehicle-miles			207	

When Interstate highways alone are considered, the net benefit is negative, because the increase in operating cost outweighs the savings in pavement damage. However, when all roads are considered the net benefit becomes positive (Table VII-26).

Table VII-26 Lighter-weight OTR Bus Benefits

Millions $ / year	Interstate	All Roads
Bus Operating Cost Savings	$ (67)	$ (128)
Bus Pavement Damage Cost Savings	$ 19	$ 320
Bus Other External Costs Savings	$ 7	$ 12
Incremental Consumer Surplus	$ (1)	$ (1)
Auto External Cost Savings	$ (8)	$ (13)
Other Mode External Cost Savings	$ (1)	$ (5)
Net Benefit	$ (50)	$ 185

Given that bus lifetimes are longer than 10 years, and that the market for lighter-weight over-the-road buses does not yet exist, a shift to lighter-weight buses could not happen immediately.

Overall Evaluation of the Re-imposition of OTR Weight Limits

When Interstate highways alone are considered, none of the responses to the re-imposition of over-the-road bus weight limits produces a net benefit. When all roads are considered, there is a net benefit from the use of lighter-weight buses. This benefit depends on the price premium for the lighter-weight bus, and it drops to zero when the price premium is approximately $20 / lb. Table VII-27 summarizes the OTR fleet manager responses.

Table VII-27 Summary of OTR Impacts from the Re-imposed Weight Limits

		Net Benefit (millions $ / yr) assuming this response is the sole response	
Response	Cost / pass-mi	Interstate	All Roads
Do nothing	0	0	0
Smaller Buses	up 9%	(255)	(336)
Reduce 4000 lb at $10 / lb	up 3%	(50)	185

The best response from the standpoint of bus fleet manager cost is a mixture of using its current fleet (in states with higher weight limits) and of using lighter-weight buses. Assuming that lighter-weight buses are available at the cost and weight savings indicated above, and are procured for 2/3 of the vehicle replacements and that no changes are made in the remaining 1/3 (because the bus is expected to operate legally in locations with higher weight limits), the net annual benefit is approximately 2/3 of $185 million, or $123 million. Similar to the transit analysis, some bus fleet managers may not comply with re-imposed weight limits; therefore, the fraction using lighter-weight buses may be lower than the 2/3 assumed here. This would cause the net annual benefit to be reduced.

Unfortunately, given lack of availability of lighter-weight vehicles, it would not be feasible for OTR fleet managers to start buying lighter-weight buses at this time.

VII.4 Expand the Current Permissive Arrangement to Interstate Transit Buses

The impacts are similar to the base policy, except that it permits heavy transit buses to be used in interstate regularly scheduled fixed-route operations.

A number of metropolitan areas have interstate transit operations. Major examples include New York City (New Jersey, New York, Connecticut), Philadelphia (Pennsylvania, New Jersey), and Washington, DC (Virginia, Maryland). Other examples may include Cincinnati, St. Louis, Kansas City, Duluth, MN, and Portland, OR.

Figure VII-2 Transit Bus used in Interstate Service (Washington, DC to Dulles Airport in Virginia)

For some of these locations, the issue of interstate transit axle weights may be moot, since the states involved have higher weight limits. For example, according to 1994 data from the U.S. DOT Comprehensive Truck Size and Weight Study *(27)*, Connecticut, New York, New Jersey and Pennsylvania all have axle weight limits for buses that are higher than the 20,000 / 34,000 lb Federal limit.

In other locations, weight limits on interstate transit operations may not be currently enforced.

For those (possibly very few) areas where States are enforcing weight limits on interstate transit operations due to the current Federal law, allowing States to exempt interstate transit operations from Federal weight limits could have the following results:

- Shifting of interstate transit service from arterials to Interstate highways (in locations where the Interstate highway weight limit is lower than the arterial weight limit)

- If small buses are currently being used to meet the weight limits, a shift to larger buses where appropriate
- If motorcoach-type buses are currently being used to meet weight limits, a shift to transit-type buses where appropriate
- Introduction of new interstate transit service, where appropriate.

The first of these responses leads to reduced pavement damage, while the next two responses reduce operating costs. The last response increases ridership, and may lead to a lower overall per-passenger operating cost. The last three responses may increase pavement damage slightly, but the analysis of the previous policy (Section VII.2) suggests that the increase in pavement damage would be less than the improvement in operating cost. Therefore, all of these responses can be expected to provide a net social benefit.

Given the extremely limited amount of interstate transit operation in states that have a 20,000 lb axle weight limit, the existing restriction has not driven the development of lighter-weight buses.

Since states are not required to impose weight limits on over-the-road buses used in either interstate or intrastate service, a similar permissive arrangement for interstate transit buses is arguably equitable. Currently, an overweight over-the-road bus may be permitted to travel on a service that is off limits to a transit bus, even though the transit bus may be better suited to the service.

VII.5 Financial Incentives to Use Lighter Weight Transit Buses

This policy would combine the following elements:

- Continue the current permissive arrangement for all transit buses
- Provide financial incentives to buy and use lighter-weight buses.

A financial incentives policy is designed to make pavement damage costs visible to bus fleet managers, so that they take them into account when making bus procurement decisions. Unlike most grants or subsidies, this policy does not attempt to dictate how the pavement damage reduction will be achieved. Rather it provides an incentive for fleet managers to encourage manufacturers to find a cost-effective way to reduce axle weights, and thus pavement damage. Ways to reduce axle-weight, and thus pavement damage, might include better load distribution, more efficient vehicle design, and the use of lightweight materials.

An economically efficient incentive would consider both the axle weight of the bus and the types of roads that the bus is expected to operate on. Given an assumed passenger loading, it is easy to assess the axle weight of a bus. Assessing the expected highway usage by road type would be more difficult and any policy that relies on actual usage by highway class may need to be deferred. A possible mechanism for providing an incentive is outlined below:

- For each new bus, assign it an axle-weight rating. This would be based on the axle-weights for that fully-fueled bus given a “standard” passenger load, such as 40 passengers on a 40-foot transit bus.

- Base the transit bus reimbursement on that axle-weight rating, and the expected pavement damage that will be caused over the lifetime of the bus. Heavier buses would receive a lower reimbursement, and lighter buses would receive a higher reimbursement.

For example, consider the difference between a 24,000 lb and a 28,000 lb transit bus:

Table VII-28 Two-Axle Transit Bus Pavement Damage Cost

Empty Weight:	24,000 lb	28,000 lb
Axle weight rating (ESALs with 40 passengers)	1.58	2.77
Pavement Damage cost / veh-mi (passenger load as in Appendix 1)	$ 0.38	$ 0.72
Miles / year	31,000	31,000
Pavement Damage cost / year	$ 11,629	$ 22,165
Bus life (years)	12	12
Discount rate	5%	5%
Pavement damage cost over lifetime of bus	$ 103,072	$ 196,456
Difference	$ 93,384	
$ / unit ESAL reduction	$ 78,000	
$ / lb weight savings	$ 23.35	

Suppose that for a two-axle transit bus, the adjustment to the reimbursement were set on a sliding scale between $10 and $30 / lb, with zero change in reimbursement when there is a 4,000 lb weight savings. (The sliding scale is necessary due to the fourth power rule: there is more advantage in reducing weight from 28,000 to 27,000 lbs than there is in reducing weight from 21,000 to 20,000 lbs.) If bus costs were taken from Table V-2 (page V-7), the resulting price premium (after the reimbursement adjustment) would be as in Table VII-29:

Table VII-29 Price Premiums for Lighter Weight Buses after Adjustment in Reimbursement

Weight savings (lbs)	Price Premium (from Chapter V)	Reimbursement Adjustment	Price Premium after Adjustment
0	0	($92,000)	$92,000
2000	$20,000	($40,000)	$60,000
3000	$30,000	($18,000)	$48,000
4000	$40,000	0	$40,000
5000	$70,000	$13,000	$57,000
8000	$160,000	$54,000	$106,000

Transit bus fleet managers would seek those buses with the lowest cost after the reimbursement adjustment. The marketplace would decide the configuration that is most cost-effective in terms of both expected pavement damage and operating cost. It might be a bus with modest weight savings at low cost, a larger weight savings at higher cost, a design that redistributes axle weights, or some combination of designs. The marketplace would also decide how the weight savings is attained. It might be through the use of lightweight materials, or through more efficient designs with existing materials. Under the assumptions of Table VII-29, the most effective configuration would be the bus with the 4,000 lb weight reduction. (It is likely, however, that given the evolution of technology, the actual price premium/weight savings tradeoff would be somewhat different than that presented in Chapter V, therefore, the optimal weight savings would also be different.) Assuming that the incentives are set correctly, and that fleet managers respond in the expected manner, such a response produces a net annual benefit of $522 million (Table VII-17 on page VII-11). This amount is probably an upper bound on the benefit that may actually be realized.

VII.6 Financial Incentives to Use Lighter Weight OTR Buses

Similar to transit buses, a possible mechanism for providing an incentive for over-the-road buses is as follows:

- For each new bus, assign it an axle-weight rating. This would be based on the axle weights of a bus with all seats occupied, plus a standard amount of baggage per seat.
- Provide a credit or assess a tax based on the expected pavement damage that would be caused over the lifetime of the bus. Credits would be provided for buses that are lighter than some threshold; taxes would be assessed for buses that are heavier. Alternatively, an annual credit or tax could be assessed based on mileage traveled.

Similar to the policy for transit, this policy would not attempt to dictate how the axle weight reduction is achieved. The value of the credit or tax would be based on the expected pavement damage caused by the bus. For example, consider the difference between a 32,000 lb and a 36,000 lb OTR bus:

Table VII-30 OTR Bus Pavement Damage Cost

Empty Weight:	32,000 lb	36,000 lb
Axle Weight Rating (ESALS with 56 passengers)	1.72	2.60
Pavement Damage Cost / vehicle-mile (passenger load as in Appendix 1)	$ 0.24	$ 0.37
Miles / year	66,000	66,000
Cost / year	$ 15,732	$ 24,587
Bus life (years)	12	12
Amortization Rate	5%	5%
Pavement damage cost over lifetime of bus	$ 139,437	$ 217,924
Difference	$ 78,487	
$ / unit ESAL reduction	$ 90,000	
$ / lb weight savings	$ 19.62	

If the amount of the credit or tax is set correctly, motorcoach fleet managers would respond as if their operating cost included expected pavement damage over the life of the bus (recall Figure IV-3). Under the assumptions of lighter-weight bus costs in Chapter IV, motorcoach fleet managers, like transit fleet managers, would likely seek buses with a 4,000 lb weight reduction. This reduction would be sought by all fleet managers, including those in states with axle weight limits higher than 20,000 lbs. This action could yield a net annual benefit (from Table VII-27, page VII-16) as high as $185 million.

VII.7 Conclusions

Five policy options were examined (Table VII-1).

The first option (Re-impose Weight Limits on Transit Buses) would produce a social benefit if lighter-weight buses were available to fleet managers at reasonable cost. The other possible responses, such as removing passengers, shifting routes off of Interstate highways, using smaller buses, or tag axles, would not produce a net benefit.

The second option (Re-impose Weight Limits on Over-the-Road Motorcoaches), like removal of the transit exemption, would produce a social benefit if lighter-weight buses were available to fleet managers at reasonable cost.

The third option (Expand the Current Permissive Arrangement to Interstate Transit Buses) may be desirable. In those (possibly very few) cases where the lack of an interstate transit exemption is constraining operations, expanding the exemption for regularly scheduled fixed-route service would enable transit fleet managers more flexibility in choosing equipment for such service, and may enable expanded transit service that crosses State lines. However, because some transit fleet managers are already engaging in interstate operations (using over-the-road buses or otherwise), the practical impact of this policy change may be very small.

The fourth and fifth options (Incentives for Lighter Weight Buses) may be worth pursuing, because lighter-weight buses would provide a significant benefit in terms of reducing pavement damage. It appears that, at least for modest weight reductions, the reduction in pavement damage will outweigh the added capital cost of the bus. While the financial incentive policy discussed here will produce some benefit, it will not be as economically efficient as the axle weight distance tax discussed in Chapter VI. A financial incentive policy that is simply based on axle weight (with an “average” pavement type) will lead to underinvestment in lighter-weight buses in situations where bus operations are primarily on light-duty pavements, and overinvestment in lighter-weight buses in situations where bus operations are primarily on heavy-duty pavements.

For those options where the impacts were quantified, a summary appears below:

Table VII-31 Summary of Policy Impacts

Policy Option	Net Annual Benefit (Millions $)	Comment
Re-impose Weight Limits on Transit Buses	$268	Positive benefit if lighter-weight buses are available at reasonable cost. Otherwise, the benefit is negative. (See Table VII-18.) Furthermore, the stated benefit represents an upper bound on what can realistically be achieved, because it assumes that States will enforce the weight limits and that bus fleet managers will obey them.
Re-impose Weight Limits on Over-the-Road Motorcoaches	$123	Positive benefit if lighter-weight buses are available at reasonable cost. Otherwise, the benefit is negative. (See page VII-16) Furthermore, the stated benefit represents an upper bound on what can realistically be achieved, because it assumes that States will enforce the weight limits and that bus fleet managers will obey them.
Financial Incentives for Transit	$522	See Table VII-17
Financial Incentives for OTR	$185	See Table VII-27

The use of an incentive program can be expected to produce a greater benefit than the simple re-imposition of weight limits. However, designing and implementing a new incentive program is a major, long-term undertaking. In the short term, options are practically limited to working within the existing weight regulation framework. Short term recommendations must also consider the current marketplace for lighter-weight buses, a marketplace that is not well developed.

Chapter VIII: Recommendations

An effective long-term policy might include a broad mix of incentives to bus fleet managers to operate lighter-weight buses. On the other hand, a policy that simply specifies a particular action for reducing pavement damage may have the undesired effect of precluding other actions that are more cost effective.

In the short term, however, the opportunity for implementing major new incentive programs is limited. One set of appropriate short-term measures is outlined below, and includes three components:

1. Continue to Allow States to Exempt Intrastate Transit Buses from Axle Weight Limits

In the absence of a well-developed market for lighter-weight buses, the options for meeting weight requirements in the absence of an exemption would include

- Shifting transit service from Interstate highways to arterials. This would increase operating costs and overall pavement damage costs, since arterials are generally less able to withstand heavy axle loads than Interstate highways (section VI.4.6). More importantly, it would slow service, thus reducing ridership.
- Spreading the passenger load among many lightly loaded buses of the same curb weight. For many fleet managers, the equipment is not available. Even if equipment were available, there would be no reduction in pavement damage because the many lightly loaded buses would cause as much or more damage as the few heavily loaded buses (see Section VI.4.3). Operating costs would also increase significantly.
- Acquiring smaller buses. The added cost would outweigh the savings in pavement damage (Table VII-11).
- Using tag axles. Due to maneuverability issues, this may not be practical on some streets. The added cost would likely outweigh the savings in pavement damage (Table VII-13).

All the above responses to re-imposed weight limits have costs in excess of the expected reduction in pavement damage. Accordingly, the current permissive arrangement for transit buses should be continued until cost-effective responses to its removal are available.

2. Continue to Allow States to Exempt Over-the-Road Buses from Axle Weight Limits

As with transit buses, there is no well-developed market for lighter-weight motorcoaches. None of the other options (such as using smaller buses) for meeting weight requirements are particularly attractive, for the same reasons that they are not attractive in transit.

Accordingly, the current permissive arrangement for over-the-road buses should be continued until cost-effective responses to its removal are available.

3. Consider Vehicle Weight Impacts in Federal Rulemakings

Any regulation that leads to a significant change in vehicle weights will have far-reaching impacts, not only on pavement damage, but also on fuel consumption, emissions, and possibly safety. A major change in vehicle weight may have impacts that are both economically and environmentally significant. These impacts may not be obvious to the agency making the rule.

For this report, Congress had requested an analysis of consideration in rulemakings of additional vehicle weight. Given the pavement damage cost per vehicle mile as a function of weight (see Appendix 2) and the vehicle miles per year (see Chapter II), one can assess the pavement damage impact of a regulation that leads to a change in axle weight.

Current rules (Executive Order 12866 of 1993, amended by Executive Order 13258 in 2002) call for a regulatory impact analysis of any regulation with significant economic impact, defined as at least $100,000,000. Each of the following actions would, in the absence of other changes, lead to approximately $100,000,000 more in pavement damage each year:

- Add 800 lb per bus to 1/2 of the transit bus fleet,
- Add 400 lb per bus to the entire transit bus fleet,
- Add 2,000 lb per bus to 1/2 of the motorcoach fleet,
- Add 1,000 lb per bus to the entire motorcoach fleet.

Therefore, in future rulemakings, Federal rulemakers should be required to take into account the effect of weight on those actions where the expected pavement damage impact (considering both the weight added and number of vehicles affected[21]) exceeds $100,000,000. Since analysis of weight impacts can involve considerable effort, this requirement should apply only to future rules, and not to existing rules.

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[21] Many regulations do not affect all vehicles in a fleet; therefore, consideration of the number of vehicles affected is important. For example, to meet over-the-road bus accessibility requirements, it is estimated that the industry will have to purchase between 10,341 and 11,301 accessible buses between 2000 and 2012, a number that is less than half of the number of over-the-road buses now on the road *(29)*.

Appendix 1: ESAL Weighted Load Factors

Estimation of pavement damage cost per bus-mile (Table III-5) requires an accurate estimate of the equivalent single axle loads (ESALs) imposed by each bus. Factors that may influence the ESALs imposed by a bus include

- Pavement strength
- Bus speed
- Pavement roughness
- Suspension type
- The empty weight of the vehicle
- Passenger loading
- Distribution of the loaded weight among the axles

Of these, the last three are by far the most significant, and will be discussed in some detail later in this appendix.

Pavement Strength

A bus will tend to impose fewer ESALs on a heavy-duty than on a light duty pavement, but the effect is small. For example, a partially loaded transit bus may impose 1.4 ESALs on an Interstate highway (heavy-duty pavement with a structural number of 5), while imposing 1.56 ESALs on a light-duty pavement with a structural number of 2. This is a difference of about 11%.

Bus Speed and Pavement Roughness

Kulakowski et al. (2002) indicated that higher bus speeds and rougher pavements are associated with higher ESAL ratings, but the impact is modest *(15)*. Figure A1-1, with data taken from *(15)*, illustrates the relationship. This study used fully loaded vehicles in its calculations, so the overall ESAL values are considerably higher than those used elsewhere in this report. In this figure, the “very good” pavement has a roughness of 60 inches / mile, while the “fair” pavement has a roughness of 170 inches / mile.

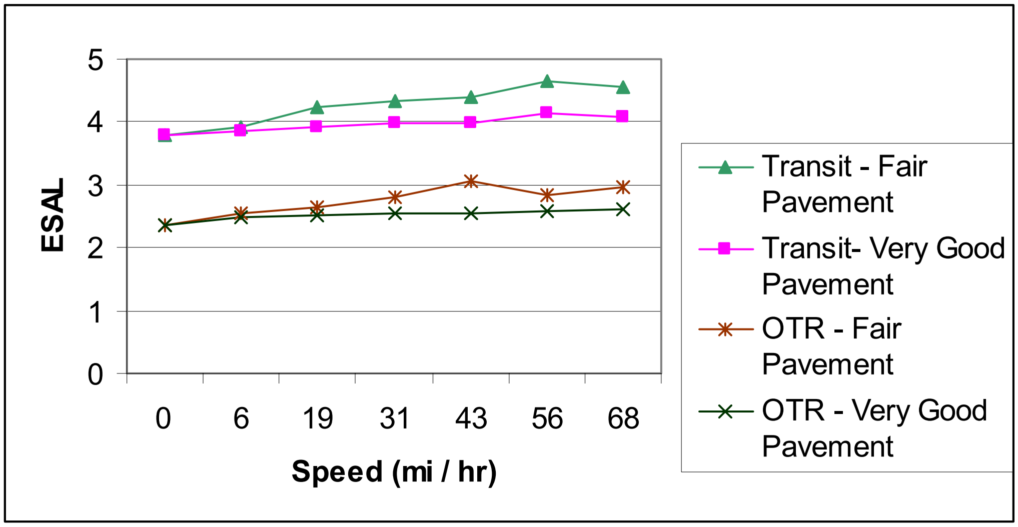

Figure A1- 1 ESAL vs. Pavement Condition and Speed

Suspension Type

According to Gillespie, et al (1993), the use of air-spring suspensions rather than leaf-spring suspensions has the potential to reduce road damage by about 20% *(21)*. Buses generally use air-spring suspensions, while trucks may use either of the suspension types. According to the U.S. DOT Comprehensive Truck Size and Weight Study *(27),* 90% of truck tractors and 70% of van trailers sold in the U.S. are equipped with air suspensions.

Passenger Load, Empty Weight and Axle Weight Distribution

The ESAL load of either a transit or over-the-road bus varies greatly with passenger load as shown in Figure A1-2.

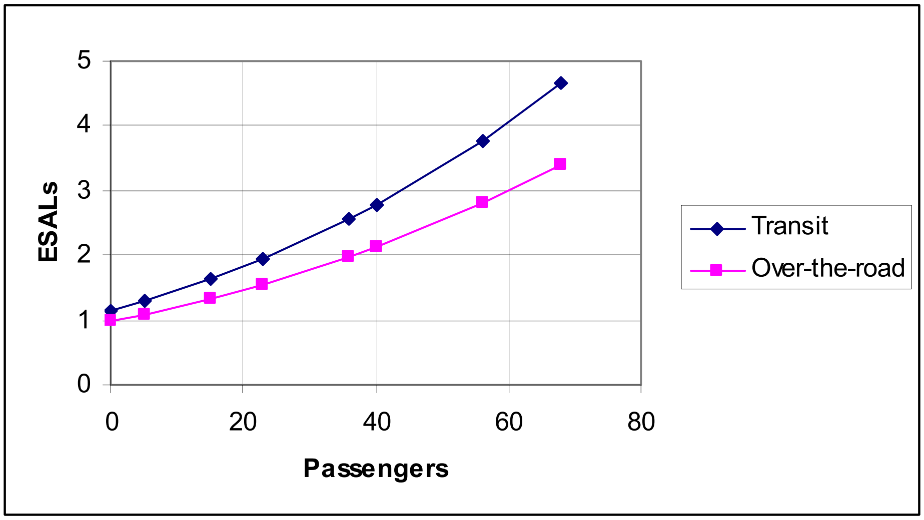

Figure A1-2 ESALs vs. Passenger Load

Since both transit buses and over-the-road buses often operate at well under full capacity, a pavement damage calculation that assumes the average vehicle is fully loaded will overstate the damage that is caused. The average passenger loading for a motorcoach is perhaps 55% in scheduled service, but 80-90% in charter service. For a transit bus, it is typically about 25% of the seated capacity. Unfortunately, because ESALs are proportional to approximately the fourth power of weight, a few heavily loaded buses contribute proportionately more to pavement damage than is saved by other lightly loaded buses. Therefore, in computing the pavement damage caused by transit and over-the-road buses, we must assume a passenger load somewhat higher than the actual average passenger load.

Transit Bus Passenger Loading and Distribution of Loaded Weight

For example, consider the following distributions of transit bus loadings for 700 passengers on 70 buses (an average of 10 passengers per bus).

Case 1: Every bus has 10 passengers on board. In this ideal case, under assumptions (a) and (c) below, the average bus would impose approximately 1.46 ESALs.

Case 2: 60 buses (86%) have 0 passengers, and 10 buses (14%) have 70 passengers on board. In this worst case, the empty bus imposes 1.15 ESALs, while the fully loaded bus imposes 4.84 ESALs, for a weighted average of 1.68 ESALs. This average is about 15% worse than the ideal case, and is similar to the ESAL loading imposed by a transit bus with 16 passengers on board.

Case 3: The distribution of transit bus passenger loads is as outlined under assumption (b) below. This yields a weighted average of 1.56 ESALs, similar to the ESAL loading of a transit bus with 13 passengers on board.

For this report, we use Case 3, and make the following assumptions for a transit bus:

a) Empty bus weight of 28,000 lbs (including the driver). Since weights have been increasing, this is on the high end of weights reported in the 1994 FHWA study.

b) Thirteen passengers on board at 150 lbs each. This is based on an ESAL-weighted average of the following types of operations:

- 20% vehicle miles operated empty (1.15 ESALs)
- 60% vehicle miles with 4 passengers onboard (1.27 ESALs)
- 17% vehicle miles with 35 passengers onboard (2.50 ESALs)
- 3% vehicle miles with 70 passengers onboard (4.84 ESALs) [22]

c) 34.4% of the weight on the front axle, leaving 65.6% on the rear axle. This is the same ratio used in Kulakowski et al *(15).*

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[22] This last case closely matches the transit axle weights given in *(15)*

Under these assumptions, the prototypical transit bus has 13 passengers on board, and a gross weight of 29,950 lbs, with 10,309 lbs on the front axle and 19,641 lbs on the rear axle. Depending on the pavement type and strength, it imposes between 1.4 and 1.6 ESALs on the pavement.

Over-the-Road Bus Passenger Loading and Distribution of Loaded Weight

Similar assumptions were made for a tandem axle motorcoach, which is assumed to have an average load of 34 passengers:

a) Empty bus weight of 36,000 lbs (including the driver). This is based on empty weights stated in *(9)* and on motorcoach manufacturer's websites.

b) 37 passengers on board at 170 lbs each (150 lbs for the person, and 20 lbs for luggage). This is based on an ESAL-weighted average of the following types of bus operation:

- 15% vehicle miles operated empty
- 40% vehicle miles with 23 passengers onboard
- 45% vehicle miles operated with 56 passengers onboard[23].

c) 30.1% of the weight on the front axle, 21.7% on the tag axle, leaving 48% on the rear drive axle. This distribution is taken from the distribution of axle weights in *(15)*.

Under these assumptions, the prototypical motorcoach 37 passengers on board, and a gross weight of 42,290 lbs, with 12,729 lbs on the front axle, 20,384 lbs on the rear drive axle, and 9,177 lbs on the tag axle. Depending on pavement type and strength, it imposes between 1.7 and 2.0 ESALs on the pavement.

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[23] This last case has a weight about 1000 lbs higher than the weight of the prototypical motorcoach in *(15)*.

Appendix 2: Pavement Damage Cost as a Function of Empty Weight

Since much of this report involves an evaluation of pavement damage versus operating cost for various bus weight scenarios, the estimated pavement damage costs per vehicle-mile for various bus weights are presented below.

Transit

Assuming a passenger load of 13 passengers (see Appendix 1) on a standard two-axle transit bus, the per mile pavement damage cost for transit bus operation is presented below. Figure A2-1 includes both the costs for Interstate highway operation and a weighted average of the costs of operating on all roads, where the distribution of bus operation among functional classes is as presented in Table III-6.

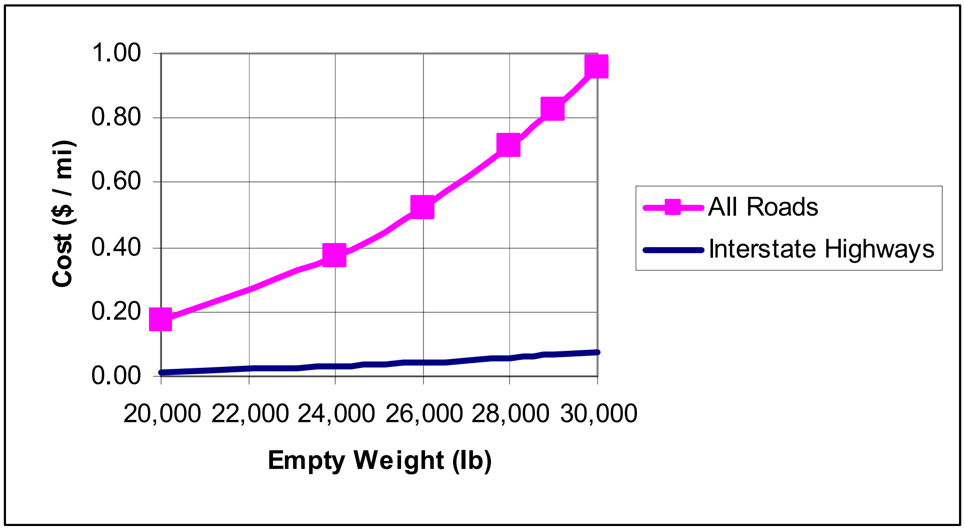

Figure A2-1 Transit Bus Pavement Damage Cost per Vehicle Mile

Over-the-Road

Assuming a passenger load of 37 passengers plus baggage (see Appendix 1), the per mile pavement damage cost for over-the-road tandem-axle bus operation is presented below. Figure A2-2 includes both the costs for Interstate highway operation, and a weighted average of the costs of operating on all roads, where the distribution of over-the-road bus operation among functional classes is as in Table III-6.

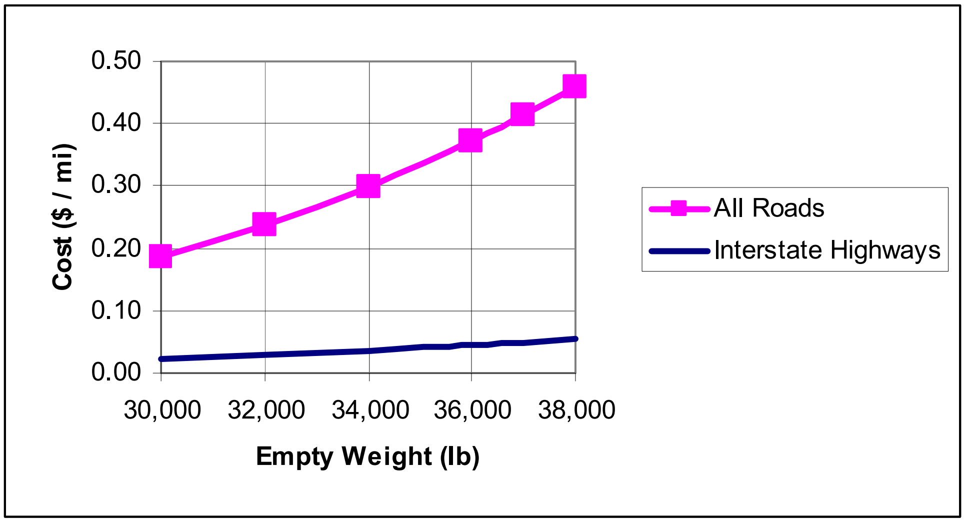

Figure A2-2 Over-the-road Bus Pavement Damage Cost per Vehicle Mile

Proposed regulations may have an impact on vehicle weight. The above charts can be used to relate the change in weight to pavement damage. One relevant question might be: “What increase in bus weight would increase pavement damage on all roads by $100,000,000?” This dollar amount is chosen because existing regulations (Executive Order 12866 of 1993, amended by Executive Order 13258 in 2002) call for a regulatory impact analysis of any regulation with significant economic impact, defined as at least $100,000,000. We assessed the minimum increase in weight that would have a total impact of at least this amount.

Transit Buses

When all roads are considered, a 400 lb increase in weight on a 28,000 lb bus can be expected to have a pavement damage impact of approximately $0.05 per vehicle mile. If this change is applied to all vehicles in the fleet (2,300 million vehicle miles per year), the total added pavement damage is approximately $100 million.

Over-the-Road Buses

When all roads are considered, a 1,000 lb increase in empty weight on a 36,000 lb bus can be expected to have a similar pavement damage impact of approximately $0.05 per vehicle mile. If the change is applied to all vehicles in the fleet, the total annual pavement damage impact is approximately $100 million.

Appendix 3: OTR Bus Benefits Versus Pavement Damage

Congress requested a benefit cost analysis relating to the axle weight of OTR buses that considers the cost of pavement wear caused by OTR buses, and the benefits of the OTR bus industry to the environment, economy and transportation system of the United States.

The following items are transfers, and should not be included in a benefit cost analysis:

- Subsidies paid to public or private bus fleet managers.
- Revenues received in taxes or user charges.
- Loss or gain of revenues by private or public bus fleet managers.
- Gain or loss of employment in the public or private bus sectors

Items that should be included in an analysis are impacts on consumer surplus, the externalities of bus travel and the externalities of activities that might substitute for bus travel (such as travel by automobile). The externalities include pavement wear, impacts on the environment (air pollution, noise) and impacts on the transportation system (congestion, crash).

To illustrate how the various externalities interact, consider a policy that has the sole effect of removing 100 vehicle-miles of over-the-road bus travel. The tradeoff is between the externalities of bus travel with the externalities generated by the lost passengers as they use other modes of transportation.

For the 100 miles of bus travel, the externalities incurred by the bus are shown in Table A3-1 (assuming that the pavement is a weighted average of all U.S. pavements that OTR buses travel on). They are listed both for the bus as a whole and on a per-passenger basis assuming an occupancy of 34 passengers.

Table A3-1 Bus Externalities

	Per Bus	Per Passenger
Pavement Damage	$ 37.25	$ 1.10
Crash	$ 3.75	$ 0.11
Congestion	$ 5.09	$ 0.15
Air Pollution	$ 3.90	$ 0.11
Noise	$ 0.54	$ 0.02
Total	$ 50.53	$ 1.49

In the unlikely event that all 34 passengers switched to the auto mode (at an average occupancy of 1.59 per automobile), auto passenger-miles would increase by 3,400, and auto vehicle miles would increase by 2,138. This means there will be approximately 21 added cars on the road traveling 100 miles each. The externalities thus created are presented below. They are presented for 21.38 automobiles (the number of automobiles that would result from 34 passengers switching to autos at a 1.59 persons/auto occupancy rate), 1 automobile and for one passenger.

Table A3-2 Change in Automobile Externalities

	21.38 Autos	Per Auto	Per Passenger
Pavement Damage	$ 0.56	$ 0.03	$ 0.02
Crash	$ 56.92	$ 2.66	$ 1.67
Congestion	$ 54.86	$ 2.57	$ 1.61
Air Pollution	$ 25.43	$ 1.19	$ 0.75
Noise	$ 0.49	$ 0.02	$ 0.01
Total	$ 138.26	$ 6.47	$ 4.07

If all the passengers were to switch to automobiles, then the loss in bus travel presents a net loss to society, because the externalities of automobile travel (total of $138.26) are higher that for over-the-road bus (total of $50.53). However, it is more likely that many of the lost passengers would forgo travel, while some would travel via other means, such as train, boat or airplane. These other activities would carry externalities that may or may not exceed the externalities of traveling by bus.

Finally, the loss of the bus travel results in some loss in consumer surplus, because the alternatives chosen by the former bus passengers are not as attractive as the travel by bus. (If they were as attractive, passengers would have chosen them in the first place.)

Appendix 4: Glossary

When the definition is taken from an external source, the source is indicated in parentheses.

Articulated Bus Extra-long (54 to 60 feet) bus with two connected passenger compartments. The rear body section is connected to the main body by a joint mechanism that allows the vehicle to bend when in operation for sharp turns and curves and yet have a continuous interior *(30)*

Bus Rubber tired passenger vehicles powered by diesel, gasoline, battery or alternative fuel engines contained within the vehicle. Class A buses have more than 35 seats, class B buses have 25 to 35 seats, and class C buses have fewer than 25 seats. *(31)*

Curb Weight Weight of a vehicle with a full fuel tank, but no passengers or baggage.

Demand Response A transit mode comprised of passenger cars, vans or class C buses operating in response to calls from passengers or their agents to the transitfleet manager, who then dispatches a vehicle to pick up the passengers and transport them to their destinations. A demand response operation is characterized by the following: (a) The vehicles do not operate over a fixed route or on a fixed schedule except, perhaps, on a temporary basis to satisfy a special need; and (b) typically, the vehicle may be dispatched to pick up several passengers at different pick-up points before taking them to their respective destinations and may even be interrupted en route to these destinations to pick up other passengers. The following types of operations fall under the above definitions provided they are not on a scheduled fixed route basis: many origins-many destinations, many origins-one destination, one origin-many destinations, and one origin-one destination. *(30)*

Equivalent Single Axle Load (ESAL) Equivalent of 18,000 lbs on a single axle.

External Cost Also called externality. Cost of an activity that is imposed on third parties. Examples of external costs of transportation include that portion of pavement damage not paid by user charges, congestion costs imposed on other users, air pollution and noise.

Flexible Pavement A pavement structure which maintains intimate contact with and distributes loads to the subgrade and depends on aggregate interlock, particle friction, and cohesion for stability. *(3)*

Gross Vehicle Weight Rating A maximum safe weight for the vehicle (including passengers and baggage) designated by the manufacturer of that vehicle

High Floor Bus A bus where the vehicle floor is high enough to require steps to be climbed between the vehicle door and floor.

Hybrid Electric Bus A bus that carries at least two sources of motive energy on board and uses electric drive to provide partial or complete drive power to the vehicle's wheels *(32)*.

Internal Cost Cost of an activity that is paid by the party engaged in the activity. Examples in transportation include labor, fuel and insurance.

Low Floor Bus A bus which, between doors 1 and 2, has a vehicle floor sufficiently low and level enough to remove the need for steps in the aisle both between these doors, and in the vicinity of the doors. *(33)*

Motorcoach Over-the-road bus

Over-the-Road Bus A bus characterized by an elevated passenger deck located over a baggage compartment. (42 U.S.C. 12181)

Pavement Structure A combination of subbase, base course, and surface course placed on a subgrade to support the traffic load and distribute it to the roadbed. *(3)*

Present Serviceability Rating A subjective rating of pavement quality based on a 0 to 5 scale. A rating of 5 is better than new, while ratings of 2 or below indicate enough deterioration to significantly affect the speed of free flow traffic. (See Exhibit 3-2 in *(19)*)

Rigid Pavement A pavement structure which distributes loads to the subgrade, having as one course a Portland cement concrete slab of relatively high bending resistance. *(3)*

Seated Weight Weight of a bus with all seats occupied, but no standees.

Structural Number Commonly used measure of flexible pavement strength. The AASHTO design guide *(3)* defines the Structural Number as "An index number derived from an analysis of traffic, roadbed soil conditions, and environment which may be converted to thickness of flexible pavement layers through the use of suitable layer coefficients related to the type of material being used in each layer of the pavement structure."

Tag Axle An axle that is (a) the rear-most axle of a tandem axle, and (b) does not transmit power. A tag axle may have only 2, rather than 4, tires.

Tandem Axle An assembly of two axles, spaced close together (typically, 4 feet or less).

Transit Bus Bus used for public transit service.

Appendix 5: References

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Specifications for various model buses were gathered from information provide by the manufacturers via their web page or personal contact. Web sites were accessed during February and March 2003. Manufacturers used are the following:

Blue-Bird (www.blue-bird.com)
Escort (www.thorindustries.com)
Gillig (www.gillig.com)
NABI Inc. (www.nabiusa.com)
    John Maddox 2/19/2003 GVWR, FAWR and RAWR's for NABI buses.
    William Coryell
Neoplan (www.neoplanusa.com)
New Flyer (www.newflyer.com)
Nova Bus (www.novabus.com)
Motor Coach Industries (MCI)
    Paul Murphy
Orion (www.orionbus.com)
    Mark Braeger
Thomas Bus (www.thomasbus.com)
    Allan Haggai – 2/24/2003 – Regarding GWWR, FAWR, and RAWR's for the Transit Liner Series
Tansmark (www.thorindustries.com)

Van Hool (www.abc-bus.com)\

Other contacts include
George Husman, Southern Research Institute
Tony Mascarin, IBIS Associates

Steve Misencik, TPI Composites

Additional information was gathered through the Altoona Bus Research and Testing Center via conversation and materials received through Mustafa El-Gindy, week of Feb. 28, 2003.