Engineering Analysis of Maine's Interstate Bridges

100,000 Pound Six-Axle Trucks

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Purpose:

In December 2009, the United States Congress authorized a one year Pilot Program that allowed Maine (and Vermont) to use State weight limits on the Interstate instead of the Federal cap of 80,000 pounds. Through two Executive Orders and then State legislation, Governor Baldacci and the Maine Legislature modified State law to allow a three-axle truck-tractor with a three-axle semi-trailer at 100,000 pounds to use Maine's entire Interstate system, effectively diverting large trucks from non-Interstate highways to the Interstate. Previously, this configuration was only authorized on the Maine Turnpike and from its southerly terminus to the New Hampshire line.

This Report documents the results of MaineDOT's engineering analysis regarding the adequacy of Maine's Interstate bridges to carry 100,000 pound, six axle trucks.

Key Findings:

1) Maine's Interstate bridges are safe to carry 100,000 pound, six-axle trucks at Maine's axle and spacing requirements (Maine's Bridge Formula).
2) Seventy-seven percent of Maine's Interstate bridges were designed to accommodate trucks heavier than the AASHTO HS-20 loading (the minimum required for the Interstate).
3) Maine's Interstate bridges are in generally good condition and have a high degree of structural redundancy.
4) The Maine Turnpike has been carrying 100,000 pound trucks for decades without any issues or a discernable increase in bridge needs.
5) Maine's Interstate truck VMT is less than ½ of 1 percent of the national total.
6) Due mainly to climate and other environmental factors, the average age of Maine's bridge replacements is 67 years, below the typical 75 year design life.
7) In MaineDOT's engineering opinion, additional Interstate bridge fatigue costs to accommodate 100,000 pound trucks on Maine's Interstate are theoretical and perhaps even zero. General deterioration is the primary factor driving bridge replacements, and Maine has yet to replace a bridge due to steel fatigue.

Introduction:

For decades, the State of Maine has supported harmonization of truck weight limits, both with other northeastern states and between its Interstate and non-Interstate highway systems. Numerous studies by MaineDOT and its consultants have quantified the benefits and costs of allowing 100,000 pound, six-axle trucks to use the non-exempt portion of the Interstate. These trucks are allowed under current law to use Interstate 95 between Kittery and Augusta, as well as the entire State highway system (most of which is also Federal Aid).

Previous studies have considered the full range of possible impacts; including safety, infrastructure costs, transport productivity, energy use, and greenhouse gas emissions. This Report has but one purpose, which is to answer the following question:

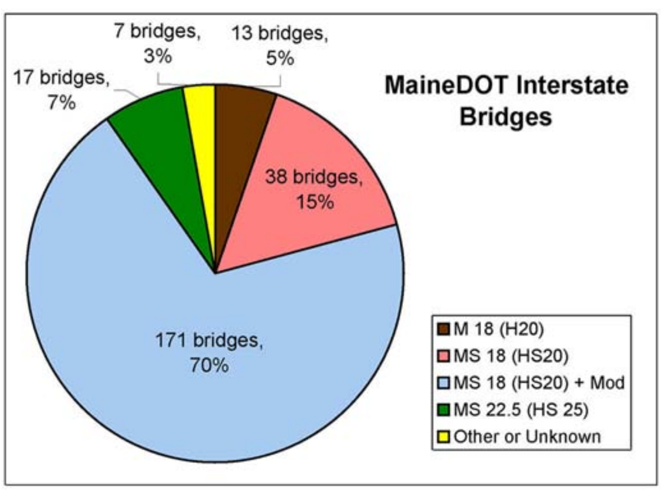
Can Maine's Interstate bridges safely carry this 100,000 pound truck configuration, and will this use significantly shorten the life of Maine's Interstate bridges?

Maine's Interstate Bridges:

For the purposes of this Report, "Maine Interstate Bridges" means only those bridges that carry the mainline Interstate, excluding the Maine Turnpike Authority (MTA) and from its southerly terminus to the New Hampshire border. The MTA is exempt from Federal Interstate weight limits and the two mile section of I-95 from the MTA to the border was exempted in 1998 by The Transportation Equity Act for the 21st Century (TEA-21).

Since the Interstate era, Maine has increased its bridge design loading system-wide to accommodate all State legal loads. This practice started with including the Alternate Military Loading on Interstate bridges, then increasing the design load to HS-25, and most recently implementing the LRFD HL-93 modified loading. The Alternate Military loading is a more severe loading for short span bridges (2 axles, 24 kips, 4 feet spacing), and the HS-25 truck is twenty-five percent heavier than the HS-20 truck commonly used for Interstate bridges. Maine was also among the first States to adopt Load Factor Design (LFD) and then Load and Resistance Factor Design (LRFD), and now all of Maine's bridges are rated using the Federal Highway Administration's preferred method – the Load and Resistance Factor Rating (LRFR) method per the AASHTO Manual of Bridge Evaluation. In 2009, Maine sent a team of structural engineers to LRFR training sponsored by USDOT.

There are currently 246 non-exempt Interstate bridges. As shown in the chart below, there are no H-15 bridges on the non-exempt Interstate. Five percent of Interstate bridges were designed for H-20 loading, fifteen percent were designed for HS-20 loading, seventy percent were designed for HS-20 plus the Alternate Military loading, seven percent were designed for HS-25, and three percent are Other (the Other structures are buried culverts). Seventy-seven percent already exceed the HS-20 loading used by many States, and capital rehabilitation projects are expected to bring Interstate bridges up to at least HL-93.



Maine's Interstate bridges are in generally good condition or better. Only six bridges are classified as Structurally Deficient (2009 data), and all of these are either already improved, funded for improvement, or will be funded in the next (2012-2013) Capital Workplan.

These Interstate bridges also have a high degree of structural redundancy; most are multi-girder superstructures with concrete decks. There are only two Fracture Critical (two girder) bridges; both were recently rehabilitated and the 2009 Fracture Critical Inspections found them free of any major defects. There are no trusses.

Prior Analyses:

Since the early 1980s, MaineDOT has been using its in-house developed Bridge Stress program to evaluate different truck weight scenarios, the adequacy of various design loadings, and to this day overlimit permit requests. This software compares simple span moment (dead load plus live load) ratios for any truck configuration versus an AASHTO live loading (or even another truck) for spans up to 130 feet, including the lane loading and impact per AASHTO specifications. It was also used to calibrate the "Maine Bridge Formula", as follows:

§2354. Six-axle limits

Notwithstanding this subchapter, a combination vehicle consisting of a three-axle truck tractor with a tri-axle semi-trailer may be operated with a maximum gross vehicle weight of: [1993, c. 683, Pt. A, §2 (NEW); 1993, c. 683, Pt. B, §5 (AFF).]

2. **100,000 pounds.** One hundred thousand pounds, as long as the vehicle meets these requirements:
   A. The distance between the extreme axles, excluding the steering axle, is not less than 36 feet as measured to the nearest foot. The maximum gross vehicle weight permitted is reduced by 2,000 pounds for each foot the distance is less than 36 feet between the extreme axles, excluding the steering axle, measured to the nearest foot; [2001, c. 267, §1 (AMD); 2001, c. 267, §16 (AFF).]
   B. The minimum distance between the steering axle and the first axle of the tandem axle group is at least ten feet as measured to the nearest foot; and [2001, c. 267, §1 (AMD); 2001, c. 267, §16 (AFF).]
   C. The maximum weight on the:
      (1) Tandem axle does not exceed 41,000 pounds; and
      (2) Tri-axle does not exceed 50,000 pounds. [1999, c. 580, §7 (AMD); 1999, c. 580, §14 (AFF).]

The tandem, tri-axle and spacing requirements differ for certain commodities, but the general reduction of 2000 pounds per foot for shorter trucks is still in force.

In 2008, MaineDOT ran this software using the proposed 100,000 pound truck versus the four different Interstate bridge design loadings from above (H-20, HS-20, HS-20 plus Alternate Military, and HS-25). The results indicated that the 100,000 pound, six-axle truck (which came to be the Pilot Study truck for Maine) would not result in an overstress condition anywhere near the Operating Rating, and many bridges would not even be at their Inventory Rating. A bridge's Operating Rating is the stress level that is safe on an infrequent basis, and the Inventory Rating level is essentially the design stress level and is acceptable indefinitely. The results are attached as Appendix A. Because it is a screening tool, this analysis is appropriately conservative since it does not account for such things as composite action between steel beams and concrete decks.

As the Pilot Program began, the Federal Highway Administration also evaluated Maine's bridges with a screening tool similar to Maine's bridge stress program. On the plus side, the FHWA software is able to evaluate continuous spans. On the minus side, it to is conservative and over-estimates stresses in the negative moment regions because it uses the single NBI Inventory and Operating Rating for each bridge, which typically is a positive moment region rating.

The FHWA screening analysis of Maine's Interstate bridges, after deleting the MTA bridges, is as follows:

% "Overstress"	Number of Bridges
>5%	23
>10%	31
>20%	15
>30%	1
>40%	0
>50%	0

The FHWA screening analysis found six bridges with a potential overstress of twenty-five percent or more. MaineDOT performed a complete LRFR rating on four of these six bridges using the two different six-axle configurations used by FHWA, with the following result.

Maine Bridge Analysis
Stress Levels Relative to a Routine (non-permit) Load

Bridge Number	FHWA Moment Ratio Potential Overstress	LRFR Rating Factor (Inventory Level)
5985	27.10%	0.96
6075	29.60%	1.05
5999 North Bound	25.40%	1.03
5999 South Bound	25.40%	1.03

As the above table shows, the FHWA screening analysis over-predicted the stress level in these four bridges for the 100,000 truck. Actual LRFR ratings indicate one bridge at approximately four percent overstress (within acceptable limits for a design check) and three bridges that are about 3% to 5% below design stress for the 100,000 pound six-axle truck. A Rating Factor of 1.0 at the Inventory level is equivalent to the design stress level, and a Rating Factor > 1.0 indicates a stress level lower than design stress.

Since the Pilot Project, MaineDOT and its consultants have continued to load rate Maine's Interstate bridges as they need rehabilitation, deck replacement, etc. LRFR Rating Factors have been 1.0 or better for the HL-93 loading, and if a bridge does not rate close to 1.0 it is strengthened as needed (this is currently underway for the Fairfield-Benton Bridge). The

AASHTO LRFR Rating Process is attached as Appendix B. The results of Maine's additional LRFR ratings on thirty-five Interstate bridges is attached as Appendix C – thirty-four have a Rating Factor of 1.0 or greater, and one is undergoing refined analysis as provided for by LRFR.

<u>In consideration of Maine's Interstate bridge design loadings and LRFR ratings to date, coupled with their generally good condition and redundancy, MaineDOT has determined that Maine's Interstate bridges can safely accommodate the 100,000 pound, six-axle truck at Maine's axle and spacing requirements.</u>

<u>Remaining Service Life</u>:

The second part of the question is whether Maine's Interstate bridges will "wear out" significantly faster due to carrying the 100,000 pound truck. Most of these bridges use steel girders as their primary load carrying members, and a portion of the steel's life is consumed with the passage of every truck. This phenomenon is known as "fatigue", and the truck traffic stream is converted into an equivalent number of 54,000 pound "fatigue trucks" using truck histograms to estimate total life at design or remaining service life for existing bridges.

Maine's truck volumes are very small compared to other States; Maine's Interstate truck VMT is about 253 million Vehicle Miles Traveled (VMT), whereas the total U.S. Interstate VMT is 70,465 million VMT. Therefore, Maine's Interstate truck VMT is less than ½ of 1 percent of the nation's total (see Appendix D). Truck volumes on some portions of Maine's Interstate are only hundreds per day. It is noted that Maine Turnpike bridges have been carrying 100,000 pound trucks for decades without any appreciable fatigue or increase in bridge needs.

As the following chart shows, the average age of Maine bridge replacements is 67 years, below the typical 75 year design life. This is thought to be due primarily to climate and other environmental factors.

Worksheet for Long Range Plan Bridge Goals
Culvert & Bridge Replacements 2000 - 2005

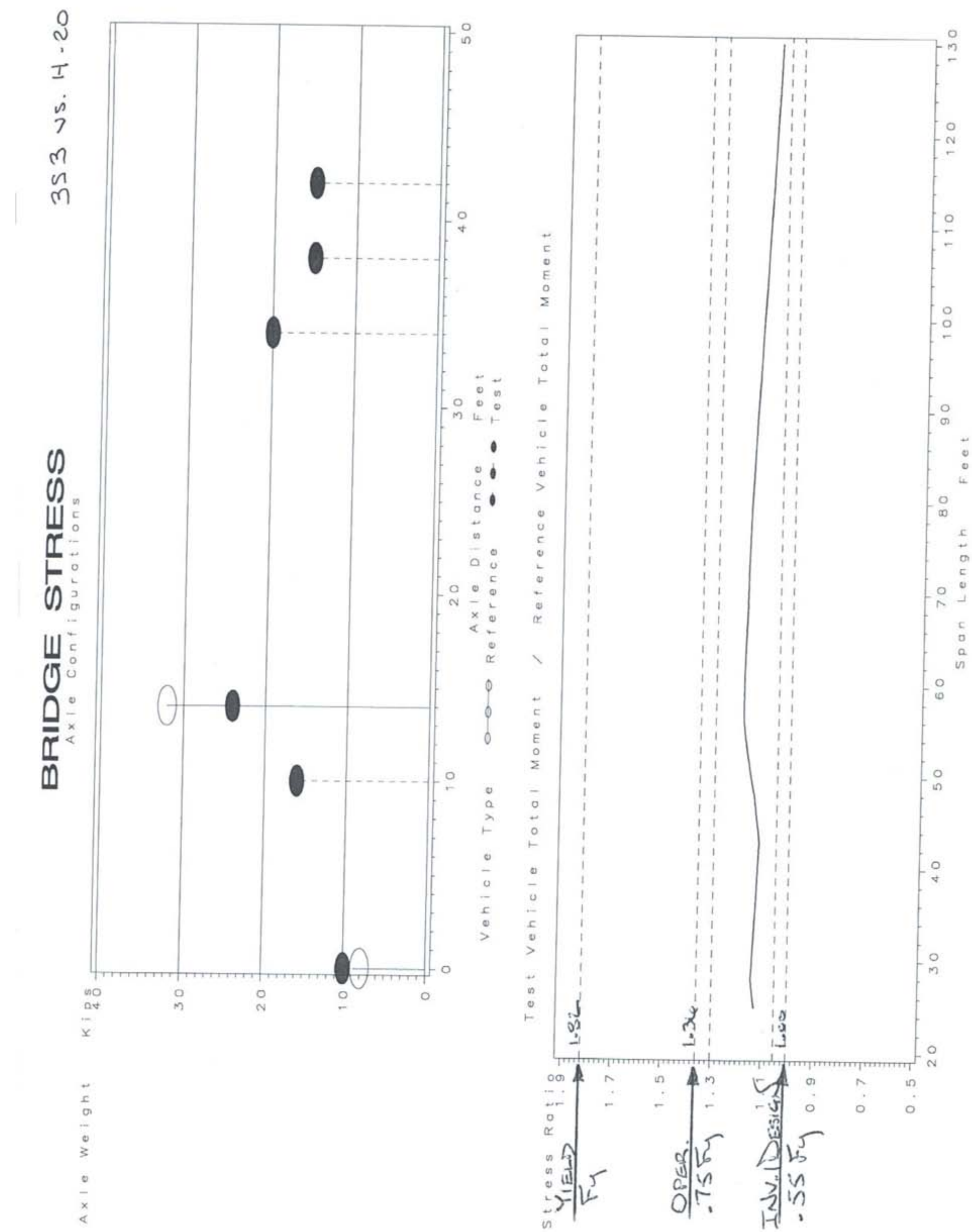
Summary

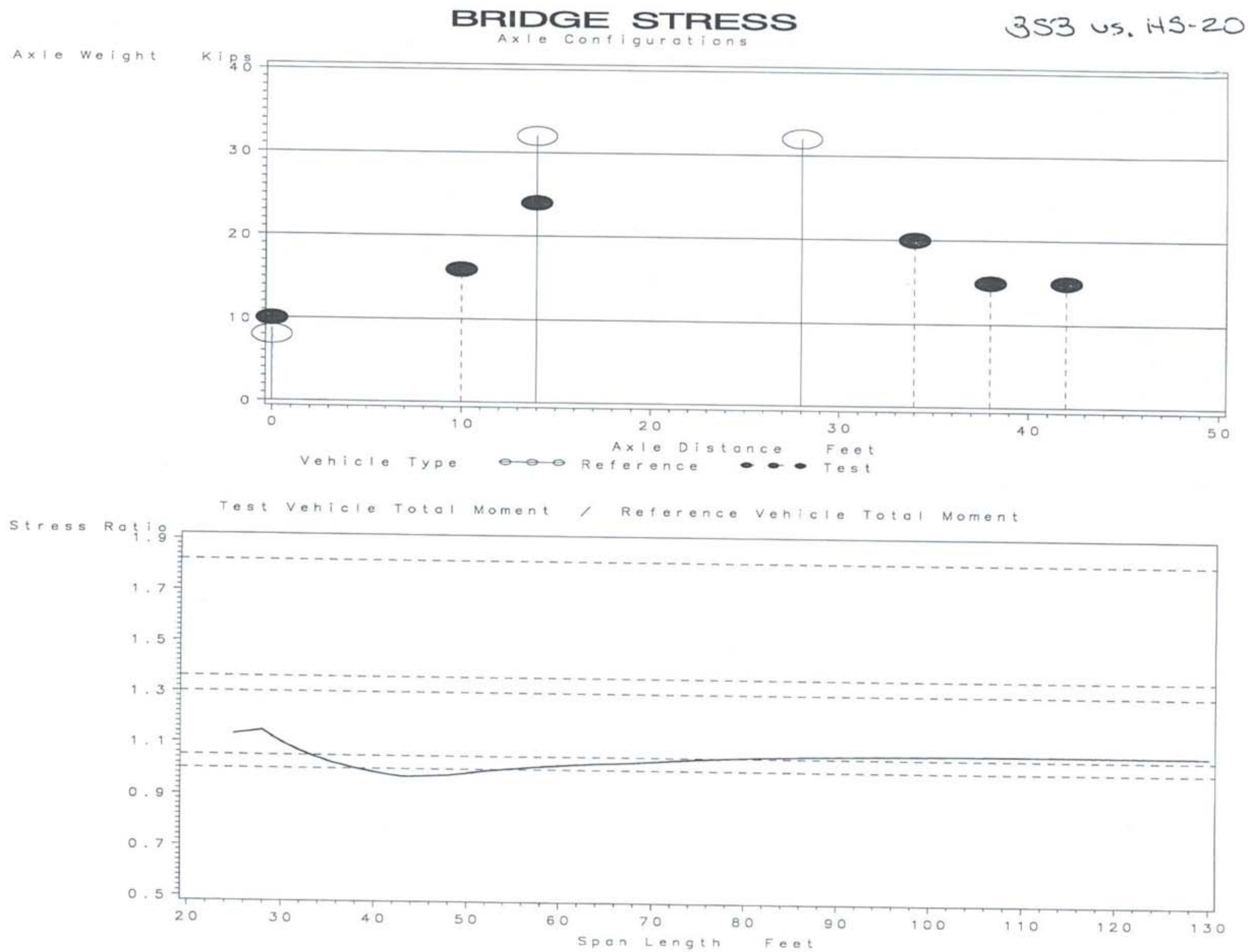
Year	Culverts	Bridges	Average Age of Old Culverts	Average Age of Old Bridges
2000	10	13	47	71
2001	6	16	44	66
2002	6	11	51	70
2003	20	9	57	66
2004	6	23	44	66
2005	2	16	41	65
Totals	50	88	284	404
Average	8.3	14.7	47.3	67.3

In MaineDOT's opinion, additional Interstate bridge fatigue costs to accommodate 100,000 trucks on Maine's Interstate are theoretical and perhaps even zero. General deterioration is the primary factor driving bridge replacements, and Maine has yet to replace a bridge due to steel fatigue. Troublesome fatigue-prone issues like connection plate/web gap details were retrofitted long ago. If fatigue is not going to drive bridge life in Maine, then there is no incremental fatigue cost to additional or heavier truck traffic.

APPENDIX A

Bridge Stress Graphs

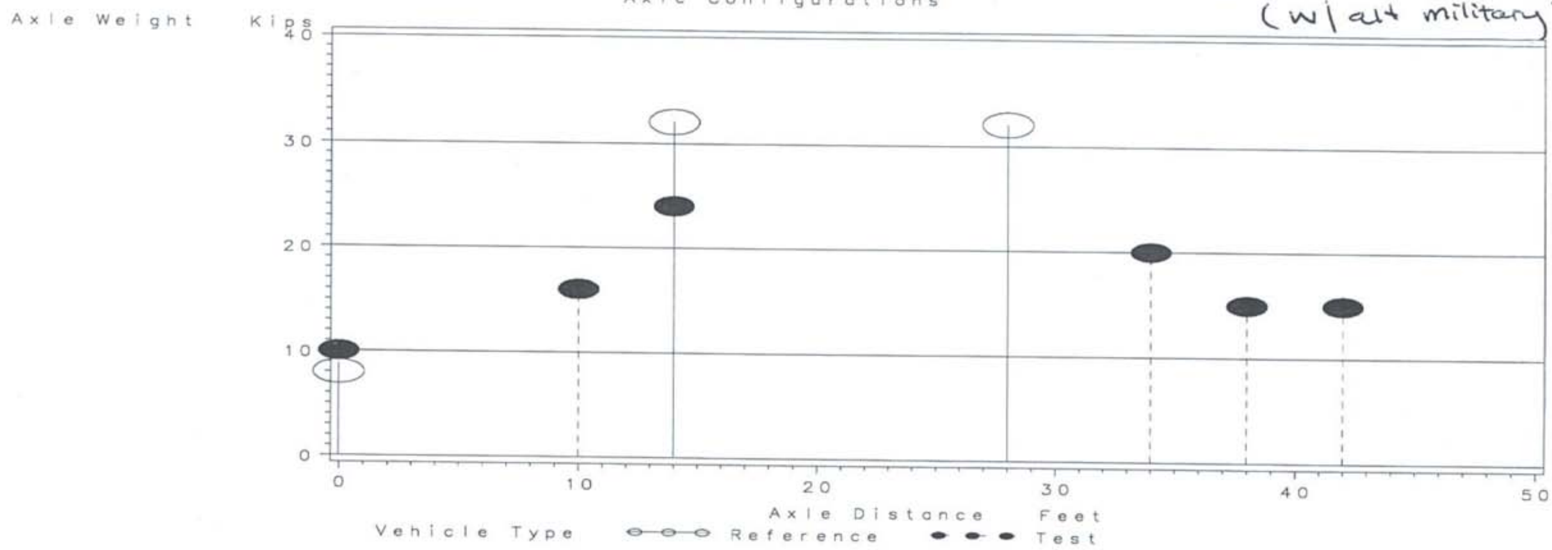

BRIDGE STRESS
Axle Configurations
353 vs. H-20
Axle Weight Kips
Vehicle Type
Axle Distance Feet
Reference
Test
Test Vehicle Total Moment / Reference Vehicle Total Moment
Stress Ratio
Span Length Feet
YIELD Fy
OPER. .75 Fy
INV./DESIGN .55 Fy
1.82
1.36
1.00

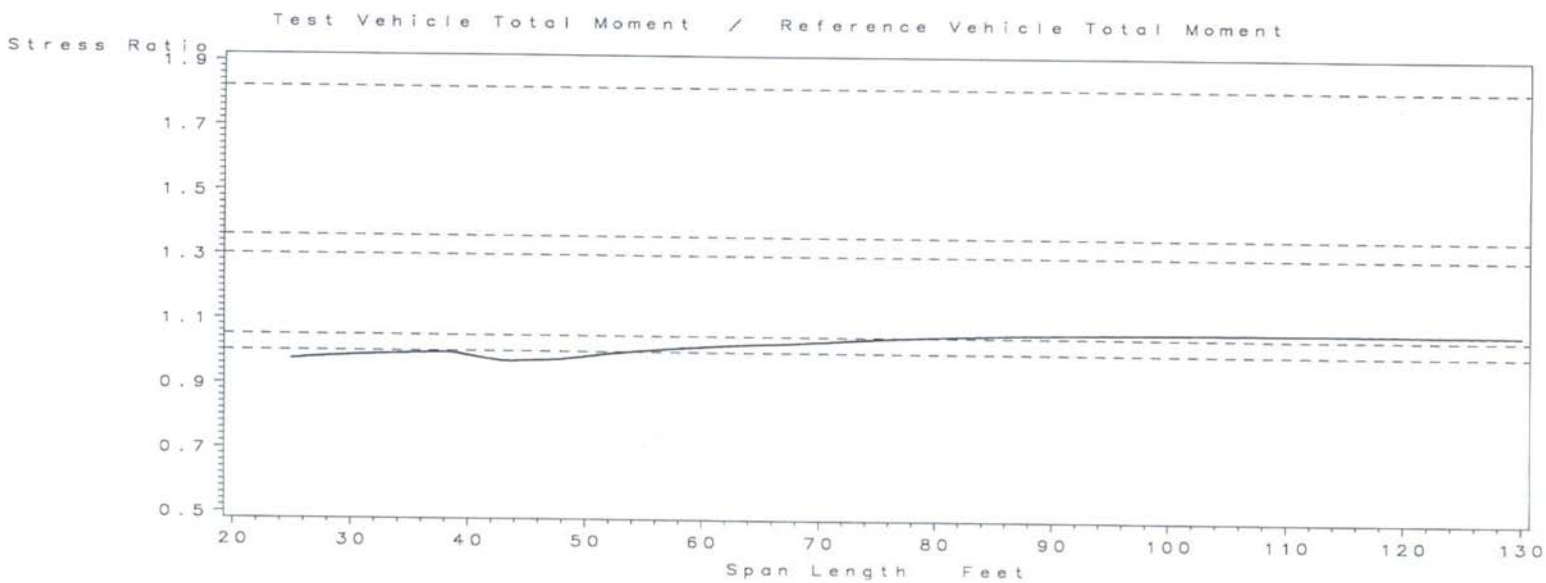


BRIDGE STRESS
Axle Configurations
3S3 vs. HS-20
Axle Weight Kips
40
30
20
10
0
0
10
20
30
40
50
Axle Distance Feet
Vehicle Type
Reference
Test
Test Vehicle Total Moment / Reference Vehicle Total Moment
Stress Ratio
1.9
1.7
1.5
1.3
1.1
0.9
0.7
0.5
20
30
40
50
60
70
80
90
100
110
120
130
Span Length Feet

BRIDGE STRESS

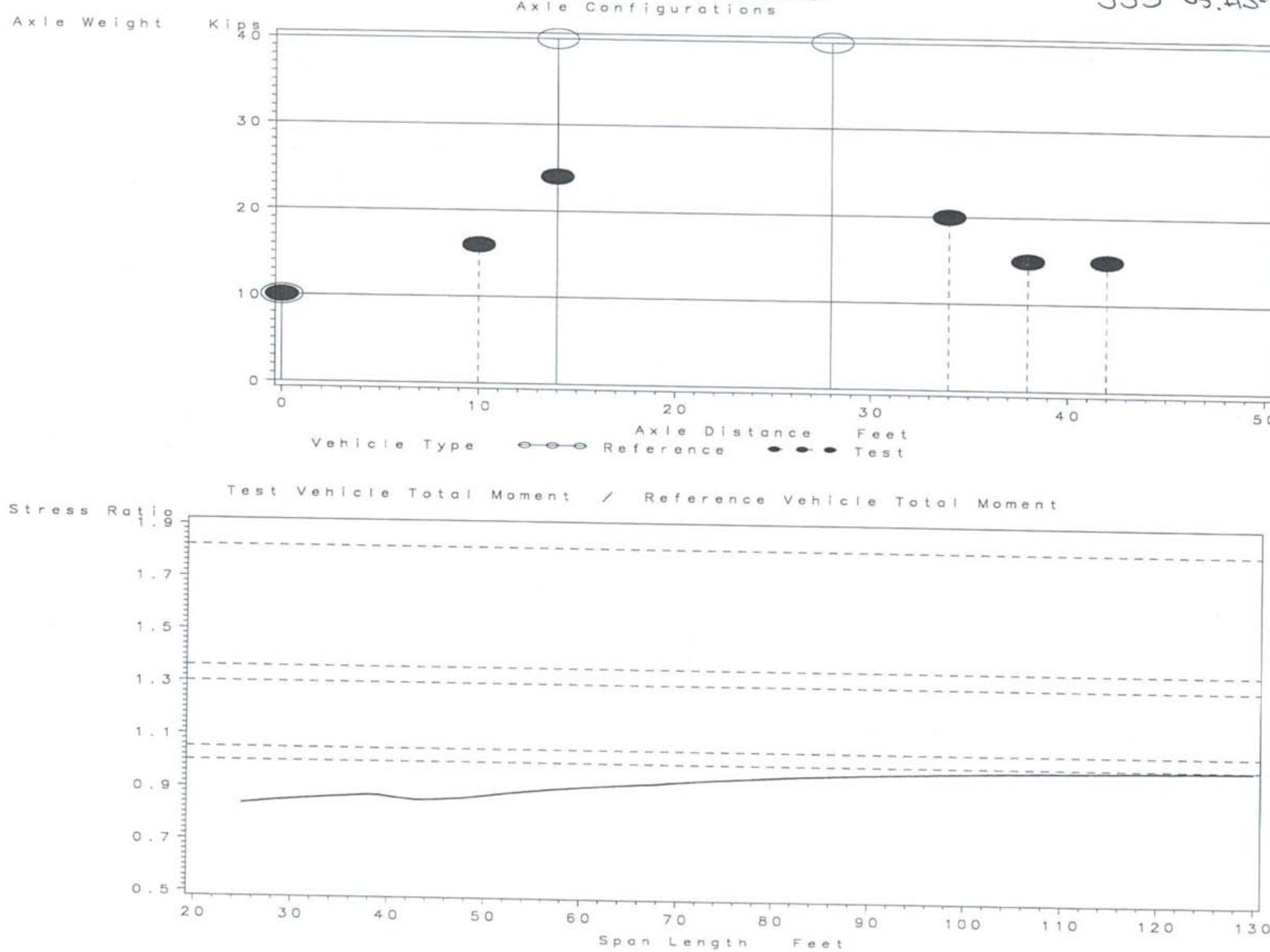
353 vs. HS-20 (w/ alt military)





BRIDGE STRESS

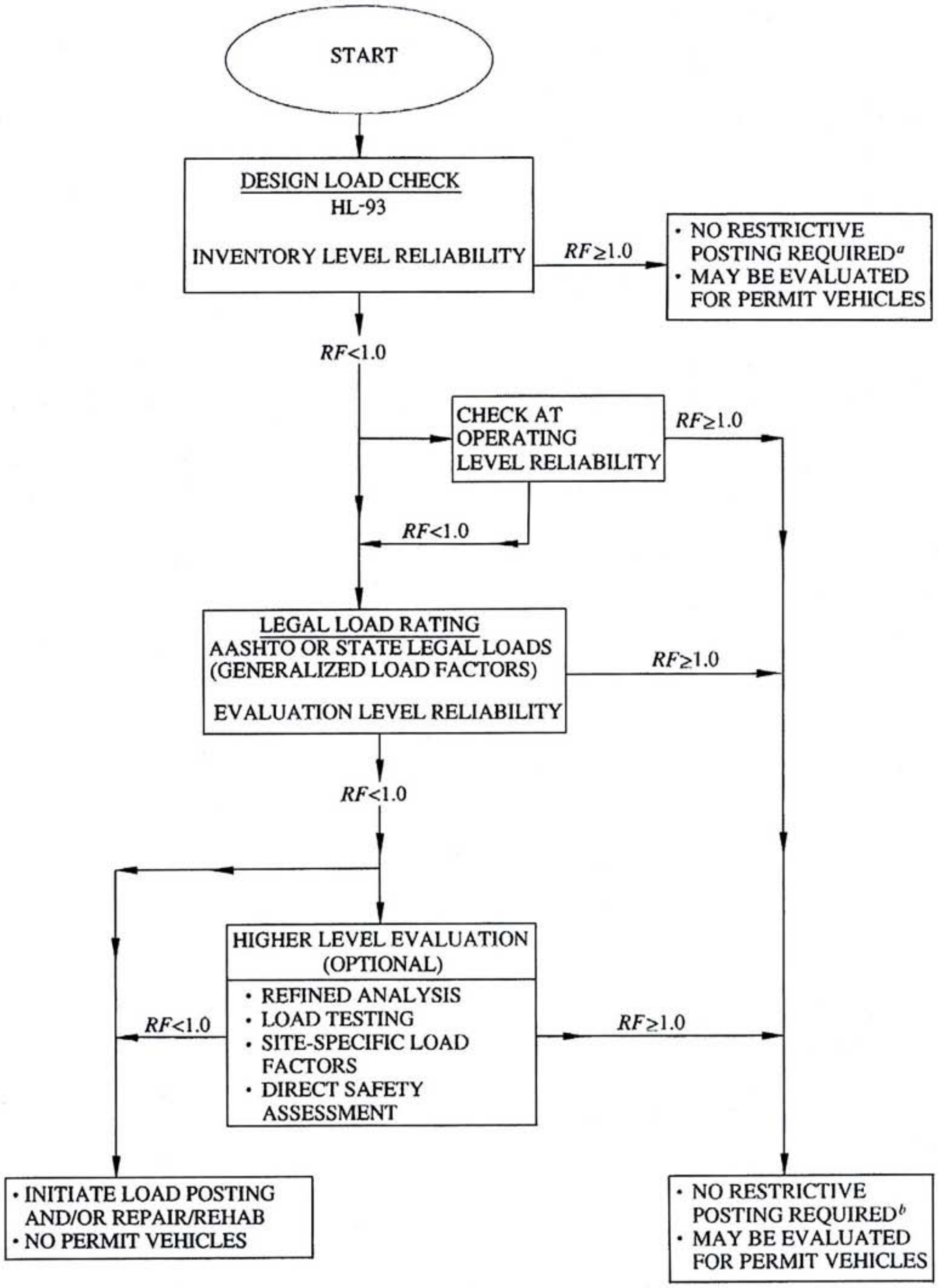
353 vs. HS-25'



APPENDIX B

LRFR Chart

APPENDIX A6A—LOAD AND RESISTANCE FACTOR RATING FLOW CHART



[a] For routinely permitted on highways of various states under grandfather exclusions to federal weight laws.

[b] For legal loads that comply with federal weight limits and Formula B.

APPENDIX C

Interstate LRFR Ratings

Interstate Bridges recently rated using LRFR

Bridge Number	Municipality	Bridge Name	LRFR Rating Factor
			Inventory Level
0158	Bangor	I-95 over Cathance River	1.63
1429	Bangor	I-95 NB over MCRR & Perry Road	1.16
1429	Bangor	I-95 SB over MCRR & Perry Road	1.25
1441	Newport	I-95 over MCRR	1.3
1509	Yarmouth	I-295 over US Route 1	0.96
1510	Brunswick-Topsham	I-295 over Androscoggin River	1
1511	Topsham	I-95 over Old Lewiston Road	1.45
1534	Gardiner	I-95 over Cobbosseecontee Stream	*
5791	Bangor	I-95 over Kenduskeag Stream	1
6294	Portland	I-295 SB over Congress & Park Streets	1.16
6281	South Portland	I-295 SB over Fore River	1.04
6296	Portland	I-295 SB over PTRR/St. John Street	1.25
6295	Portland	I-295 SB over St. James Street	1.47
6297	Portland	I-295 SB over St. John Street	1.68
1513	Portland	I-295 SB over State Route 703/8239 E	1.4
1505	Falmouth	I-295 SB over Presumpscot River	1.04
6300	Portland	I-295 SB over Franklin Street	1.25
6298	Portland	I-295 SB over Forest Avenue	1.46
3088	Portland	I-295 SB over Back Bay (Tukey's Bridge)	1.18
6292	Portland	I-295 SB over Fore River Parkway (Westbrook Arterial)	1.62
6291	Portland	I-295 SB over PTRR	1.38
6249	South Portland	I-295 SB over Westbrook Street (Route 9)	1.58
6299	Portland	I-295 SB over Preble Street Extension	1.23
5616	Portland	I-295 SB over CNRR	1.09
0816	Portland	I-295 SB over Washington Avenue	1.09
5617	Portland	I-295 SB over Sherwood Street	1.08
5618	Portland	I-295 SB over Kensington Street	1.08
1395	Oakfield	I-95 NB over B&ARR Yard	1.02
1396	Oakfield	I-95 NB over East Branch of Mattawamkeag River	1.14
1397	Oakfield	I-95 NB over Oakfield Smyrna Road	1.06
1401	Island Falls	I-95 NB over West Branch of Mattawamkeag River	1.78
1402	Island Falls	I-95 NB over Fish Stream & Bog Brook Road	1.48
1403	Island Falls	I-95 NB over Patten Road & B&ARR	1.52
6083	Oakfield	I-95 SB over Oakfield Smyrna Road	1.08
6084	Oakfield	I-95 SB over East Branch of Mattawamkeag River	1.23

*refined analysis in progress.

APPENDIX D

VMT Data

Hpms 6.01 2009 HPMS data

Travel Activity by Vehicle Type Interstate

2009

State: 23 - Maine

2/23/2011

9:17 AM

Basic Data

Percent of Travel

		Motor Cycles [Optional]	Passenger Car (2 Axel, 4 Tire)	Light Trucks (2 Axel, 4 Tire)	Buses	Single-Unit Trucks	Combination Trucks	Total
	Rural							
Rural	Interstate	0.003	0.661	0.197	0.002	0.042	0.095	1.000
	Interstate VMT	6,591,173	1,452,255,061	432,820,328	4,394,115	92,276,415	208,720,463	2,197,057,555
	Urban							
Urban	Interstate	0.004	0.737	0.170	0.003	0.032	0.054	1.000
	Interstate VMT	3,302,572	608,498,908	140,359,318	2,476,929	26,420,578	44,584,725	825,643,030
	Statewide	0.003	0.682	0.190	0.002	0.039	0.084	1.000
	Total VMT	9,893,745	2,060,753,969	573,179,645	6,871,044	118,696,994	253,305,188	3,022,700,586

combo trucks

US Truck VMT on Interstate (2008)

= 70,465 million VMT

ME

= 253 million VMT

∴ Maine Interstate Truck VMT is 0.36% of nat'l total

[less than 1/2 of 1%]

ANNUAL VEHICLE DISTANCE TRAVELED IN MILES AND RELATED DATA - 2008 1/
BY HIGHWAY CATEGORY AND VEHICLE TYPE

December 2009 TABLE VM-1

YEAR	ITEM	PASSENGER CARS	MOTOR-CYCLES	BUSES	OTHER 2-AXLE 4-TIRE VEHICLES 3/	SINGLE-UNIT 2-AXLE 6-TIRE OR MORE TRUCKS 4/	COMBINATION TRUCKS	SUBTOTALS: PASSENGER CARS AND OTHER 2-AXLE 4-TIRE VEHICLES	SUBTOTALS: SINGLE-UNIT 2-AXLE 6-TIRE OR MORE AND COMBINATION TRUCKS	ALL MOTOR VEHICLES 2/
	Motor-Vehicle Travel: (millions of vehicle-miles)									
2008	Interstate Rural	115,532	1,348	1,027	77,842	7,299	40,242	193,373	47,542	243,290
2007		122,183	1,420	986	82,030	7,188	42,632	204,212	49,819	256,438
2008	Other Arterial Rural	191,897	2,418	1,020	139,867	13,646	25,426	331,764	39,071	374,273
2007		204,123	2,305	1,015	145,985	13,877	26,160	350,108	40,037	393,465
2008	Other Rural	195,684	1,929	1,772	144,171	15,478	13,820	339,855	29,298	372,855
2007		203,485	1,820	1,722	148,612	15,659	14,101	352,097	29,760	385,400
2008	All Rural	503,112	5,695	3,819	361,880	36,423	79,488	864,993	115,911	990,418
2007		529,791	5,546	3,723	376,627	36,723	82,893	906,418	119,616	1,035,303
2008	Interstate Urban	262,321	2,738	1,077	169,605	10,127	30,223	431,926	40,350	476,091
2007		267,559	2,631	1,052	170,669	10,143	31,262	438,228	41,405	483,315
2008	Other Urban	850,417	6,051	2,218	577,117	37,400	33,797	1,427,534	71,197	1,507,000
2007		875,118	5,444	2,205	564,975	35,147	30,892	1,440,093	66,039	1,513,781
2008	All Urban	1,112,738	8,789	3,295	746,722	47,527	64,019	1,859,460	111,547	1,983,091
2007		1,142,677	8,075	3,257	735,644	45,290	62,153	1,878,320	107,444	1,997,096
2008	Total Rural and Urban	1,615,850	14,484	7,114	1,108,603	83,951	143,507	2,724,453	227,458	2,973,509
2007		1,672,467	13,621	6,980	1,112,271	82,014	145,046	2,784,738	227,060	3,032,399
2008	Number of motor vehicles	137,079,843	7,752,926	843,308	101,234,849	6,790,882	2,215,856	238,314,692	9,006,738	255,917,664
2007	registered 5/	135,932,930	7,138,476	834,436	101,469,615	6,806,630	2,220,995	237,402,545	9,027,624	254,403,081
2008	Average miles traveled	11,788	1,868	8,436	10,951	12,362	64,764	11,432	25,254	11,619
2007	per vehicle	12,304	1,908	8,365	10,962	12,049	65,307	11,730	25,152	11,920
2008	Person-miles of travel 6/	2,553,043	18,395	150,827	1,921,960	83,951	143,507	4,475,004	227,458	4,871,683
2007	(millions)	2,642,498	17,298	147,985	1,928,319	82,014	145,046	4,570,818	227,060	4,963,161
2008	Fuel consumed 7/	71,497,204	256,358	1,109,636	61,198,934	9,888,729	26,814,441	132,696,139	36,703,170	170,765,303
2007	(thousand gallons)	74,377,197	242,241	1,144,861	61,836,216	10,043,778	28,545,442	136,213,413	38,589,220	176,189,735
2008	Average fuel consumption per	522	33	1,316	605	1,456	12,101	557	4,075	667
2007	vehicle (gallons) 7/	547	34	1,372	609	1,476	12,853	574	4,275	693
2008	Average miles traveled per	22.6	56.5	6.4	18.1	8.5	5.4	20.5	6.2	17.4
2007	gallon of fuel consumed 7/	22.5	56.2	6.1	18.0	8.2	5.1	20.4	5.9	17.2

1/ The 50 states and the District of Columbia report travel by highway category, number of motor vehicles registered, and total fuel consumed. The travel and fuel data by vehicle type and stratification of trucks are estimated by the Federal Highway Administration (FHWA). Estimation procedures include use of State supplied data, the 2002 Census of Transportation Vehicle Inventory and Use Survey (VIUS), and other sources.

2/ Totals by highway category are from table VM-2. Some changes between rural and urban roadways can be attributed to 2002 census boundary changes.

3/ Other 2-Axle 4-Tire Vehicles which are not passenger cars. These include vans, pickup trucks, and sport/utility vehicles.

4/ Single-Unit 2-Axle 6-Tire or More Trucks on a single frame with at least two axles and six tires.

5/ Truck registration figures are from tables MV-1 and MV-9 with truck distribution estimated by the FHWA.

6/ Vehicle occupancy is estimated by the FHWA from the 2001 National Household Travel Survey (NHTS); For heavy trucks, 1 motor vehicle miles travelled = 1 person-miles traveled.

7/ Total fuel consumption figures are from tables MF-21 and MF-27. Distribution by vehicle type is estimated by the FHWA based on miles per gallon for both diesel and gasoline powered vehicles using State-supplied data, the 2002 VIUS, and other sources with nominal inputs for motorcycles and buses.