NCHRP 20-07 Task 390

Parametric Study and Cost Effects for the USDOT Truck Size and Weight Study Vehicles

Progress Report
To
AASHTO T-5

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Project Scope

- Task 1. Develop a methodology to determine comparative force effects for the AASHTO design trucks and the six trucks used in the USDOT TS&W Study.
- Task 2. Determine the replacement costs for each state for each of the six scenario trucks.
- Task 3. Prepare a roadmap of study items and actions necessary to make the true cost effects of increasing legal loads known by decision makers.
- Task 4. Present the research findings to the AASHTO SCOBS T-5 and T-18
- Task 5. Submit a final report

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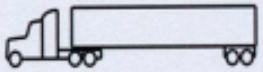
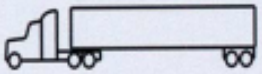
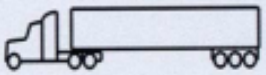
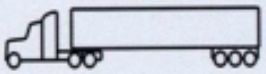
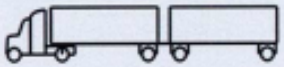
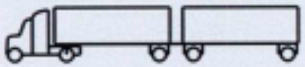
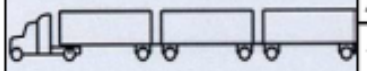
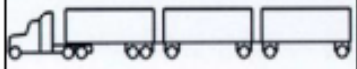
NCHRP 20-07 Task 390

Study Trucks

Configuration	Description	Details								
Control Vehicle CS5 (3S2)	5-axle vehicle (GVW = 80)	Axle Data								
		Axle Locations	0	197	247	739	789			
		Allowed Max. Loads (kips)	12.0	17.0	17.0	17.0	17.0			
Truck 1 CS5 (3S2) ATC 1	5-axle vehicle (GVW = 88)	Axle Data								
		Axle Locations	0	197	247	739	789			
		Allowed Max. Loads (kips)	12.0	19.0	19.0	19.0	19.0			
Truck 2 CS6 (3S3) ATC 2	6-axle vehicle (GVW = 91)	Axle Data								
		Axle Locations	0	197	247	688	739	789		
		Allowed Max. Loads (kips)	12.0	15.8	15.8	15.8	15.8	15.8		
Truck 3 CS6 (3S3) ATC 3	6-axle vehicle (GVW = 97)	Axle Data								
		Axle Locations	0	197	247	688	739	789		
		Allowed Max. Loads (kips)	12.0	17.0	17.0	17.0	17.0	17.0		
LCV Control Vehicle 2S1-2 (DS5)	Tractor plus two 28-foot trailers (GVW = 80)	Axle Data								
		Axle Locations	0	138	372	499	753			
		Allowed Max. Loads (kips)	12.0	17.0	17.0	17.0	17.0			
Truck 4 2S1-2 (DS5) ATC 4	Tractor plus two 33-foot trailers (GVW = 80)	Axle Data								
		Axle Locations	0	138	419	499	800			
		Allowed Max. Loads (kips)	12.0	17.0	17.0	17.0	17.0			
Truck 5 2S1-2-2 (DS7) ATC 5	Tractor plus three 28-foot trailers (GVW = 105.5)	Axle Data								
		Axle Locations	0	138	372	499	753	880	1134	
		Allowed Max. Loads (kips)	12.0	15.6	15.6	15.6	15.6	15.6	15.6	
Truck 6 3S2-2-2 (DS7+) ATC 6	Tractor plus three 28-foot trailers (GVW = 129)	Axle Data								
		Axle Locations	0	197	247	406	456	583	837	964	1218
		Allowed Max. Loads (kips)	12.0	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6

Note: Axle locations are measured in inches from the steering axle.
Gross vehicle weight and axle loads are expressed in units of 1000 lb. or "kips".

Span Lengths Used in the Study

Span length for analysis	10	30	50	70	100	130	160	200	250
Span range for which the load effect ratio is used	0:<20	20:<40	40:<60	60:<85	85:<115	115:<145	145:<180	180:<225	225:<275

Both simple spans and 2-span continuous bridges were analyzed.

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Design and Proposed Loads Compared

H10 truck	HS15 Load	CSS (3S2)
H15 truck	H20 Load	CS5 (3S2) ATC 1
HS15 truck	HS20 Load	CS6 (3S2) ATC 2
H20 truck	HS25 Load	CS6 (3S2) ATC 3
HS20 truck	HL93 Load	2S1-2 (DS5)
HS25 truck	Type 3 Truck	2S1-2 (DS5) ATC 4
H10 Load	Type 3S2	2S1-2-2 (DS7) ATC 5
H15 Load	Type 3-3	3S2-2-2 (DS7+) ATC 6

- **In addition, SU4, SU5, SU6 and SU7 were analyzed**

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Load Effects

- Load effects
- (100 ft. spans shown)

	Simple Span		Two Span Continuous		
	LL Max +M (k-ft)	LL Max V (k)	LL Max +M (k-ft)	LL Max -M* (k-ft)	LL Max V (k)
H10 Load	763.6	35.4	601.9	-699.9	40.3
H15 Load	1145.4	53.2	902.8	-1049.8	60.5
H20 Load	1527.2	70.9	1203.8	-1399.8	80.7
HS15 Load	1396.9	59.8	1131.0	-1049.8	62.1
HS20 Load	1862.5	79.8	1508.0	-1399.8	82.8
HS25 Load	2328.1	99.7	1885.0	-1749.7	103.5
Type 3 Truck	1341.3	56.6	1092.0	-571.1	58.3
Type 3S2	1627.7	71.6	1299.2	-760.7	76.4
Type 3-3	1641.5	74.4	1286.8	-794.6	80.2
Max of Type 3, 3S2, 3-3	1641.5	74.4	1299.2	-794.6	80.2
SU4 Truck	1486.2	61.7	1212.1	-617.9	63.4
SU5 Truck	1662.2	69.8	1355.6	-704.3	72.0
SU6 Truck	1857.8	76.0	1507.5	-787.6	79.3
SU7 Truck	2043.6	82.4	1646.7	-874.4	86.9
Max of SU4, SU5, SU6 and SU7	2043.6	82.4	1646.7	-874.4	86.9
CSS (3S2)	1404.7	67.4	1129.1	-783.2	73.1
CS5 (3S2) ATC 1	1547.8	74.7	1245.3	-858.7	80.9
CS6 (3S2) ATC 2	1585.3	80.6	1288.3	-869.1	86.7
CS6 (3S2) ATC 3	1705.0	86.4	1385.1	-924.6	92.9
2S1-2 (DS5)	1574.0	67.3	1225.8	-753.4	73.8
2S1-2 (DS5) ATC 4	1546.5	65.6	1209.1	-732.1	72.1
2S1-2-2 (DS7) ATC 5	1550.5	70.8	1203.7	-957.3	79.6
3S2-2-2 (DS7+) ATC 6	2073.5	92.6	1634.4	-1212.8	102.3

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Load Effect Ratios

- Load effect Ratios
- (100 ft. spans shown)
- Ratios to HS20 loading shown

	Simple Span			Two Span Continuous			
	LL Max +M (k-ft)	LL Max V (k)	Max Simple Span	LL Max +M (k-ft)	LL Max -M* (k-ft)	LL Max V (k)	Max Continuous span
Max of Type 3, 3S2, 3-3	0.88	0.93	0.93	0.86	0.57	0.97	0.97
Max of SU4, SU5, SU6 and SU7	1.10	1.03	1.10	1.09	0.62	1.05	1.09
Max of legal/specialized loads	1.10	1.03	1.10	1.09	0.62	1.05	1.09
CSS (3S2)	0.75	0.84	0.84	0.75	0.56	0.88	0.88
CS5 (3S2) ATC 1	0.83	0.94	0.94	0.83	0.61	0.98	0.98
CS6 (3S2) ATC 2	0.85	1.01	1.01	0.85	0.62	1.05	1.05
CS6 (3S2) ATC 3	0.92	1.08	1.08	0.92	0.66	1.12	1.12
2S1-2 (DS5)	0.85	0.84	0.85	0.81	0.54	0.89	0.89
2S1-2 (DS5) ATC 4	0.83	0.82	0.83	0.80	0.52	0.87	0.87
2S1-2-2 (DS7) ATC 5	0.83	0.89	0.89	0.80	0.68	0.96	0.96
3S2-2-2 (DS7+) ATC 6	1.11	1.16	1.16	1.08	0.87	1.23	1.23

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Load Effect Ratios

- Comparison Study trucks to HL93. Simple Spans

	Simple Span Length (ft.)								
	10	30	50	70	100	130	160	200	250
Max of legal/specialized loads for L<=200 ft and L>200 ft as appropriate	0.68	0.88	0.90	0.85	0.79	0.73	0.68	0.63	0.57
CSS (3S2)	0.62	0.61	0.57	0.56	0.62	0.62	0.61	0.58	0.54
CS5 (3S2) ATC 1	0.69	0.68	0.63	0.63	0.68	0.69	0.67	0.64	0.60
CS6 (3S2) ATC 2	0.57	0.76	0.67	0.70	0.74	0.73	0.71	0.67	0.63
CS6 (3S2) ATC 3	0.62	0.82	0.73	0.75	0.79	0.78	0.76	0.72	0.67
2S1-2 (DS5)	0.49	0.49	0.55	0.58	0.62	0.62	0.61	0.58	0.54
2S1-2 (DS5) ATC 4	0.49	0.53	0.50	0.59	0.60	0.61	0.60	0.57	0.54
2S1-2-2 (DS7) ATC 5	0.45	0.45	0.51	0.57	0.65	0.69	0.70	0.69	0.66
3S2-2-2 (DS7+) ATC 6	0.53	0.55	0.61	0.66	0.73	0.81	0.89	0.92	0.91

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Load Effect Ratios

- Comparison Study trucks to HL93. Continuous Spans

	two-Span Continuous, Length of each span (ft.)								
	10	30	50	70	100	130	160	200	250
Max of legal/specialized loads for L<=200 ft and L>200 ft as appropriate	0.78	0.86	0.90	0.86	0.80	0.75	0.70	0.65	0.59
CSS (3S2)	0.63	0.60	0.69	0.55	0.61	0.61	0.59	0.55	0.53
CS5 (3S2) ATC 1	0.70	0.66	0.76	0.62	0.68	0.67	0.65	0.61	0.58
CS6 (3S2) ATC 2	0.74	0.75	0.79	0.68	0.73	0.71	0.68	0.63	0.59
CS6 (3S2) ATC 3	0.80	0.81	0.84	0.74	0.78	0.76	0.73	0.68	0.64
2S1-2 (DS5)	0.50	0.51	0.58	0.59	0.62	0.61	0.60	0.58	0.55
2S1-2 (DS5) ATC 4	0.50	0.55	0.59	0.60	0.60	0.60	0.59	0.57	0.54
2S1-2-2 (DS7) ATC 5	0.57	0.50	0.64	0.60	0.67	0.69	0.70	0.68	0.66
3S2-2-2 (DS7+) ATC 6	0.52	0.62	0.68	0.72	0.79	0.81	0.88	0.90	0.88

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Load Effect Ratios

- Comparison Study trucks to HS20. Simple Spans

	Simple Span Length (ft.)								
	10	30	50	70	100	130	160	200	250
Max of legal/specialized loads	0.90	1.19	1.12	1.11	1.10	1.09	1.02	0.88	0.75
CSS (3S2)	0.80	0.78	0.70	0.71	0.84	0.90	0.84	0.76	0.67
CS5 (3S2) ATC 1	0.89	0.88	0.78	0.80	0.94	1.00	0.93	0.84	0.74
CS6 (3S2) ATC 2	0.74	1.02	0.84	0.89	1.01	1.06	0.98	0.87	0.76
CS6 (3S2) ATC 3	0.80	1.10	0.90	0.95	1.08	1.14	1.04	0.93	0.82
2S1-2 (DS5)	0.53	0.61	0.66	0.73	0.85	0.91	0.90	0.80	0.70
2S1-2 (DS5) ATC 4	0.53	0.71	0.62	0.75	0.83	0.90	0.89	0.80	0.70
2S1-2-2 (DS7) ATC 5	0.49	0.56	0.61	0.72	0.89	1.00	1.02	0.95	0.85
3S2-2-2 (DS7+) ATC 6	0.72	0.79	0.88	1.03	1.16	1.26	1.28	1.18	1.05

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Load Effect Ratios

- Comparison Study trucks to HS20. Continuous Spans

	two-Span Continuous, Length of each span (ft.)								
	10	30	50	70	100	130	160	200	250
Max of legal/specialized loads	1.00	1.18	1.11	1.10	1.09	1.09	1.07	0.92	0.79
CSS (3S2)	0.89	0.80	0.95	0.80	0.88	0.83	0.86	0.79	0.70
CS5 (3S2) ATC 1	0.99	0.90	1.05	0.88	0.98	0.91	0.95	0.87	0.77
CS6 (3S2) ATC 2	0.92	1.03	1.09	0.90	1.05	0.94	0.98	0.89	0.79
CS6 (3S2) ATC 3	0.99	1.11	1.16	0.97	1.12	1.01	1.05	0.95	0.85
2S1-2 (DS5)	0.54	0.72	0.80	0.78	0.89	0.89	0.91	0.82	0.73
2S1-2 (DS5) ATC 4	0.54	0.76	0.81	0.79	0.87	0.88	0.91	0.82	0.72
2S1-2-2 (DS7) ATC 5	0.65	0.70	0.89	0.89	0.96	0.95	1.03	0.96	0.87
3S2-2-2 (DS7+) ATC 6	0.76	0.87	0.91	1.10	1.23	1.22	1.30	1.20	1.08

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Identification of Affected Bridges (1)

Criteria:

Scenario I: A bridge is considered to be affected by a loading scenario when:

The current operating rating in the NBIS is $\geq$ 1.0

And,

The operating rating under the proposed truck is <1.0

i.e. a bridge that is currently not posted will require posting

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Identification of Affected Bridges (2)

Scenario II:

A bridge is considered to be affected by a certain truck when:

The operating rating under the proposed truck is <1.0

i.e. a bridge will be considered affected by a certain truck if it will require posting to accommodate this truck regardless of it being currently posted or not.

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Basic Assumptions

- All culverts are considered not to be affected (culverts are affected by axle weights not vehicle weights. Proposed trucks' axle configurations are less significant than the 32 kips axles of the design trucks for all reasonable culvert spans.
- For any bridge, the load rating under proposed trucks is performed using the same rating method used for the rating in the NBIS
- Force effect corresponding to the highest load effect ratio (moment or shear) is assumed to control the NBIS rating

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Basic Assumptions

- Proposed trucks are considered legal loads resulting in the following load factors for the proposed trucks:
  - ASR and LFR: 1.3
  - LRFR: A function of ADTT

- NBIS operating load factor:
  - ASR and LFR: 1.3 HS20
  - LRFR: 1.35 HL93

- Proposed trucks applied one truck per lane

Table 6A.4.4.2.3a-1—Generalized Live Load Factors, γ_L for Routine Commercial Traffic

Traffic Volume (one direction)	Load Factor ~~for Type 3, Type 3S2, Type 3-3, and Lane Loads~~
Unknown	~~1.80~~ 1.45
ADTT ≥ 5,000	~~1.80~~ 1.45
ADTT ≤ 1,000	~~1.65~~ 1.30
~~*ADTT* ≤ 100~~	~~1.40~~

Linear interpolation is permitted for *ADTT* values between 5,000 and 1,000.

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Load Rating Factor Calculation

The legal trucks load rating factor =

(the NBIS rating factor for the operating rating) x

(load factor for the legal truck / load factor for operating rating) /

(force effect ratio of the proposed truck/NBIS rating load)

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Load Rating Factor Calculation

- EXAMPLE:

A 130 ft. simple span bridge with an operating rating factor of 1.05 in the NBIS using LFD (HS20 rating load). What is the rating factor for this bridge under the 3S2-2-2 (DS7+) ATC 6?

Load factor for operating rating = 1.3

Load factor in LFD for legal loads = 1.3

The maximum ratio between the 3S2-2-2 (DS7+) ATC 6 load effects and the HS20 load effects for 130 ft. simple span = 1.26 from Table 3 above

Rating factor under the 3S2-2-2 (DS7+) ATC 6 truck =

$$1.05 * (1.3/1.3)/1.26 = 0.833$$

Load Rating Factor Calculation

- EXAMPLE:

The same bridge in Example 1. Load rating factor of 1.05 in the NBIS using LRFR rating (HL-93 design load). The bridge exists on a route with one direction ADTT of 5000. What is the rating factor for this bridge under the 3S2-2-2 (DS7+) ATC 6?

Load factor for operating rating = 1.35

Load factor for the legal load for LRFR = 1.45 from MBE Table 6A.4.4.2.3a-1

The maximum ratio between the 3S2-2-2 (DS7+) ATC 6 load effects and the HL93 load effects for 130 ft. simple span = 0.81 from Table 5 above

Rating factor under the 3S2-2-2 (DS7+) ATC 6 truck = 1.05 *(1.35/1.45)/0.81 = 1.21 > 1.0

RF for 3S2-2-2 (DS7+) ATC 6 = 1.21, i.e. >1.0, the bridge is then considered not to need replacement under the 3S2-2-2 (DS7+) ATC 6 scenario.

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Bridge Replacement Unit Cost

- Three cases are considered:
  - $235 per sq. ft. (same as USDOT study. Used for comparison)
  - FHWA 2011 cost data for individual states x 1.04^6 to convert to 2017 dollars assuming 4% inflation. Unit cost is then multiplied by 2 to account for other project costs.
  - FHWA 2011 cost data for individual states x 1.04^6 to convert to 2017 dollars assuming 4% inflation. Unit cost is then multiplied by a cost factor to be collected from the states.

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FHWA Unit Cost Data

2017 unit cost taken as 2011 unit cost adjusted for 4% inflation over 6 years

State	Bridge Unit Cost (dollars/ft^2)	State	Bridge Unit Cost (dollars/ft^2)
Alabama	109	Montana	143
Alaska	301	Nebraska	105
Arizona	125	Nevada	138
Arkansas	148	New Hampshire	373
California	197	New Jersey	418
Colorado	108	New Mexico	142
Connecticut	420	New York	258
Delaware	314	North Carolina	213
District of Columbia	399	North Dakota	130
Florida	140	Ohio	257
Georgia	75	Oklahoma	104
Hawaii	519	Oregon	182
Idaho	127	Pennsylvania	254
Illinois	180	Puerto Rico	242
Indiana	138	Rhode Island	435
Iowa	106	South Carolina	119
Kansas	116	South Dakota	123
Kentucky	171	Tennessee	100
Louisiana	97	Texas	66
Maine	272	Utah	238
Maryland	253	Vermont	309
Massachusetts	357	Virginia	208
Michigan	159	Washington	245
Minnesota	228	West Virginia	243
Mississippi	75	Wisconsin	119
Missouri	135	Wyoming	106

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Number and Replacement Cost of Affected Bridges

Scenario I, $235 per. Sq. ft.

	CSS (3S2)		CS5 (3S2) ATC 1		CS6 (3S2) ATC 2		CS6 (3S2) ATC 3	
	No. of Br.	Cost (Millions)	No. of Br.	Cost (Millions)	No. of Br.	Cost (Millions)	No. of Br.	Cost (Millions)
Alabama	0	0	2	3	121	119	293	714
Alaska	0	0	0	0	1	0	8	4
Arizona	0	0	10	28	227	358	254	523
Arkansas	0	0	2	8	37	38	163	105
California	0	0	9	11	78	86	293	322
Colorado	0	0	12	21	107	80	324	445
Connecticut	0	0	0	0	3	1	5	1
Delaware	0	0	0	0	0	0	1	0
DC	0	0	0	0	1	15	3	16
Florida	0	0	3	4	26	50	139	233

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Number and Replacement Cost of Affected Bridges

Scenario I, $235 per. Sq. ft.

	CSS (3S2)		CS5 (3S2) ATC 1		CS6 (3S2) ATC 2		CS6 (3S2) ATC 3	
	No. of Br.	Cost (Millions)	No. of Br.	Cost (Millions)	No. of Br.	Cost (Millions)	No. of Br.	Cost (Millions)
South Dakota	0	0	0	0	1	2	138	208
Tennessee	0	0	0	0	0	0	132	724
Texas	0	0	0	0	78	959	1,259	5,241
Utah	0	0	0	0	22	66	143	485
Vermont	0	0	0	0	1	1	28	23
Virginia	0	0	0	0	1	3	61	257
Washington	0	0	0	0	6	20	171	929
West Virginia	0	0	0	0	0	0	33	77
Wisconsin	0	0	0	0	0	0	116	370
Wyoming	0	0	0	0	0	0	28	53

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Summary of Number and Replacement Cost of Affected Bridges, Scenario I

	CSS (3S2)		CS5 (3S2) ATC 1		CS6 (3S2) ATC 2		CS6 (3S2) ATC 3	
	No. of Bridges	Cost (Millions)	No. of Bridges	Cost (Millions)	No. of Bridges	Cost (Millions)	No. of Bridges	Cost (Millions)
Scenario I, $235/sq. ft.	0	0	740	1,074	9,528	9,559	15,922	17,309
Scenario I, 2.0 FHWA Unit Cost	0	0	740	1,338	9,528	11,344	15,922	20,296
USDOT Study				400	4,845	1,100	6,215	2,200

	2S1-2 (DS5)		2S1-2 (DS5) ATC 4		2S1-2-2 (DS7) ATC 5		3S2-2-2 (DS7+) ATC 6	
	No. of Bridges	Cost (Millions)	No. of Bridges	Cost (Millions)	No. of Bridges	Cost (Millions)	No. of Bridges	Cost (Millions)
Scenario I, $235/sq. ft.	0	0	0	0	258	2,599	6,909	29,356
Scenario I, 2.0 FHWA Unit Cost	0	0	0	0	258	2,845	6,909	38,794
USDOT Study				1,100		700	5,425	5,400

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Summary of Number and Replacement Cost of Affected Bridges, Scenario II

	CSS (3S2)		CS5 (3S2) ATC 1		CS6 (3S2) ATC 2		CS6 (3S2) ATC 3	
	No. of Bridges	Cost (Millions)	No. of Bridges	Cost (Millions)	No. of Bridges	Cost (Millions)	No. of Bridges	Cost (Millions)
Scenario II, $235/sq. ft.	53,491	22,755	65,680	30,067	75,683	42,022	87,118	52,723
Scenario II, 2.0 FHWA Unit Cost	53,491	29,779	65,680	39,297	75,683	53,823	87,118	66,641

	2S1-2 (DS5)		2S1-2 (DS5) ATC 4		2S1-2-2 (DS7) ATC 5		3S2-2-2 (DS7+) ATC 6	
	No. of Bridges	Cost (Millions)	No. of Bridges	Cost (Millions)	No. of Bridges	Cost (Millions)	No. of Bridges	Cost (Millions)
Scenario II, $235/sq. ft.	37,244	19,325	40,433	19,980	36,412	24,985	63,739	62,304
Scenario II, 2.0 FHWA Unit Cost	37,244	25,714	40,433	26,482	36,412	32,913	63,739	83,155

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THANK YOU FOR YOUR ATTENTION

QUESTIONS?

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