Simulation Modeling Training

Webinar 4: How to Interpret and Apply Simulation Model Results

presented to

Caltrans

presented by

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CAMBRIDGE SYSTEMATICS

Think Forward

January 28, 2019

Webinar Four-part Series

- **Webinar 1** - Transportation Analysis and Simulation Overview
- **Webinar 2** – Scoping a Simulation Project
- **Webinar 3** - How to Develop, Calibrate & Review Models
- **TODAY - Webinar 4 - How to Interpret and Communicate Model Results and How to Produce Output for Design Support and Transportation Studies from Simulation Models**

Today: Webinar 4 Overview

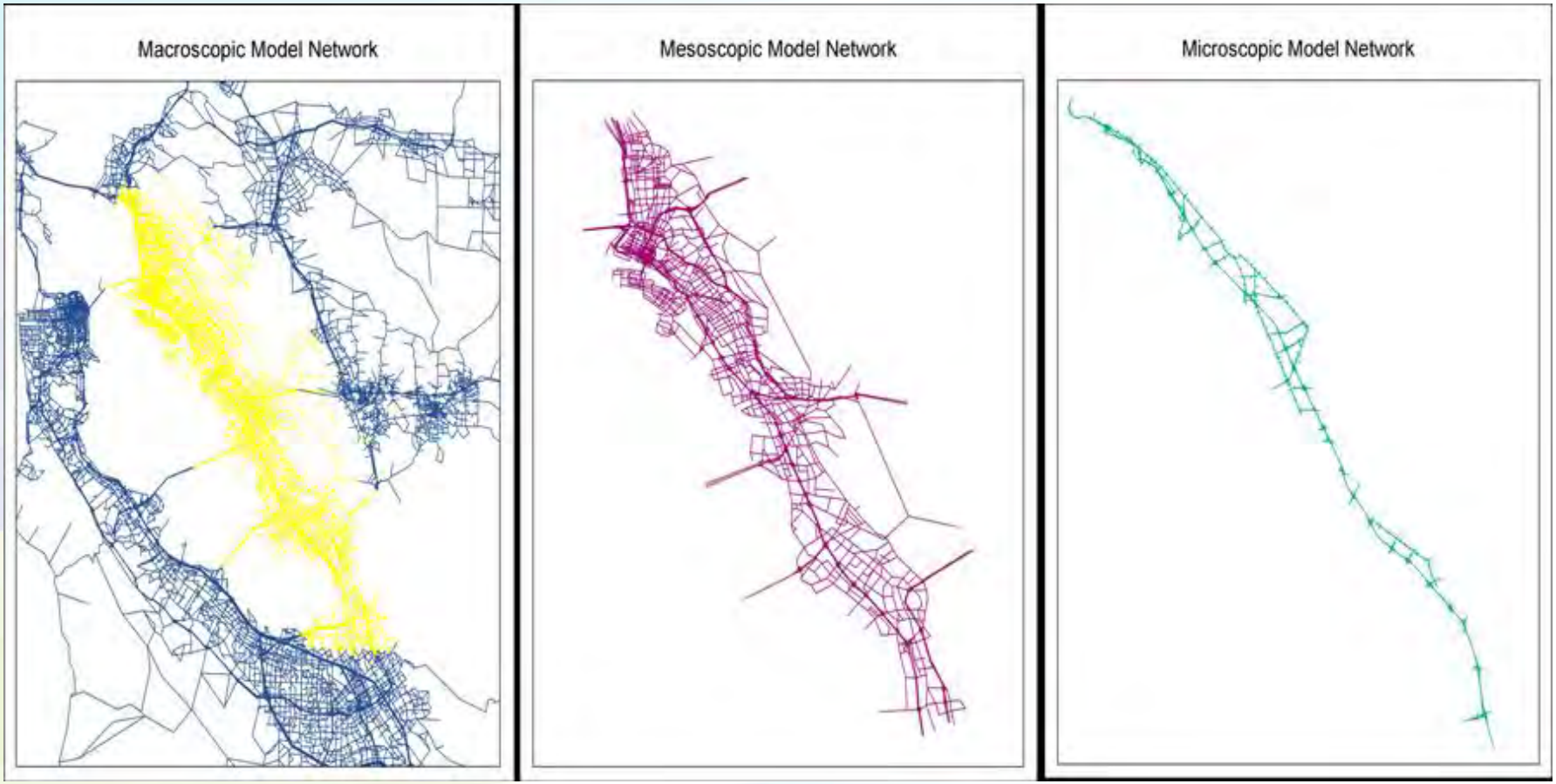
- **Overview of Simulation Model Output;**
- **Examples of Typical RAW and REFINED model output;**
- **Case Studies: Modeling Output Examples**
  - Highway Capacity Improvement
  - Bus Rapid Transit (BRT)
  - Managed Lanes
  - Road Diet/One-way Streets
  - Active Transportation and Demand Management
- **Output for Draft and Final Reports**

Travel Demand vs. Simulation Model Applications

Model Type	Benefits	Challenges
Travel Demand Model	Best at estimating regional-level impacts of long-term travel demand changes resulting from capacity changes and mode shift	Cannot analyze system optimization strategies; not good for estimating route shifts due to incompatibility with dynamic nature of travel choices. **Output is link level and not detailed**
Mesoscopic Simulation	Best at evaluating dynamic traveler diversions in large-scale networks	Less effective and reliable in analyzing system optimization strategies at specific intersections or corridors than microscopic models
Microscopic Simulation	Best at analyzing traffic control strategies at smaller scales; allows the use of static and dynamic assignment methods. **Produces detailed & more accurate output**	Not compatible for larger network analyses

Analysis Resolutions and Output

- **Output differs by model type and study area**



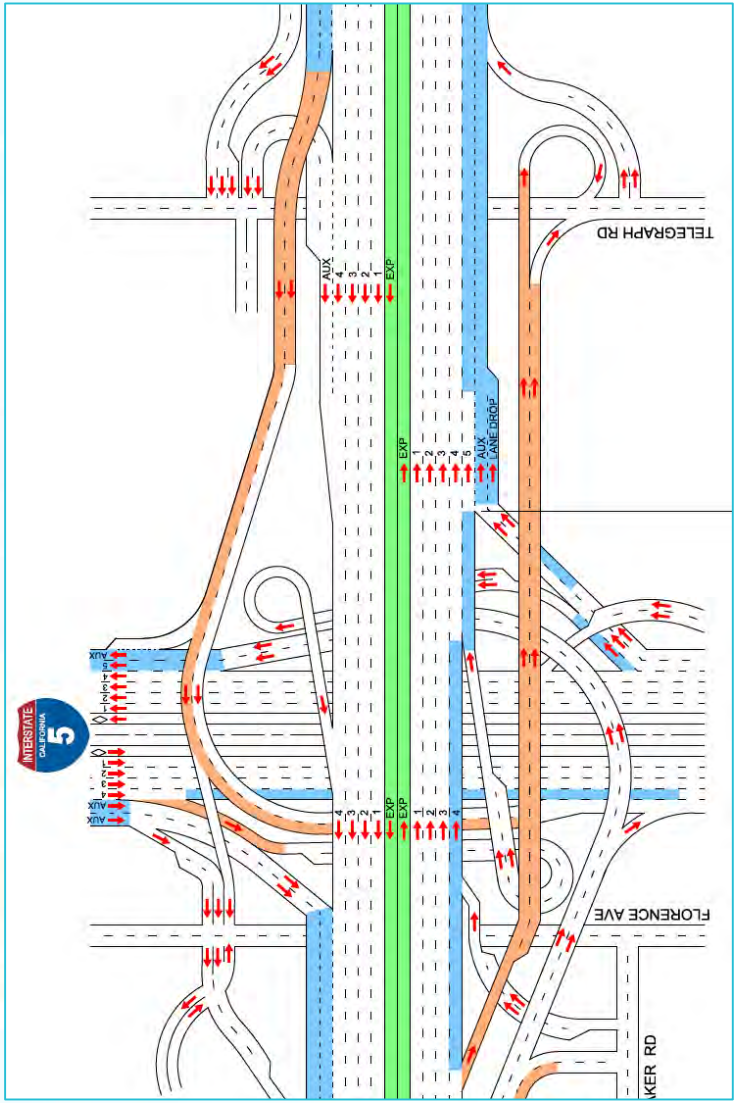
Travel Demand vs. Simulation Output

Model Output	Travel Demand Model		Microsimulation	
	Peak Period	Daily	Peak Period	Daily
Volume Forecasts	✓	✓	Flow	Flow
Speeds	Estimate	Estimate	Accurate	Accurate
Trip Length	✓	✓	✓	✓
Travel Time	Estimate	Estimate	Accurate	Accurate
VMT	✓	✓	✓	✓
VHT	Estimate	Estimate	Accurate	Accurate
Delay	Estimate	Estimate	Link level + Intersection	Link level + Intersection
Stops/Stopped Time	No	No	✓	✓
LOS	Link level	Link level	Detailed	Detailed
Queuing	Estimate	Estimate	Accurate	Accurate
Bottleneck	Estimate	Estimate	Accurate	Accurate

Note: Need to run simulation for 24 hours for daily results

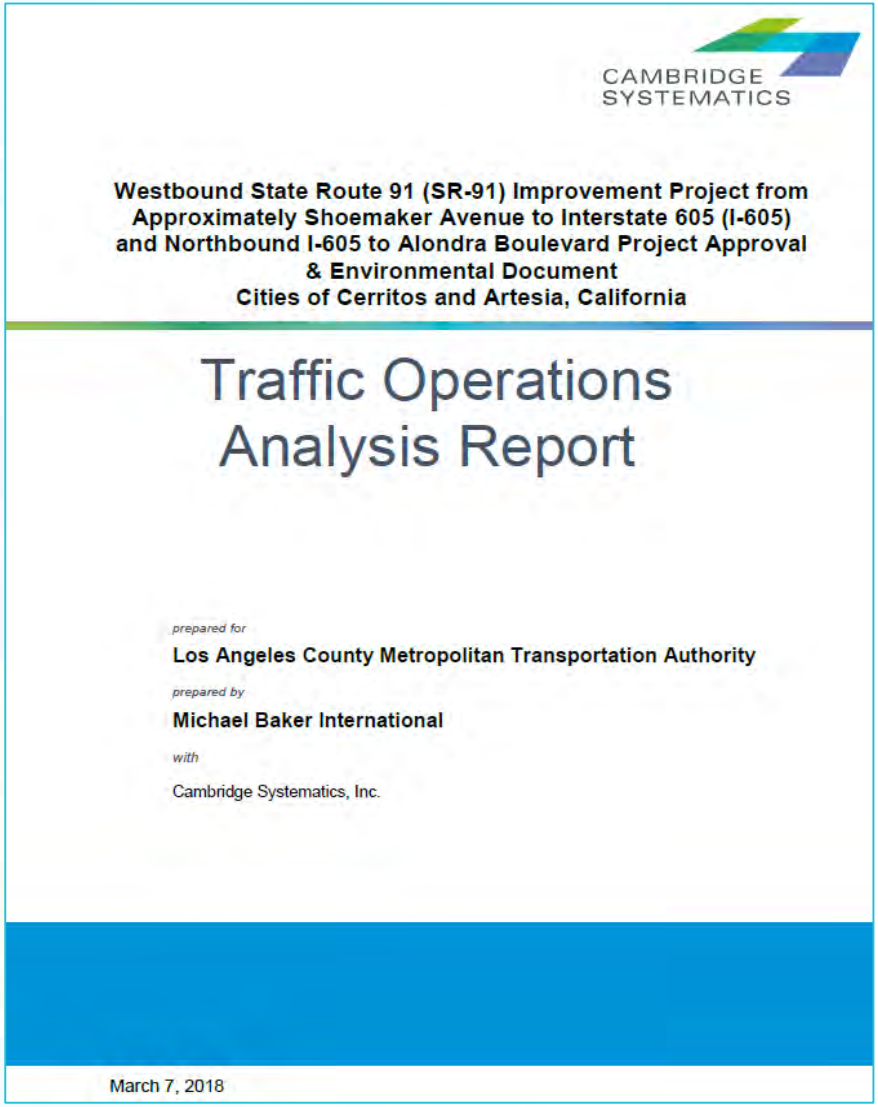
Microsimulation Modeling Supports:

- **Design Refinement**
  - Density (LOS)
  - Delay (LOS)
  - Queue Length
  - Volume throughput
- **Alternative Analysis**
  - VMT
  - VHD
  - Travel Time
  - Volume/Person throughput



Microsimulation Modeling Supports:

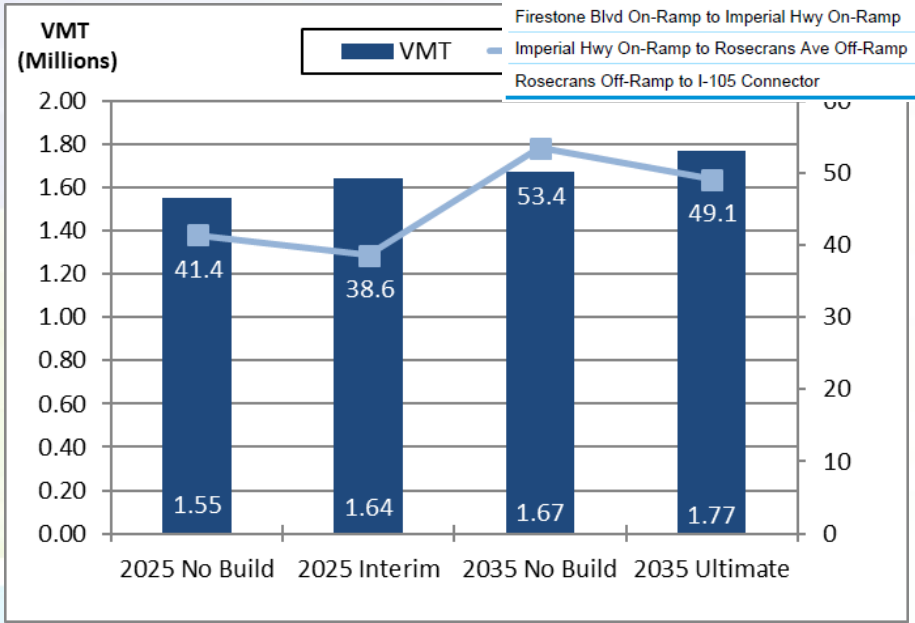
- **Environmental Studies**
  - Air Quality
    - Volumes
    - VMT
    - Speeds
  - Noise
    - Volumes
    - Truck Percentages
- **Traffic Studies**
    - LOS
    - Delay
    - queues



Common Microsimulation Output

- Speeds
- Travel Times
- VMT
- VHT

Freeway Segment	6:00-7:00	7:00-8:00	8:00-9:00	9:00-10:00
I-605 Southbound General Purpose Lanes				
North of Washington Blvd Off-Ramp	14.4	15.1	14.0	15.4
Washington Blvd Off-Ramp to Slauson Ave Off-Ramp	14.1	28.4	30.3	31.4
Slauson Ave Off-Ramp to Washington Blvd/Slauson Ave On-Ramp	10.5	12.3	11.2	13.8
Washington Blvd/Slauson Ave On-Ramp to I-5 Connector	16.8	16.5	14.5	18.6
Telegraph Rd Off-Ramp to I-5 Connector	18.9	17.2	16.4	19.4
I-5 Connector to Telegraph Rd On-Ramp	17.8	15.6	15.8	18.0
Telegraph Rd On-Ramp to I-5 NB Connector	16.1	14.2	13.2	12.9
I-5 NB Connector to I-5 SB Connector	38.8	29.3	27.4	24.2
I-5 SB Connector to Florence Rd On-Ramp	40.9	32.9	31.4	28.0
Florence Rd On-Ramp to Firestone Blvd Off-Ramp	42.9	39.2	40.1	36.2
Firestone Blvd Off-Ramp to I-105/Imperial Hwy Off-Ramp	57.8	57.3	58.0	57.1
I-105/Imperial Hwy Off-Ramp to Firestone Blvd On-Ramp	65.3	65.4	65.5	65.5
Firestone Blvd On-Ramp to Imperial Hwy On-Ramp	63.1	61.9	62.3	63.8
Imperial Hwy On-Ramp to Rosecrans Ave Off-Ramp	63.9	63.4	62.4	64.6
Rosecrans Off-Ramp to I-105 Connector	63.4	61.9	61.8	63.8



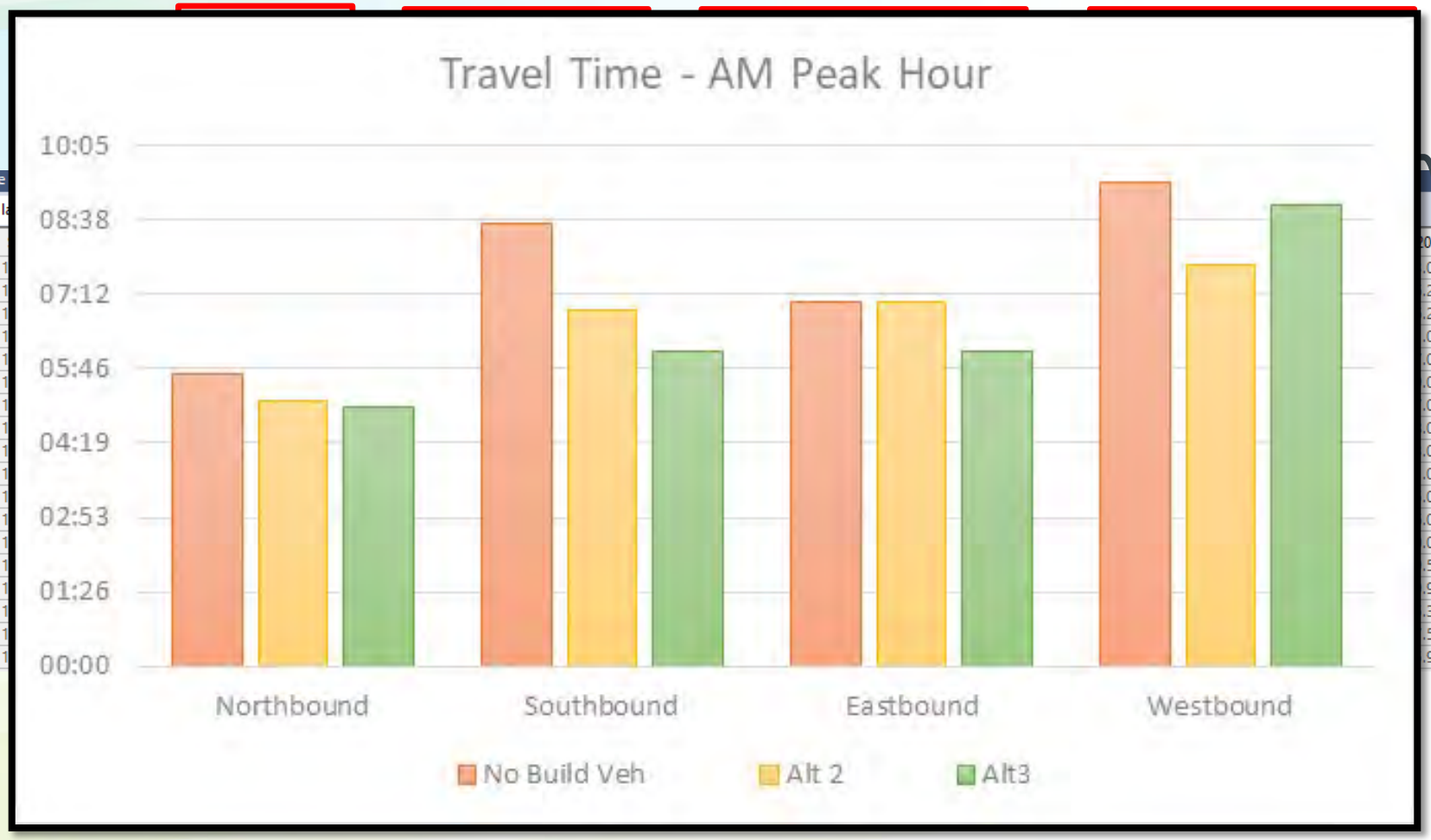
Common Microsimulation Output

- Delay
- Density
- LOS
- Queues
- Videos

Freeway Segment	6:00-7:00	7:00-8:00	8:00-9:00	9:00-10:00
I-605 Southbound General Purpose Lanes				
North of Washington Blvd Off-Ramp	F	F	F	F
Washington Blvd Off-Ramp to Slauson Ave Off-Ramp	F	F	F	F
Slauson Ave Off-Ramp to Washington Blvd/Slauson Ave On-Ramp	F	F	F	F
Washington Blvd/Slauson Ave On-Ramp to I-5 Connector	F	F	F	F
Telegraph Rd Off-Ramp to I-5 Connector	F	F	F	F
I-5 Connector to Telegraph Rd On-Ramp	F	F	F	F
Telegraph Rd On-Ramp to I-5 NB Connector	F	F	F	F
I-5 NB Connector to I-5 SB Connector	F	F	F	F
I-5 SB Connector to Florence Rd On-Ramp	E	F	F	F
Florence Rd On-Ramp to Firestone Blvd Off-Ramp	D	E	D	E
Firestone Blvd Off-Ramp to I-105/Imperial Hwy Off-Ramp	C	C	C	C
I-105/Imperial Hwy Off-Ramp to Firestone Blvd On-Ramp	C	C	C	C
Firestone Blvd On-Ramp to Imperial Hwy On-Ramp	C	D	C	C
Imperial Hwy On-Ramp to Rosecrans Ave Off-Ramp	C	C	C	C
Rosecrans Off-Ramp to I-105 Connector	C	D	D	C
I-105 Connector to Rosecrans Ave Loop On-Ramp	D	D	D	C

EXAMPLES OF "RAW" SIMULATION MODEL OUTPUT

“Raw” Simulation Outputs – Segment



"Raw" Simulation Output - Intersection

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	Sim Ru	Time	Movement	Qlen	Qlen M	Veh	Per	Veh De	Per Del	top De	Stops		Veh x Delay	Avg Delay	
422	Average	900-4500	7: Diamond Bar Blvd & SR-57 SB Ramps - 123@207.8 - 199@98.9	4.1	39.7	828	828	2.8	2.8	1.5	0.1		1744.9	2.8	
423	Average	900-4500	7: Diamond Bar Blvd & SR-57 SB Ramps - 132@163.3 - 123@21.1	201.7	750.4	5	5	68.8	68.8	38.7	0.9		344.0	68.8	
424	Average	900-4500	7: Diamond Bar Blvd & SR-57 SB Ramps - 132@163.3 - 199@98.9	210.2	764.4	56	56	19.5	19.5	2.4	1.2		1094.1	19.5	
425	Average	900-4500	7: Diamond Bar Blvd & SR-57 SB Ramps - 132@163.3 - 10137@84.2	201.7	750.4	451	451	77.9	77.9	54.9	1.2		35115.2	77.9	
426	Average	900-4500	7: Diamond Bar Blvd & SR-57 SB Ramps - 135@6.4 - 123@21.1	70.8	291.0	225	225	64.2	64.2	45.7	1.3		14448.7	64.2	
427	Average	900-4500	7: Diamond Bar Blvd & SR-57 SB Ramps - 534@1492.4 - 123@21.1	8.3	173.2	710	710	9.1	9.1	0.2	0.2		6439.2	9.1	
428	Average	900-4500	7: Diamond Bar Blvd & SR-57 SB Ramps - 534@1492.4 - 10135@71.7	18.0	149.4	395	395	15.1	15.1	10.3	0.4		5959.5	15.1	26.4
429	Average	900-4500	8: Diamond Bar Blvd & SR-57 NB Ramps - 5@2852.0 - 5@2884.7	0.0	0.0	830	830	4.4	4.4	1.4	0.1				
430	Average	900-4500	8: Diamond										216.5	108.3	
431	Average	900-4500	8: Diamond										22933.7	90.3	
432	Average	900-4500	8: Diamond										38225.2	108.6	
433	Average	900-4500	8: Diamond										890.1	55.6	
434	Average	900-4500	8: Diamond										7341.9	8.8	
435	Average	900-4500	8: Diamond										47.3	0.3	
436	Average	900-4500	8: Diamond										7112.7	14.3	
437	Average	900-4500	8: Diamond												
438	Average	900-4500	8: Diamond												
439	Average	900-4500	8: Diamond												36.6
440	Average	900-4500	9: Grand Av										6173.6	11.1	
441	Average	900-4500	9: Grand Av										0.0	0.0	
442	Average	900-4500	9: Grand Ave & SR-60 WB Ramps - 273@699.8 - 308@429.7	30.3	274.7	1147	1147	14.0	14.0	6.3	6.3		16046.3	14.0	
443	Average	900-4500	9: Grand Ave & SR-60 WB Ramps - 300@295.4 - 271@197.9	74.6	259.1	310	310	166.4	166.4	46.5	4.6		51574.4	166.4	
444	Average	900-4500	9: Grand Ave & SR-60 WB Ramps - 300@295.4 - 303@406.3	74.6	259.1	0	0						0.0	0.0	
445	Average	900-4500	9: Grand Ave & SR-60 WB Ramps - 300@295.4 - 308@429.7	74.6	259.1	601	601	165.1	165.1	45.1	4.6		99219.6	165.1	
446	Average	900-4500	9: Grand Ave & SR-60 WB Ramps - 302@177.8 - 271@197.9	6.6	63.6	18	18	67.4	67.4	61.2	1.0		1213.6	67.4	
447	Average	900-4500	9: Grand Ave & SR-60 WB Ramps - 302@177.8 - 298@22.2	6.6	63.6	0	0						0.0	0.0	
448	Average	900-4500	9: Grand Ave & SR-60 WB Ramps - 302@177.8 - 308@429.7	0.7	21.4	2	2	69.3	69.3	62.2	1.0		138.7	69.3	
449	Average	900-4500	9: Grand Ave & SR-60 WB Ramps - 552@4053.2 - 271@197.9	21.7	200.0	2544	2544	10.4	10.4	3.5	0.3		26508.4	10.4	
450	Average	900-4500	9: Grand Ave & SR-60 WB Ramps - 552@4053.2 - 298@22.2	0.0	0.0	0	0						0.0	0.0	
451	Average	900-4500	9: Grand Ave & SR-60 WB Ramps - 552@4053.2 - 303@406.3	21.7	200.0	2	2	5.3	5.3	2.3	0.3		10.7	5.3	38.8

Intersection	No Build	
	Delay	LOS
Diamond Bar Blvd & SR-57 SB Ramps	26.4	C
Diamond Bar Blvd & SR-57 NB Ramps	36.6	D
Grand Ave & SR-60 WB Ramps	38.8	D

EXAMPLES OF REFINED SIMULATION MODEL OUTPUT

Measures of Effectiveness (MOE)

- SR-91 Westbound Imp. Project PA/ED

Table 4-51 – Corridor Performance Measures – AM Period

Time Period	Performance Measure	2044 No-Build	2044 Build	Difference	2044 Diamond Ramps	Difference
AM Period (05:00 to 11:00)	Average Vehicle Delay (s)	131	37	-94 s	49	-82 s
	Total Travel Time (hr)	1,411	995	-30%	1,086	-23%
	Average Flow (veh/hr)	3,235	3,560	+10%	3,613	+12%
	Average Speed (mph)	37.0	53.4	+16.4 mph	51.1	+14.1 mph
AM Peak Period (07:00 to 08:00)	Average Vehicle Delay (s)	179	28	-151 s	33	-146 s
	Total Travel Time (hr)	274	162	-41%	168	-39%
	Average Flow (veh/hr)	3,198	3,695	+16%	3,698	+16%
	Average Speed (mph)	30.0	54.9	+24.9 mph	53.5	+23.5 mph

Source: Cambridge Systematics, Inc., 2017.

Measures of Effectiveness (MOE)

- I-605 CIP Project PA/ED

MOE	Existing	Future Alt 2	Future Alt 3
AM Peak Period			
Average Speed	25.9	36.0	40.1
Vehicle Hours of Delay (VHD)	18,100	12,900	9,300
Vehicle Miles of Travel (VMT)	846,140	973,140	1,053,450
PM Peak Period			
Average Speed	33.5	40.3	40.2
Vehicle Hours of Delay (VHD)	11,400	8,800	8,800
Vehicle Miles of Travel (VMT)	890,670	1,024,910	1,023,990

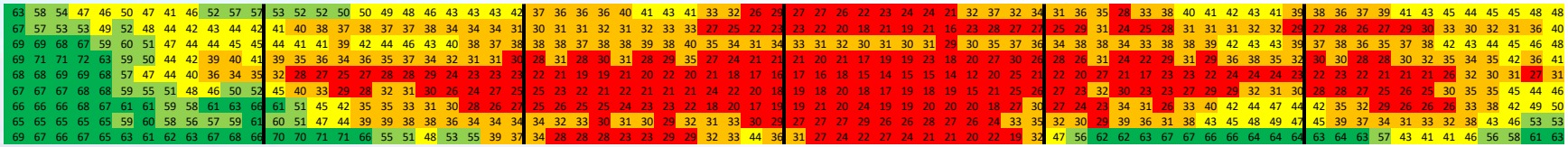
Source: Cambridge Systematics, Inc.

Model Calibration Output

- Model Calibrated to traffic counts (fall 2016) and PeMS speed data.

Connector Ramp to I- 605

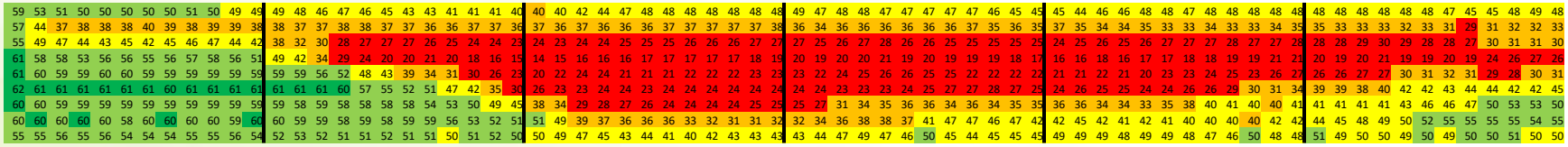
Actual Speeds



Carmenita 06:00 07:00 08:00 09:00 10:00

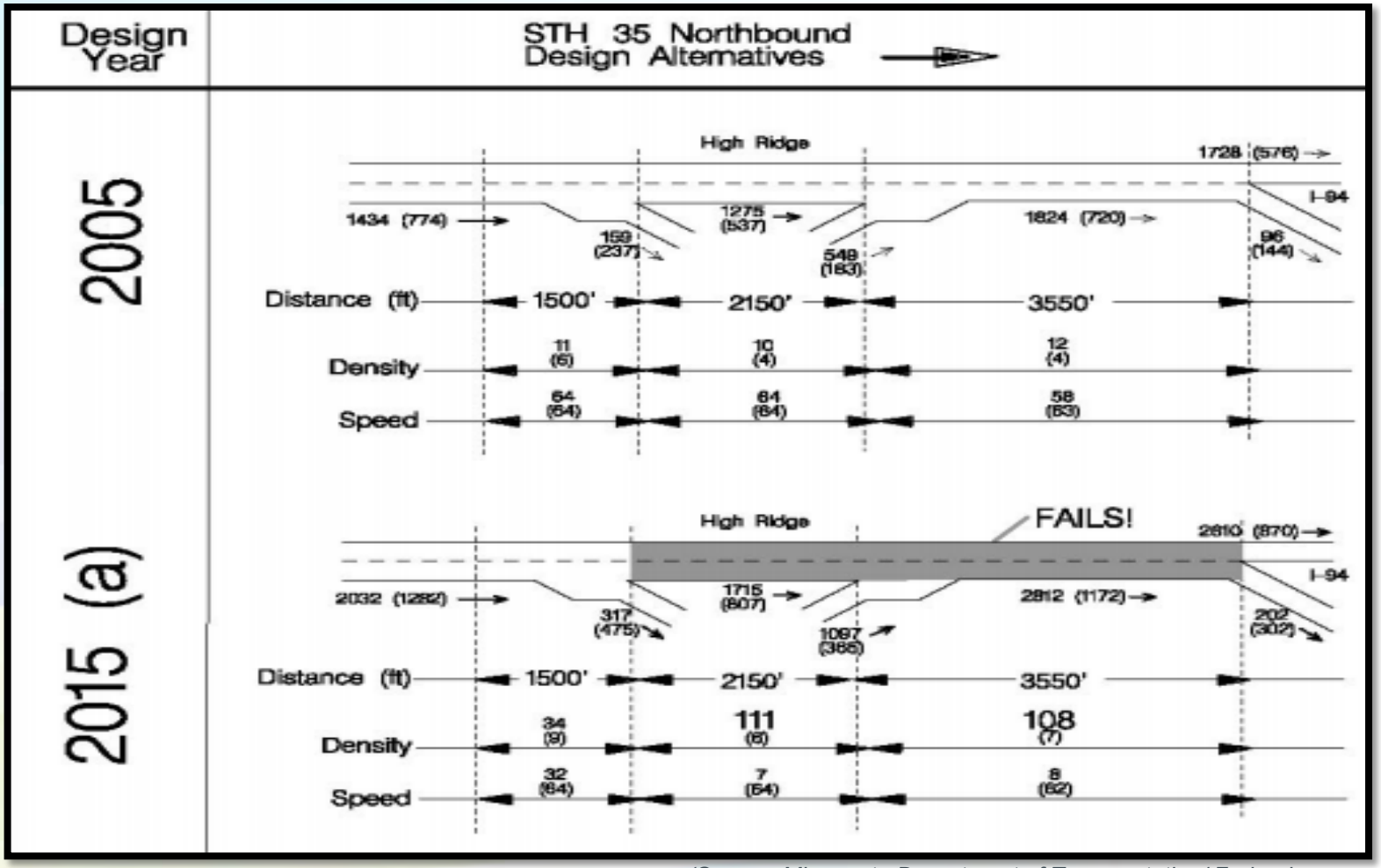
Connector Ramp to I- 605

Simulated Speeds



Carmenita 06:00 07:00 08:00 09:00 10:00

Output - Schematic Comparison



(Source: Minnesota Department of Transportation/ Federal Highway Administration Traffic Analysis Toolbox Volume IV.)

Environmental Study Output

			Control Type		Peak Hour Approach Volumes		LOS		Delay	
					AM	PM	AM	PM	AM	PM
Northbound Ramps	Existing		One-Way Stop Sign	North Leg	0	0	C	F	15.4	61.3
				South Leg	251	322				
				East Leg	293	1012				
				West Leg	973	505				
	Horizon Year (2040)	NB	One-Way Stop Sign	North Leg	0	0	C	F	18.2	200.5
				South Leg	260	344				
				East Leg	479	1375				
				West Leg	1019	536				
		Build	Roundabout	North Leg	0	0	A	A	4.0	4.8
				South Leg	260	344				
				East Leg	479	1375				
				West Leg	1019	536				

- **Delay, Level of Service, Speeds**

Visual Results to Support Design

Numbers don't tell the story so visualization is needed:

Without Mitigation

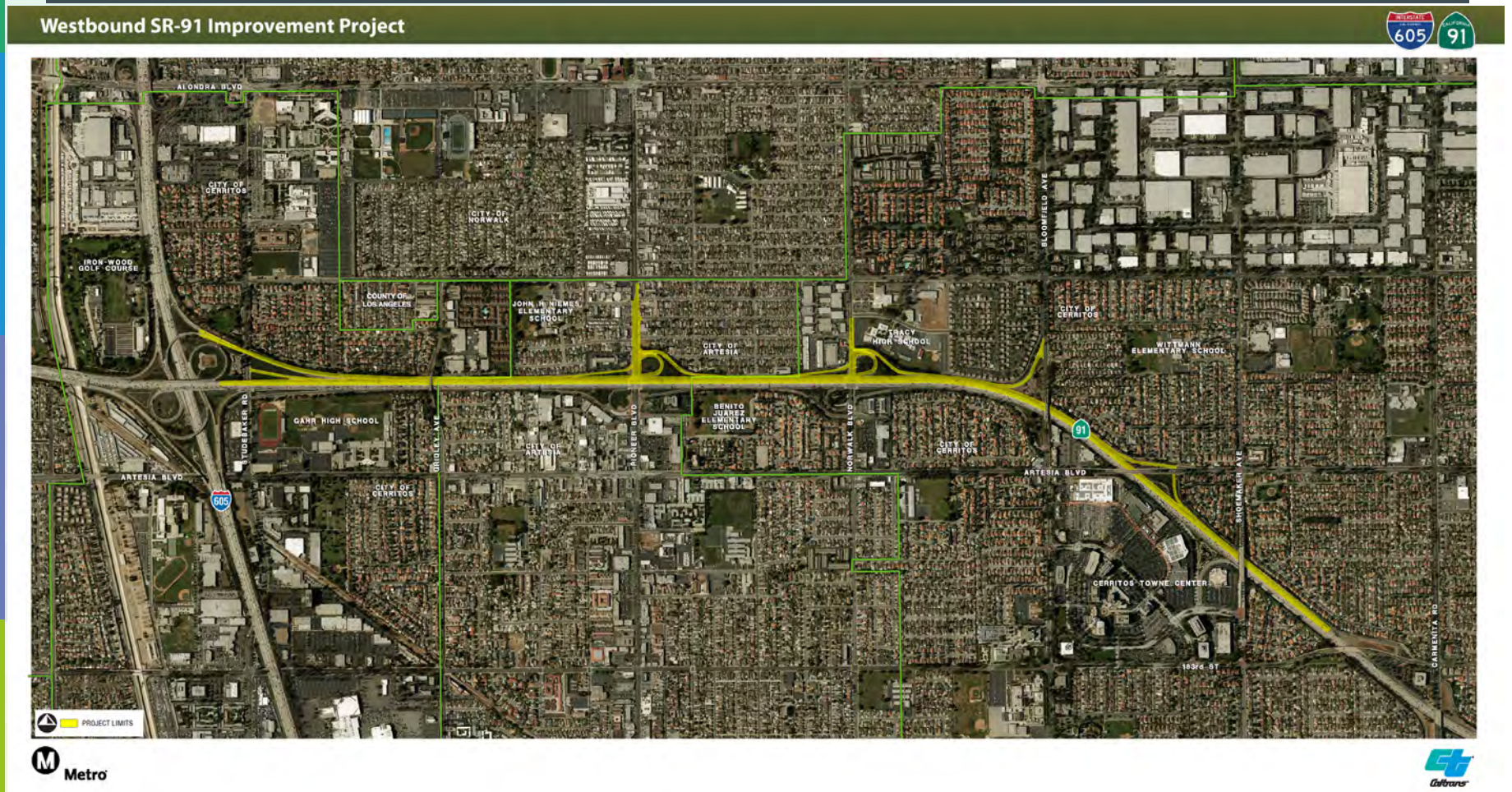
With Mitigation

Simulation Output: 5 Case Studies

1. Highway Capacity Improvement
2. Active Transportation and Demand Management
3. Bus Rapid Transit
4. Managed/HOT Lanes
5. Road Diet/One-way Streets

OUTPUT CASE STUDY 1: HIGHWAY CAPACITY IMPROVEMENT

SR-91 Westbound Improvement



- 3 mile westbound corridor

SR-91 Westbound Improvement

Project Objectives

- Mitigate freeway to freeway congestion
- Improve weaving/operations
- Reduce delay
- Improve LOS
- Mitigate high crash locations

Project Features

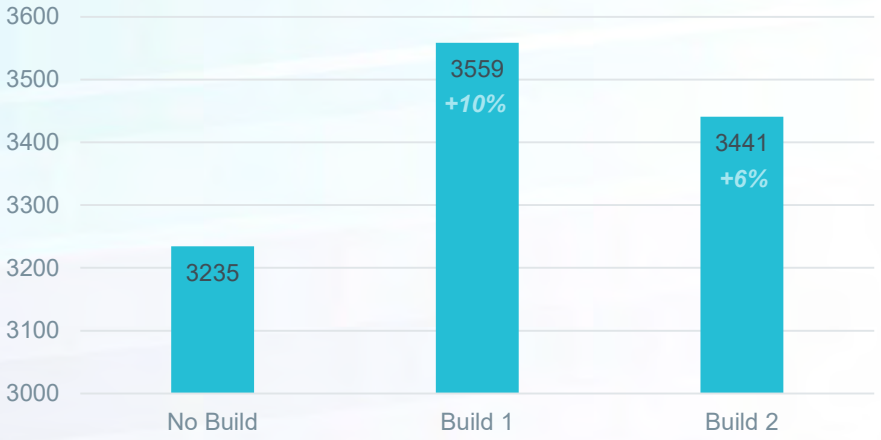
- Add one lane
- Reconfigure Interchanges
- Improve system connector ramp
- Improve alignments

Highway Capacity Simulation

- **Key Output:**
  - Total network delay
  - Delay by location/segment
  - Speeds
  - VMT/VHT
  - Intersection/Approach delay at ramps
  - Average queue length at ramps and mainline
  - Travel time – corridor and segment
  - Animations/visualizations

Output Comparisons – Flow vs. Speed

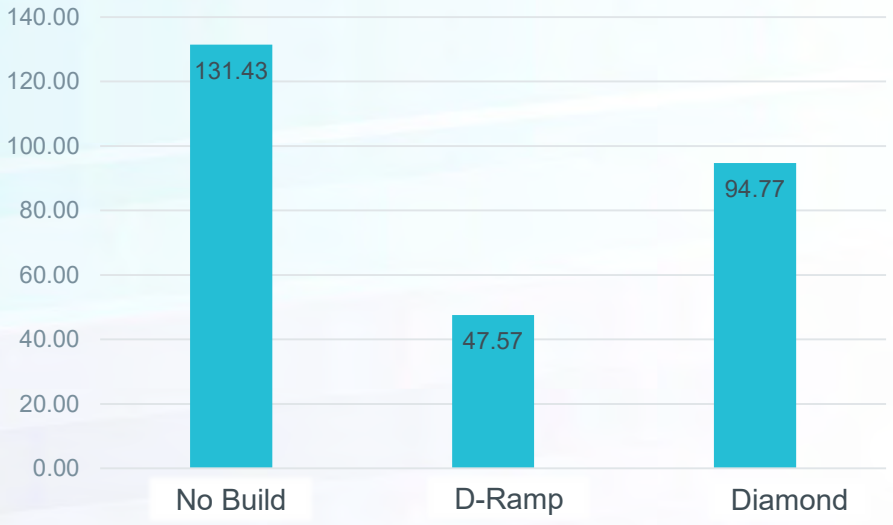
Average Flow (veh/hr)



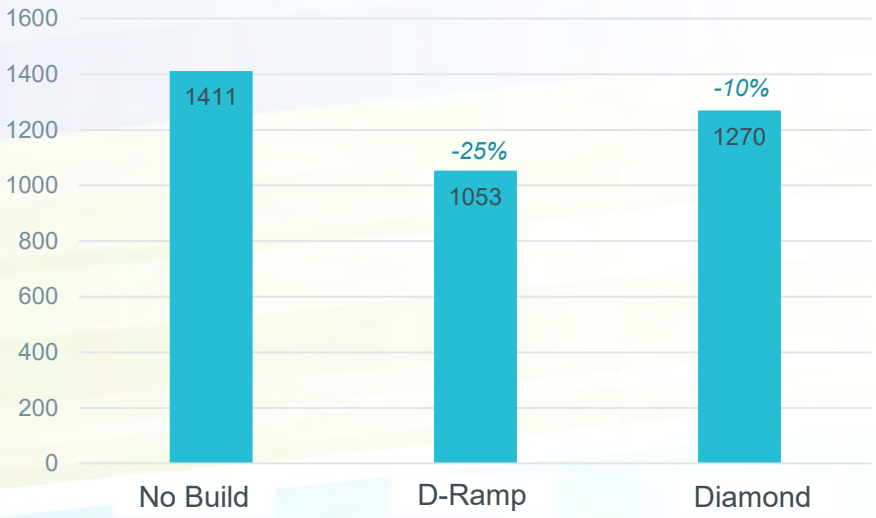
Average Speed (mph)

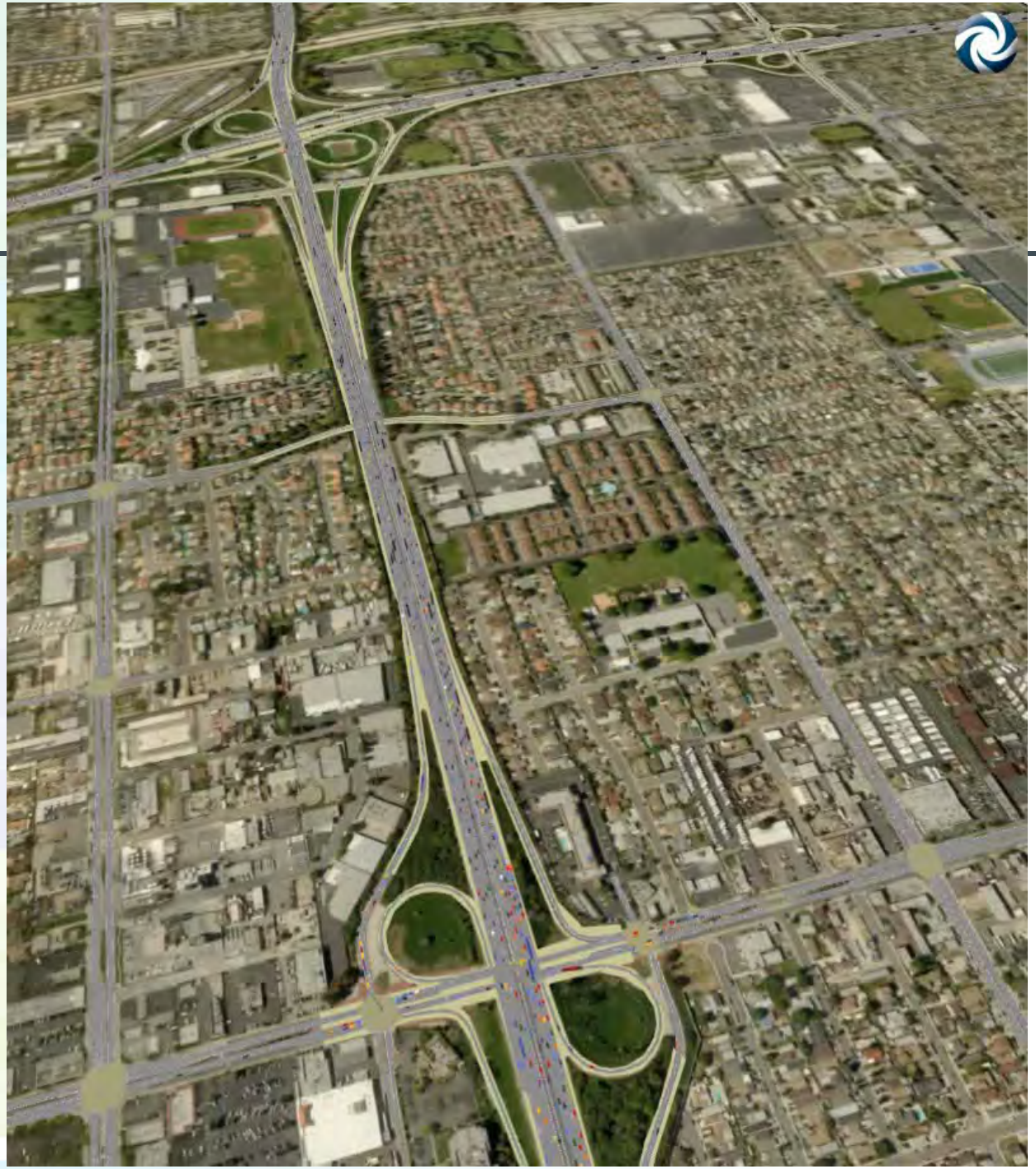
Output Comparisons – Delay & Travel Time

Average Vehicle Delay (sec)



Total Travel Time (hr)

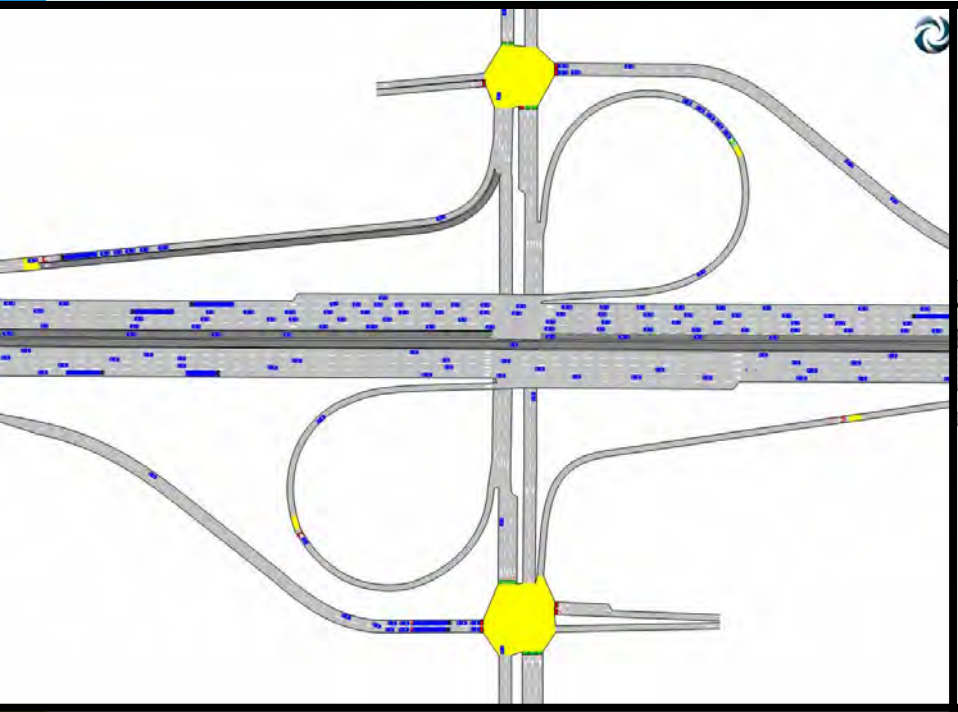


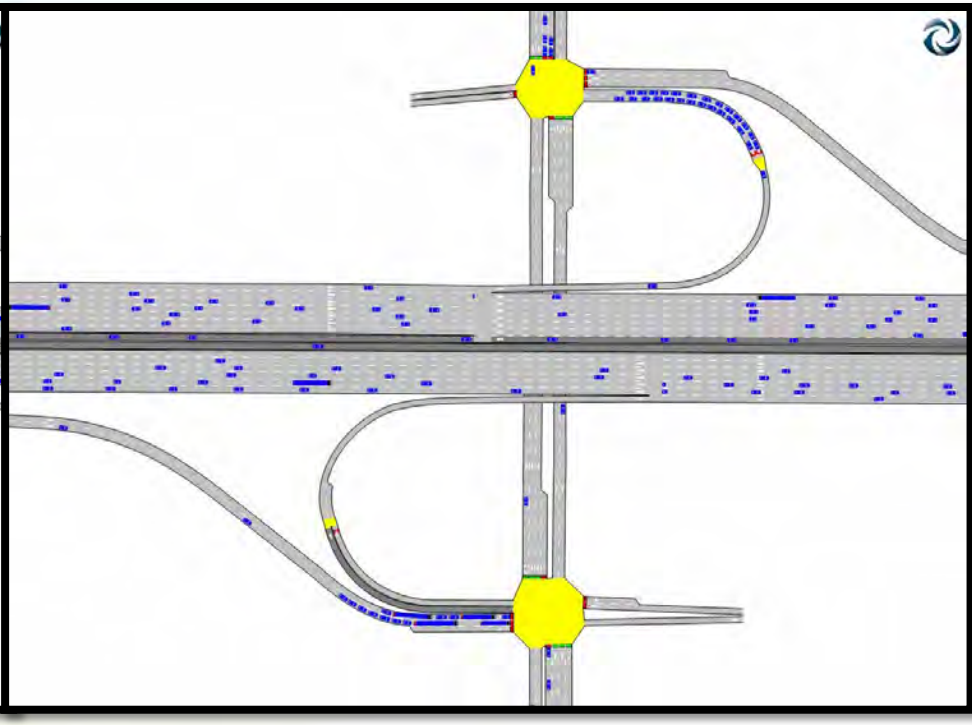


Simulation of Ramp Modification

Base Year Model

2035 'Build' Scenario

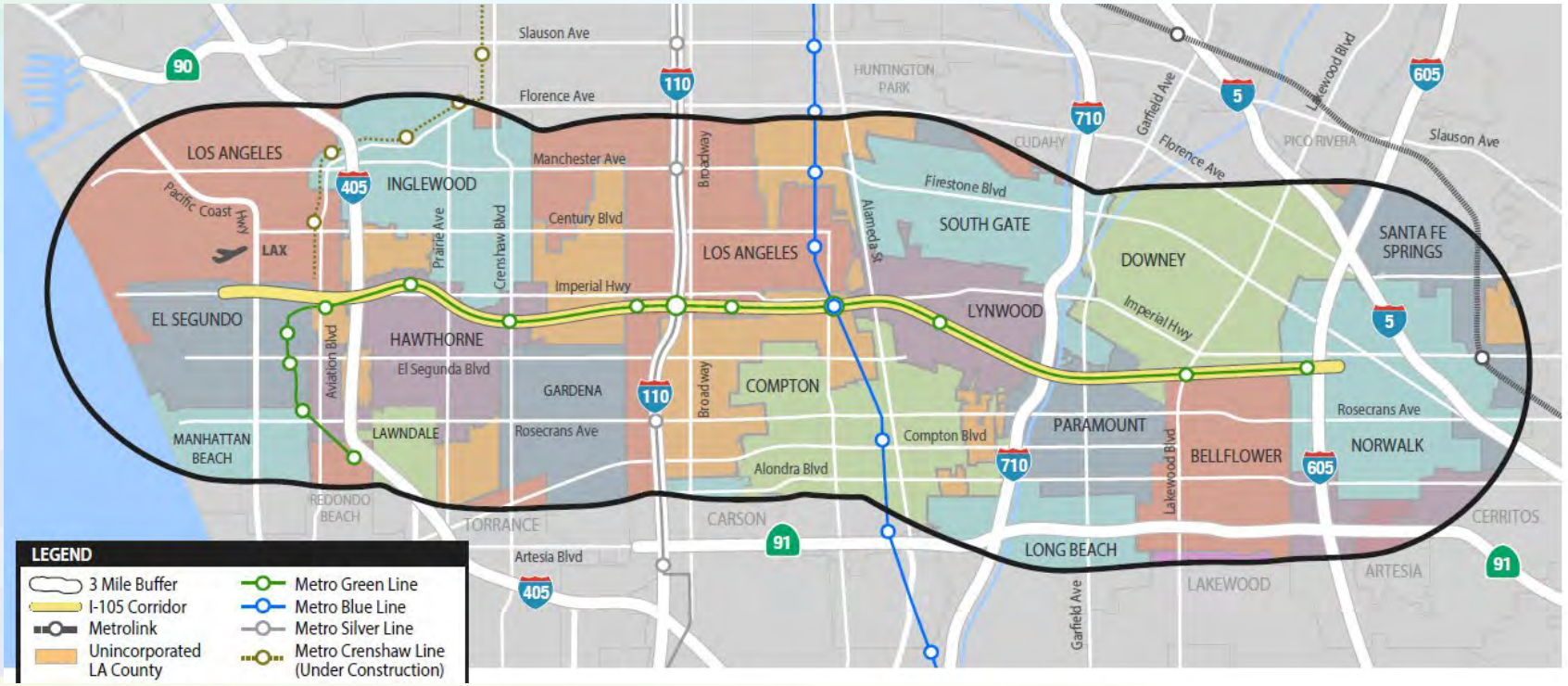




SR-91 & Pioneer

OUTPUT CASE STUDY 2: ACTIVE TRANSPORTATION AND DEMAND MANAGEMENT IMPROVEMENTS

I-105 Frwy. Active Transportation and Demand Management



Project Objectives: Test Active Transportation and Demand Management Strategies for I-105 Freeway Corridor

Active Transportation and Demand Management

- **Key Output:**
  - Total network delay
  - Delay by location/segment
  - Speeds
  - VMT/VHT
  - Intersection/Approach delay at ramps
  - Average queue length at ramps and mainline
  - Travel time – corridor and segment
  - Animations/visualizations
  - Similar output to capacity analysis project
  - Visualizations can portray ATDM benefits

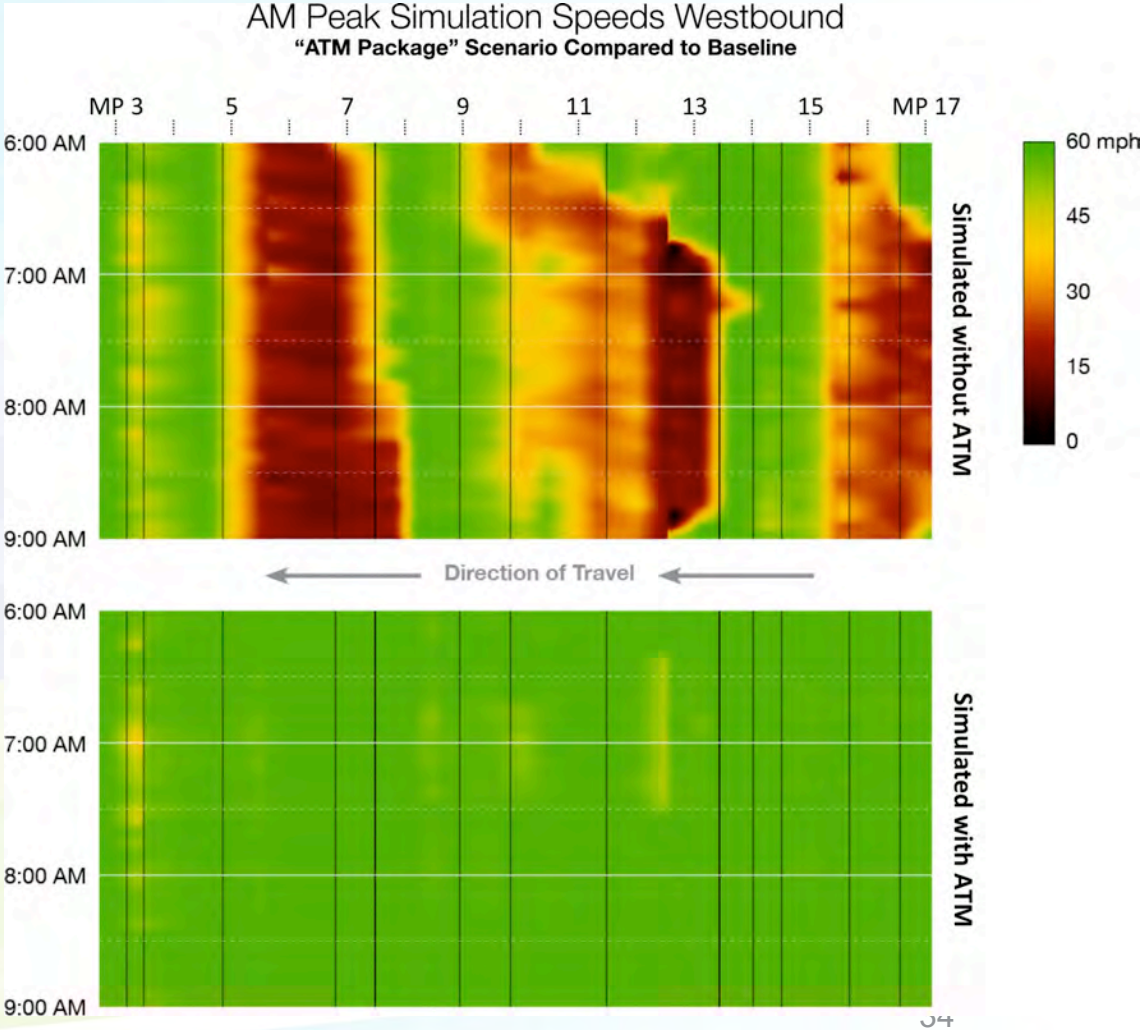
Performance Measures Output

AM Performance Measures

System-wide, for a typical day

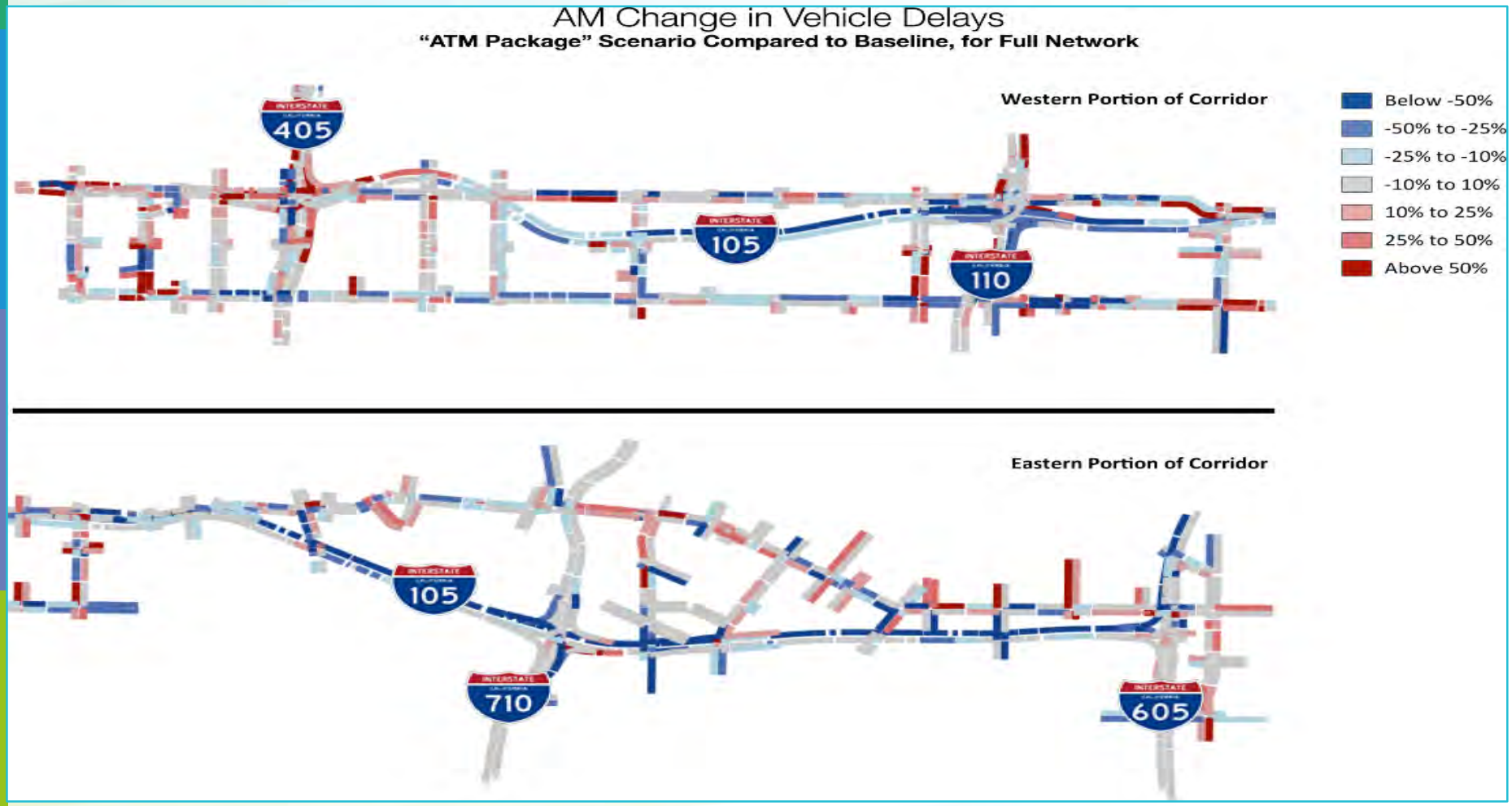
Metric	Without ATM	Percent Change from Baseline	
		ATM Package	*HSR Only*
VMT (vehicle miles)	1,400,468	1.51%	0.70%
VHT (vehicle hours)	44,832	-26.74%	-22.13%
Vehicle Hours of Delay (vehicle hours)	20,451	-59.59%	-48.64%
Person-Miles Traveled (passenger miles)	1,953,167	1.35%	0.50%
Person-Hours Traveled (passenger hours)	60,453	-25.06%	-20.87%
Person-Hours of Delay (passenger hours)	26,677	-57.68%	-47.30%
Average Travel Time (seconds per mile)	115.24	-27.83%	-22.67%
Average Trip Time (minutes per trip)	6.34	-27.31%	-22.47%

Heat Map Comparison of Freeway Speeds between Alternatives



(Source: Federal Highway Administration.)

Comparison of Change in Delays



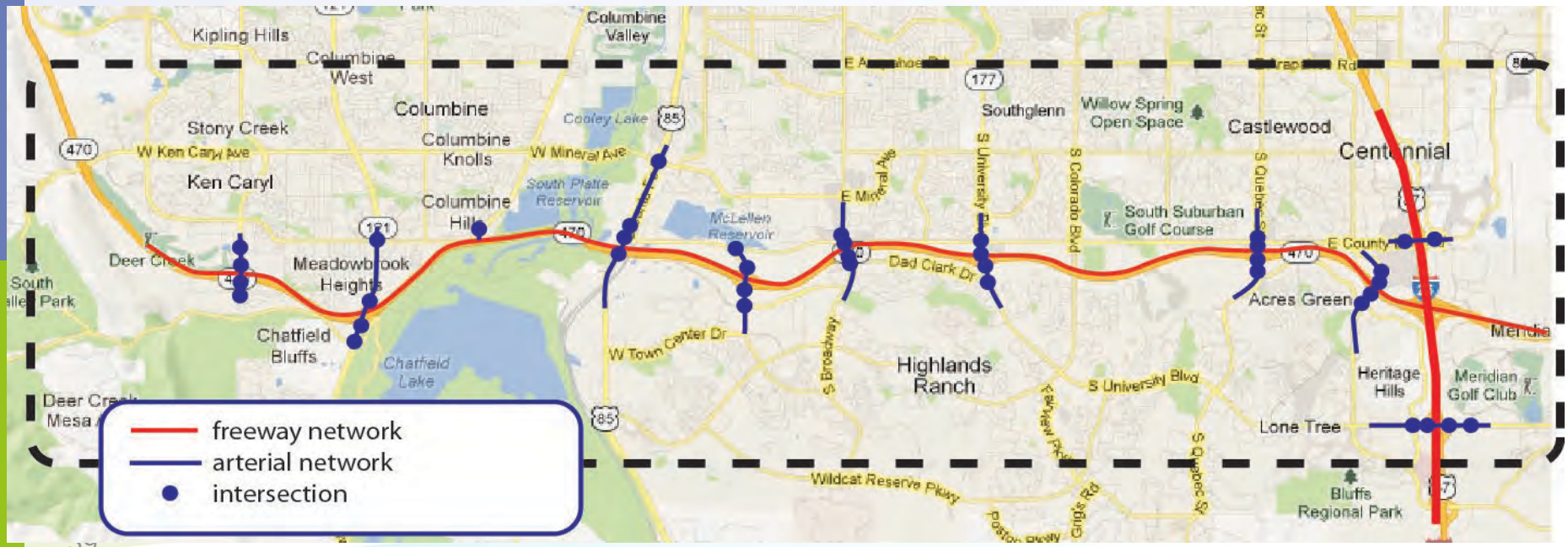
Hard Shoulder Running Visualization

I-105, East of Central Ave

OUTPUT CASE STUDY 3: MANAGED/EXPRESS LANES

Toll & Revenue Study

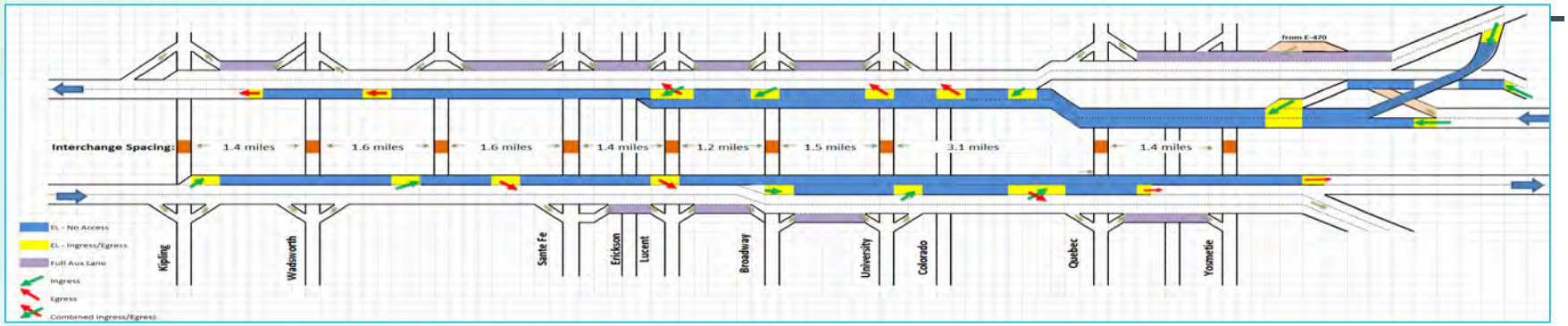
- **Project Objective**
  - To analyze traffic operations and revenue of a managed lane system proposed on the C-470 corridor (Denver)



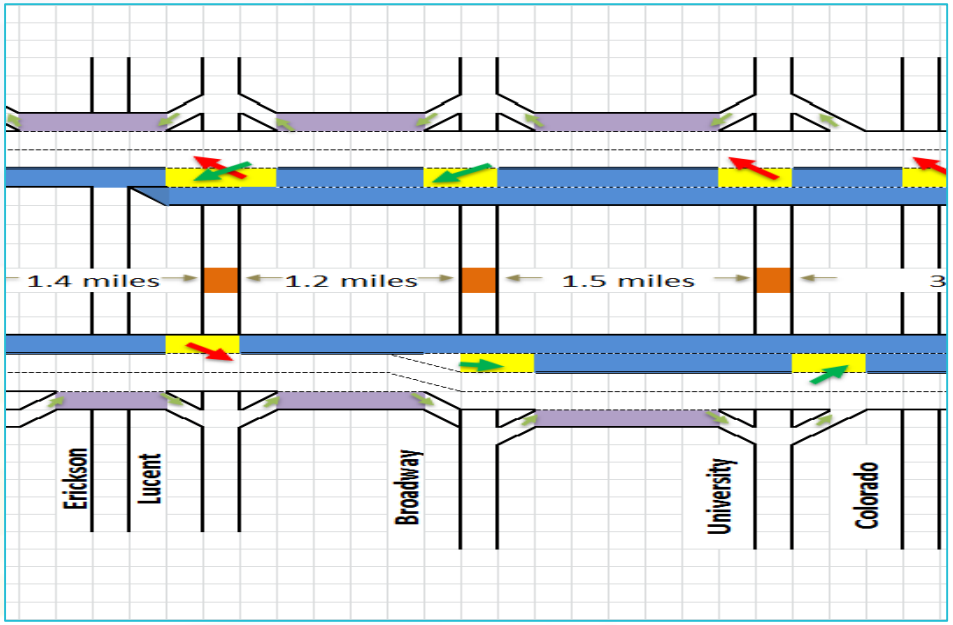
Toll & Revenue Simulation

- **Key Output:**
  - Total network delay
  - Delay by location/segment
  - Speeds
  - VMT/VHT
  - Intersection/Approach delay at ramps
  - Average queue length at ramps and mainline
  - Travel time – corridor and segment
  - Animations/visualizations
  - *Managed Lanes vs. General Purpose Lanes*
  - *Transactions and Revenue*

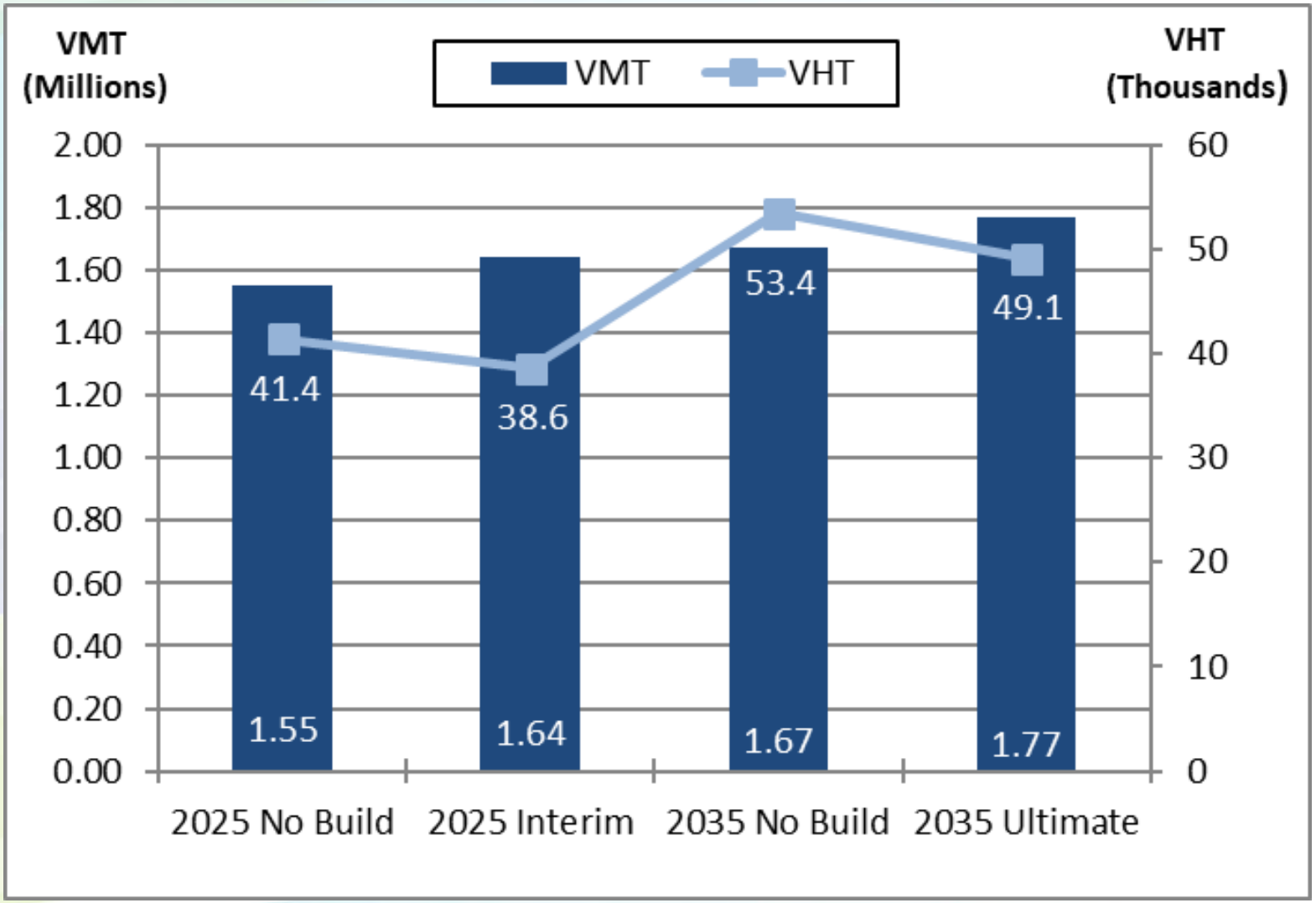
Dynamic Toll & Revenue Simulation



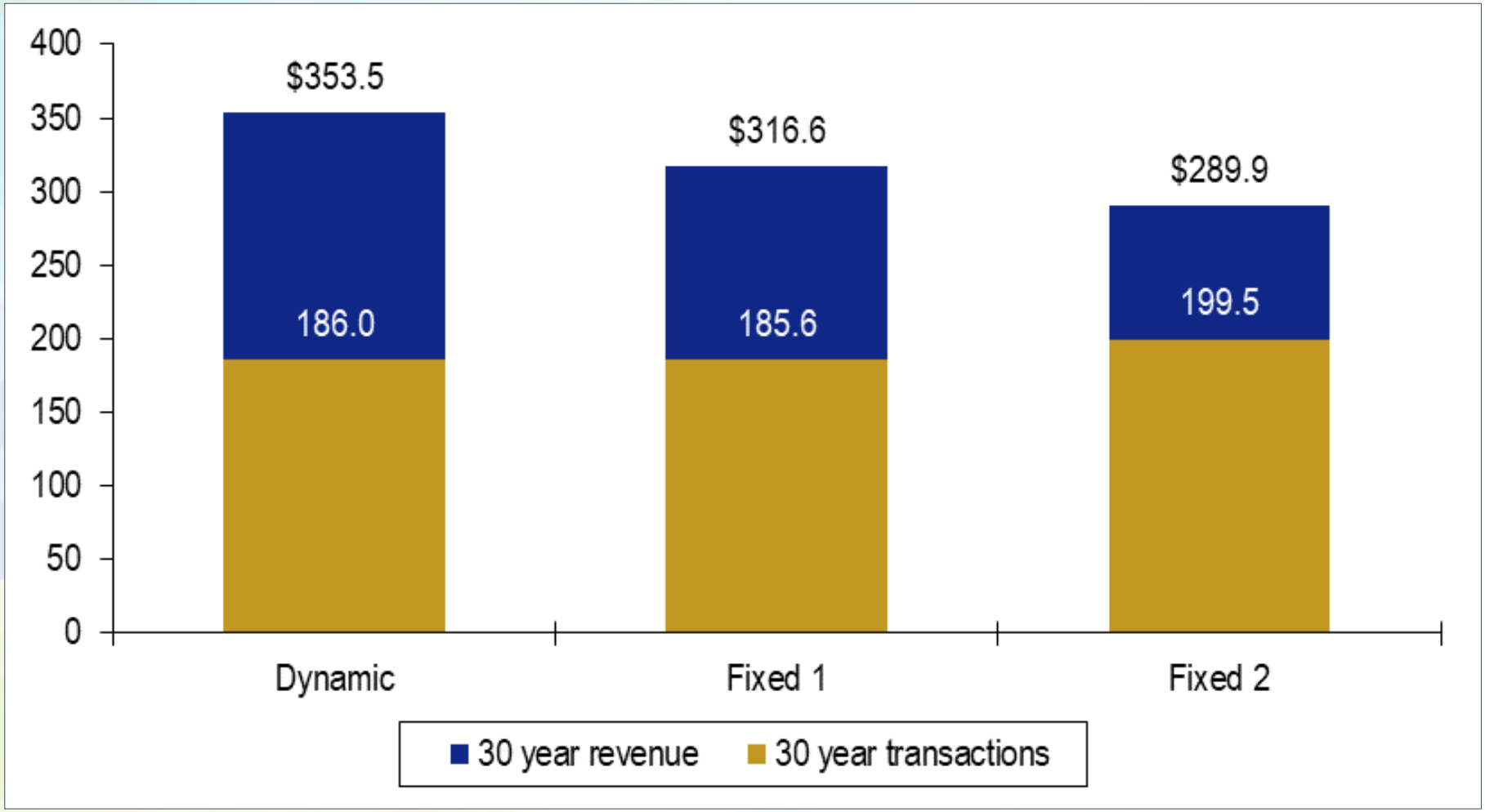
- Toll rates varies by time of day and congestion
- Output for general purpose and managed lanes
- Output focus: corridor-wide and ingress/egress locations



Toll & Revenue Simulation



Toll & Revenue Simulation



Toll & Revenue Simulation

Toll Lane Travel Time Savings

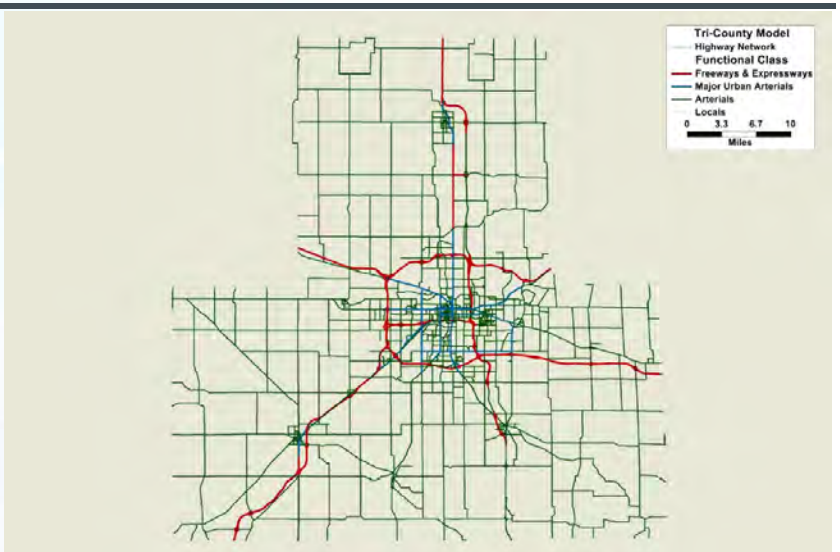
	Travel Times (Minutes)			
	No-Build 2025	**Interim 2025**	**No-Build 2035**	**Ultimate 2035**
GP	39.0	31.6	47.8	41.7
ETL	-	16.9	-	18.9
ETL Savings	-	14.7	-	22.8

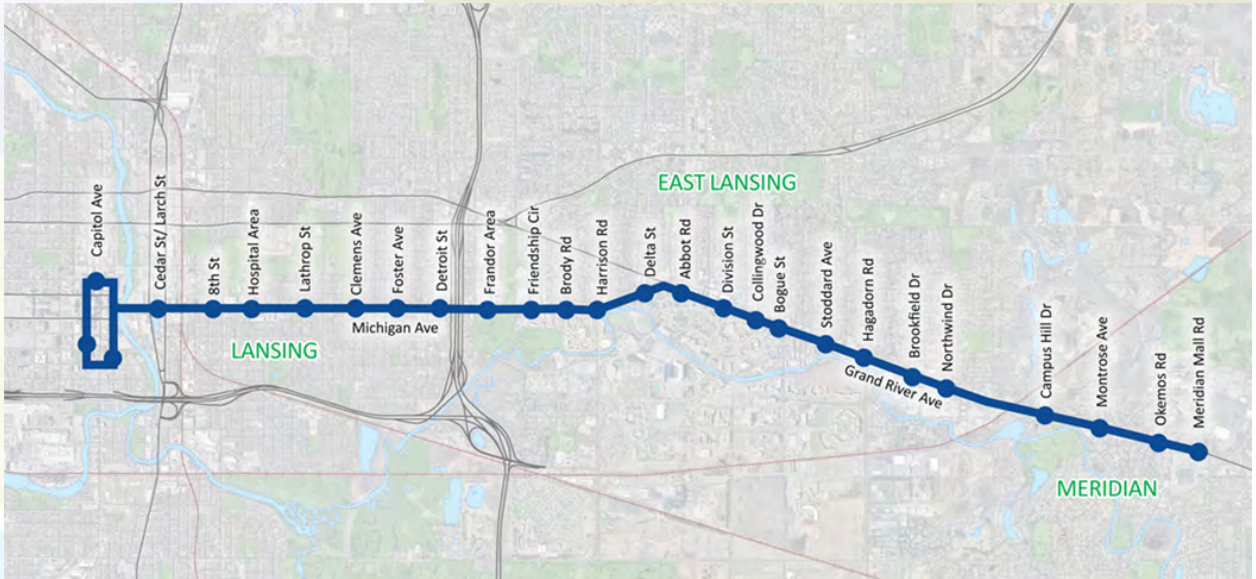
Toll & Revenue Simulation

OUTPUT CASE STUDY 4: BUS RAPID TRANSIT (BRT)

Bus Rapid Transit (BRT) Study

- **Project Objective**
  - To test the feasibility of a number of different alternatives for providing BRT services to the main corridor of downtown Lansing and East Lansing, Michigan





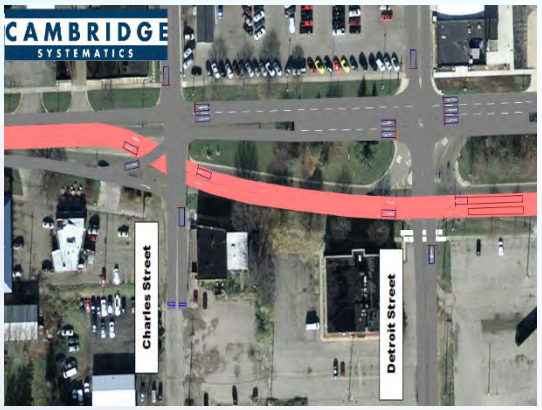
BRT Simulation

- **Key Output:**
  - Total network delay
  - Delay by location/segment
  - Speeds
  - VMT/VHT
  - Intersection/Approach delay at ramps
  - Average queue length at ramps and mainline
  - Travel time – corridor and segment
  - Animations/visualizations
  - *Person throughput and delay vs. vehicle delay*
  - *Signal priority impacts*
  - *Pedestrian impacts*

BRT Alternatives Simulation

» Test the feasibility of different BRT alternatives

Exclusive ROW



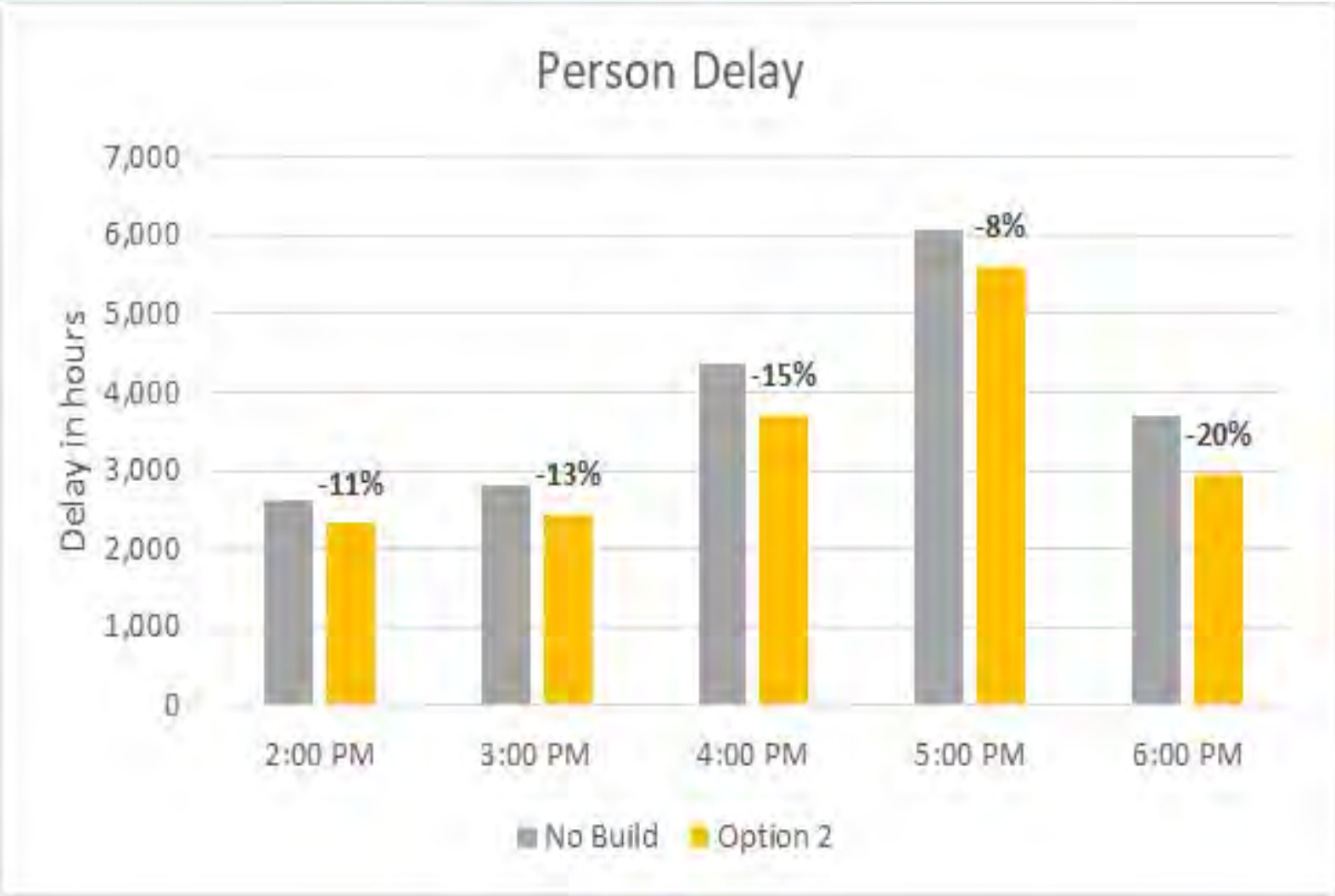
Exclusive Lane

BRT Alternatives Simulation

Tota
Netv

Tota
Pers

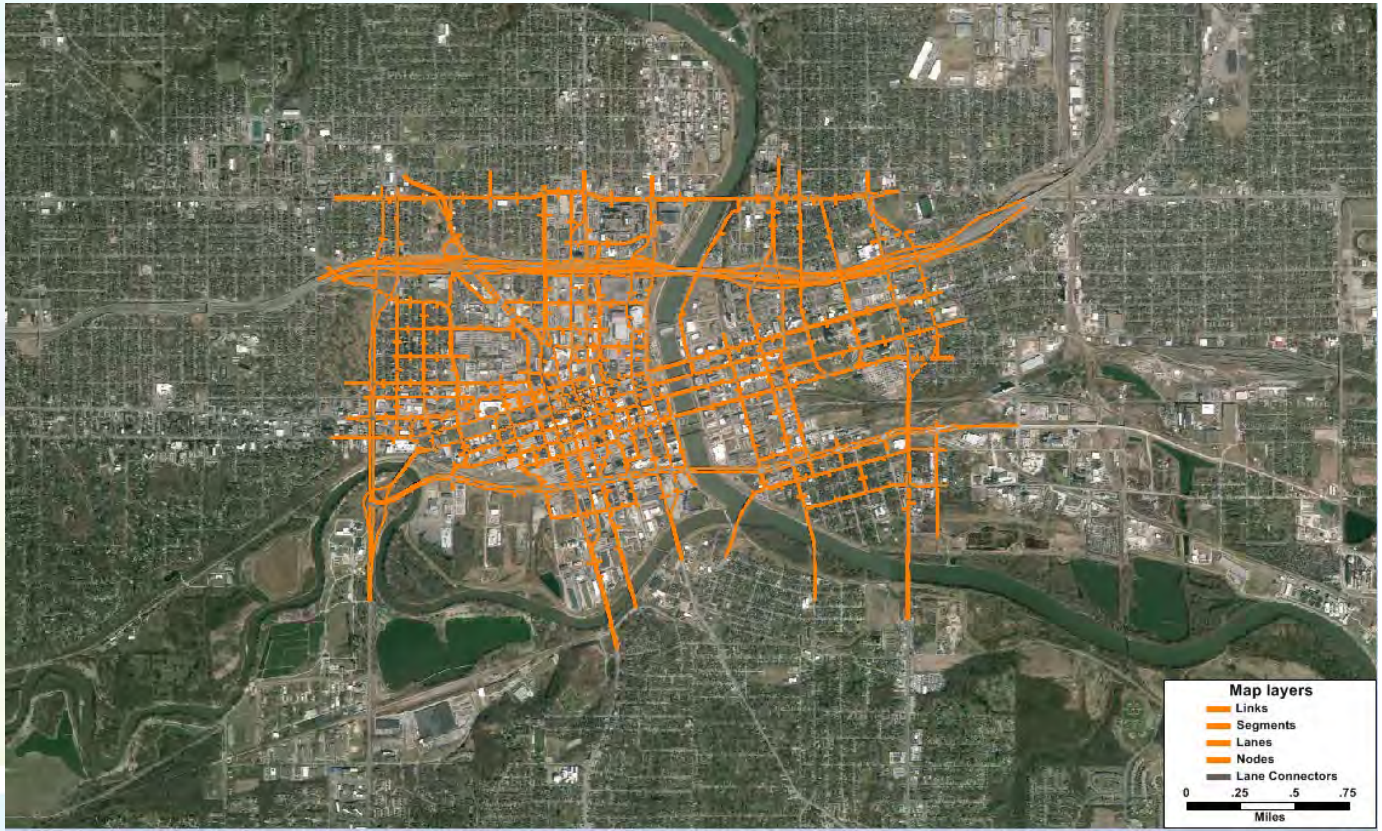
VMT



OUTPUT CASE STUDY 5: ROAD DIETS/ONE WAY STREETS

Downtown Area Study

- **Project Objective**
  - Assess impacts and benefits of removing lanes, adding bike lanes and one-way conversions in Des Moines

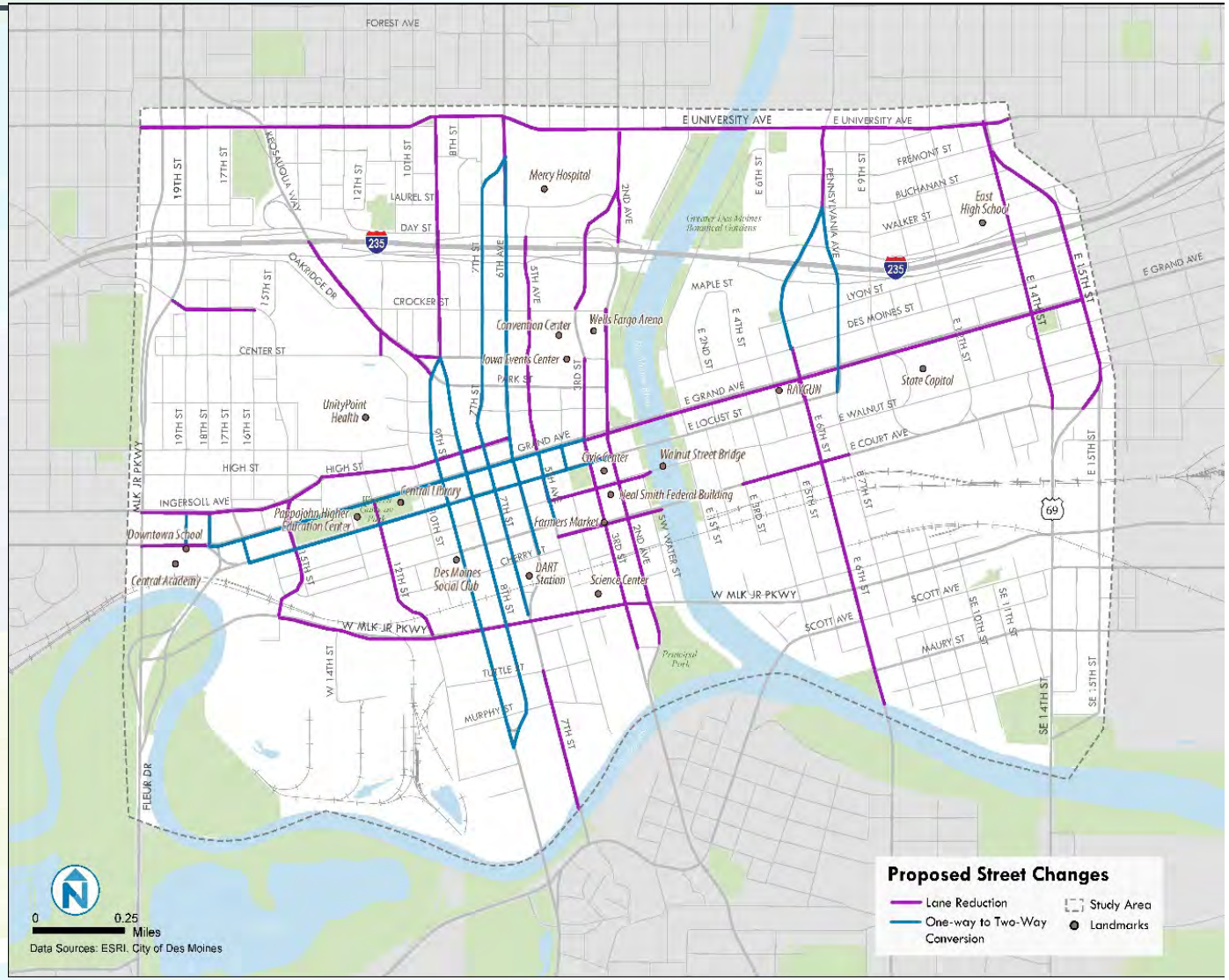


Road Diets/One-way Simulation

- **Key Output:**
  - Total network delay
  - Delay by location/segment
  - Speeds
  - VMT/VHT
  - Intersection/Approach delay at ramps
  - Average queue length at ramps and mainline
  - Travel time – corridor and segment
  - Animations/visualizations
  - Intersection LOS
  - Systemwide performance measures for capacity reduction

Road Diets/One-way Streets

- Lane reduction
- One-way to two-way



Road Diets/One-way Streets

- Intersection LOS Output

No Build

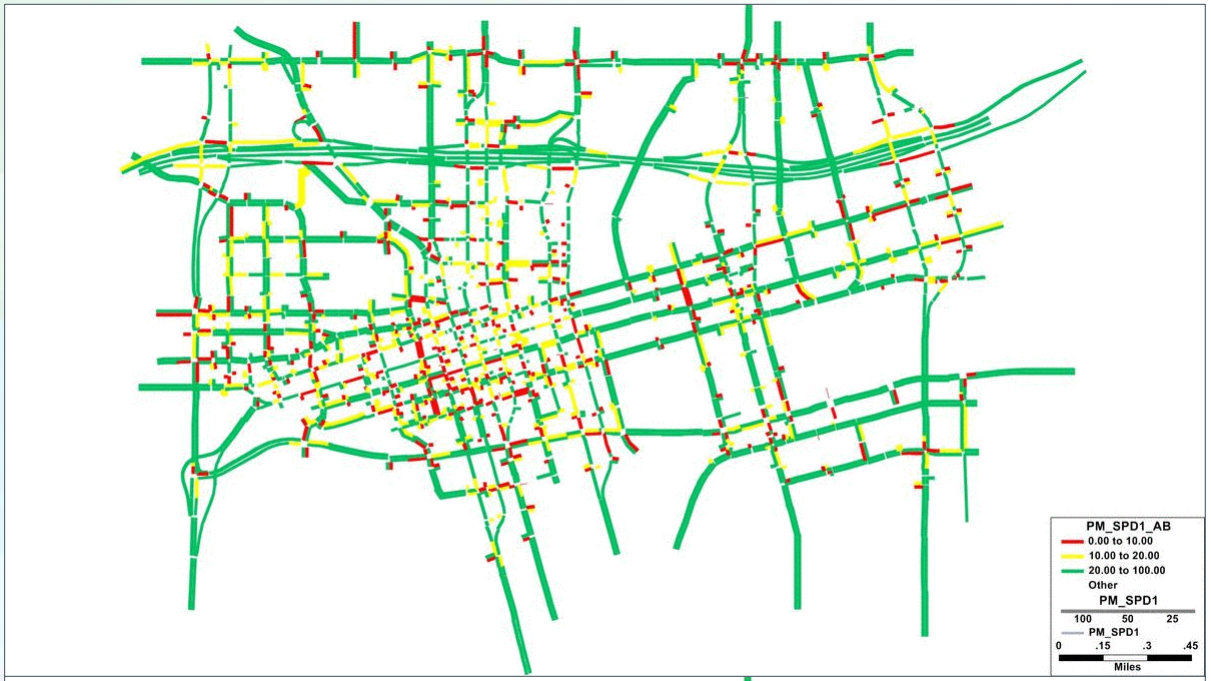
With Road Diet

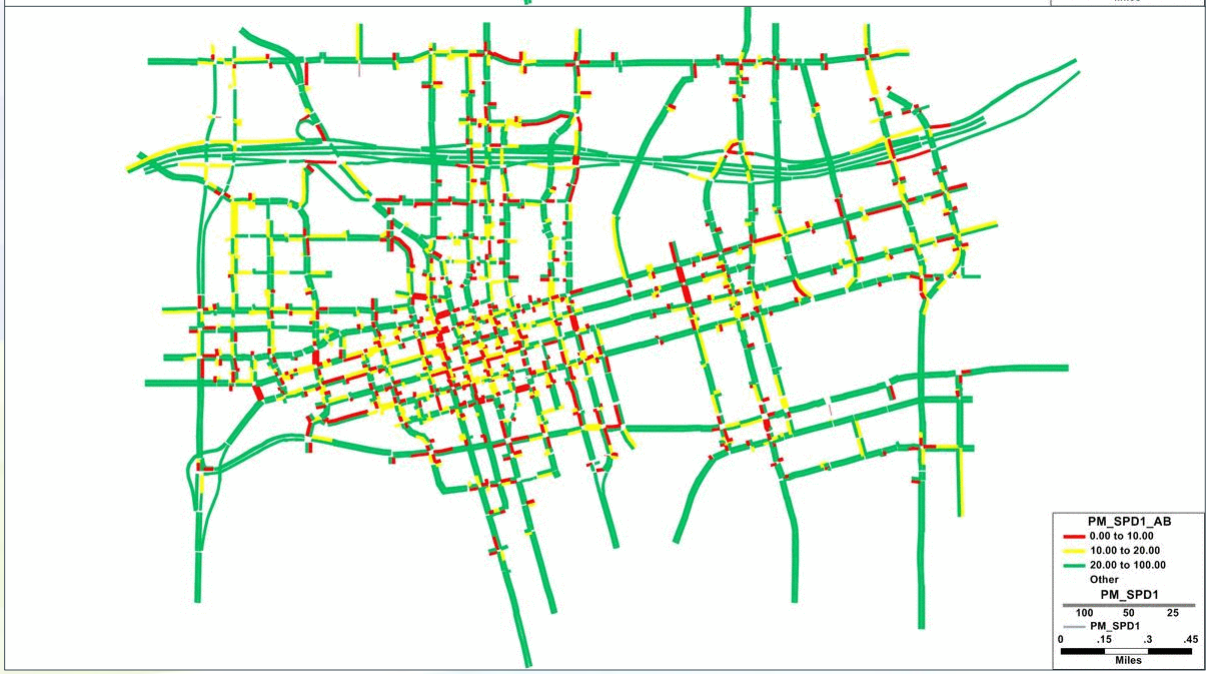
Road Diets/One-way Streets

- Link Speed Output

No Build

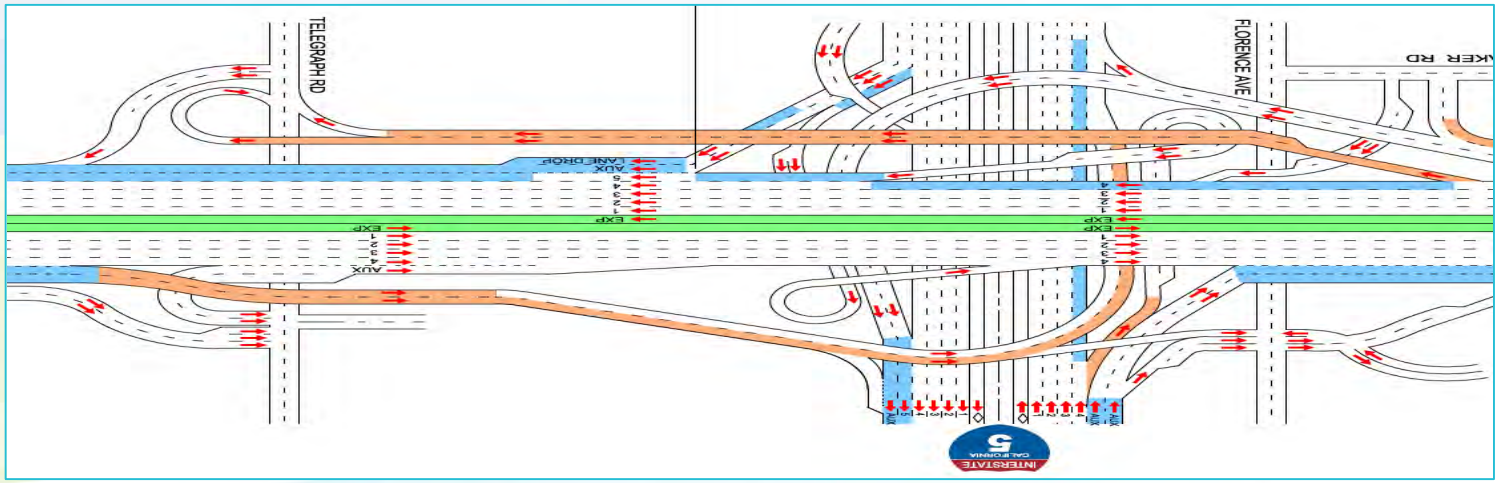
With Road Diet





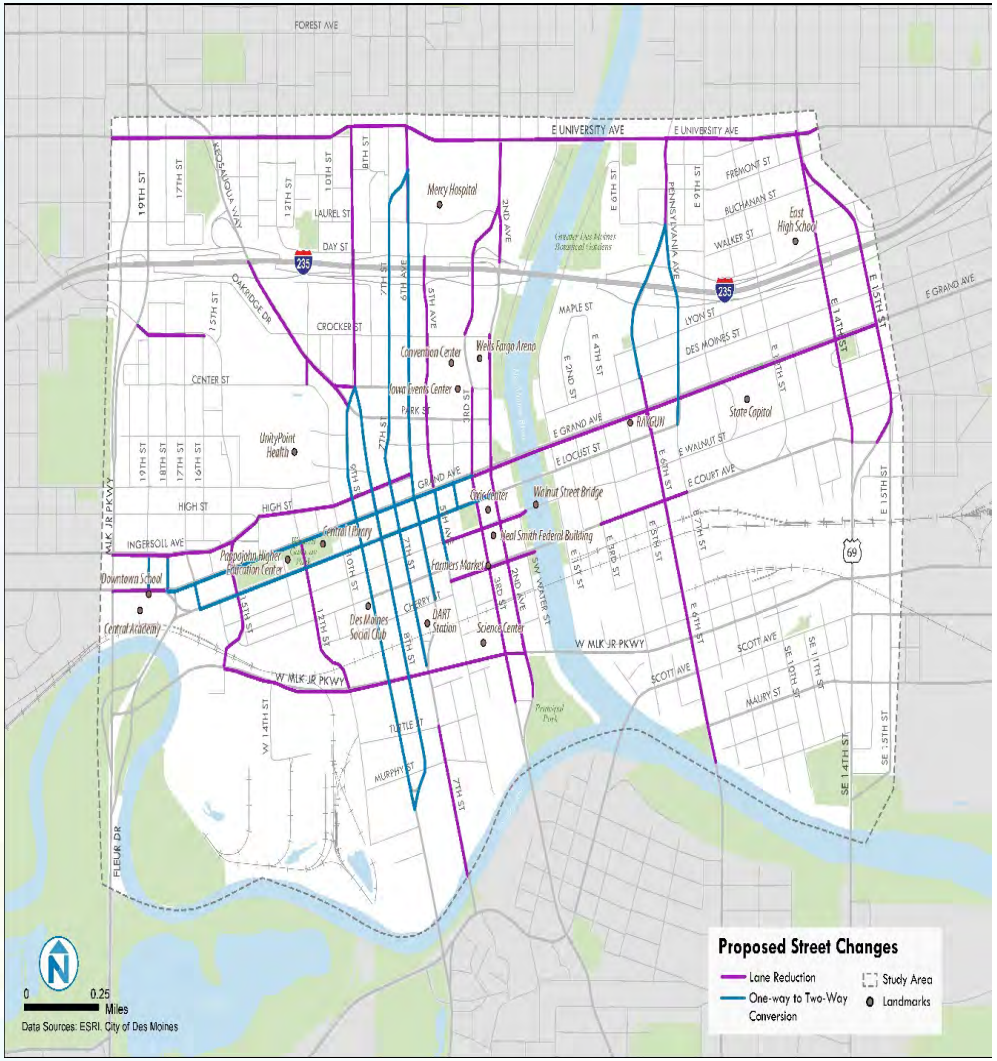
Simulation Output Summary (1)

- **Output for many *types of Projects*:**
  - Highway capacity enhancements (add GP lanes)
  - Reductions in vehicle lane capacity (road diets, conversions)
  - Transit/person throughput
  - Revenue/tolling (add managed lanes)
  - Operational improvements



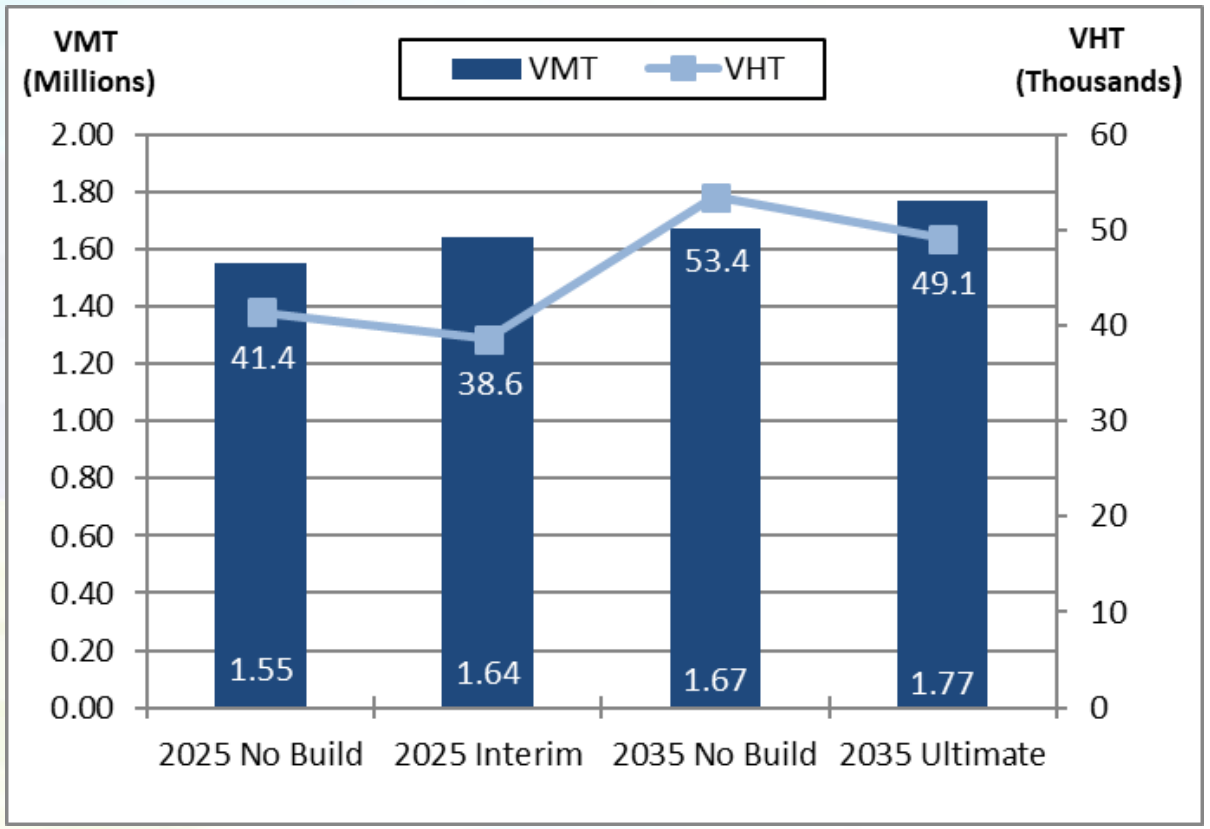
Simulation Output Summary (2)

- **Output for different *parts of transportation systems:***
  - Single segment
  - Intersections
  - Corridors
  - Interchanges
  - Whole Networks



Simulation Output Summary (3)

- **Output for many *performance measures:***
  - Flow
  - Speed
  - Travel time
  - Delay
  - VMT/VHT
  - Level of service
  - Queues



QUESTIONS & COMMENTS

THANK YOU!

For comments/ questions contact:

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