DEVELOPMENT OF MANAGED LANE MODEL BASED ON MESO-SCOPIC SIMULATION APPROACH

NCDOT MUG Meeting

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Sponsored by Florida DOT

In conjunction with Florida International University

OVERVIEW

- Managed Lanes?
- Mesoscopic Simulation Model
- Managed Lane Modeling
- Application of Model
- Model Validation by O-D Matrix Estimation

MANAGED LANES?

FHWA says "Managed Lanes are defined as highway facilities or a set of lanes where operational strategies are proactively implemented and managed in response to changing conditions."

Source: Freeway Management System, Federal Highway Administration, US Department of Transportation (http://ops.fhwa.dot.gov/freewaymgmt/mngd_lns_hov.htm)

TYPES OF MANAGED LANES (ML)

- High Occupancy Vehicles (HOV)
- High Occupancy Toll (HOT) Lanes
- Express Toll Lanes (ETL)
- Truck Only Toll (TOT)
- Open Road Tolling
- Dynamic Tolling
- Transit/Busway
- Pre-pay and/or Pay per use (toll booths)
- ITS Solutions (Traffic calming, speed advisories, incident management)

HIGH OCCUPANCY VEHICLE (HOV)

Source: Managed Lanes a Primer, Federal Highway Administration,
US Department of Transportation (2008)

HIGH OCCUPANCY TOLL (HOT) LANES

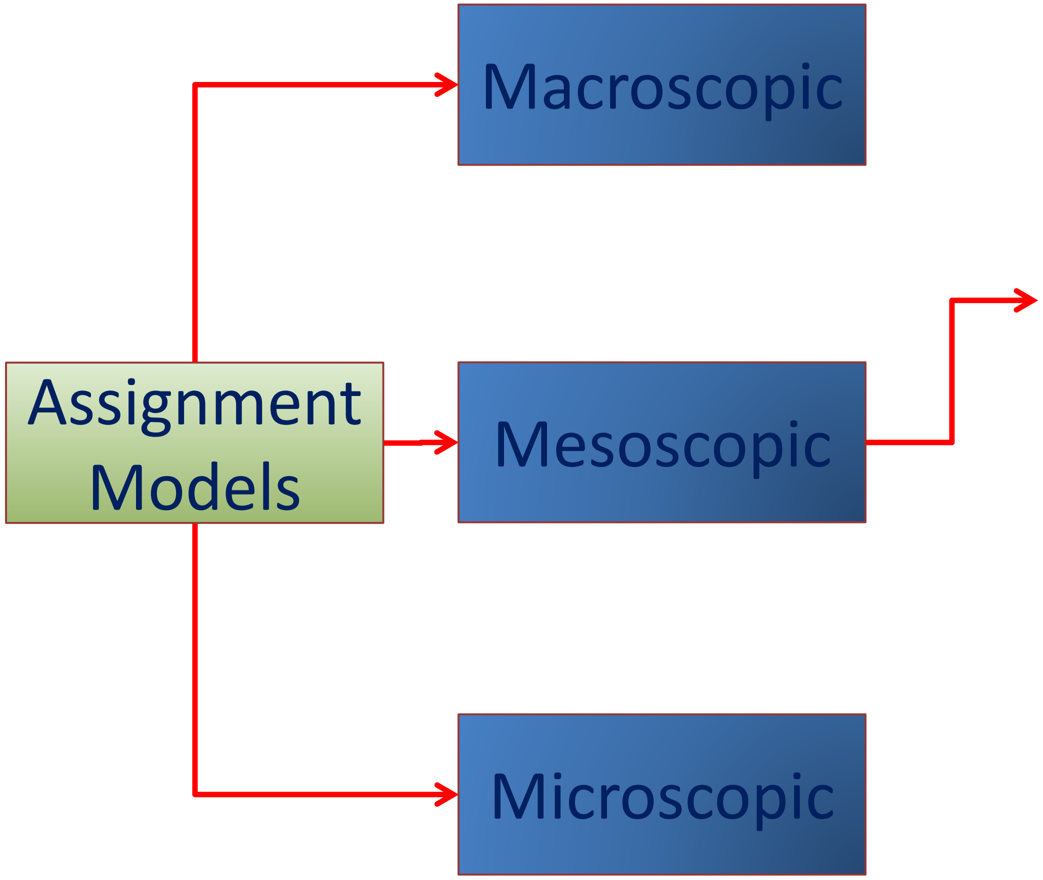
Source: We Want Toll Lanes Done Right, The Transit Coalition (2012)

EXPRESS TOLL LANES (ETL)

Source: Florida Department of Transportation(2013)

Mesoscopic Simulation Model

MESOSCOPIC SIMULATION APPROACH



- Mesoscopic models try to find a middle group between macro and micro models
- Vehicles are analysed as "packets" of vehicles by studying fundamental variables (flow, speed, density)
- Mesoscopic models techniques can study traffic flows over time (Dynamic)

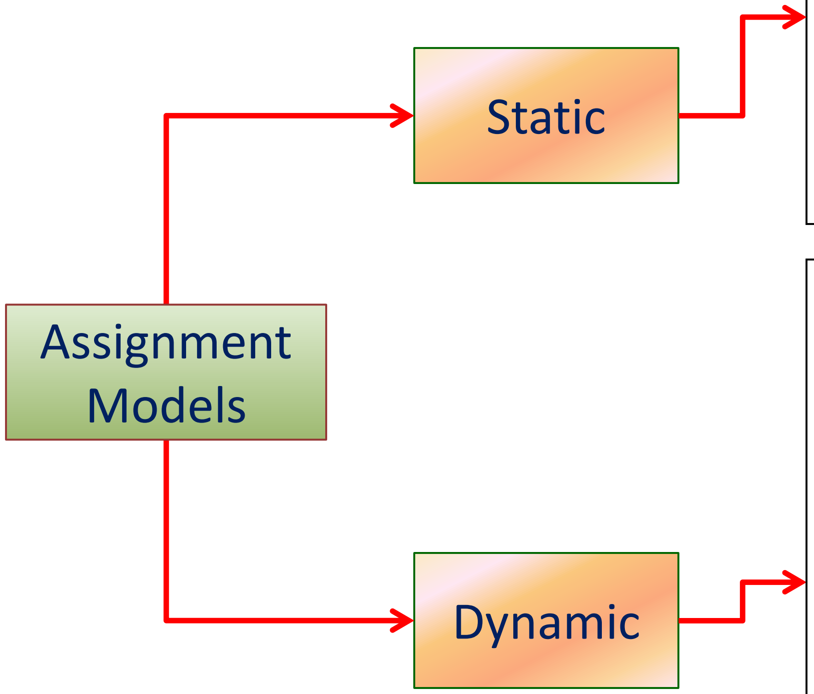
- Mesoscopic models the lowest-cost path for the traffic volume for each packet of vehicles
- Mesoscopic models compute congestion effect, through volume-capacity rations and also interaction among vehicles units ("packets of vehicles")

COMPARISON OF SIMULATION MODELS

- Macro-meso-micro methods can be most easily distinguished by how they represent *flow* and evaluate *congestion*
- Flow can be either continuous (streams) or discrete (vehicles/packets)
- Performance functions can be either aggregate (evaluated for a whole time interval) or disaggregate (evaluated for individual flow quanta)

Typology of assignment models		Performance functions	
		Aggregate	Disaggregate
Flow Representation	Continuous	MACRO	N/A
	Discrete	MESO	MICRO

STATIC MODEL vs. DYNAMIC MODEL



During the "model period" the following variables are constant and do not change:

- Origin-destination flows (travel demand)
- Routing and path proportions
- Link flows (vehicle volumes)
- Link costs (congested times)
- Path costs (origin-destination skims)

These models process time-varying inputs and outputs.

- Inputs:
  - Time-varying origin-destination travel demand (flow per time segment)
  - Average link costs by time segment
  - Capacities (max flow/period by segment)
- Outputs:
  - Dynamic path/link flows (total entering vehicles by time segment) and path/link costs
  - Simulation-based record of actual trajectories

COMPARISON BETWEEN STATIC & DYNAMIC ASSIGNMENTS

Static Assignment

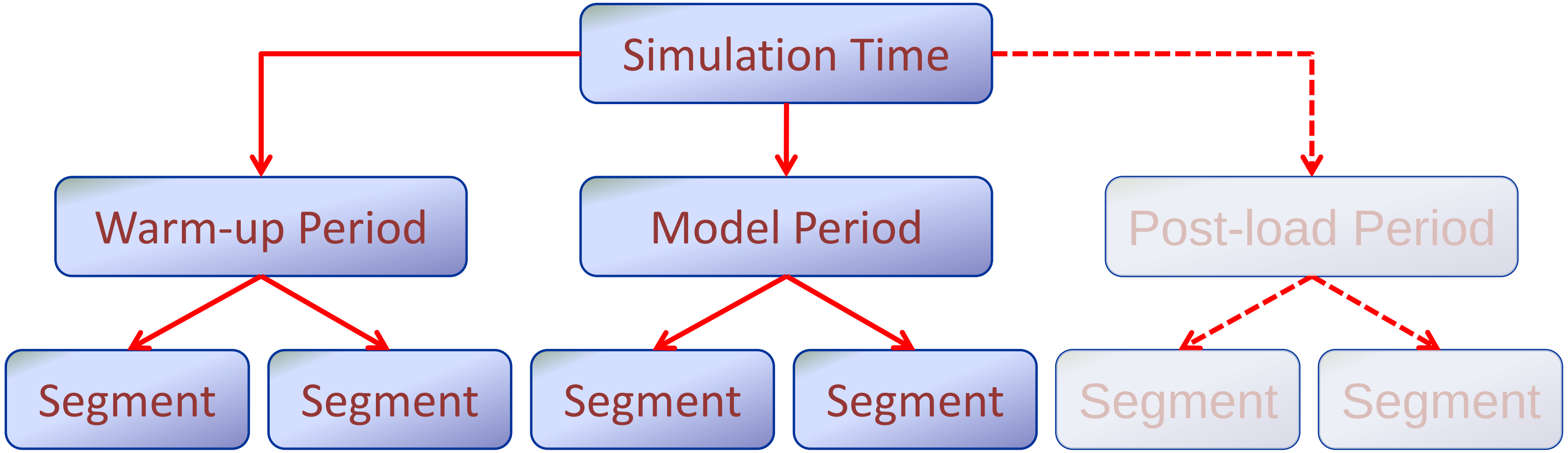
- A vehicle exists everywhere along its route during period
- Variables do not change over the duration of the period to be modelled
- Capacity constraints not strictly enforced; V/C > 1
- No link storage constraint
- Link volumes and costs are separable and independent
- Time = Link Travel Time + Junction Delay (if using)

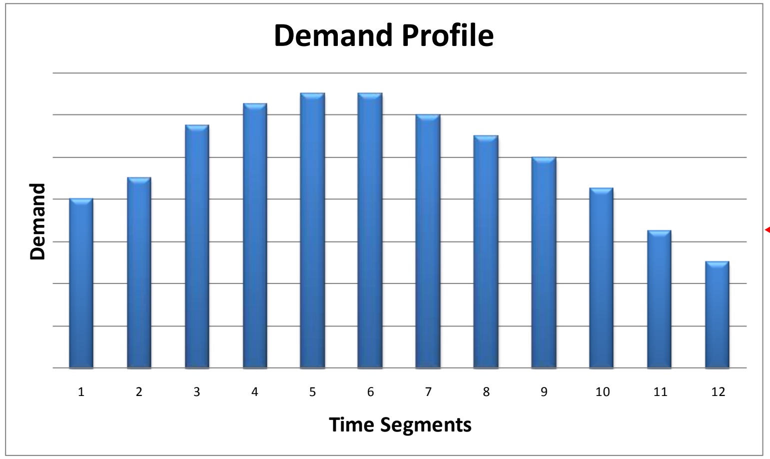
Dynamic Assignment

- Simulated packets can only be in one place at a time
- Model period divided into “time segments” with varying flow rates
- Capacity strictly enforced using “flow gates”
- Storage strictly enforced
- Simulation of queues affects preceding link volume, cost
- Time = Link Travel Time + Queue Time + Junction Delay (if using)

SIMULATION PERIOD BY TIME SEGMENT

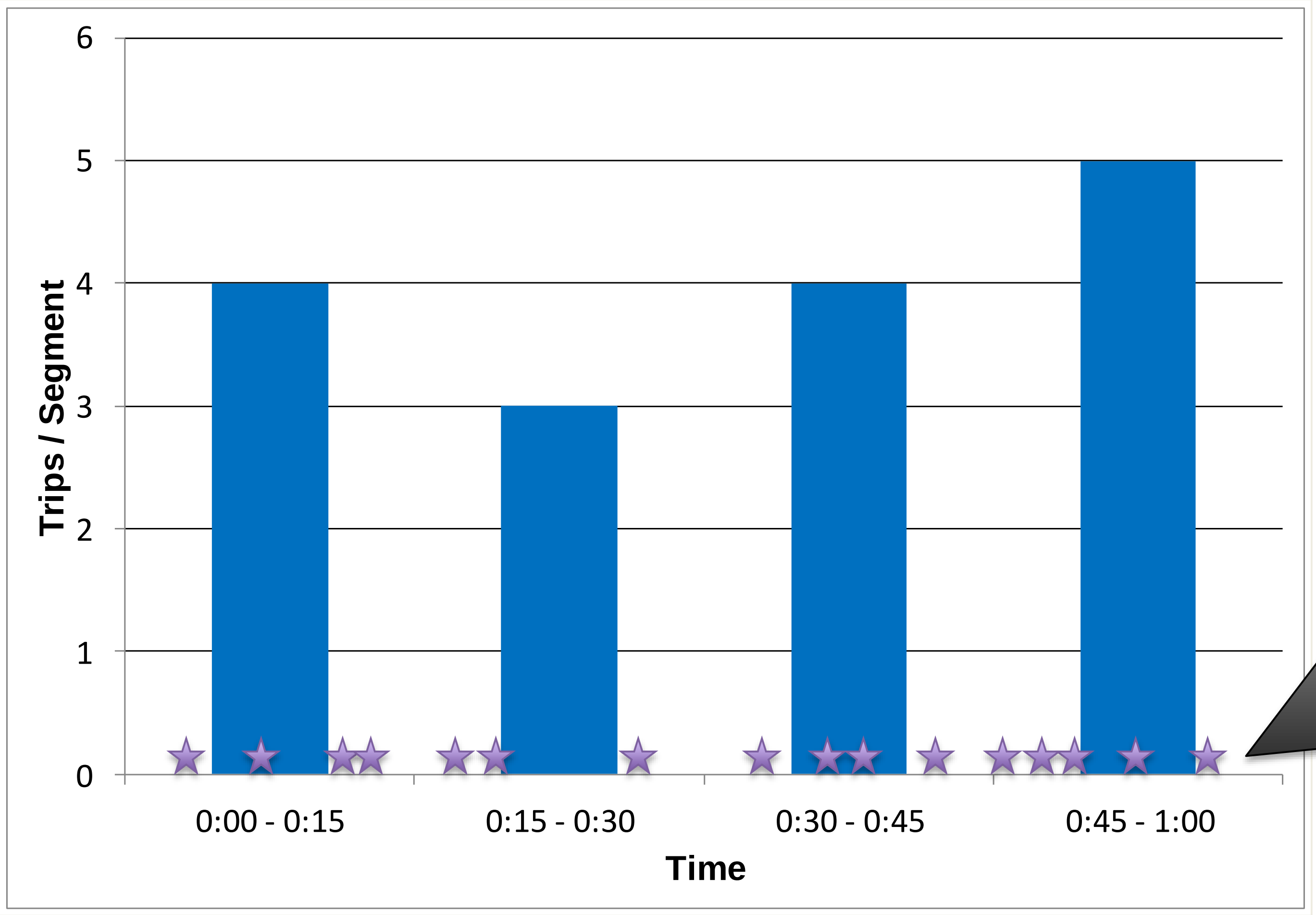
- The model duration is explicitly defined and divided into smaller time segments





The demand is assumed to be constant during each time segment

DISAGGREGATED TRIPS BY PACKETS

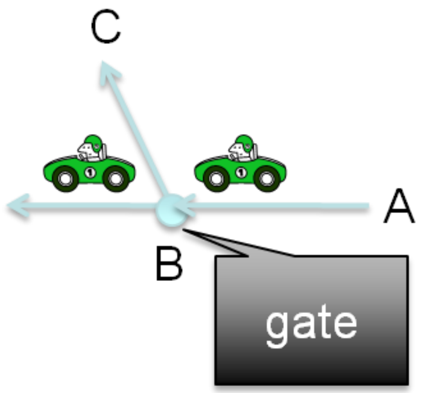


Departure times chosen randomly (uniform distribution)

An internal random number generator randomly draws a departure time for each packet departing in a given interval.

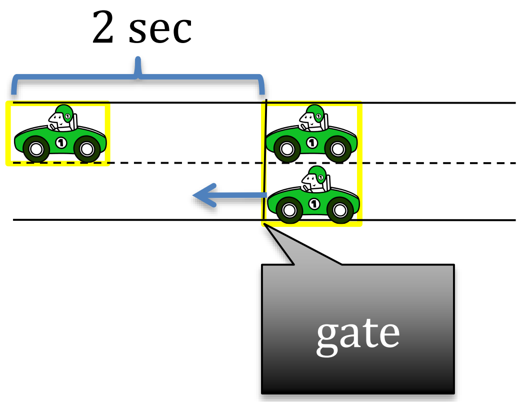
EVENT-BASED SIMULATION

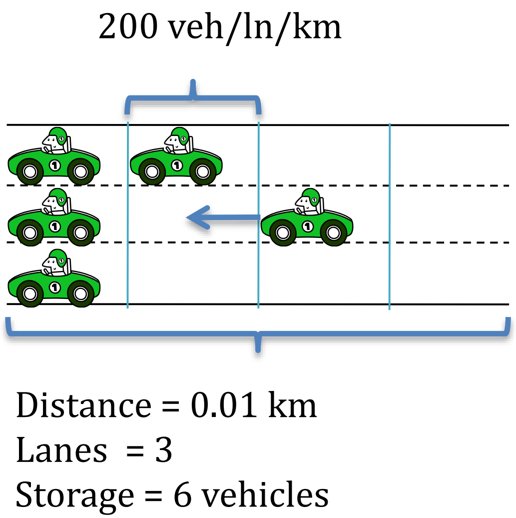
- Simulation processes events as they are encountered by packets moving along their paths
- Packets can be in one of two states:
  - Moving on a link
  - In queue (waiting on a link)
- A vehicle may have to wait if:
  - Cars leaving a link exceed its exit flow capacity (***Capacity*** Constraints)
  - Cars entering a link exceed its entrance flow capacity (***Capacity*** Constraints)
  - There is no room for it on the next link (***Storage*** Constraints)
- These criteria are evaluated by A-B-C movement
- Turn capacity is also checked if output by a junction model (intersection analysis, e.g. HCM 2010)
- Constraint is the minimum of constraints at node



MINIMUM HEADWAY and STORAGE

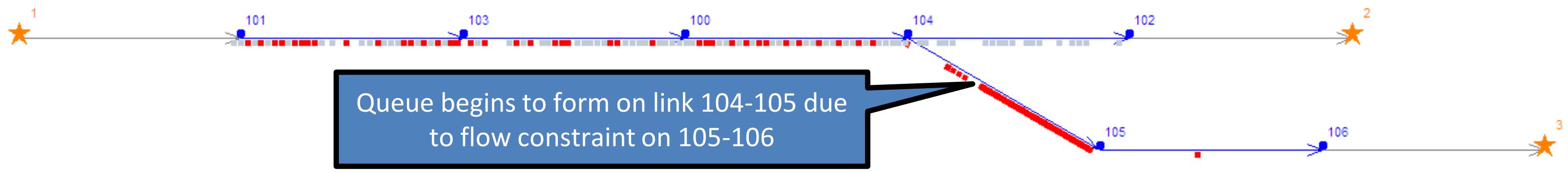
- Capacity and storage constraints are maintained by "gates" on each link
- In practice, *minimum headway* is used rather than *maximum flow*
- Consider a 2-lane freeway link with per-lane flow capacity of 1800 vehicles per hour and total flow capacity of 3600 vehicles per hour:
  - This is equivalent to a headway (or gap) of one sec/vehicle
  - So if a packet with two vehicles arrives at the gate, it cannot leave the link any sooner than two seconds after the packet ahead of it.



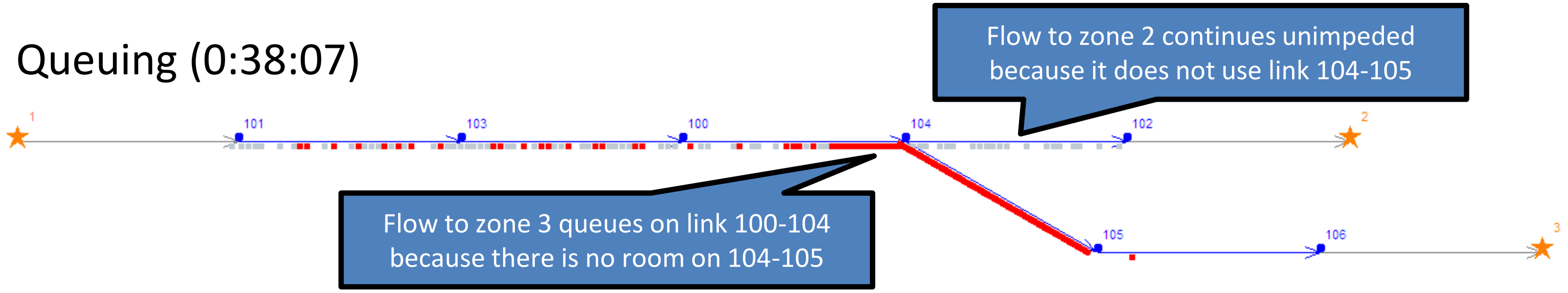


QUEUE PROPAGATION

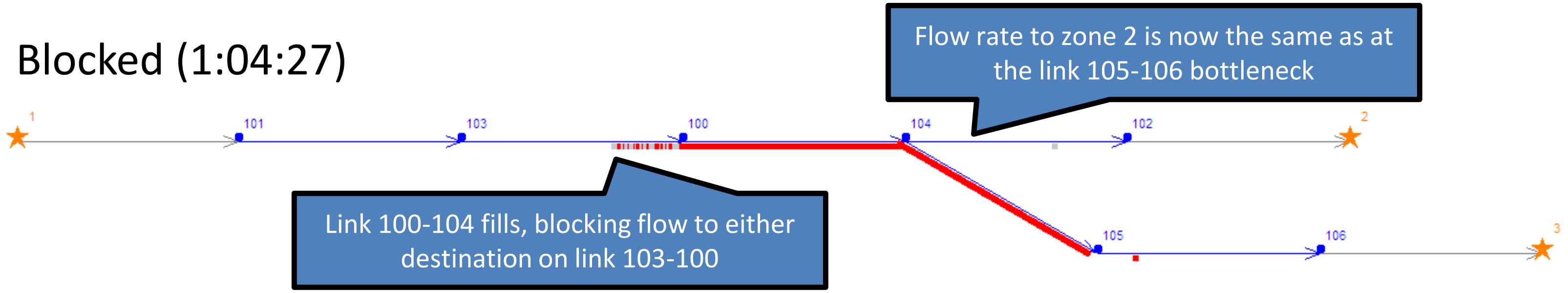
Backing up (0:20:15)



Queuing (0:38:07)



Blocked (1:04:27)

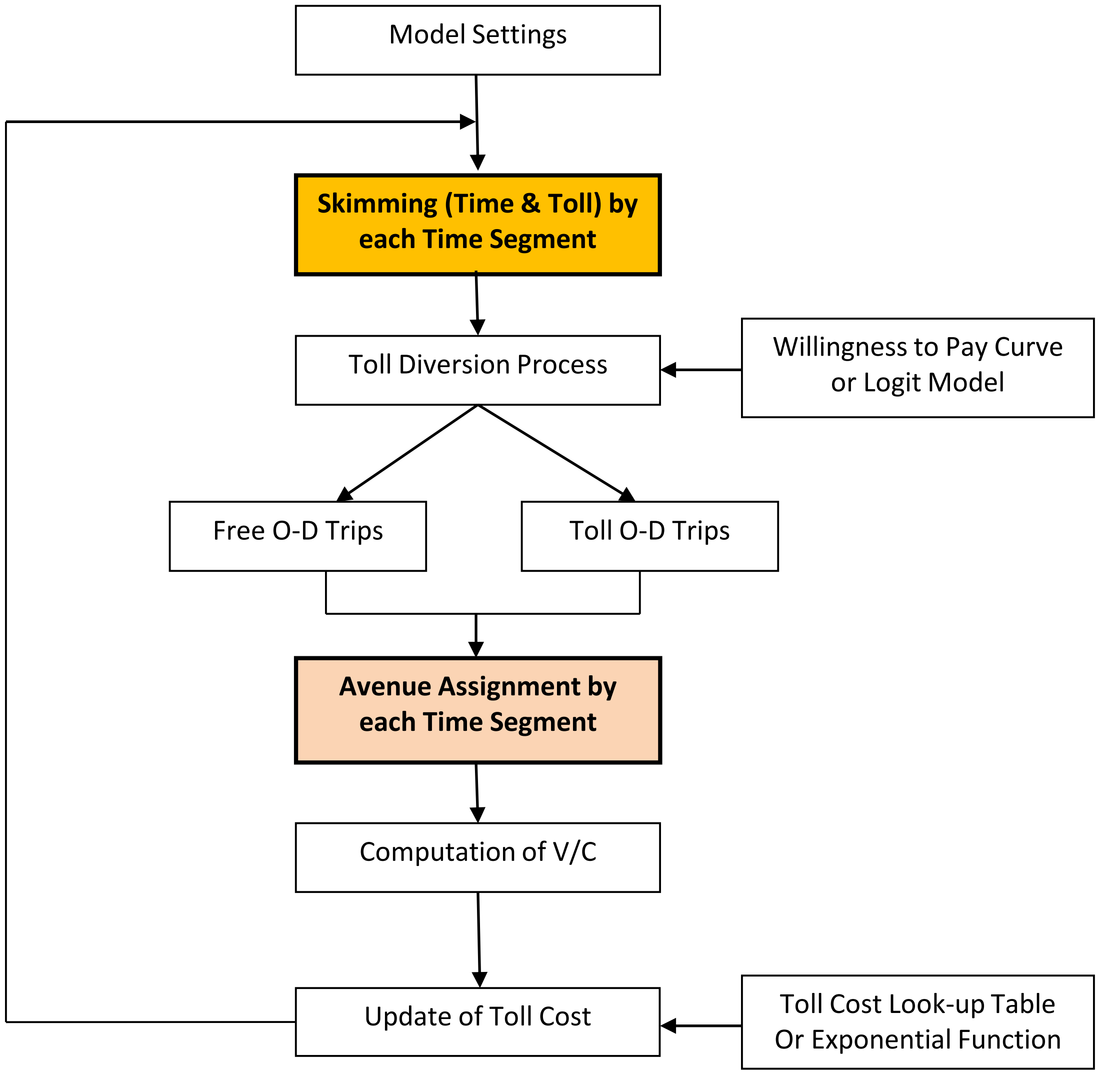


MESOSCOPIC MODELING APPLICATIONS

- A mesoscopic model allows to complete new types of analyses:
  - Quantify impact of upstream traffic congestion
  - Measure queuing at intersection and merge points in a network
  - Isolate secondary impacts from one intersection through another
  - Evaluate the benefits of ITS (Intelligent Transportation System) projects
  - Simulate alternative infrastructure, operational and policy changes to optimise
  - Emergency evacuation plans and strategies
  - Test strategies to improve arrival and departure from stadiums and other special event facilities
  - ...

Managed Lane Modeling

PROCEDURE FOR MANAGED LANE MODELING



MAJOR CONCERNS IN MODEL DEVELOPMENT

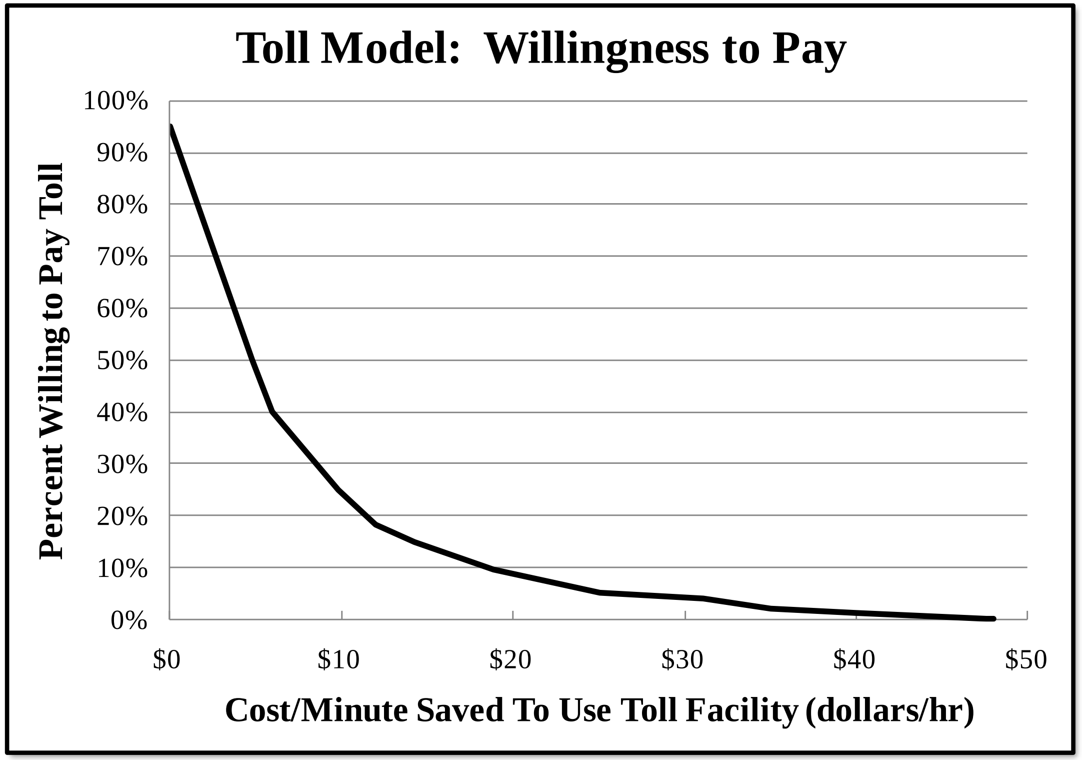
- Toll diversion model (Free vs. Toll)
  - Willingness-to-pay curve
  - Binary logit model

- Update of toll cost
  - Lookup table by V/C
  - Lookup table by density
  - Using exponential formula

- Toll update process in Avenue
  - Iteration-by-iteration basis
  - Time segment-by-time segment basis

TOLL DIVERSION TYPE 1: WILLINGNESS-TO-PAY CURVE

$$\text{Toll Cents per Minute Saved} = \frac{\text{Total toll cost (cents) for toll route}}{\text{Free route time (min)} - \text{Toll route time (min)}}$$



- Demand% is the share of toll trips.

TOLL DIVERSION TYPE 2: BINARY LOGIT MODEL (1/2)

$$\boldsymbol{P_{toll}} = \frac{\mathbf{1.0}}{\mathbf{1.0} + \boldsymbol{e}^{[\boldsymbol{\alpha}(\boldsymbol{T_{toll}} - \boldsymbol{T_{free}}) + \boldsymbol{\beta}(\boldsymbol{C_{toll}})]}} \times \mathbf{100\%}$$

Where,

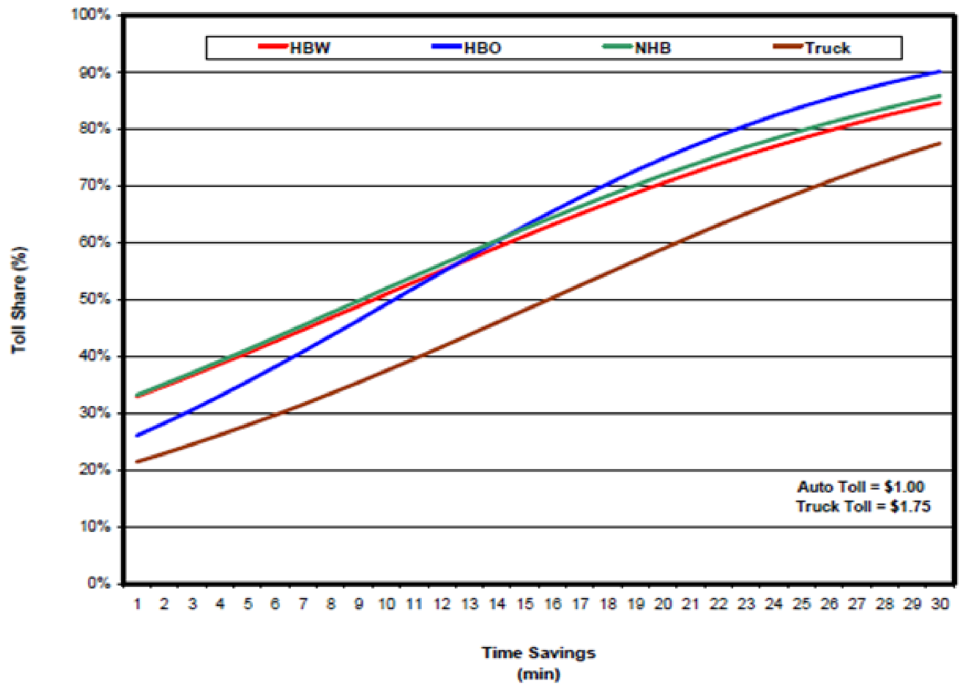
P_{toll}	=	toll trip proportion (%) for toll route
T_{toll}	=	travel time (min) for toll route
T_{free}	=	travel time (min) for free route
C_{toll}	=	total toll cost ($) for toll route
α	=	coefficient for time
β	=	coefficient for toll cost

TOLL DIVERSION TYPE 2: BINARY LOGIT MODEL (2/2)

Toll Diversion Model Parameters

Trip Purpose / Mode	Time Coefficient (a)	Cost Coefficient (b)	Value of Time ($/hour)	Toll Bias Constant	Equivalent Penalty (min)
AUTO					
Home-Based Work	0.0833	3.4230	$16.06	0.4852	5.8
Home-Based Other	0.1122	0.5816	$11.57	0.5744	5.1
Non-Home-Based	0.0862	4.2470	$13.40	0.4002	4.6
TRUCK	0.0874	0.1757	$29.86	1.0800	12.4

Note: For HBW and NHB, value of time is based on estimated 2005 median income of $59,855 within the study area.



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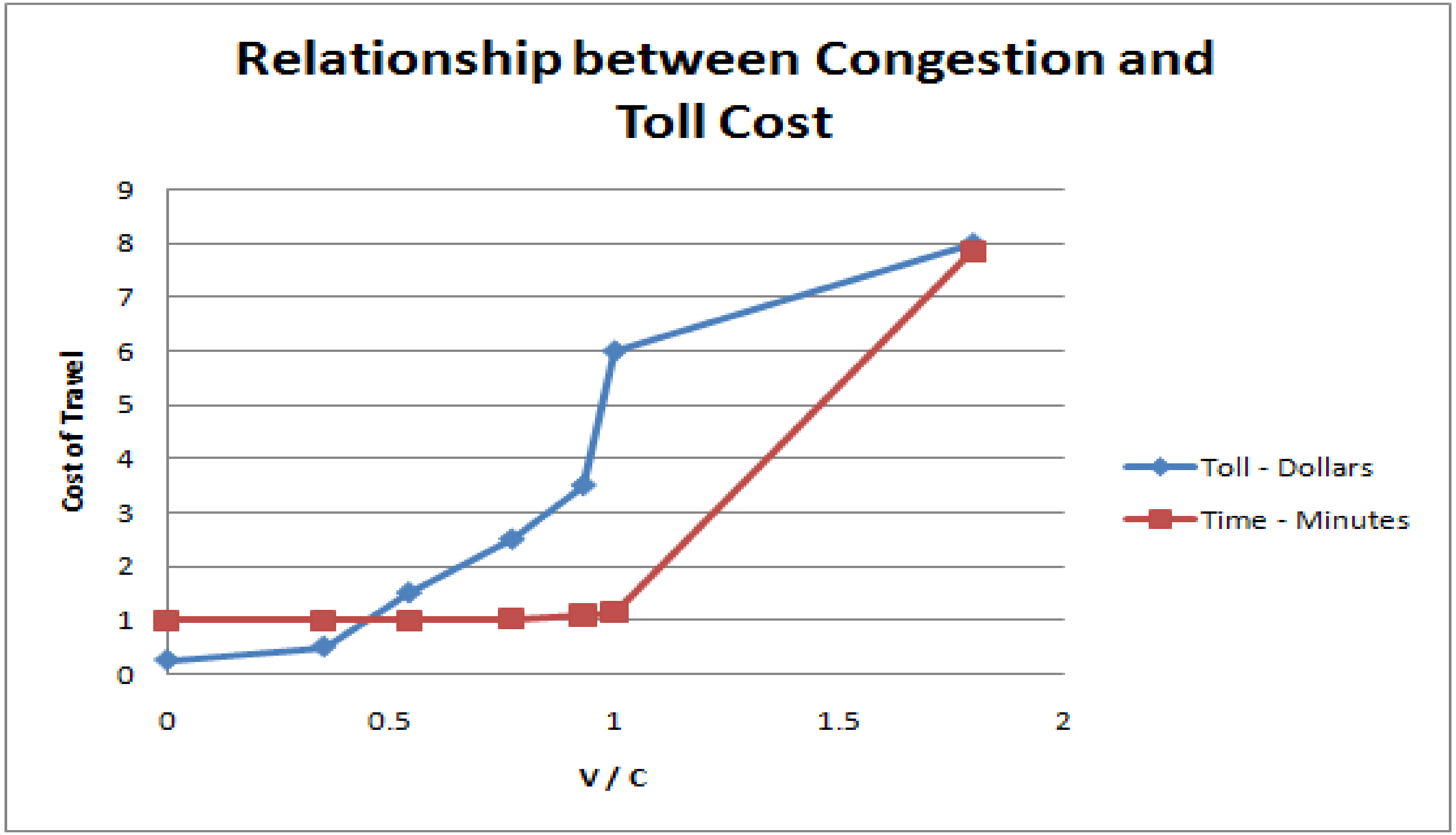
DYNAMIC TOLL COST UPDATE TYPE 1: BY V/C

- Referred on the final report of "Managed lane modeling application for FSUTMS (Phase I)"



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DYNAMIC TOLL COST UPDATE TYPE 2: BY LINK DENSITY (1/2)

- Referred on “Florida Department of Transportation District VI Standard Operating Guidelines”

LOS	Road Density		Toll Cost ($)	
	Minimum	Maximum	Minimum	Maximum
A	0	11	$0.25	$0.25
B	12	18	$0.50	$1.25
C	19	26	$1.50	$2.75
D	27	35	$3.00	$3.75
E	36	45	$3.75	$6.00
F	>45		$6.00	$7.00

DYNAMIC TOLL COST UPDATE TYPE 2: BY LINK DENSITY (2/2)

- Unit: Vehicles per Mile per Lane (VPMPL)

$$\boldsymbol{Link\ Density = \frac{Houly\ Link\ Volumes\ \div Lanes}{Link\ Speed\ (mph)}}$$

DYNAMIC TOLL COST UPDATE TYPE 3: EXPONENTIAL FORMULA

$$TOLL = 0.05 \times EXP\left(\frac{V}{C} \times 6\right)$$

HOW TO UPDATE TOLLS (1/2)

- Update of toll costs by an iteration-by-iteration process

ITERLOADINC = 0
MAXITERS = 2

< Iteration: 1 >

Time Segment	Initial Toll	Road Density	Updated Toll
1	$0.25	22	$2.04
2	$0.25	18	$1.25
3	$0.25	26	$2.75

< Iteration: 2 >

Time Segment	Toll from Iter# 1	Road Density	Updated Toll
1	$2.04	20	$1.68
2	$1.25	27	$3.00
3	$2.75	24	$2.39

HOW TO UPDATE TOLLS (2/2)

- Update of toll costs by a time segment-by-time segment process

ITERLOADINC = 2
MAXITERS = 3

< Time Segment: 1 >

Iteration	Initial/current Toll	Road Density	Updated Toll
1	$0.25	20	$1.68
2	$1.68	16	$1.00
3	$1.00	19	$1.50

< Time Segment: 2 >

Iteration	Initial/current Toll	Road Density	Updated Toll
3	$0.25	28	$3.10
4	$3.10	23	$2.00
5	$2.00	25	$2.57

< Time Segment: 3 >

Iteration	Initial/current Toll	Road Density	Updated Toll
5	$0.25	22	$2.04
6	$2.04	24	$2.39
7	$2.39	20	$1.68

MAJOR CONCERNS IN HIGHWAY NETWORK

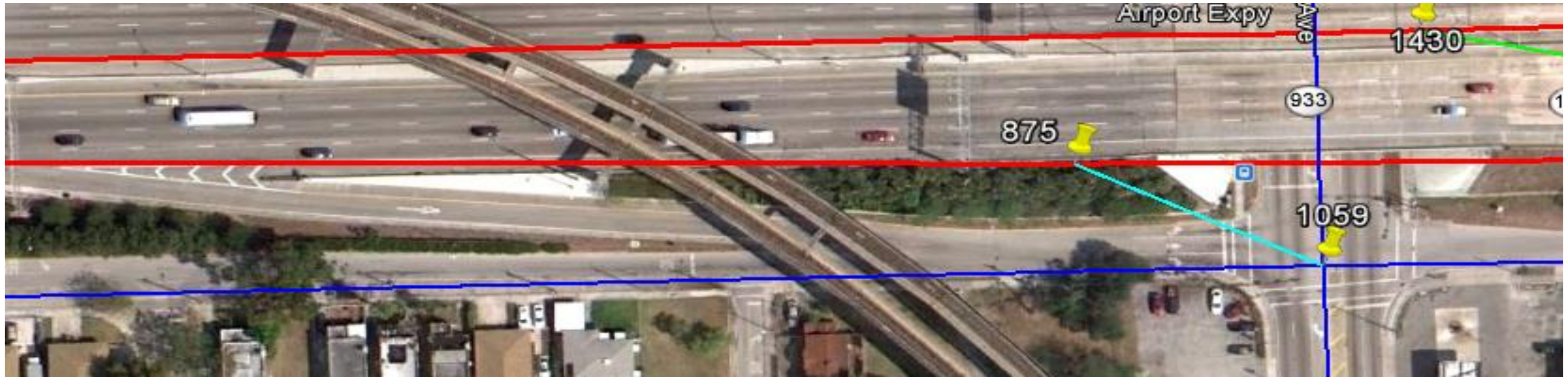
- Review of short links
  - Use of true shape
  - Use of consolidating process in Cube
- Review for short of link storages
  - Use of packet animation in Avenue to see the traffic queue locations
- Review for short of link capacities

EXAMPLES OF NETWORK DIAGNOSTIC CHECK (1/2)

The ramps are adjusted by the true shape.

EXAMPLES OF NETWORK DIAGNOSTIC CHECK (2/2)

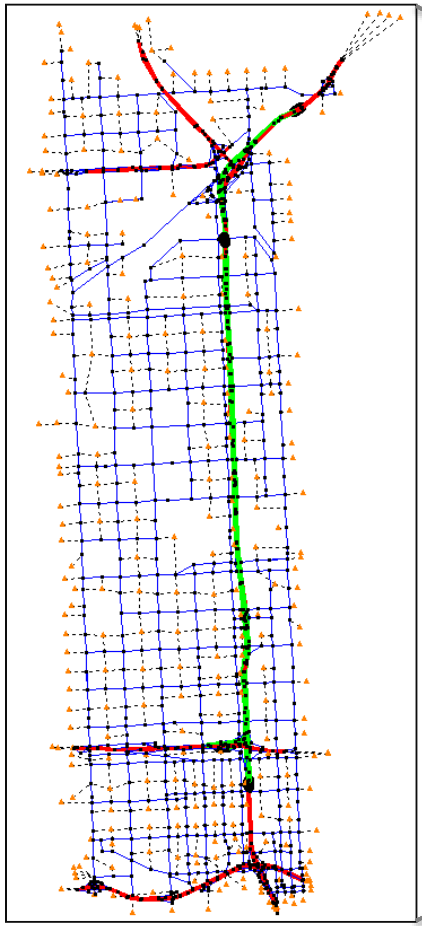
The short ramps cause the queues of vehicles due to the low storages.

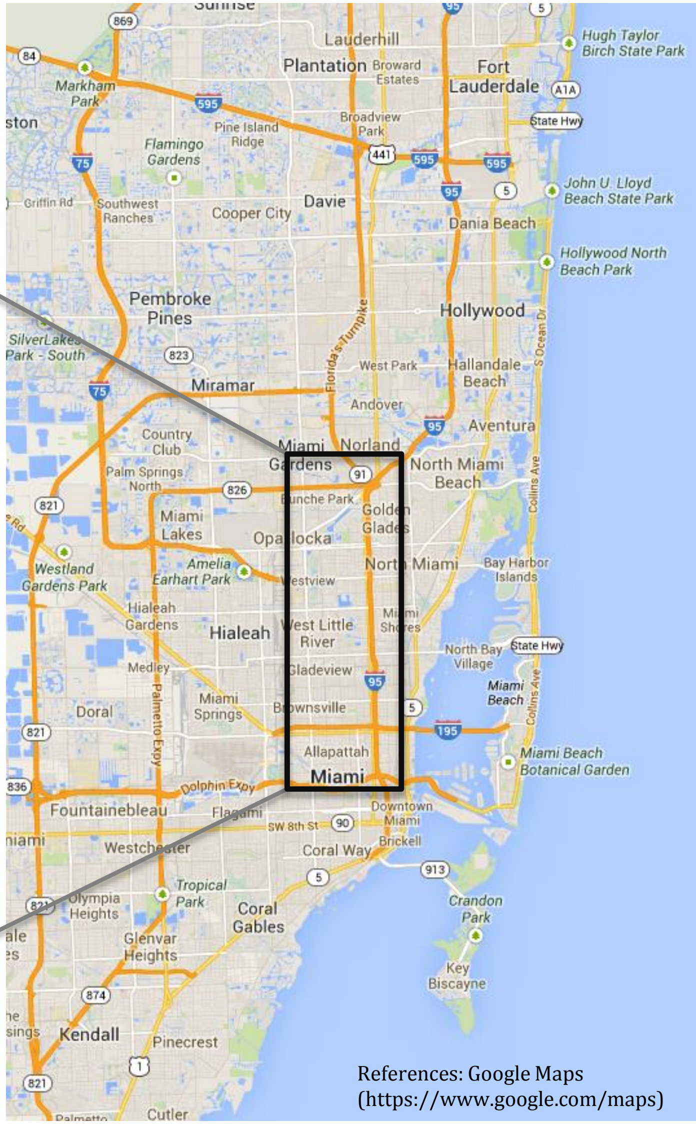


Application of Model

CORRIDOR OF STUDY

- I-95 HOT facility in Miami

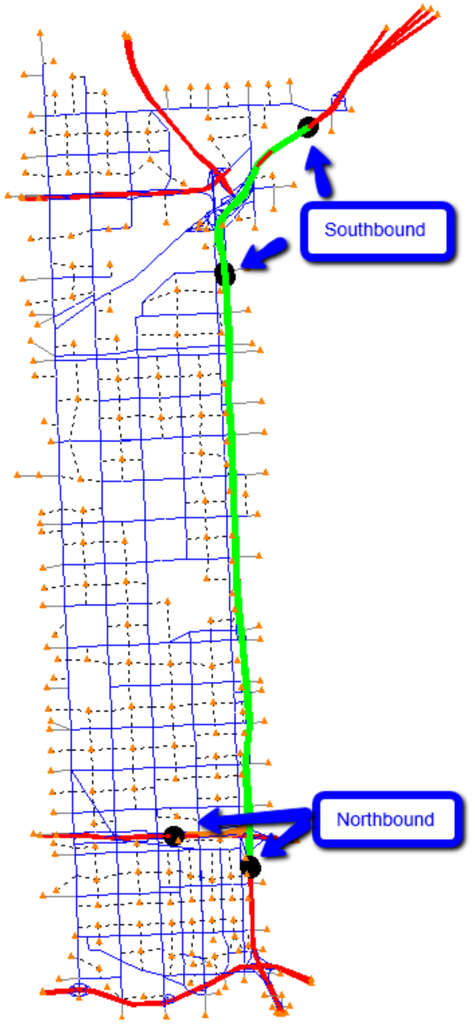




References: Google Maps (https://www.google.com/maps)

TOLL ENTRANCES IN I-95 HOT LANES

- Two southbound locations
- Two northbound locations
- It is assumed that each direction utilizes the same toll rate in both locations.
- The dynamic toll values are estimated based on the largest density for each directional road on the I-95 HOT corridor.



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MAJOR INPUT & OUTPUT DATA

File Type	File Name	Description
Input File	DTA_Highway.NET	Input Cube highway network (*.NET)
	SOV_TS_12.MAT	O-D vehicle trips for drive alone (DA) & two persons (SR2) modes by12 time segments
	SR3_TS_12.MAT	O-D vehicle trips for three or more persons (SR3P) mode by 12 time segments
	Truck_TS_12.MAT	O-D vehicle trips for truck mode by 12 time segments
	NoWilling_to_Pay_Proprtions.dbf	Non-willing to pay proportions (%) for toll diversion process
	TollCost_by_Density.dbf	Toll rates ($) by by road density (vehicles per mile per lane)
Output File	DTA_Managed_Lanes_Loaded.NET	Output loaded network (*.NET)
	DTA_Managed_Lanes_Loaded.LOG	Packet log from assignemnt

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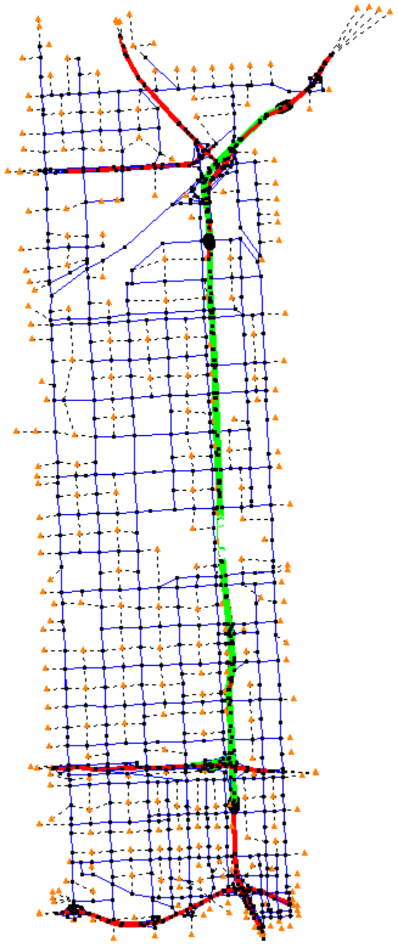
REQUIREMENTS IN INPUT HIGHWAY NETWORK

- Link distance (mile)
- Link capacity (hourly or period)
- Link facility type
- Number of lanes
- Free flow speed (mph)
- Link storage (e.g. 220 vehicles per mile)
- Alpha and Beta for BPR function
- HOT corridor indicators
- Toll facility locations
- Initial toll costs

Highway Links

AX/BX	916646.88	916567.56
AY/BY	553073.69	555323.19
A	1051	
B	1071	
DISTANCE	0.4561	
FTC2	88	
SPEED	30	
TIME	0.9122	
CAPACITY	2030	
CARTOLL	0	
FT	88	
AT	3	
LANES	2	
STORAGE	200.684	
COEF	0.34	
EXPO	7.75	
TOLLTYPE	0	
PLAZADESC	0	
TOLL_FIXED	0	
TOLL_HOT	0	
HOV_LINK	0	
TOLL_LINK	0	
HOT_LINK	1	
HOT_SEG1_SB	0	
HOT_SEG1_NB	1	
HOT_TOLL_NB	0	
HOT_TOLL_SB	0	
HOT_TOLL	0	



SETTING OF 12 TIME SEGMENTS

- Each time segment – 15 min
- 3 hours period (180 min)
- 12 time segments (=180/15)

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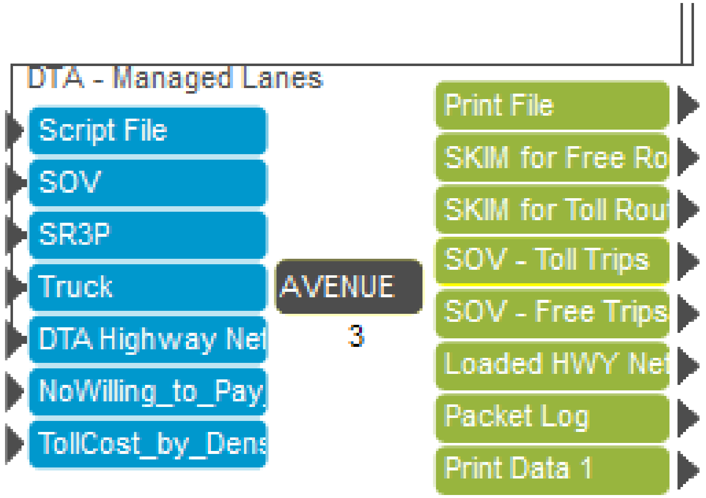
OUTPUT – MAJOR OUTPUT FILES



- Skim matrices (Time & Tolls)
- SOV+HOV2 toll O-D trips
- SOV+HOV2 free O-D trips
- Loaded highway network
- Packet log

OUTPUT – LOADED NETWORK (1/2)

Toll Costs

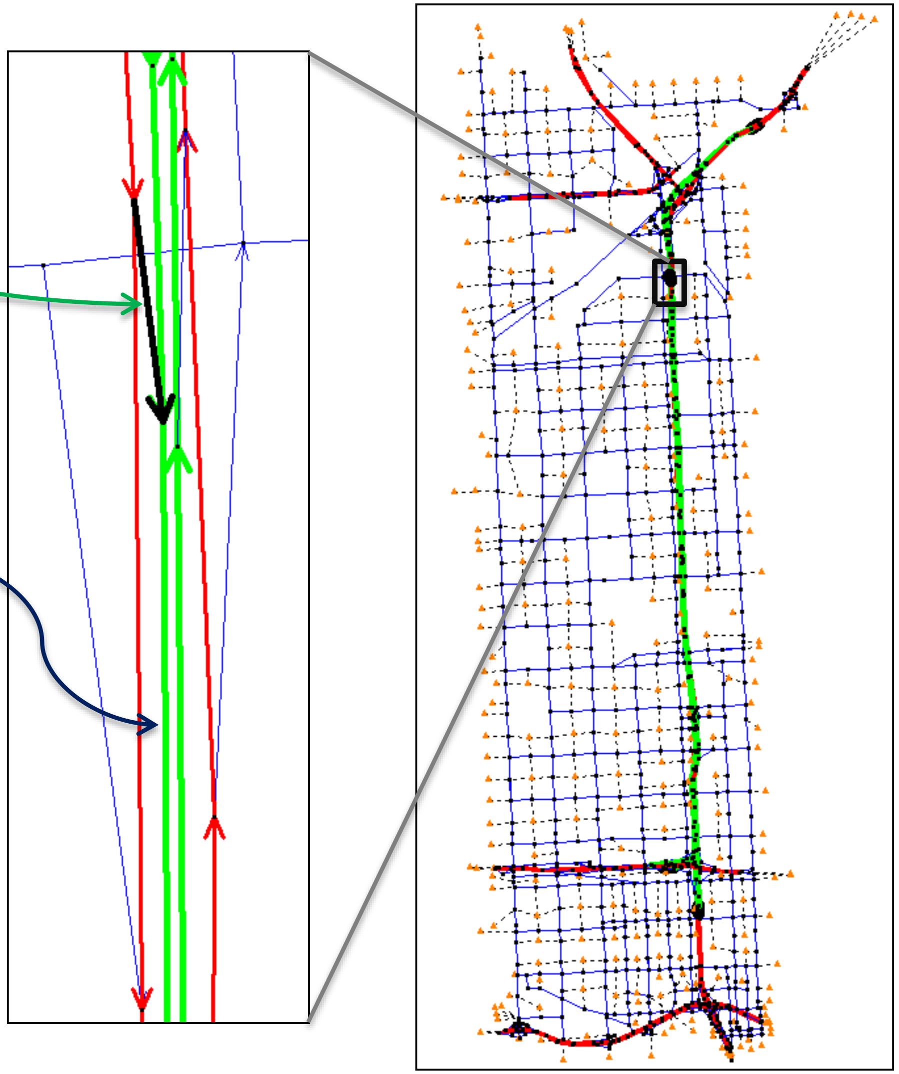
Highway Links

AX/BX	915758.69	915807.06
AY/BY	574964.69	574583.31
A	1428	
B	1427	
LW_TOLL1_1	0.7661	
LW_TOLL2_1	2.1879	
LW_TOLL3_1	2.3657	
LW_TOLL4_1	2.5293	
LW_TOLL5_1	2.7152	
LW_TOLL6_1	3.2822	
LW_TOLL7_1	4.6325	
LW_TOLL8_1	4.0611	
LW_TOLL9_1	3.2903	
LW_TOLL10_1	2.5925	
LW_TOLL11_1	2.608	
LW_TOLL12_1	2.5785	

Assigned Volumes

Highway Links

AX/BX	915807.06	915821.63
AY/BY	574583.31	572707.81
A	1427	
B	1121	
V2SMP_1	1613.4885	
V2S1_1	34.9136	
V2S2_1	94.6661	
V2S3_1	88.1108	
V2S4_1	87.7852	
V2S5_1	109.9004	
V2S6_1	148.5627	
V2S7_1	148.8932	
V2S8_1	158.795	
V2S9_1	158.7627	
V2S10_1	203.3355	
V2S11_1	193.9458	
V2S12_1	185.8175	



OUTPUT – LOADED NETWORK (2/2)

Queues in HOT entrance

Highway Links

AX/BX	915758.69	915807.06
AY/BY	574964.69	574583.31
A	1428	
B	1427	
QUEUEVS1_1	0.0007	
QUEUEVS2_1	0.0043	
QUEUEVS3_1	0.0011	
QUEUEVS4_1	0.0087	
QUEUEVS5_1	0.0064	
QUEUEVS6_1	0.0065	
QUEUEVS7_1	0.0106	
QUEUEVS8_1	0.0248	
QUEUEVS9_1	0.0096	
QUEUEVS10_1	0.0191	
QUEUEVS11_1	0.0181	
QUEUEVS12_1	0.0175	

Vehicles in Transit (VIT)

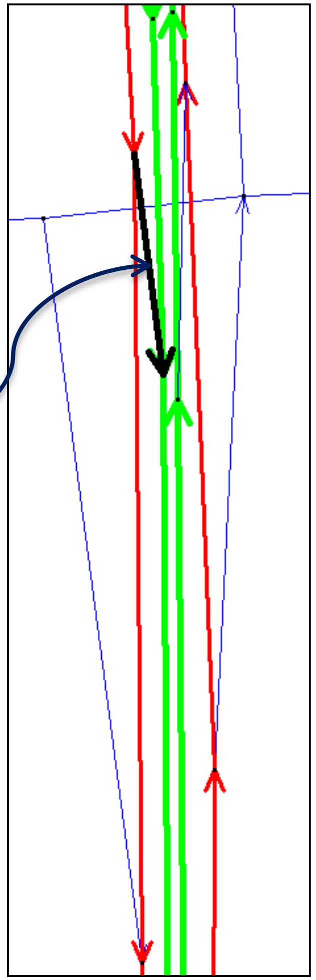
Highway Links

AX/BX	915758.69	915807.06
AY/BY	574964.69	574583.31
A	1428	
B	1427	
VITS1_1	0.468	
VITS2_1	2.241	
VITS3_1	0.5657	
VITS4_1	3.7807	
VITS5_1	3.1035	
VITS6_1	5.2159	
VITS7_1	5.8506	
VITS8_1	9.9436	
VITS9_1	6.8428	
VITS10_1	5.2713	
VITS11_1	7.2736	
VITS12_1	2.7299	

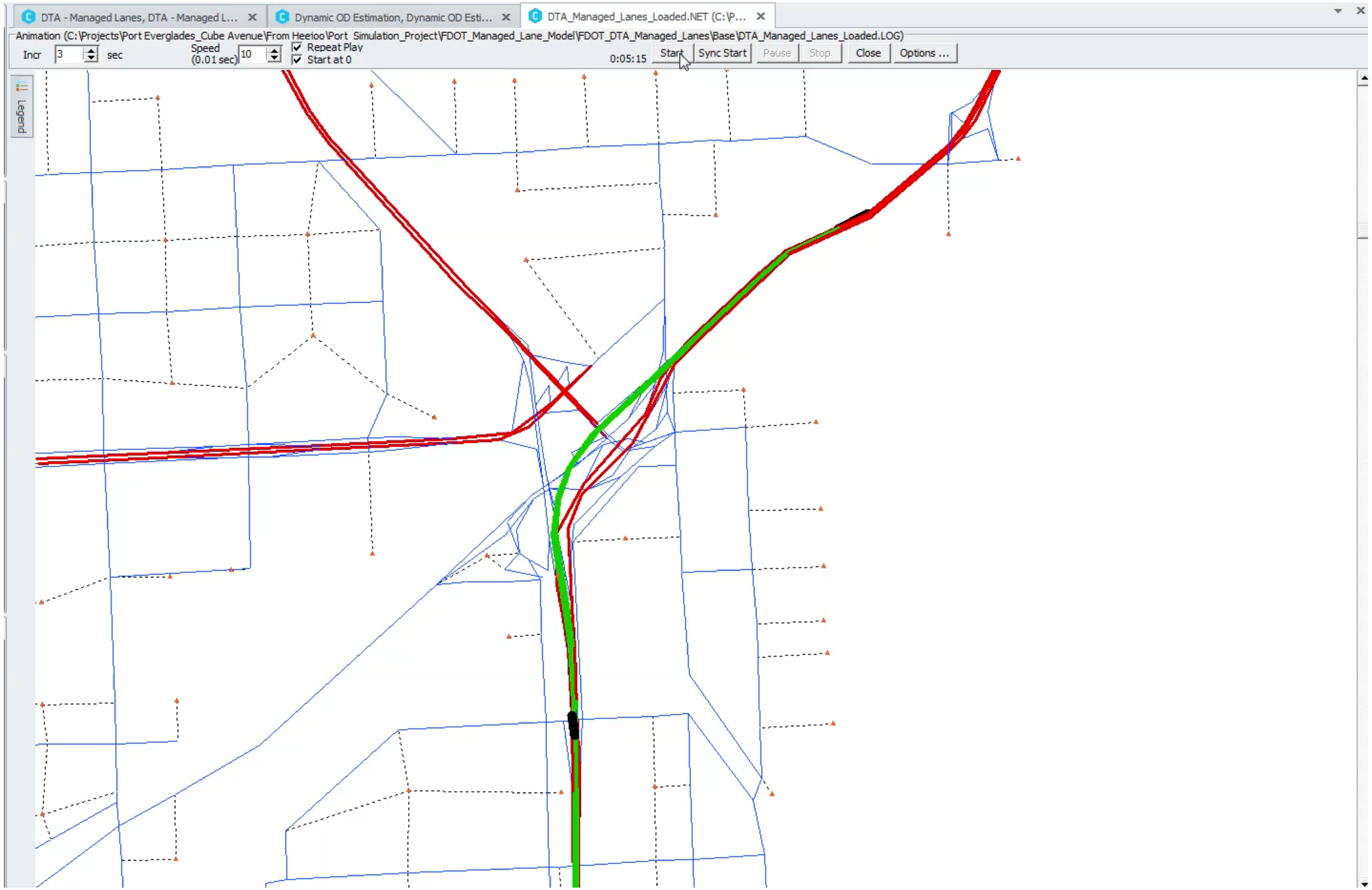
Blocked vehicles

Highway Links

AX/BX	915758.69	915807.06
AY/BY	574964.69	574583.31
A	1428	
B	1427	
BLOCKVS1_1	0	
BLOCKVS2_1	0	
BLOCKVS3_1	0	
BLOCKVS4_1	0	
BLOCKVS5_1	0	
BLOCKVS6_1	0	
BLOCKVS7_1	0	
BLOCKVS8_1	0	
BLOCKVS9_1	0	
BLOCKVS10_1	0	
BLOCKVS11_1	0	
BLOCKVS12_1	0	

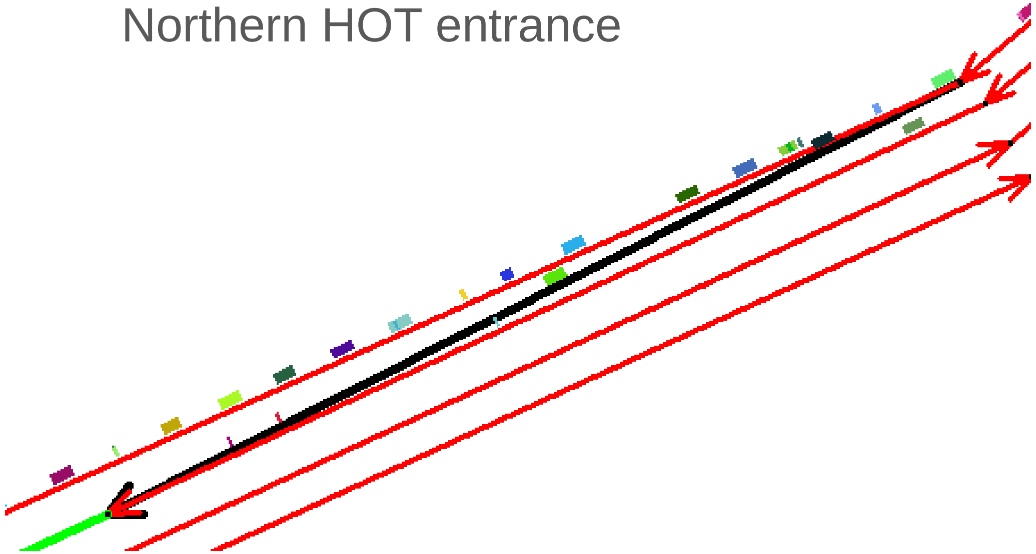


OUTPUT – VEHICLE ANIMATION (1/2)

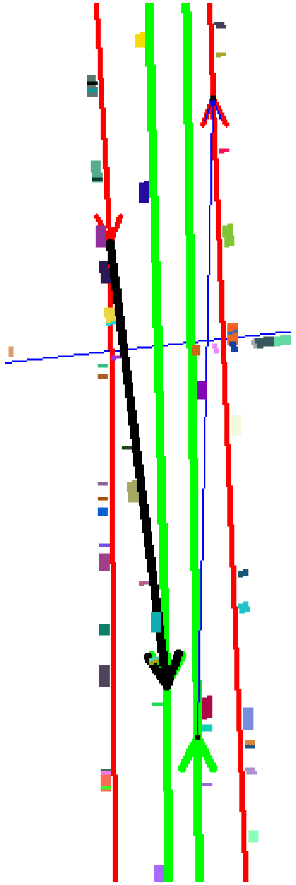


OUTPUT – VEHICLE ANIMATION (2/2)

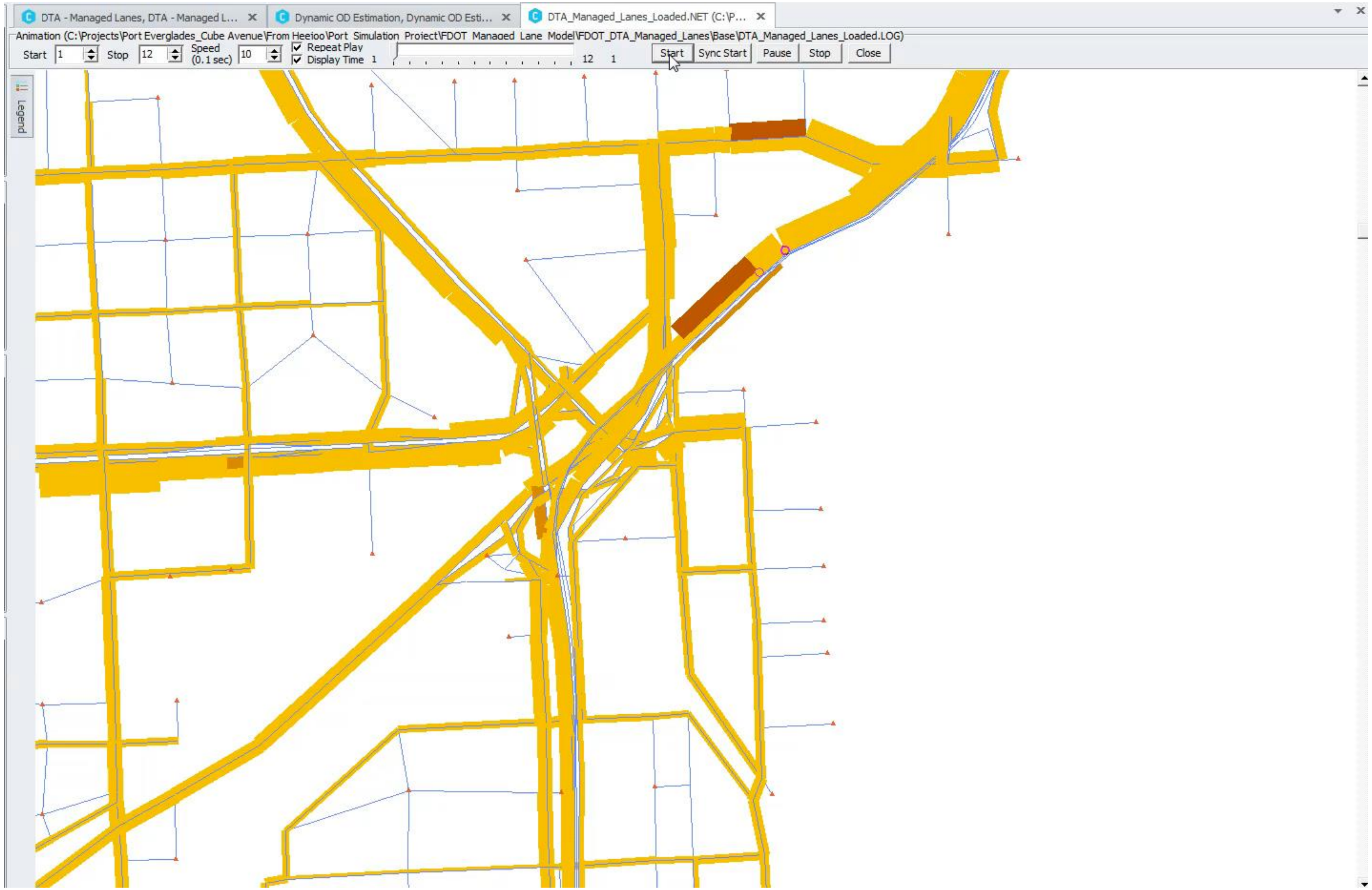
Northern HOT entrance



Southern HOT entrance



OUTPUT – VOLUME & QUEUE ANIMATION



Model Validation by O-D Matrix Estimation

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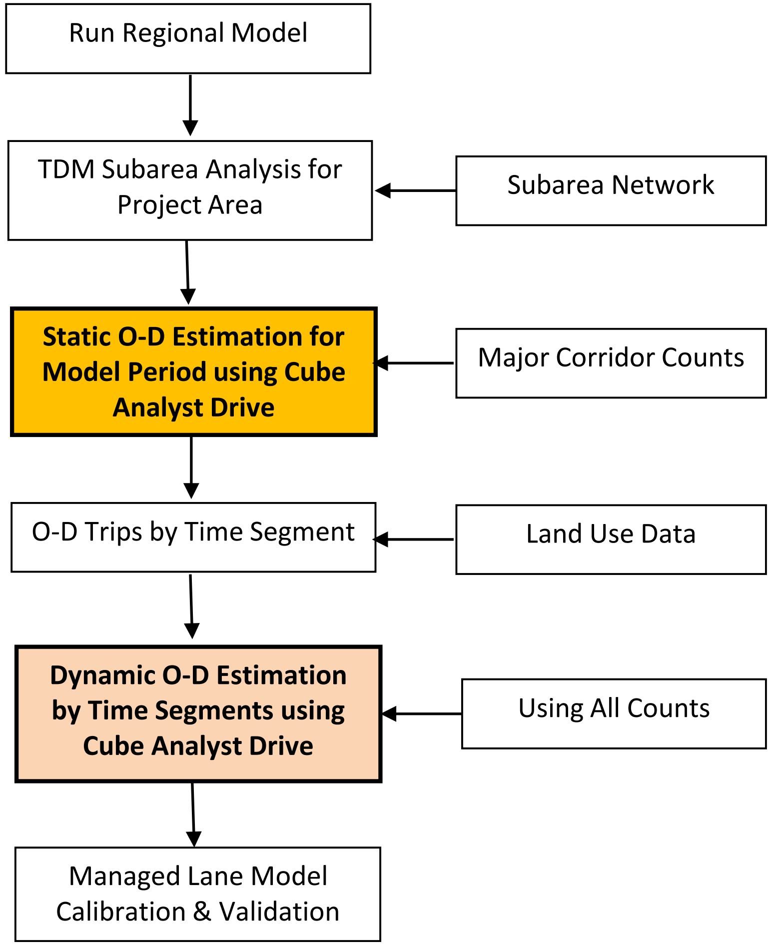
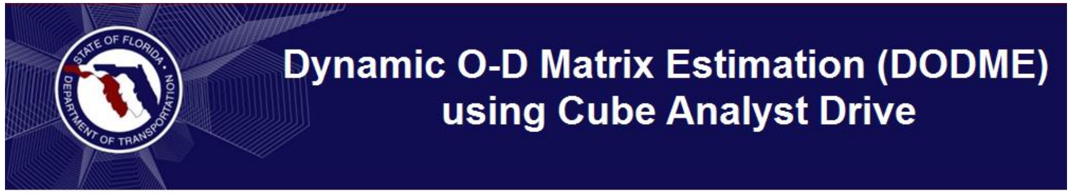
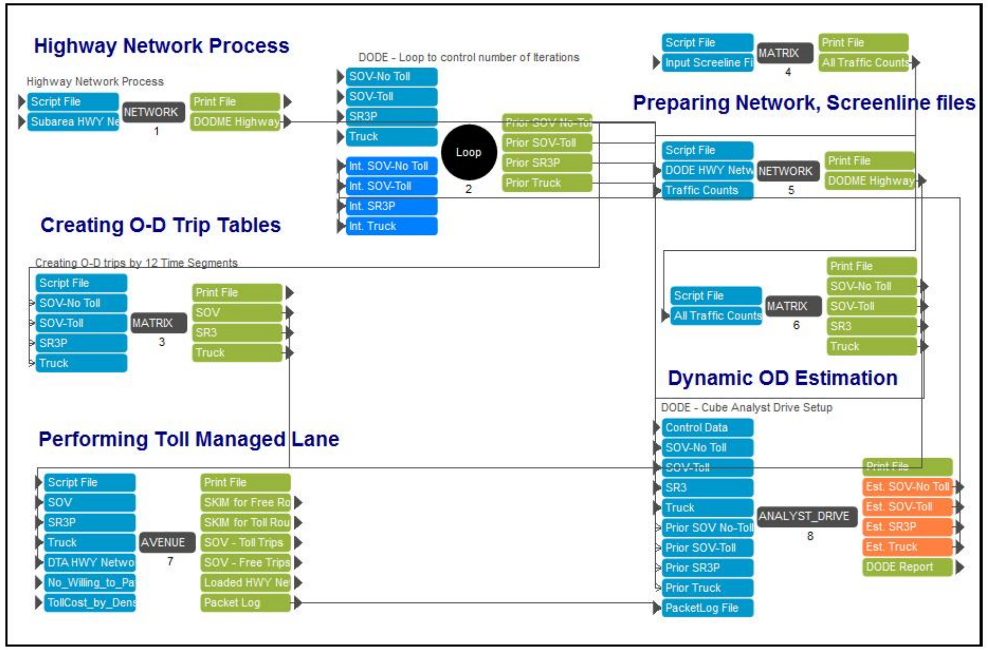
STATIC & DYNAMIC O-D ESTIMATION







THANK YOU!

Any questions?

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