Evaluation of Alternative Truck Lane Management Strategies

Presented by: Hesham Rakha, Ph.D., P.Eng.
Director, Center for Sustainable Mobility
Professor, Charles E. Via Jr. Dept. of CEE

Co-authors:
Sangjun Park, Mazen Arafeh, and Ihab El-Shawarby

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Presentation Layout

- Study area
- Study objectives
- INTEGRATION model description
- Model calibration
  - O-D demand, supply, and vehicle characteristics
- Results
- Benefit-cost analysis
- Conclusions

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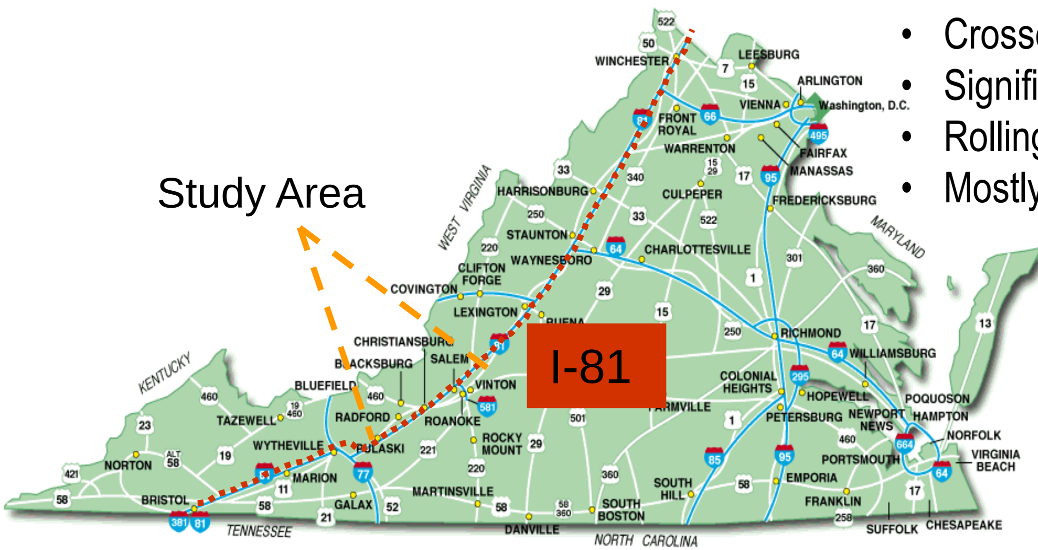
Study Area



- 325.5 Miles
- Crosses 12 Counties
- Significant Truck Volume
- Rolling to Mountainous Terrain
- Mostly rural areas & some large urban areas

- I-81 was designed for 15 percent truck traffic, however trucks currently account for somewhere between 20 to 40 percent of the total traffic.
- The Study Area connects the town of Blacksburg, City of Salem, and City of Roanoke.
- The corridor covers a total of 14 mi from milepost 132 to milepost 118.
  - Contains 3 interchanges and a rest area in the northbound direction.
  - Two-lane freeway in most segments with some locations with three lanes for truck climbing lanes.

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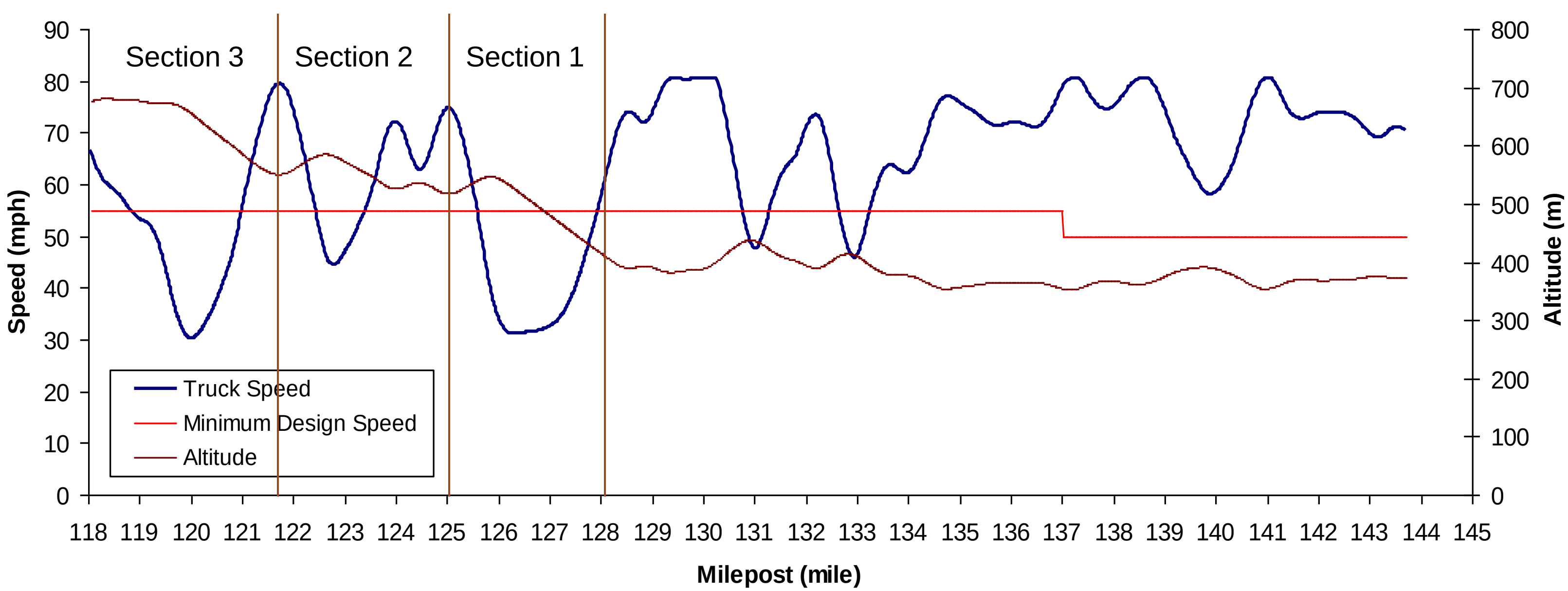
Scenarios Considered

- Four scenarios considered:

Classification	Milepost		Number of lanes			
	Begin	End	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Section 1	128.1	125.0	3	3	4	4
Section 2	125.0	120.7	2	3	3	4
Section 3	121.7	119.6	3	3	4	4



Study Objectives

- Compare alternative truck and lane management strategies along a significant grade section of I-81 in the state of Virginia
- These strategies are compared in terms of:
  - System efficiency, energy consumption, environmental, and safety impacts using microscopic traffic simulation
- Conduct a benefit-cost analysis to compare all alternatives in an objective manner

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INTEGRATION Model

Overview

- The INTEGRATION model was selected for the study because of some unique capabilities of the model:
  - Explicit modeling of vehicle dynamics and the impact of gear shifting on the performance of vehicles
  - Most aspects of the model have been validated against traffic flow theory and field data and documented in the literature:
    - Longitudinal vehicle motion, lateral vehicle motion, queue formation, energy and emission modeling.
  - Advanced microscopic energy and emission models
  - Mesoscopic crash prediction models

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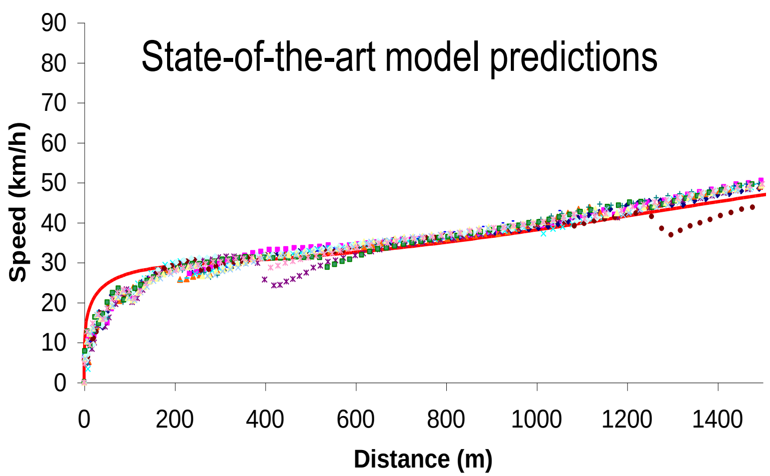
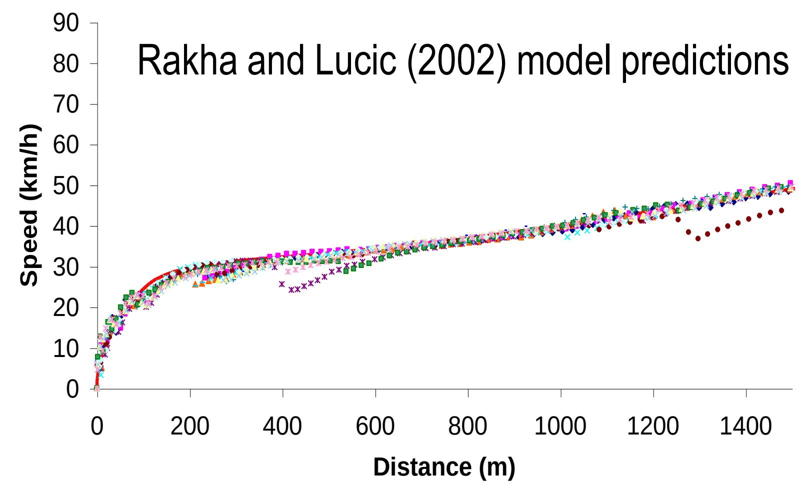
INTEGRATION Model

Vehicle Dynamics Modeling

- Model considers:
  - Vehicle tractive force, aerodynamic, rolling, and grade resistance forces in computing the maximum vehicle acceleration levels.
- Model accounts for losses in power during gear shifts
- Model validated for 40 weight-to-power combinations:
  - Four trucks: 350, 430, 470, and 500 hp
  - Ten weight configurations





INTEGRATION Model

Energy Consumption and Emission Estimation

- The model uses the VT-Micro model to compute instantaneous vehicle fuel consumption and emission levels
  - Computations conducted every second
  - Based on instantaneous speed and acceleration levels
  - Accounts for the impact of grades on engine loads
- Model developed for:
  - Light duty vehicles
  - Light duty trucks
  - Buses
  - Heavy duty trucks
- Model validated against field measurements along the Smart Road test facility
  - Both instantaneous and trip measurements

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INTEGRATION Model

Crash Risk Prediction

- The model uses a time-dependent crash rate that is consistent with General Estimates System (GES) crash rates and is multiplied by the temporal exposure to compute a crash risk
- Proposed model computes a facility-specific and time-dependent crash risk
  - Crash rate increases as vehicles spend more time on a network
- Crash risk computed for:
  - 14 crash types
  - 5 injury levels
    - No injuries, possible injuries, non-incapacitating injuries, incapacitating injuries, and fatal injuries
  - 4 vehicle damage levels
    - No damages, minor damages, moderate damages, and severe damages
- Crash rate in ballpark of field data and consistent in trend with limited field study

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INTEGRATION Model

Crash Risk Prediction

- Model applied to GPS second-by-second floating car data along an arterial corridor
  - 140 runs before and 160 after signal timings
    - Reduction in crash risk ranged from 2 to 20 percent with an 8% average
- Independent study by SAIC using local crash databases:
  - Analyzed 158 traffic signals in the Phoenix Area (121 coordinated and 37 uncoordinated)
  - 5 years of crash data (total of 345,000 crashes)
  - Crash rates for coordinated traffic signals were less than those for uncoordinated traffic signals in the range of 14 to 43 percent
- Conclusion:
  - Safety model produced results that were reasonable in trend and consistent with other independent studies

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Traffic Demand Calibration

Overview

- The traffic O-D demand was estimated synthetically using the QueensOD software:
  - Maximum likelihood approach to estimating the O-D table

$$\text{Max.} \quad T\ln\left(\frac{T}{t}\right)-\sum_{ij}T_{ij}\ln\left(\frac{T_{ij}}{t_{ij}}\right)-\sum_{ij}\left(\lambda_{ij}\cdot 2\left(\sum_{a}\left(V_a\cdot p_{ij}^{a}\right)-\left(\sum_{a}p_{ij}^{a}\left(\sum_{xy}T_{xy}p_{xy}^{a}\right)\right)\right)\right)$$

Where:

T_{ij}	= Estimated number of trips between zones *i* and *j* for the analysis period for all trip purposes
t_{ij}	= Seed trips between zones *i* and *j*
T	= Total number of trips ($\Sigma\Sigma T_{ij} = T$)
t	= Total number of trips based on seed O-D matrix ($\Sigma\Sigma t_{ij} = t$)
p^{a}_{ij}	= Probability O-D pair *ij* utilizes link *a*
λ_{ij}	= Lagrange multiplier for O-D pair *ij*
V_a	= Actual observed link volume on link "*a*"

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Traffic Demand Calibration

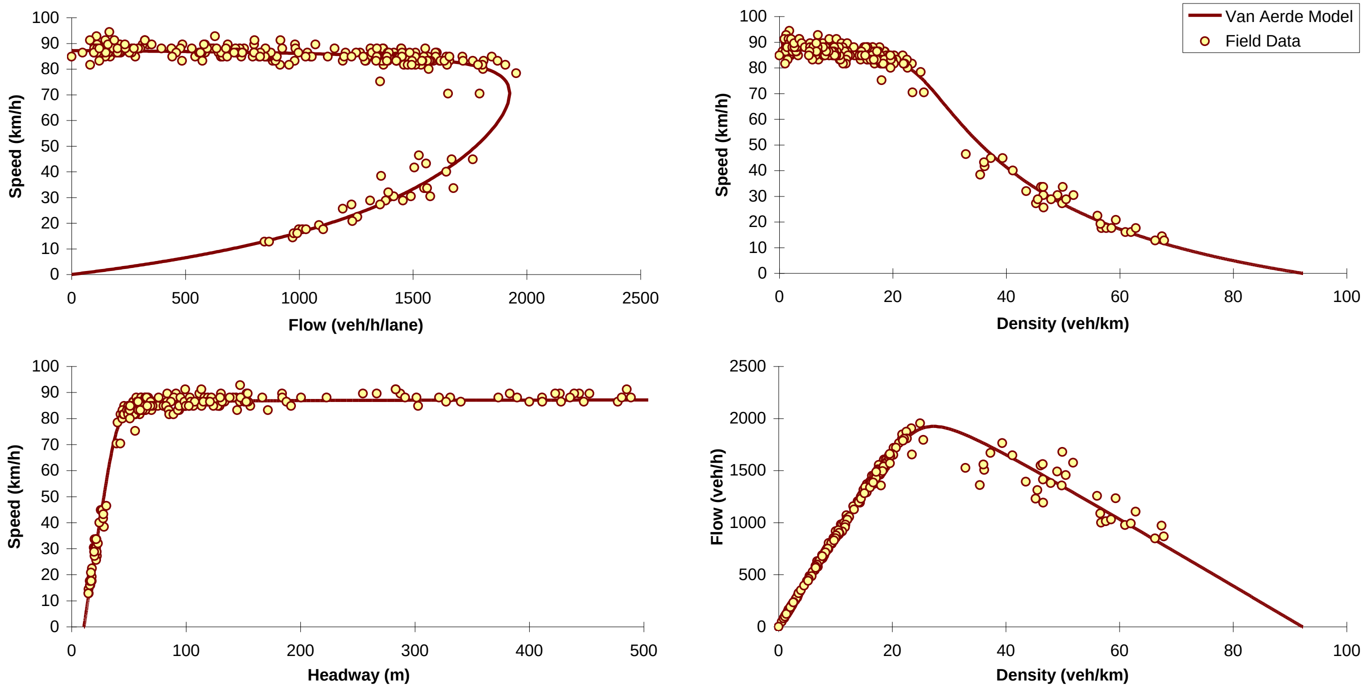
Estimation of Link Flows

- The 2004 existing peak hour traffic volumes and the 2035 design hour traffic volumes were provided in the I-81 Corridor Improvement Study Technical Report
- Using the two sets of volume counts link specific growth rates were computed
  - Varied between 0.0% and 3.6% in the case of light duty vehicles and 2.3% and 3.0% in the case of the heavy duty trucks
- Traffic volumes for 2010, 2015, 2020, 2025, and 2030 were computed
- Estimated O-Ds consistent with field data
  - R^2 ranged from 0.9854 to 0.9857 for cars and 0.9825 to 0.9830 for trucks, respectively

Traffic Supply Calibration

Estimation of Link Parameters

- Calibration of steady-state traffic stream behavior involves estimating:
  - Lane capacity (HCM), free-flow speed (field observation), speed-at-capacity (typical freeways), and jam density (typical freeways)



Vehicle Parameter Calibration

- Trucks were modelled based on an earlier research effort that characterized the trucks along the study section of I-81
  - Two types of trucks were modeled, namely a truck with a 20,411 kg mass and engine power of 336 kW (67%) and another with a mass of 31,751 kg and an engine power of 261 kW (33%)
- Light duty vehicles were modeled as light-duty vehicle 3 (LDV3)
  - Model year 1995 or later, an engine size less than 3.2 L, and an average mileage of less than 83,653 km.

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Traffic Simulation Analysis

Scenarios

- All four scenarios were modeled at 7 5-year increments from 2004 to 2035
  - 20 repetitions with a different random number seed
    - In total 560 simulation runs were executed (7x4x20)
- The number of lanes at network entrance (milepost 133.6 to 128.1) was increased from two to four lanes
  - To ensure that the total demand could be loaded onto the study section

Traffic Simulation Analysis

Travel Times

MOE	Year	All				Cars				Trucks			
		Sc. 1	Sc. 2	Sc. 3	Sc. 4	Sc. 1	Sc. 2	Sc. 3	Sc. 4	Sc. 1	Sc. 2	Sc. 3	Sc. 4
Avg. Travel Time (min)	2004	11.53	11.35 -1.6%	11.26 -2.3%	11.18 -3.0%	10.69	10.53 -1.5%	10.43 -2.4%	10.38 -2.9%	17.83	17.51 -1.8%	17.53 -1.7%	17.27 -3.1%
	2010	11.80	11.57 -1.9%	11.48 -2.7%	11.38 -3.5%	10.90	10.70 -1.8%	10.58 -2.9%	10.51 -3.6%	18.20	17.79 -2.2%	17.91 -1.6%	17.57 -3.5%
	2015	12.06	11.80 -2.2%	11.69 -3.1%	11.57 -4.0%	11.11	10.88 -2.1%	10.73 -3.4%	10.65 -4.1%	18.49	18.00 -2.6%	18.16 -1.8%	17.79 -3.8%
	2020	12.48	12.18 -2.4%	12.01 -3.8%	11.87 -4.9%	11.43	11.17 -2.2%	10.95 -4.2%	10.86 -5.0%	19.21	18.61 -3.1%	18.75 -2.4%	18.39 -4.3%
	2025	13.20	12.80 -3.0%	12.51 -5.2%	12.32 -6.6%	11.97	11.65 -2.7%	11.30 -5.6%	11.16 -6.7%	20.66	19.77 -4.3%	19.91 -3.6%	19.37 -6.2%
	2030	14.31	13.78 -3.7%	13.37 -6.5%	13.18 -7.9%	12.77	12.36 -3.2%	11.88 -7.0%	11.75 -8.0%	23.12	21.92 -5.2%	21.93 -5.1%	21.36 -7.6%
	2035	16.39	15.52 -5.3%	15.09 -7.9%	14.87 -9.3%	14.48	13.88 -4.1%	13.32 -8.0%	13.21 -8.7%	26.84	24.51 -8.7%	24.71 -7.9%	23.89 -11%
Travel Speed (mph)	2004	61.38	62.35 1.6%	62.81 2.3%	63.25 3.0%	64.67	65.66 1.5%	66.27 2.5%	66.62 3.0%	46.43	47.29 1.8%	47.24 1.7%	47.93 3.2%
	2010	60.21	61.38 1.9%	61.86 2.7%	62.41 3.7%	63.65	64.84 1.9%	65.57 3.0%	65.99 3.7%	45.53	46.58 2.3%	46.28 1.6%	47.17 3.6%
	2015	59.11	60.42 2.2%	60.97 3.1%	61.59 4.2%	62.65	63.97 2.1%	64.83 3.5%	65.33 4.3%	44.74	45.96 2.7%	45.57 1.8%	46.50 3.9%
	2020	57.31	58.74 2.5%	59.57 3.9%	60.23 5.1%	61.05	62.45 2.3%	63.70 4.3%	64.26 5.3%	43.08	44.48 3.3%	44.13 2.4%	45.01 4.5%
	2025	54.37	56.07 3.1%	57.33 5.5%	58.23 7.1%	58.45	60.07 2.8%	61.94 6.0%	62.68 7.2%	40.00	41.80 4.5%	41.50 3.8%	42.66 6.6%
	2030	50.31	52.25 3.8%	53.83 7.0%	54.63 8.6%	54.91	56.75 3.4%	59.03 7.5%	59.69 8.7%	35.72	37.67 5.5%	37.66 5.4%	38.66 8.2%
	2035	44.05	46.51 5.6%	47.87 8.7%	48.58 10.3%	48.56	50.67 4.3%	52.79 8.7%	53.23 9.6%	30.76	33.69 9.5%	33.42 8.6%	34.57 12.4%

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Traffic Simulation Analysis

Energy and Emissions

- In the case of HC and CO emissions
  - Scenario 4 produces the largest decrease in emissions for all vehicles, cars, and trucks
  - Scenario 3 outperforms Scenario 2 when all vehicles are considered and for light duty vehicles
    - However, in the case of trucks Scenario 2 outperforms Scenario 3
- System-wide NO_x emissions are minimized in Scenarios 2 and 4

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Traffic Simulation Analysis

Expected Crashes

- The study demonstrates significant reductions as a result of the various scenarios.
- The safety benefits increase as time progresses from the 2004 base year to the 2035 horizon year
  - Reductions in the total number of crashes range from 1.5% to 2.2% to 2.9% for Scenarios 2, 3, and 4 for the 2004 base year, respectively
  - These benefits increase to 4.8%, 7.6%, and 8.9% for Scenarios 2, 3, and 4, respectively for the 2035 horizon year

Traffic Simulation Analysis

Section Specific Results

- Significant improvements along section 1
  - Ranging from 23% to 29% reduction in travel time
- Increases in overall vehicle speeds in the range of 12.8% to 18.3% as a result of the various enhancements along section 2
  - Light duty vehicles benefit most from these enhancements with increases in travel speeds ranging from 13.2% to 19.6%
- Section 3 has a reduction in the overall vehicle speeds with an increase in the number of lanes along the study section

Benefit-Cost Analysis

Overview

- The benefit-cost analysis was conducted using the Highway Project Benefit-Cost Analysis System (BCA.Net) developed by FHWA
- Model input include:
  - AADT for the base year (2005), the final near-term year (2010), and the project horizon year (2035)
  - Percentage trucks for each of the three years
  - Capacity, number of lanes, length, free-flow speed, average grade, operating and maintenance costs, initial Pavement Service Index (PSI)
  - Distribution of traffic demand for each of the three study sections for each of the three years including the percent of AADT in a typical peak and shoulder hour and the directional distribution of traffic demand
  - Various social costs including the discount rate, the depreciation rate, the value of time for auto and truck drivers, the monetary value of fatal, injury, and property damage crashes, the base price of gasoline and diesel fuel, oil and emission costs

Benefit-Cost Analysis

Model Input

- Crash rates were derived from the INTEGRATION output
- Construction costs were derived from cost proposals submitted by contractors bidding on the project

MOE	Year	Section 1				Section 2				Section 3			
		Sc. 1	Sc. 2	Sc. 3	Sc. 4	Sc. 1	Sc. 2	Sc. 3	Sc. 4	Sc. 1	Sc. 2	Sc. 3	Sc. 4
Crash Rate Per Million VMT	2004	1.25	1.23	1.21	1.20	1.22	1.14	1.15	1.12	1.27	1.28	1.25	1.25
	2010	1.28	1.25	1.23	1.21	1.25	1.15	1.16	1.13	1.30	1.31	1.28	1.27
	2015	1.30	1.27	1.24	1.23	1.27	1.17	1.18	1.13	1.32	1.34	1.30	1.29
	2020	1.34	1.29	1.26	1.24	1.31	1.18	1.19	1.15	1.35	1.38	1.33	1.32
	2025	1.41	1.32	1.28	1.26	1.34	1.19	1.21	1.16	1.38	1.42	1.37	1.34
	2030	1.54	1.36	1.31	1.28	1.36	1.21	1.23	1.17	1.40	1.48	1.43	1.39
	2035	1.80	1.39	1.37	1.30	1.38	1.23	1.24	1.18	1.43	1.57	1.51	1.42

Benefit-Cost Analysis

Model Input

Input Parameter	Base Year (2005)			Final Near-Term Year (2010)			Project Horizon year (2035)			Source
	Sect. 1	Sect. 2	Sect. 3	Sect. 1	Sect. 2	Sect. 3	Sect. 1	Sect. 2	Sect. 3	
AADT	35,380			40,084			67,425			Field data
Peak Period Duration (h)	8			8			8			Field data
Shoulder Period Duration (h)	10			10			10			Field data
Percent Truck	41.4	14.2	41.4	41.4	14.6	41.4	41.4	16.6	41.4	Field data

Input Parameter	Section 1	Section 2	Section 3	Source
<u>Base Year (2005)</u> Number of lanes	3	2	3	Field Observation
Free Flow Speed (mph)	70	70	70	Field Observation
Maximum Flow Rate (veh/hr/lane)	2400	2400	2400	[37]
Length (miles)	3.47	4.01	1.6	VDOT Design Plan
Average Percent Grade	0.02	0.01	0.04	VDOT Design Drawings
Operating and Maintenance Cost (thous. $/facility-mile)	4.5	3.0	4.5	[42]
Pavement Service Index (PSI)	4.5	4.5	4.5	[41]
Pavement Deterioration (Annual change in PSI)	0.1	0.1	0.1	[41]
<u>Costs of Improvement / Maintenance</u> Construction Cost (thous. $/lane-mile)	11,988.5	10,213.9	10,213.9	VDOT
Rehabilitation Cost ($/lane-mile)	362,043			[42]
Operating and Maintenance Cost ($/lane-mile)	1,515			[42]

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Summary Results

- Scenario 2 offers the best B/C ratio

Variable	Scenario 2	Scenario 3	Scenario 4
Travel time savings, thous. present value (PV) $	191968.1	192395.3	192538.1
Vehicle operating cost savings, thous. PV$	-5539.0	-6579.4	-6833.8
Safety benefits, thous. PV$	164.9	1403.0	1403.1
Environmental benefits, thous. PV$	-35.2	-36.6	-36.8
Project residual value, thous. PV$	2094.1	4962.2	7204.4
Disbenefit of traffic disruption from construction, thous. PV$	0.0	0.0	0.0
Total benefits, thous. PV$	188652.9	192144.6	194275.0
Of this, benefits to new users, thous. PV$	9565.4	9565.4	9554.5
Total costs, thous. PV$	35237.6	83718.2	121595.5
Net benefits, thous. PV$	153415.3	108426.4	72679.6
Benefit-cost ratio	5.35	2.30	1.60
Rate of return, percent	16.33	9.86	7.61