
Exploring Models
Dr Nagui M. Rouphail [USA]
“Traffic models in the era of big data”
Hosted by Dr Rahmi Akçelik and the SIDRA Team
SIDRASOLUTIONS.COM

Introduction by Dr Rahmi Akçelik
Director SIDRA SOLUTIONS

Welcome to the second SIDRA SOLUTIONS Exploring Models event …

I'd like to begin by acknowledging the Traditional Owners of the land on which we meet today. I would also like to pay my respects to Elders past and present.

Our Guest Presenter
Dr Nagui Rouphail

Nagui Rouphail is currently Professor in the Department of Civil, Construction, and Environmental Engineering at North Carolina State University in Raleigh, NC, USA.

Dr Nagui M. Rouphail served as Director of the Institute for Transportation Research and Education (ITRE) at North Carolina State University during 2002 - 2016.

Our Guest Presenter
Nagui Rouphail

Nagui is an internationally recognized scholar in the areas of highway capacity and operations, traffic simulation and intelligent transport systems, and the interface of traffic flow and air quality.

He has published over one-hundred and sixty refereed journal articles, including ten best paper awards from TRB, ASCE and ITE.

Presentation by Nagui Rouphail

Traffic models in the era of big data

"**All** models are wrong but some are useful"

George Box, Famous British Statistician, in a
1976 paper published in the Journal of the American Statistical Association

Outline

I. Introduction and definitions
II. Link-based data and modeling applications
III. Vehicle-based data and modeling applications
IV. Emerging research and application opportunities
V. Questions and discussion

I. Introduction: What is Big Data…

- Has been given a variety of definitions:
  - *Describes a collection of datasets so large and complex that they become difficult to process using traditional data processing applications*
  - *Describes the exponential growth and availability of data both structured and unstructured in terms of volume, velocity, diversity and variability*
  - *Describes the use of predictive analytics, user behavior analytics, or other advanced analytics that extract value from data, regardless of size*

Sample : Connected Vehicle Big Data (SPMD)

BsmP1 (Primary Basic Safety Message File) 14.8 min

RxDevice: ID of the device that logs a BSM
sample entry: 1566

Latitude: in 1/10th integer microdegrees
sample entry: 42.41119

FileId: Reference number to locate data source
sample entry: 1158354

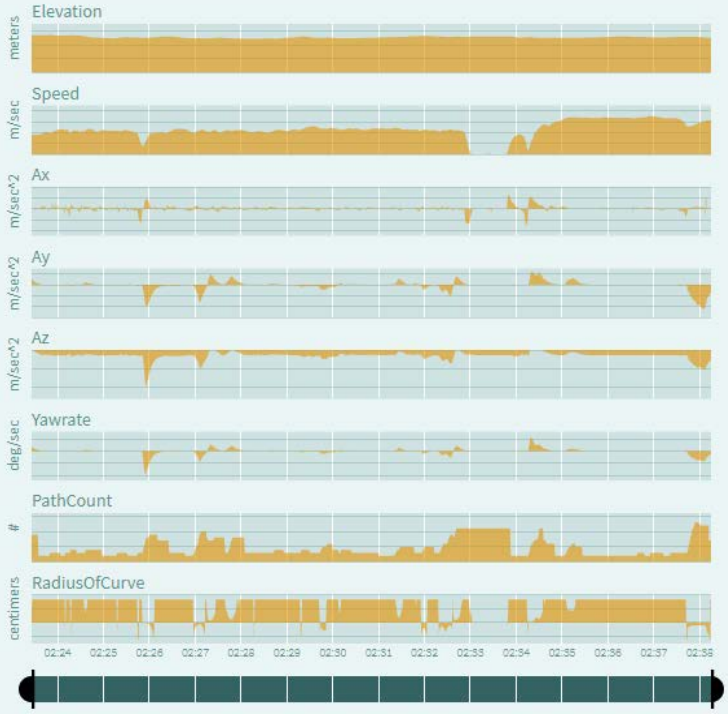
DSeconds: Time in milliseconds
sample entry: 35800

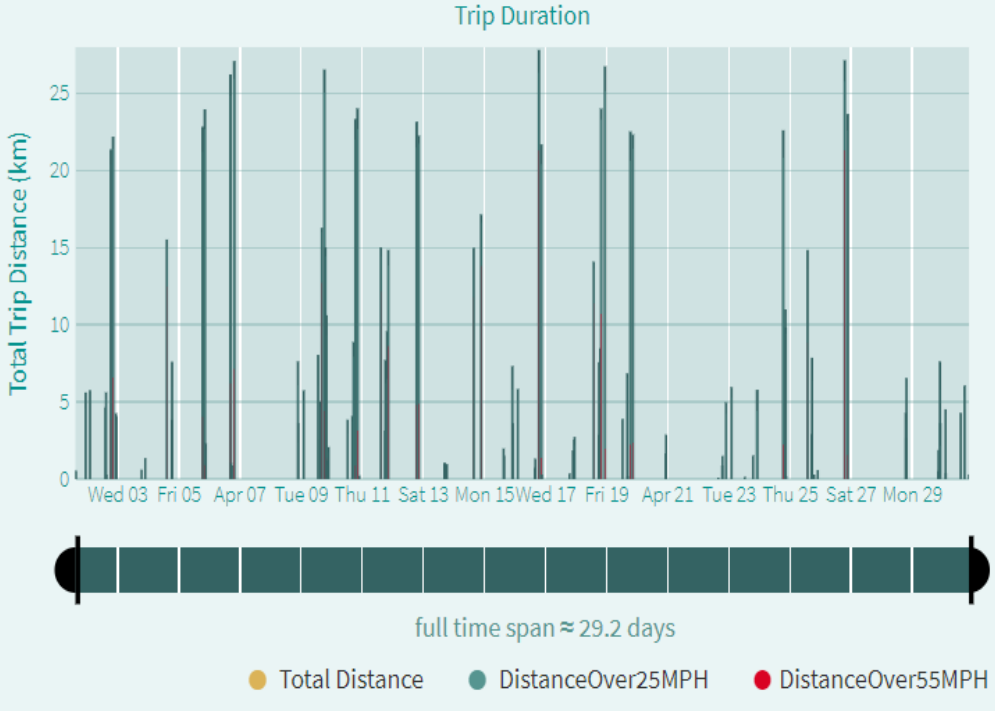
TxDevice: ID (number) of the device that transmits a BSM
sample entry: 1566

Longitude: in 1/10th integer microdegrees
sample entry: -83.874352

MsgCount: Sequence number within stream of messages with the same DSRCMsgId and from the same sender
sample entry: 19

GenTime: a more secure form of Epoch time
sample entry: 291864241884364





Sample Test Location in a BsmP1 File

Ann Arbor, Michigan

- 10 seconds worth of data
- 100 Latitude-Longitude Pairs
- ~ 200 meters of travel
- ~ 70 kph average speed

Traffic data timeline evolution…

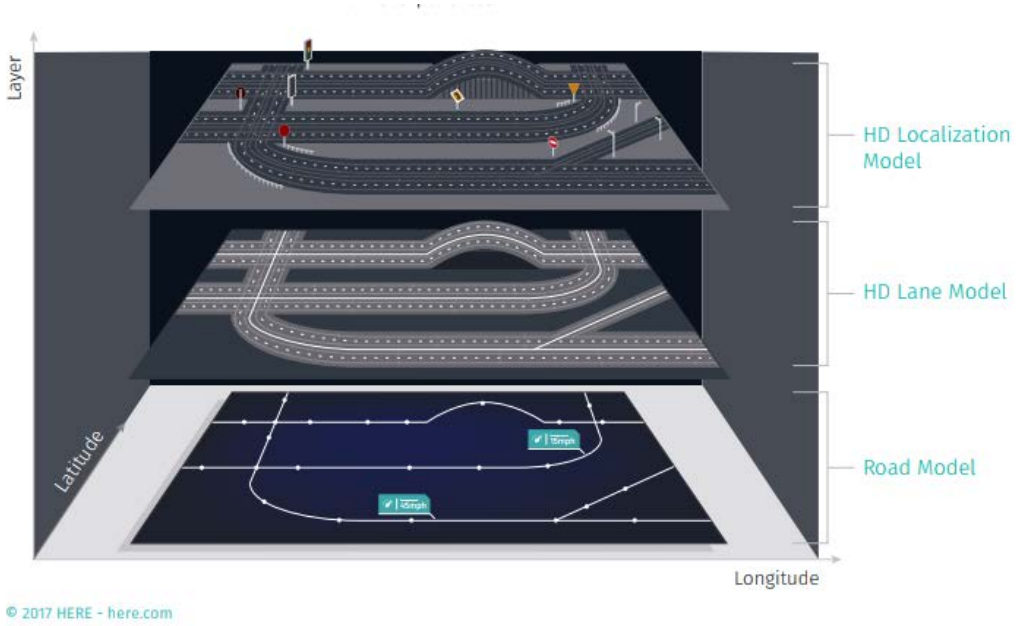
1950's	1970's	1990's	2010's	2030's
MANUAL	INFRASTRUCTURE BASED	VEHICLE PROBE BASED	TRAVELER BASED	CONNECTED / AUTONOMOUS
• Intersection Turn Mvmt Counts • Radar Guns • Tube Counters • Manual License Plate Recording	• Loop Detectors • RTMS and Acoustic Sensors • Video Imaging • Satellite Imaging	• AVL/ GPS • AVI/ Toll Tag Readers • Smart Cards • Automated License Plate Readers	• Mobile Devices • Blue Tooth Readers • Mobile Car-Chip or OBD-II readers • Zip cars	• 360° Vehicle and Infrastructure Representation • High Resolution BSM's • Truck Platoons

The focus of this presentation

- Emerging data sources
  - Digital infrastructure
  - Link-based traffic data and applications
  - Individual and connected vehicle data

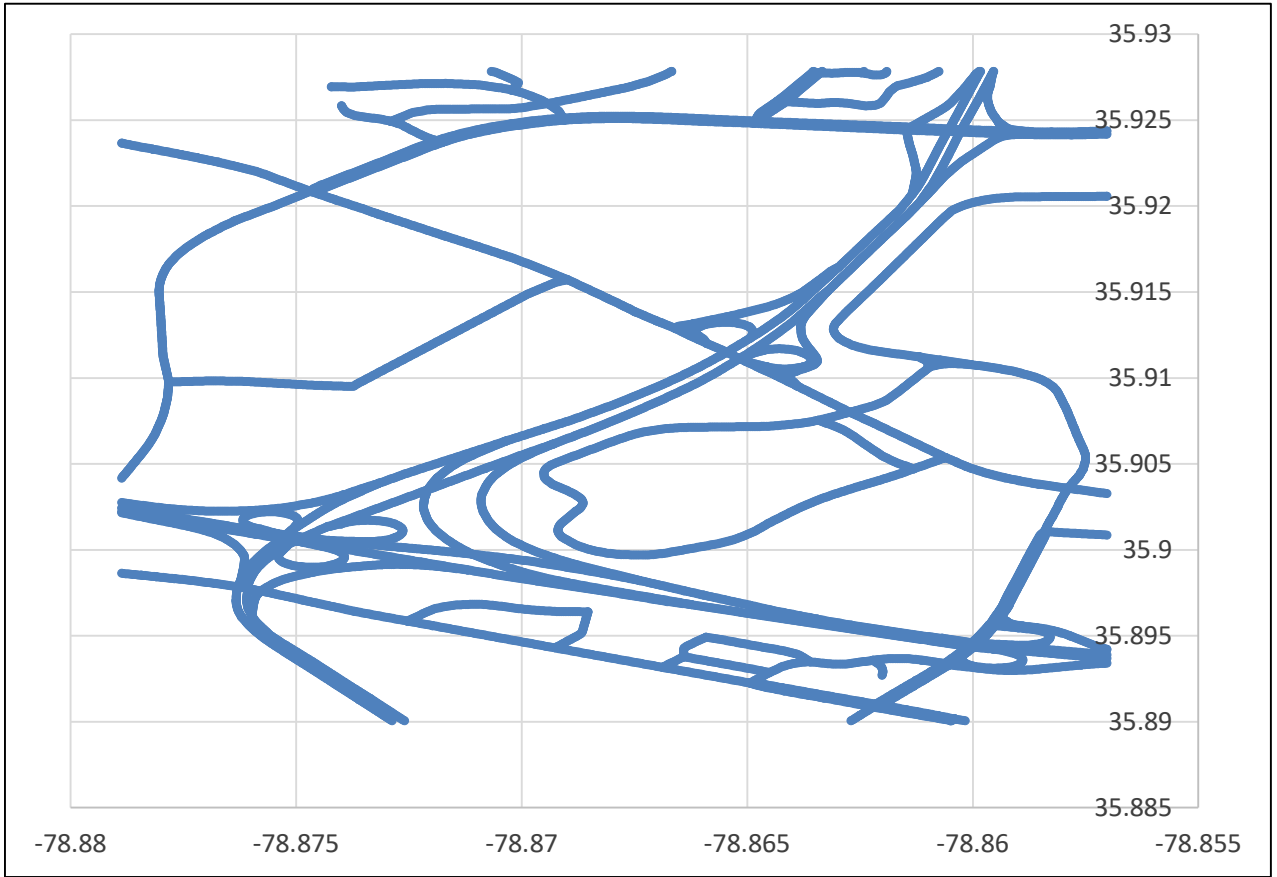
Digital Infrastructure

- "HERE" data example in preparation of AV deployment
- Three levels of details
  - Road model (topology and attributes)
  - HD Lane model (same but for each lane)
  - Localized data (signs, signals, other local)
- Current coverage: most of the USA and Europe



Digital Infrastructure: Road Model

- Local network in NC
- Over 10,000 Lat Long positions
- Major roads only
- Total centerline kilometers: 25



I. Introduction and definitions

II. Link-based data and modeling applications

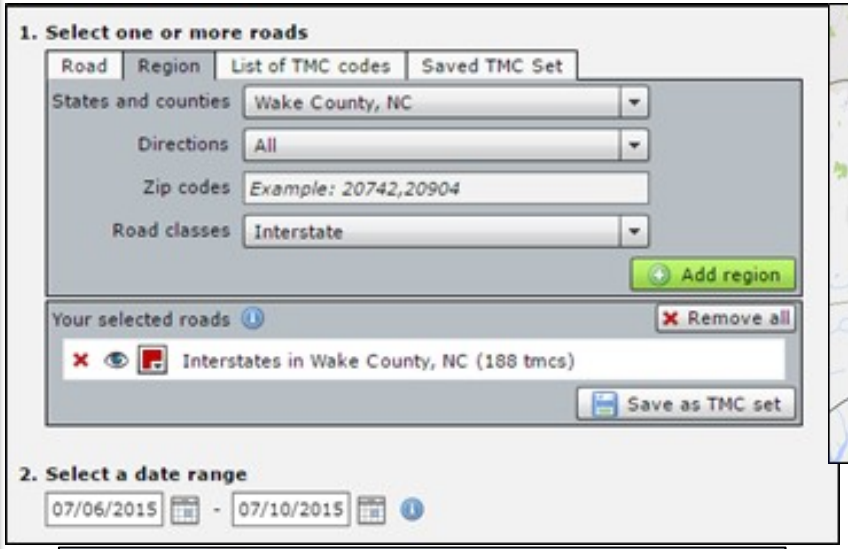
III. Vehicle-based data and modeling applications

IV. Emerging research and application opportunities

V. Questions and discussion

II. Link-Based Speed/Travel Time Data

- Current state of practice: reduce reliance on fixed infrastructure sensors (issue?)
- 3rd Party data providers (INRIX, HERE, TomTom
- Contract with state agency (DOT) to provide data for various road classes
- Massive data downloads or real time data displays at multi resolutions



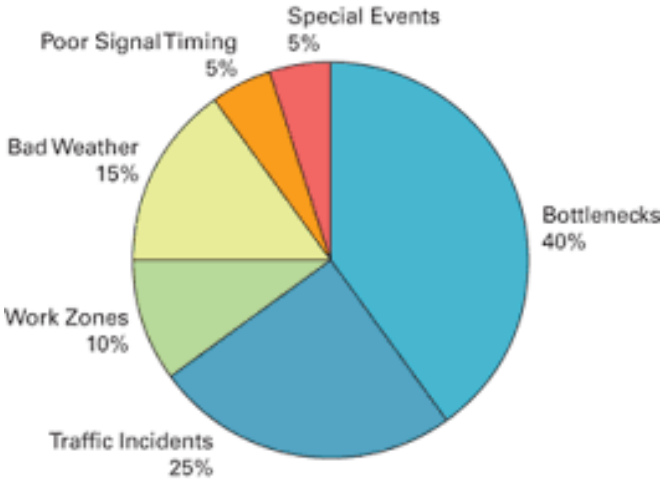
Interface for Selecting and Downloading Traffic Message Channel (TMC) Data by time and space On the RITIS Platform

How do Link-Based Sensors Gather Data

- Each participating vehicle probe reports position (latitude-longitude), instantaneous speed each second to a data server (phone or OBD)
- Positions are matched to TMC's and data aggregated over an interval (e.g. 30 sec, 1 minute) and speed archived for each link for each interval
- Data are checked for internal consistency, and aggregated at multiple levels, depending on agency needs.
- Ideal for generating RELIABILITY performance measures over extended periods of time
- However, no indication of probe sample size, or missing data but a "confidence metric" is provided
- Link or route based data can also be gathered using blue tooth or AVI sensors yielding individual vehicle link speed and travel (or trip) times.

Modeling Applications of Link-Based Probe Speed and Travel Time Data

- Measuring link, route and system *reliability* (all sources of congestion)
- Recurring bottlenecks identification and ranking
- Macroscopic and mesoscopic model calibration and validation



Recurring Bottleneck Identification &Ranking

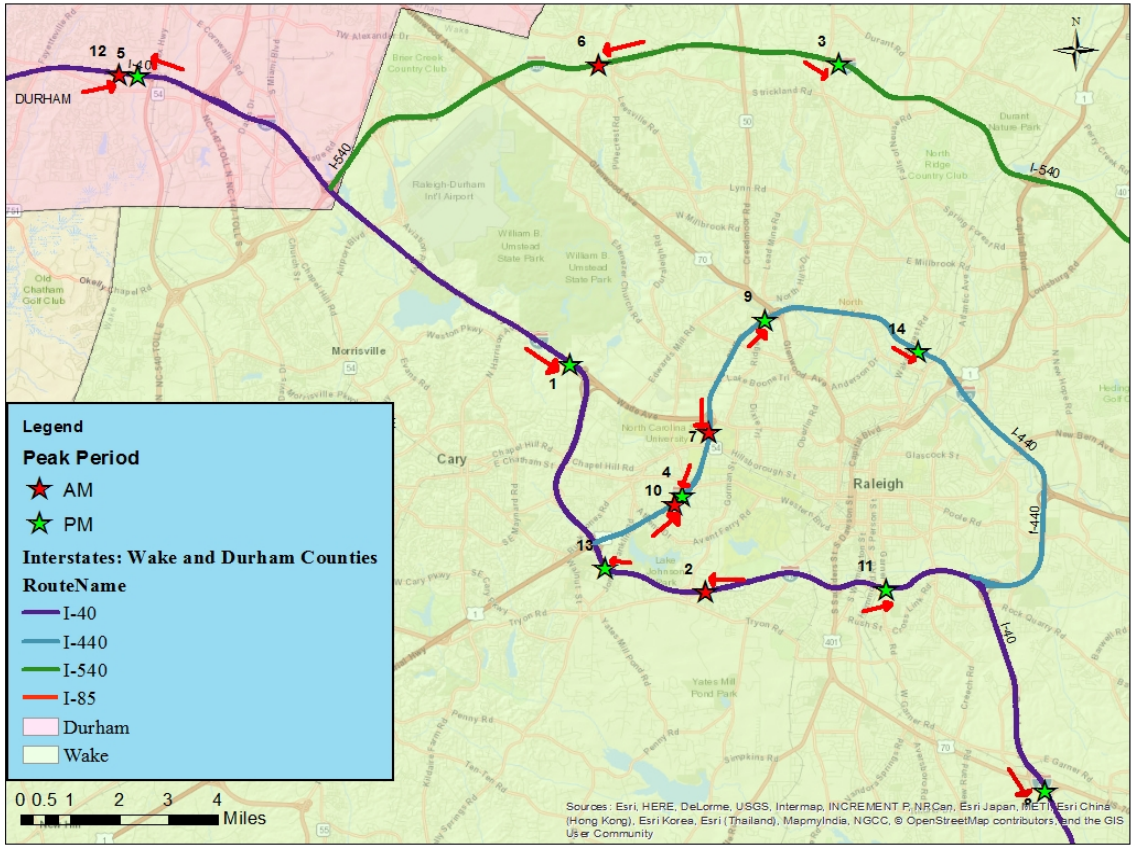
- Single day, spatiotemporal congestion Index (CI) based on: speed/FFS. Threshold **CI ≤ 0.70**

TMC ID	Length (mi)	TMC Tag	4:00 PM	4:15 PM	4:30 PM	4:45 PM	5:00 PM	5:15 PM	5:30 PM	5:45 PM	6:00 PM	6:15 PM
125-17000	3.282	0	0	0	0	0	0	0	0	0	0	0
125N04836	0.751	1	0	1	1	1	1	1	1	1	1	0
125-04836	1.053	2	0	1	1	1	1	1	1	1	0	0
125N04837	0.846	3	0	0	0	0	1	1	1	1	0	0
125-04837	1.313	4	0	0	0	0	0	1	1	1	0	0
125N04838	0.863	5	0	0	0	0	0	0	0	0	0	0

- Aggregation across multiple days based on Average Historic Congestion Index (AHCI). Threshold **AHCI > 33%**

TMC ID	Length (mi)	TMC Tag	3:45 PM	4:00 PM	4:15 PM	4:30 PM	4:45 PM	5:00 PM	5:15 PM	5:30 PM	5:45 PM	6:00 PM	6:15 PM	6:30 PM	6:45 P
125-17000	3.336	0	5.14	8.70	8.70	13.44	18.18	15.81	14.23	22.13	26.88	27.27	31.62	28.06	18.25
125N04836	0.677	1	24.51	33.99	48.22	60.87	66.80	75.79	83.73	87.75	80.63	73.12	59.29	41.50	25.79
125-04836	1.177	2	24.51	33.99	48.22	60.87	66.80	75.79	83.73	87.75	80.63	73.12	59.29	41.50	25.79
125N04837	0.775	3	22.53	30.43	42.29	58.10	66.01	72.73	81.03	82.61	78.26	65.61	47.83	32.81	14.68
125-04837	1.366	4	22.53	30.43	42.29	58.10	66.01	72.73	81.03	82.61	78.26	65.61	47.83	32.81	14.68
125N04838	0.780	5	20.45	29.55	36.36	52.27	56.82	58.43	63.33	64.44	62.22	55.56	37.78	20.00	7.87
125N04960	0.249	6	20.45	29.55	29.55	29.55	29.55	30.43	30.43	30.43	30.43	29.55	22.53	22.53	22.53

Study area and top Ranked Bottlenecks

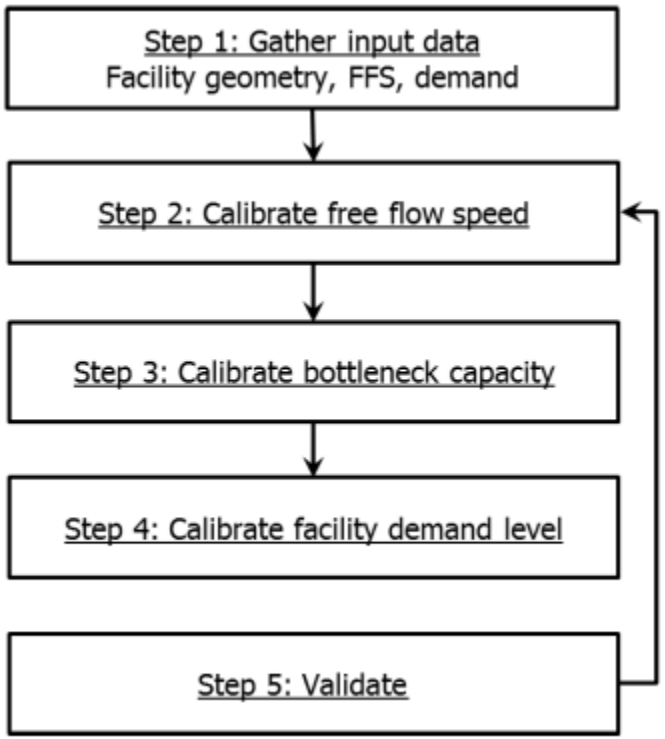


Rank *RBIF*	Bottleneck Location	Activation Period	Probability of Activation (in 88 weekdays)	Overall *RBIFmi. hrs)*
1	I-40 Eastbound at Wade Avenue/MM 289	16:00-19:00	0.91	749
2	I-40 Westbound at Gorman St/MM 295	6:30-9:00	0.88	707
3	I-540 Eastbound at Six Forks Rd/ MM 11	16:30-18:45	0.88	539
4	I-440 Westbound at Western Blvd./MM 2	16:15-18:30	0.90	513
5	I-40 Westbound at NC-55/MM 278	17:00-18:45	0.84	327
6	I-540 Westbound at Leesville Rd/ MM 7	7:15-9:00	0.84	315
7	I-440 Westbound at Wade Ave./MM 4	7:15-9:00	0.86	312
8	I-40 Eastbound at US-70	16:15-18:45	0.83	293
9	I-440 Eastbound at US-70	16:45-18:30	0.78	200
10	I-440 Eastbound at Melbourne Rd/ MM 1	7:30-9:00	0.67	56
11	I-40 Eastbound at Hammond Rd/ MM 299	17:00-18:15	0.66	54
12	I-40 Eastbound ay NC-55/ MM 278	7:45-8:45	0.53	39
13	I-40 Westbound at Gorman St/MM 295	17:15-17:45	0.41	23
14	I-440 Eastbound at US-401/US-1/Capital Blvd/MM 11	17:30-18:00	0.52	8

Probe Data for Model Calibration & Validation

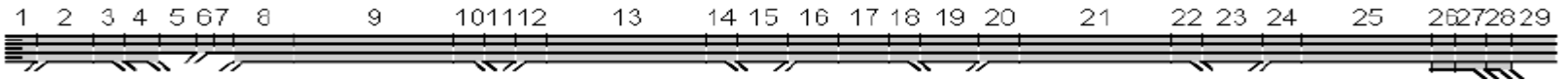
- FREEVAL: macroscopic model for analyzing freeway facilities.
- Embodies the US-HCM 6th Edition method published in 2016
- Analyzes facilities up to 40 km long and up to 24 hrs (96 int.)
- Facilities are modeled as a contiguous series of basic, ramp and weaving segments, each with geometric and demand properties
- Handles both under and oversaturated flow regimes, including the effect of queue spillback, blockages and demand starvation
- Calibration challenge: Detailed demand data (?) and local segment capacity often unknown and variable

Calibration Process



- Code the facility in FREEVAL using model defaults estimates of demand (AADT profile) and capacity and run
- Generate model speed contours by segment and time period
- Convert empirical link-based speeds from RITIS to HCM segment values
- Run the calibration process (GA) to calibrate demand and capacity parameters to optimize speed matches

Initial Comparison with Uncalibrated Model



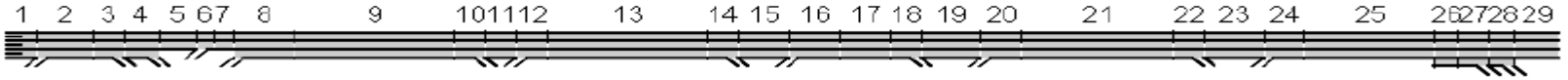
Analysis Period	Seg. 1	Seg. 2	Seg. 3	Seg. 4	Seg. 5	Seg. 6	Seg. 7	Seg. 8	Seg. 9	Seg. 10	Seg. 11	Seg. 12	Seg. 13	Seg. 14	Seg. 15	Seg. 16	Seg. 17	Seg. 18	Seg. 19	Seg. 20	Seg. 21	Seg. 22	Seg. 23	Seg. 24	Seg. 25	Seg. 26	Seg. 27	Seg. 28	Seg. 29
#1 6:00 - 6:15	65.4	72.6	72.6	72.6	73.0	73.0	73.0	73.0	73.0	73.0	73.4	74.1	74.1	74.1	73.6	73.7	73.7	73.7	72.4	70.5	70.5	70.5	71.8	71.1	71.1	71.1	71.1	72.8	72.8
#2 6:15 - 6:30	68.9	70.4	70.4	70.4	72.5	72.5	72.5	72.1	72.1	72.1	73.3	73.9	73.9	73.9	74.0	74.3	74.3	74.3	74.1	73.4	73.4	73.4	74.5	74.5	74.5	74.5	74.5	72.7	72.7
#3 6:30 - 6:45	73.2	70.8	70.8	70.8	71.1	71.1	71.1	71.5	71.5	71.5	73.1	72.5	72.5	72.5	73.5	73.1	73.1	73.1	72.5	72.0	72.0	72.0	71.7	73.7	73.7	73.7	73.7	72.9	72.9
#4 6:45 - 7:00	72.5	72.6	72.6	72.6	71.3	71.3	71.3	71.6	71.6	71.6	70.8	71.0	71.0	71.0	72.4	71.7	71.7	71.7	71.7	70.8	70.8	70.8	72.0	72.9	72.9	72.9	72.9	73.5	73.5
#5 7:00 - 7:15	73.7	70.3	70.3	70.3	70.7	70.7	70.7	71.9	71.9	71.9	73.3	71.9	71.9	71.9	72.5	72.5	72.5	72.5	72.5	70.8	70.8	70.8	71.7	72.1	72.1	72.1	72.1	73.7	73.7
#6 7:15 - 7:30	68.6	67.6	67.6	67.6	68.4	68.4	68.4	68.4	68.4	68.4	67.4	67.3	67.3	67.3	69.4	68.3	68.3	68.3	69.8	69.1	69.1	69.1	71.7	72.1	72.1	72.1	72.1	71.7	71.7
#7 7:30 - 7:45	67.9	64.7	64.7	64.7	68.6	68.6	68.6	60.9	60.9	60.9	46.5	48.8	48.8	48.8	63.9	62.8	62.8	62.8	59.0	59.1	59.1	59.1	66.4	70.1	70.1	70.1	70.1	70.9	70.9
#8 7:45 - 8:00	71.3	68.7	68.7	68.7	67.8	67.8	67.8	53.9	53.9	53.9	31.5	38.7	38.7	38.7	45.3	46.4	46.4	46.4	36.0	53.9	53.9	53.9	64.8	68.5	68.5	68.5	68.5	68.5	68.5
#9 8:00 - 8:15	71.3	68.1	68.1	68.1	67.1	67.1	67.1	56.1	56.1	56.1	36.8	41.0	41.0	41.0	36.9	43.9	43.9	43.9	44.2	55.1	55.1	55.1	62.3	67.6	67.6	67.6	67.6	70.2	70.2
#10 8:15 - 8:30	72.7	68.7	68.7	68.7	67.5	67.5	67.5	67.3	67.3	67.3	55.9	43.0	43.0	43.0	35.8	43.8	43.8	43.8	42.2	56.9	56.9	56.9	64.6	69.1	69.1	69.1	69.1	71.1	71.1
#11 8:30 - 8:45	70.3	70.8	70.8	70.8	73.0	73.0	73.0	70.5	70.5	70.5	64.3	59.0	59.0	59.0	57.7	54.9	54.9	54.9	46.7	57.0	57.0	57.0	63.8	69.5	69.5	69.5	69.5	70.2	70.2
#12 8:45 - 9:00	71.8	70.9	70.9	70.9	71.1	71.1	71.1	70.1	70.1	70.1	70.3	70.0	70.0	70.0	63.4	54.9	54.9	54.9	57.8	62.4	62.4	62.4	65.7	68.1	68.1	68.1	68.1	70.0	70.0
#13 9:00 - 9:15	73.3	70.9	70.9	70.9	69.7	69.7	69.7	70.3	70.3	70.3	72.9	72.9	72.9	72.9	72.6	73.0	73.0	73.0	73.1	71.2	71.2	71.2	72.5	72.2	72.2	72.2	72.2	73.2	73.2
#14 9:15 - 9:30	73.8	69.8	69.8	69.8	71.3	71.3	71.3	73.6	73.6	73.6	73.3	72.6	72.6	72.6	72.5	73.0	73.0	73.0	72.6	72.3	72.3	72.3	74.4	73.3	73.3	73.3	73.3	73.9	73.9
#15 9:30 - 9:45	70.1	68.5	68.5	68.5	68.3	68.3	68.3	69.8	69.8	69.8	71.4	72.7	72.7	72.7	73.1	73.4	73.4	73.4	73.9	71.7	71.7	71.7	72.1	72.2	72.2	72.2	72.2	73.0	73.0
#16 9:45 - 10:00	67.2	68.7	68.7	68.7	68.2	68.2	68.2	68.1	68.1	68.1	68.9	70.1	70.1	70.1	71.0	71.1	71.1	71.1	71.1	70.5	70.5	70.5	71.9	71.3	71.3	71.3	71.3	72.9	72.9
#17 10:00 - 10:15	69.8	69.1	69.1	69.1	67.4	67.4	67.4	67.7	67.7	67.7	68.1	69.7	69.7	69.7	69.0	70.7	70.7	70.7	71.4	70.7	70.7	70.7	72.7	72.3	72.3	72.3	72.3	72.6	72.6
#18 10:15 - 10:30	72.5	66.9	66.9	66.9	69.1	69.1	69.1	72.7	72.7	72.7	74.4	74.0	74.0	74.0	72.9	72.1	72.1	72.1	72.3	71.1	71.1	71.1	73.5	74.2	74.2	74.2	74.2	73.9	73.9
#19 10:30 - 10:45	69.9	69.8	69.8	69.8	70.9	70.9	70.9	70.5	70.5	70.5	70.7	71.4	71.4	71.4	71.1	71.6	71.6	71.6	73.7	73.3	73.3	73.3	73.3	73.6	73.6	73.6	73.6	73.5	73.5
#20 10:45 - 11:00	69.0	67.0	67.0	67.0	68.0	68.0	68.0	68.3	68.3	68.3	69.4	69.7	69.7	69.7	69.6	70.5	70.5	70.5	71.4	70.8	70.8	70.8	71.5	71.8	71.8	71.8	71.8	73.1	73.1
#21 11:00 - 11:15	68.7	70.4	70.4	70.4	67.8	67.8	67.8	68.0	68.0	68.0	69.5	70.3	70.3	70.3	70.5	73.5	73.5	73.5	74.1	72.0	72.0	72.0	71.1	71.5	71.5	71.5	71.5	72.5	72.5
#22 11:15 - 11:30	68.0	70.3	70.3	70.3	67.7	67.7	67.7	70.4	70.4	70.4	68.1	70.2	70.2	70.2	73.2	73.5	73.5	73.5	72.9	72.2	72.2	72.2	71.4	72.4	72.4	72.4	72.4	72.7	72.7

ACTUAL

Analysis Period	Seg. 1	Seg. 2	Seg. 3	Seg. 4	Seg. 5	Seg. 6	Seg. 7	Seg. 8	Seg. 9	Seg. 10	Seg. 11	Seg. 12	Seg. 13	Seg. 14	Seg. 15	Seg. 16	Seg. 17	Seg. 18	Seg. 19	Seg. 20	Seg. 21	Seg. 22	Seg. 23	Seg. 24	Seg. 25	Seg. 26	Seg. 27	Seg. 28	Seg. 29
#1 6:00 - 6:15	75.0	71.0	69.4	74.6	71.9	63.3	70.9	71.0	73.5	68.8	74.3	66.9	72.0	69.4	73.5	69.1	71.6	68.5	73.2	67.7	71.7	68.6	73.1	67.9	71.5	74.7	70.4	74.5	74.4
#2 6:15 - 6:30	74.6	70.4	69.3	73.7	69.1	61.6	67.6	70.2	71.6	68.6	73.1	65.6	69.2	68.9	71.6	67.7	68.5	68.3	71.1	66.6	68.7	68.5	71.0	66.7	68.4	73.8	70.0	74.5	73.3
#3 6:30 - 6:45	73.9	69.8	69.2	72.3	65.4	59.0	63.3	69.0	69.0	68.5	71.3	64.1	65.6	65.6	69.1	64.6	64.6	64.6	68.4	64.8	64.8	64.8	68.2	64.4	64.4	72.4	69.6	74.4	71.6
#4 6:45 - 7:00	72.7	69.0	69.1	70.3	60.8	55.1	57.9	65.7	65.7	65.7	68.9	61.0	61.0	61.0	65.7	59.7	59.7	59.7	64.8	60.0	60.0	60.0	64.5	59.4	59.4	70.5	69.2	73.6	69.3
#5 7:00 - 7:15	71.1	66.4	66.9	29.7	35.9	54.1	56.8	64.3	64.3	64.3	67.8	58.5	58.5	58.5	63.9	56.6	56.6	56.6	62.5	56.7	56.7	56.7	62.0	55.8	55.8	69.0	69.0	72.9	67.5
#6 7:15 - 7:30	71.6	62.5	24.6	18.4	35.1	54.2	56.9	64.6	64.6	64.6	68.0	59.1	59.1	59.1	64.4	57.5	57.5	57.5	63.2	57.6	57.6	57.6	62.7	56.9	56.9	69.4	69.0	73.1	68.1
#7 7:30 - 7:45	66.3	36.3	20.8	18.4	35.3	54.2	56.9	64.9	64.9	64.9	68.2	59.7	59.7	59.7	64.8	58.2	58.2	58.2	63.7	58.4	58.4	58.4	63.3	57.7	57.7	69.8	69.1	73.3	68.5
#8 7:45 - 8:00	61.2	34.4	20.8	18.4	35.5	54.2	56.9	65.1	65.1	65.1	68.4	60.2	60.2	60.2	65.2	58.9	58.9	58.9	64.2	59.2	59.2	59.2	64.0	58.7	58.7	70.2	69.1	73.5	68.9
#9 8:00 - 8:15	67.3	51.7	21.3	18.5	35.6	54.2	56.9	65.3	65.3	65.3	68.6	60.8	60.8	60.8	65.6	59.5	59.5	59.5	64.7	60.0	60.0	60.0	64.5	59.5	59.5	70.5	69.2	73.6	69.3
#10 8:15 - 8:30	73.8	69.3	54.2	26.6	36.4	54.2	56.9	65.9	65.9	65.9	69.0	62.0	62.0	62.0	66.5	61.2	61.2	61.2	65.9	61.8	61.8	61.8	65.9	61.5	61.5	71.3	69.4	74.0	70.3
#11 8:30 - 8:45	74.4	70.2	69.3	73.1	67.3	60.2	65.2	69.6	70.3	68.6	72.2	64.9	67.4	67.4	70.3	66.6	66.6	66.6	69.8	65.8	66.8	66.8	69.6	65.8	66.4	73.1	69.8	74.5	72.5
#12 8:45 - 9:00	74.8	70.6	69.4	74.0	69.8	62.0	68.4	70.4	72.1	68.7	73.4	66.0	69.9	69.1	72.1	68.0	69.3	68.4	71.7	66.9	69.4	68.5	71.6	67.0	69.1	74.0	70.1	74.5	73.6
#13 9:00 - 9:15	75.0	70.9	69.4	74.6	71.7	63.1	70.6	70.9	73.3	68.8	74.2	66.8	71.7	69.4	73.3	68.9	71.3	68.5	73.0	67.6	71.4	68.6	72.9	67.8	71.2	74.6	70.4	74.5	74.3
#14 9:15 - 9:30	75.0	71.1	69.4	74.6	72.4	63.5	71.5	71.1	73.7	68.8	74.5	67.1	72.4	69.5	73.8	69.3	72.0	68.5	73.5	67.9	72.1	68.7	73.4	68.1	71.9	74.8	70.5	74.5	74.6
#15 9:30 - 9:45	75.0	71.2	69.4	74.6	73.0	63.9	72.2	71.3	74.1	68.8	74.5	67.3	73.0	69.6	74.1	69.6	72.7	68.6	73.9	68.2	72.7	68.7	73.8	68.4	72.6	74.9	70.6	74.5	74.7
#16 9:45 - 10:00	75.0	71.3	69.4	74.6	73.5	64.2	72.6	71.5	74.4	68.8	74.5	67.6	73.5	69.8	74.4	69.8	73.2	68.6	74.2	68.4	73.3	68.8	74.2	68.6	73.2	75.0	70.7	74.5	74.9
#17 10:00 - 10:15	75.0	71.5	69.4	74.6	73.9	64.4	72.7	71.6	74.6	68.9	74.5	67.8	74.0	69.9	74.6	70.1	73.7	68.7	74.5	68.6	73.8	68.8	74.5	68.9	73.7	75.0	70.8	74.6	75.0
#18 10:15 - 10:30	75.0	71.5	69.4	74.6	73.9	64.4	72.7	71.6	74.6	68.9	74.5	67.8	73.9	69.9	74.6	70.1	73.7	68.7	74.5	68.6	73.8	68.8	74.5	68.8	73.7	75.0	70.8	74.6	75.0
#19 10:30 - 10:45	75.0	71.5	69.4	74.6	73.9	64.4	72.7	71.6	74.6	68.9	74.5	67.8	73.9	69.9	74.6	70.1	73.7	68.7	74.5	68.6	73.7	68.8	74.5	68.8	73.7	75.0	70.8	74.6	75.0
#20 10:45 - 11:00	75.0	71.5	69.4	74.6	73.9	64.4	72.7	71.6	74.6	68.9	74.5	67.8	73.9	69.9	74.6	70.1	73.7	68.7	74.5	68.6	73.7	68.8	74.5	68.8	73.6	75.0	70.8	74.6	75.0
#21 11:00 - 11:15	75.0	71.4	69.4	74.6	73.8	64.4	72.7	71.6	74.6	68.9	74.5	67.8	73.9	69.9	74.6	70.1	73.7	68.7	74.5	68.6	73.7	68.8	74.5	68.8	73.6	75.0	70.8	74.6	75.0
#22 11:15 - 11:30	75.0	71.4	69.4	74.6	73.8	64.4	72.7	71.6	74.6	68.9	74.5	67.7	73.8	69.8	74.6	70.0	73.6	68.6	74.4	68.6	73.6	68.8	74.4	68.8	73.5	75.0	70.8	74.6	74.9

MODEL

After Demand Calibration



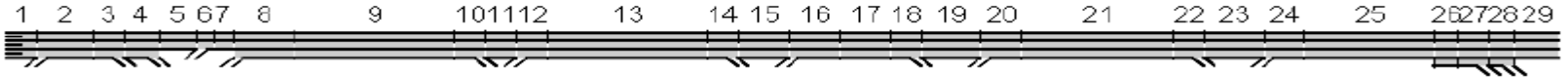
ACTUAL

Analysis Period	Seg. 1	Seg. 2	Seg. 3	Seg. 4	Seg. 5	Seg. 6	Seg. 7	Seg. 8	Seg. 9	Seg. 10	Seg. 11	Seg. 12	Seg. 13	Seg. 14	Seg. 15	Seg. 16	Seg. 17	Seg. 18	Seg. 19	Seg. 20	Seg. 21	Seg. 22	Seg. 23	Seg. 24	Seg. 25	Seg. 26	Seg. 27	Seg. 28	Seg. 29
#1 6:00 - 6:15	65.4	72.6	72.6	72.6	73.0	73.0	73.0	73.0	73.0	73.0	73.4	74.1	74.1	74.1	73.6	73.7	73.7	73.7	72.4	70.5	70.5	70.5	71.8	71.1	71.1	71.1	71.1	72.8	72.8
#2 6:15 - 6:30	68.9	70.4	70.4	70.4	72.5	72.5	72.5	72.1	72.1	72.1	73.3	73.9	73.9	73.9	74.0	74.3	74.3	74.3	74.1	73.4	73.4	73.4	74.5	74.5	74.5	74.5	74.5	72.7	72.7
#3 6:30 - 6:45	73.2	70.8	70.8	70.8	71.1	71.1	71.1	71.5	71.5	71.5	73.1	72.5	72.5	72.5	73.5	73.1	73.1	73.1	72.5	72.0	72.0	72.0	71.7	73.7	73.7	73.7	73.7	72.9	72.9
#4 6:45 - 7:00	72.5	72.6	72.6	72.6	71.3	71.3	71.3	71.6	71.6	71.6	70.8	71.0	71.0	71.0	72.4	71.7	71.7	71.7	71.7	70.8	70.8	70.8	72.0	72.9	72.9	72.9	72.9	73.5	73.5
#5 7:00 - 7:15	73.7	70.3	70.3	70.3	70.7	70.7	70.7	71.9	71.9	71.9	73.3	71.9	71.9	71.9	72.5	72.5	72.5	72.5	72.5	70.8	70.8	70.8	71.7	72.1	72.1	72.1	72.1	73.7	73.7
#6 7:15 - 7:30	68.6	67.6	67.6	67.6	68.4	68.4	68.4	68.4	68.4	68.4	67.4	67.3	67.3	67.3	69.4	68.3	68.3	68.3	69.8	69.1	69.1	69.1	71.7	72.1	72.1	72.1	72.1	71.7	71.7
#7 7:30 - 7:45	67.9	64.7	64.7	64.7	68.6	68.6	68.6	60.9	60.9	60.9	46.5	48.8	48.8	48.8	63.9	62.8	62.8	62.8	59.0	59.1	59.1	59.1	66.4	70.1	70.1	70.1	70.1	70.9	70.9
#8 7:45 - 8:00	71.3	68.7	68.7	68.7	67.8	67.8	67.8	53.9	53.9	53.9	31.5	38.7	38.7	38.7	45.3	46.4	46.4	46.4	36.0	53.9	53.9	53.9	64.8	68.5	68.5	68.5	68.5	68.5	68.5
#9 8:00 - 8:15	71.3	68.1	68.1	68.1	67.1	67.1	67.1	56.1	56.1	56.1	36.8	41.0	41.0	41.0	36.9	43.9	43.9	43.9	44.2	55.1	55.1	55.1	62.3	67.6	67.6	67.6	67.6	70.2	70.2
#10 8:15 - 8:30	72.7	68.7	68.7	68.7	67.5	67.5	67.5	67.3	67.3	67.3	55.9	43.0	43.0	43.0	35.8	43.8	43.8	43.8	42.2	56.9	56.9	56.9	64.6	69.1	69.1	69.1	69.1	71.1	71.1
#11 8:30 - 8:45	70.3	70.8	70.8	70.8	73.0	73.0	73.0	70.5	70.5	70.5	64.3	59.0	59.0	59.0	57.7	54.9	54.9	54.9	46.7	57.0	57.0	57.0	63.8	69.5	69.5	69.5	69.5	70.2	70.2
#12 8:45 - 9:00	71.8	70.9	70.9	70.9	71.1	71.1	71.1	70.1	70.1	70.1	70.3	70.0	70.0	70.0	63.4	54.9	54.9	54.9	57.8	62.4	62.4	62.4	65.7	68.1	68.1	68.1	68.1	70.0	70.0
#13 9:00 - 9:15	73.3	70.9	70.9	70.9	69.7	69.7	69.7	70.3	70.3	70.3	72.9	72.9	72.9	72.9	72.6	73.0	73.0	73.0	73.1	71.2	71.2	71.2	72.5	72.2	72.2	72.2	72.2	73.2	73.2
#14 9:15 - 9:30	73.8	69.8	69.8	69.8	71.3	71.3	71.3	73.6	73.6	73.6	73.3	72.6	72.6	72.6	72.5	73.0	73.0	73.0	72.6	72.3	72.3	72.3	74.4	73.3	73.3	73.3	73.3	73.9	73.9
#15 9:30 - 9:45	70.1	68.5	68.5	68.5	68.3	68.3	68.3	69.8	69.8	69.8	71.4	72.7	72.7	72.7	73.1	73.4	73.4	73.4	73.9	71.7	71.7	71.7	72.1	72.2	72.2	72.2	72.2	73.0	73.0
#16 9:45 - 10:00	67.2	68.7	68.7	68.7	68.2	68.2	68.2	68.1	68.1	68.1	68.9	70.1	70.1	70.1	71.0	71.1	71.1	71.1	71.1	70.5	70.5	70.5	71.9	71.3	71.3	71.3	71.3	72.9	72.9
#17 10:00 - 10:15	69.8	69.1	69.1	69.1	67.4	67.4	67.4	67.7	67.7	67.7	68.1	69.7	69.7	69.7	69.0	70.7	70.7	70.7	71.4	70.7	70.7	70.7	72.7	72.3	72.3	72.3	72.3	72.6	72.6
#18 10:15 - 10:30	72.5	66.9	66.9	66.9	69.1	69.1	69.1	72.7	72.7	72.7	74.4	74.0	74.0	74.0	72.9	72.1	72.1	72.1	72.3	71.1	71.1	71.1	73.5	74.2	74.2	74.2	74.2	73.9	73.9
#19 10:30 - 10:45	69.9	69.8	69.8	69.8	70.9	70.9	70.9	70.5	70.5	70.5	70.7	71.4	71.4	71.4	71.1	71.6	71.6	71.6	73.7	73.3	73.3	73.3	73.3	73.6	73.6	73.6	73.6	73.5	73.5
#20 10:45 - 11:00	69.0	67.0	67.0	67.0	68.0	68.0	68.0	68.3	68.3	68.3	69.4	69.7	69.7	69.7	69.6	70.5	70.5	70.5	71.4	70.8	70.8	70.8	71.5	71.8	71.8	71.8	71.8	73.1	73.1
#21 11:00 - 11:15	68.7	70.4	70.4	70.4	67.8	67.8	67.8	68.0	68.0	68.0	69.5	70.3	70.3	70.3	70.5	73.5	73.5	73.5	74.1	72.0	72.0	72.0	71.1	71.5	71.5	71.5	71.5	72.5	72.5
#22 11:15 - 11:30	68.0	70.3	70.3	70.3	67.7	67.7	67.7	70.4	70.4	70.4	68.1	70.2	70.2	70.2	73.2	73.5	73.5	73.5	72.9	72.2	72.2	72.2	71.4	72.4	72.4	72.4	72.4	72.7	72.7

MODEL

Analysis Period	Seg. 1	Seg. 2	Seg. 3	Seg. 4	Seg. 5	Seg. 6	Seg. 7	Seg. 8	Seg. 9	Seg. 10	Seg. 11	Seg. 12	Seg. 13	Seg. 14	Seg. 15	Seg. 16	Seg. 17	Seg. 18	Seg. 19	Seg. 20	Seg. 21	Seg. 22	Seg. 23	Seg. 24	Seg. 25	Seg. 26	Seg. 27	Seg. 28	Seg. 29
#1 6:00 - 6:15	75.0	72.1	69.3	74.6	75.0	65.7	73.0	72.2	75.0	68.6	74.4	67.9	74.6	70.5	74.8	70.0	73.7	69.4	74.1	68.4	73.3	68.8	74.1	68.7	73.3	75.0	71.3	74.6	74.7
#2 6:15 - 6:30	75.0	71.8	69.4	74.6	75.0	65.5	72.9	72.0	75.0	68.6	74.5	67.5	74.1	70.3	74.5	69.7	73.1	69.4	73.5	68.2	72.6	68.7	73.8	68.5	72.9	74.9	71.5	74.6	74.4
#3 6:30 - 6:45	75.0	71.5	69.6	74.6	74.7	65.0	72.8	71.7	74.7	68.8	74.5	66.7	72.7	70.0	73.3	68.8	71.1	69.3	71.7	67.3	70.3	68.5	72.2	67.8	70.9	74.5	71.4	74.6	73.3
#4 6:45 - 7:00	75.0	71.0	69.6	74.6	73.1	64.0	72.4	71.1	73.8	68.8	74.5	65.3	70.0	69.7	70.9	67.3	67.7	67.7	68.5	65.9	66.5	66.5	69.6	66.7	67.9	73.6	71.3	74.5	71.1
#5 7:00 - 7:15	74.5	70.4	69.6	73.4	69.6	62.0	68.3	70.3	71.9	68.8	73.1	62.9	65.5	65.5	66.8	62.3	62.3	62.3	63.3	60.7	60.7	60.7	65.4	63.0	63.0	71.9	71.2	73.2	67.2
#6 7:15 - 7:30	73.3	69.7	69.5	71.6	64.6	58.7	62.8	69.5	69.7	68.7	71.4	60.1	61.0	61.0	62.6	57.1	57.1	57.1	58.3	55.0	55.0	55.0	61.4	58.4	58.4	70.1	70.1	71.7	63.4
#7 7:30 - 7:45	72.1	69.2	69.5	70.0	60.2	55.1	58.0	67.6	67.6	67.6	69.5	56.1	49.5	42.5	32.7	56.8	50.5	54.4	38.5	56.8	56.8	56.8	63.0	60.3	60.3	70.8	70.8	72.3	64.7
#8 7:45 - 8:00	71.8	69.0	69.1	69.4	57.9	53.0	55.5	66.1	59.6	37.1	24.0	40.0	40.1	34.9	30.2	49.4	48.0	41.2	35.7	56.9	56.9	56.9	63.3	60.6	60.6	71.0	71.0	72.3	64.7
#9 8:00 - 8:15	72.6	69.3	69.5	70.5	60.3	55.2	58.1	67.3	48.1	31.1	20.4	37.1	40.7	35.8	29.5	48.0	45.8	48.5	36.7	56.9	56.9	56.9	63.7	61.1	61.1	71.1	71.1	72.4	65.1
#10 8:15 - 8:30	73.9	70.0	69.6	72.3	65.0	58.9	63.1	69.4	64.4	44.4	22.2	37.0	42.0	44.0	32.6	47.3	45.4	40.3	35.3	56.9	56.9	56.9	63.9	61.2	61.2	71.2	71.2	72.5	65.3
#11 8:30 - 8:45	74.8	70.6	69.6	73.8	69.3	61.8	67.9	70.2	71.8	68.8	66.1	56.7	47.7	39.7	31.3	49.3	42.1	37.6	35.2	56.9	56.9	56.9	64.1	61.5	61.5	71.3	71.2	72.6	65.7
#12 8:45 - 9:00	75.0	71.2	69.6	74.6	72.5	63.6	71.6	71.0	73.6	68.8	74.4	60.9	61.5	62.9	43.7	48.0	41.0	39.5	35.3	56.9	56.9	56.9	64.2	61.5	61.5	71.3	71.1	72.7	66.0
#13 9:00 - 9:15	75.0	71.6	69.5	74.6	74.3	64.6	72.7	71.5	74.5	68.8	74.5	62.7	68.1	68.1	69.4	68.4	62.7	62.3	48.3	59.8	59.8	59.8	66.1	63.6	63.6	72.1	71.2	73.3	67.6
#14 9:15 - 9:30	75.0	71.8	69.4	74.6	74.9	65.2	72.8	71.8	74.9	68.7	74.5	63.6	69.8	69.5	71.0	67.2	67.6	67.6	68.3	65.7	66.0	66.0	70.1	66.8	68.2	73.7	71.5	74.5	71.1
#15 9:30 - 9:45	75.0	72.0	69.2	74.6	75.0	65.5	72.9	72.1	75.0	68.6	74.4	64.5	71.2	69.7	72.3	68.0	69.4	69.3	70.0	66.4	68.0	68.0	71.3	67.3	69.6	74.2	71.6	74.6	72.2
#16 9:45 - 10:00	75.0	72.2	69.1	74.6	75.0	65.7	73.0	72.2	75.0	68.4	74.4	65.0	72.1	69.7	73.1	68.6	70.6	69.4	71.2	67.0	69.4	68.1	72.1	67.7	70.7	74.5	71.5	74.6	73.0
#17 10:00 - 10:15	75.0	72.3	69.1	74.6	75.0	65.8	73.0	72.4	75.0	68.3	74.4	65.3	72.7	69.8	73.6	69.0	71.5	69.4	72.1	67.3	70.5	68.2	72.7	68.0	71.4	74.7	71.7	74.6	73.4
#18 10:15 - 10:30	75.0	72.3	69.0	74.6	75.0	65.9	73.0	72.4	75.0	68.3	74.4	65.6	73.1	69.8	74.0	69.2	72.0	69.4	72.5	67.5	71.0	68.3	73.1	68.1	71.8	74.7	71.6	74.6	73.7
#19 10:30 - 10:45	75.0	72.4	68.9	74.6	75.0	65.9	73.0	72.5	75.0	68.3	74.4	68.0	74.9	70.5	74.8	70.6	74.6	69.5	74.8	68.8	74.2	68.6	74.8	69.2	74.3	75.0	72.0	74.7	74.9
#20 10:45 - 11:00	75.0	72.4	68.9	74.5	75.0	65.9	73.0	72.5	75.0	68.3	74.4	68.2	75.0	70.5	74.8	70.6	74.7	69.5	74.8	68.9	74.3	68.6	74.8	69.2	74.3	75.0	72.0	74.7	74.9
#21 11:00 - 11:15	75.0	72.4	68.9	74.5	75.0	66.0	73.0	72.6	75.0	68.3	74.4	68.3	75.0	70.6	74.8	70.8	74.9	69.5	74.8	69.0	74.6	68.6	74.8	69.4	74.6	75.0	71.7	74.7	75.0

After Demand and Capacity Calibration

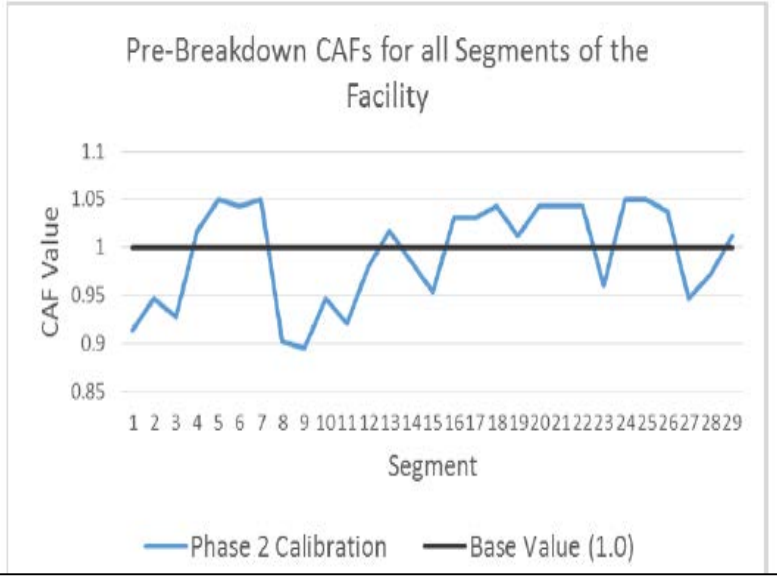


Analysis Period	Seg. 1	Seg. 2	Seg. 3	Seg. 4	Seg. 5	Seg. 6	Seg. 7	Seg. 8	Seg. 9	Seg. 10	Seg. 11	Seg. 12	Seg. 13	Seg. 14	Seg. 15	Seg. 16	Seg. 17	Seg. 18	Seg. 19	Seg. 20	Seg. 21	Seg. 22	Seg. 23	Seg. 24	Seg. 25	Seg. 26	Seg. 27	Seg. 28	Seg. 29
#1 6:00 - 6:15	65.4	72.6	72.6	72.6	73.0	73.0	73.0	73.0	73.0	73.0	73.4	74.1	74.1	74.1	73.6	73.7	73.7	73.7	72.4	70.5	70.5	70.5	71.8	71.1	71.1	71.1	71.1	72.8	72.8
#2 6:15 - 6:30	68.9	70.4	70.4	70.4	72.5	72.5	72.5	72.1	72.1	72.1	73.3	73.9	73.9	73.9	74.0	74.3	74.3	74.3	74.1	73.4	73.4	73.4	74.5	74.5	74.5	74.5	74.5	72.7	72.7
#3 6:30 - 6:45	73.2	70.8	70.8	70.8	71.1	71.1	71.1	71.5	71.5	71.5	73.1	72.5	72.5	72.5	73.5	73.1	73.1	73.1	72.5	72.0	72.0	72.0	71.7	73.7	73.7	73.7	73.7	72.9	72.9
#4 6:45 - 7:00	72.5	72.6	72.6	72.6	71.3	71.3	71.3	71.6	71.6	71.6	70.8	71.0	71.0	71.0	72.4	71.7	71.7	71.7	71.7	70.8	70.8	70.8	72.0	72.9	72.9	72.9	72.9	73.5	73.5
#5 7:00 - 7:15	73.7	70.3	70.3	70.3	70.7	70.7	70.7	71.9	71.9	71.9	73.3	71.9	71.9	71.9	72.5	72.5	72.5	72.5	72.5	70.8	70.8	70.8	71.7	72.1	72.1	72.1	72.1	73.7	73.7
#6 7:15 - 7:30	68.6	67.6	67.6	67.6	68.4	68.4	68.4	68.4	68.4	68.4	67.4	67.3	67.3	67.3	69.4	68.3	68.3	68.3	69.8	69.1	69.1	69.1	71.7	72.1	72.1	72.1	72.1	71.7	71.7
#7 7:30 - 7:45	67.9	64.7	64.7	64.7	68.6	68.6	68.6	60.9	60.9	60.9	46.5	48.8	48.8	48.8	63.9	62.8	62.8	62.8	59.0	59.1	59.1	59.1	66.4	70.1	70.1	70.1	70.1	70.9	70.9
#8 7:45 - 8:00	71.3	68.7	68.7	68.7	67.8	67.8	67.8	53.9	53.9	53.9	31.5	38.7	38.7	38.7	45.3	46.4	46.4	46.4	36.0	53.9	53.9	53.9	64.8	68.5	68.5	68.5	68.5	68.5	68.5
#9 8:00 - 8:15	71.3	68.1	68.1	68.1	67.1	67.1	67.1	56.1	56.1	56.1	36.8	41.0	41.0	41.0	36.9	43.9	43.9	43.9	44.2	55.1	55.1	55.1	62.3	67.6	67.6	67.6	67.6	70.2	70.2
#10 8:15 - 8:30	72.7	68.7	68.7	68.7	67.5	67.5	67.5	67.3	67.3	67.3	55.9	43.0	43.0	43.0	35.8	43.8	43.8	43.8	42.2	56.9	56.9	56.9	64.6	69.1	69.1	69.1	69.1	71.1	71.1
#11 8:30 - 8:45	70.3	70.8	70.8	70.8	73.0	73.0	73.0	70.5	70.5	70.5	64.3	59.0	59.0	59.0	57.7	54.9	54.9	54.9	46.7	57.0	57.0	57.0	63.8	69.5	69.5	69.5	69.5	70.2	70.2
#12 8:45 - 9:00	71.8	70.9	70.9	70.9	71.1	71.1	71.1	70.1	70.1	70.1	70.3	70.0	70.0	70.0	63.4	54.9	54.9	54.9	57.8	62.4	62.4	62.4	65.7	68.1	68.1	68.1	68.1	70.0	70.0
#13 9:00 - 9:15	73.3	70.9	70.9	70.9	69.7	69.7	69.7	70.3	70.3	70.3	72.9	72.9	72.9	72.9	72.6	73.0	73.0	73.0	73.1	71.2	71.2	71.2	72.5	72.2	72.2	72.2	72.2	73.2	73.2
#14 9:15 - 9:30	73.8	69.8	69.8	69.8	71.3	71.3	71.3	73.6	73.6	73.6	73.3	72.6	72.6	72.6	72.5	73.0	73.0	73.0	72.6	72.3	72.3	72.3	74.4	73.3	73.3	73.3	73.3	73.9	73.9
#15 9:30 - 9:45	70.1	68.5	68.5	68.5	68.3	68.3	68.3	69.8	69.8	69.8	71.4	72.7	72.7	72.7	73.1	73.4	73.4	73.4	73.9	71.7	71.7	71.7	72.1	72.2	72.2	72.2	72.2	73.0	73.0
#16 9:45 - 10:00	67.2	68.7	68.7	68.7	68.2	68.2	68.2	68.1	68.1	68.1	68.9	70.1	70.1	70.1	71.0	71.1	71.1	71.1	71.1	70.5	70.5	70.5	71.9	71.3	71.3	71.3	71.3	72.9	72.9
#17 10:00 - 10:15	69.8	69.1	69.1	69.1	67.4	67.4	67.4	67.7	67.7	67.7	68.1	69.7	69.7	69.7	69.0	70.7	70.7	70.7	71.4	70.7	70.7	70.7	72.7	72.3	72.3	72.3	72.3	72.6	72.6
#18 10:15 - 10:30	72.5	66.9	66.9	66.9	69.1	69.1	69.1	72.7	72.7	72.7	74.4	74.0	74.0	74.0	72.9	72.1	72.1	72.1	72.3	71.1	71.1	71.1	73.5	74.2	74.2	74.2	74.2	73.9	73.9
#19 10:30 - 10:45	69.9	69.8	69.8	69.8	70.9	70.9	70.9	70.5	70.5	70.5	70.7	71.4	71.4	71.4	71.1	71.6	71.6	71.6	73.7	73.3	73.3	73.3	73.6	73.6	73.6	73.6	73.6	73.5	73.5
#20 10:45 - 11:00	69.0	67.0	67.0	67.0	68.0	68.0	68.0	68.3	68.3	68.3	69.4	69.7	69.7	69.7	69.6	70.5	70.5	70.5	71.4	70.8	70.8	70.8	71.5	71.8	71.8	71.8	71.8	73.1	73.1
#21 11:00 - 11:15	68.7	70.4	70.4	70.4	67.8	67.8	67.8	68.0	68.0	68.0	69.5	70.3	70.3	70.3	70.5	73.5	73.5	73.5	74.1	72.0	72.0	72.0	71.1	71.5	71.5	71.5	71.5	72.5	72.5
#22 11:15 - 11:30	68.0	70.3	70.3	70.3	67.7	67.7	67.7	70.4	70.4	70.4	68.1	70.2	70.2	70.2	73.2	73.5	73.5	73.5	72.9	72.2	72.2	72.2	71.4	72.4	72.4	72.4	72.4	72.7	72.7

Analysis Period	Seg. 1	Seg. 2	Seg. 3	Seg. 4	Seg. 5	Seg. 6	Seg. 7	Seg. 8	Seg. 9	Seg. 10	Seg. 11	Seg. 12	Seg. 13	Seg. 14	Seg. 15	Seg. 16	Seg. 17	Seg. 18	Seg. 19	Seg. 20	Seg. 21	Seg. 22	Seg. 23	Seg. 24	Seg. 25	Seg. 26	Seg. 27	Seg. 28	Seg. 29
#1 6:00 - 6:15	75.0	72.0	69.3	74.6	75.0	65.7	73.0	72.1	74.5	68.6	74.5	67.8	74.6	70.5	74.2	69.9	74.0	69.4	74.0	68.3	73.8	68.8	73.0	68.5	74.0	75.0	71.2	74.6	74.7
#2 6:15 - 6:30	75.0	71.8	69.5	74.6	75.0	65.4	72.9	71.9	74.0	68.6	74.5	67.4	74.2	70.2	73.5	69.5	73.4	69.3	73.4	68.0	73.3	68.6	72.4	68.4	73.6	75.0	71.4	74.6	74.4
#3 6:30 - 6:45	74.9	71.4	69.6	74.6	74.9	64.9	72.8	71.5	72.7	68.7	74.3	66.5	72.8	70.0	71.5	68.5	71.6	69.3	71.5	67.0	71.3	68.4	70.1	67.5	72.1	74.7	71.3	74.6	73.2
#4 6:45 - 7:00	74.2	70.9	69.6	74.6	73.8	63.7	72.5	70.4	70.1	68.8	72.8	64.9	70.1	68.5	67.9	66.8	68.4	69.1	68.2	65.5	68.1	68.1	66.5	66.3	69.6	74.0	71.2	73.8	70.9
#5 7:00 - 7:15	72.5	70.3	69.6	73.4	71.0	61.5	70.0	66.3	65.9	68.8	69.7	62.2	65.6	63.1	62.0	63.4	63.4	64.4	62.8	62.7	63.0	63.0	60.8	64.0	65.5	72.5	68.9	72.0	66.8
#6 7:15 - 7:30	69.9	68.1	67.0	71.6	66.8	57.7	65.3	62.2	61.6	65.7	66.7	57.1	61.0	57.8	56.2	58.5	58.5	59.8	57.6	57.9	57.9	57.9	55.4	61.5	61.6	70.9	66.2	70.0	62.9
#7 7:30 - 7:45	67.6	65.7	64.2	70.0	63.1	53.5	61.2	58.4	57.7	62.6	63.5	52.2	47.5	42.6	37.9	58.3	58.3	58.7	42.4	58.9	58.9	58.9	56.7	62.2	62.6	71.3	67.0	70.4	63.7
#8 7:45 - 8:00	67.0	64.8	63.3	69.4	61.1	50.9	59.1	55.8	54.9	62.8	28.9	47.1	39.5	37.7	37.1	58.3	52.7	41.6	40.3	58.9	58.9	58.9	57.2	62.4	62.9	71.5	67.2	70.5	63.8
#9 8:00 - 8:15	68.5	66.4	65.1	70.5	63.2	53.5	61.3	57.9	56.1	60.4	30.1	46.0	47.8	42.3	37.6	43.7	40.8	38.9	39.7	58.9	58.9	58.9	57.8	62.7	63.4	71.6	67.5	70.7	64.2
#10 8:15 - 8:30	71.1	69.3	68.3	72.3	67.2	57.9	65.6	62.0	61.5	65.4	39.1	42.3	38.6	41.0	38.6	48.4	45.8	40.0	39.6	58.9	58.9	58.9	57.9	62.8	63.4	71.7	67.5	70.8	64.4
#11 8:30 - 8:45	73.3	70.5	69.6	73.9	70.8	61.2	69.6	66.2	65.8	68.8	58.8	49.2	42.5	60.4	52.5	52.9	46.8	41.1	39.6	58.9	58.9	58.9	58.3	62.9	63.7	71.8	67.7	71.0	64.8
#12 8:45 - 9:00	74.6	71.0	69.6	74.6	73.4	63.3	72.4	69.9	69.6	68.8	72.4	60.4	65.8	62.1	61.6	59.1	57.5	50.2	43.0	59.0	59.0	59.0	58.5	63.0	63.8	71.8	67.8	71.1	65.2
#13 9:00 - 9:15	75.0	71.5	69.6	74.6	74.7	64.5	72.7	71.4	72.1	68.8	74.0	62.3	68.5	66.6	66.2	65.7	66.8	67.5	66.2	64.4	66.1	66.1	65.6	65.8	68.8	73.7	71.2	73.3	69.7
#14 9:15 - 9:30	75.0	71.8	69.4	74.6	75.0	65.1	72.8	71.7	73.4	68.7	74.5	63.4	70.2	68.6	68.4	66.9	68.7	69.2	68.3	65.4	68.0	67.8	67.4	66.5	70.1	74.2	71.5	73.9	71.1
#15 9:30 - 9:45	75.0	72.0	69.3	74.6	75.0	65.4	72.9	72.0	74.2	68.6	74.4	64.3	71.5	69.6	70.2	67.8	70.3	69.3	70.0	66.2	69.7	68.0	69.1	67.1	71.2	74.5	71.5	74.4	72.2
#16 9:45 - 10:00	75.0	72.1	69.2	74.6	75.0	65.6	72.9	72.2	74.6	68.4	74.4	64.8	72.4	69.7	71.5	68.4	71.4	69.3	71.2	66.8	70.9	68.1	70.2	67.5	72.1	74.7	71.5	74.6	73.0
#17 10:00 - 10:15	75.0	72.2	69.1	74.6	75.0	65.7	73.0	72.3	74.9	68.4	74.4	65.2	72.9	69.7	72.3	68.8	72.2	69.3	72.1	67.2	71.7	68.2	71.1	67.8	72.6	74.8	71.6	74.6	73.4
#18 10:15 - 10:30	75.0	72.3	69.0	74.6	75.0	65.8	73.0	72.4	75.0	68.4	74.4	65.4	73.3	69.7	72.8	69.1	72.6	69.4	72.5	67.4	72.2	68.3	71.5	68.0	72.9	74.9	71.6	74.6	73.7
#19 10:30 - 10:45	75.0	72.3	68.9	74.6	75.0	65.9	73.0	72.5	75.0	68.3	74.4	67.1	74.6	70.1	74.4	70.0	74.3	69.4	74.2	68.3	73.9	68.5	73.5	68.7	74.2	75.0	71.8	74.7	74.7
#20 10:45 - 11:00	75.0	72.3	68.9	74.6	75.0	65.9	73.0	72.5	75.0	68.3	74.4	68.1	75.0	70.5	74.8	70.5	74.8	69.5	74.8	68.7	74.6	68.6	74.3	69.1	74.7	75.0	71.9	74.7	74.9
#21 11:00 - 11:15	75.0	72.3	68.9	74.5	75.0	65.9	73.0	72.5	75.0	68.3	74.4	68.3	75.0	70.5	74.8	70.7	74.9	69.5	74.8	68.9	74.8	68.6	74.6	69.3	74.9	75.0	71.7	74.7	75.0

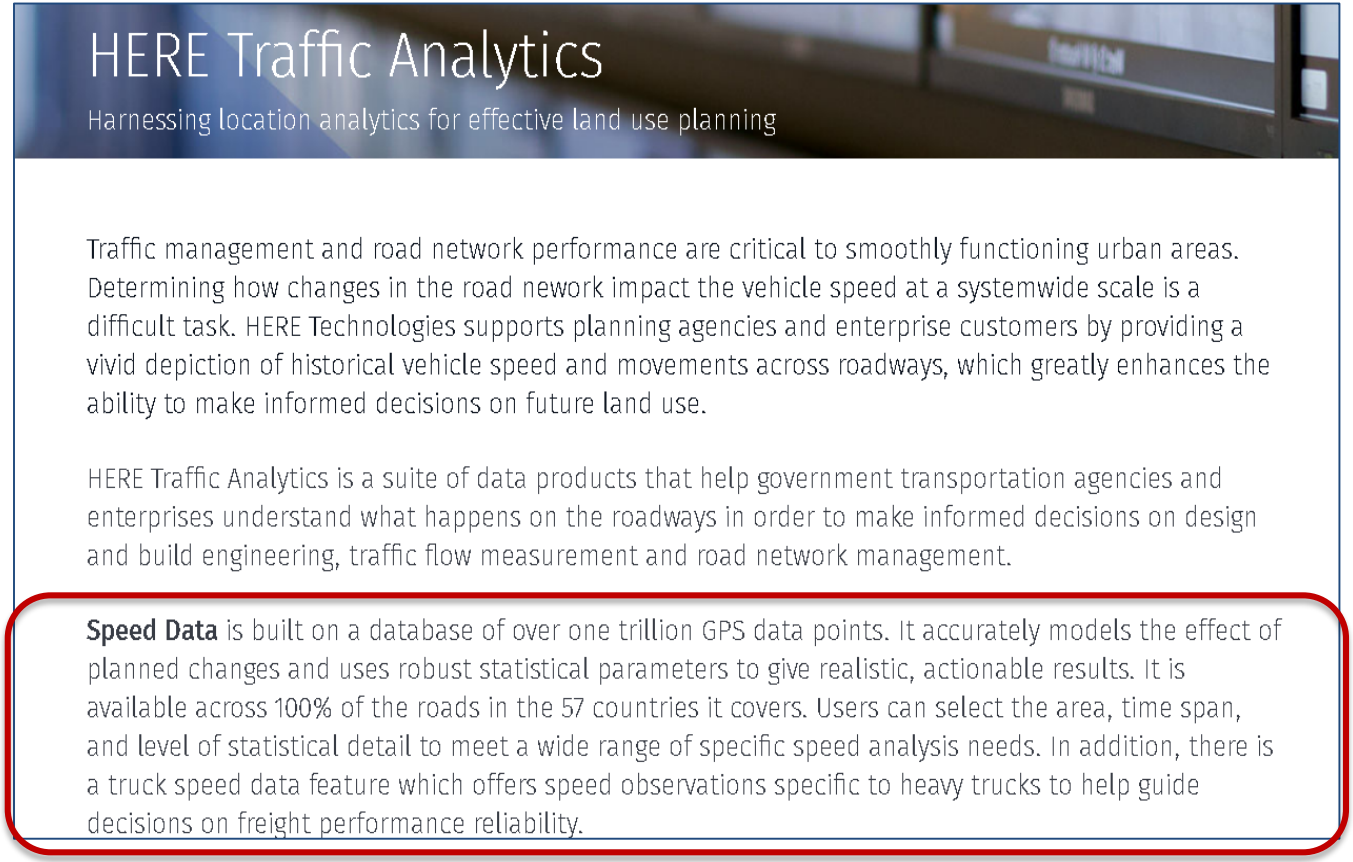
Calibration Results

Error	All Speeds	$v_{i,p} < 65$	$v_{i,p} < 55$	$v_{i,p} < 45$	$v_{i,p} < 35$
Uncalibrated	6.12 mph	12.91 mph	17.21 mph	21.83 mph	36.86 mph
After Phase 1	4.15 mph	7.24 mph	6.55 mph	4.19 mph	7.54 mph
% Improvement	32.09%	43.86%	61.97%	80.78%	79.53%
After Phase 2	3.73 mph	4.85 mph	4.67 mph	3.32 mph	2.62 mph
% Improvement over Phase 1	10.13%	33.05%	28.55%	20.86%	65.28%
% Improvement over uncalibrated	39.05%	62.43%	72.86%	84.79%	92.89%



Advanced Speed Reports

- Available from HERE
- “Speed Data” feature
- Provides more detailed speed info
- Recognizes levels of gap filling
- Truck reports available



HERE Traffic Analytics

Harnessing location analytics for effective land use planning

Traffic management and road network performance are critical to smoothly functioning urban areas. Determining how changes in the road nework impact the vehicle speed at a systemwide scale is a difficult task. HERE Technologies supports planning agencies and enterprise customers by providing a vivid depiction of historical vehicle speed and movements across roadways, which greatly enhances the ability to make informed decisions on future land use.

HERE Traffic Analytics is a suite of data products that help government transportation agencies and enterprises understand what happens on the roadways in order to make informed decisions on design and build engineering, traffic flow measurement and road network management.

Speed Data is built on a database of over one trillion GPS data points. It accurately models the effect of planned changes and uses robust statistical parameters to give realistic, actionable results. It is available across 100% of the roads in the 57 countries it covers. Users can select the area, time span, and level of statistical detail to meet a wide range of specific speed analysis needs. In addition, there is a truck speed data feature which offers speed observations specific to heavy trucks to help guide decisions on freight performance reliability.

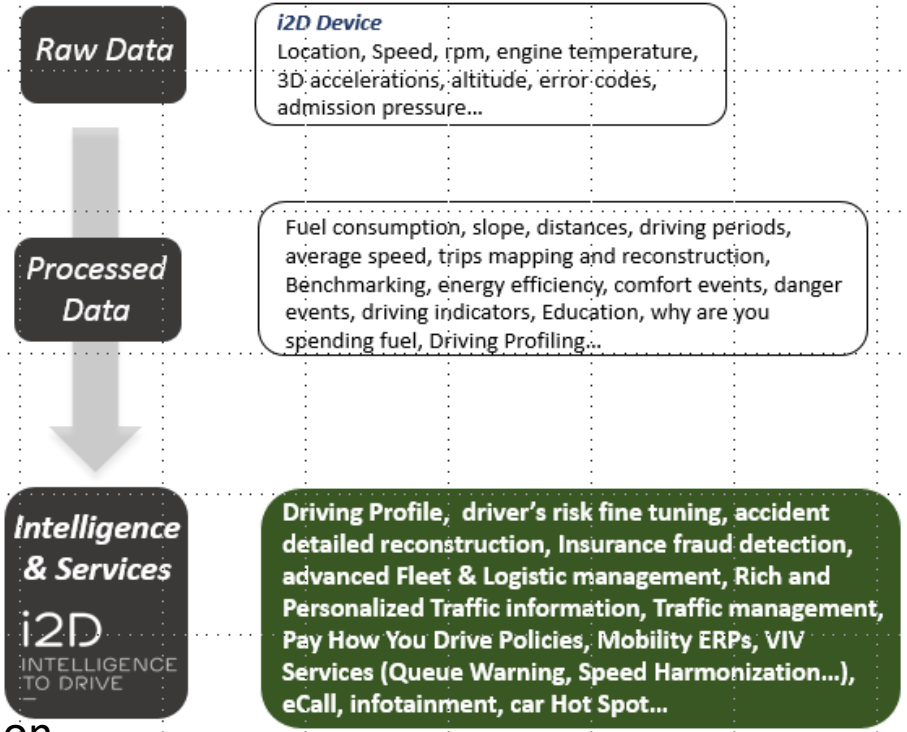
I. Introduction and definitions
II. Link-based data and modeling applications
III. Vehicle-based data and modeling applications
IV. Emerging research and application opportunities
V. Questions and discussion

III. Individual Vehicle Based Data

- Data sources: GPS, AVL, OBDII, Mobile device, CV sensors
- Provides detailed vehicle trajectories at various time resolution from 1→ 100 Hz.
- Types of data generated depends on the source
- Will focus here on an OBD-II based system at NC State operating on a fleet of about 30 vehicles using volunteer drivers in a naturalistic driving setting (part of larger fleet)
- Will also demo data visualization from CV sensors, time permitting

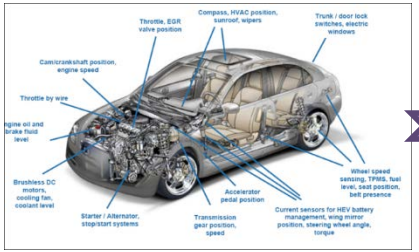
i2D –Intelligence to Drive

- About 50 million records of data recorded at ITRE/ NC State and continuing
- About 40 data items extracted each second
- Archived in a SQL database
- Can provide individual and fleet-wide information



i2D Technology Integration Process

Vehicles Sensors



OBD Port

i2D Device

Web Access

Additional Sensors

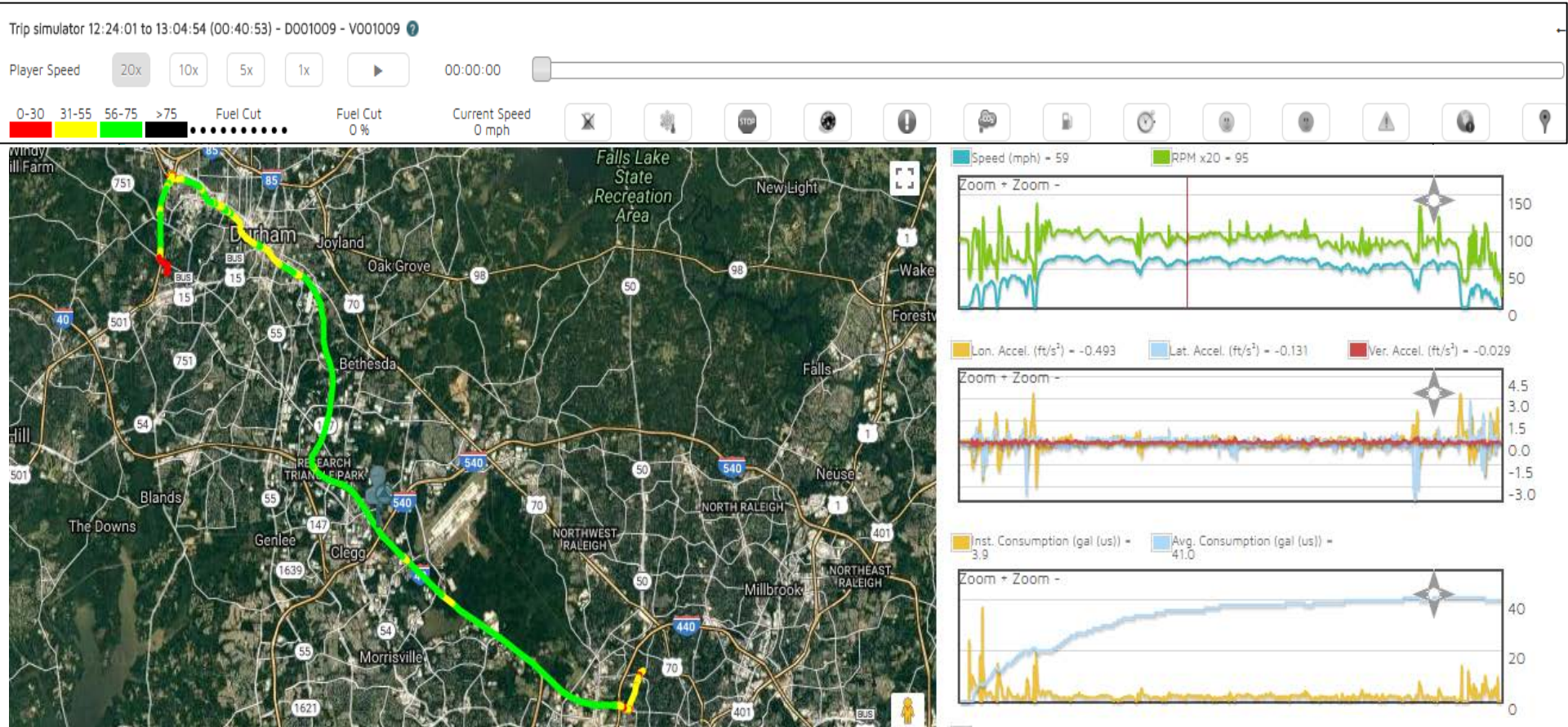
Memory

Processor

Cellular Network

Trips and Trip Statistics

https://app.i2d.co

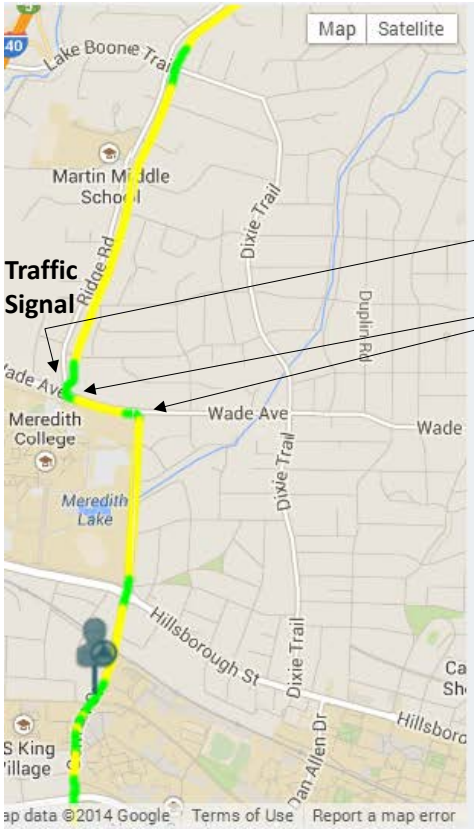


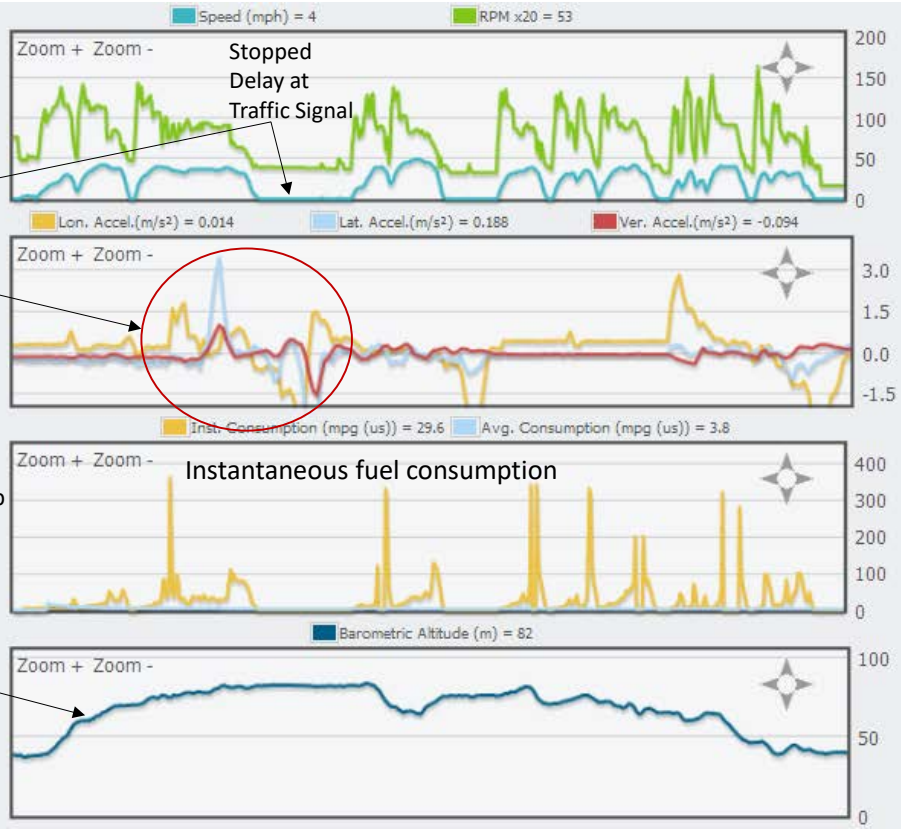
Modeling Applications of Vehicle Data

- Calibration of vehicle dynamics data at intersections
- Predicting shock wave speeds and their reach
- Detecting, documenting and characterizing lane changes

Network monitoring of high deceleration events. Portugal

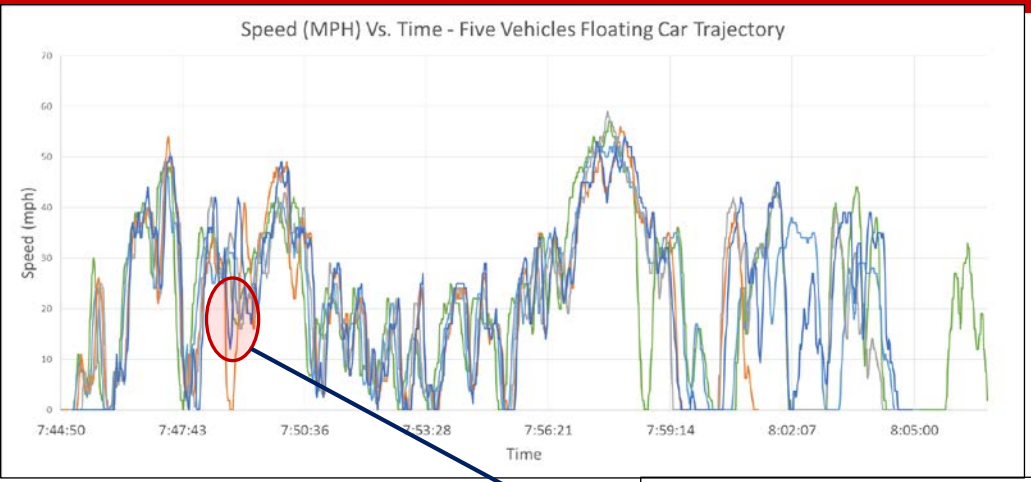
Trajectory Details and Contextual Data





The blue lines to the right show the lateral acceleration The up and down pulse indicates two consecutive turns in the opposite direction as shown in the map

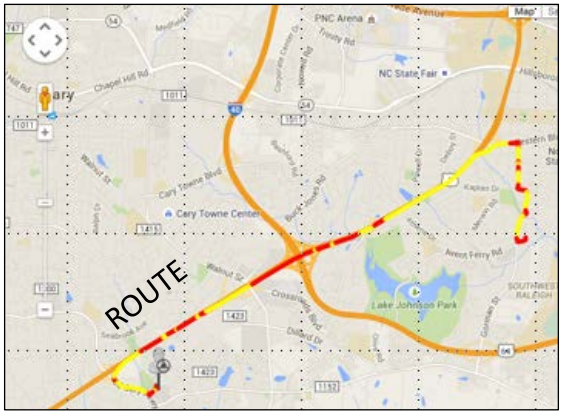
The line to the right shows road elevations measured using a barometric altimeter

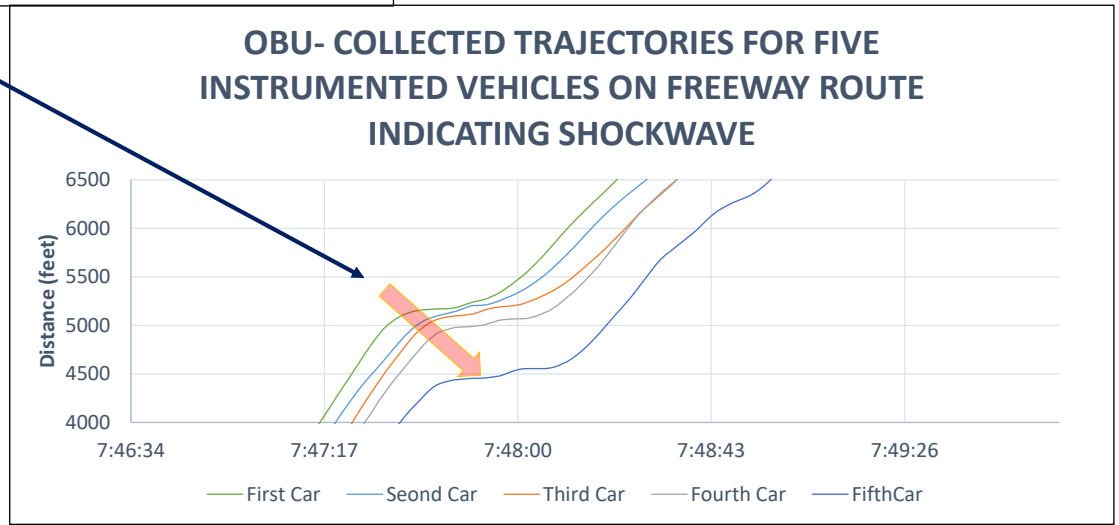


ITRE DATA LAB- FREEWAY ROUTE

ITRE DATA (Driver and Transportation Analytics) lab continuously collect 1Hz data for 15-20 vehicles in their naturalistic driving environment. Data dates back to April 2014 until now.

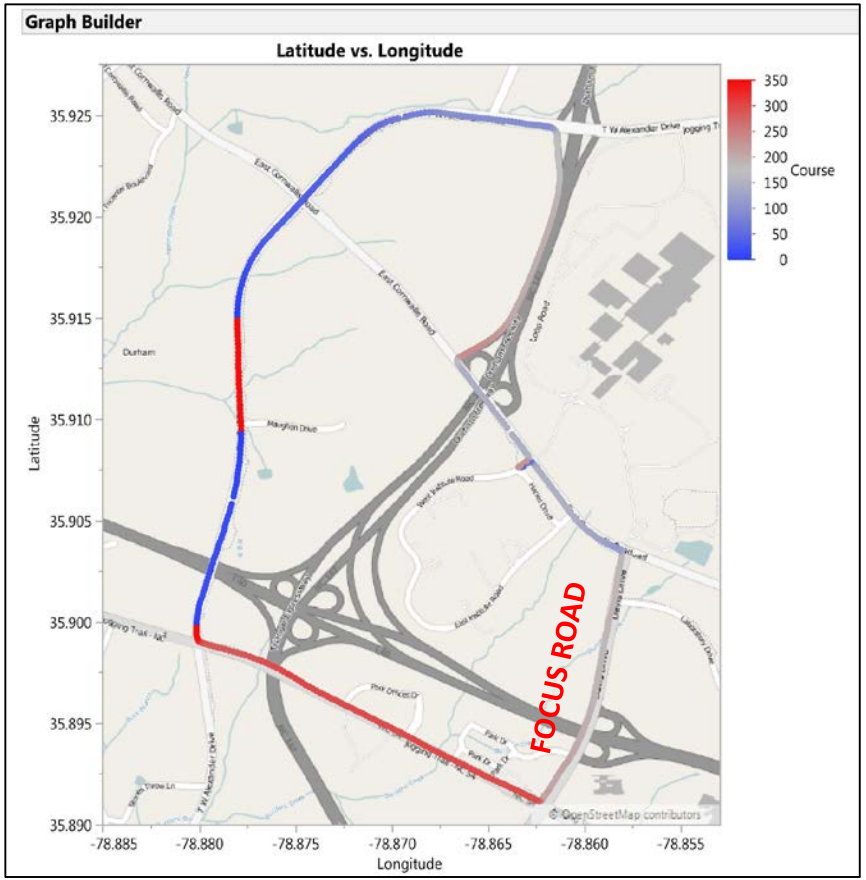
The data in this slide are collected at 1Hz resolution from On-Board-Units (OBU) connected to OBD-II. Instrumented vehicles were deployed, in a controlled experiment setting, at 1-3 minutes headways on a freeway route during the congested peak period (see map). Vehicle trajectories indicate the incidence of a shock wave affecting the first vehicle about 1 mile after entry and affecting the 5th vehicle tailing the others as well. Estimate of shockwave speed can be derived from the trajectories.





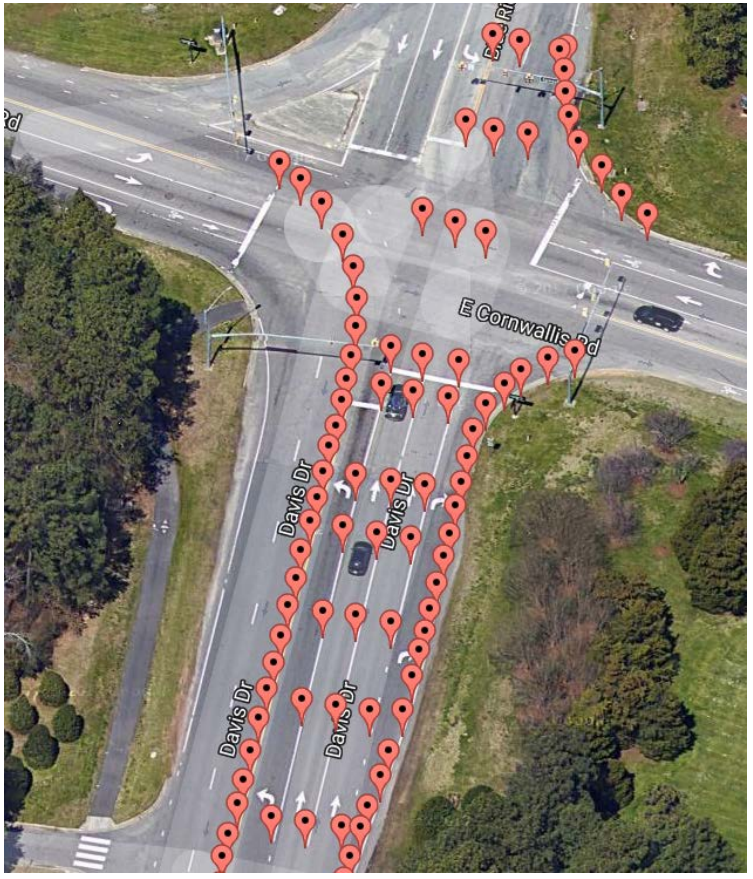
Detecting and Characterizing Lane Changes

- Enabled by integrating digital road infrastructure and vehicle position data
- Emulates how autonomous vehicles will eventually navigate urban road environments using own sensors
- Pilot testing on a 10km testbed using pre-planned lane changes to validate the lane detection model
- 6 trips, 3 in each direction (CW, CCW) were made and videotaped to confirm lane change position and timing.

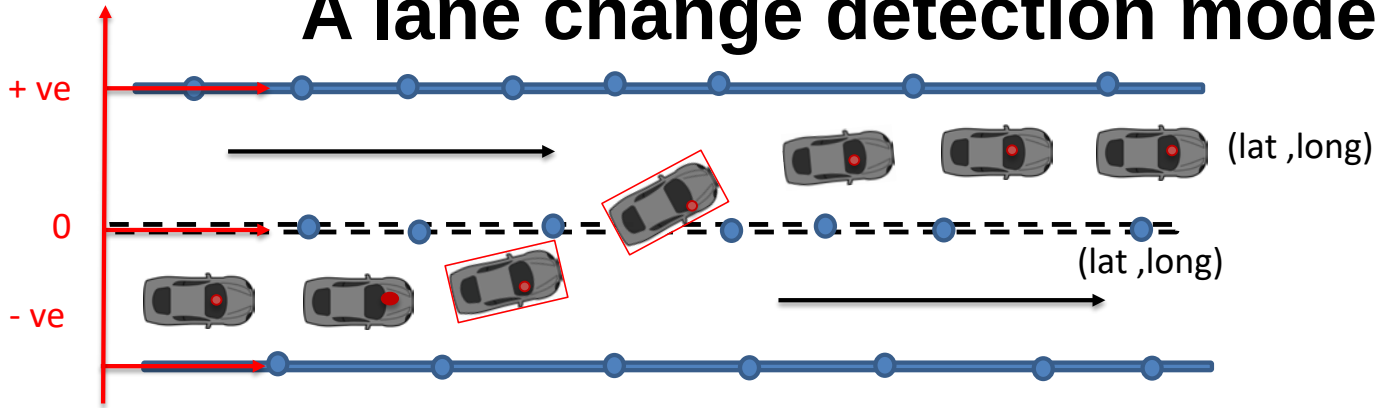


Digitizing the Route

- Latitude and longitude for each lane edge and lane separator was extracted into a road database on the pilot testbed
- This was done in intervals of 12 m for the interior lanes, and 4 m on the outer edges
- At intersections, both through and turning paths are also digitized



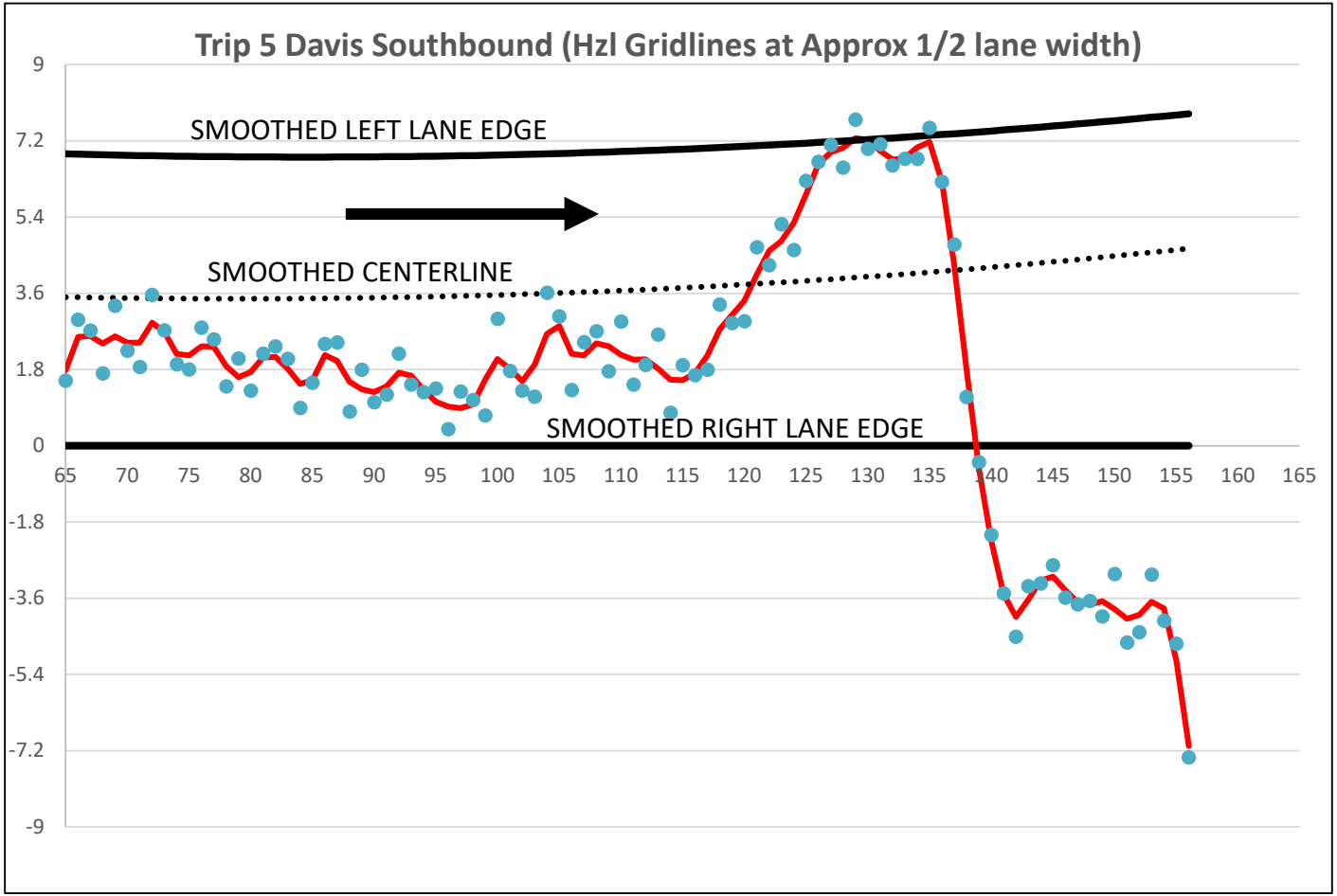
A lane change detection model



- Model assumes vehicle GPS data are reliable and accurate (?)
- Each lane edge of the road is digitized with its lats & longs at 1 Hz intervals
- Vehicle GPS *knows* its lats & longs at 1-10 Hz resolution
- Conceptually simple: calculate the distance from the vehicle GPS receiver to each lane edge
- Distances and lane positions smoothed to account for GPS data noise; lane changes detected when CL is crossed and are tracked until distance stabilizes

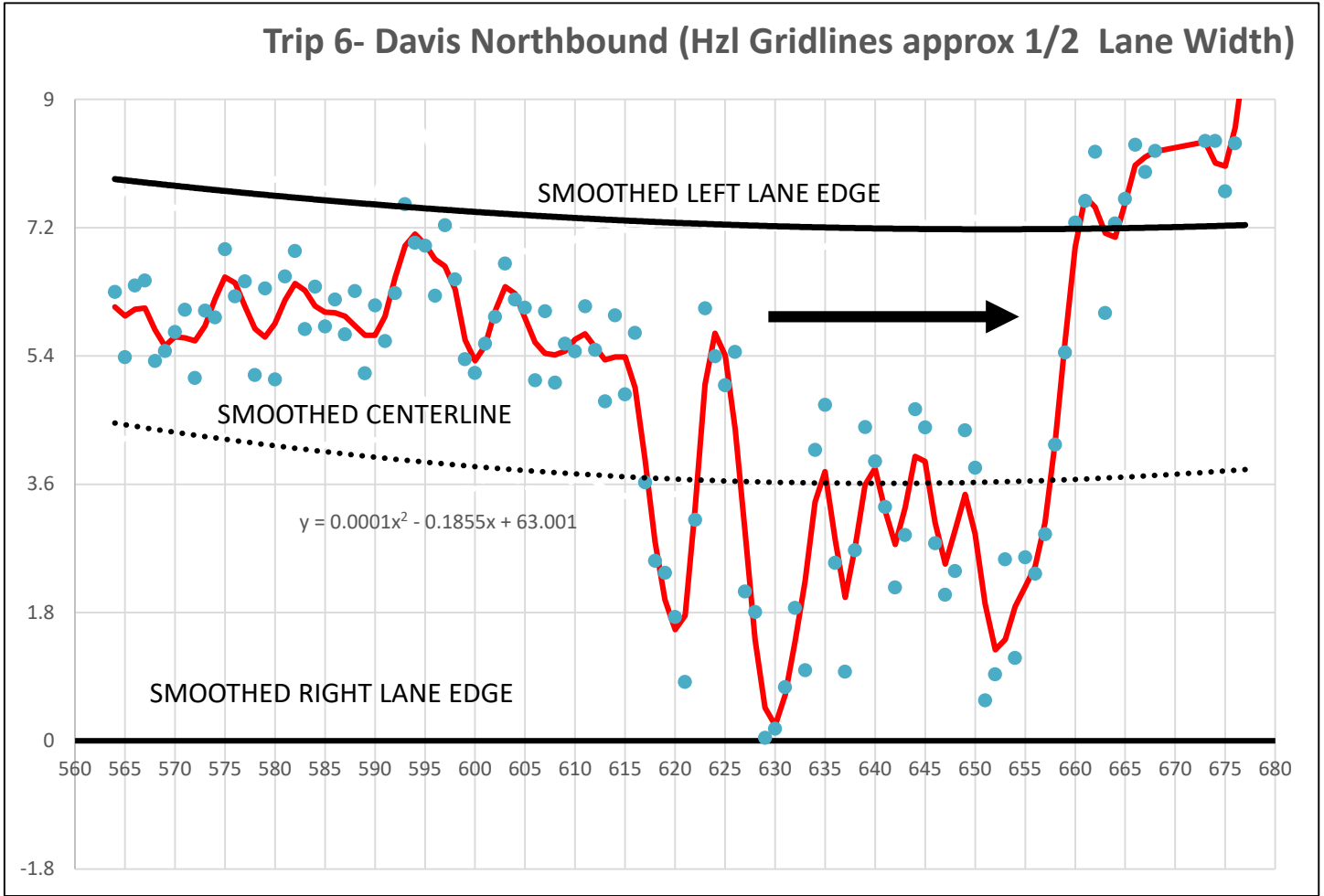
The lane change model

- Relies strictly on basic vehicle and digital road position reference points
- Fuses 1 Hz vehicle “trip” position and the digitized road information using the “R” open source coding platform
- Invokes an R- utility that calculates the minimum distance between each trip point lat-long point, and the various lanes or lane separator edge lines. Also can distinguish on which side of an edge line the vehicle is present
- Focused initially on lane changes between two through lanes on a North-South arterial road (Davis Dr.) in North Carolina
- Detects lane changes when the vehicle lateral distance from the centerline changes from +ve to –ve and vice versa
- Identifies start and end of the lane change maneuver at the point where distance to centerline stabilize at both ends.
- Continually tracks vehicle lane position



Sample Result- Two Lane Changes SB Trip..

Then entering a far right turn pocket



Sample Result- Twelve Lane Changes NB Trip

Then entering a left turn pocket

Summary of Calibrated Model Results

Trip #	Detected Lane Changes	Missed Lane Changes	Falsely Identified Lane Changes	Range of Lateral Speed (m/s)
1	4	0	0	0.86-1.013
3	3	0	4	0.12-1.42
5	2	0	0	0.506-1.58
2	2	0	0	1.65-2.03
4	3	0	0	0.6-1.05
6	10	2	0	0.58-1.28
TOTAL	24	2	4	

I. Introduction and definitions
II. Link-based data and modeling applications
III. Vehicle-based data and modeling applications
IV. Emerging research and application opportunities
V. Questions and discussion

IV. Emerging Research and Application Opportunities

- High resolution data will help improve microscopic simulation models of driver behavior (car following, lane selection, lane changing, desired speed, gap acceptance, etc.)
- Signal timing schemes, performance measurement models based on real-time probe samples rather than from static fixed sensor locations, including vehicle priority schemes See *Multimodal Intelligent Traffic Signal System (MMITS*)
  - http://i95coalition.org/wp-content/uploads/2016/03/Head.MMITSS.I-95.06.20.2016.pdf?66d0ea

IV. Emerging Research and Application Opportunities

- Enabling the testing of some long held assumptions embedded in traffic models: deceleration response to clearance intervals, approach/ departure speeds, queue discharge patterns, etc.
- Real-time shockwave prediction models from probe trajectory samples, and traveler information response (queue warning). Similar approach for incident detection modeling.
- Testing basic assumptions present in travel demand models: trip generation models, effects of demographics, route and departure time choice models, etc.

IV. Emerging Research and Application Opportunities

- Predictive models of high crash locations based on microscale driver behavioral data (high density of severe longitudinal or lateral acceleration/ deceleration events)
- Increased focus on naturalistic driving studies

Composite image showing a driver's head position in relation to the dashboard and windshield, calibrated with eyes forward (*at left*) and looking at the speedometer (*at right*). The SHRP 2 Naturalistic Driving Study has equipped participants' cars with data-collecting devices to gain a deeper understanding of driving behavior.

Data Acquisition System Channels

- Multiple videos
- Machine vision
  - Eyes forward monitor
  - Lane tracker
- Accelerometer data (3 axis)
- Rate sensors (3 axis)
- GPS: latitude, longitude, elevation, time, velocity
- Forward radar
  - X and Y positions
  - X and Y velocities
- Cell phone
  - Automatic collision notification, health checks, location notification
  - Health checks, remote upgrades
- Illuminance sensor
- Infrared illumination
- Passive alcohol sensor
- Incident push button—audio (only on incident push button)
- Turn signals
- Vehicle network data
  - Accelerator
  - Brake pedal activation
  - Automatic braking system
  - Gear position
  - Steering wheel angle
  - Speed
  - Horn
  - Seat belt information
  - Airbag deployment
  - Many more variables

IV. Emerging Research and Application Opportunities

- On the fly signal timing model schemes with knowledge of individual vehicles' position, speeds and destinations by RSE's
- Developing new data visualization schemes to convey insights as well as anomalies. See https://www.its-rde.net/RDE-Visualizations/element6/
- Short term flow rate prediction based on detailed speed / travel time data (State DOT's in the USA slowly abandoning expensive, high maintenance infrastructure-based sensors) flocking to 3rd party data

The Challenge for Traffic Engineers

- Be aware / cautious of the black box syndrome of certain big data analytics (e.g. use of AI and machine learning)
- Understand data limitations; verify that they meet traffic flow expectations
- Chose the data elements from which you can extract traffic value
- Learn how to work with and manipulate new data elements (e.g. lat-longs)
- Identify new safety and operational applications not heretofore possible given the type of data available:
  - What are predictive abilities the “new” data provide ?
  - What driver characteristics can we now (better) understand ?

In Conclusion

- Expect to be inundated with data at high resolution (≥ 10Hz), at multiscale and not necessarily all ready for model use
- The immediate advantage for traffic modelers is an ability to enhance model calibration with the availability of new data elements
- There are opportunities to develop new intersection control schemes based on projected individual connected vehicle arrivals at the junction -- virtually a scheduling / reservation exercise
- Expect efforts to be initially focused towards data modeling rather than new model development
- The $64,000 question is: Will data eventually replace models? Likely not, if long term prediction are still essential

Thank you very much for your attention …

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