City of Seattle

Gregory J. Nickels, Mayor

Seattle Department of Transportation
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MEMORANDUM

DATE:	**21 May 2007 (Update)**
TO:	**Charles Bookman, SDOT Pavement Engineering and Management** **James Dare, SDOT Street Maintenance** **Richard Miller, SDOT Capital Projects and Roadway Structures**
FROM:	**Benjamin Hansen, SDOT Pavement Engineering and Management** **John Buswell, SDOT Roadway Structures**
SUBJECT:	**Metro Bus Damage on Pavements and Structures**

SUMMARY

SDOT and Metro have shared interest in balancing the wear on public infrastructure with the mobility and environmental benefits provided by transit. Rider satisfaction suffers as street condition deteriorates, and more frequently performed construction leads to congestion and user delay. Heavier buses increase wear and tear on pavements, bridges and utility structures. Major maintenance activities, such as asphalt pavement resurfacing, are no longer practical on older facilities whose design did not anticipate the current loading. Reconstruction and modernization of those facilities will become necessary, at a considerable cost premium over the preservation work that has traditionally been performed.

With a fully seated load, it is estimated 47% of Metro's current fleet exceeds the current standard single axle legal transit limit of 24,000 lb established by Washington State (RCW 46.44) and federal law (23 USC 127). In 1993, none of the buses in the Metro fleet exceeded that amount. Pavement damage increases exponentially with weight, with small increases leading to much greater damage factors. Overall, the average pavement damage factor per bus is estimated to have increased by around 30% since 1993, with a corresponding decrease in pavement life expected as a result.

Buses and the streets they operate on must function together as a system. Future transit procurements can further this objective by specifically addressing bus axle weight. Metro and SDOT should reach written agreement on bus weight limits to guide the design of new infrastructure.

BACKGROUND

Motor vehicle size and weight regulations are among the most important factors determining road and bridge design. The strength of pavements and bridges and their geometry are

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dictated by the heaviest vehicles on the road. Passenger vehicles, cars and light trucks, do not factor significantly in the structural design of roadways that carry heavy vehicles. Current vehicle weight limits have their basis in federal law. Federal limits were first enacted in 1956 to protect the federal investment in roads and bridges, allow uniform highway design and promote interstate commerce through standardization.

The issue of overweight buses in Seattle first arose around1989, with the opening of the Metro Bus Tunnel. Metro contracted with Breda Construzioni Ferroviarie to manufacture buses capable of operating on electric power inside the bus tunnel and on diesel power outside. On delivery, the buses scaled significantly heavier than anticipated, exceeding while empty the 20,000 lb legal axle weight limits in law at the time. Concerned that many streets and bridges were not designed to handle such heavy loads, City of Seattle officials considered delaying the bus tunnel opening or billing Metro for the anticipated damage[1].

In 1990 and 1991, Seattle and the State of Washington moved to resolve the bus weight issue. The State of Washington issued Metro $100 yearly permits to operate their buses up to a 22,000 lb single axle limit and set a deadline of 30 April 1993 for Metro to bring the buses into compliance with the standard 20,000 lb axle limit in RCW 46.44[2]. It does not appear this deadline or the weight limit was ever enforced.

In 1993, the Seattle Engineering Department, with support from WSDOT and the University of Washington, issued a report on the impacts of heavy vehicles on Seattle's pavements[3]. The report estimated that Metro buses constitute 55% to 97% of all heavy vehicle traffic using Seattle's streets. It concluded that older, thinner pavements would be most susceptible to damage caused by overweight vehicles and that bus streets should be reconstructed with pavement designs that anticipate overweight vehicles. The report recommended that future bus procurements make every effort to ensure the vehicles meet standard legal axle weight limits.

Parallel to local events, the federal Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 created an axle weight exemption for transit buses. Under ISTEA, states and local governments were free to set their own weight limits to reflect the condition of their infrastructure, but no federal limit was set. The first federal waiver was to last three years, but it has been has been extended repeatedly. The most recent Federal legislation on this matter (SAFETEA-LU[4]), extends the waiver until 1 October 2009 and requires any State previously enforcing a single axle weight limit of 20,000 lb on transit buses to increase that limit to 24,000 lb.

States have two choices on transit buses: they may exempt them from axle weight limits or they may choose to enforce a single axle limit of not less than 24,000 lb. Washington state law does not specifically address transit bus weights. Absent any specific guidance in the state law, the standard axle weight limits in RCW 46.44.041 (i.e. single axle legal limit of

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[1] Wallace, James. "New buses too heavy for streets." Seattle Post-Intelligencer. 9 February 1989.
Nelson, Robert T. "Streets can't bear heavy traffic, $55 million needed for repairs." Seattle Times. Circa 1989.
Unknown. "City may bill Metro for street damage." Seattle Times. 15 February 1989.
Bruscas, Angelo. "Overweight buses may delay opening of Metro tunnel." Seattle Post-Intelligencer. Circa 1989.

[2] Berentson, Duane (WSDOT Secretary of Transportation). Letter to Richard K. Sandaas (METRO Director). 18 September 1990.

[3] De Boldt, Peter G and Esther Chinn. "HEAVY VEHICLES vs. URBAN PAVEMENTS." Washington State Department of Transportation Report No. WA-RD 341.1. December 1993

[4] Federal Register / Vol. 72, No. 33, pp. 7741, 7747-7748 / Tuesday, February 20, 2007 / Rules and Regulations

20,000 lb at spacing determined by the bridge formula) are assumed to apply to transit buses. Federal guidelines now require Washington to increase that limit to 24,000 lb.

Contacts with WSDOT and State Patrol suggest that 24,000 is currently recognized by some as the maximum single axle weight for buses, with an additional 400 lb allowed for hybrid power units. As a practical matter, weight limits are not enforced on transit buses. Buses are not scaled at weigh stations or otherwise checked by enforcement agents.

BUS WEIGHTS

Using fleet specifications provided by Metro, SDOT engineering staff estimated the operational axle weights of each bus model in Metro's current fleet. Axle weights of the 1993 and 2006 bus fleets are shown in Table 1. The standard legal weight limit for a single axle is 20,000 lb, and not less than 24,000 lb for transit buses (by SAFETEA-LU). Axles exceeding those limits are highlighted.

Metro buses utilize only single axles. Tandems or other load distributing combinations are not used. The 100% passenger loading assumes a bus with all seats filled and 130% passenger loading assumes passengers standing. For the 2006 fleet, Metro specifications provide only the total empty weight and 130% passenger load weight. Loaded axle weights were estimated by distributing the passenger load over the wheelbase of the bus. An average passenger weight of 174 lb was used to reach 100% load calculation. This is the average passenger weight recommended by the National Transportation Safety Board, based on Federal Aviation Administration and Centers for Disease Control and Prevention studies[5]. It assumes an equal number of male and female passengers in summer clothing, without personal effects.

PAVEMENT DAMAGE

Pavements suffer structural damage through the mechanism of fatigue, damage caused by repetitive loading. Structural failures may occur after the application of a small number of heavy loads or a large number of light loads. In pavements, the relationship between load and structural damage is exponential, with small increases in weight leading to much greater damage factors.

American Association of State Highway and Transportation Officials (AASHTO) research indicates a fourth power relationship between pavement damage and axle weight, i.e. if the axle weight is doubled, pavement damage increases 16-fold. Put another way, if a single axle increases from the standard legal weight of 20,000 lb to 24,000 lb, the damage caused by that vehicle axle increases by approximately 200%, or doubles.

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[5] Federal Register / Vol. 71, No. 80, pp. 24733 / Wednesday, April 26, 2007 / Notices
NTSB Safety Recommendation M-04-04, 20 December 2004
Federal Aviation Administration Advisory Circular 120-27D, 11 August 2004

Table 1. Bus Axle Weights

Bus	# in Fleet	Gross Vehicle Weight (Empty / 130% PAX, lb)	Empty Axle Weights (lb)			100% PAX All Seats Filled Axle Weights (lb)			130% PAX Standing Overload Axle Weights (lb)		
			1st	2nd	3rd	1st	2nd	3rd	1st	2nd	3rd
2006 Metro Bus Fleet[A]											
New Flyer DE60LF	214	44,659 / 55,969	9,457	12,282	22,920	11,436	16,721	**26,594**	11,674	17,257	**27,038**
New Flyer D60LF	30	41,820 / 54,359	9,020	11,280	21,520	10,990	15,742	**25,180**	11,468	16,824	**26,067**
New Flyer D40LF	100	28,200 / 37,340	9,150	19,730	---	11,608	23,362		12,565	**24,775**	---
New Flyer D60	274	42,780 / 55,530	10,620	11,540	20,620	12,645	16,354	**24,918**	12,938	17,051	**25,541**
Gillig Phantom ETB	100	31,205 / 39,605	11,440	19,765	---	14,315	**24,198**		14,744	**24,861**	---
Gillig Phantom	95	25,970 / 32,015	7,791	18,179	---	9,511	21,679		9,782	22,233	---
Gillig Phantom	15	26,725 / 33,745	9,438	17,287	---	11,592	21,049		11,994	21,751	---
Gillig Phantom	395	29,420 / 37,610	10,920	18,500	---	13,795	22,933		14,142	23,468	---
Breda ADPB 350[B]	59	49,500 / 61,112	12,740	16,610	20,150	15,253	19,421	23,588	15,773	20,861	**24,478**
MAN ETB[B]	46	40,440 / 53,310	12,100	14,220	14,120	14,000	18,670	17,640	14,490	20,320	18,500
ST Gillig Phantom	70	29,420 / 37,610	10,920	18,500	---	13,795	22,933		14,142	23,468	---
ST New Flyer D60LF	37	41,820 / 54,359	9,020	11,280	21,520	10,990	15,742	**25,180**	11,468	16,824	**26,067**
1993 Metro Bus Fleet[B]											
AM General Trolley 40'	109	25,900 / 34,900	8,320	17,580	---	11,140	21,660		12,090	22,810	---
AM General Diesel 40'	223	26,280 / 35,280	7,840	18,440	---	10,510	22,670		11,440	23,840	---
Flyer Diesel 40'	224	26,720 / 36,021	8,460	18,260	---	11,410	22,510		12,360	23,661	---
Flyer Diesel 35'	35	26,160 / 33,960	7,800	18,360	---	9,920	22,240		10,660	23,300	---
MAN Diesel 40'	157	28,240 / 37,090	10,000	18,240	---	12,300	22,690		13,160	23,930	---
MAN Diesel 60' 1400-1550	150	35,460 / 49,720	10,660	15,680	9,120	13,030	20,280	13,110	13,570	22,090	14,060
MAN Diesel 60' 2000-2201	202	36,680 / 50,520	12,240	15,320	9,120	14,400	19,840	13,090	14,920	21,580	14,020
Man ETB 60'	46	40,560 / 53,310	12,220	14,420	13,920	14,000	18,670	17,640	14,490	20,320	18,500
Breda 60'	236	48,850 / 61,112	13,267	15,433	20,150	15,253	19,421	23,588	15,773	20,861	**24,478**

[A] Hansen calculations 2 April2007; Metro Transit / King County Department of Transportation Fleet Specifications

[B] Metro scale weights 28 May 1993 (provided during Chinn / De Boldt research)

Exceeds standard 20,000 lb single axle weight limit standard RCW 46.44, 23 USC 127

Exceeds new federal 24,000 lb transit axle weight standard

AASHTO pavement design guidelines (used by the City and State) convert axle loads of different magnitudes to an equivalent number of standard loads. The most commonly used standard fore quantifying pavement damage is an 18,000-pound equivalent single axle load (18-kip ESAL). Table 2 shows the calculated damage factors of the 1993 and 2006 Metro bus fleets, assuming a typical heavy vehicle flexible pavement section.

Table 2. Pavement Damage Factors, Flexible Pavement 18-kip ESALs[C]

Bus	# in Fleet	Gross Vehicle Weight (Empty / 130% PAX, lb)	Damage Factor Flexible (AC) Pavement 18-kip ESALs[C]		
			Empty	100% PAX All Seats Filled	130% PAX Standing Overload
2006 Metro Bus Fleet					
New Flyer DE60LF	214	44,659 / 55,969	2.83	5.35	5.75
New Flyer D60LF	30	41,820 / 54,359	2.21	4.34	5.05
New Flyer D40LF	100	28,200 / 37,340	1.49	2.90	3.64
New Flyer D60	274	42,780 / 55,530	1.98	4.41	4.89
Gillig Phantom ETB	100	31,205 / 39,605	1.60	3.52	3.91
Gillig Phantom	95	25,970 / 32,015	1.07	2.13	2.35
Gillig Phantom	15	26,725 / 33,745	0.92	2.01	2.28
Gillig Phantom	395	29,420 / 37,610	1.24	2.89	3.16
Breda ADPB 350	59	49,500 / 61,112	2.52	4.70	5.63
MAN ETB	46	40,440 / 53,310	0.95	2.44	3.14
ST Gillig Phantom	70	29,420 / 37,610	1.24	2.89	3.16
ST New Flyer D60LF	37	41,820 / 54,359	2.21	4.34	5.05
		Fleet Weighted Average	***1.73***	***3.66***	***4.09***
1993 Metro Bus Fleet					
AM General Trolley 40'	109	25,900 / 34,900	0.95	2.19	2.70
AM General Diesel 40'	223	26,280 / 35,280	1.13	2.55	3.11
Flyer Diesel 40'	224	26,720 / 36,021	1.10	2.53	3.09
Flyer Diesel 35'	35	26,160 / 33,960	1.11	2.36	2.83
MAN Diesel 40'	157	28,240 / 37,090	1.14	2.66	3.28
MAN Diesel 60' 1400-1550	150	35,460 / 49,720	0.75	2.14	2.90
MAN Diesel 60' 2000-2201	202	36,680 / 50,520	0.79	2.14	2.86
Man ETB 60'	46	40,560 / 53,310	0.96	2.44	3.14
Breda 60'	236	48,850 / 61,112	2.38	4.70	5.63
		Fleet Weighted Average	***1.23***	***2.79***	***3.46***

[C] Calculated using SN=5 and TSI=2.5

By fleet weighted average, damage factors per bus have increased between 1993 and 2006 from 1.23 to 1.73 empty (41%), from 2.79 to 3.66 with all seats filled (31%), and from 3.46 to 4.09 in overload (18%).

BRIDGE AND STRUCTURE DAMAGE

The effect of vehicle weight on bridge structures is also a concern. A newer bridge, with few or no defects and built to AASHTO requirements of HS 20, has a capacity to take axle weights up to 32,000 lbs. Compared to reported bus axle weights of 27,000 lbs this provides an acceptable margin of safety. Unfortunately, Seattle has many bridges that were built in the first half of the twentieth century and are over 50 years old. These bridges were not built to the current AASHTO standards and suffer from deterioration due to age and years of use. Currently, SDOT has 28 bridges that were not built to handle the HS 20 loading. Eight of these bridges are posted with weight limits. Others do not allow over weight vehicles and are closely monitored for heavy load inducing defects.

As SDOT works to maintain its inventory of bridge assets, transit operators must be mindful of the load carrying capacity of that system. To continue to deploy heavier buses will result in a significant acceleration in the deterioration rate on bridges. Seattle has 43 bridges over 60 years old. The replacement value of those assets is estimated at more than $800 million.

SDOT has 10 bridges with fracture critical elements. Fracture critical is define by FHWA as a steel bridge element that should it fail would result in catastrophic failure of the bridge. Although, bridge engineers closely monitor these bridge elements, fatigue due to overload is the primary cause of crack development in these bridge members.

For concrete bridges, the effects of heavy loads generally results in the development of cracks in the reinforced concrete. The cracks result in two significant deterioration processes. First, the cracks provide a route for moisture to reach the steel reinforcing bars. This introduces the needed elements for cathodic corrosion. As corrosion continues, the surrounding concrete often falls off exposing more steel to corrosion ultimately reducing the steel cross section and strength. The second process relates to fatigue. Once the reinforced concrete structure cracks the sectional stiffness of the element is greatly reduced. This results in greater stress on the steel reinforcement. This can then result in more rapid fatigue damage to the bridge element.

Studies by FHWA have estimated the cost of overload vehicles related to bridges. They have quantified both the increased maintenance cost during the life of the bridge and they have studied the reduce service life of the structure. FHWA reports an effect equal to 13% of the structure cost. This represents approximately $247 million dollars when applied to the SDOT bridge inventory.

At this time, SDOT does not have good information on the load carrying capacity of the many different utility structures found within the right-of-way. Seattle City Light has indicated some concern about the affect of heavy axle loads on their vaults and other utility structures. More investigation is needed.

RECOMMENDATIONS

Busses constitute the majority of heavy vehicle traffic on many of Seattle's streets, and therefore govern the design of pavements, bridges and other infrastructure. Bus weights have increased significantly in the last 10-15 years, affecting the streets and structures on which they operate. Buses, streets, bridges and other infrastructure must operate together as a system to maintain a high level of transit service to Seattle's citizens. Toward this goal, the following actions are recommended:

- SDOT and Metro should jointly establish maximum bus weight limits. This provides an agreed upon standard to be used in the design of new infrastructure, and predictability in planning for the replacement of existing facilities.

- Transit streets should be rehabilitated to accommodate future bus traffic levels.

- Bus procurements should hold manufacturers to the agreed upon weight limits. Proposals should call for manufacturers to provide alternate axle configurations and associated costs in their proposals. Axle weight should be one criteria on which proposals are scored. In addition, it is recommended Metro should study the use of lightweight materials. These have potential to reduce bus weights while improving fuel economy and emissions.

The federally mandated increase in transit axle weights disproportionately affects large cities such as Seattle, where buses make up a high percentage of total heavy vehicle traffic. Older city infrastructure designed and maintained with the old 23 USC 127 weight limits in mind, which have not changed for heavy trucks, is being made obsolete by the transit exemption. In seeking state and federal funds, Seattle can make the case that infrastructure replacement is necessary to expand and sustain transit service.