# Final Report

# SCAG DTA Model Development & Training

Submitted To:

**SCAG**

SOUTHERN CALIFORNIA ASSOCIATION of GOVERNMENTS

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## Background

This report is intended to document the methods and assumptions used in developing a prototype of SCAG DTA model using DynusT and DynuStudio. The focus of this project was to demonstrate the use of DTA including network conversion, demand conversion, visualization and scenario analysis. More importantly, this project was stressed in training SCAG staff to better understand DTA and to obtain hands-on experience. Therefore, there were two workshops conducted at SCAG.

Because the project was demonstrative in nature, no formal calibration and validation effort was invested. Nonetheless, basic checking was still performed to ensure the model can function properly and the results are reasonable. It is very important to note that the results presented in this report should not be quoted for any real use without further checking and validation. The same caution also applies to the use of the accompanied dataset.

This report also includes all slides presented at the workshops in the appendixes.

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# Task 1: Regional Model Import & Conversion

## 1.1 Export SCAG TransCAD model to shapefiles.

SCAG regional highway network was exported from TransCAD to ArcView compatible shapefiles which included both highway links and centroid links. The exported link data fields and their essential attributes are listed in Appendix 1. Meantime, the TAZ layer was also exported to shapefiles.

## 1.2 Import shape files into DynuStudio

The network shapefiles were first imported into DynuStudio as an arclink layer then converted to a searchable node/link based network. The network was constructed by indexing A_NODE and B_NODE numbers embedded in the arclink layer. Also, the DIR flag was used to identify arc heading directions and one-way streets. All geo feature points are kept in a separate shape matrix which can be switched on/off as needed. Meantime, TAZ shapefiles were imported into Boundary-1 layer. The area code of County, RSA and CSA were converted to super zone code and stored as node attributes respectively. The resulting network and zone system are shown in Figure 1, 2 and 3. The key network stats are shown in Table 1 below:

Table 1: SCAG Regional DTA Network – Key Stats

| | |
|---|---|
| Highest Zone Number | 4,192 |
| Total Number of Nodes | 35,368 |
| Highest Node Number | 125,360 |
| Total Number of Links | 108,283 |
| Total Lane Miles | 178,812 |

Figure 1: SCAG Network – Full View

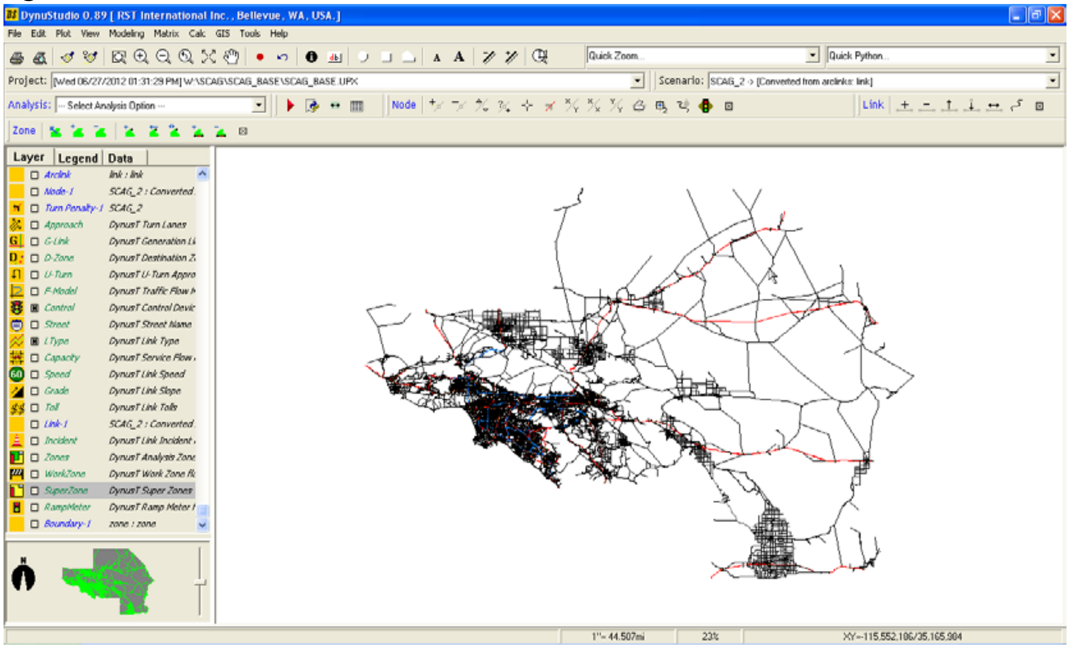


Figure 2: SCAG TAZ System – Full View

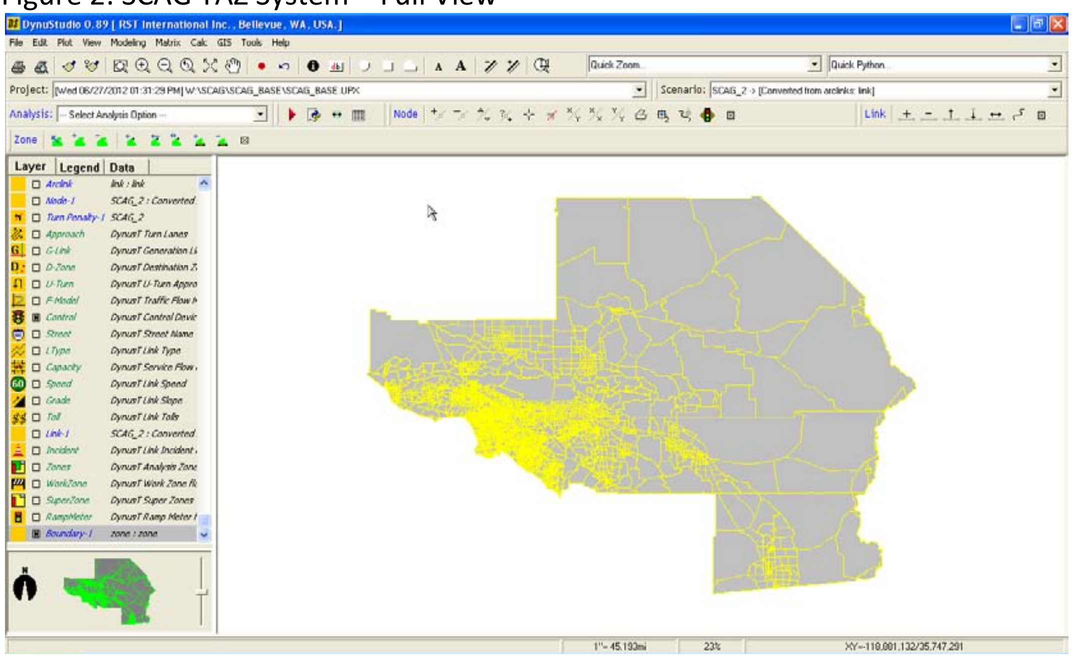
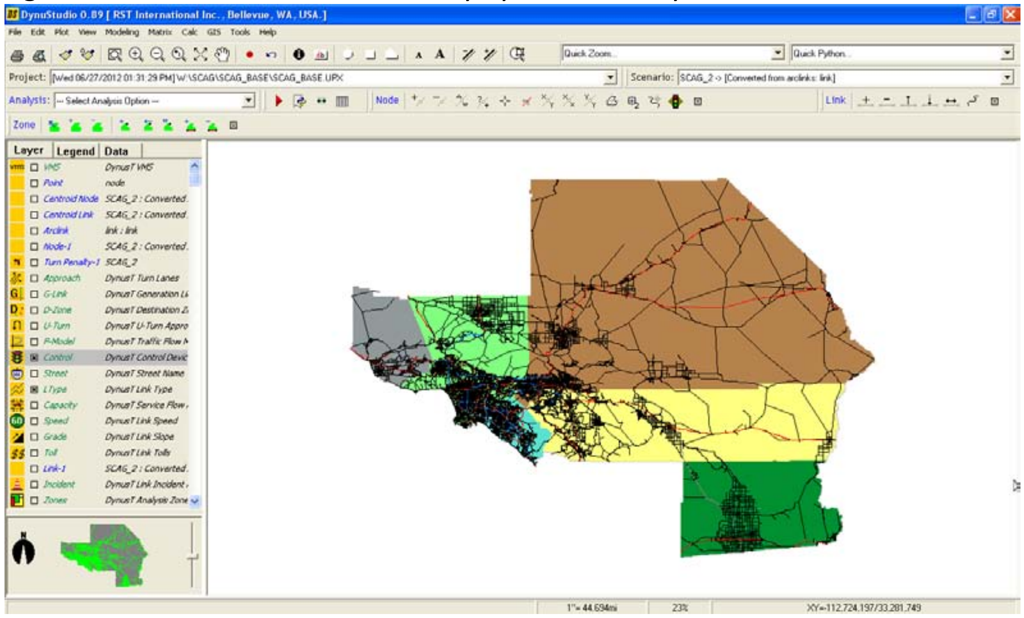


Figure 3: SCAG Network with County System Overlay



## 1.3 Import demand tables into DynuStudio

The demand import and conversion was a two steps process. Firstly, the vehicle OD tables were exported to CSV files by zone pair, time period and mode (SOV, HOV & Truck). There were four time periods defined in the SCAG model as shown in Table 2:

Table 2: SCAG Model Time Periods

| | |
|---|---|
| AM Peak (AM) | 6AM to 9AM |
| Midday (MD) | 9AM to 3PM |
| PM Peak (PM) | 3PM to 7PM |
| Night (NT) | 7PM to 6AM |

OD Tables were also provided by zone group as shown in Table 3:

Table 3: SCAG Model OD Table Groups

| | |
|---|---|
| II | Internal - Internal |
| XI & IX | Internal - External & External - Internal |
| XX | External - External |
| AIR | Airport bound trips |
| PORT | Water port bound trips |

Secondly, a Python script was written to read in all files into DynuStudio and saved in table format for further processing. Table 4 shows the total trips breakdown by mode and period.

Moreover, the period based OD demand was sliced into hourly demand by the weighted diurnal factors for the period. Lastly, the hourly OD demand was stitched together to form the hourly 24-hour demand. This process was repeated for each of the three modes and saved to DynusT format.

## 1.4 Data conversion from TransCAD to DynuStudio

Essential link attributes were cross copied from arclink layer to the corresponding links, they were: posted speeds, lanes, length (miles), street names and grade. Also, the link type was converted into DynusT types using lookup table as shown in Table 5.

## 1.5 Check and fix network connectivity

Network connectivity in DynuStudio is defined by node orientation and link turning movements. The node orientation identifies the connecting node directions for an intersection, such as, N, S, E, W, NE, NW, SE and SW. Once the node orientation was identified, the major link movements can be identified automatically, such as, left, thru and right.  Both node directions and link movements can be calculated using the built-in tools. However, the initial calculation may not be always correct especially for odd intersections with skewed angles or more than 4 approaching legs. Therefore, manual checking and adjustments are always required.

Ultimately, a series of quick one-shot simulation runs with small demand was also performed to check the path related issues. Those issues could reveal incorrect movement coding or one-way link in the wrong direction. Such quick runs need to be performed repeatedly until all trips can find paths to the destinations in reasonable manner and no errors reported by DynusT.

Table 4: SCAG Model Auto Trips OD Demand Summary

| SOV | II | XIIX | XX | AIR | PORT | TOTAL |
|---|---|---|---|---|---|---|
| AM | 4,891,093 | 89,299 | 7,765 | 4,473 | | 4,992,630 |
| MD | 7,962,568 | 115,693 | 4,265 | 12,146 | | 8,094,672 |
| PM | 5,922,295 | 121,192 | 4,467 | 21,987 | | 6,069,941 |
| NT | 10,322,584 | 106,560 | 3,927 | 26,504 | | 10,459,575 |
| **DAILY** | **29,098,540** | **432,745** | **20,424** | **65,110** | | **29,616,818** |
| | | | | | | |
| **HOV** | II | XIIX | XX | AIR | | TOTAL |
| AM | 2,093,837 | 44,603 | 1,645 | 4,881 | | 2,144,966 |
| MD | 4,125,165 | 57,838 | 2,131 | 13,772 | | 4,198,906 |
| PM | 2,753,612 | 60,583 | 2,232 | 24,520 | | 2,840,947 |
| NT | 7,086,378 | 53,054 | 1,962 | 29,910 | | 7,171,304 |
| **DAILY** | **16,058,992** | **216,077** | **7,971** | **73,083** | | **16,356,123** |
| | | | | | | |
| **TRUCK** | II | XIIX | XX | AIR | PORT | TOTAL |
| AM | 153,406 | | | 826 | 9,612 | 154,232 |
| MD | 427,149 | | | 1,481 | 20,600 | 428,629 |
| PM | 240,319 | | | 1,735 | 13,249 | 242,054 |
| NT | 550,034 | | | 1,790 | 4,412 | 551,824 |
| **DAILY** | **1,370,909** | | | **5,831** | | **1,376,740** |

Table 5: SCAG Link Type Conversion

| SCAG Type | DynuStudio Type | Remark |
|---|---|---|
| 10,80 | 1 | Freeway GP |
| 20-25 | 10 | Freeway HOV |
| 30-32 | 7 | Highway |
| 40-75 | 5 | Arterial |
| 81,85 | 4 | Off-ramp |
| 82,83,84,86 | 3 | On-ramp |
| 32,89 | 9 | Freeway Toll/HOT Lane |

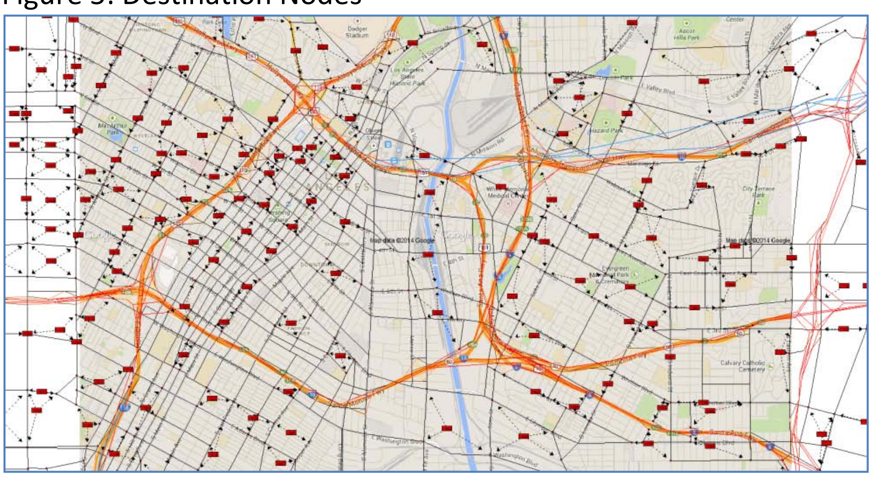
## 1.6 Convert centroids

Unlike traditional demand models where trips are loaded from a single point at centroids, DTA model loads trips at multiple points. In DynusT, trips are loaded from indefinite points on links so called generation links. Those points are randomly defined by the program. However, users can define the loading weights for each generation link to control how many trips from a zone will be loaded on each link. On the other hand, destination nodes are also defined for each zone.

Generation links and destination nodes can be easily converted from existing centroids by using the connecting links and nodes on the regular roadways. For this project, the built-in tool in DynuStudio was used for such conversion. By default, the loading weights were calculated based on total lane miles among all generation links of a zone.

Figure 4: Generation Links

Figure 5: Destination Nodes



## 1.7 Check and fix default signal setting

Because actual signal setting was not available, the default setting was used initially. The default actuated signal was assumed for every node that has 3 or more approaching legs, except for freeway nodes. Figure 6 shows the geographical distribution of default signals. In addition, a generic two-phase phasing scheme was used with default timings assumed as:

Max green time = 60 seconds
Min green time = 5 seconds
Amber time = 5 seconds

Figure 7 shows the phasing scheme for a 4-leg signal. Also, only one timing plan was assumed throughout the entire simulation period.

Figure 6: SCAG Default Signals for the DTA Network

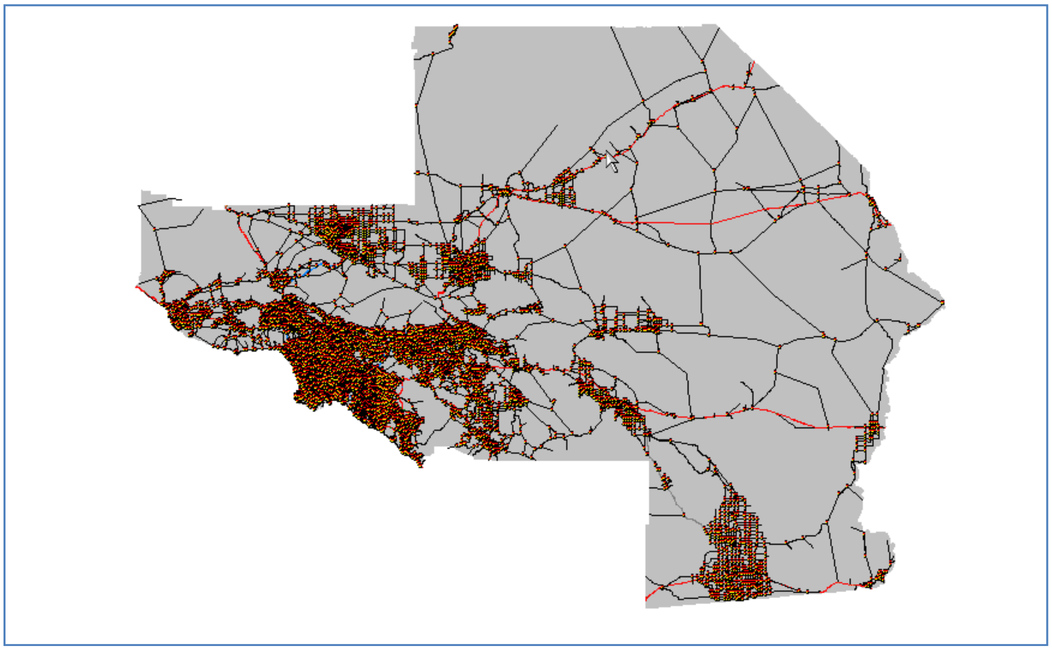
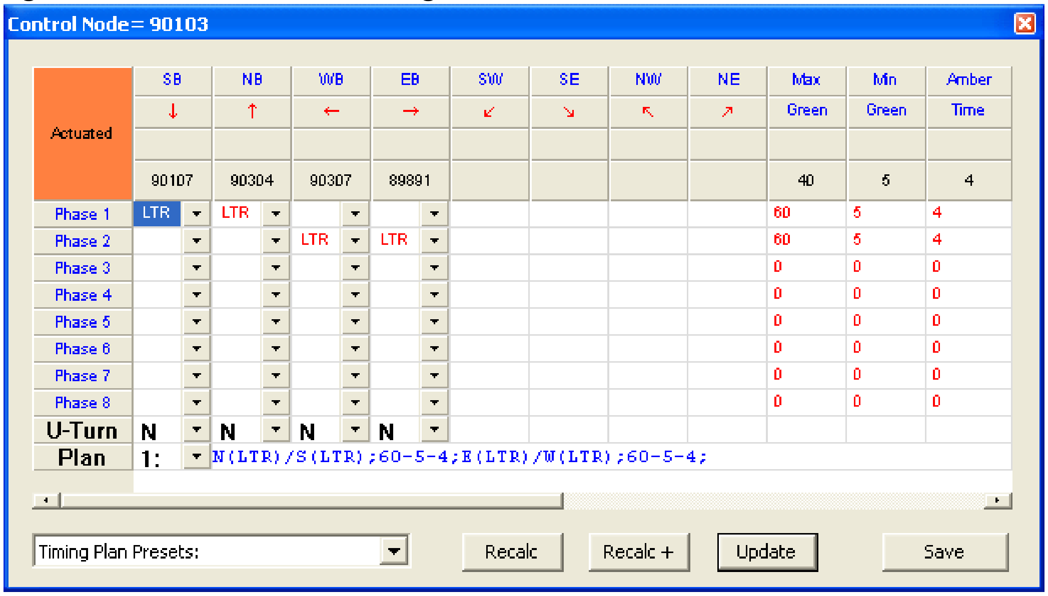


Figure 7: Default Actuated Timing Plan




## 1.8 Prepare Traffic Flow Models

Traffic flow models in DTA depict the speed-density and speed-flow relationship. Comparing to volume-delay functions (VDF) used in the static model, traffic flow models are more capacity constrained. Ideally, there should be different traffic flow model for each roadway type estimated from observed count data. For this project, however, only two generic models were used: one for freeway and one for arterial. The freeway model is a two-regime curve which allows free flow speeds when the density is below 25. For arterials, the curve is monotonic and continuous decreasing with no free flow regime. Figure 8 & 9 show the curves and pertaining parameters for the two curves.

## 1.9 Prepare DynusT demand with hourly factors

Since the OD demand was aggregated from time period based tables with large time span, be default, the trips will be evenly distributed within the period which is deemed not realistic. Therefore, a better temporal profile was borrowed from SCAG activity based model project which was derived from the travel survey. The diurnal factors were calculated from hourly total trips provided by Ya-Li Chen of UCSB in March 2012 as shown in Table 6. Since no mode specific temporal profiles were provided, the same diurnal factors were was applied to all modes. Figure 8 shows the resulting diurnal profile.

Figure 8: Traffic Flow Model for Freeway

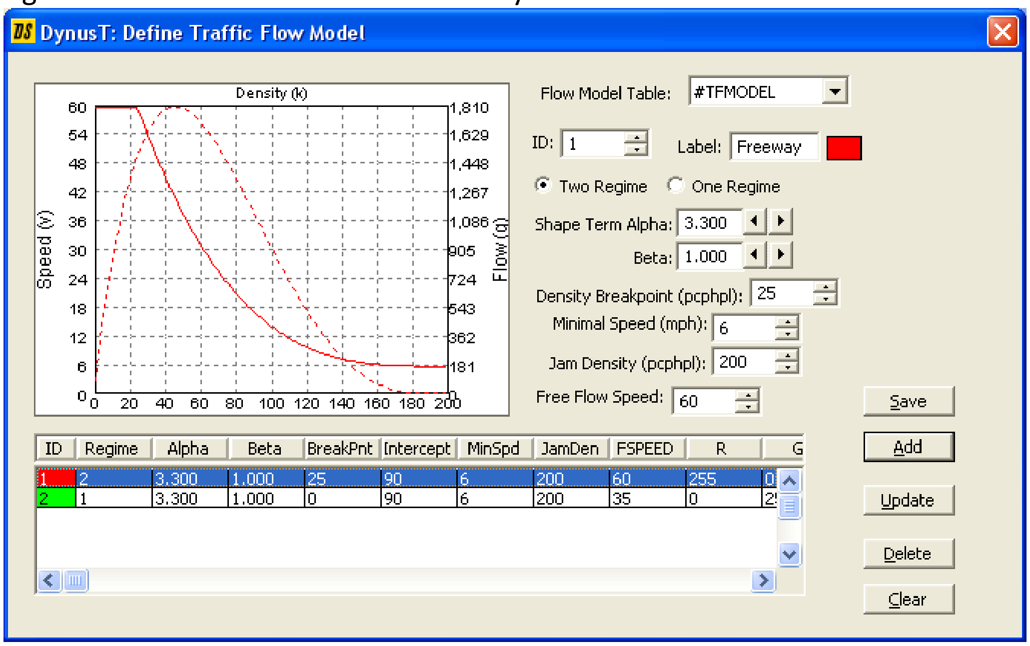



Figure 7: Traffic Flow Model for Arterial

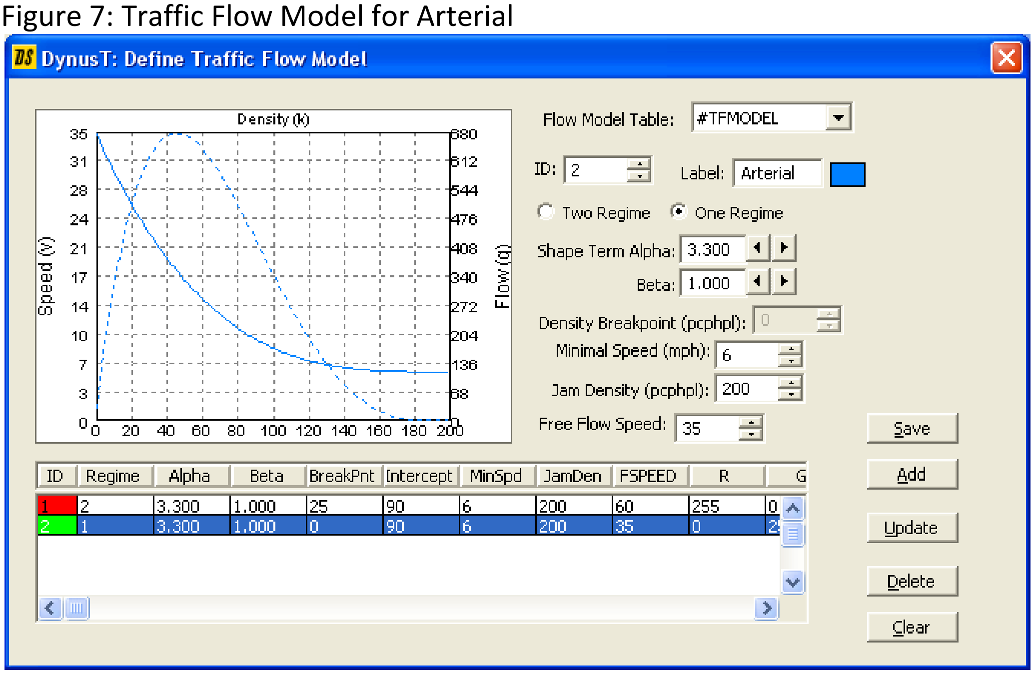
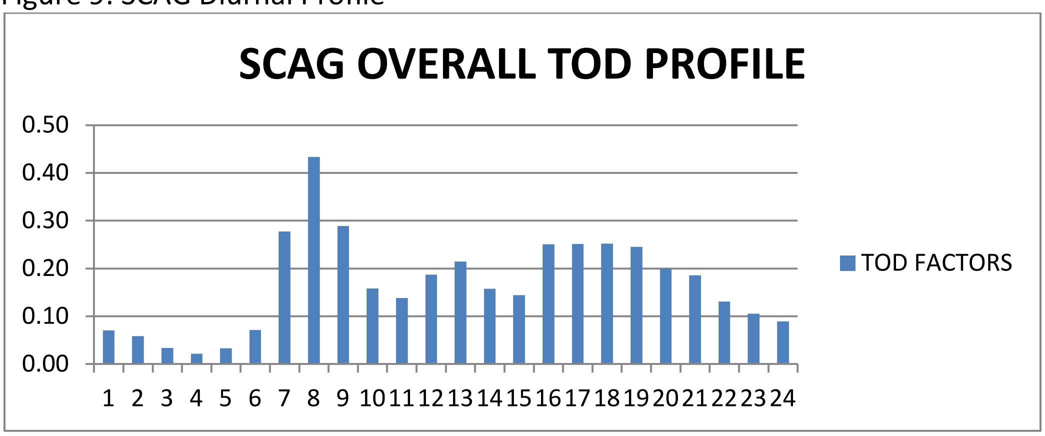


Table 6: SCAG Overall Diurnal Factors

| PERIOD | HOURS | TRIPS | TOD FACTORS |
|---|---|---|---|
| NT | 0:00 | 820,903 | 0.07 |
| NT | 1:00 | 677,681 | 0.06 |
| NT | 2:00 | 391,152 | 0.03 |
| NT | 3:00 | 252,165 | 0.02 |
| NT | 4:00 | 382,608 | 0.03 |
| NT | 5:00 | 823,446 | 0.07 |
| AM | 6:00 | 3,120,340 | 0.28 |
| AM | 7:00 | 4,874,473 | 0.43 |
| AM | 8:00 | 3,250,242 | 0.29 |
| MD | 9:00 | 2,672,591 | 0.16 |
| MD | 10:00 | 2,336,592 | 0.14 |
| MD | 11:00 | 3,168,652 | 0.19 |
| MD | 12:00 | 3,623,956 | 0.21 |
| MD | 13:00 | 2,667,092 | 0.16 |
| MD | 14:00 | 2,444,814 | 0.14 |
| PM | 15:00 | 2,772,404 | 0.25 |
| PM | 16:00 | 2,785,401 | 0.25 |
| PM | 17:00 | 2,792,356 | 0.25 |
| PM | 18:00 | 2,715,648 | 0.25 |
| NT | 19:00 | 2,311,742 | 0.20 |
| NT | 20:00 | 2,155,178 | 0.19 |
| NT | 21:00 | 1,517,504 | 0.13 |
| NT | 22:00 | 1,218,410 | 0.11 |
| NT | 23:00 | 1,036,399 | 0.09 |

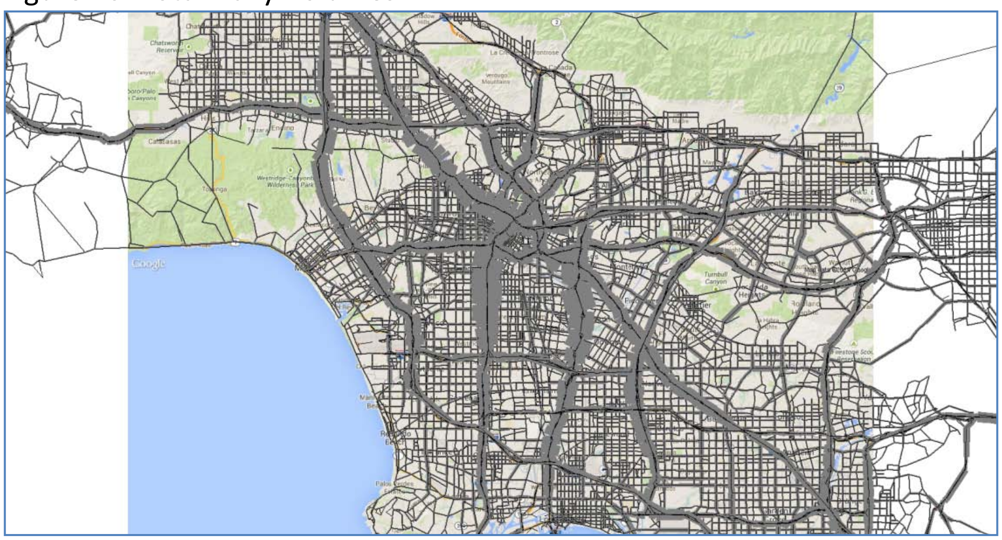
Figure 9: SCAG Diurnal Profile



## 1.10 DTA test runs and calibration

After network and demand data were properly configured, full DynusT runs can be began. Because the total daily demand was too large to be handled with the available machine, only 50% of demand were assigned to the network initially. A series of runs were conducted to check the assignment reasonableness. Because the nature of this project is mainly for demonstration and training purposes, no formal calibration and validation procedures were performed. Nonetheless, extensive visual checking was performed to ensure  the results were matching to the results found in the regional demand model. Figure 10 shows the total assigned daily volumes in bandwidth.

Figure 10: Total Daily Volumes



## Task 2: Subarea Cut

Subarea cut is a powerful feature in DynuStudio which allows user to extract network and pertaining demand for a defined subarea. Subarea cut is necessary tool for a regional DTA model to reduce run time and to be integrated with micro models. Comparing to subarea cut tools found in the static models, DTA subarea cut not only extract the network but also the temporal information in the trajectories. Therefore, the resulting subarea model can maintain high traffic consistency with the regional model. More importantly, the subarea model can reduce the run time to a more manageable range and therefore allows more detailed calibration and scenario analyses. For this project, a subarea that contains the downtown core was defined and extracted as shown in Figure 11.

Figure 11: SCAG Subarea Demo

Furthermore, different plots can be produced to capture the snapshots of temporal traffic characteristics of the subarea network using the tools in DynuStudio.

Figure 12: Cumulative Volumes Snapshot

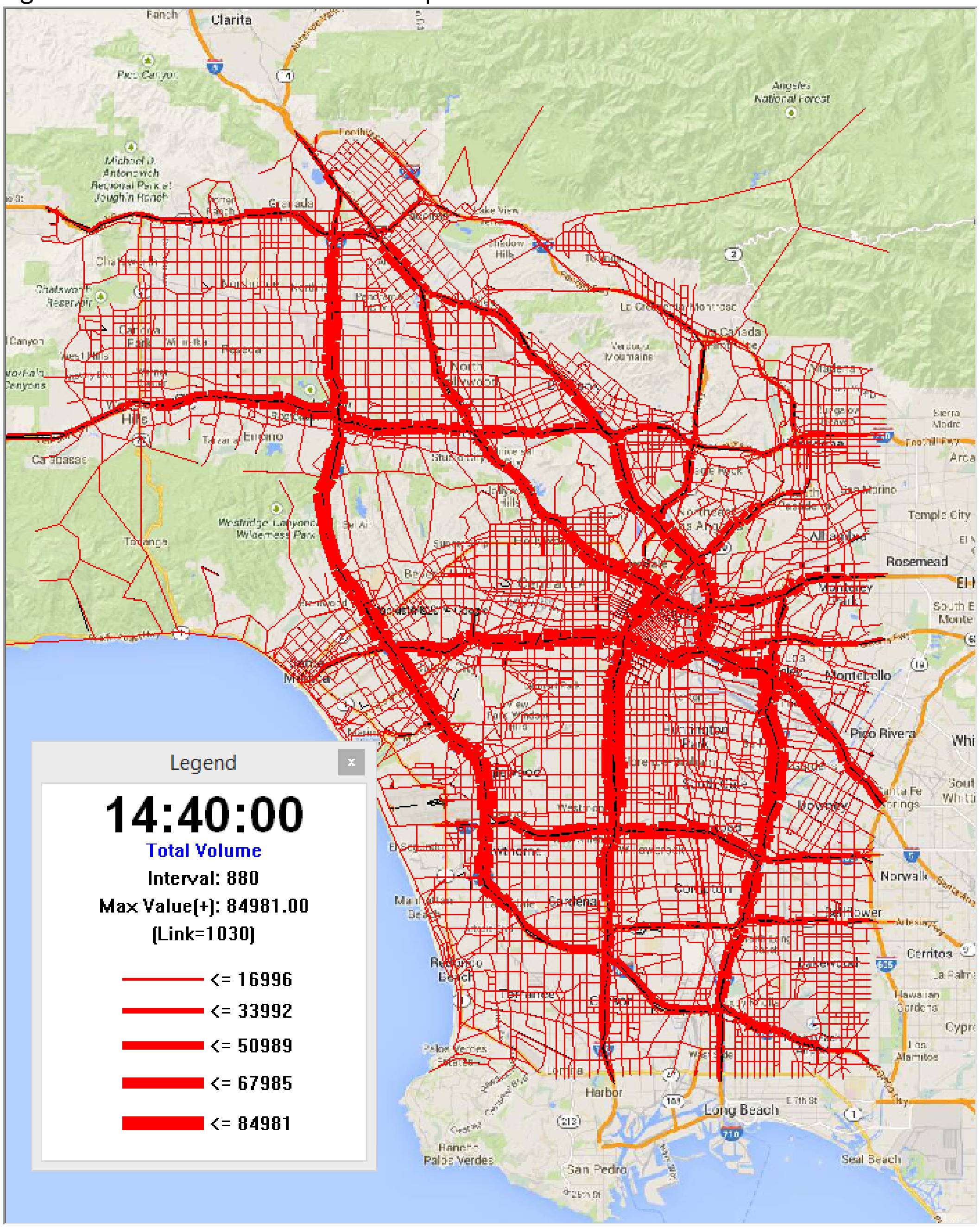


Figure 13: Link Density Snapshot

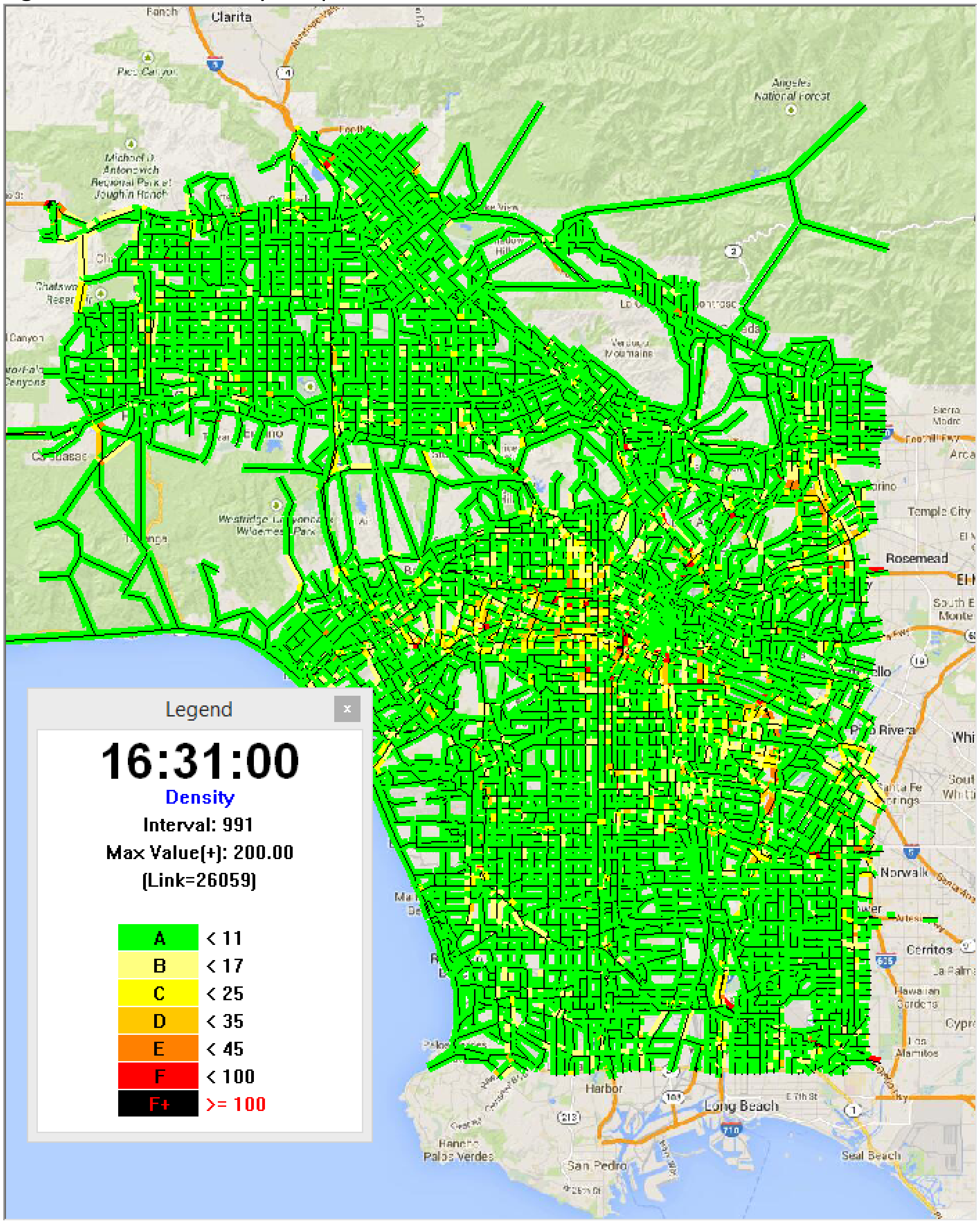


Figure 14: Link Speed Snapshot

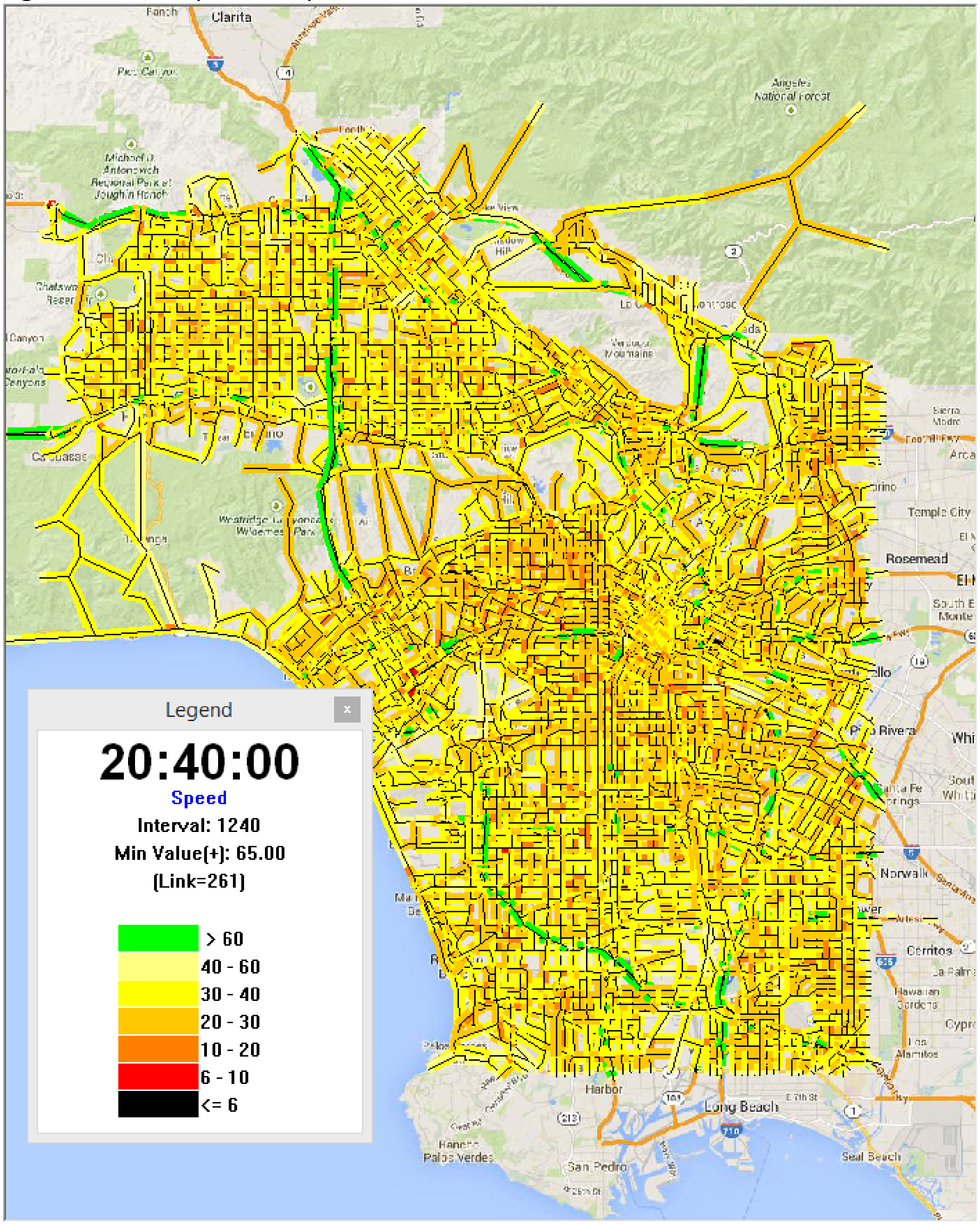


Figure 15: Link Flow by Density Snapshot

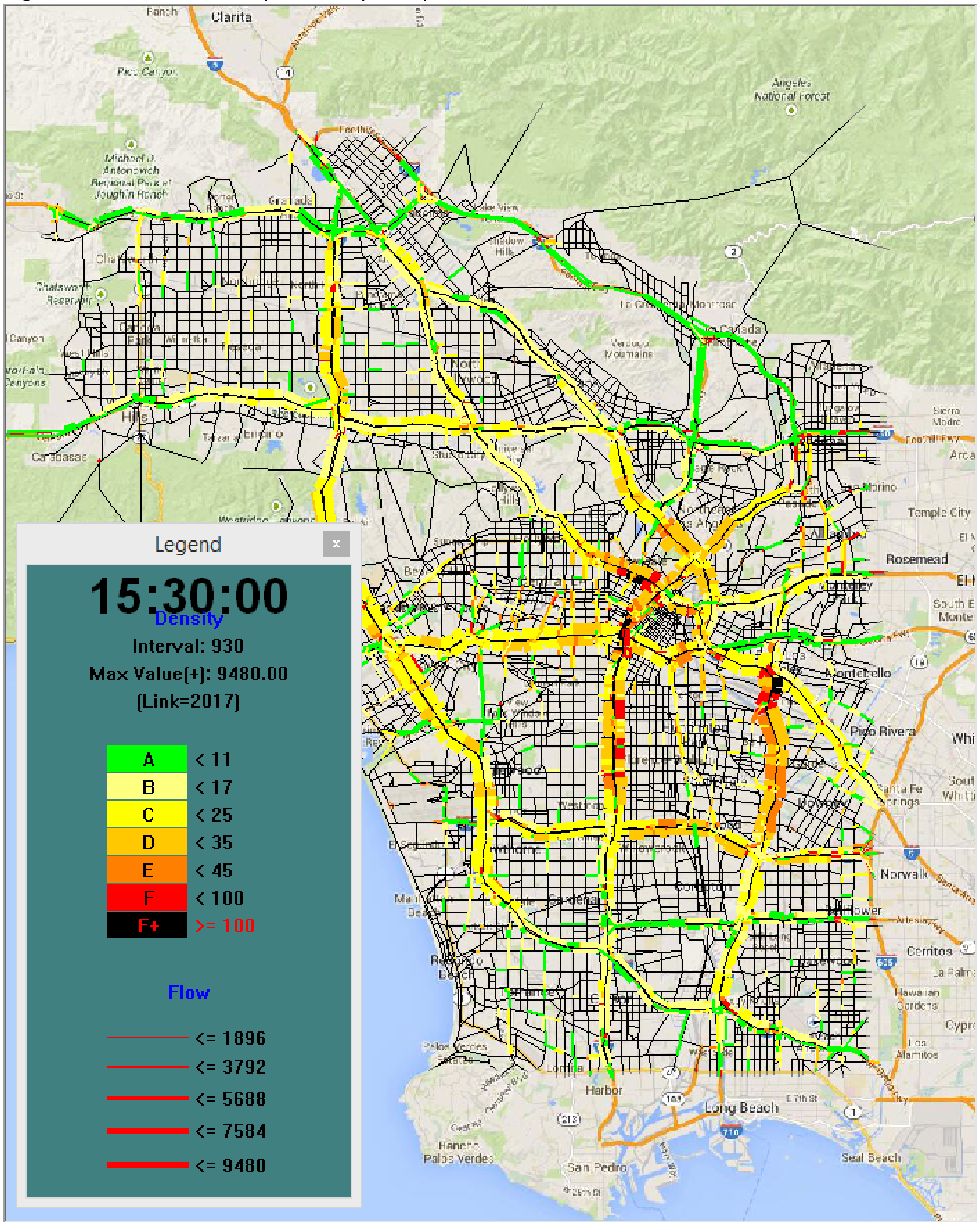


Figure 16: Diurnal Profiles

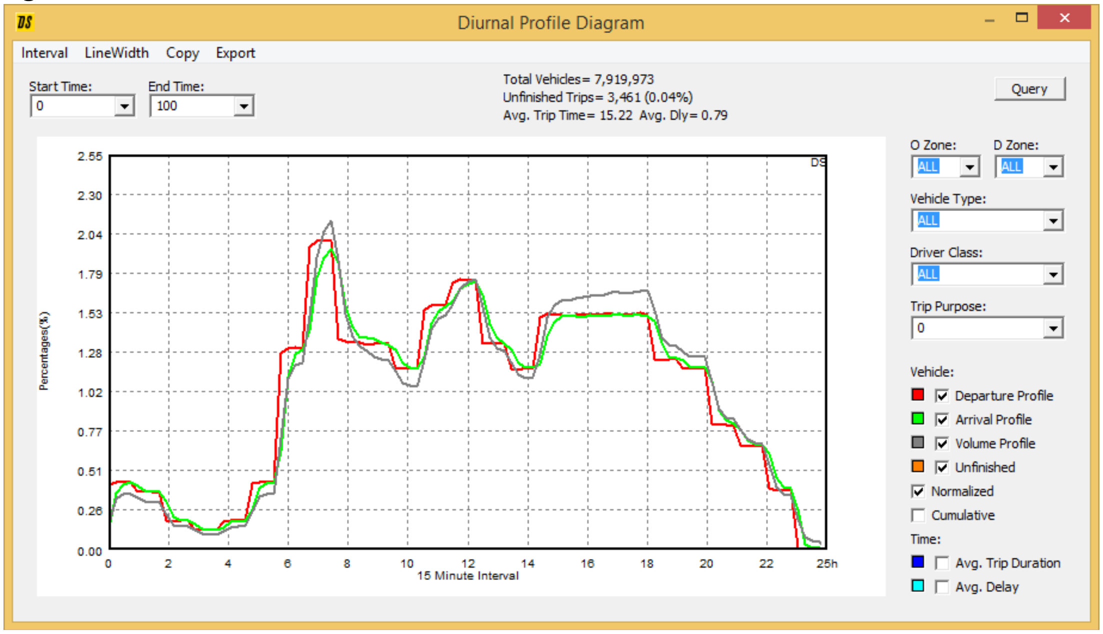
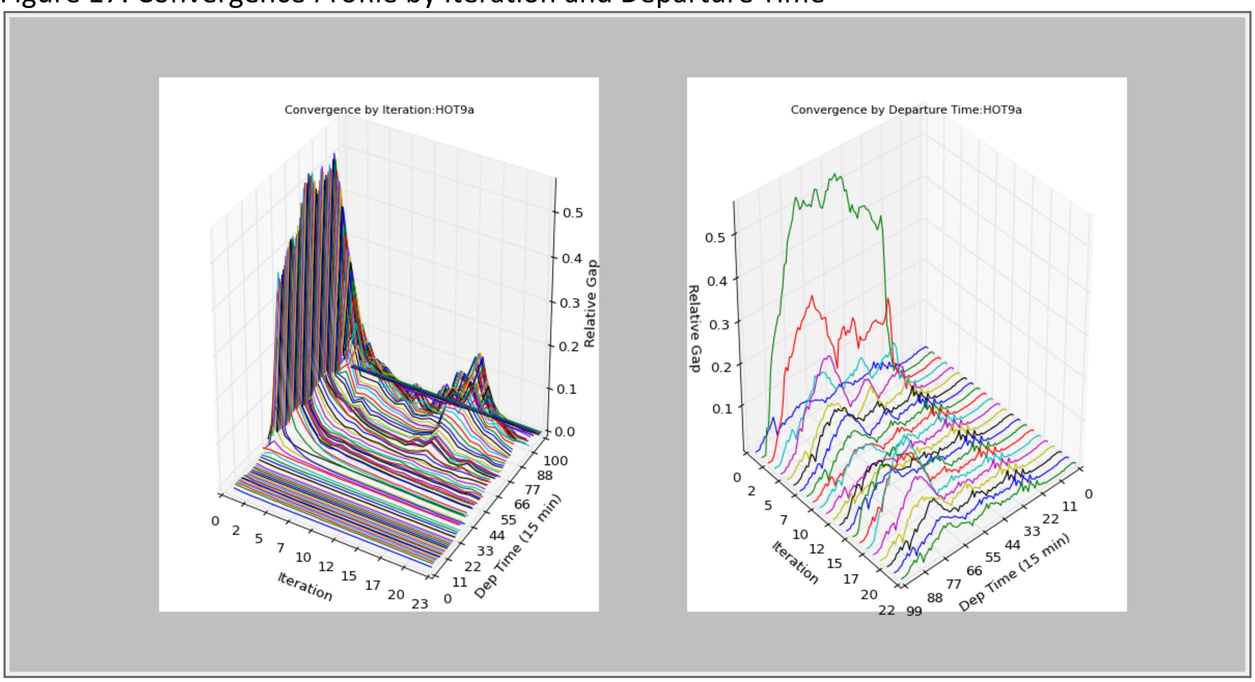



Figure 17: Convergence Profile by Iteration and Departure Time

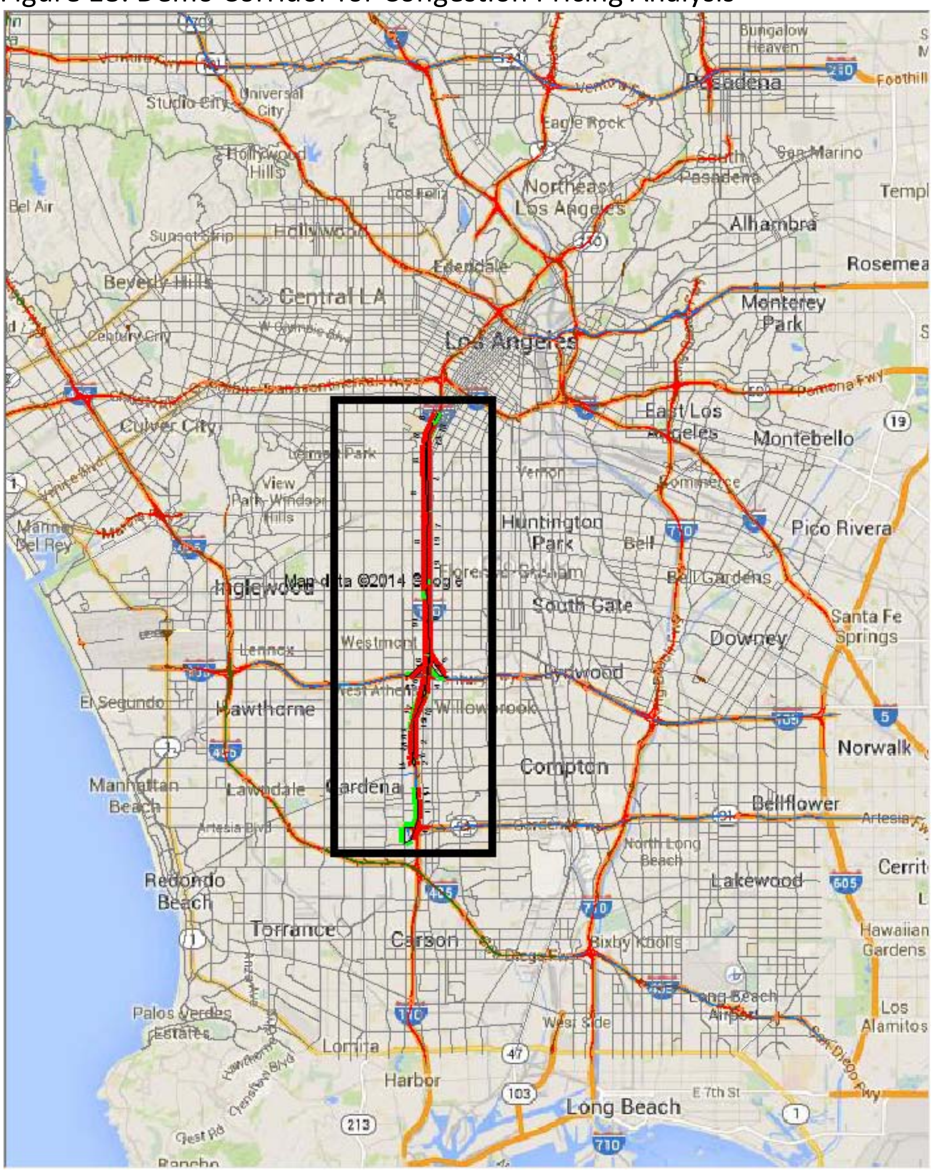


# Task 3: Congestion Pricing Analysis Demo

Congestion pricing is a method to calculate the optimal tolls for vehicles to enter managed lane (or HOT) without severely degrading its speeds and meantime maximizing the total toll revenues for the entire system. DynusT employees a sophisticate algorithm that can calculate such optimal tolls for each time interval efficiently.

To demonstrate the application of congestion pricing, a section on I-110 was selected as shown in Figure 16.

Figure 18: Demo Corridor for Congestion Pricing Analysis

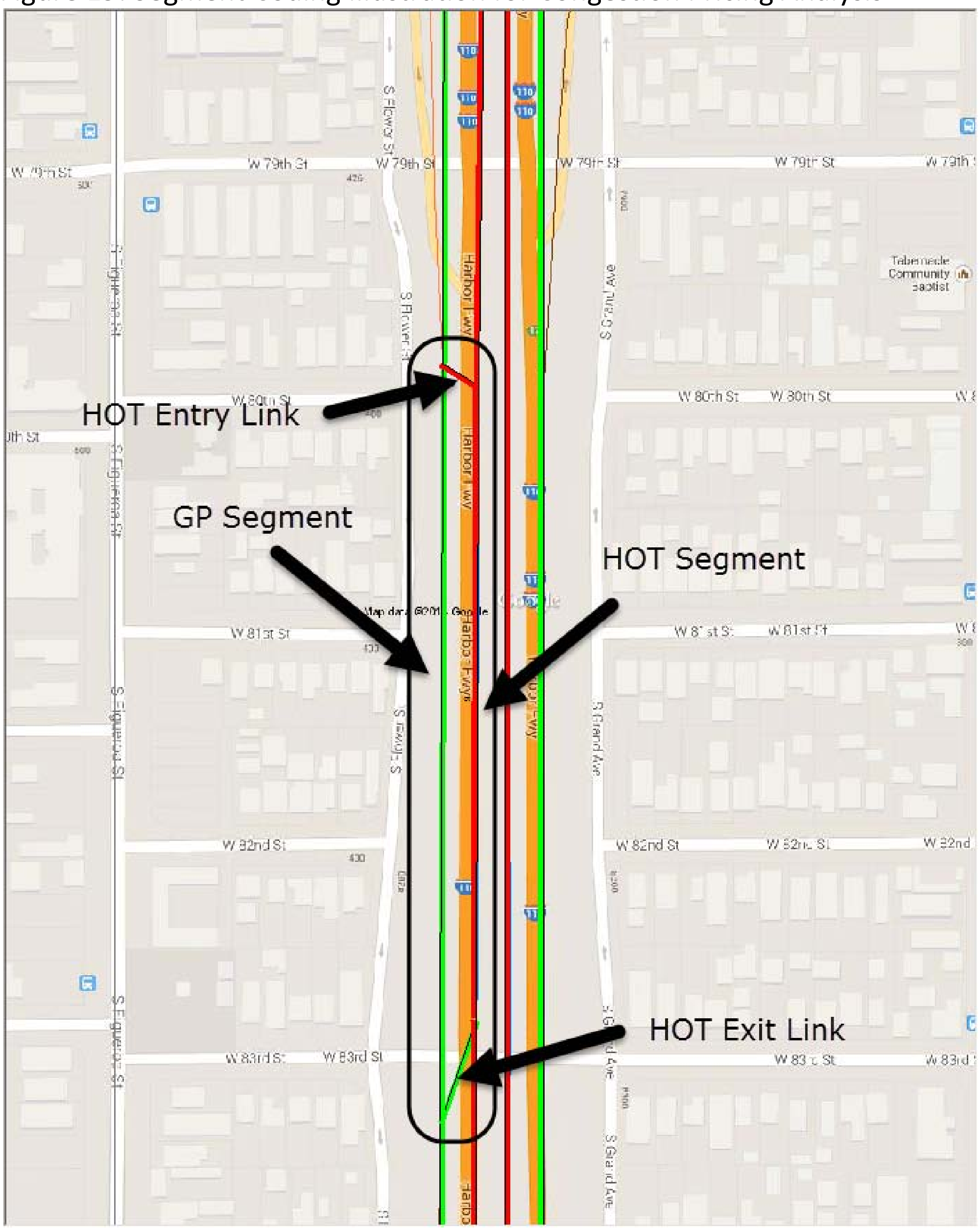


The congestion pricing involves several key steps as described below:

## 3.1 Identify coupled GP and HOT segments

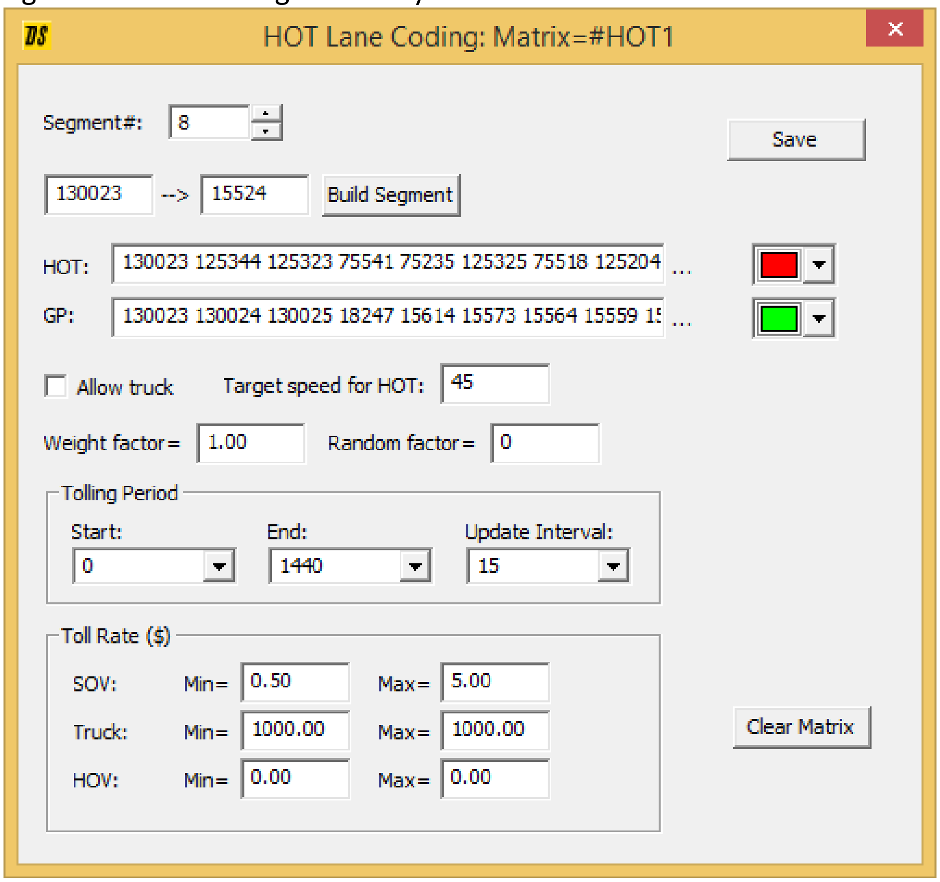
For congestion pricing mechanism to work, a series of coupled GP and HOT lane segments must be coded for the targeted corridor without missing any links as illustrated by Figure 17.

Figure 19: Segment Coding Illustration for Congestion Pricing Analysis



The segment coding can be easily done by using the editing tool in DynuStudio as shown in Figure 18. The editing tool can identify the consecutive nodes for a coupled segment automatically between a starting and ending node pair.

Figure 20: HOT Editing Tool in DynuStudio




## 3.2 Specify speed threshold for HOT lane

This specifies the minimum speed that HOT lane needs to maintain so that traffic can move efficiently. No more vehicles will be allowed to enter HOT lanes if the speed is dropping below the threshold which typically set at 45 MPH.

## 3.3 Specify toll rate ranges

Optimal tolls can be calculated between minimum and maximum values specified by the user for each vehicle mode. Usually, higher tolls are used for truck mode if it is allowed to use HOT lane. On the other hand, HOV vehicles are usually free to use HOT lane.

### 3.4 Prepare ConestionPricingConfig.dat

"CongestionPricingConfig.dat" is the key input file for DynusT to perform optimal toll calculation which has the format as shown in Figure 19. This file will be automatically generated by DynuStudio if pricing option is enabled.

Figure 19: File format of CongestionPricingConfig.dat

```
16
1    45  0.500     5.0     0.0     0.0 1000.0 1000.0     1.0     0.0
   1   7   119599 125209 130000 130001 130002 130003 15263
   1   8   119599 92119 92120 15103 15289 75124 15293 15263
1    45  0.500     5.0     0.0     0.0 1000.0 1000.0     1.0     0.0
   2   7   15224 130006 130007 130008 125332 83172 15232
   2   4   15224 73060 15228 15232
1    45  0.500     5.0     0.0     0.0 1000.0 1000.0     1.0     0.0
   3   4   15232 125206 83316 15491
   3   3   15232 15304 15491
1    45  0.500     5.0     0.0     0.0 1000.0 1000.0     1.0     0.0
   4   5   15491 125205 125329 75495 119592
   4   3   15491 15498 119592
1    45  0.500     5.0     0.0     0.0 1000.0 1000.0     1.0     0.0
   5   7   18192 125027 75911 75495 125333 125328 15543
   5   8   18192 18235 15591 15585 15596 15541 120533 15543
1    45  0.500     5.0     0.0     0.0 1000.0 1000.0     1.0     0.0
   6   7   15177 125026 75468 75495 125333 125328 15543
   6   8   15177 15326 15591 15585 15596 15541 120533 15543
1    45  0.500     5.0     0.0     0.0 1000.0 1000.0     1.0     0.0
   7   5   15562 125203 125326 75549 15593
   7  10   15562 15597 15598 15599 15583 15578 15572 15574 15588 15593
1    45  0.500     5.0     0.0     0.0 1000.0 1000.0     1.0     0.0
   8   9   130023 125344 125323 75541 75235 125325 75518 125204 15524
   8  17   130023 130024 130025 18247 15614 15573 15564 15559 15558 15566 15584 15577 15576 15546 15544 15529 15524
1    45  0.500     5.0     0.0     0.0 1000.0 1000.0     1.0     0.0
   9   4   15529 75518 125204 15524
   9   2   15529 15524
1    45  0.500     5.0     0.0     0.0 1000.0 1000.0     1.0     0.0
  10   7   120534 125327 75537 75532 125330 124841 15335
  10   8   120534 15520 15604 77741 15567 15492 15477 15335
1    45  0.500     5.0     0.0     0.0 1000.0 1000.0     1.0     0.0
  11   7   15221 125207 125331 130009 130010 130011 15233
  11   3   15221 15217 15233
1    45  0.500     5.0     0.0     0.0 1000.0 1000.0     1.0     0.0
  13   4   75549 125324 125345 18213
  13   4   75549 15593 18244 18213
```

### 3.5 Prepare Toll.dat

Another key input file for congestion pricing analysis is toll.dat. In this file, user must specify how frequent the toll rate will be updated and the starting toll rate for each mode. Figure 20 shows a snippet of such file. DynuStudio will produce this file automatically if enabled.

### 3.6 Calculate toll rates and revenues

DynusT calculates optimal toll rates for each HOT segment and for each time interval in an iterative manner based on the equilibrated volumes. After the assignment is properly converged, the total revenues for each segment will be calculated according to the final toll rates. Those info are saved in TollRevenue.dat. In addition, the initial toll rates in the toll.dat will be updated with the final toll rates.

Figure 20: File format of Toll.dat

```
15224 130006 1395.0 1409.9    1      0.500      0.000  1000.000
15224 130006 1410.0 1424.9    1      0.500      0.000  1000.000
15224 130006 1425.0 1439.9    1      0.500      0.000  1000.000
15232 125206    0.0   14.9    1      0.500      0.000  1000.000
15232 125206   15.0   29.9    1      0.500      0.000  1000.000
15232 125206   30.0   44.9    1      0.500      0.000  1000.000
15232 125206   45.0   59.9    1      0.500      0.000  1000.000
15232 125206   60.0   74.9    1      0.500      0.000  1000.000
15232 125206   75.0   89.9    1      0.500      0.000  1000.000
15232 125206   90.0  104.9    1      0.500      0.000  1000.000
15232 125206  105.0  119.9    1      0.500      0.000  1000.000
15232 125206  120.0  134.9    1      0.500      0.000  1000.000
15232 125206  135.0  149.9    1      0.500      0.000  1000.000
15232 125206  150.0  164.9    1      0.500      0.000  1000.000
15232 125206  165.0  179.9    1      0.500      0.000  1000.000
15232 125206  180.0  194.9    1      0.500      0.000  1000.000
15232 125206  195.0  209.9    1      0.500      0.000  1000.000
15232 125206  210.0  224.9    1      0.500      0.000  1000.000
15232 125206  225.0  239.9    1      0.500      0.000  1000.000
15232 125206  240.0  254.9    1      0.500      0.000  1000.000
15232 125206  255.0  269.9    1      0.500      0.000  1000.000
15232 125206  270.0  284.9    1      0.500      0.000  1000.000
15232 125206  285.0  299.9    1      0.500      0.000  1000.000
15232 125206  300.0  314.9    1      0.500      0.000  1000.000
15232 125206  315.0  329.9    1      0.500      0.000  1000.000
15232 125206  330.0  344.9    1      0.500      0.000  1000.000
15232 125206  345.0  359.9    1      0.500      0.000  1000.000
15232 125206  360.0  374.9    1      0.500      0.000  1000.000
15232 125206  375.0  389.9    1      0.500      0.000  1000.000
15232 125206  390.0  404.9    1      0.500      0.000  1000.000
15232 125206  405.0  419.9    1      0.500      0.000  1000.000
15232 125206  420.0  434.9    1      0.500      0.000  1000.000
15232 125206  435.0  449.9    1      0.500      0.000  1000.000
15232 125206  450.0  464.9    1      0.500      0.000  1000.000
```

Figure 21: Snippet of TollRevenue.dat

```
Hour    17 Link  124841->   83163   VMT (sov, hov, truck) =      0.0    436.2      0.0   Volume (sov, hov, truck) =     0.0    520.0      0.0  Toll Revenue($) (sov, hov, truck)=      0.0      0.0      0.0
Hour    18 Link  124841->   83163   VMT (sov, hov, truck) =      0.0    458.8      0.0   Volume (sov, hov, truck) =     0.0    547.0      0.0  Toll Revenue($) (sov, hov, truck)=      0.0      0.0      0.0
Hour    19 Link  124841->   83163   VMT (sov, hov, truck) =      2.5    489.9      0.0   Volume (sov, hov, truck) =     3.0    584.0      0.0  Toll Revenue($) (sov, hov, truck)=      1.5      0.0      0.0
Hour    20 Link  124841->   83163   VMT (sov, hov, truck) =      3.4    364.1      0.0   Volume (sov, hov, truck) =     4.0    434.0      0.0  Toll Revenue($) (sov, hov, truck)=      2.0      0.0      0.0
Hour    21 Link  124841->   83163   VMT (sov, hov, truck) =      0.0    190.4      0.0   Volume (sov, hov, truck) =     0.0    227.0      0.0  Toll Revenue($) (sov, hov, truck)=      0.0      0.0      0.0
Hour    22 Link  124841->   83163   VMT (sov, hov, truck) =      0.0    153.5      0.0   Volume (sov, hov, truck) =     0.0    183.0      0.0  Toll Revenue($) (sov, hov, truck)=      0.0      0.0      0.0
Hour    23 Link  124841->   83163   VMT (sov, hov, truck) =      0.0     99.0      0.0   Volume (sov, hov, truck) =     0.0    118.0      0.0  Toll Revenue($) (sov, hov, truck)=      0.0      0.0      0.0
Hour    24 Link  124841->   83163   VMT (sov, hov, truck) =      0.0     52.8      0.0   Volume (sov, hov, truck) =     0.0     63.0      0.0  Toll Revenue($) (sov, hov, truck)=      0.0      0.0      0.0
Hour    25 Link  124841->   83163   VMT (sov, hov, truck) =      0.0      0.0      0.0   Volume (sov, hov, truck) =     0.0      0.0      0.0  Toll Revenue($) (sov, hov, truck)=      0.0      0.0      0.0
Hour     1 Link  125328->   75527   VMT (sov, hov, truck) =      0.0     43.4      0.0   Volume (sov, hov, truck) =     0.0     38.0      0.0  Toll Revenue($) (sov, hov, truck)=      0.0      0.0      0.0
Hour     2 Link  125328->   75527   VMT (sov, hov, truck) =      0.0     43.4      0.0   Volume (sov, hov, truck) =     0.0     38.0      0.0  Toll Revenue($) (sov, hov, truck)=      0.0      0.0      0.0
Hour     3 Link  125328->   75527   VMT (sov, hov, truck) =      0.0     37.7      0.0   Volume (sov, hov, truck) =     0.0     33.0      0.0  Toll Revenue($) (sov, hov, truck)=      0.0      0.0      0.0
Hour     4 Link  125328->   75527   VMT (sov, hov, truck) =      0.0     16.0      0.0   Volume (sov, hov, truck) =     0.0     14.0      0.0  Toll Revenue($) (sov, hov, truck)=      0.0      0.0      0.0
Hour     5 Link  125328->   75527   VMT (sov, hov, truck) =      0.0     20.5      0.0   Volume (sov, hov, truck) =     0.0     18.0      0.0  Toll Revenue($) (sov, hov, truck)=      0.0      0.0      0.0
Hour     6 Link  125328->   75527   VMT (sov, hov, truck) =      0.0     54.8      0.0   Volume (sov, hov, truck) =     0.0     48.0      0.0  Toll Revenue($) (sov, hov, truck)=      0.0      0.0      0.0
Hour     7 Link  125328->   75527   VMT (sov, hov, truck) =      1.1    622.1      0.0   Volume (sov, hov, truck) =     1.0    545.0      0.0  Toll Revenue($) (sov, hov, truck)=      0.5      0.0      0.0
Hour     8 Link  125328->   75527   VMT (sov, hov, truck) =     13.7   2416.5      0.0   Volume (sov, hov, truck) =    12.0   2117.0      0.0  Toll Revenue($) (sov, hov, truck)=     45.0      0.0      0.0
Hour     9 Link  125328->   75527   VMT (sov, hov, truck) =     40.0   1563.8      0.0   Volume (sov, hov, truck) =    35.0   1370.0      0.0  Toll Revenue($) (sov, hov, truck)=     81.3      0.0      0.0
Hour    10 Link  125328->   75527   VMT (sov, hov, truck) =     18.3    858.4      0.0   Volume (sov, hov, truck) =    16.0    752.0      0.0  Toll Revenue($) (sov, hov, truck)=     19.9      0.0      0.0
Hour    11 Link  125328->   75527   VMT (sov, hov, truck) =      9.1    534.2      0.0   Volume (sov, hov, truck) =     8.0    468.0      0.0  Toll Revenue($) (sov, hov, truck)=      4.0      0.0      0.0
Hour    12 Link  125328->   75527   VMT (sov, hov, truck) =     35.4   1188.3      0.0   Volume (sov, hov, truck) =    31.0   1041.0      0.0  Toll Revenue($) (sov, hov, truck)=     53.9      0.0      0.0
Hour    13 Link  125328->   75527   VMT (sov, hov, truck) =    118.7   1723.6      0.0   Volume (sov, hov, truck) =   104.0   1510.0      0.0  Toll Revenue($) (sov, hov, truck)=    106.0      0.0      0.0
Hour    14 Link  125328->   75527   VMT (sov, hov, truck) =     52.5   1168.9      0.0   Volume (sov, hov, truck) =    46.0   1024.0      0.0  Toll Revenue($) (sov, hov, truck)=     91.4      0.0      0.0
Hour    15 Link  125328->   75527   VMT (sov, hov, truck) =     52.5    648.4      0.0   Volume (sov, hov, truck) =    46.0    568.0      0.0  Toll Revenue($) (sov, hov, truck)=     77.3      0.0      0.0
Hour    16 Link  125328->   75527   VMT (sov, hov, truck) =    197.5   1261.3      0.0   Volume (sov, hov, truck) =   173.0   1105.0      0.0  Toll Revenue($) (sov, hov, truck)=    373.3      0.0      0.0
Hour    17 Link  125328->   75527   VMT (sov, hov, truck) =    164.4   1420.0      0.0   Volume (sov, hov, truck) =   144.0   1244.0      0.0  Toll Revenue($) (sov, hov, truck)=     73.0      0.0      0.0
Hour    18 Link  125328->   75527   VMT (sov, hov, truck) =      3.4   1352.7      0.0   Volume (sov, hov, truck) =     3.0   1185.0      0.0  Toll Revenue($) (sov, hov, truck)=      5.0      0.0      0.0
Hour    19 Link  125328->   75527   VMT (sov, hov, truck) =     12.6   1510.2      0.0   Volume (sov, hov, truck) =    11.0   1323.0      0.0  Toll Revenue($) (sov, hov, truck)=     30.9      0.0      0.0
Hour    20 Link  125328->   75527   VMT (sov, hov, truck) =    132.4   1068.4      0.0   Volume (sov, hov, truck) =   116.0    936.0      0.0  Toll Revenue($) (sov, hov, truck)=    333.3      0.0      0.0
Hour    21 Link  125328->   75527   VMT (sov, hov, truck) =      4.6    795.6      0.0   Volume (sov, hov, truck) =     4.0    697.0      0.0  Toll Revenue($) (sov, hov, truck)=      2.0      0.0      0.0
Hour    22 Link  125328->   75527   VMT (sov, hov, truck) =      0.0    446.3      0.0   Volume (sov, hov, truck) =     0.0    391.0      0.0  Toll Revenue($) (sov, hov, truck)=      0.0      0.0      0.0
Hour    23 Link  125328->   75527   VMT (sov, hov, truck) =      3.4    245.4      0.0   Volume (sov, hov, truck) =     3.0    215.0      0.0  Toll Revenue($) (sov, hov, truck)=      1.5      0.0      0.0
Hour    24 Link  125328->   75527   VMT (sov, hov, truck) =      0.0     71.9      0.0   Volume (sov, hov, truck) =     0.0     63.0      0.0  Toll Revenue($) (sov, hov, truck)=      0.0      0.0      0.0
Hour    25 Link  125328->   75527   VMT (sov, hov, truck) =      0.0      0.0      0.0   Volume (sov, hov, truck) =     0.0      0.0      0.0  Toll Revenue($) (sov, hov, truck)=      0.0      0.0      0.0
Total VMT(miles) =        54787.7  Total Revenue($) =          6024.1
```

# Appendix 1: SCAG TransCAD Link Data Fields

| ID | NAME | FORMAT | MIN | MAX |
|---|---|---|---|---|
| 1 | ID | f10.0 | 10404 | 2666488 |
| 2 | LENGTH | f10.2 | 0 | 61.37 |
| 3 | DIR | f2.0 | -1 | 1 |
| 4 | A_NODE | f8.0 | 2 | 125360 |
| 5 | B_NODE | f8.0 | 1 | 125360 |
| 6 | PROJECT_ID | c20 | | |
| 7 | PROJECT_I1 | c20 | | |
| 8 | COMMENTS | c50 | | |
| 9 | ROAD_NAME | c65 | | |
| 10 | ROUTE_NAME | c6 | | |
| 11 | ROAD_TYPE | c37 | | |
| 12 | NUMBER | c8 | | |
| 13 | AB_NEW_FAC | f10.0 | 0 | 100 |
| 14 | BA_NEW_FAC | f10.0 | 0 | 100 |
| 15 | AB_POSTEDS | f8.0 | 0 | 70 |
| 16 | BA_POSTEDS | f8.0 | 0 | 65 |
| 17 | AB_AMLANES | f10.0 | 0 | 9 |
| 18 | BA_AMLANES | f10.0 | 0 | 9 |
| 19 | AB_PMLANES | f10.0 | 0 | 9 |
| 20 | BA_PMLANES | f10.0 | 0 | 9 |
| 21 | AB_MDLANES | f10.0 | 0 | 9 |
| 22 | BA_MDLANES | f10.0 | 0 | 9 |
| 23 | AB_NTLANES | f10.0 | 0 | 9 |
| 24 | BA_NTLANES | f10.0 | 0 | 9 |
| 25 | TYPE1_THRU | f10.0 | 0 | 6 |
| 26 | TYPE2_AUX_ | f10.0 | 0 | 4 |
| 27 | TYPE3_OTHE | f10.0 | 0 | 1 |
| 28 | TOLL_FLAG | f10.0 | 0 | 1 |
| 29 | TRUCK_CLIM | f10.0 | 0 | 1 |
| 30 | HOV_FLAG | f10.0 | 0 | 1 |
| 31 | SIGNALS_FL | f10.0 | 0 | 2 |
| 32 | TRUCK_PROH | f10.0 | 0 | 1 |
| 33 | SPEED_MULT | f10.2 | 0 | 1 |
| 34 | CAPACITY_M | f10.2 | 0 | 1 |
| 35 | RSA | f10.0 | 1 | 56 |
| 36 | COUNTY | f10.0 | 1 | 6 |

| | | | | |
|---|---|---|---|---|
| 37 | TAZ | f10.0 | 1 | 4109 |
| 38 | AIR_BASIN | f8.0 | 1 | 4 |
| 39 | SUB_AIR_BA | f8.0 | 11 | 43 |
| 40 | AB_MEDIANS | f8.0 | 0 | 4 |
| 41 | BA_MEDIANS | f8.0 | 0 | 4 |
| 42 | AB_AREATYP | f10.0 | 0 | 7 |
| 43 | BA_AREATYP | f10.0 | 0 | 7 |
| 44 | MMA_COUNT | f10.0 | 0 | 808 |
| 45 | COUNT_ID | f10.0 | 0 | 373 |
| 46 | AB_GRADEPE | f8.0 | 0 | 24 |
| 47 | BA_GRADEPE | f8.0 | 0 | 24 |
| 48 | ABGRADE | f10.4 | -283794.96 | 342393.15 |
| 49 | BAGRADE | f10.4 | -342393.14 | 283794.96 |
| 50 | AB_TYPE | f8.0 | 0 | 32 |
| 51 | BA_TYPE | f8.0 | 0 | 0 |
| 52 | AB_SERV_TI | f10.3 | 0 | 8 |
| 53 | BA_SERV_TI | f10.3 | 0 | 0 |
| 54 | AB_TOLL_LA | f8.0 | 0 | 4 |
| 55 | BA_TOLL_LA | f8.0 | 0 | 0 |
| 56 | AB_TOLLV_A | f10.3 | 0 | 2.205 |
| 57 | AB_TOLLV_P | f10.3 | 0 | 2.205 |
| 58 | AB_TOLLV_M | f10.3 | 0 | 1.66 |
| 59 | AB_TOLLV_N | f10.3 | 0 | 1.66 |
| 60 | BA_TOLLV_A | f10.3 | 0 | 0 |
| 61 | BA_TOLLV_P | f10.3 | 0 | 0 |
| 62 | BA_TOLLV_M | f10.3 | 0 | 0 |
| 63 | BA_TOLLV_N | f10.3 | 0 | 0 |
| 64 | CCSTYLE | f8.0 | 0 | 600 |
| 65 | WALKTIME | f10.2 | 0 | 1227.42 |
| 66 | MODE | f8.0 | 0 | 26 |
| 67 | AB_PKTIME | f10.2 | 0 | 73.05 |
| 68 | BA_PKTIME | f10.2 | 0 | 71.96 |
| 69 | AB_OPTIME | f10.2 | 0 | 61.37 |
| 70 | BA_OPTIME | f10.2 | 0 | 61.37 |
| 71 | AB_AMPENAL | f10.2 | 0 | 4 |
| 72 | BA_AMPENAL | f10.2 | 0 | 4 |
| 73 | AB_PMPENAL | f10.2 | 0 | 4 |
| 74 | BA_PMPENAL | f10.2 | 0 | 4 |
| 75 | AB_MDPENAL | f10.2 | 0 | 6 |

| | | | | |
|---|---|---|---|---|
| 76 | BA_MDPENAL | f10.2 | 0 | 6 |
| 77 | AB_NTPENAL | f10.2 | 0 | 10 |
| 78 | BA_NTPENAL | f10.2 | 0 | 10 |
| 79 | AB_AMPARK | f10.0 | 0 | 1 |
| 80 | BA_AMPARK | f10.0 | 0 | 1 |
| 81 | AB_PMPARK | f10.0 | 0 | 1 |
| 82 | BA_PMPARK | f10.0 | 0 | 1 |
| 83 | AB_MDPARK | f10.0 | 0 | 1 |
| 84 | BA_MDPARK | f10.0 | 0 | 1 |
| 85 | AB_PKPARKC | f10.2 | 0 | 30 |
| 86 | BA_PKPARKC | f10.2 | 0 | 30 |
| 87 | AB_OPPARKC | f10.2 | 0 | 30 |
| 88 | BA_OPPARKC | f10.2 | 0 | 30 |
| 89 | AB_PKCOST | f10.2 | 0 | 99.18 |
| 90 | BA_PKCOST | f10.2 | 0 | 99.18 |
| 91 | AB_OPCOST | f10.2 | 0 | 99.28 |
| 92 | BA_OPCOST | f10.2 | 0 | 99.09 |
| 93 | GRADE_A | f10.2 | 0 | 9.7 |
| 94 | GRADE_B | f10.2 | 0 | 8.3 |
| 95 | GRADE_C | f10.2 | 0 | 8 |
| 96 | GRADE_D | f10.2 | 0 | 3.29 |
| 97 | GRADE_E | f10.2 | 0 | 0.9 |
| 98 | GRADE_F | f10.2 | 0 | 0 |
| 99 | GRADE_AVG | f10.2 | 0 | 5.34 |
| 100 | SCREENLINE | f10.0 | 0 | 23 |
| 101 | AB_ADT | f10.2 | 0 | 185150 |
| 102 | BA_ADT | f10.2 | 0 | 38411 |
| 103 | AB_MDV | f10.2 | 0 | 179133 |
| 104 | BA_MDV | f10.2 | 0 | 35653 |
| 105 | AB_HD | f10.2 | 0 | 21050 |
| 106 | BA_HD | f10.2 | 0 | 3759 |
| 107 | TOT_ADT | f10.2 | 0 | 185150 |
| 108 | TOT_MDV | f10.2 | 0 | 179133 |
| 109 | TOT_HD | f10.2 | 0 | 21050 |
| 110 | POSTMILE_O | f10.0 | 0 | 54081 |
| 111 | POSTMILE_1 | f10.0 | 0 | 472482 |
| 112 | POSTMILE | c10 | | |
| 113 | PEMS_DIREC | c1 | | |
| 114 | PEMS_ID | f10.0 | 0 | 1213133 |

| | | | | |
|---|---|---|---|---|
| 115 | AB_OLD_FAC | f10.0 | 0 | 9 |
| 116 | BA_OLD_FAC | f10.0 | 0 | 8 |
| 117 | NEW_LINK | f10.0 | 0 | 0 |


DynusT SCAG Region

Final Workshop

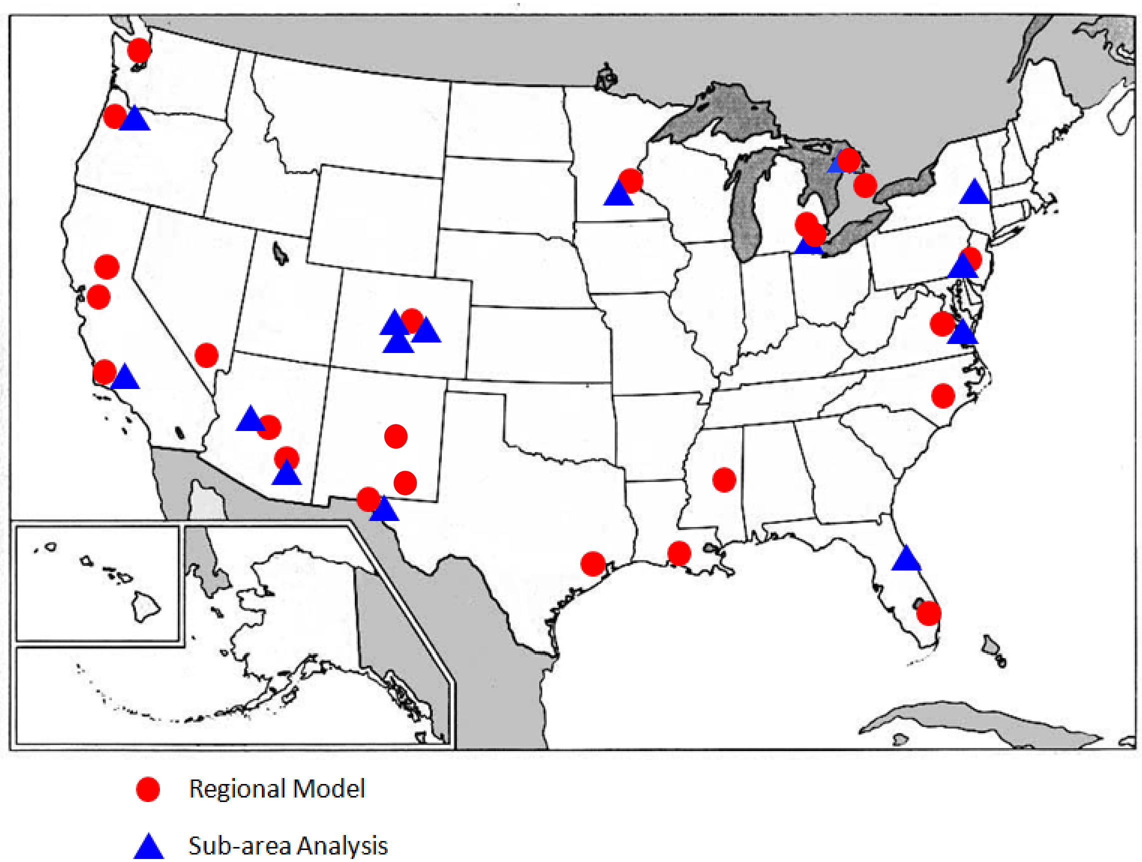
February 27-28, 2014

# Goals

- Latest development/deployment status of DynsuT.
- Comparison of DTA and STA.
- How DynusT can be used for SCAG region.

# DynusT (Dynamic urban systems for Transportation)

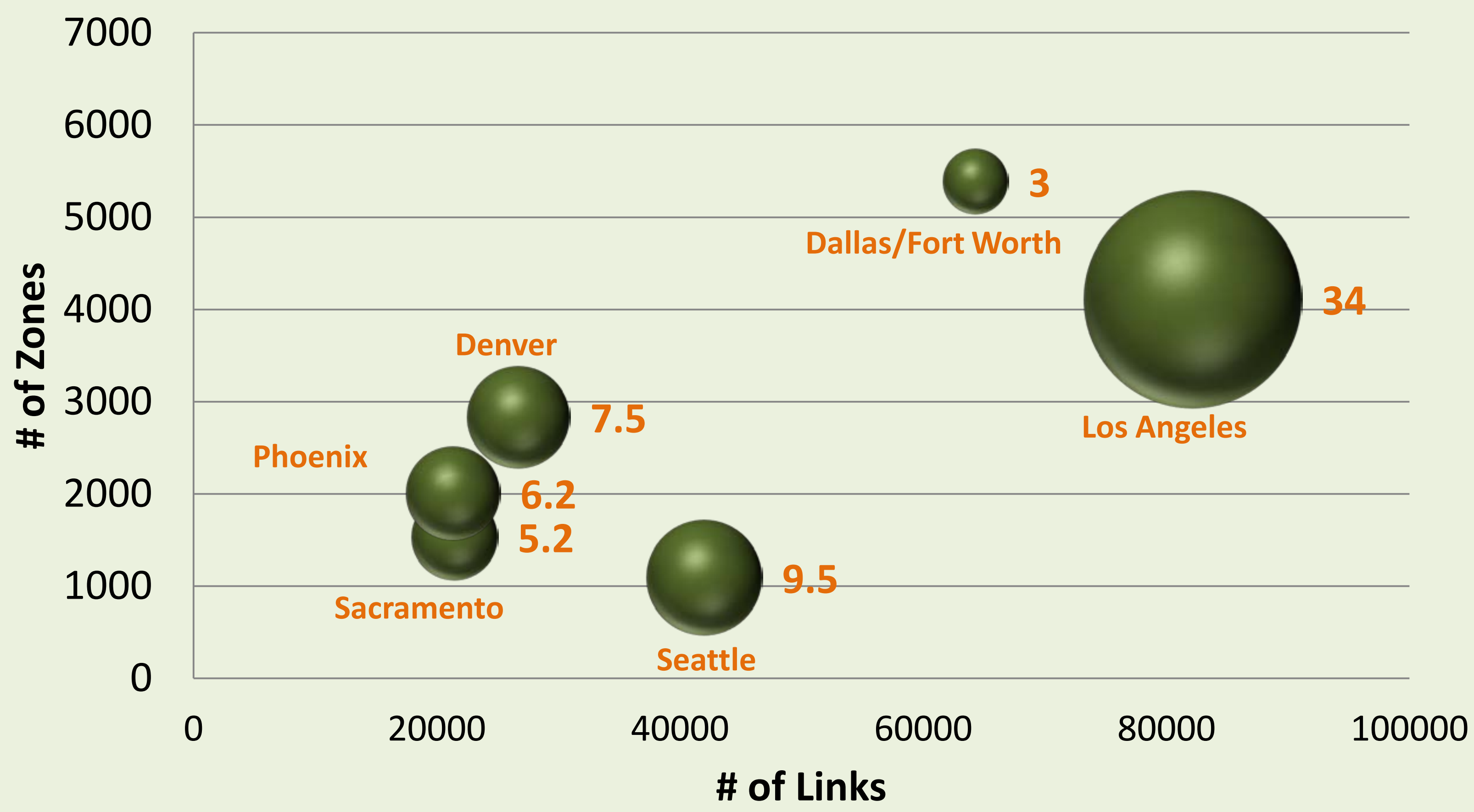
- **Simple**, **lean** and easy **integration** with macro and micro models.
- Developed since 2002,  applied to 50+ regions since.
- 1000+ uses world-wide since 2011.



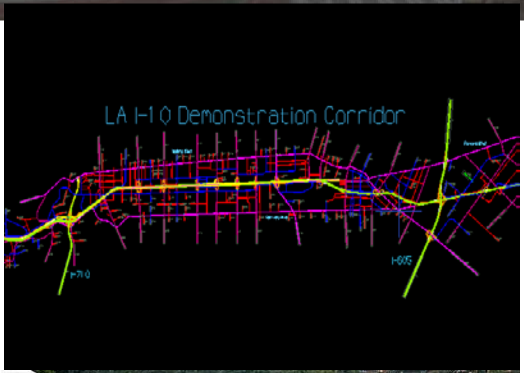
# DynusT Professional Developments

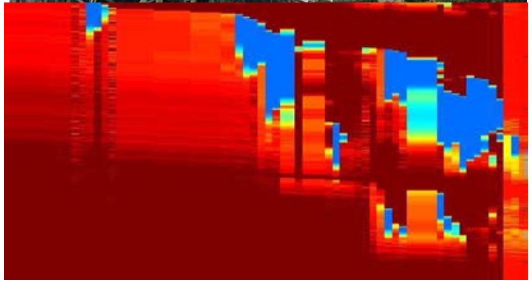
- Metropia Inc.
  - Established in 2011
  - 12 full-time staff (3 PhDs)
  - Clients – SCAG, LADOT, NYCDOT, FHWA, ELPMPO, H-GAC
  - DynusT Modeling, software development, consulting
- University of Arizona
  - DynusT Laboratory
  - Research and Development

# DynusT Daily Regional Models



# DynusT Applications



- **Interstate highway corridor improvement** (TTI, **TxDOT**, **ELPMPO**, Kittleson, **ADOT, CDOT**)
- **Value pricing** (ORNL, **FHWA**; SRF, **Mn/DOT**, TTI, **TxDOT**, UA, **CDOT/DRCOG, Atkins/CDOT, RST/WSDOT)**
- **Evacuation operational planning** (TTI, **TxDOT**, UA, **ADOT**; LSU, **LDOT**; Noblis, **FHWA**; Univ. of Toronto, Cornell Univ. Jackson State Univ., **MDOT**, Univ. of Missouri, **MDOT**)
- **Integrated Corridor Management modeling** (CS, **FHWA**, **MAG**, NCSU, **NCDOT, MAG**)
- **Four-step model integration** (**Portland Metro, RST/FHWA, H-GAC**)
- **Activity-based model integration** (**SHRP2 C10**, **FHWA EARP**)
- **Work zone impact management** (**SHRP2 R11**)

SOUTHERN CALIFORNIA ASSOCIATION of GOVERNMENTS

metropia

# Modeling Capabilities

- Capacity Improvement/restrictions
- Congestion pricing (fixed pricing, time-of-day pricing, congestion responsive pricing, truck-only, truck restriction)
  - Dynamic user equilibrium
  - Generalized cost with heterogeneous individual attributes (e.g. value of time)

# Modeling Capabilities

- ITS Strategies
- Active Traffic/Demand Linking with activity-based models.
- TDM (travel demand management)
  - Peak spreading
  - Ridesharing/TNC (ongoing)
- Linking with air quality models.

SOUTHERN CALIFORNIA ASSOCIATION of GOVERNMENTS



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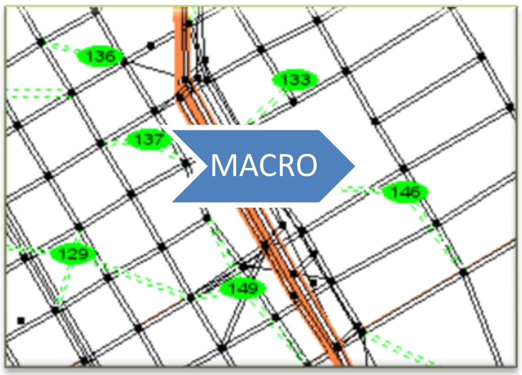
# Multi-resolution Modeling

(MRM)



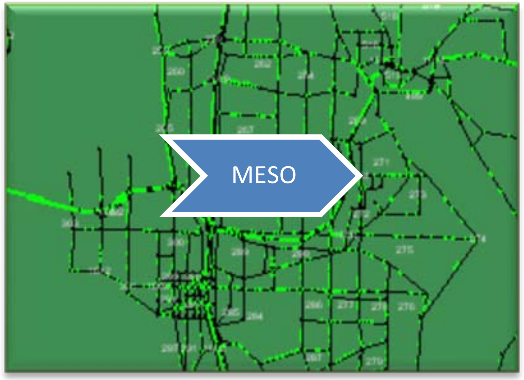

- •Static/Instantaneous Paths
- •Region Wide
- •Centroid based zonal Trips
- •Analytical Equilibrium
- •Demand Driven
- •Planning/Forecasting

Vehicle OD

DTA

Vehicle Trajectory


- •Static Paths
- •Corridor/Intersection
- •Individual Vehicles
- •Simulation One-Shot
- •Supply Driven
- •Operational




- •Dynamic/Time Varying Paths
- •Subarea / Corridor
- •Vehicle Platoons

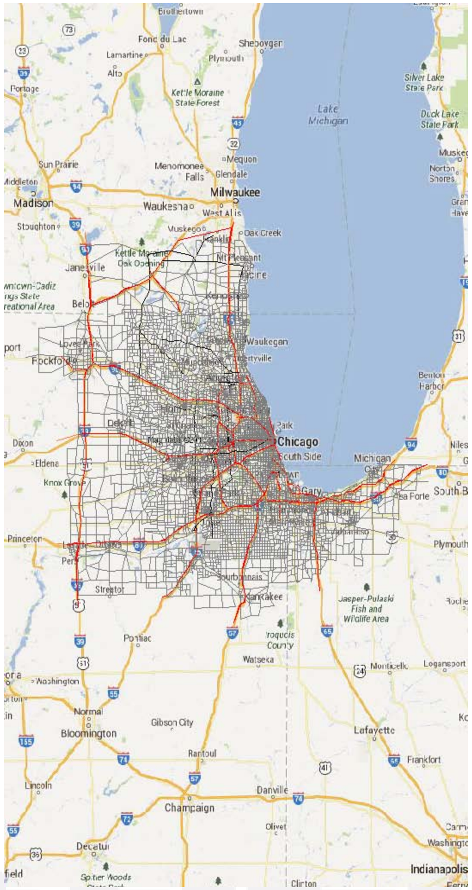
- •Simulation Equilibrium
- •Supply Driven
- •Planning/Operational

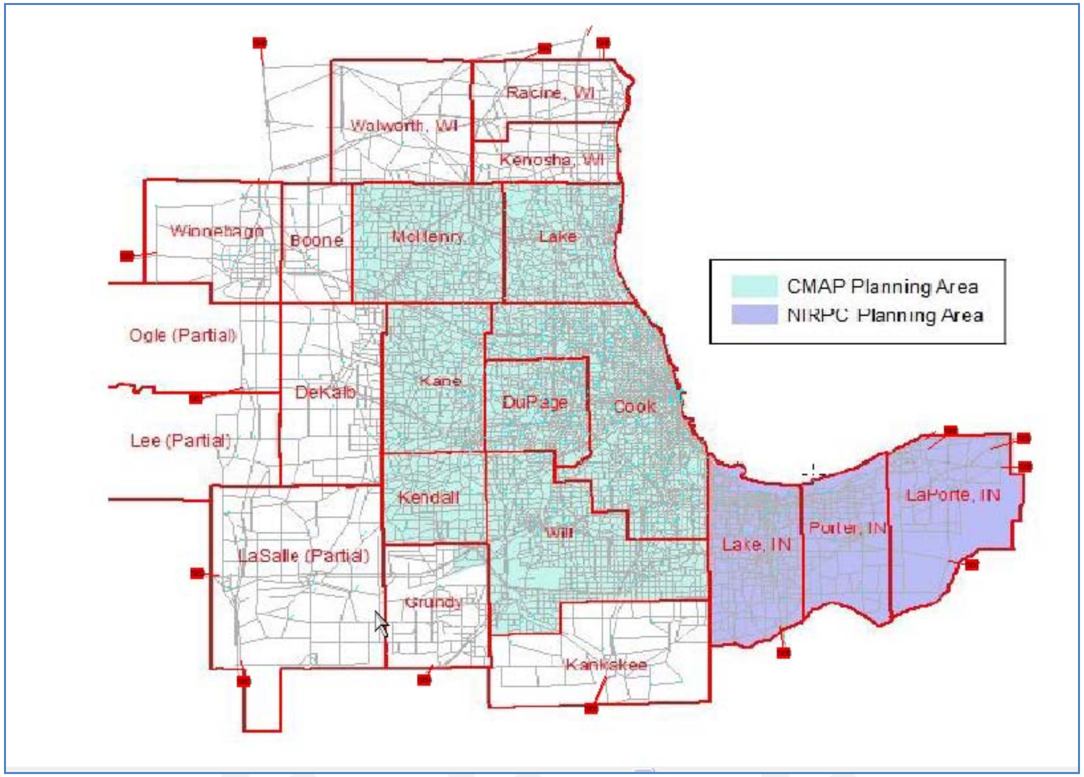
# GREAT LAKES AND MISSISSIPPI RIVER INTERBASIN STUDY

## CHICAGO REGIONAL BASELINE DTA MODEL DEVELOPMENT

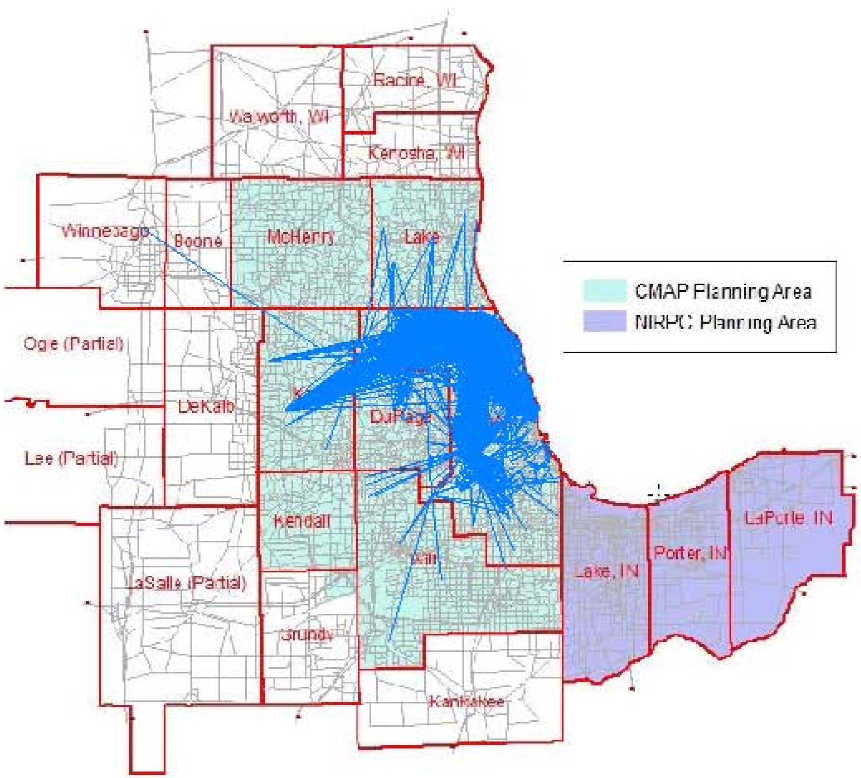
Cooperate Reduce Traffic Plant a Tree Arrive on Time

# Study Area:




Racine, WI
Walworth, WI
Kenosha, WI
Winnebago
Boone
McHenry
Lake
CMAP Planning Area
NIRPC Planning Area
Ogle (Partial)
DeKalb
Kane
DuPage
Cook
Lee (Partial)
Kendall
Will
Lake, IN
Porter, IN
LaPorte, IN
LaSalle (Partial)
Grundy
Kankakee

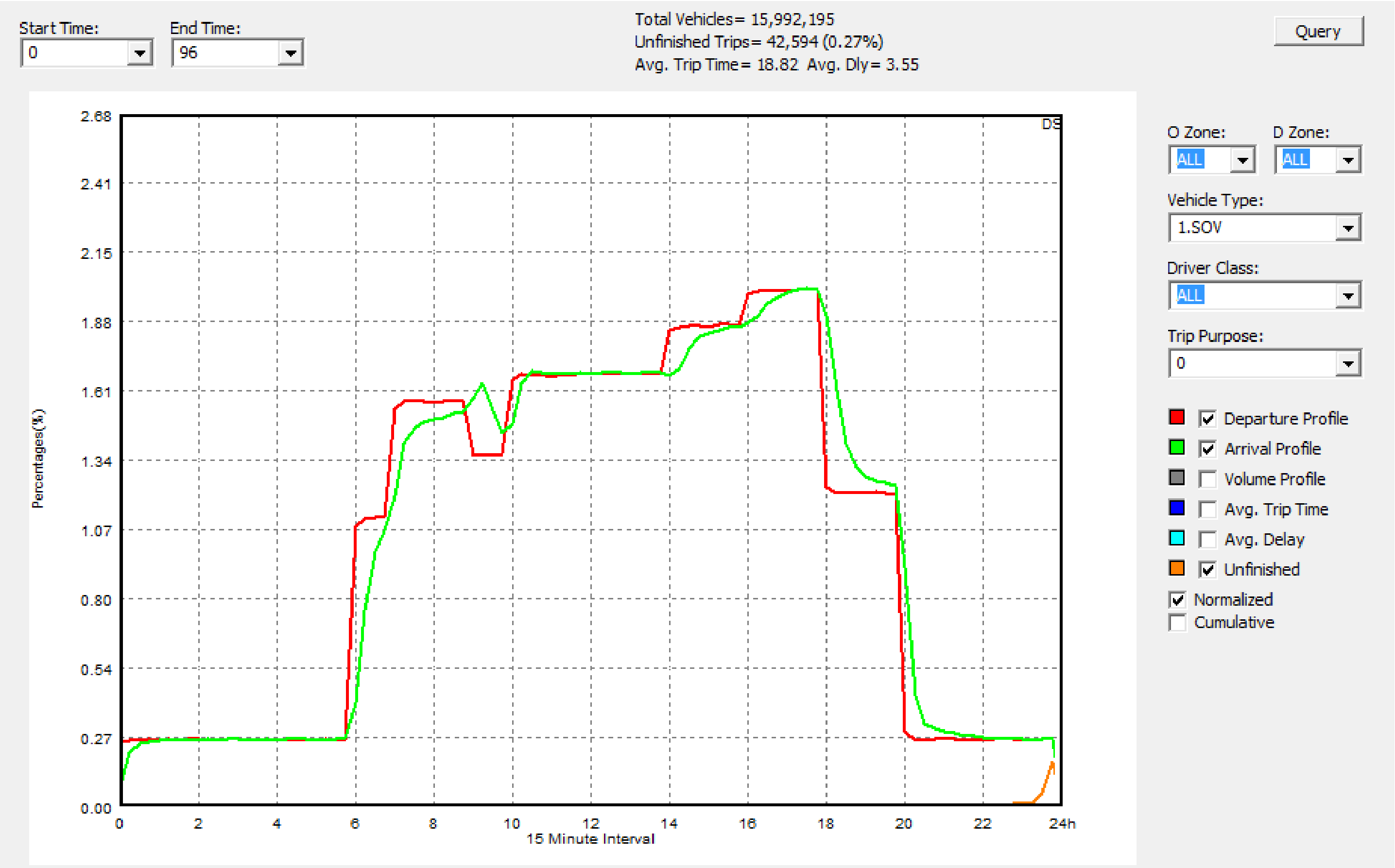
# Demand Desire Lines: Truck



# Validation:

*Diurnal Profiles – Departure/Arrival*

*SOV*



# Validation:

*DTA vs. CMAP*

| CMAP | Total Veh | Total VMT | Total VHT | Avg Time | Avg VMT |
|---|---|---|---|---|---|
| 6AM-7AM | 902,901 | 12,155,500 | 368,358 | 24.48 | 13.46 |
| 7AM-9AM | 2,844,901 | 37,022,400 | 1,286,800 | 27.14 | 13.01 |
| 9AM-10AM | 1,327,542 | 15,108,300 | 461,293 | 20.85 | 11.38 |
| | | | | | |
| 2PM-4PM | 3,121,481 | 34,633,600 | 1,146,740 | 22.04 | 11.10 |
| 4PM-6PM | 2,932,672 | 33,542,600 | 1,142,030 | 23.36 | 11.44 |
| 6PM-8PM | 1,660,219 | 18,243,700 | 548,662 | 19.82 | 10.99 |
| | | | | | |
| **AM+PM** | **12,789,716** | **150,706,100** | **4,953,883** | **23.24** | **11.78** |

| DTA | Total Veh | Total VMT | Total VHT | Avg Time | Avg VMT |
|---|---|---|---|---|---|
| 6AM-7AM | 901,948 | 11,717,398 | 321,485 | 21.39 | 12.99 |
| 7AM-9AM | 2,842,342 | 37,039,212 | 1,215,081 | 25.65 | 13.03 |
| 9AM-10AM | 1,235,103 | 15,564,740 | 524,106 | 23.73 | 11.75 |
| | | | | | |
| 2PM-4PM | 3,118,837 | 34,581,352 | 1,178,682 | 22.68 | 11.09 |
| 4PM-6PM | 2,930,357 | 30,745,333 | 1,032,591 | 21.14 | 10.49 |
| 6PM-8PM | 1,658,462 | 15,034,794 | 412,888 | 14.94 | 9.07 |
| | | | | | |
| **AM+PM** | **12,690,049** | **144,682,829** | **4,684,833** | **22.14** | **11.40** |
| **Diff to CMAP** | **-1%** | **-4%** | **-5%** | **-5%** | **-3%** |

# Modeling Process

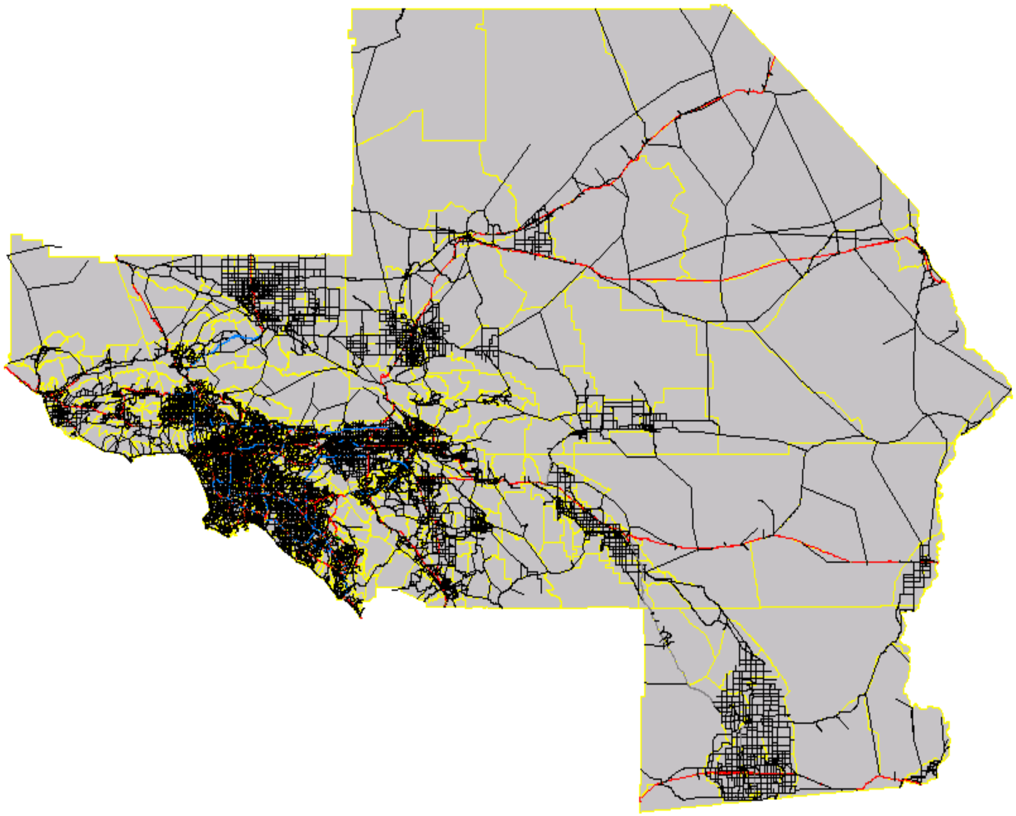
- SCAG Regional Model
  - Dataset preparation
  - Model diagnostics
- DynusT Congestion Pricing Modeling Methodology
  - Pricing Model
  - Route Choice Model
- Case Study
  - I-110

# SCAG Regional DynusT Model

Cooperate Reduce Traffic Plant a Tree Arrive on Time

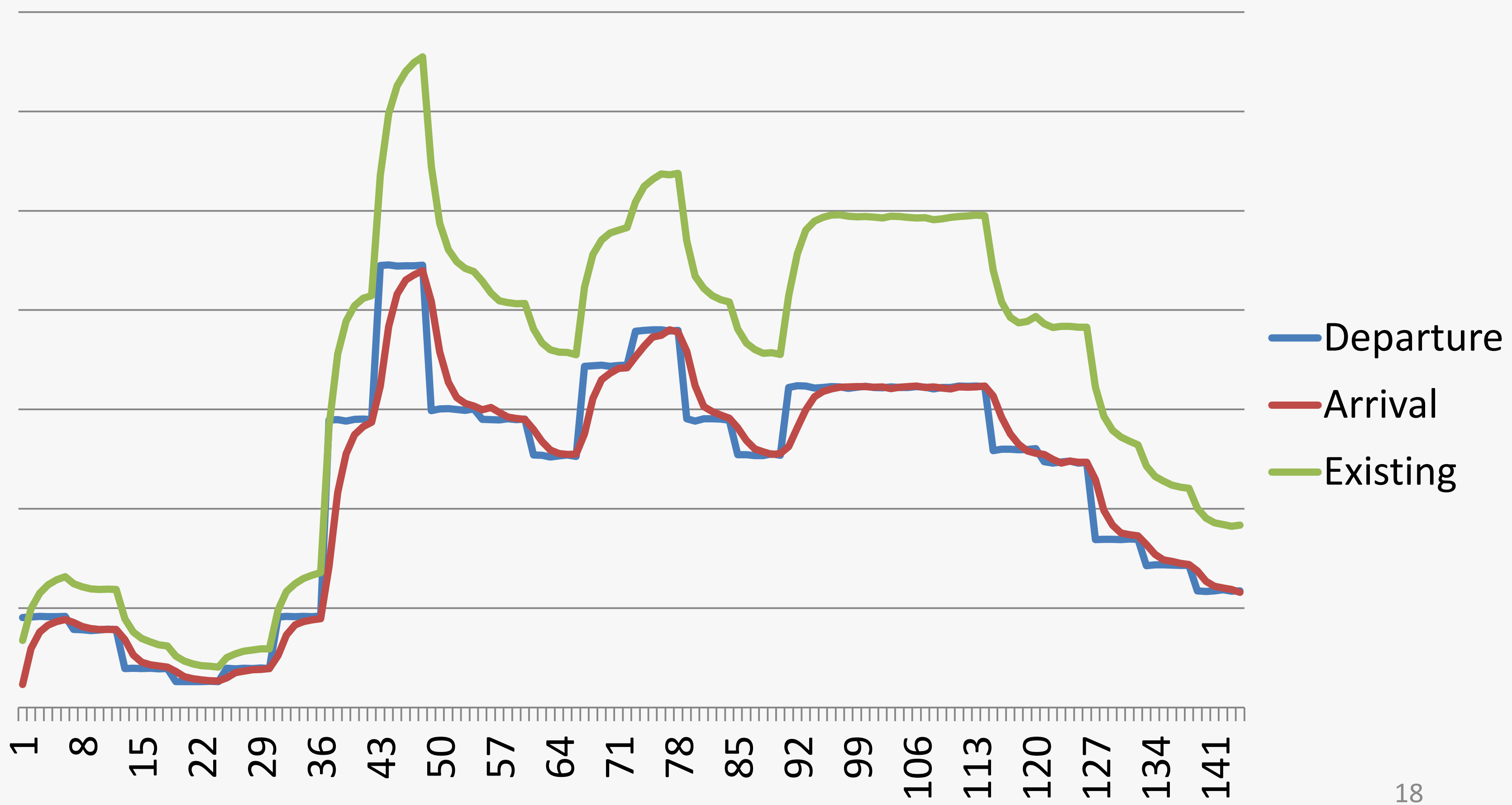
# SCAG Regional Model

- 20K center line miles
- 31k nodes
- 82k links
- 4k/11k zones



# 24-hr Loading

- Loading – 33 M



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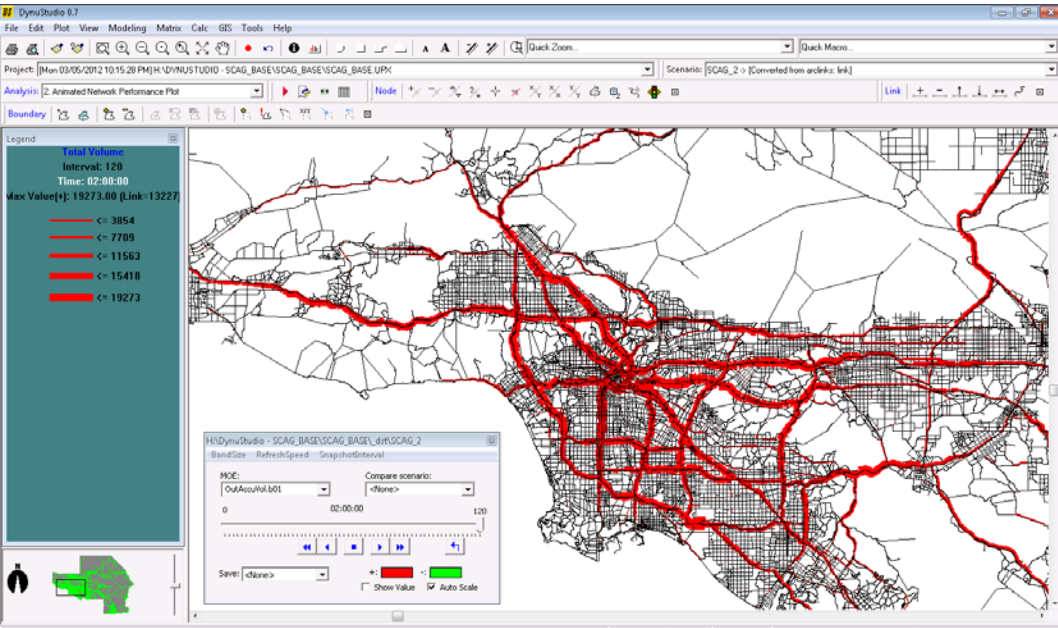
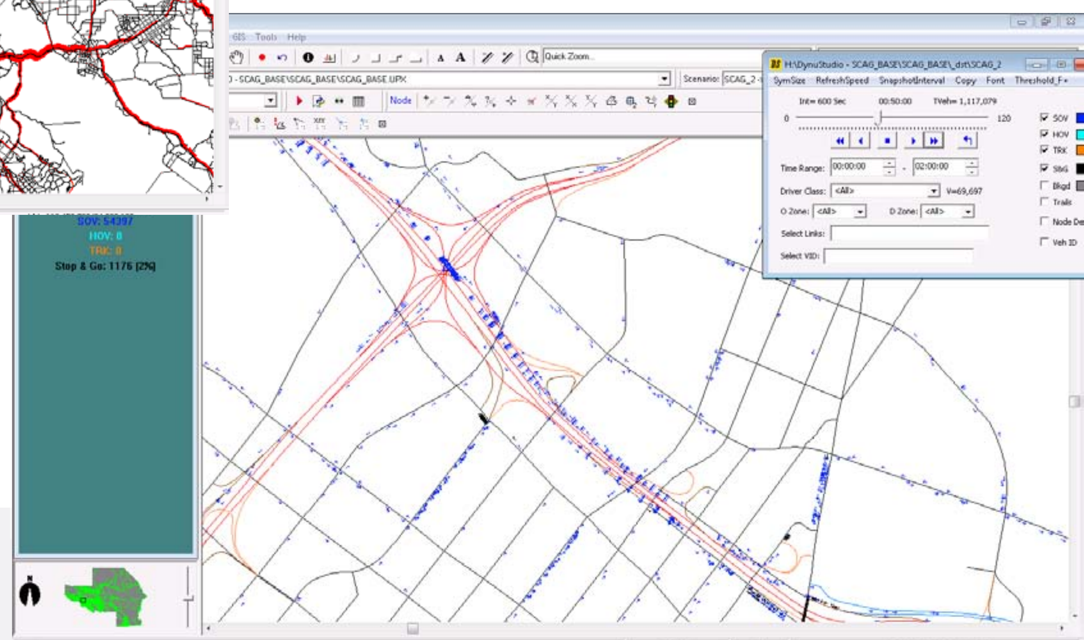
# Computational Characteristics

- Peak Memory – 50GB
- Per iteration (hr)
  - Simulation – 1.5
  - Assignment – 2.0
- Improvement Opportunities
  - Run time
    - Solid-State Drive (SSD)
    - 64 GB 48 Core server
    - Reduce locking/critical regions
    - Use of static stacks v.s. dynamic allocate

# Video Demo

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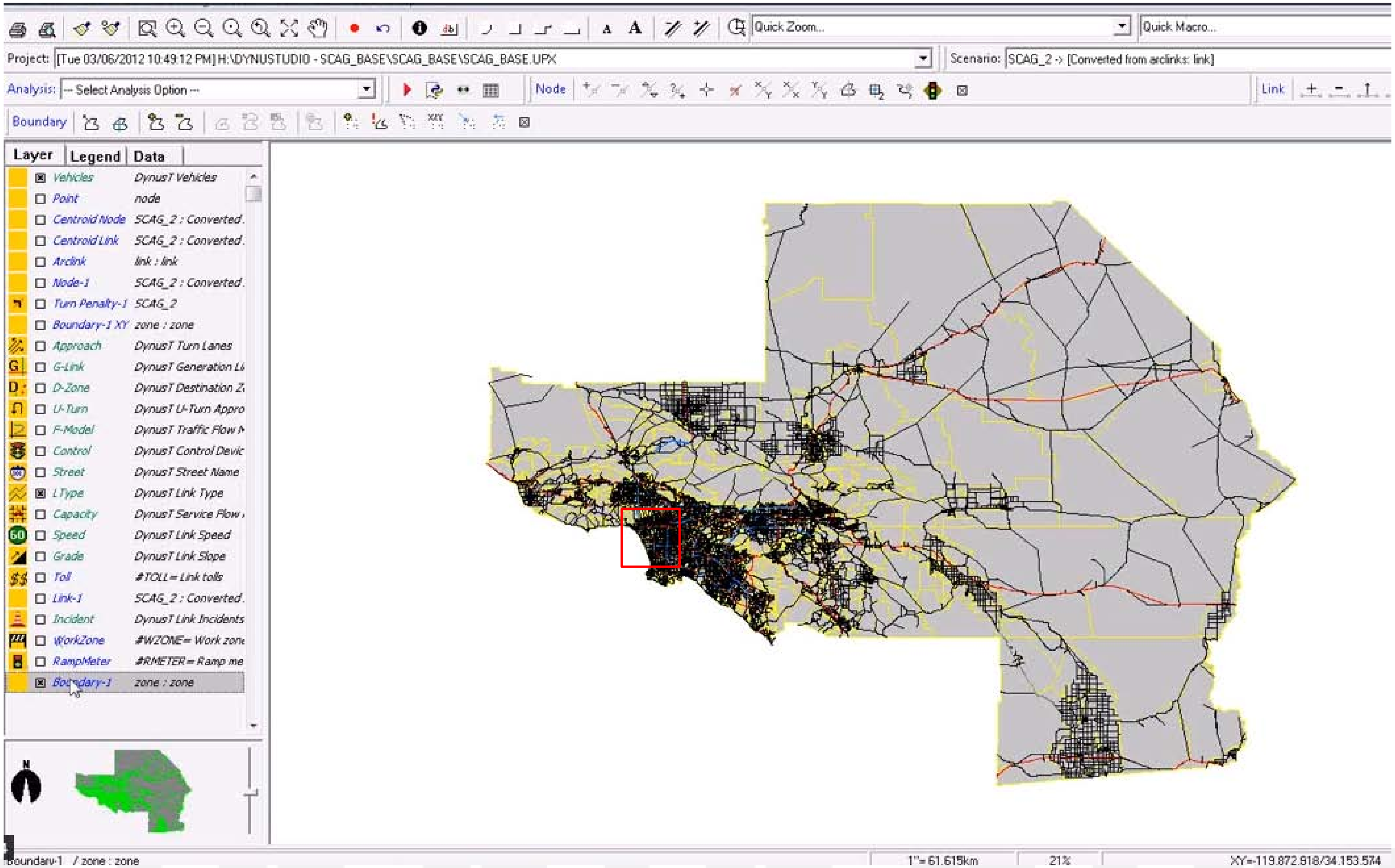
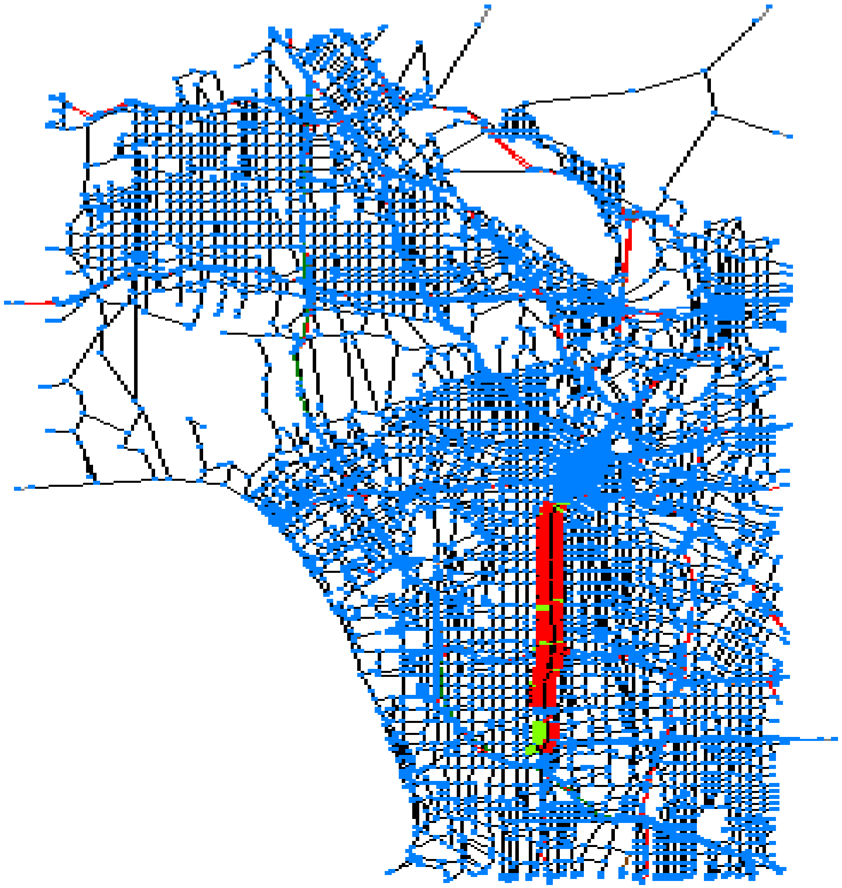
# SCAG Model Applications – Congestion Pricing

Cooperate Reduce Traffic Plant a Tree Arrive on Time

# Regional DynusT Model

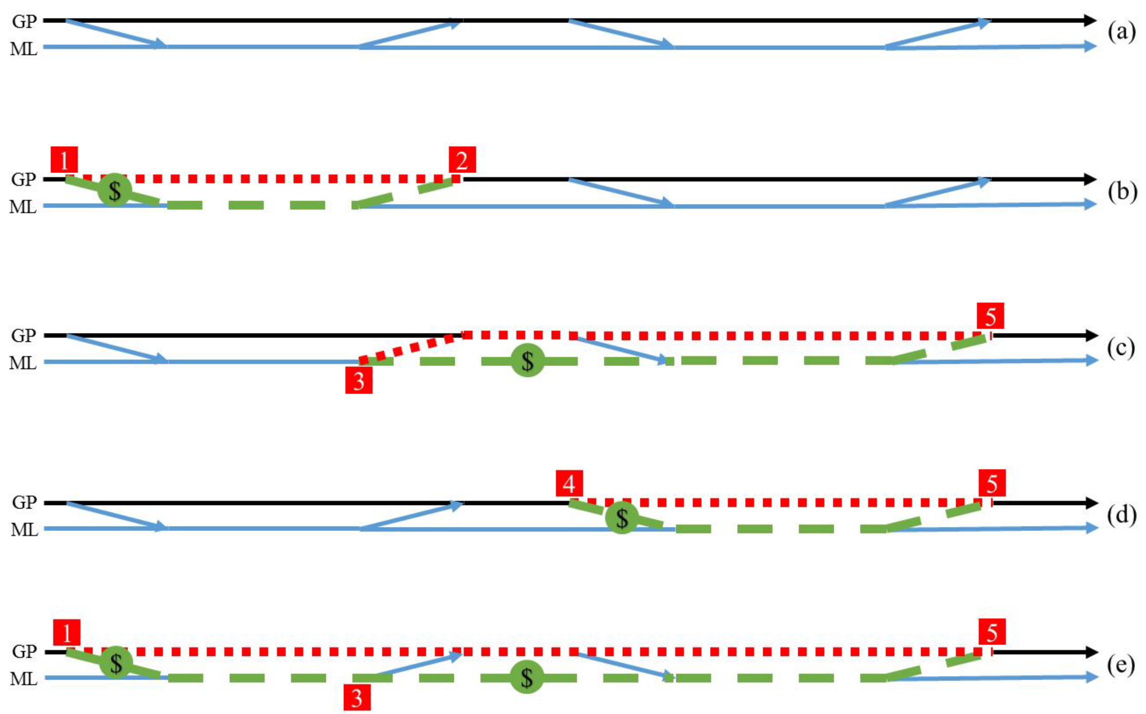


# Sub-Area and HOT Scenario



# Pricing Segments

- Paired HOT-GP Segment defined by ingress-egress points.
- Each segment operates independent pricing scheme



# Route Choice Model

- Dynamic User Equilibrium

$$G_{l,n}^{t} = h_{l,n}^{t} + \frac{S_l^t}{\theta_n}, \qquad \forall\, l \in L, t \in T, n \in N$$

Where,

$N$ : set of vehicle types; $N = [SOV, HOV, truck]$

$n$ : vehicle type in set $N$

$T$ : set of time intervals

$t$ : time unit in set $T$

$L$ : set of links

$l$ : link in set $L$

$G_{l,n}^{t}$ : generalized cost for link $l$ at time $t$

$h_{l,n}^{t}$ : travel time on link

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# Pricing Model

- Throughput Optimization

$$\max Z = \sum_{l \in L} \sum_{t \in T} k_l^t v(k_l^t)$$

Subject to,

$$v(k_l^t) \geq v_l^0, \qquad \forall\, l \in L, t \in T$$

$$\frac{d_l}{\theta_n}\left(\frac{1}{\bar{v}_l^t} - \frac{1}{v(k_l^t)}\right) \leq \pi_l^t, \qquad \forall\, l \in L, t \in T, n \in N$$

$$\frac{d_l}{\theta_n}\left(\frac{1}{\bar{v}_l^t} - \frac{1}{v(k_l^t)}\right) \geq \pi_l^t - \varepsilon, \qquad \forall\, l \in L, t \in T, n \in N$$

$$Other\ DUE\ Conditions$$

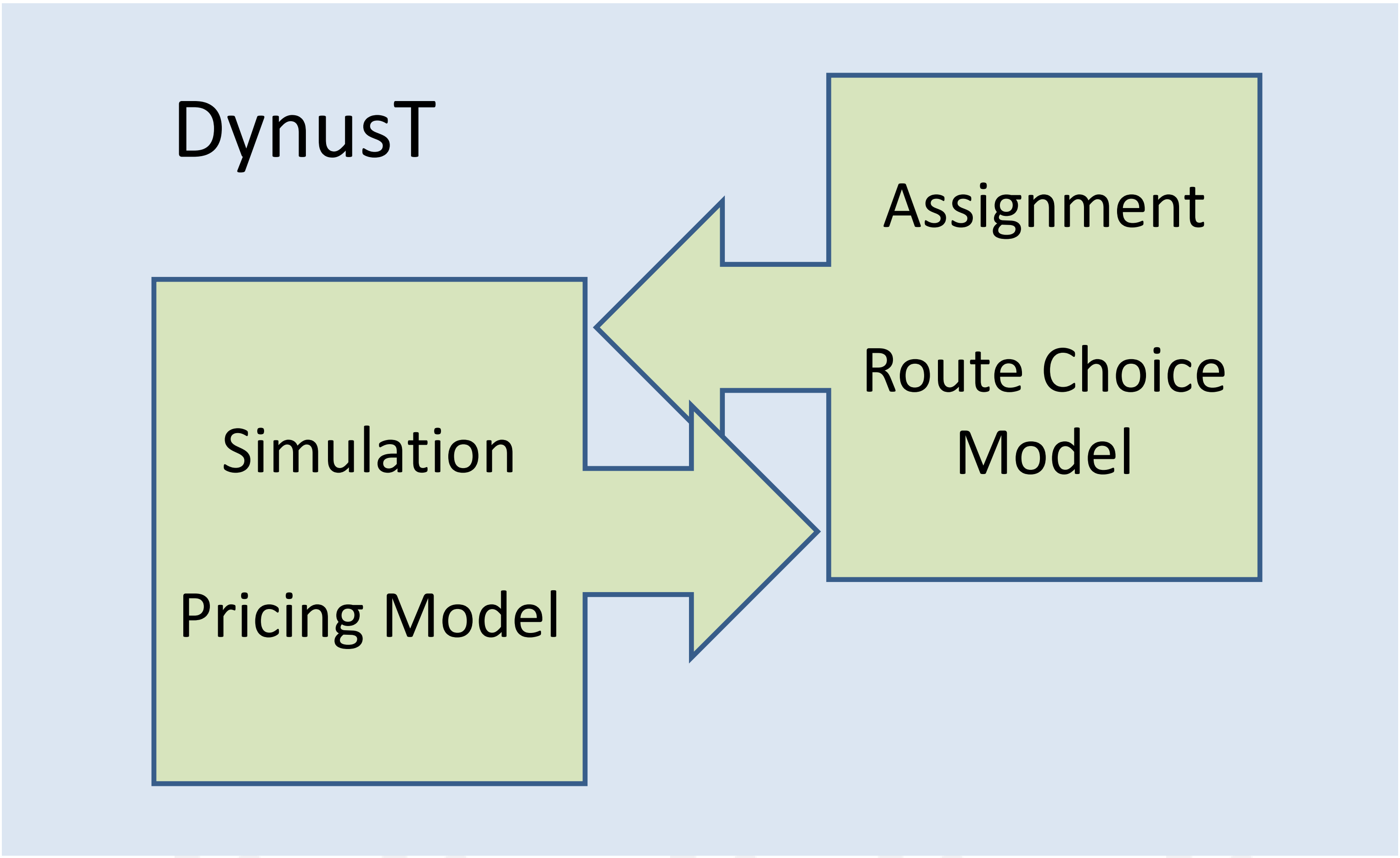
Where,

$Z$ : managed lane flow

$N$ : set of vehicle types; $N = [SOV, HOV, truck]$

$n$ : vehicle type in set $N$

# Solution Algorithm

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# Case Study

- Demonstrate use of DynusT regional model through congestion pricing modeling.
- Congestion pricing modeled as a joint throughput maximization and DUE route choice problem.
- Considering Value-of-Time.
  - SOV = $20
  - HOV = $35
  - Trucks = $60

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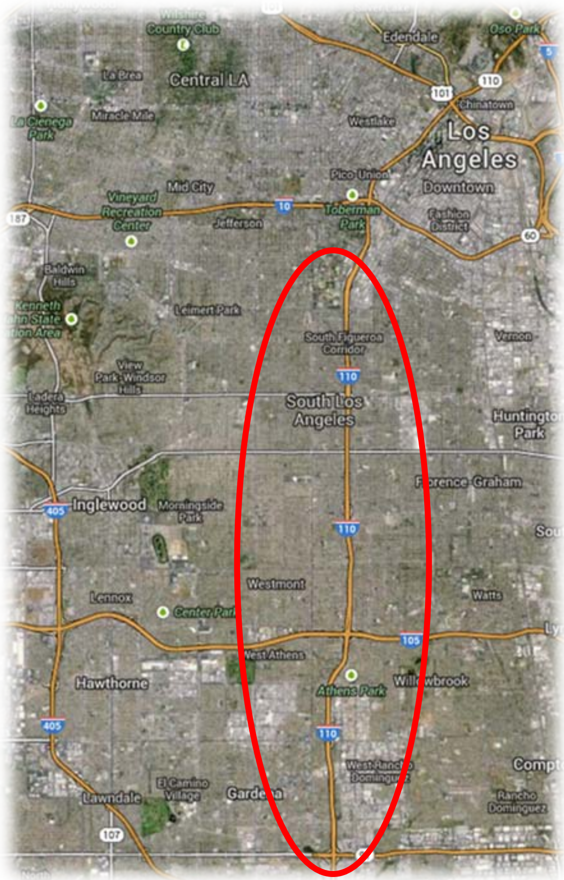
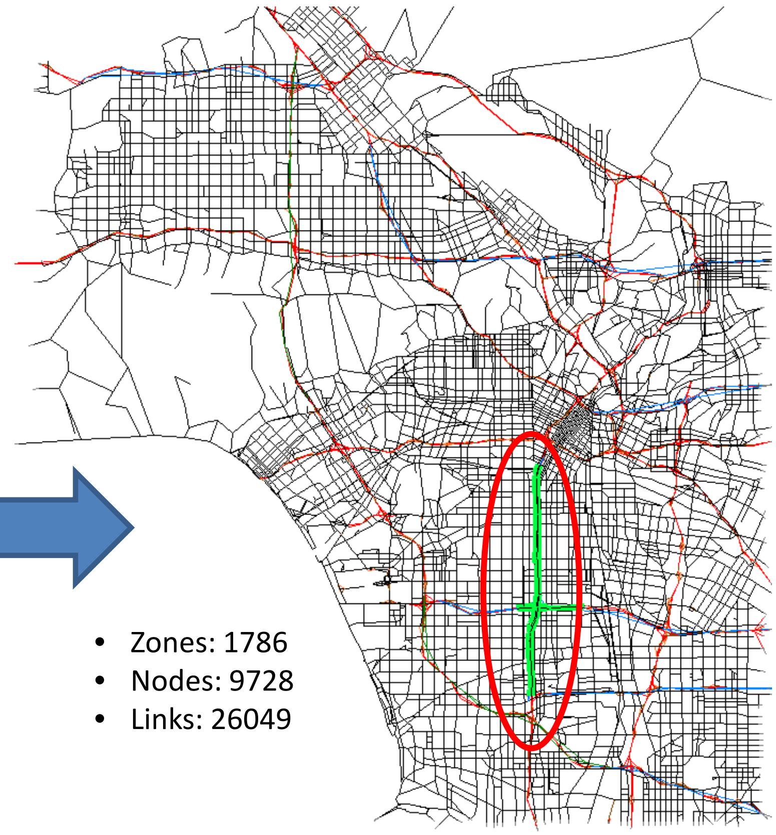
# Case Study Network

## I-110 Corridor



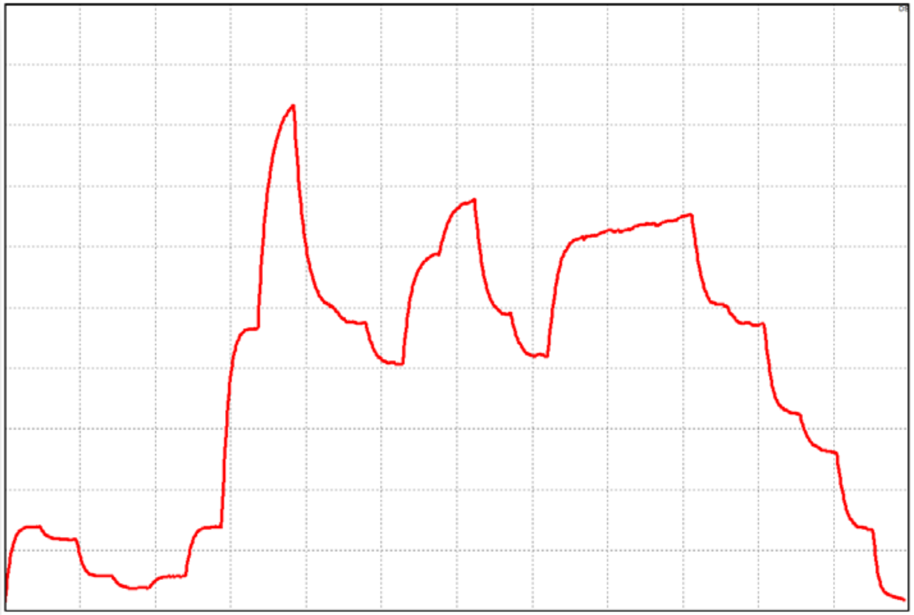

## DynuStudio Sub-Area Cut



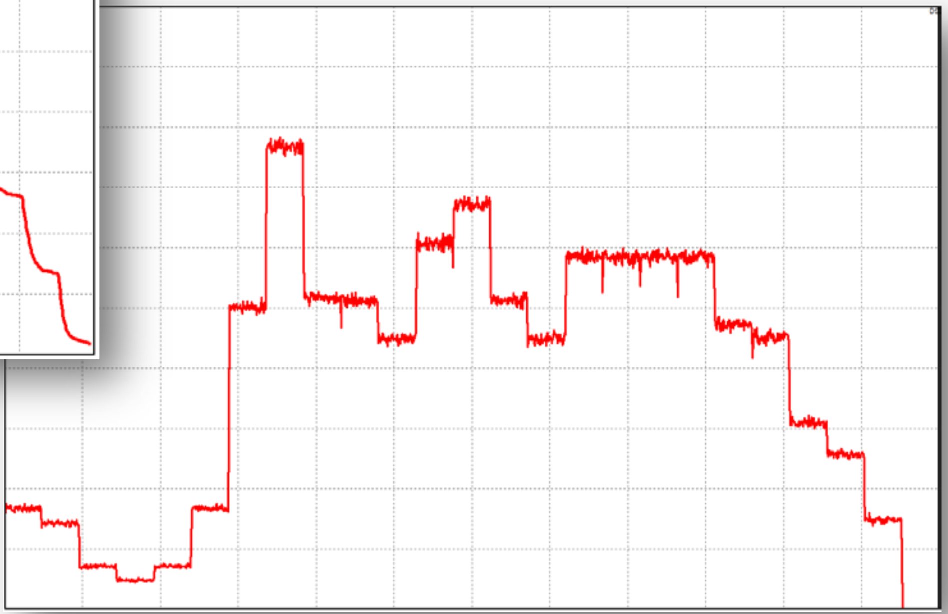
- Zones: 1786
- Nodes: 9728
- Links: 26049

# System-Wide Conditions

System Volume Profile



System Departure Profile



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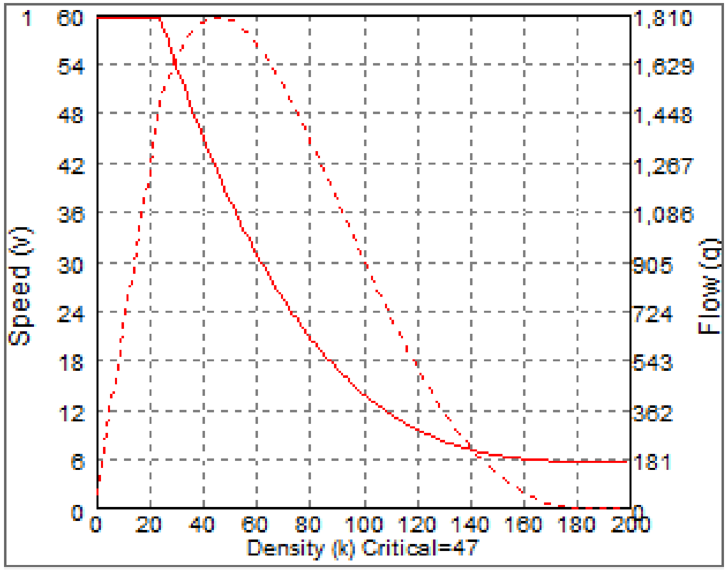
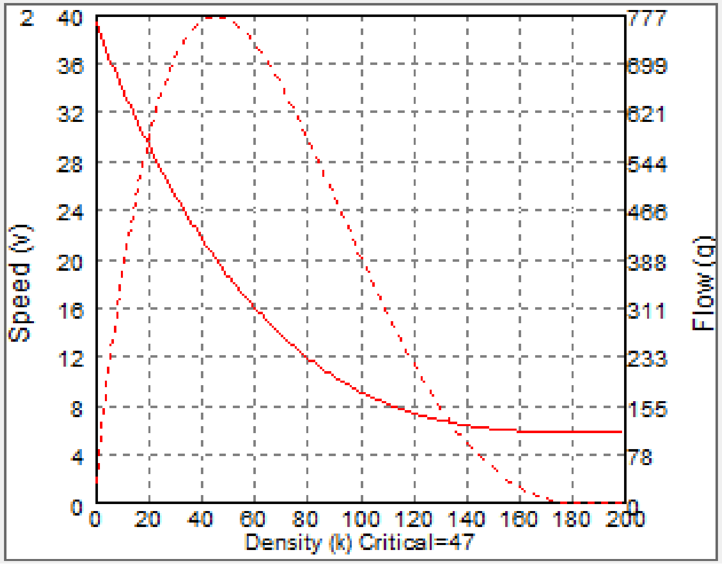
# Traffic Flow Models

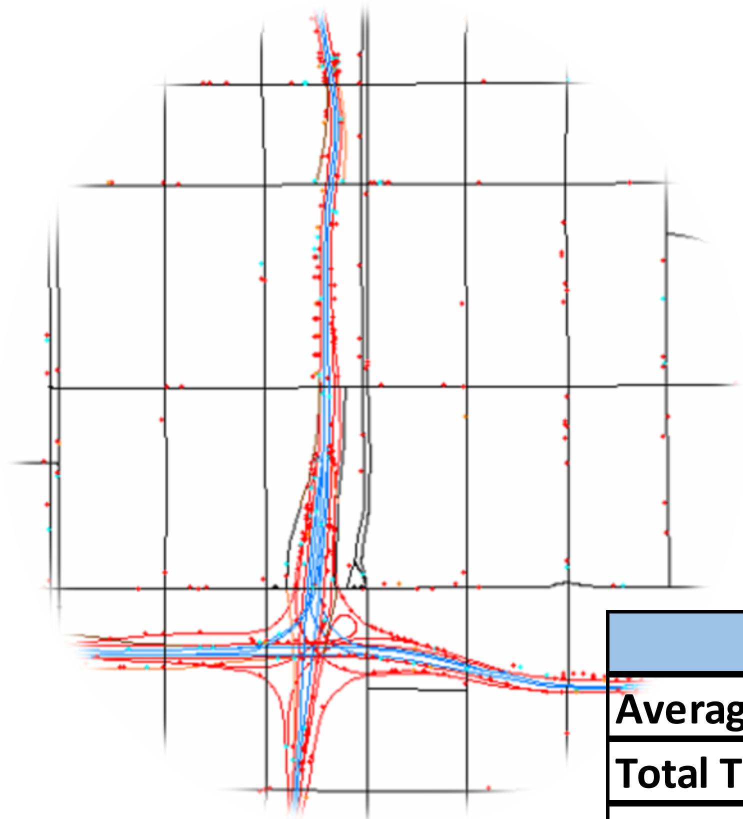
Uninterrupted Flow




Interrupted Flow



# Overall Statistics



| | Base | HOT |
|---|---|---|
| Average Travel Time | 15.1887 | 15.1676 |
| Total Travel Time (Minutes) | 2,010,098 | 2,002,110 |
| Average Trip Time | 15.2281 | 15.2069 |
| Average Trip Distance | 9.8854 | 9.8532 |
| Total Trip Distance (Miles) | 78,292,408 | 78,036,952 |
| Toll Revenue ($) | $0.00 | $6,024.10 |

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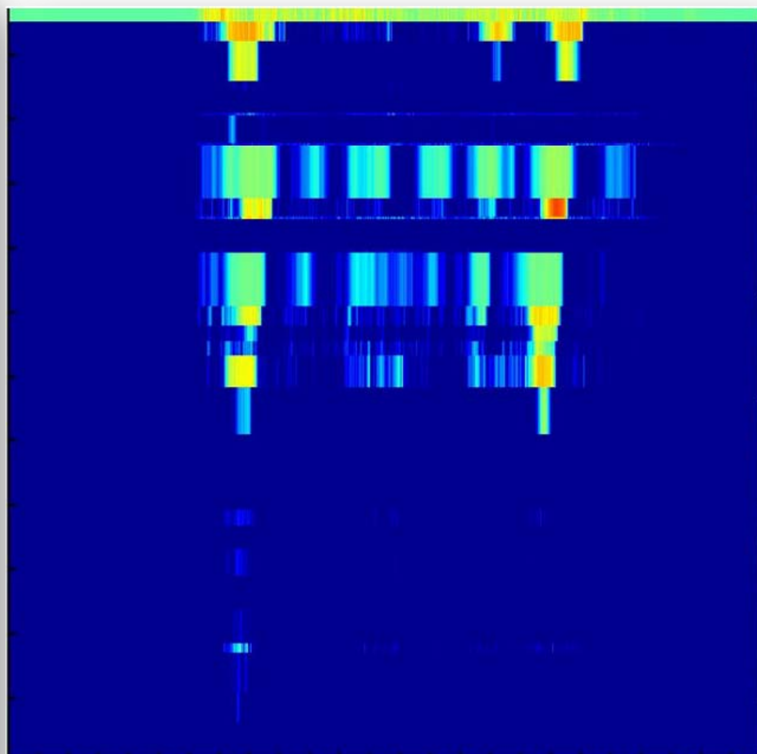
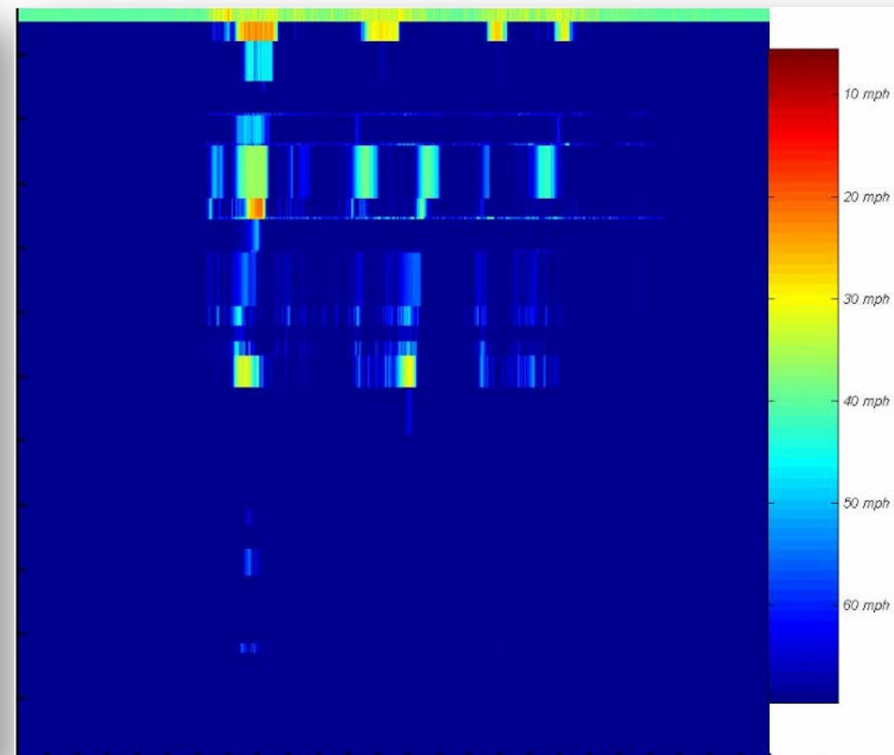
# Case Study Network

## I-110 Northbound


Base Scenario



HOT Scenario




Time of Day

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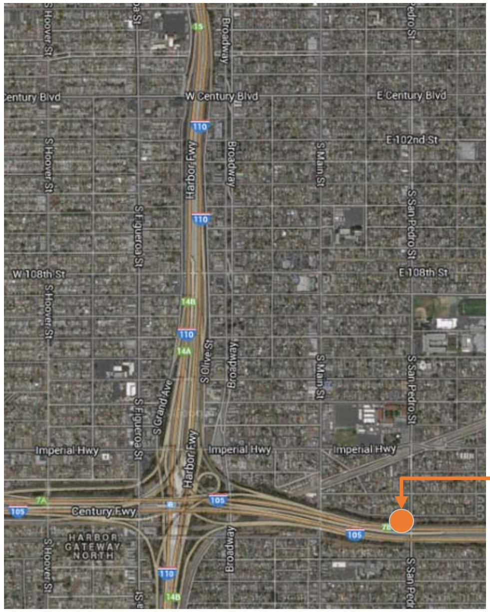
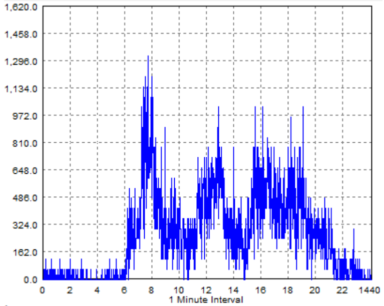
# Time-Varying Pricing Scheme

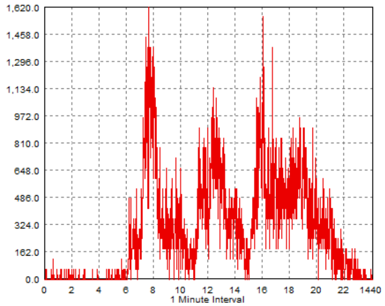




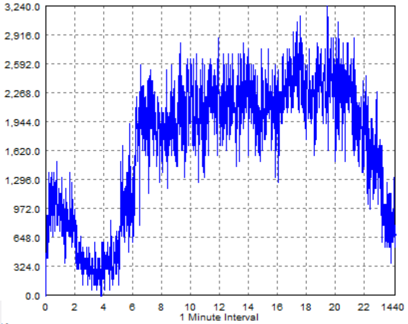
Base – HOV Segment Volume



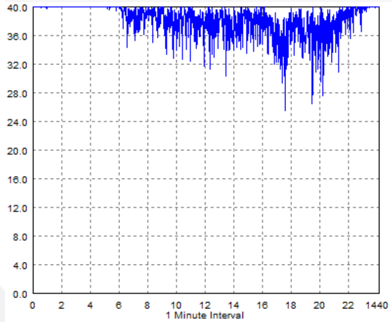

HOT – HOT Segment Volume



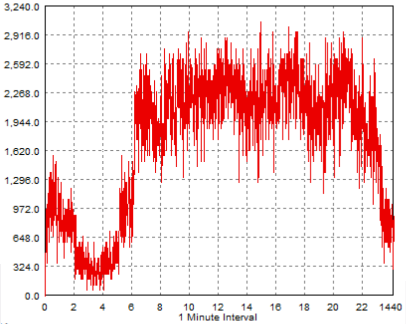

Base – GP Segment Volume



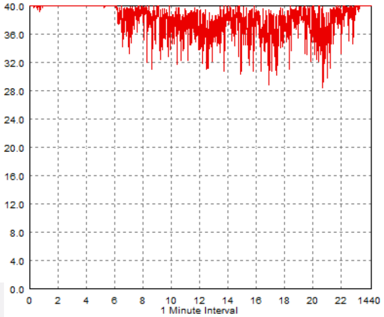

Base – GP Segment Speed




HOT – GP Segment Volume




HOT– GP Segment Speed

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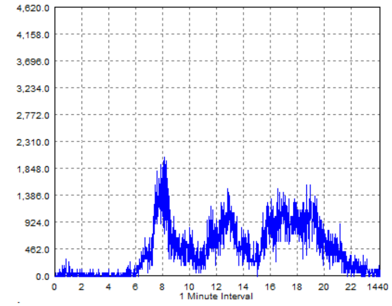
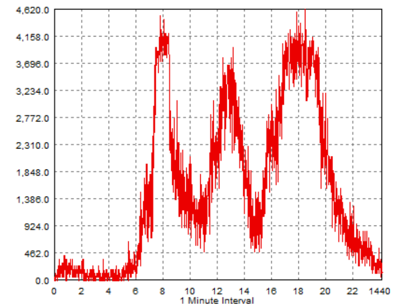
# Time-Varying Pricing Scheme

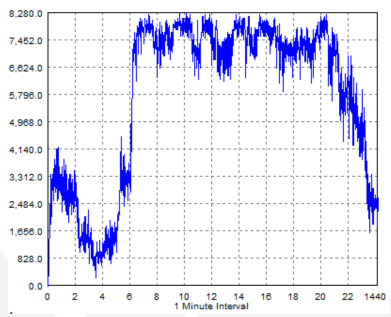
Base – HOV Segment Volume



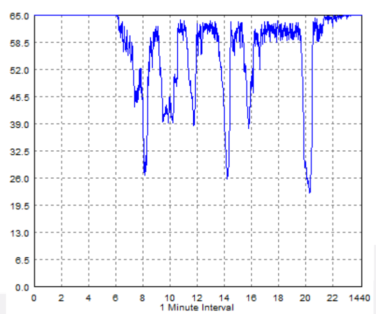

HOT – HOT Segment Volume



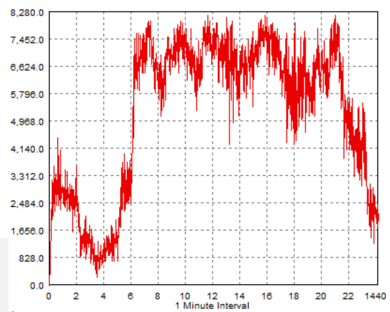

Base – GP Segment Volume



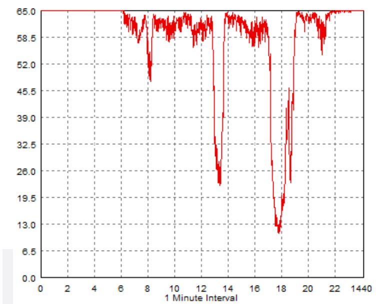

Base – GP Segment Speed




HOT – GP Segment Volume

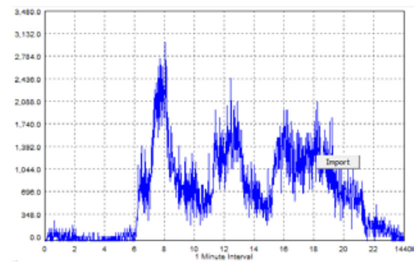



HOT– GP Segment Speed

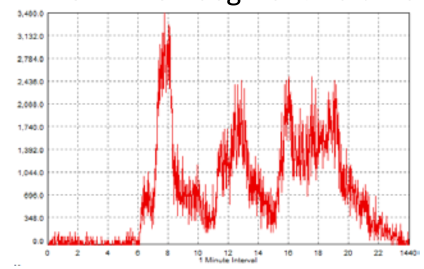


# Time-Varying Pricing Scheme

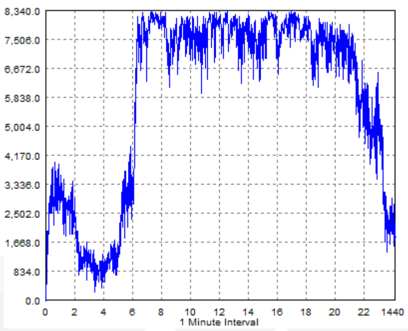
Base – HOV Segment Volume



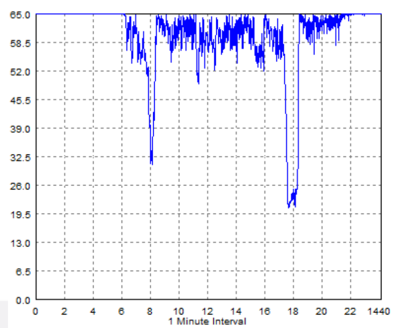

HOT – HOT Segment Volume



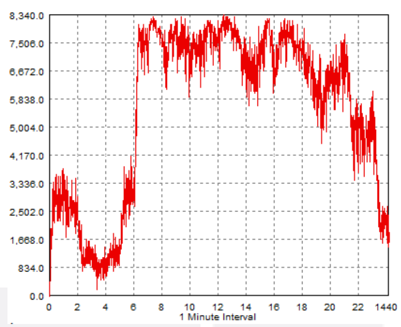

Base – GP Segment Volume



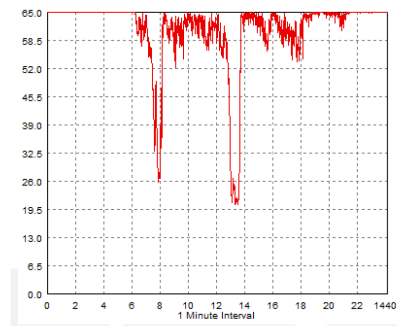

Base – GP Segment Speed

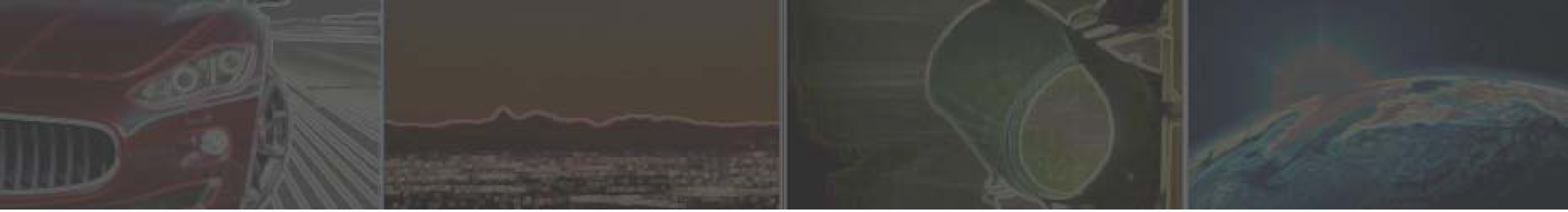



HOT – GP Segment Volume




HOT – GP Segment Speed





# Thank You

DynusT

# Simulation-Based Dynamic Traffic Assignment: From the Labs to the Trenches

Yi-Chang Chiu, Ph.D.
Associate Professor
Department of Civil Engineering and Engineering Mechanics
University of Arizona

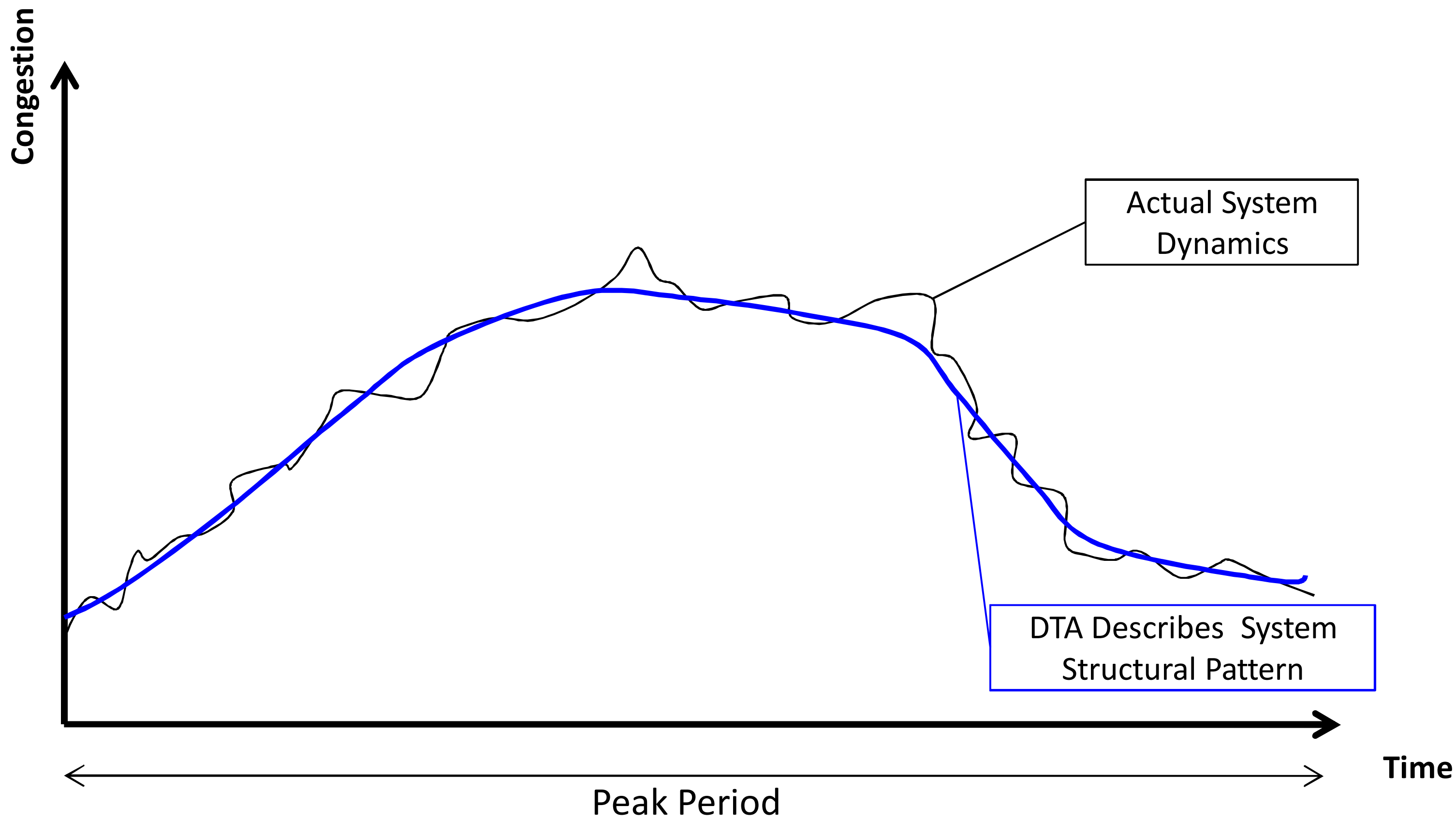
Presented to SCAG
February 27-28, 2014

# Outlines

- Simulation-Based Dynamic Traffic Assignment (DTA) in a nutshell
- Overview of Dynamic Urban Systems for Transportation (DynusT)
  - Anisotropic Mesoscopic Simulation (AMS)
  - Dynamic OD Calibration
  - Method of Isochronal Vehicle Assignment
  - Gap-Function Vehicle Assignment
- Multi-Resolution Modeling (MRM)
- Research Challenges and Opportunities

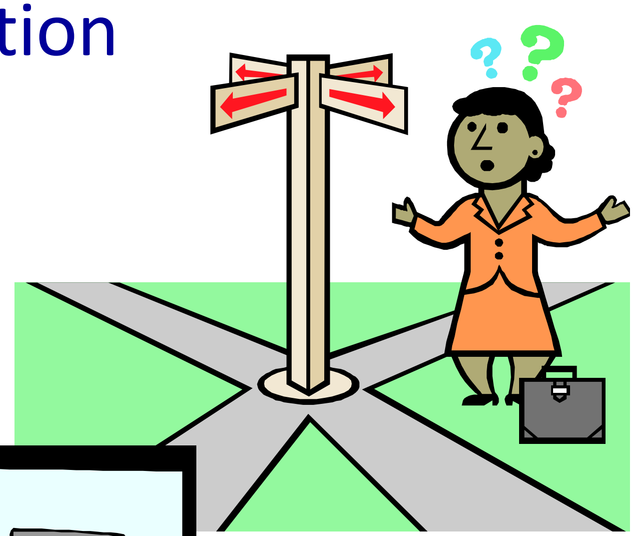
# What is Dynamic Traffic Assignment

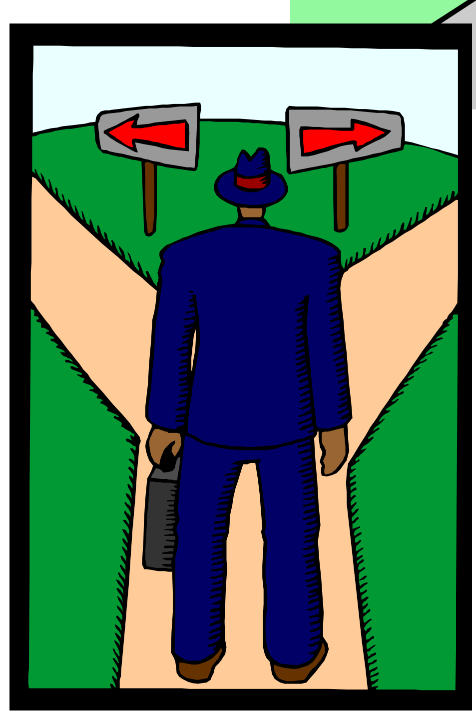
- A simulation-based approach to capturing system dynamics at regional/corridor level



# What is Dynamic Traffic Assignment (cont'd)

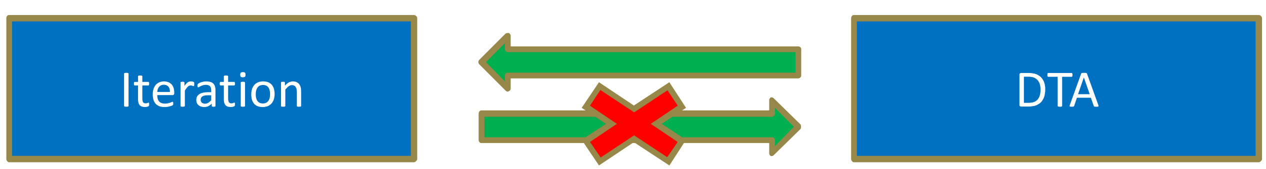
- Rich Traveler Behavior Representation
  - Driving behavior
    - Car following
    - Lane changing
  - Travel choice behavior
    - When to leave
    - Which route to take
    - Diversion or not
    - Reaction to
      - Work zone
      - Congestion
      - Information
      - Pricing
      - Evacuation scenarios





# What do we see here?

- The experienced travel time cannot be seen at departure, unless through prior day experience. To account for prior experience, the algorithm needs to iterate.
- Selecting shortest path calculated using snapshot travel time at departure leads to inferior paths
- Network congestion is worse than what it should be because learning is not properly account for
- However,



# Chronicles of DTA Research

- 1970s – 1980s
  - **Math programming and VI formulations (DSO)**
- 1980s – 1990s
  - **Math programming, VI and optimal control formulation (DSO and DUE)**
- 1990s – 2000s
  - **Optimal control and VI formulation**
  - **Simulation-based approach (deterministic DUE)**
- 2000s – present and beyond
  - **SBDTA algorithm improvement**
  - **Deployment and field testing**
  - **Integrated modeling concepts and approaches**
  - **Heterogeneity vs. stability**

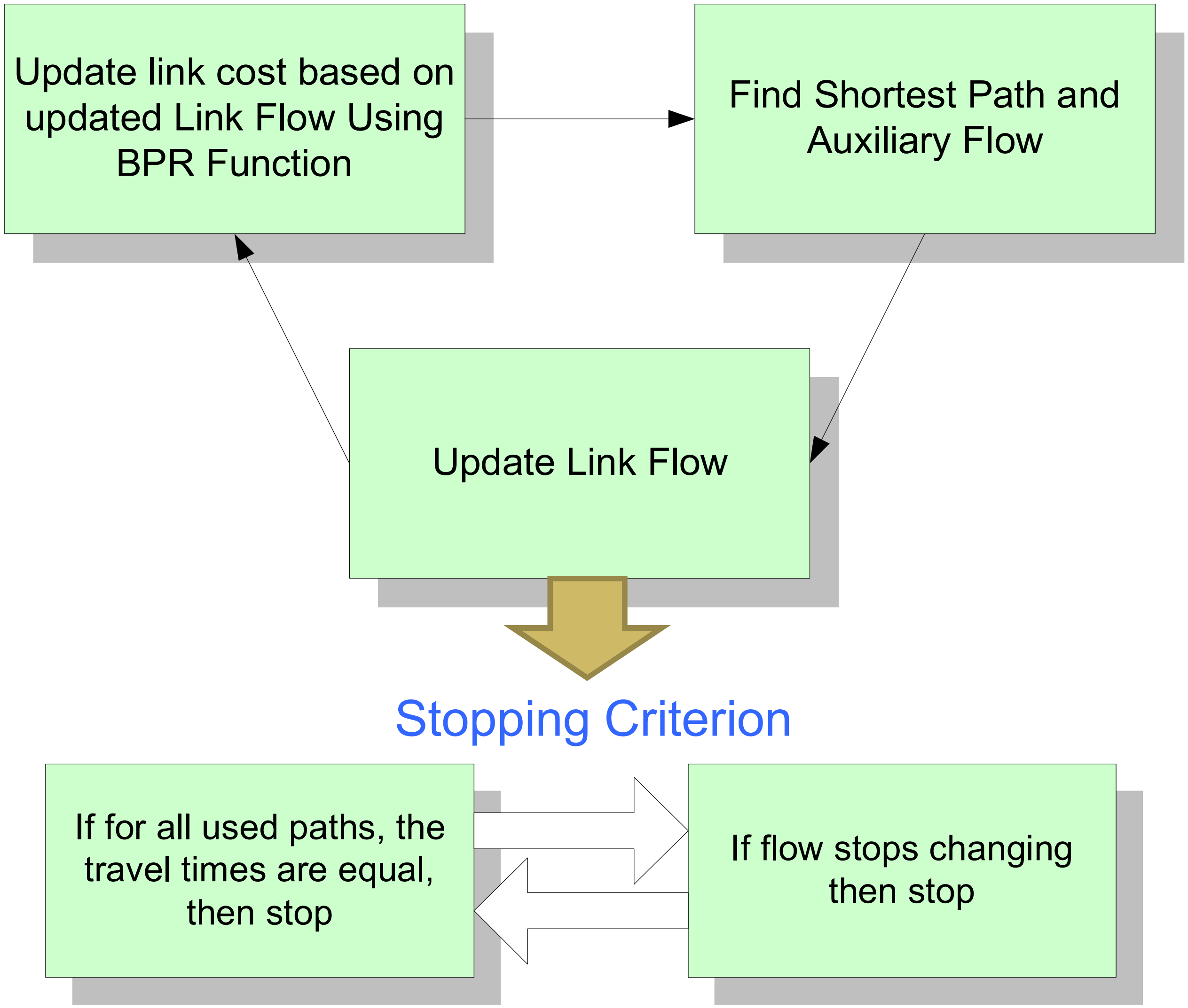
# What is (Road) Traffic Assignment

- Many definitions
  - **Basic** - A method to predict traffic pattern under congestion, given a certain route choice behavior assumption.
  - **Procedure** – a procedure for loading and origin-destination (OD) trip table onto links of a network
  - **Practice** – A step in the sequential (4-step) planning process. It determines link and OD travel times and enable feedback for influencing OD choices or mode choices
- Widely used Wardrop's User Equilibrium (UE) principle (1952')
  - In a network with many OD zones, for ***each OD pair***, all used routes have equal and lowest ***travel time (generalized cost)***. No user may lower his travel time through unilateral action (deterministic).
- Bottom line
  - Account for collective learning of travelers, important to assess impacts of future scenarios

# What is Static Traffic Assignment (STA)

- Time of interest is of substantial length
- Trips are not time-varying
- Congestion in the network is relatively constant (not time-varying)
- Link travel time increases with a higher flow (often depicted by a mathematical function)
- Assuming users have perfect travel time information (deterministic) or plus some defined random errors (stochastic)

# STA Solution Algorithm



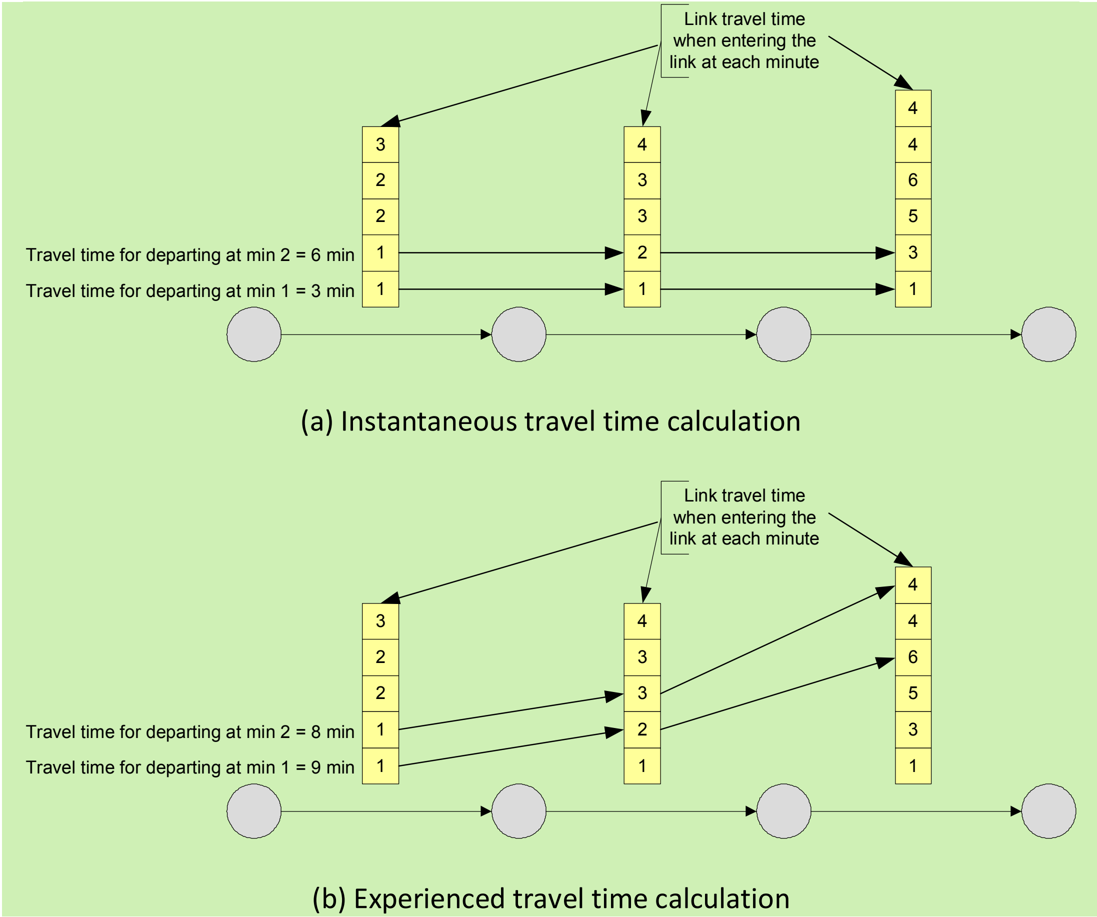
# Why we need Dynamic Traffic Assignment

- Still need to account for learning because impacts of future scenarios is the outcome of user's responses/learning/adaptation to the scenarios
- Need to
  - Better represent network dynamics and congestion
  - Account for impact of information, ITS technologies
  - Represent existing controls

# What is Dynamic Traffic Assignment (DTA)

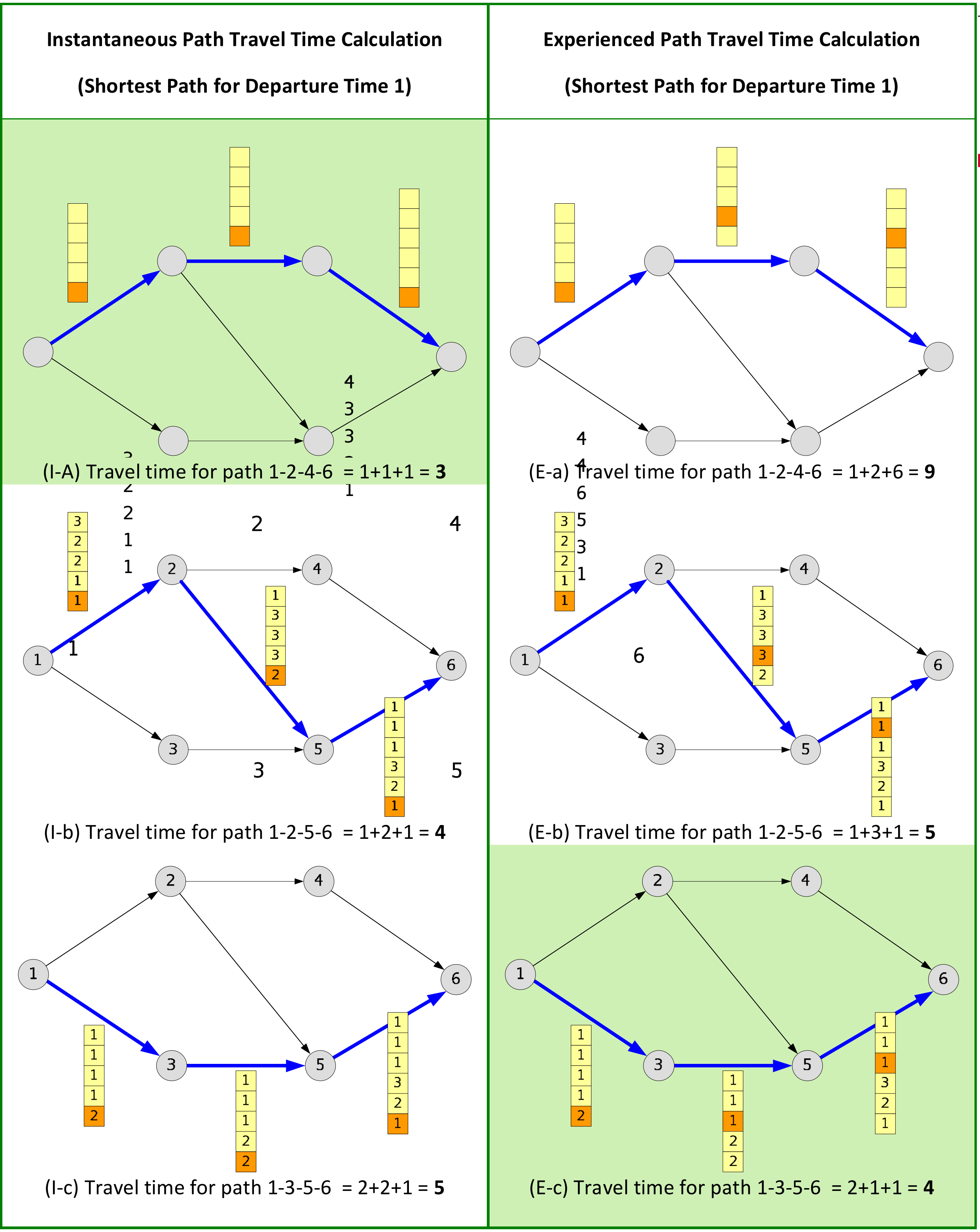
- In a network with many OD zones and a time period of interest, for ***each OD pair and departure time***, all used routes have equal and lowest ***experienced travel time (generalized cost)***. No user may lower his experienced travel time through unilateral action (deterministic).
- Compared with STA below
- In a network with many OD zones, for ***each OD pair***, all used routes have equal and lowest ***travel time (generalized cost)***. No user may lower his travel time through unilateral action (deterministic).

# Experienced vs. Instantaneous Travel Time




Experienced travel time is affected by vehicles departing later

Experienced travel time can only be realized after the fact




(I-A) Travel time for path 1-2-4-6 = 1+1+1 = **3**

(E-a) Travel time for path 1-2-4-6 = 1+2+6 = **9**

(I-b) Travel time for path 1-2-5-6 = 1+2+1 = **4**

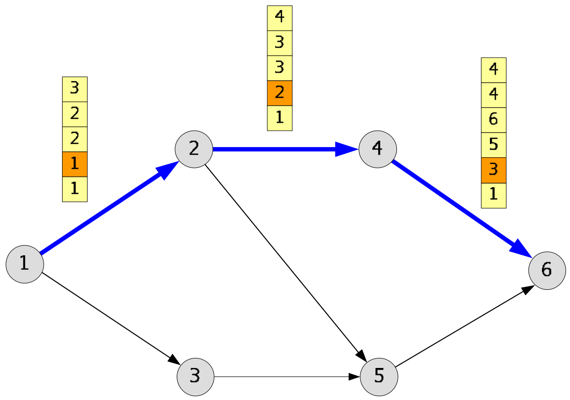
(E-b) Travel time for path 1-2-5-6 = 1+3+1 = **5**

(I-c) Travel time for path 1-3-5-6 = 2+2+1 = **5**

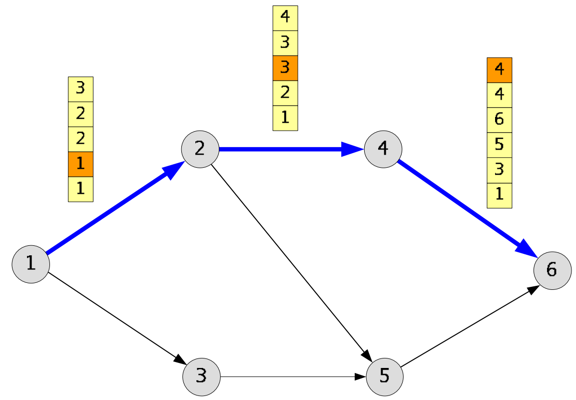
(E-c) Travel time for path 1-3-5-6 = 2+1+1 = **4**

- Different shortest paths obtained by instantaneous travel time and experienced travel time approaches (departure time 1)

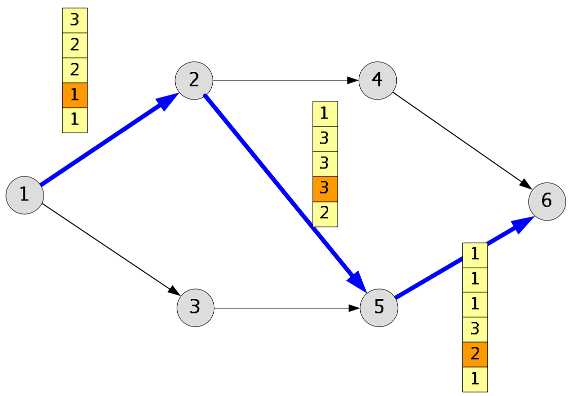
| Instantaneous Path Travel Time Calculation (Shortest Path for Departure Time 2) | Experienced Path Travel Time Calculation (Shortest Path for Departure Time 2) |
|---|---|



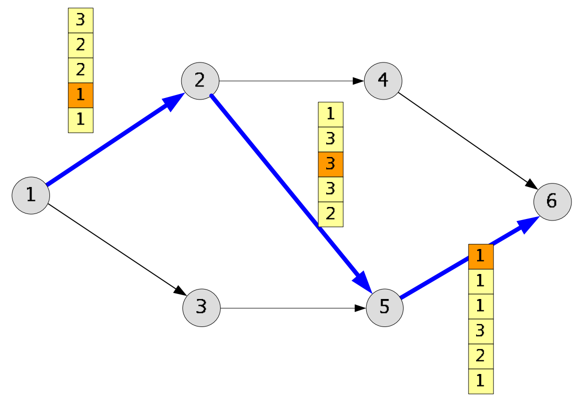

(I-A) Travel time for path 1-2-4-6 = 1+2+3 = **6**



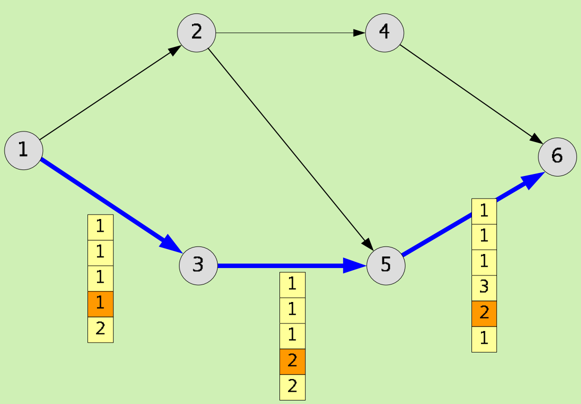

(E-a) Travel time for path 1-2-4-6 = 1+3+4 = **8**



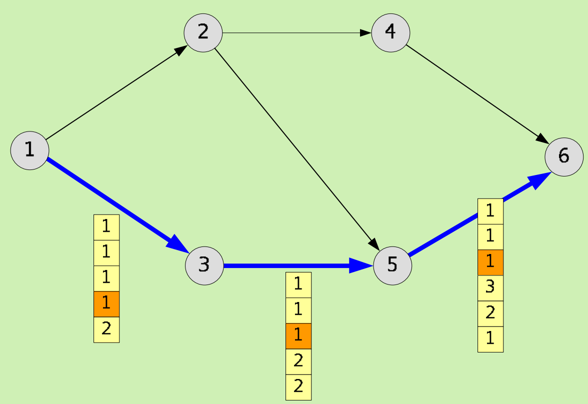

(I-b) Travel time for path 1-2-5-6 = 1+3+2 = **6**




(E-b) Travel time for path 1-2-5-6 = 1+3+1 = **5**




(I-c) Travel time for path 1-3-5-6 = 1+2+2 = **5**

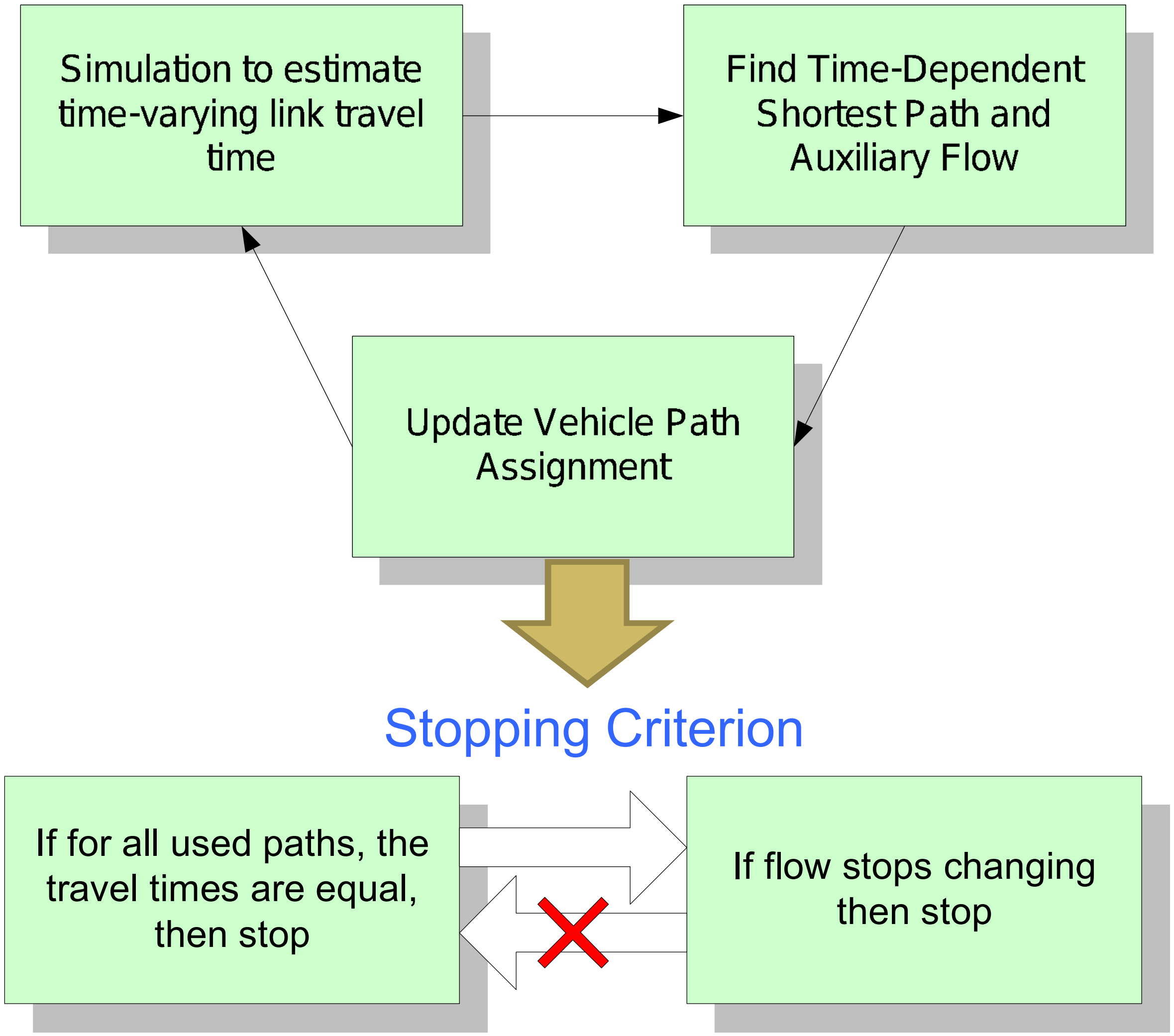



(E-c) Travel time for path 1-3-5-6 = 1+1+1 = **3**

- Different shortest paths obtained by instantaneous travel time and experienced travel time approaches (departure time 2)

# DTA Solution Algorithmic Framework

- If paths are not found using TDSP, the simulation results will look unreasonable and congestion being inflated.
- This problem persists even a model "iterates."



# Practical Context – DTA is….

- A capability to describe how tripmakers with different OD and **departure time** may follow UE principle in choosing **self-optimizing** alternative routes under:
  - Normal (baseline) network condition
  - Alternative (scenario) network condition
- Fundamental qualifiers
  - Self-optimizing - minimal experienced travel time
  - Different minimal experienced travel time paths for Different departure time
  - **The paths chosen by those who departing at the same time, between the same OD pair should have equal experienced travel time**

# Short-Term Reaction vs. Learning/Habit Reforming

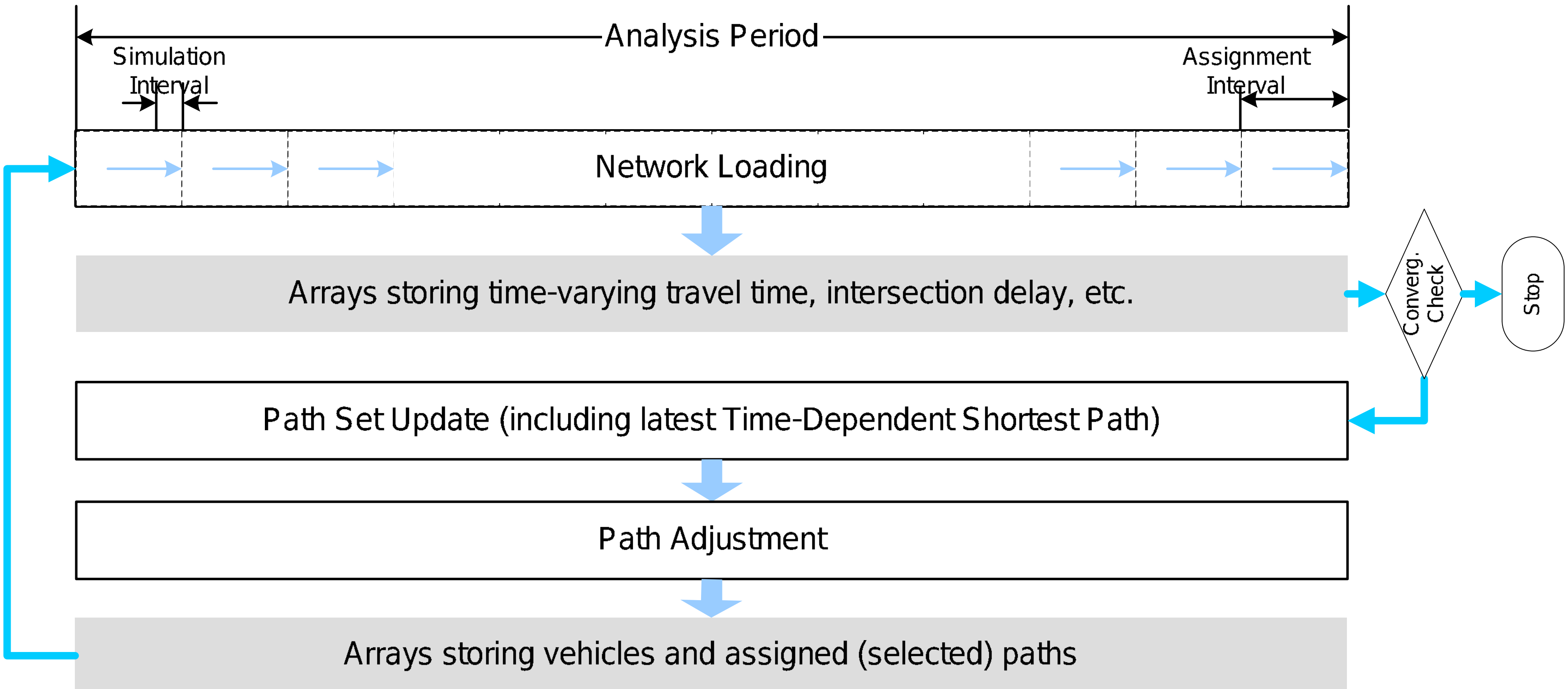
- Short-Term Reaction
  - Try new routes
  - More rely on information and trial experience
- Learning/Habit Reforming
  - Settle down to limited choices based on EXPERIENCE
- What kind of modeling approaches capture above decision contexts?
  - == Your answers:

# What is Dynamic User Equilibrium (DUE) Solution?

- In a network with many OD zones and a time period of interest, for ***each OD pair and departure time***, all used routes have equal and lowest ***experienced travel time***. No user may lower his experienced travel time through unilateral action (deterministic).
- A Solution tells how to assign trips (vehicles) to routes such that the above condition is met
- In real-world situation, solution can only be iteratively numerically approached (approximated)

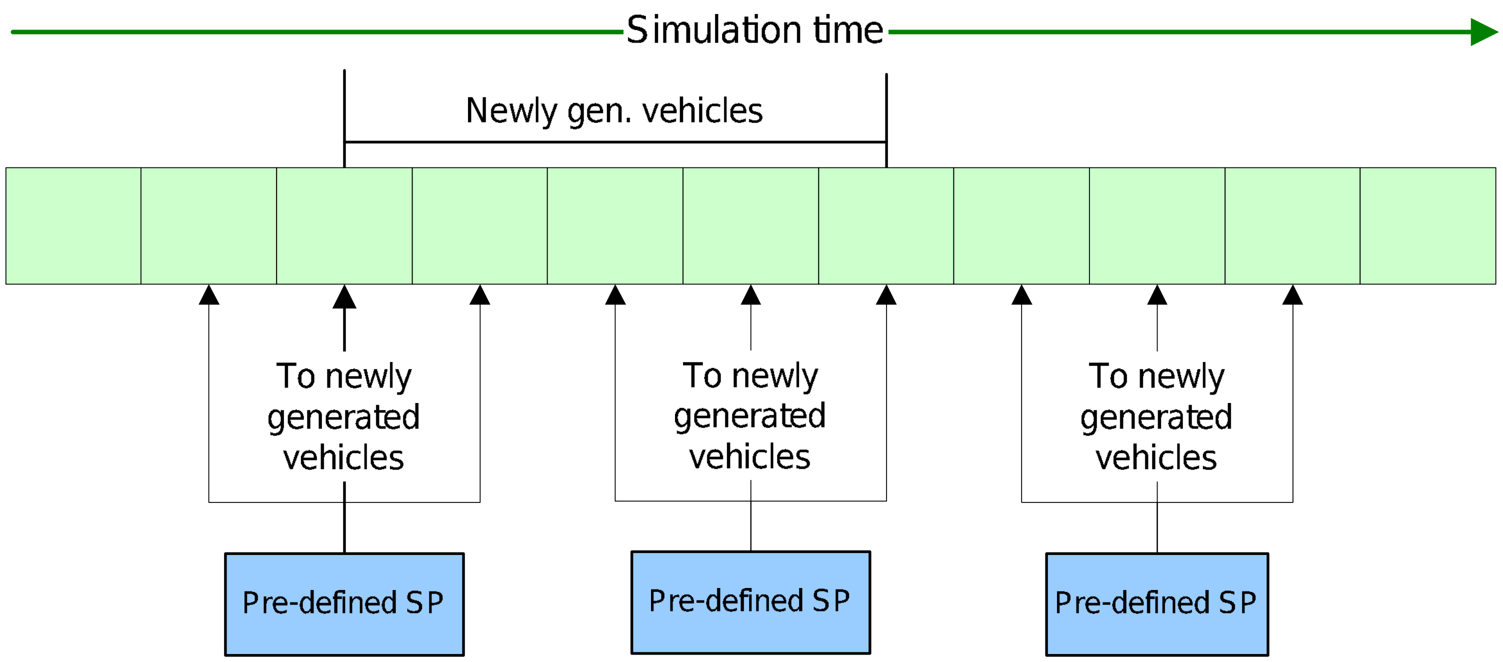
# DTA Algorithmic Structure (simulation-based)

- Network loading
- Path set update
- Path flow adjustment



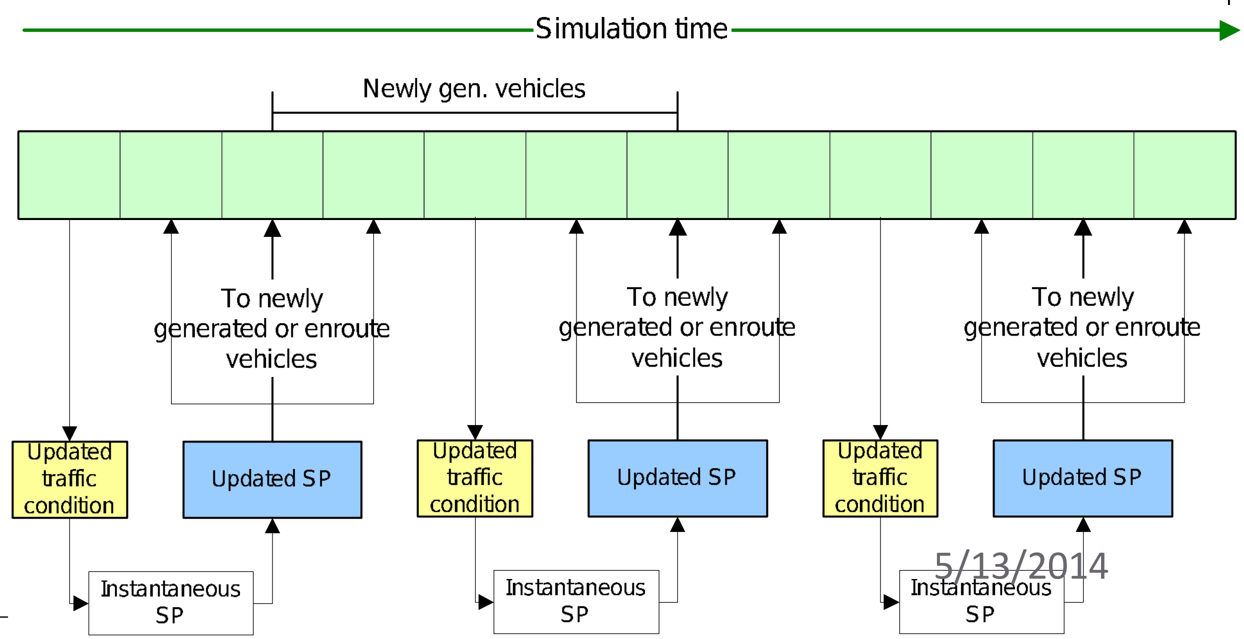
# Comparison with One-Shot Microscopic Simulation

- Give vehicles with pre-set path and flow proportion in a one-shot simulation
  - Not DTA, subject to modeler's subjective judgment



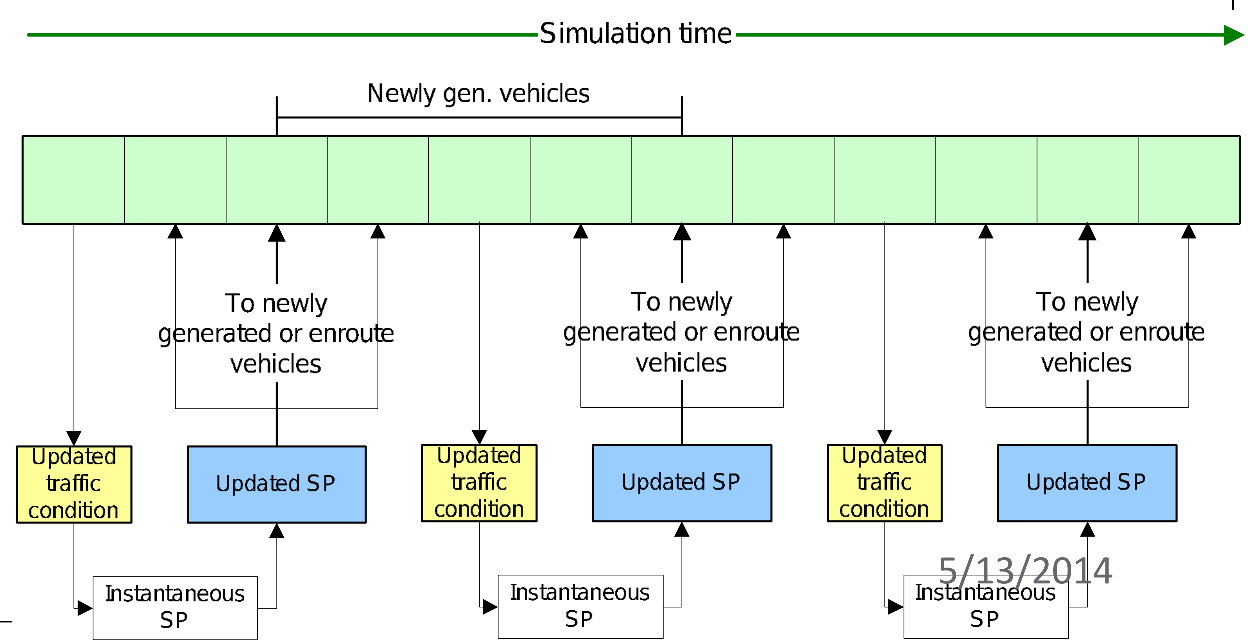
# Comparison with One-Shot Microscopic Simulation

- Give newly generated vehicles with regularly updated path a one-shot simulation
  - Not DTA as experienced travel time can not be calculated in one-shot simulation
  - Can be behaviorally interpreted as receiving pre-trip information
  - Applied to a fraction of travelers but not all



# Comparison with One-Shot Microscopic Simulation

- Give newly generated vehicles with regularly updated path a one-shot simulation, existing vehicles can be rerouted to this new path
  - Not DTA as experienced travel time can not be calculated in one-shot simulation
  - Can be behaviorally interpreted as receiving pre-trip and enroute information
  - Applied to a fraction of travelers but not all



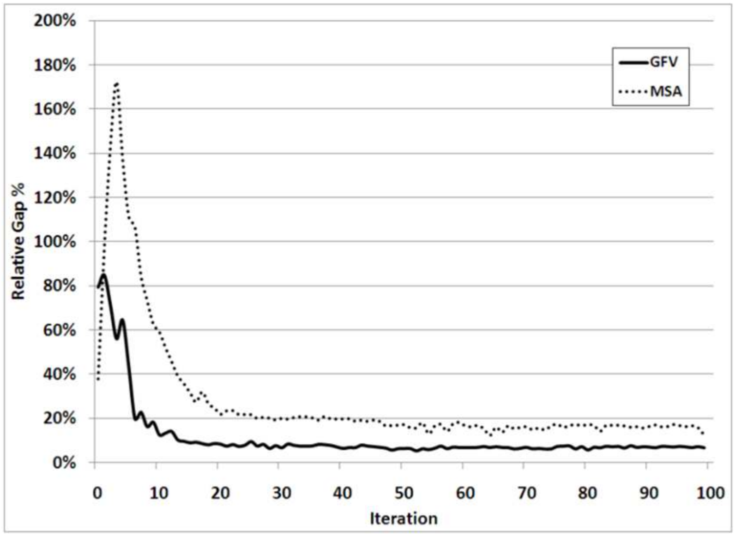
# What can be used to define a good DTA solution?

- Two discussed below, but not limited to:
- Convergence: measures how close to DUE condition
  - Relative Gap

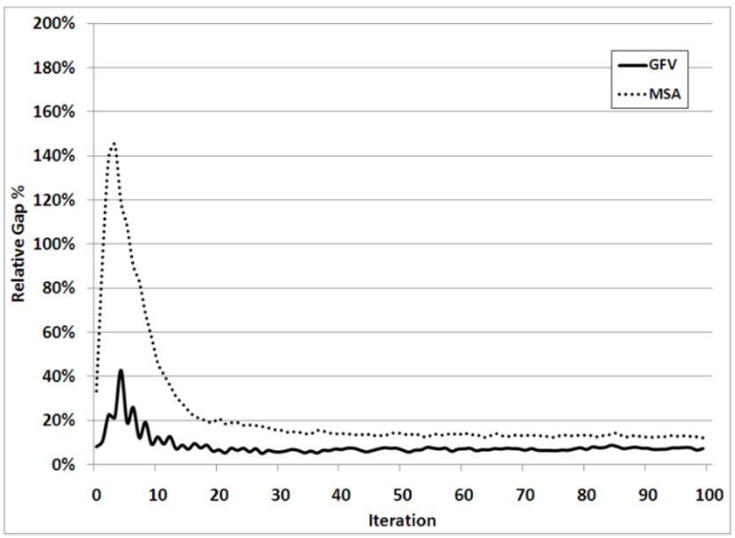
$$rel\_gap = \frac{\sum_t \sum_{i \in I} \sum_{k \in K_i} f_k^t \tau_k^t - \sum_t \sum_{i \in I} d_i^t u_i^t}{\sum_t \sum_{i \in I} d_i^t u_i^t}$$

- Stability: small perturbation (e.g. change a link capacity) does not significantly affect all links in the entire network
  - Poor convergence -> no stability
  - Good convergence -> stability (not guaranteed, if the solution algorithm does not starts from the proximity of the baseline UE solution as it may converge to a different solution -> uniqueness of the DUE solution is not guaranteed in real-life situations)

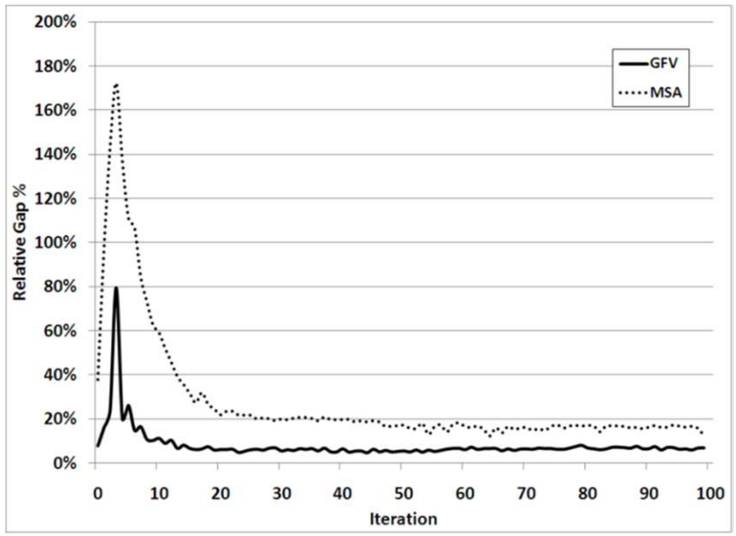
# An Example



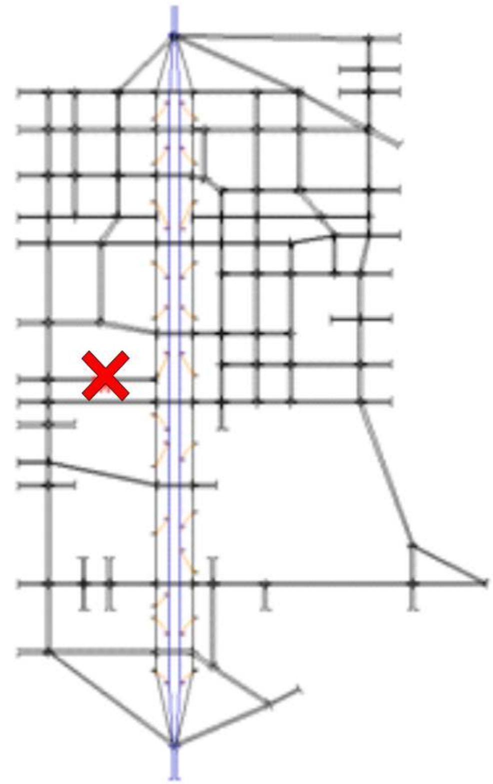

Baseline Case (starts from afar)




Baseline Case (starts from UE)

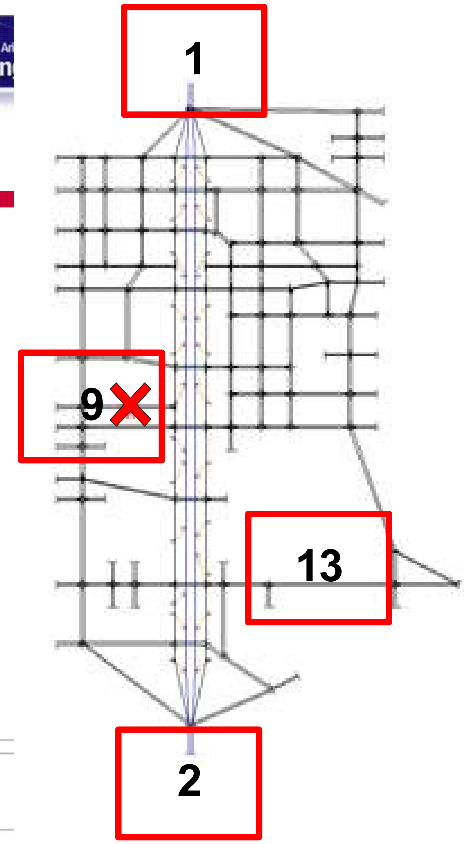


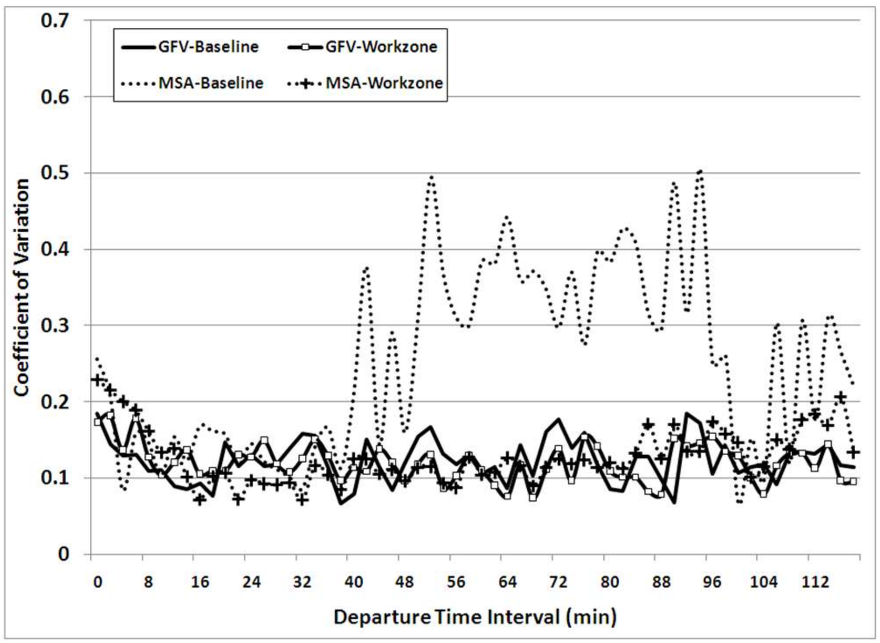

Work Zone Addition (starts from UE)



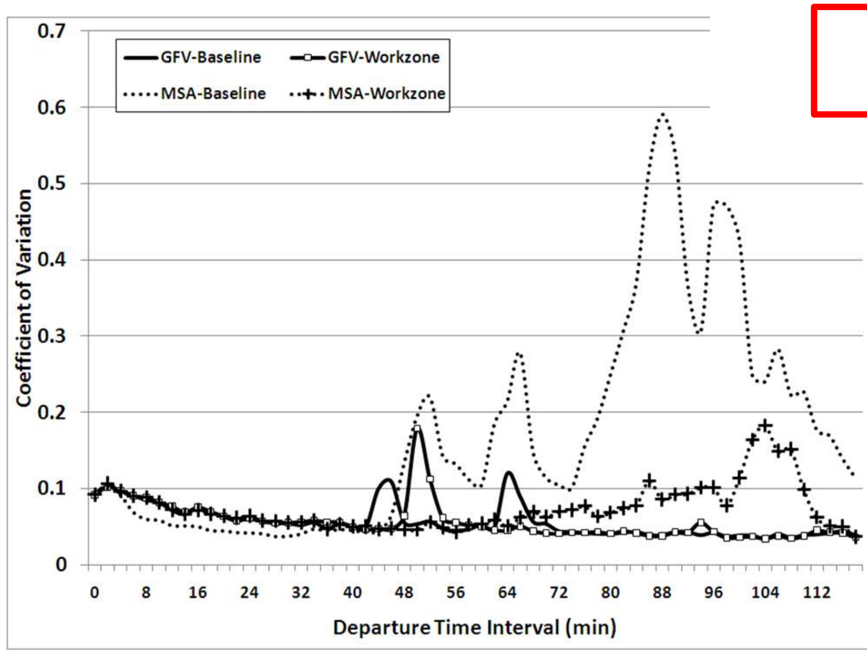
# An Example

- Path travel time variations
- Selected OD pair
- Over all departure times




Affected OD Pair zone 9 to zone 13



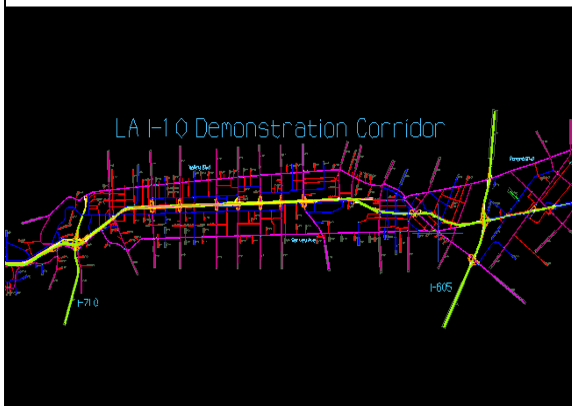

Non Affected OD Pair zone 1 to zone 2

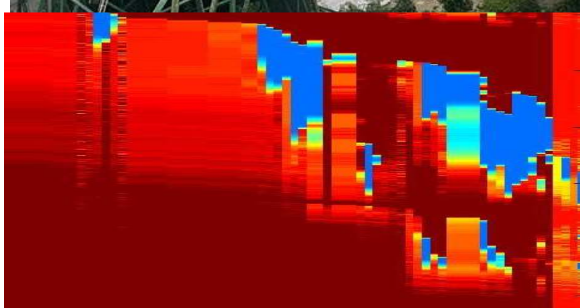
# **DynusT** (Dynamic Urban Systems for Transportation)

# DynusT (Dynamic Urban Systems in Transportation)

- **Simple** , **lean** and easy to **integrate** with macro and micro models
- Developed since 2002, tested (in test) for 20 regions since 2005
  - ELP, PAG, MAG, DRCOG, PSRC, SFCTA, HGAC, Las Vegas, NC Triangle, Guam, Florida, SEMCOG, Toronto, SACOG, Mississippi, North Virginia, I-95, US36, New York, Bay Area)
  - Used in several national projects
- Memory efficient
  - The only DTA capable of large-Scale 24-hr simulation assignment
- Fast simulation/computation
  - Multi-threaded
- Realistic microlike mesoscopic traffic simulation
  - Anisotropic Mesoscopic Simulation (AMS)
- Managed Open Source in 2010/2011

# DynusT Ongoing Efforts to Support Users and Agencies



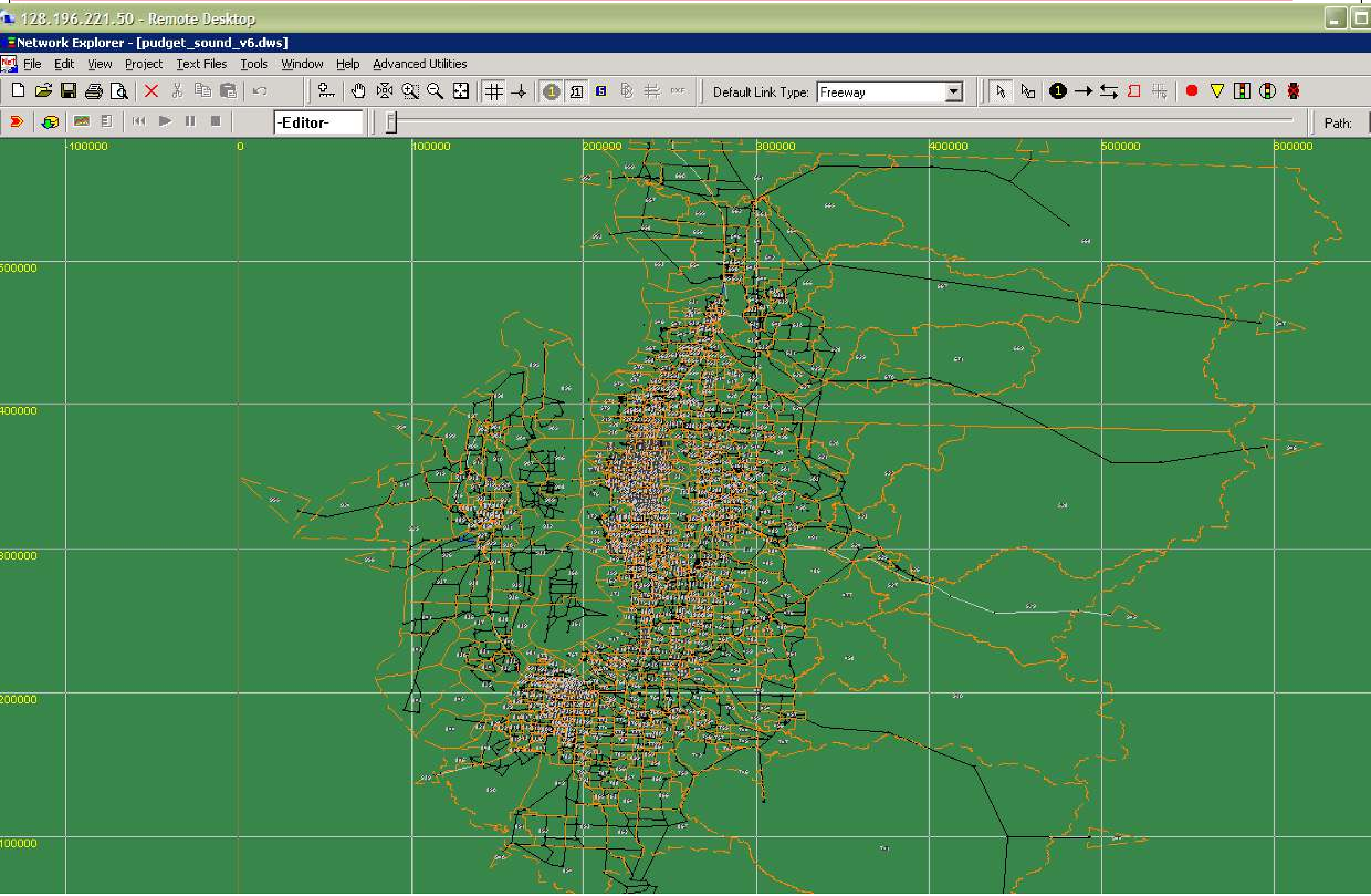



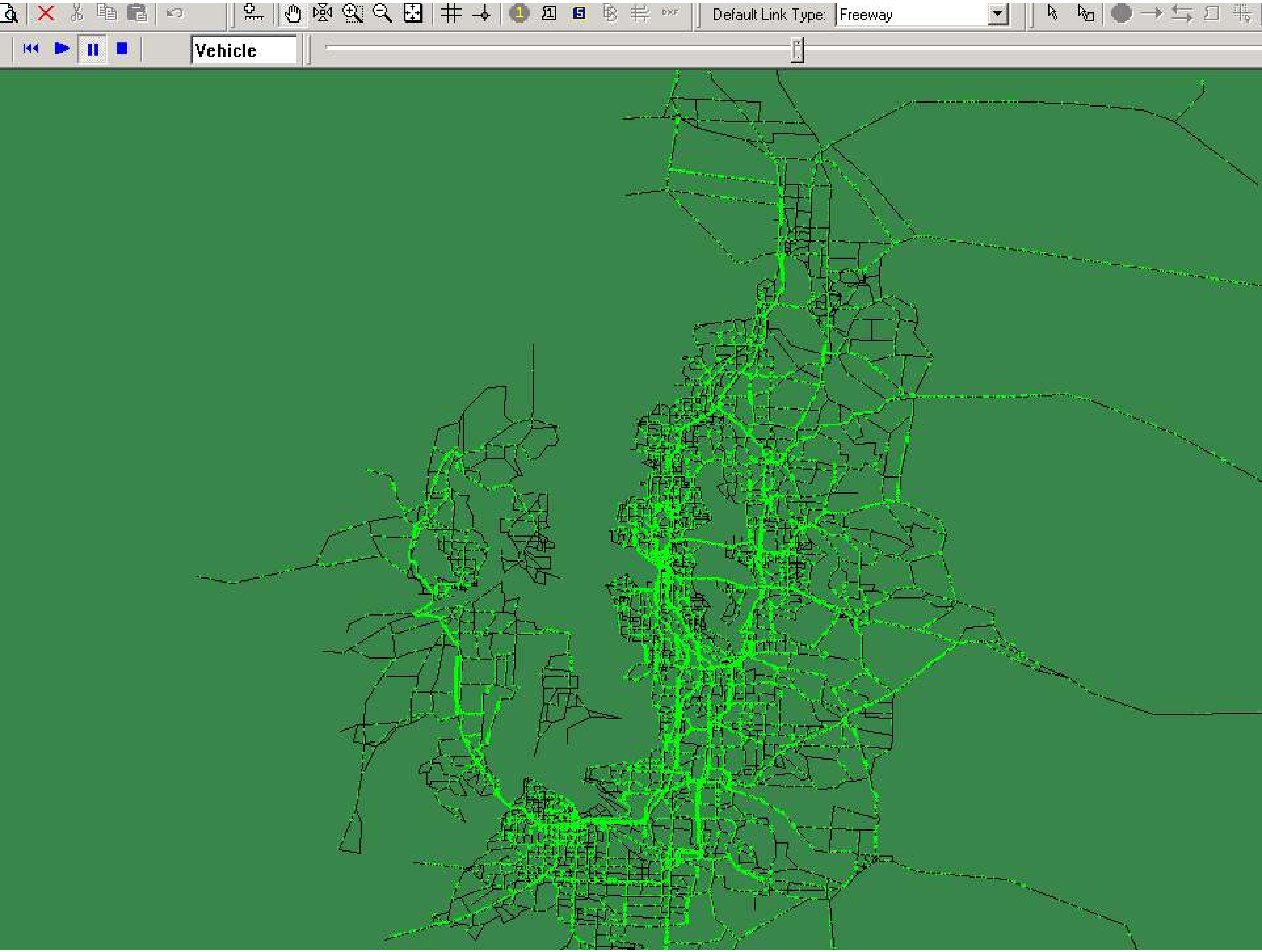
- **Military deployment transportation improvement in Guam** (PB, **FHWA**)
- **Interstate highway corridor improvement** (TTI, **TxDOT**, **ELPMPO**, Kittleson, **ADOT**, UA, **CDOT**)
- **Value pricing** (ORNL, **FHWA**; SRF, **Mn/DOT**, TTI, **TxDOT**, UA, **CDOT/DRCOG**)
- **Evacuation operational planning** (TTI, **TxDOT**, UA, **ADOT**; LSU, **LDOT**; Noblis, **FHWA**; Univ. of Toronto, Cornell Univ. Jackson State Univ., **MDOT**, Univ. of Missouri, **MDOT**)
- **Integrated Corridor Management modeling** (CS, **FHWA**, **MAG**, NCSU, **NCDOT**, **MAG**)
- **Pilot studies** (**Portland Metro**)
- **Activity-based model integration** (UA, **SHRP2 C10**, **FHWA EARP**)
- **Work zone impact management** (**SHRP2 R11**)

# Community-Based Open Source (2011 or 2012)

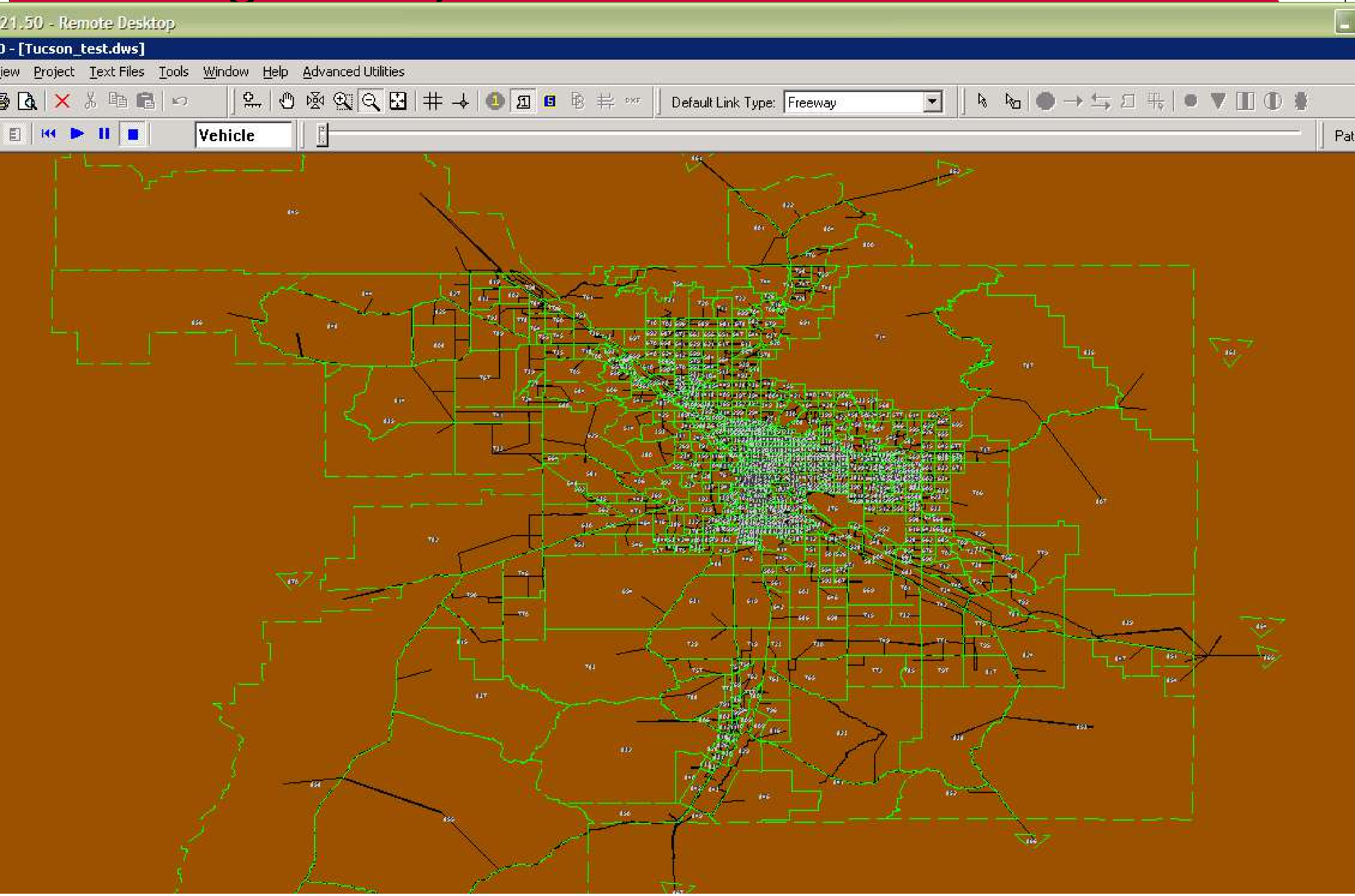
- Existing Developers
  - Univ. of Utah(*)
    - Travel demand model importer
  - Texas Transportation Institute
    - VISUM - DynusT interface (PTV)
    - DynusT - VISSIM interface
  - Parsons Brinckerhoff(*)
    - Synchro - DynusT importer
    - Google Earth displayer
    - DynusT - DYNAMEQ (PB)
    - DynusT - VISTA (PB)
  - Pima Associations of Governments(*)
    - Synchro - DynusT importer
  - AECOM
    - TRANSIMS - DynusT converter

# Puget Sound Regional DynusT Model

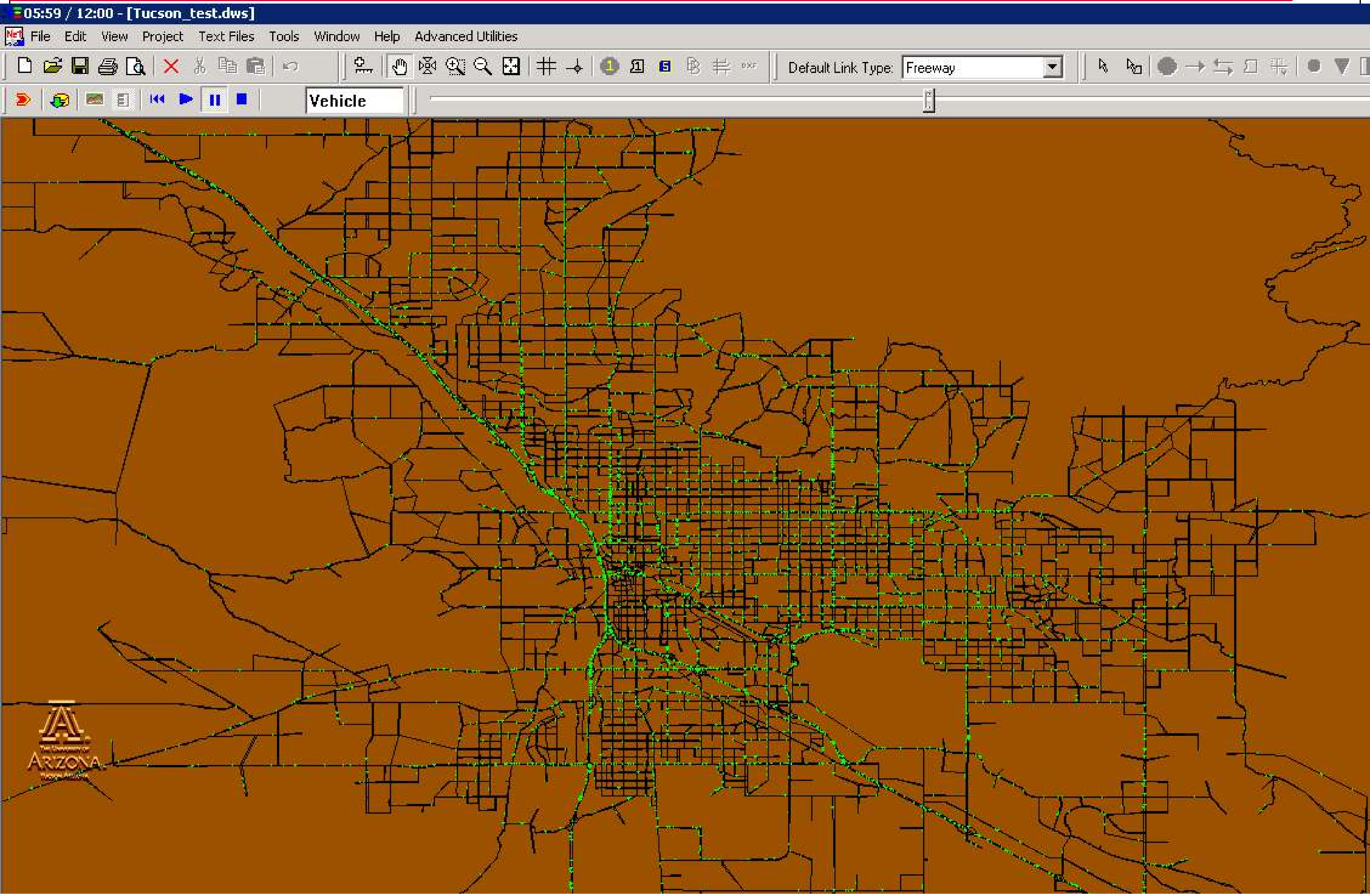



Default Link Type:
Freeway
Vehicle

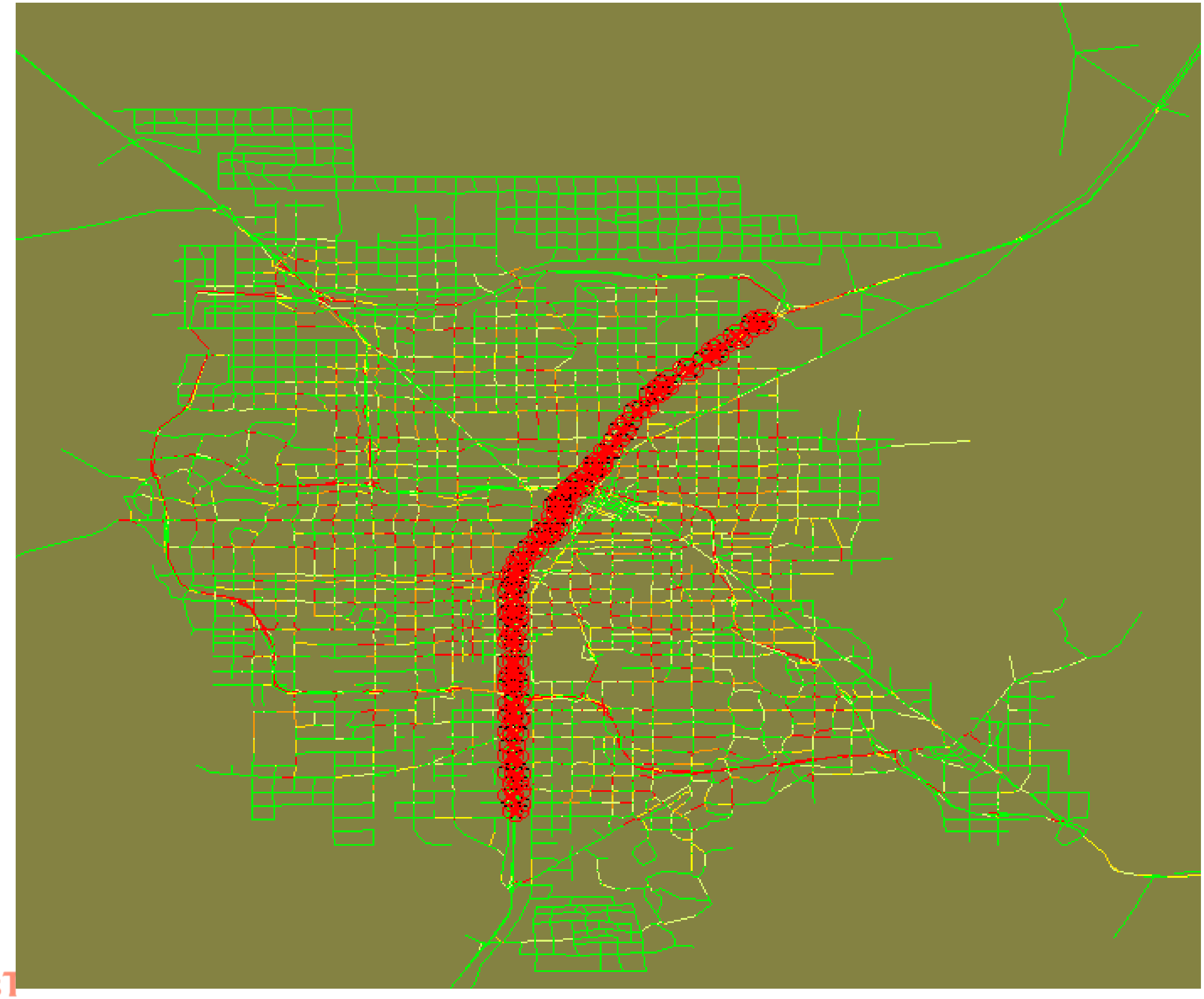
# PAG Regional DynusT Model



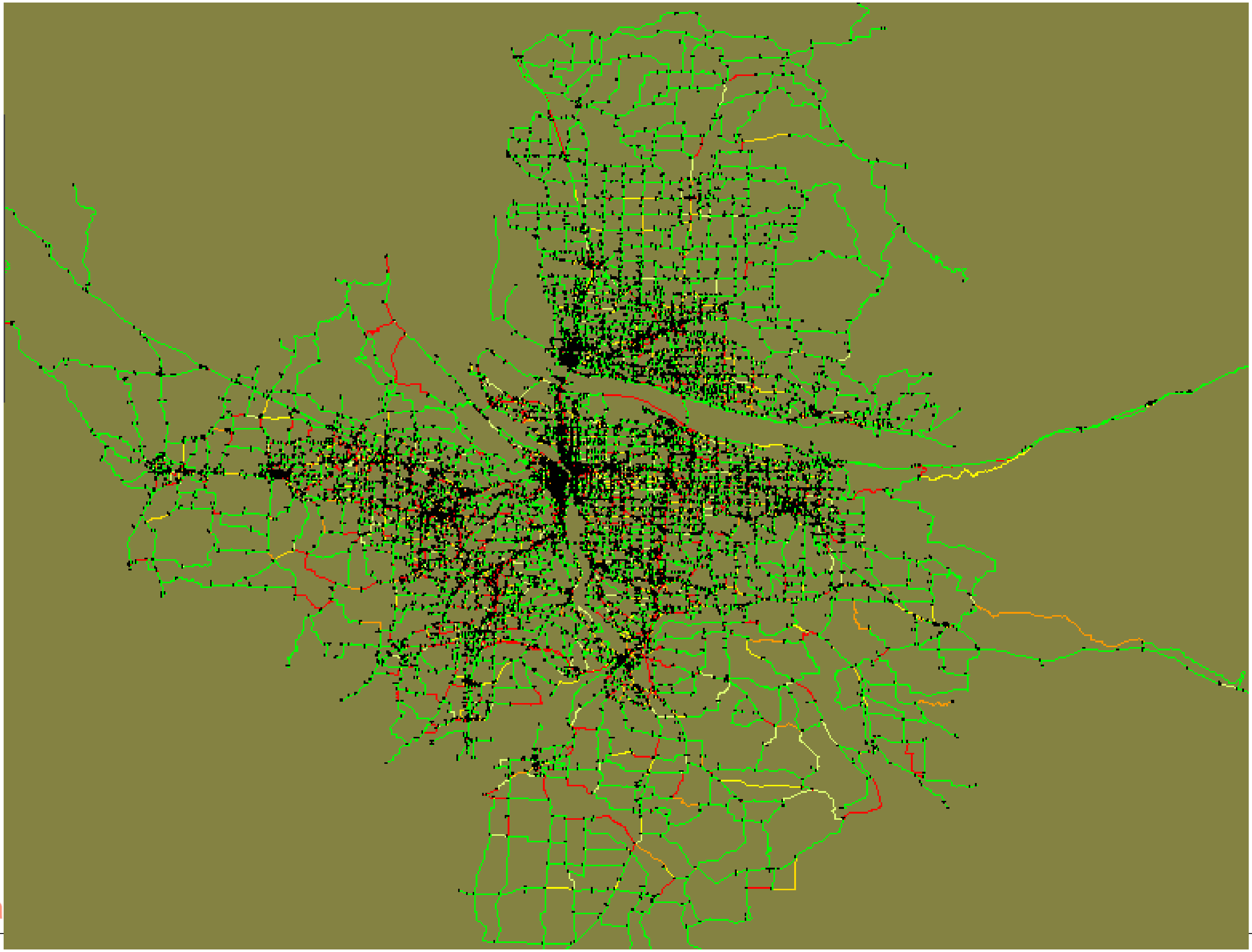
# PAG Regional DynusT Model



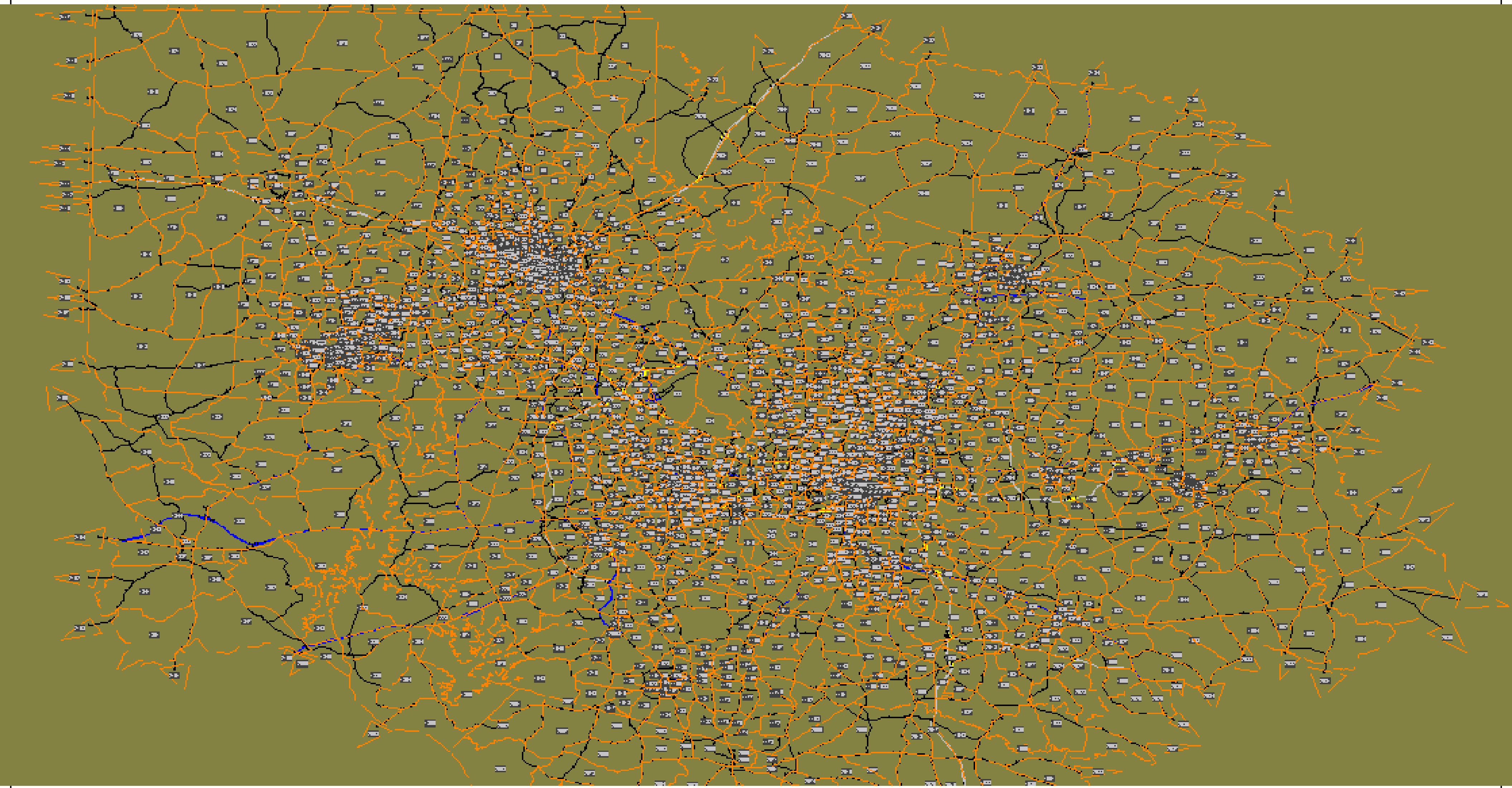
# Las Vegas Regional DynusT Model



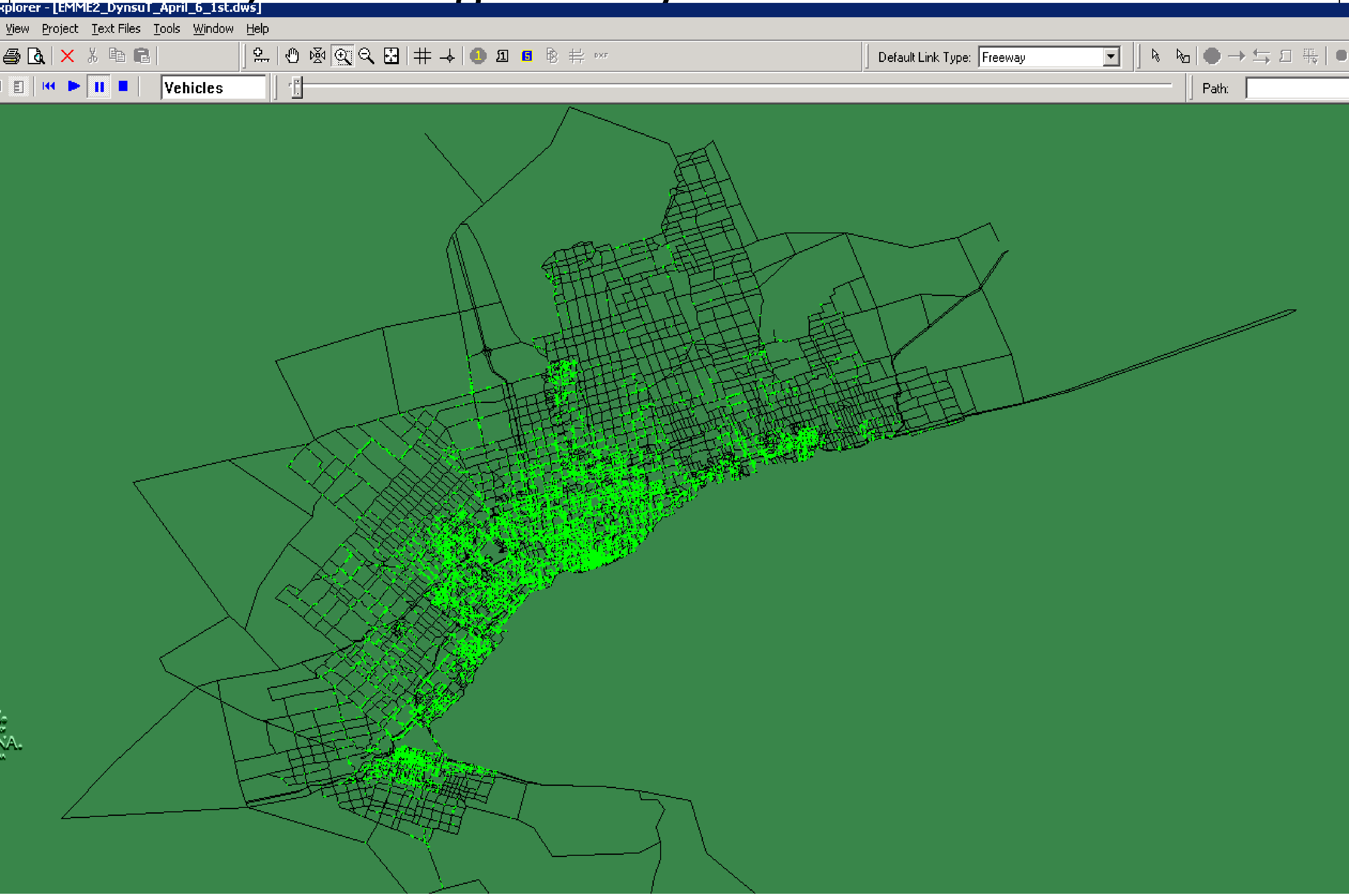
# Portland Regional DynusT Model



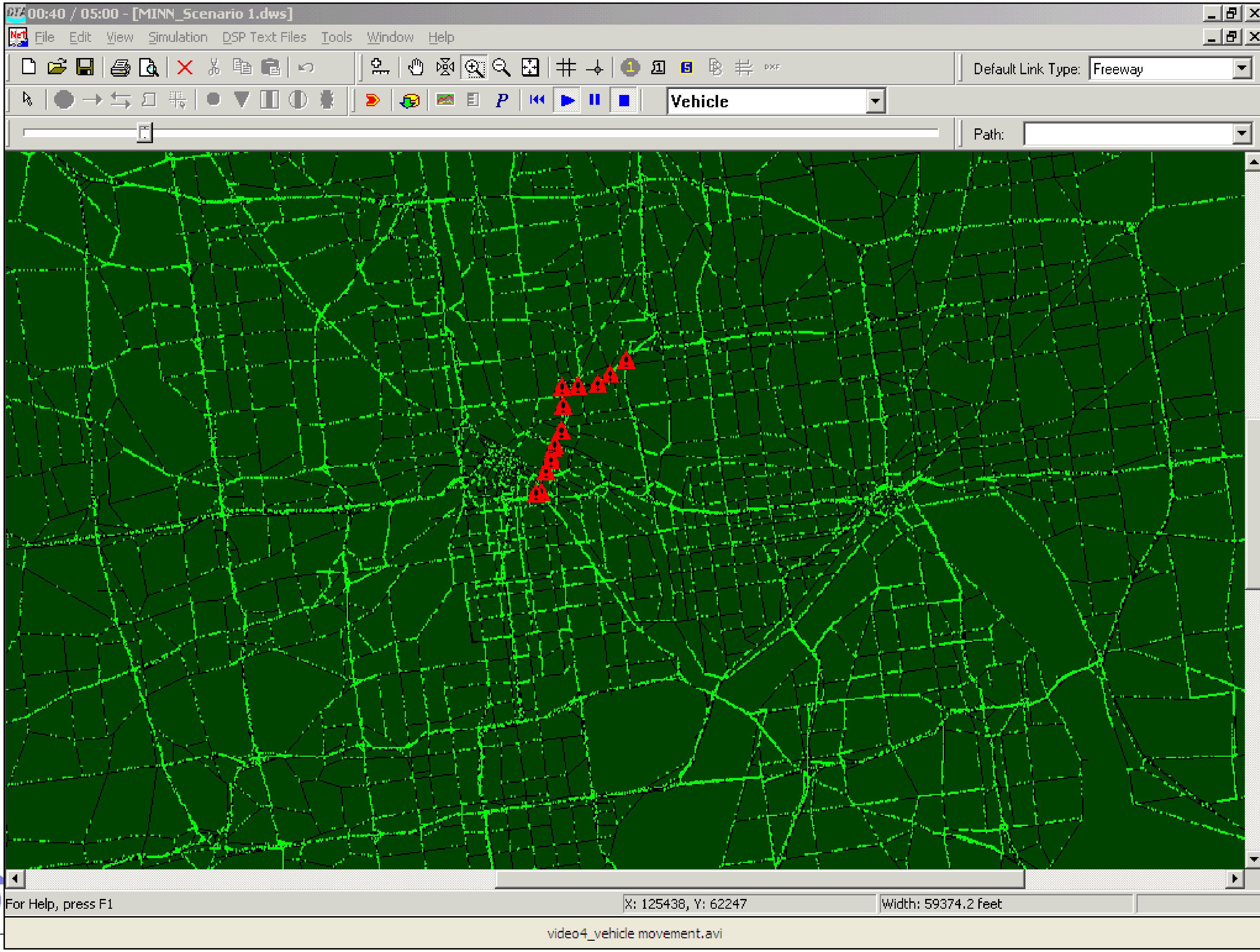
# Triangle, NC Regional DynusT Model

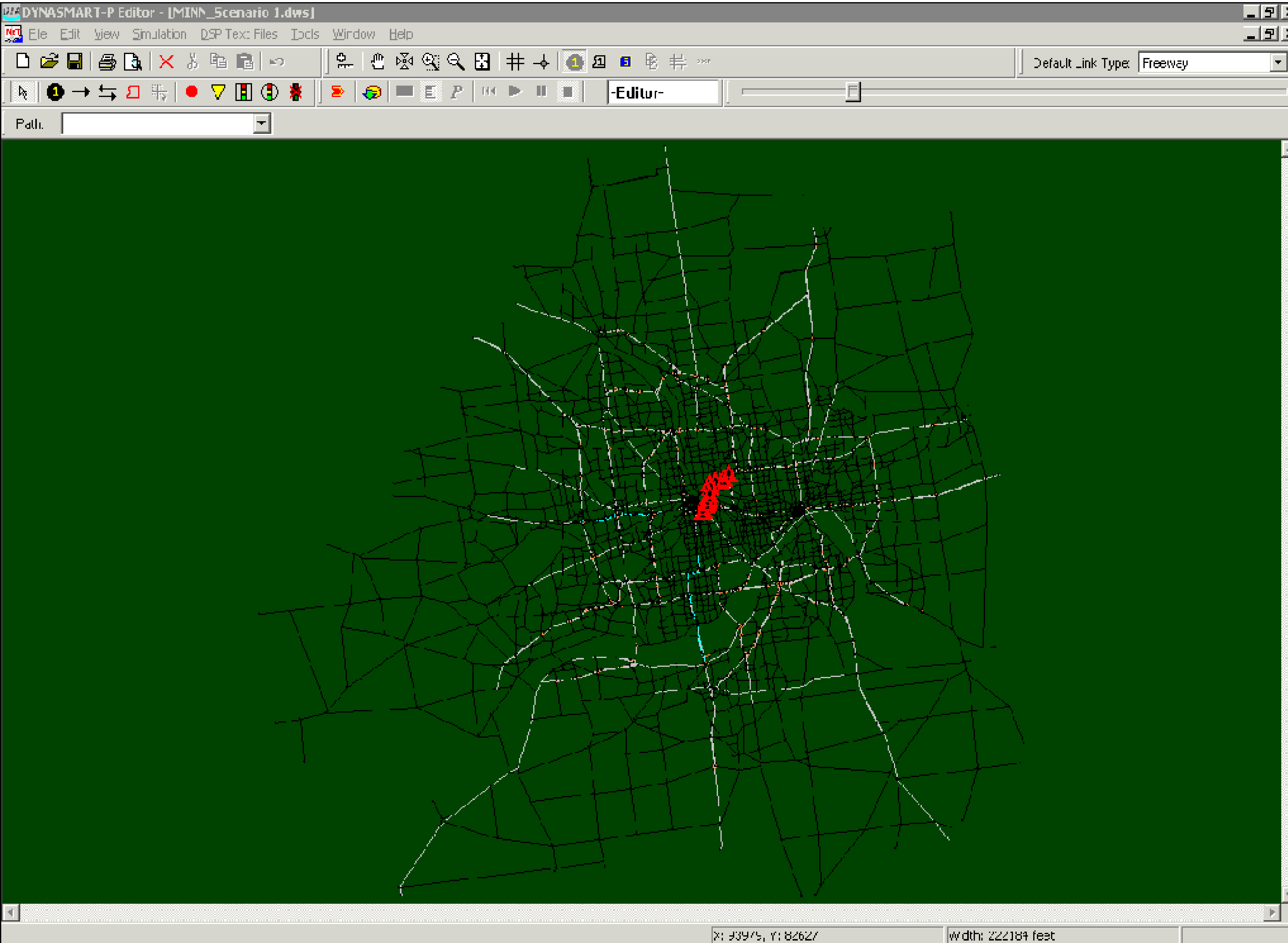


# Toronto, CAN Regional DynusT Model



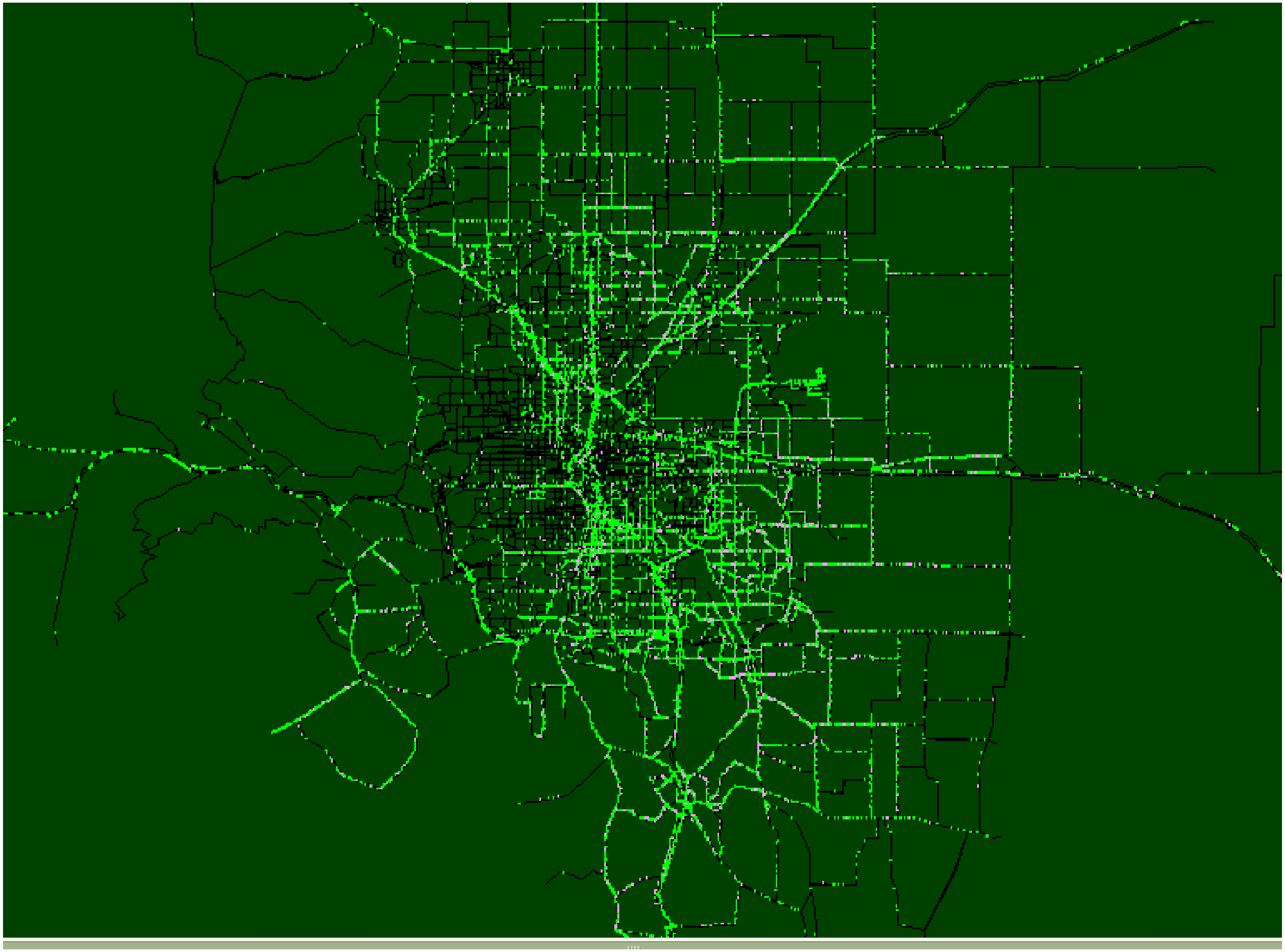
# Minneapolis Regional DynusT Model






video3_multiple scenario results.avi

# DRCOG (Denver)



# Modeling Demand/Supply Interactions in DynusT

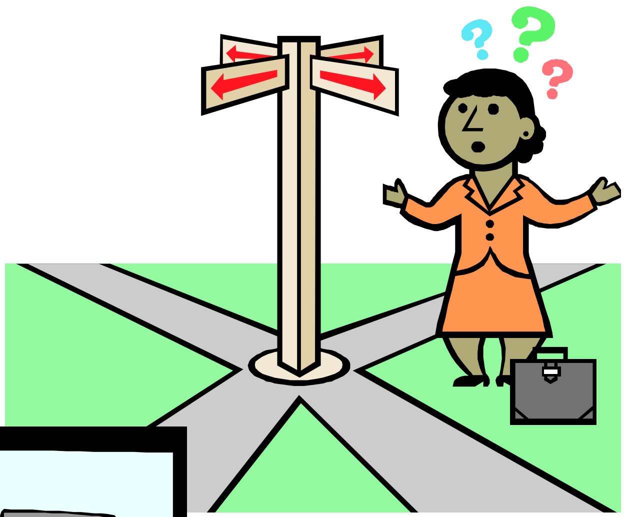
- Four fundamental elements for a transportation System
  - **Infrastructure**
    - Geometries

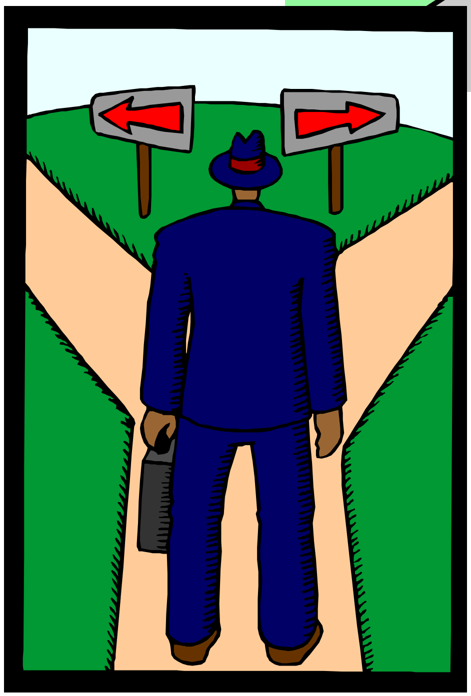
  - **Traffic flows**
    - Speed, density, flow, shockwaves, queue

  - **Control systems**
    - Signals, ramp meters
  - **Information**
    - Traveler information, message sings

# Rich Travel Behavior Representation

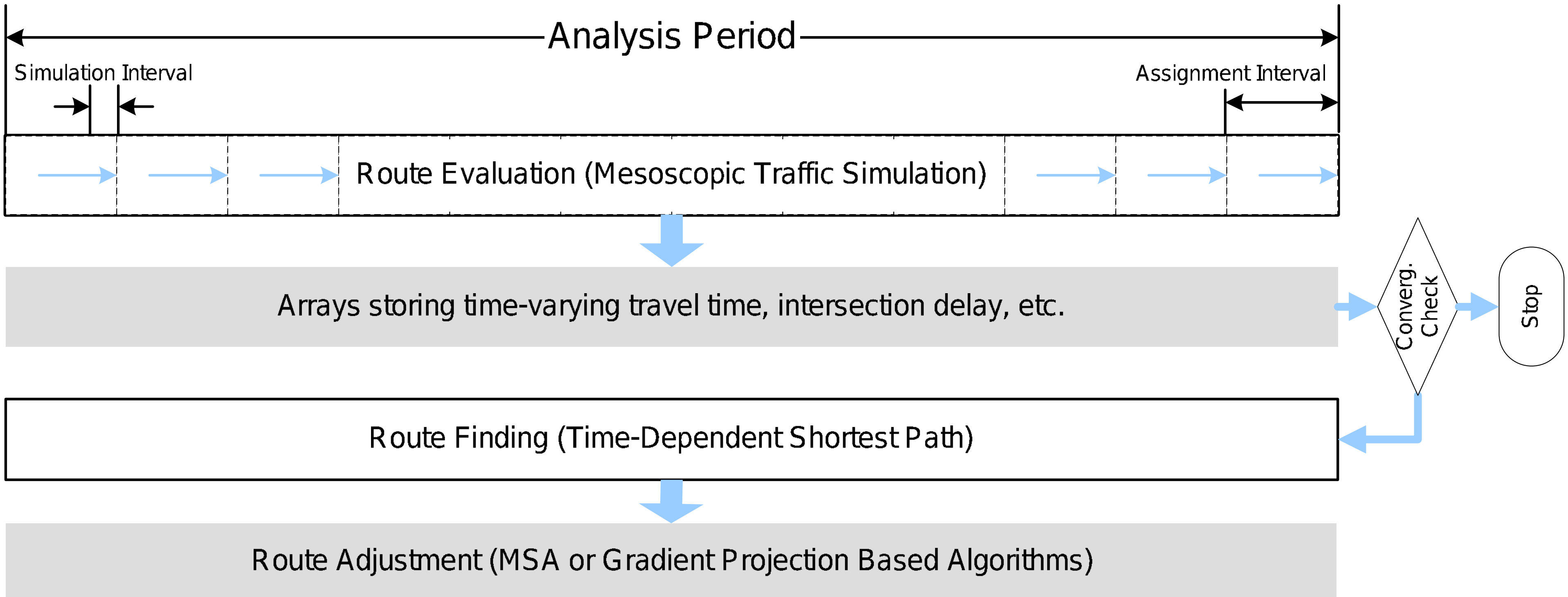
- Driving behavior
  - Car following
  - Lane changing
- Travel choice behavior
  - When to leave
  - Which route to take
  - Diversion or not
  - Reaction to
    - Work zone
    - Congestion
    - Information
    - Pricing
    - Evacuation scenarios



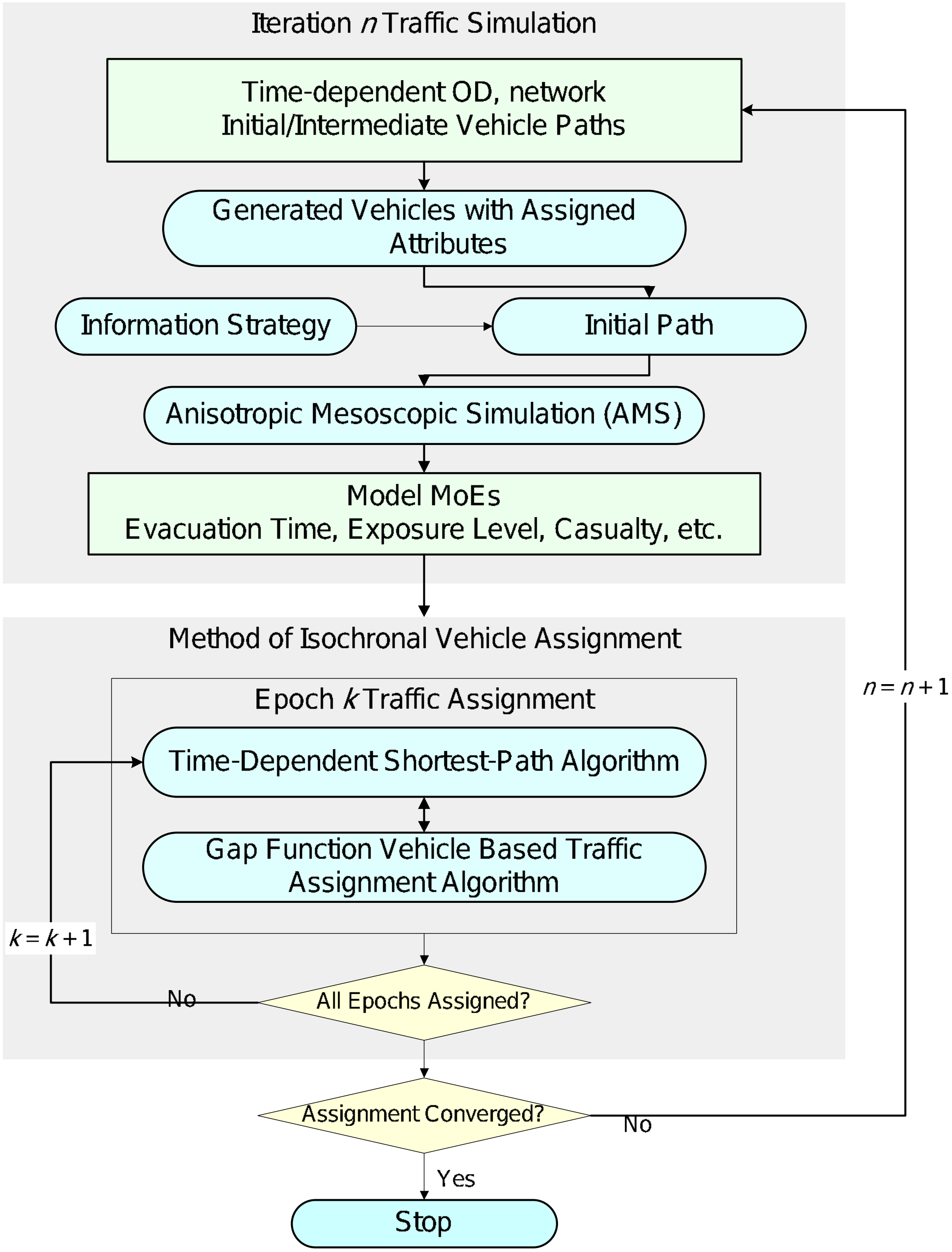


# DynusT Simulation-Based Dynamic Traffic Assignment

- Typical algorithmic structure



# DynusT Simulation Assignment Framework



# Anisotropic Mesoscopic Simulation

The University of Arizona Civil Engineering and Engineering Mechanics

# Mesoscopic Traffic Model

- General definition of “mesoscopic”
  - The time scale at which one can reasonably discuss the properties of a phenomenon without having to discuss the behavior of individual vehicles, and concepts of averages are useful.

DynusT

atlas

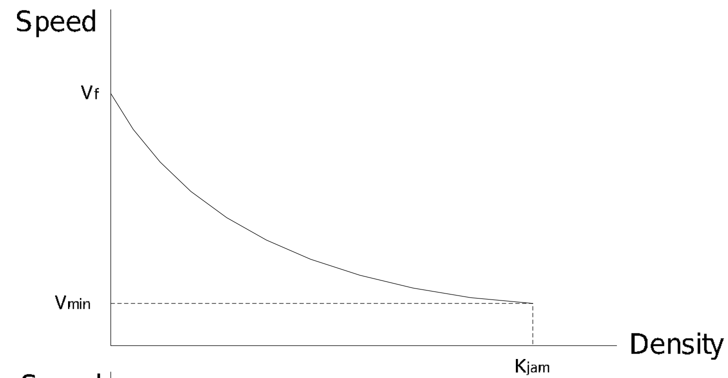
# Queue-Server Time-Based with Vehicle Positioning

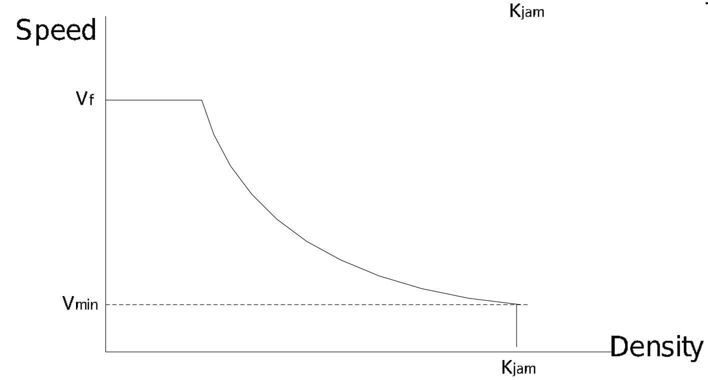
- At each time step *t*

$$x_n^t = x_n^{t-1} + v_i^t \cdot \Delta$$

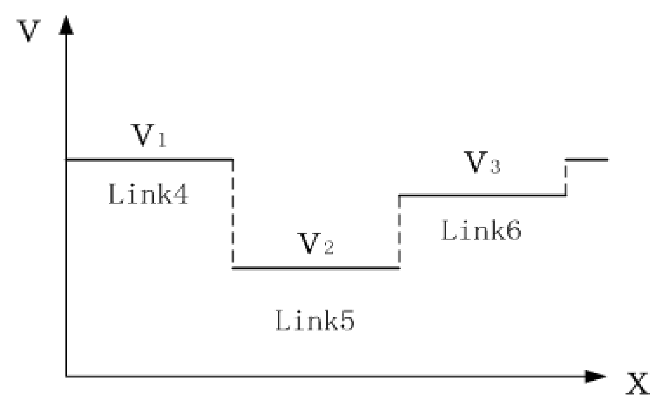
$$v_i^t = \wp\left(k_i^t\right)$$

  - Avg. link density
  - Minimal speed
  - Virtual queue at stop bar

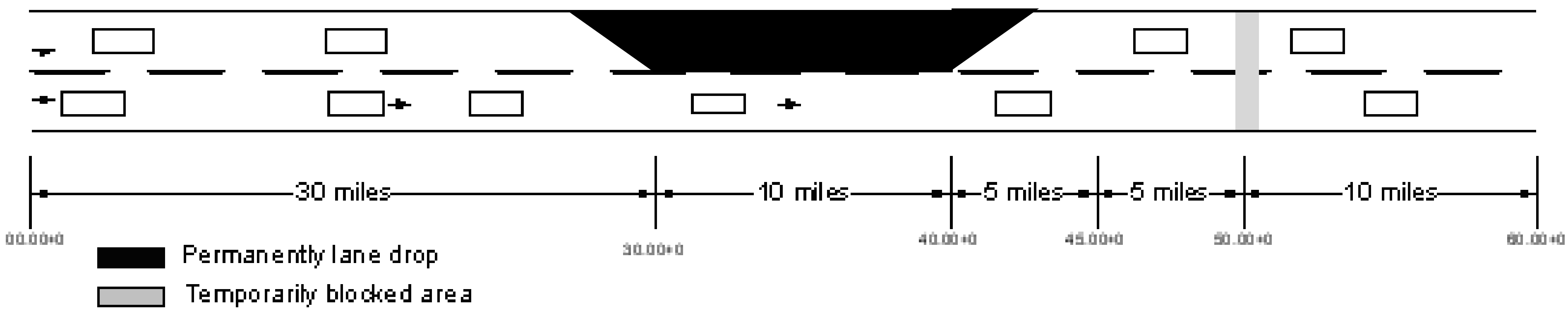


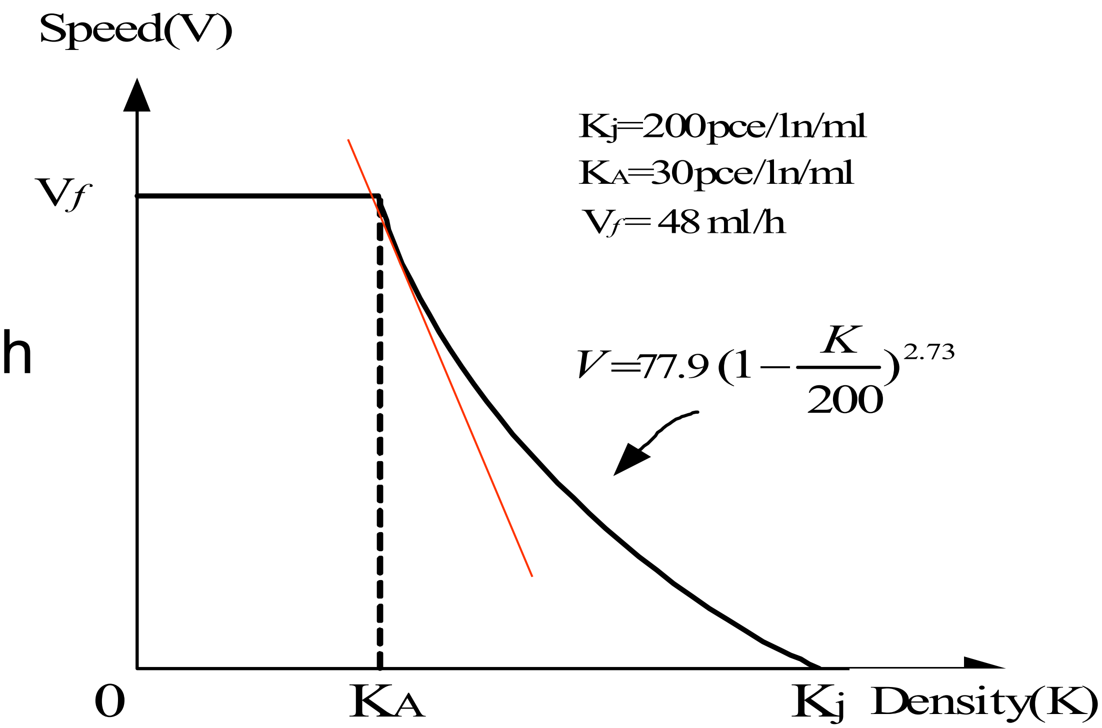

- The problem
  - Forward shockwaves
  - Sensitive to link length and minimal speed
  - Speed profile discontinuity



# An Example

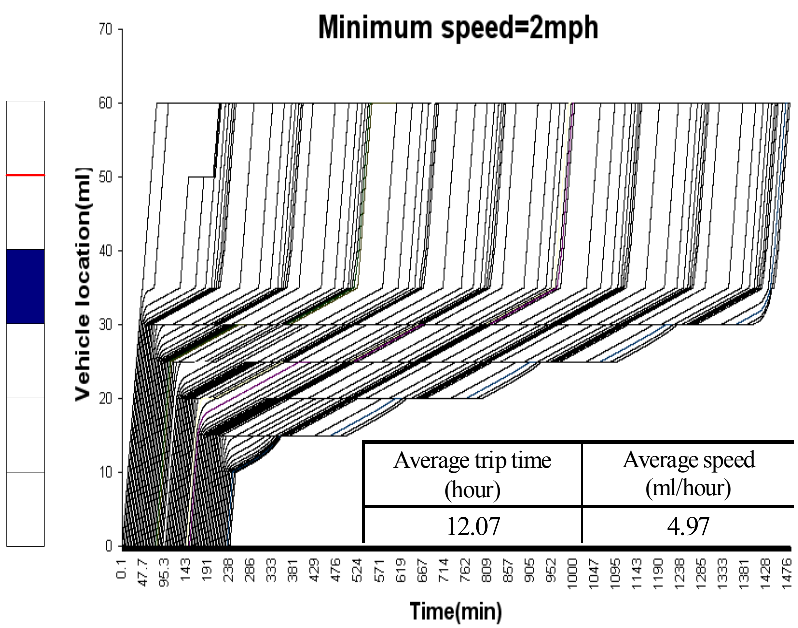



- 60 miles
- 100-min blockage
- 10-mile lane drop
- Constant loading 3,000 vph
- 4 hour loading

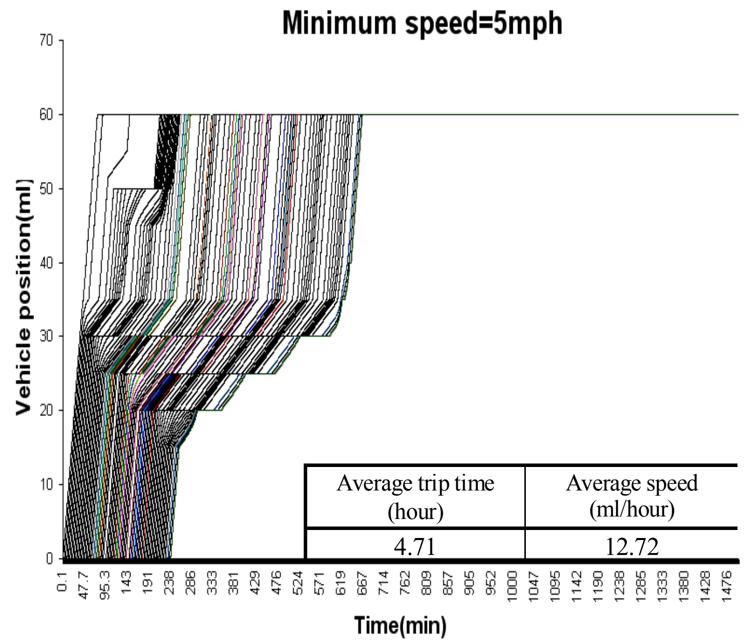



(a)

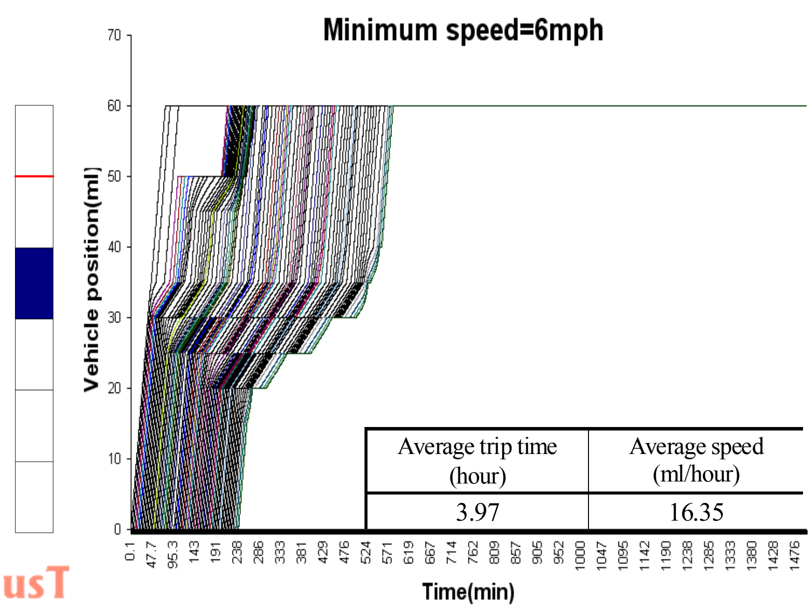
# Issues Queue-Server Based with Vehicle Positioning



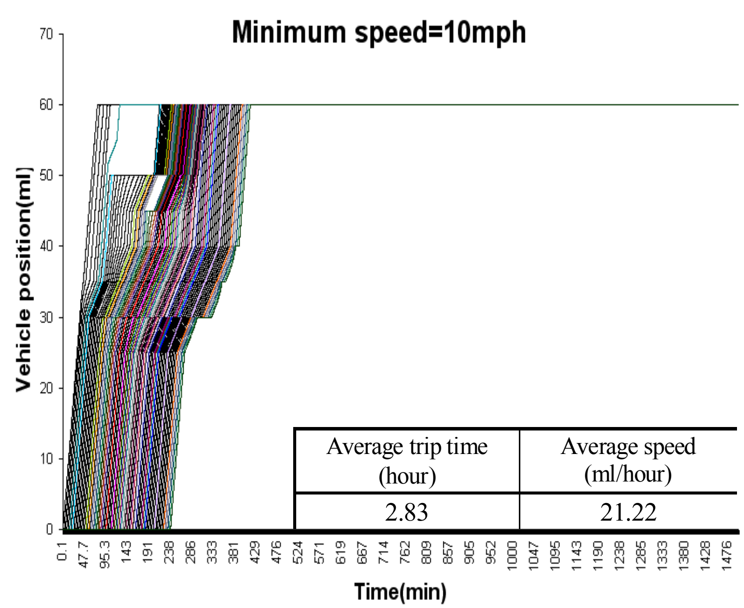

| Average trip time (hour) | Average speed (ml/hour) |
|---|---|
| 12.07 | 4.97 |




| Average trip time (hour) | Average speed (ml/hour) |
|---|---|
| 4.71 | 12.72 |

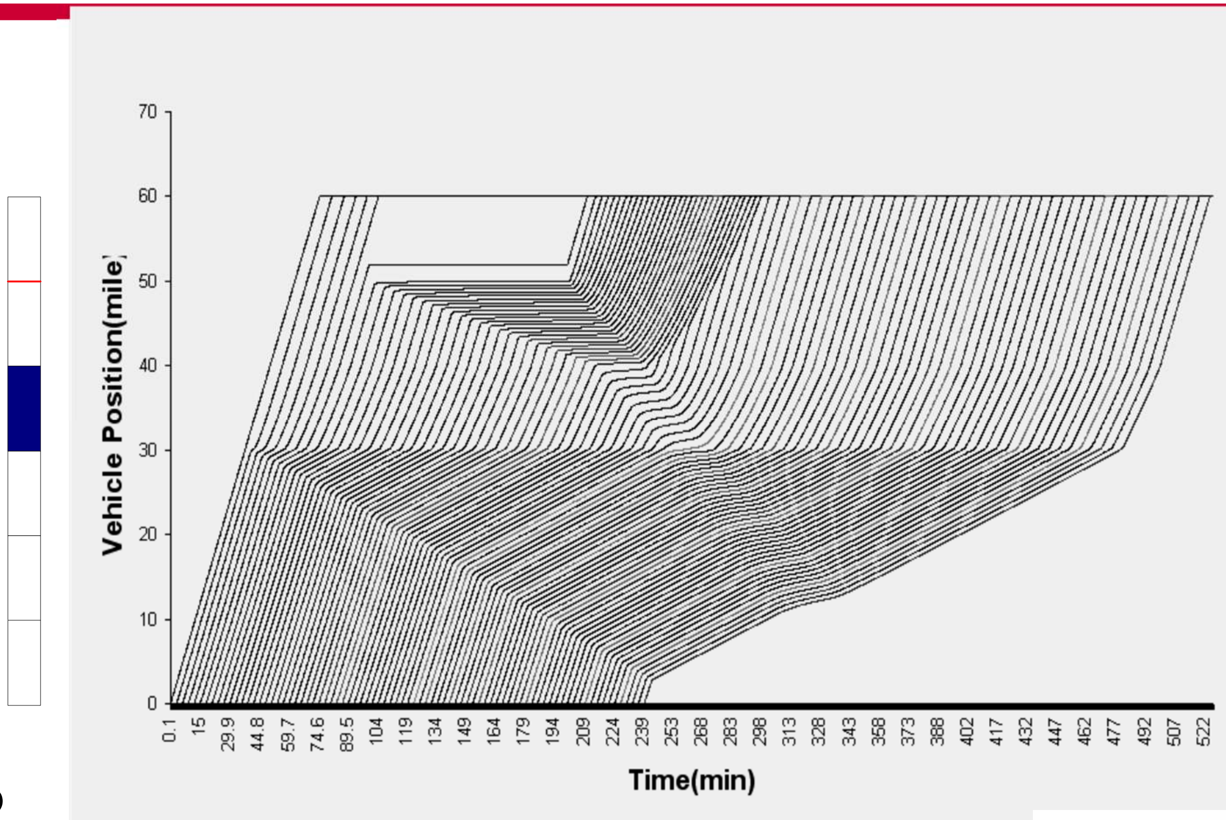


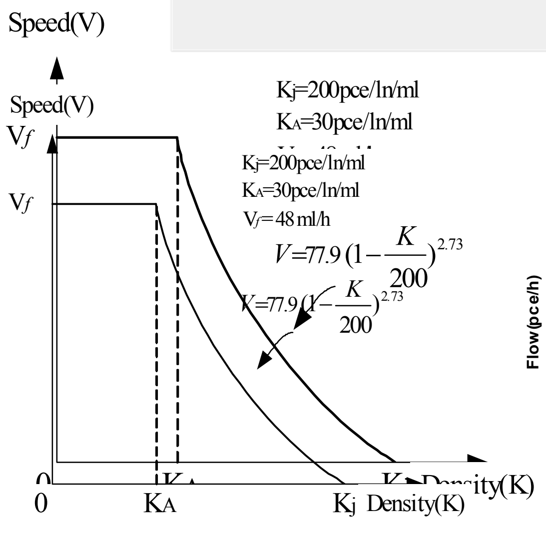

| Average trip time (hour) | Average speed (ml/hour) |
|---|---|
| 3.97 | 16.35 |



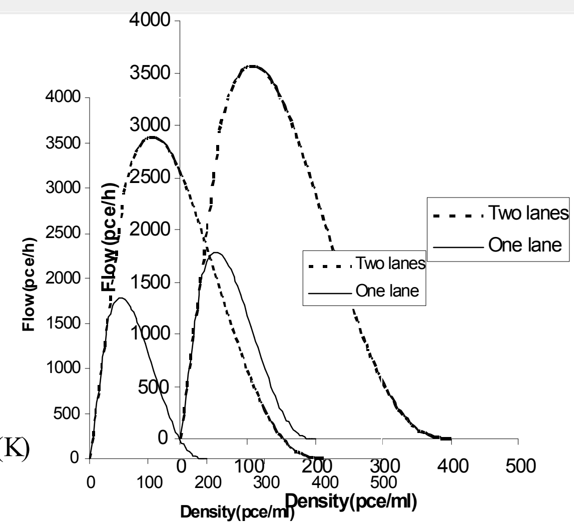

| Average trip time (hour) | Average speed (ml/hour) |
|---|---|
| 2.83 | 21.22 |

# This is More Reasonable

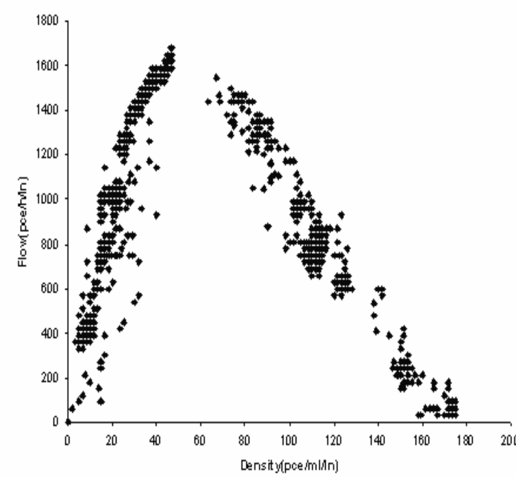



(a)




(b)




(c)

(a) (b) (c)

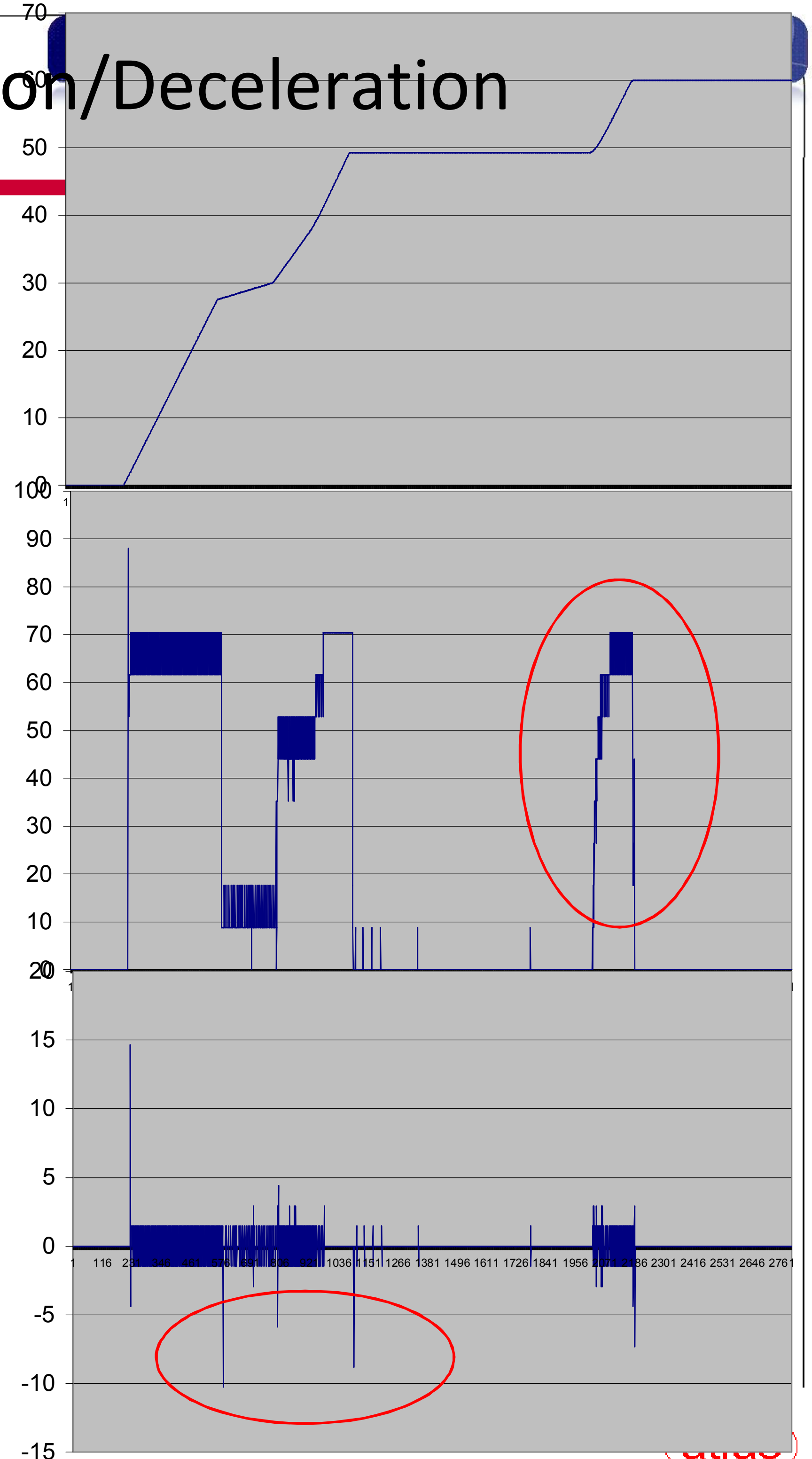
# Comparison with VISSIM

- Travel Time MoE

| Average travel time by VISSIM (min) | Average travel time by the AMTS model (min) | | Deviation (%) |
|---|---|---|---|
| **69.79** | SIR=200ft | 70.52 | **1.1** |
| | SIR=220ft | 69.91 | **0.1** |
| | SIR=240ft | 68.98 | **1.2** |
| | SIR=260ft | 68.55 | **1.8** |
| | SIR=280ft | 68.41 | **2.0** |
| | SIR=300ft | 67.94 | **2.7** |

- Computational Speedups – 800+ times

# Numerical Properties for Acceleration/Deceleration




- Reasonable speed and acceleration range for individual vehicles
- Max deceleration observed is -10 ft/s^2, in range with microscopic models (-8 to -12 ft/s^2)
- Gradual and responsive acceleration during discharge

DynusT

# AMS Basic Modeling Concepts

- Stimulus-response type
- **Net influence** for speed adjustment primarily comes from traffic in the front
- A vehicle's speed is affected only by the **average traffic condition** in the front (same lane or adjacent lanes)
- Can define different "average traffic condition" to model uninterrupted and interrupted flow conditions

# AMS Basic Modeling Concepts

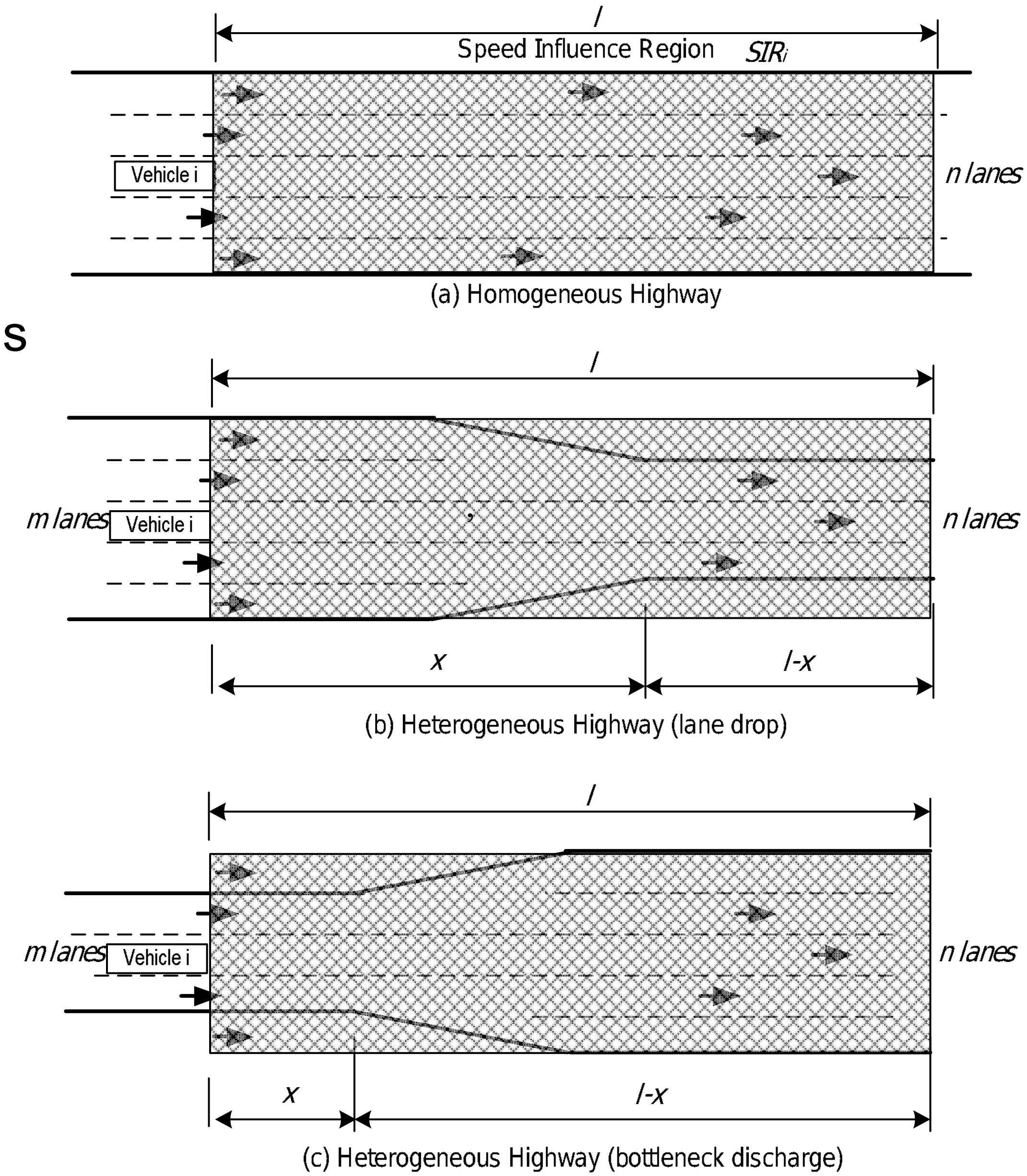
$$v_i^t = \wp\left(k_i^{t-1}\right)$$

$$k_i^{t-1} = \frac{N_i^{t-1}}{nl}$$

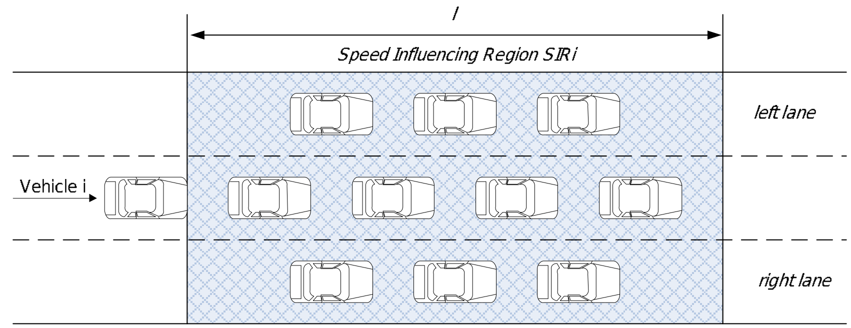
Homogeneous

$$k_i^{t-1} = \min\left[k_{queue}, \frac{N_i^{t-1}}{mx + n(l-x)}\right]$$

Non-Homogeneous

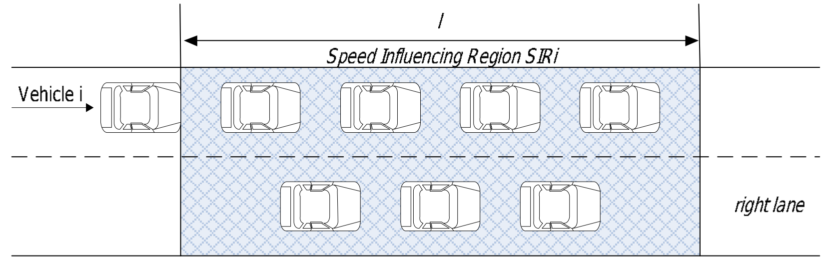


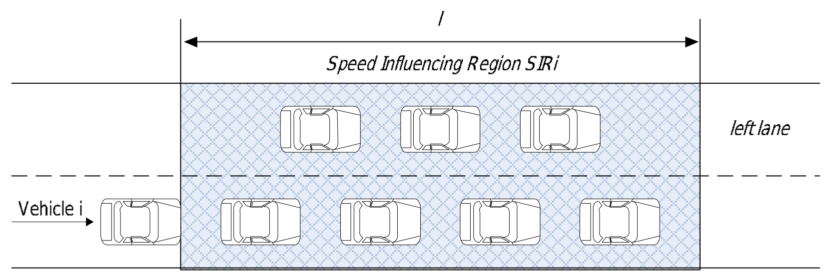
# A Bit More Complicated Formulation



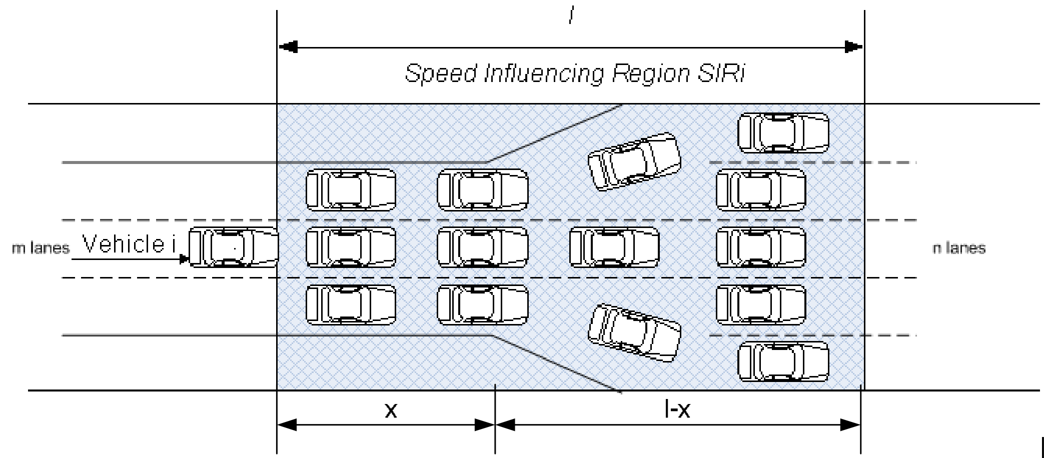

$$v_i^t = \wp\left(k_i^{t-1}\right), k_i^{t-1} = \min\left[k_{queue}, \frac{N_i^{t-1} + I_L N_{i(L)}^{t-1} + I_R N_{i(R)}^{t-1}}{(1 + I_L + I_R)l}\right]$$

Homogeneous



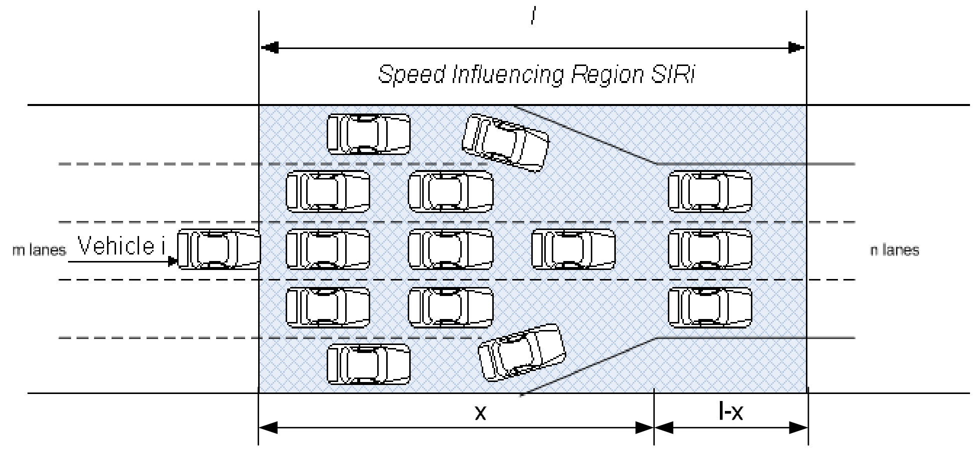



# A Bit More Complicated Formulation

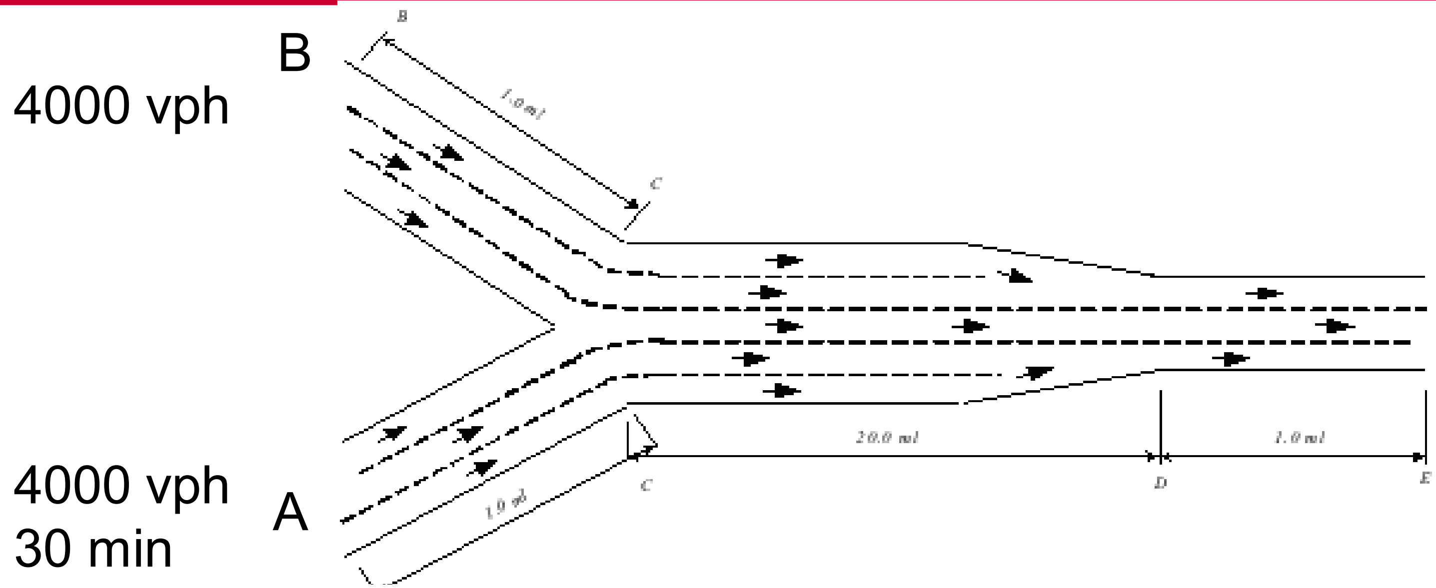


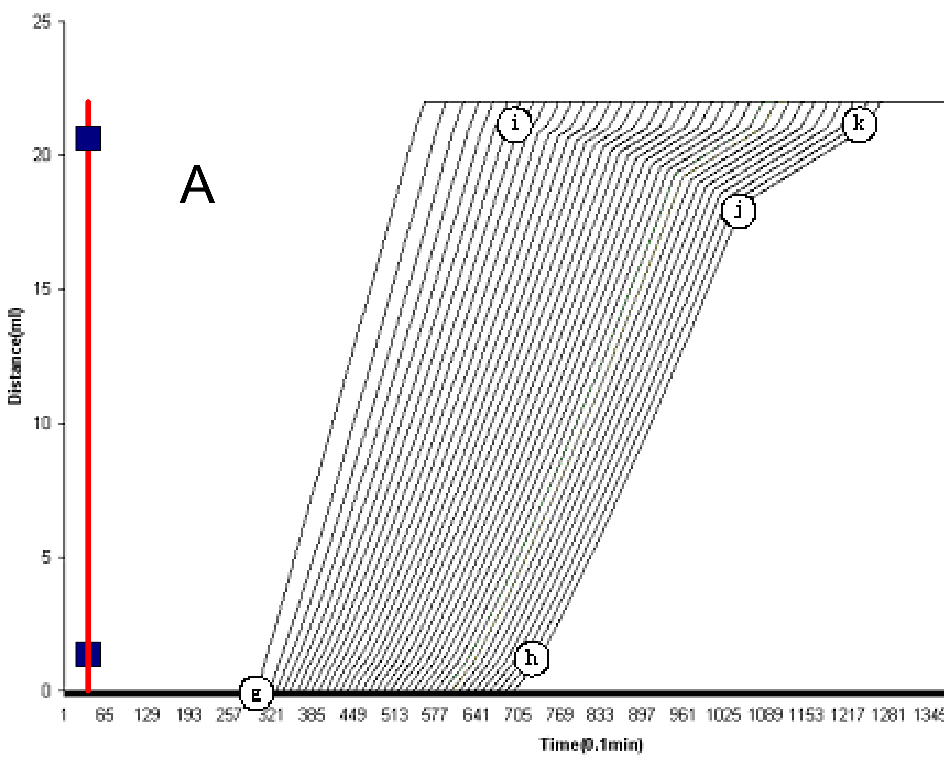

$$v_i^t = \wp\left(k_i^{t-1}\right)k_i^{t-1} = \min\left[k_{queue}, \frac{N_i^{t-1} + I_L N_{i(L)}^{t-1} + I_R N_{i(R)}^{t-1}}{m(1+I_L+I_R)x + n(1+I_L+I_R)(l-x)}\right]$$

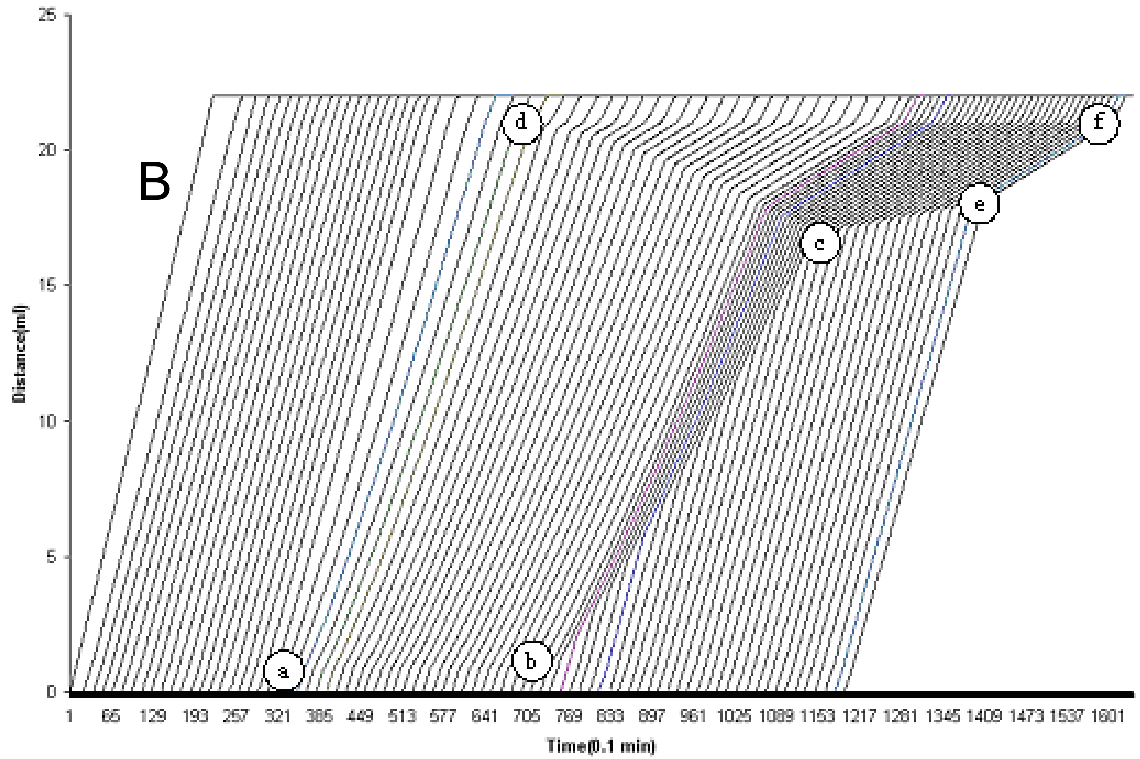
Non-homogeneous



# Highway Merge Example

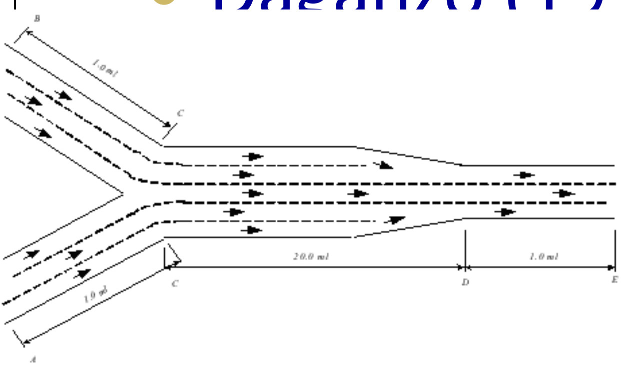


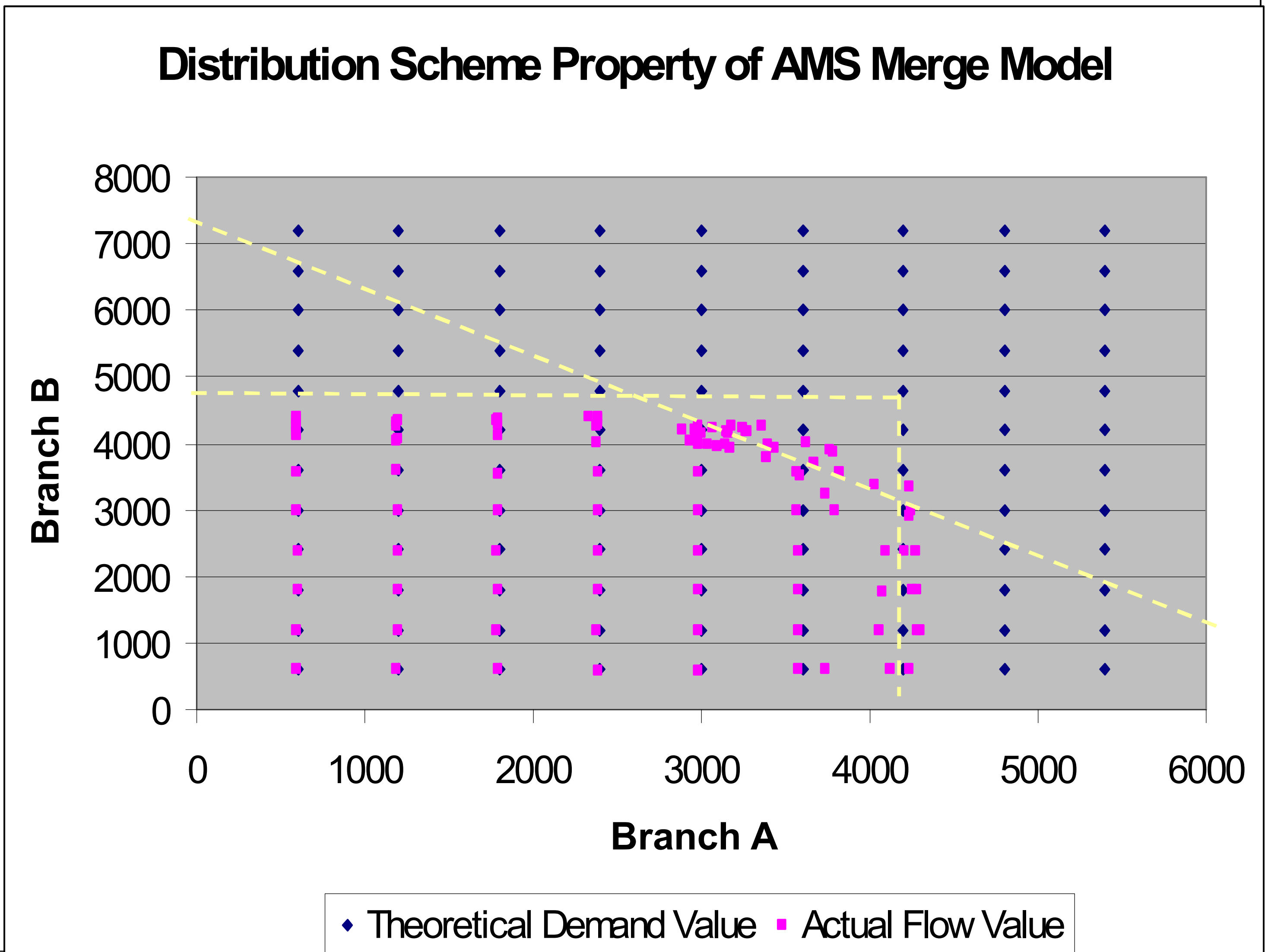



# Consistent Demand-Supply Relationship at Merging

- Daganzo (1995), Labacque (1996), Jin (2003), Ni (2004)





# Analytical Properties

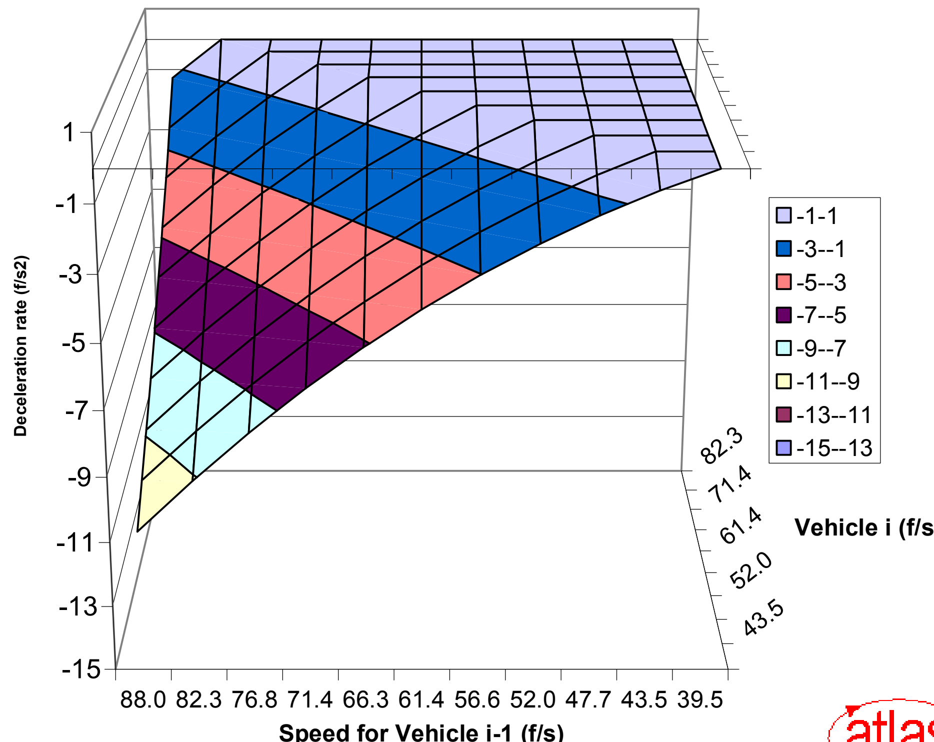
- Queue jumping avoidance condition

1. Speed-density function $\wp : k \to v$ is non-increasing, and

2. The length of the Speed Influencing Region (SIR) $l \geq -\min\left(\wp'\right) \Delta t \cdot k_{queue}$

- Deceleration bound

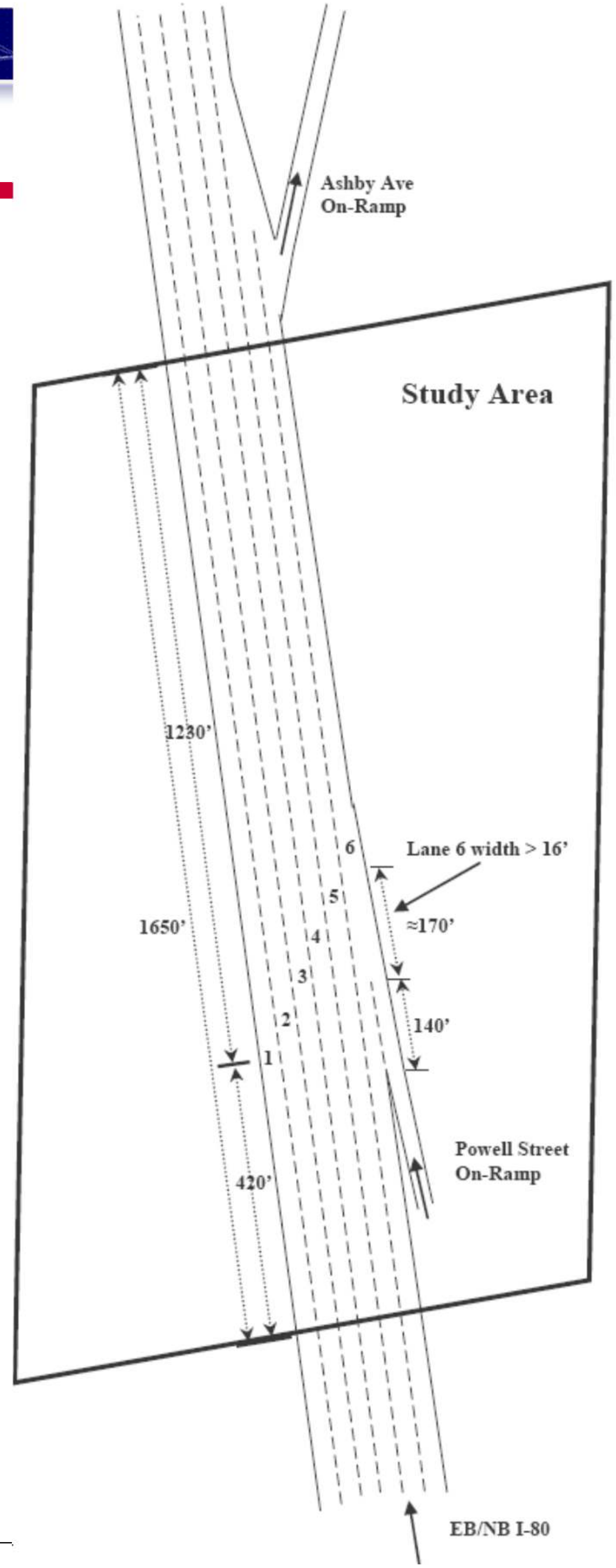
$$a_{i-1}^{t} \leq \wp'(k_{i-1}^{t-1}) \cdot \frac{\left[\wp(k_{i-1}^{t-1}) - \wp(k_{i}^{t-1})\right] \cdot k_{queue}}{l}$$



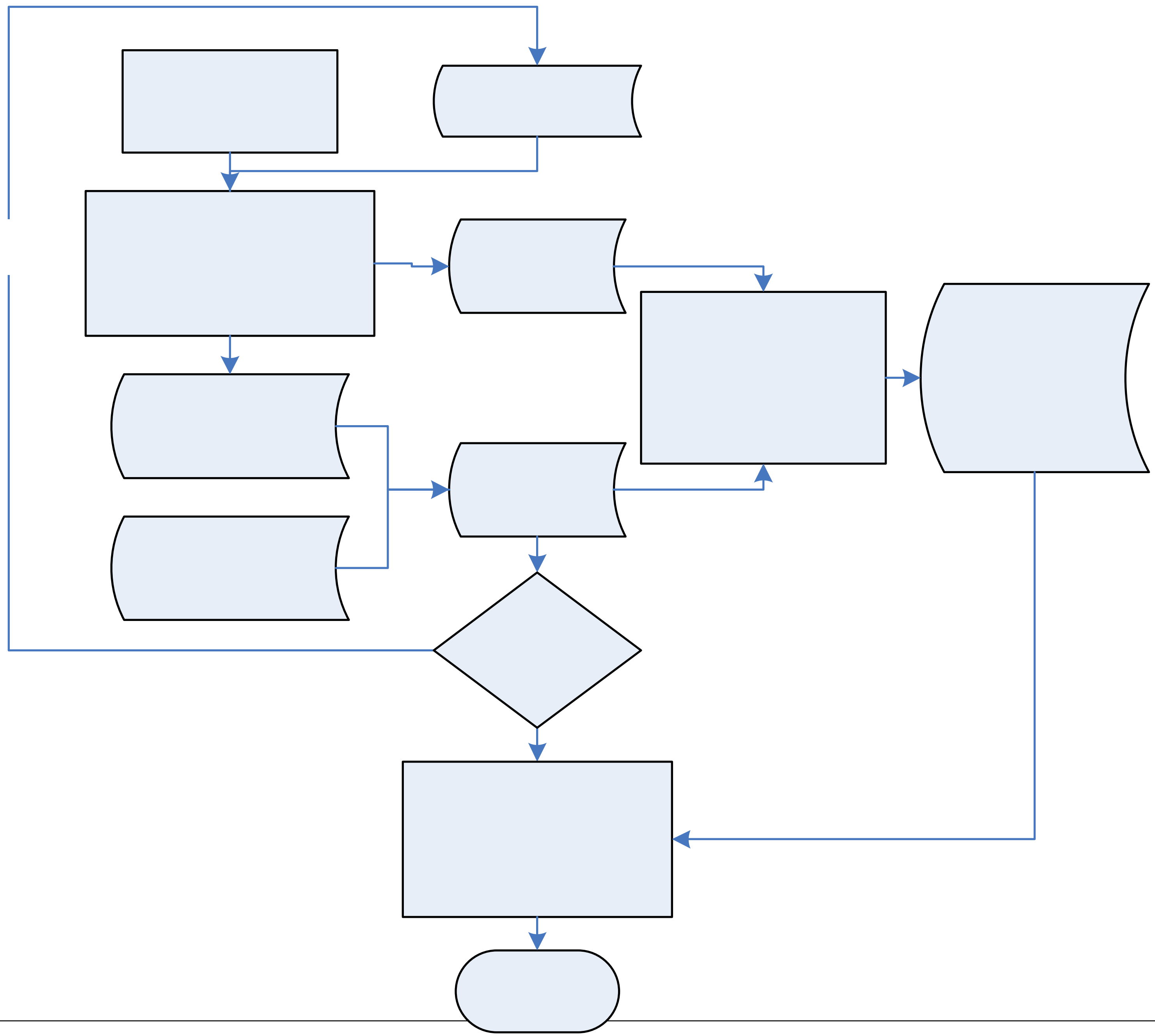
# Calibration with NGSIM Data

- NGSIM data
  - Detailed vehicle trajectories on I-8, CA
  - Datasets range from light to congested traffic conditions
  - Collected in 2003-2005
  - More than 160,000 data points

| Veh. ID | Frame No | Total No. of Frames | | Y Coordinate | | Lane | |
|---|---|---|---|---|---|---|---|
| 1 | 12 | 884 | .... | 48.213 | .... | 2 | .... |
| 1 | 13 | 884 | .... | 49.463 | .... | 2 | .... |
| 1 | 14 | 884 | .... | 50.712 | .... | 2 | .... |
| 1 | 15 | 884 | .... | 51.963 | .... | 2 | .... |
| . | ... | ... | .... | ......... | .... | . | .... |
| 1 | 892 | 884 | .... | 1631.965 | .... | 2 | .... |
| . | ... | ... | .... | ......... | .... | . | .... |
| 1 | 894 | 884 | .... | 1637.441 | .... | 2 | .... |
| 1 | 895 | 884 | .... | 1639.941 | .... | 2 | .... |
| 2 | 338 | 415 | .... | 66.048 | .... | 1 | .... |
| 2 | 344 | 415 | .... | 75.933 | .... | 1 | .... |
| 2 | 345 | 415 | .... | 77.173 | .... | 1 | .... |



# Calibration Methodology



# Calibration Results

$$\min_{L,V_f,\alpha,K_b} f = \frac{1}{2} X^T X$$

$$V = \begin{cases} V_f \; \grave{\lambda} \quad K \in [0, K_b] \\ V_f \left(1 - \dfrac{K}{k_{queue}}\right)^{\alpha} \; \grave{\lambda} \quad K \in [K_b, 180 veh/ml] \end{cases}$$

$$X = \begin{pmatrix} V_1^{calculated} - V_1^{observed} \\ \text{ə́} \\ V_i^{calculated} - V_i^{observed} \\ \text{ə́} \end{pmatrix}$$

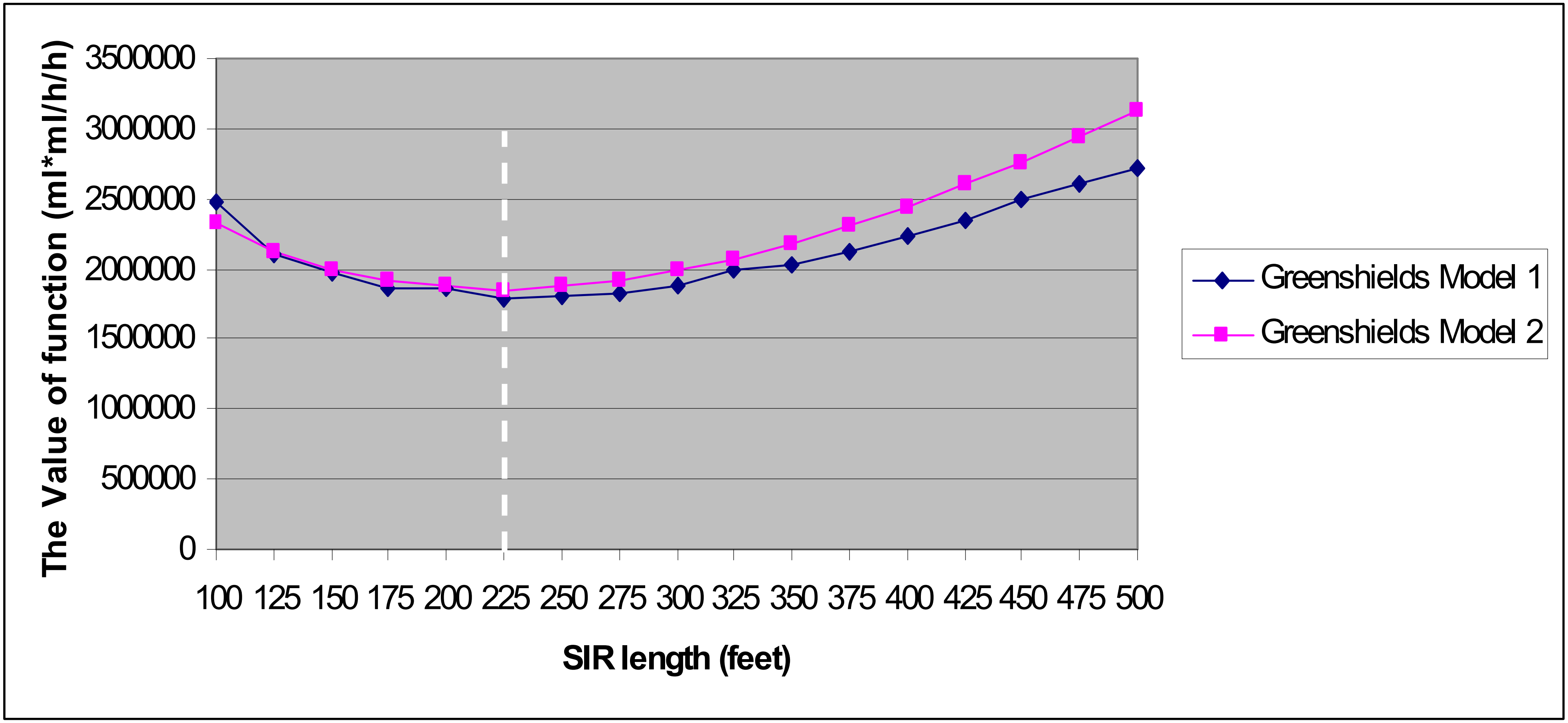
## Greenshield Type 1

$$v^{cal} = \begin{cases} v_f, & k \le k_b \\ v_f \left[ 1 - \left( \dfrac{k - k_b}{k_q - k_b} \right)^{\beta} \right]^{\alpha} & , k_b \le k \le k_q \end{cases}$$

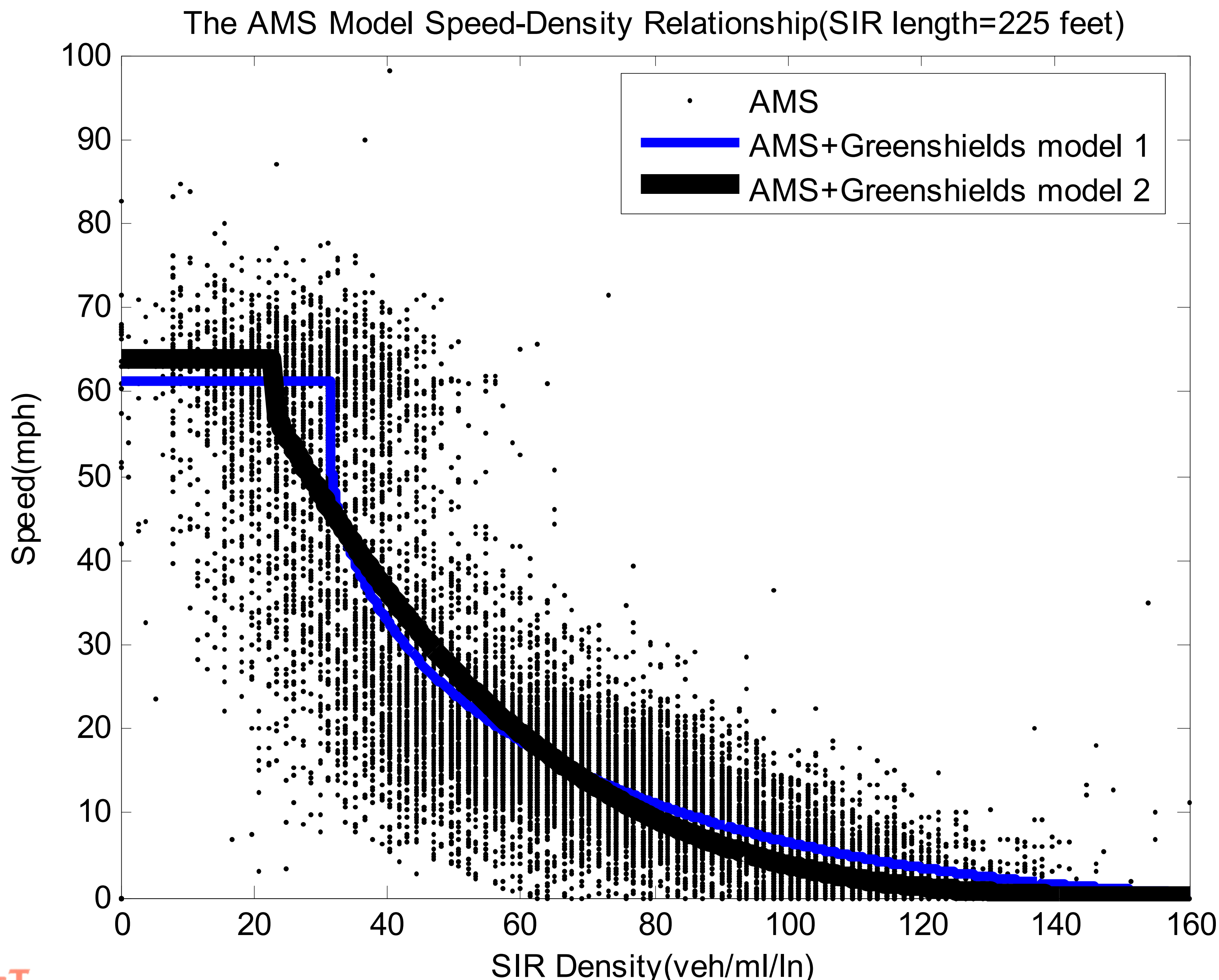
## Greenshield Type 2

$$v^{cal} = \begin{cases} v_f, & k \le k_b \\ v_f \left[ 1 - \left( \dfrac{k - k_b}{k_q - k_b} \right) \right]^{\alpha} & , k_b \le k \le k_q \end{cases}$$

# Calibration Results



# Calibration Results



# AMS for Interrupted Flows

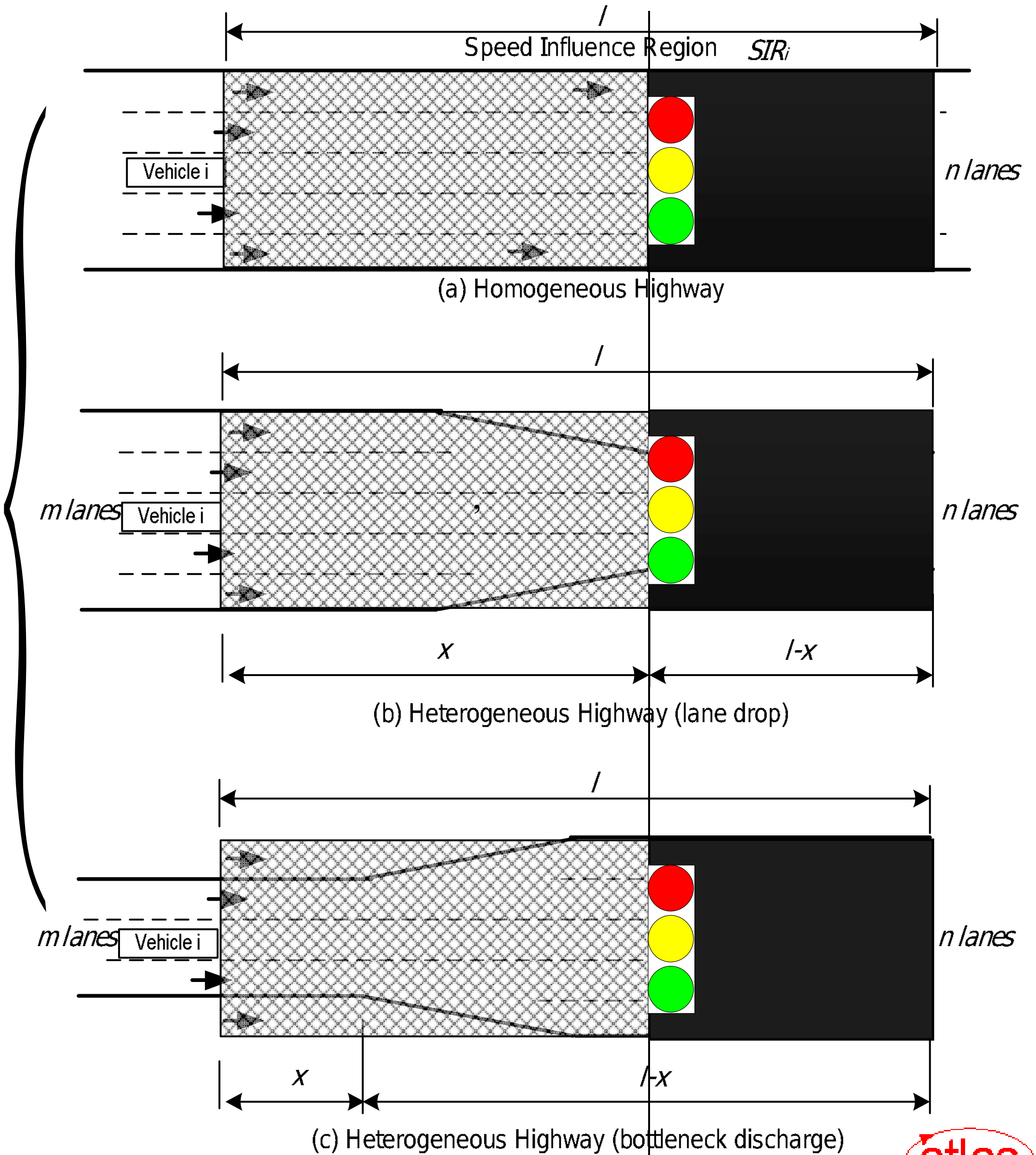
- Similar model structure

$$v_i^t = \wp\left(k_i^{t-1}\right)$$

$$k_i^{t-1} = \min\left[k_{tg}, \frac{N_i^{t-1}}{mx + 0(l-x)}\right]$$

$$k_i^{t-1} = \min\left[k_{queue}, \frac{\eta_i^{t-1} + \left(\frac{m\cdot(l-x)\cdot k_{queue}}{5280}\right)}{mx + 0(l-x)}\right]$$

$$k_{tg} = \wp^{-1} :\rightarrow \wp = v_{tg}$$



# Gap-Function Vehicle Assignment

# Introduction

- Gap Function Vehicle-Based (GFV) Solution Algorithm
  - Gradient-like search direction
  - Variable step size
  - Satisfactory solution quality and properties
    - Rate of convergence
    - Consistency
    - Stability

# Background

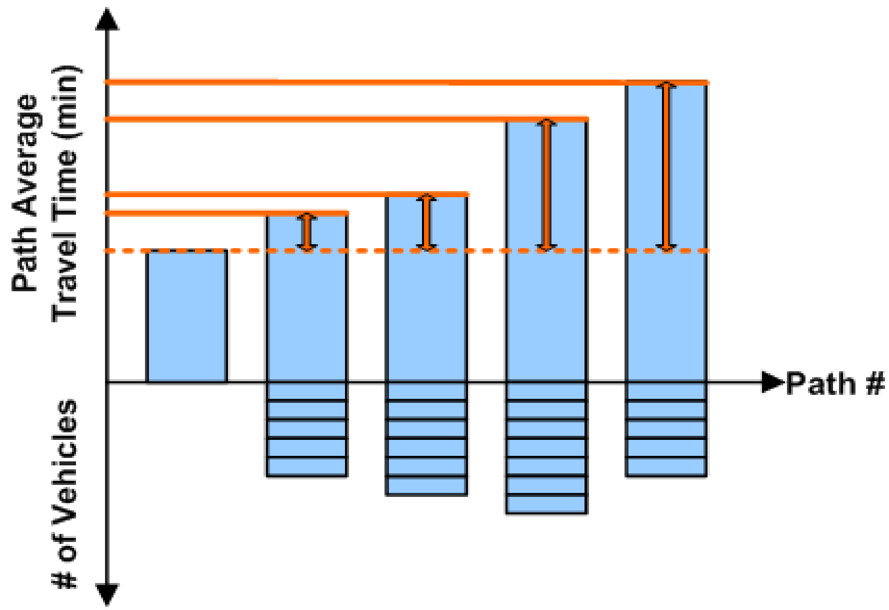
- Gradient-like projection approach
  - Route swapping heuristics
    - Search direction is linear proportionality
    - GFV uses similar concept, but different in determining proportionality
- Step Size Approach
  - "Swapping rate"
    - Pre-determined step size
    - GFV uses variable step size based on experience of latest path assignment

# High-level Design of GFV

- Assignment Interval
  - AKA: Departure Interval
- Vehicle-based assignment
  - Feasible path set is not preserved through iterations
  - Vehicles retain latest path assignment
    - Collection of vehicles' latest paths creates used (feasible) path set

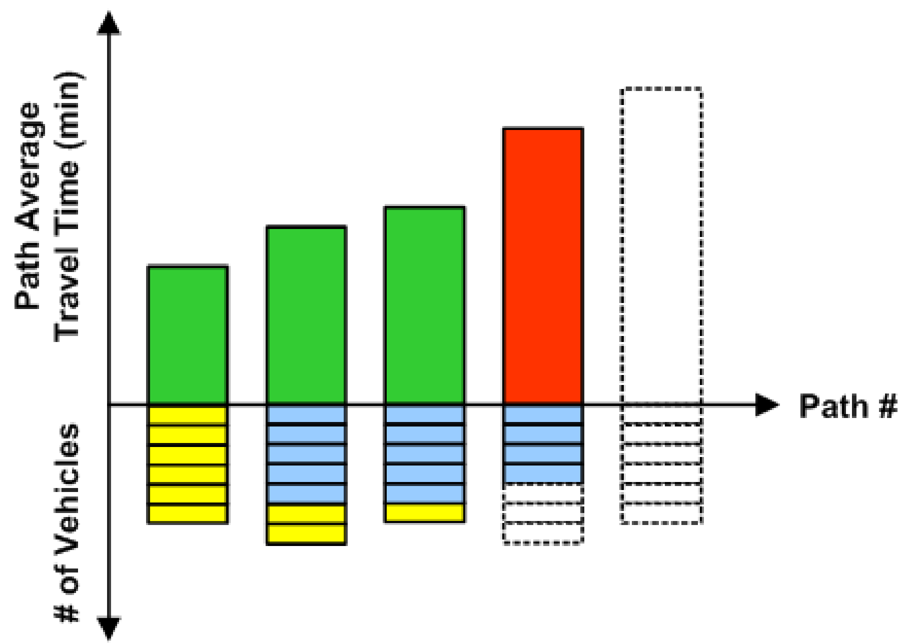
# GFV: High-Level Design

- From specific origin, destination, departure time
  - Determine path set from select vehicles
    - Sort paths by travel time
    - Sort vehicles within each path by travel time



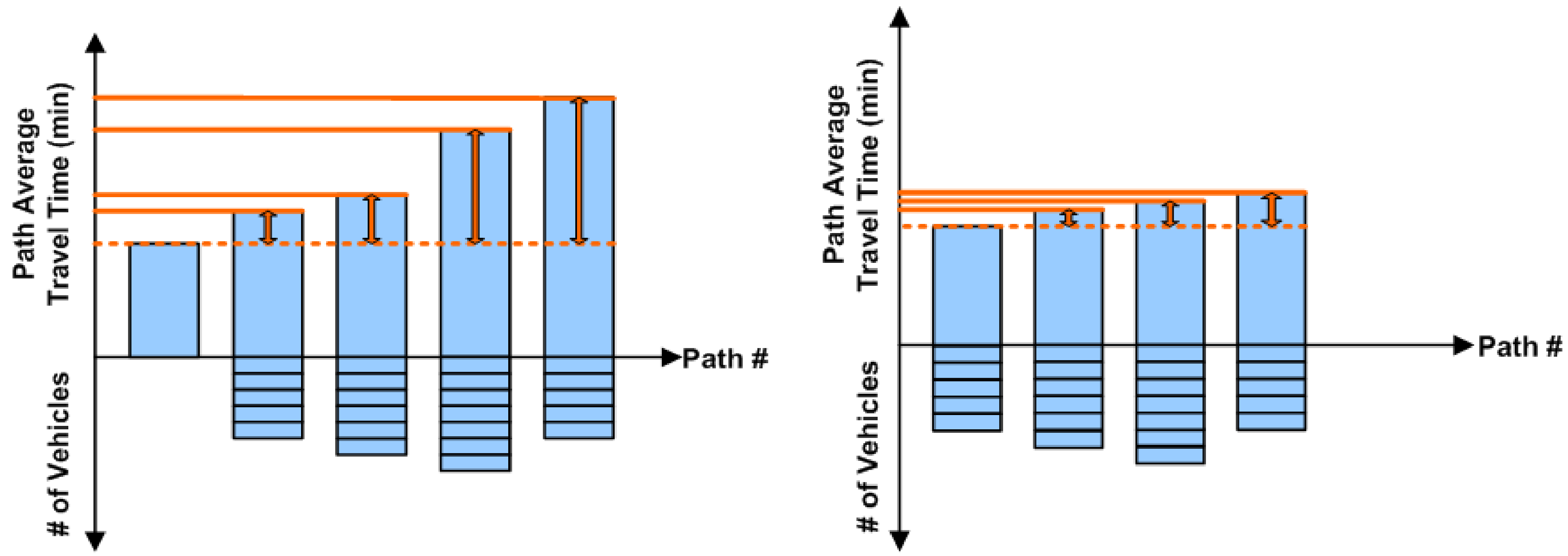
# GFV: High-Level Design

- Step size and search direction
  - Determine underperforming paths
    - Step size determines break point between “good” and “bad” paths
  - Swap vehicles from “bad” to “good” paths
    - Logit-based proportionality



# GFV: High-Level Design

- Path assignment convergence
  - Iteratively update path assignment based on previous iteration's experienced travel time
  - Converges when all experienced travel time of paths in path set are minimal and equal (DUE)



# GFV Formulation

- The relative gap function (RG) value s determined for each path *k*

$$[illegible]$$

- RG value is determined for entire solution

$$[illegible]$$

- With stop criteria:

$$[illegible]$$

# GFV Formulation

- Step Size choice

$$?_{?,?}^{?,?} = \min\{?^0, ?'\}$$

- User-specified step size:

$$?'$$

- RG-based step size

$$?' = \left\{ \frac{\sum_{?} ???_{?}}{|??^{?}(?,?,?)|} \right\}$$

# GFV Formulation

- Used path subsets:
  - Increasing flow [illegible]$^{+}$
  - Decreasing flow [illegible]$^{-}$
- Total path set

- Paths are sorted by increasing travel time

[illegible]$^{+} \cup$ [illegible]$^{-} =$ [illegible]

[illegible] $= \frac{\sum \text{[illegible]}}{|\text{[illegible]}|}, \forall$ [illegible] $\in$ [illegible]

[illegible]$_{1} \leq$ [illegible]$_{2} \leq \cdots \leq$ [illegible]

# GFV Formulation

- Decreasing-flow path set is determined by

$$P^{k}(i,j,t)^{-} = \left\{ p = \hat{p}, \ldots, |P^{k}(i,j,t)| \,\middle|\, \sum_{p=1}^{\hat{p}-1} r_{i,j,p}^{k,t} < \left(1 - \gamma_{i,j}^{k,t}\right) \cdot r_{i,j}^{k} \le \sum_{p=1}^{\hat{p}} r_{i,j,p}^{k,t} \right\}$$

  - With $\hat{p}$ as path cut-off point

# GFV Formulation

- Vehicle subsets
  - Increasing-flow $\quad ?^{?}(?,?,?,?)^{+}$
  - Decreasing-flow $\quad ?^{?}(?,?,?,?)^{-}$
- Total vehicle set
- Decreasing-flow vehicle set determined by

$$?^{?}(?,?,?,?)^{+} \cup ?^{?}(?,?,?,?)^{-} = ?^{?}(?,?,?)$$

  - With ? as vehicle cut-off point

$$?^{?}(?,?,?,?)^{-} = \left\{ ? = ?,\ldots,\left|?^{?}(?,?,?)\right| \;\middle|\; ? = \sum_{?=1}^{\left|?^{?}(?,?,?)^{-}\right|-1} ?^{?,?}_{?,?} + \left( ?^{?,?}_{?,?} \cdot ?^{?}_{?,?} - \sum_{?=1}^{\left|?^{?}(?,?,?)^{-}\right|-1} ?^{?,?}_{?,?} \right) \right\}$$

# GFV Formulation

- Search Direction

[illegible]

- Increasing-flow path set increased by

[illegible]

# GFV Formulation

- Decreasing-flow path set for [illegible] $\in$ [illegible] $\setminus$ [illegible]

$$-\,\square_{\square,\square}^{\square,\square}\cdot\square_{\square,\square}^{\square}\cdot\frac{\left|\square^{\square}(\square,\square,\square,\square)\right|}{\square_{\square,\square}^{\square,\square}\cdot\square_{\square,\square}^{\square}}$$

- Decreasing-flow path set for [illegible] $=$ [illegible]

$$-\left\{\square_{\square,\square}^{\square,\square}\cdot\square_{\square,\square}^{\square}-\left(\sum_{\square=1}^{\left|\square^{\square}(\square,\square,\square)\right|-1}\left|\square^{\square}(\square,\square,\square,\square)\right|\right)\right\}.$$

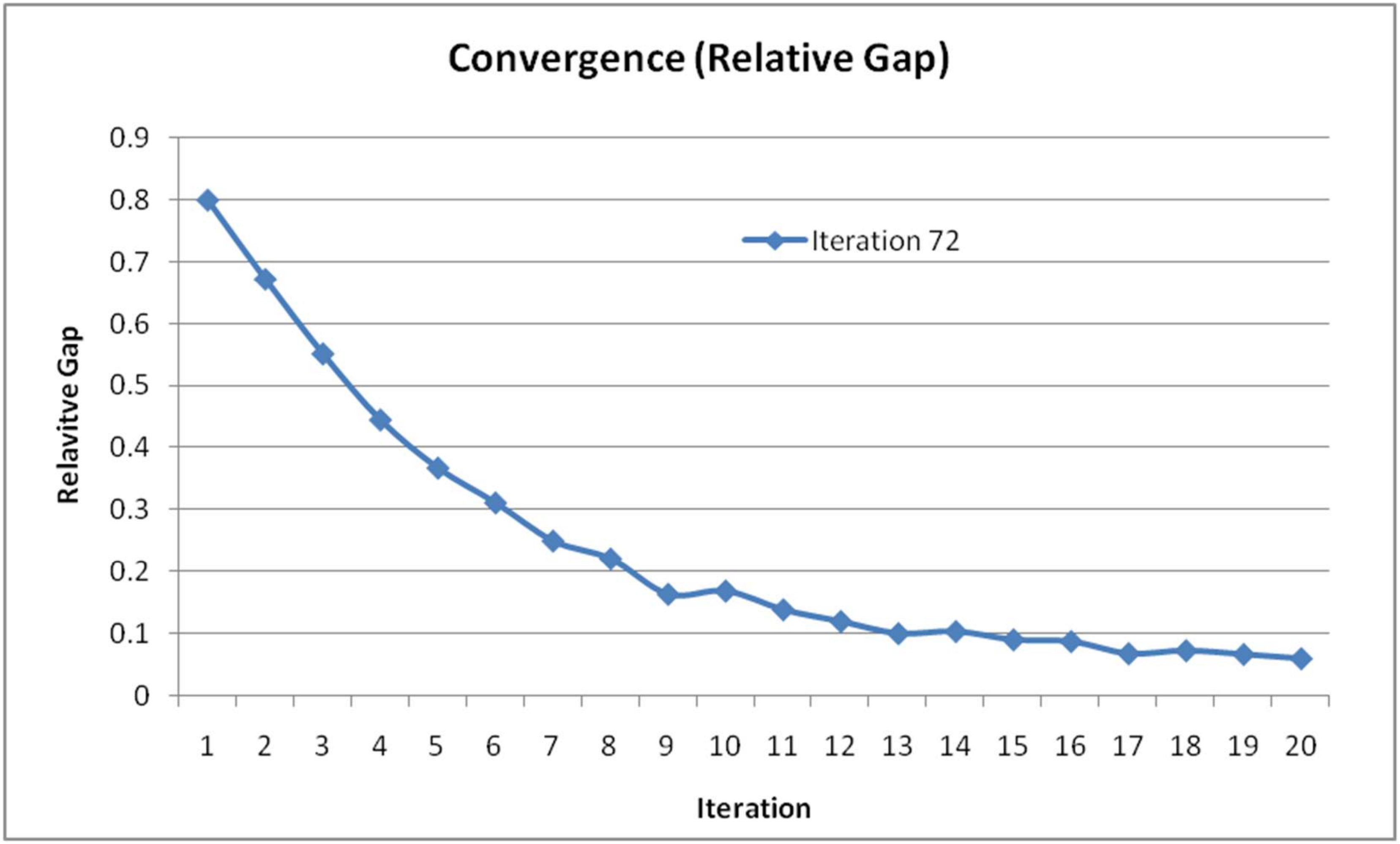
# GFV Formulation

- Path flow update for next iteration

$$?_{?,?,??}^{??,?+1} = ?_{?,?,??}^{??,?} + ?_{?,?}^{??,?} \cdot ?_{?,??}^{?} \cdot ?_{??}^{?}\ , \forall ?? \in ??^{?}??,?,??$$

# Gap-Function Vehicle Based Assignment

- Driven by Gap Function



# Method of Isochronal Vehicle Assignment

# Introduction

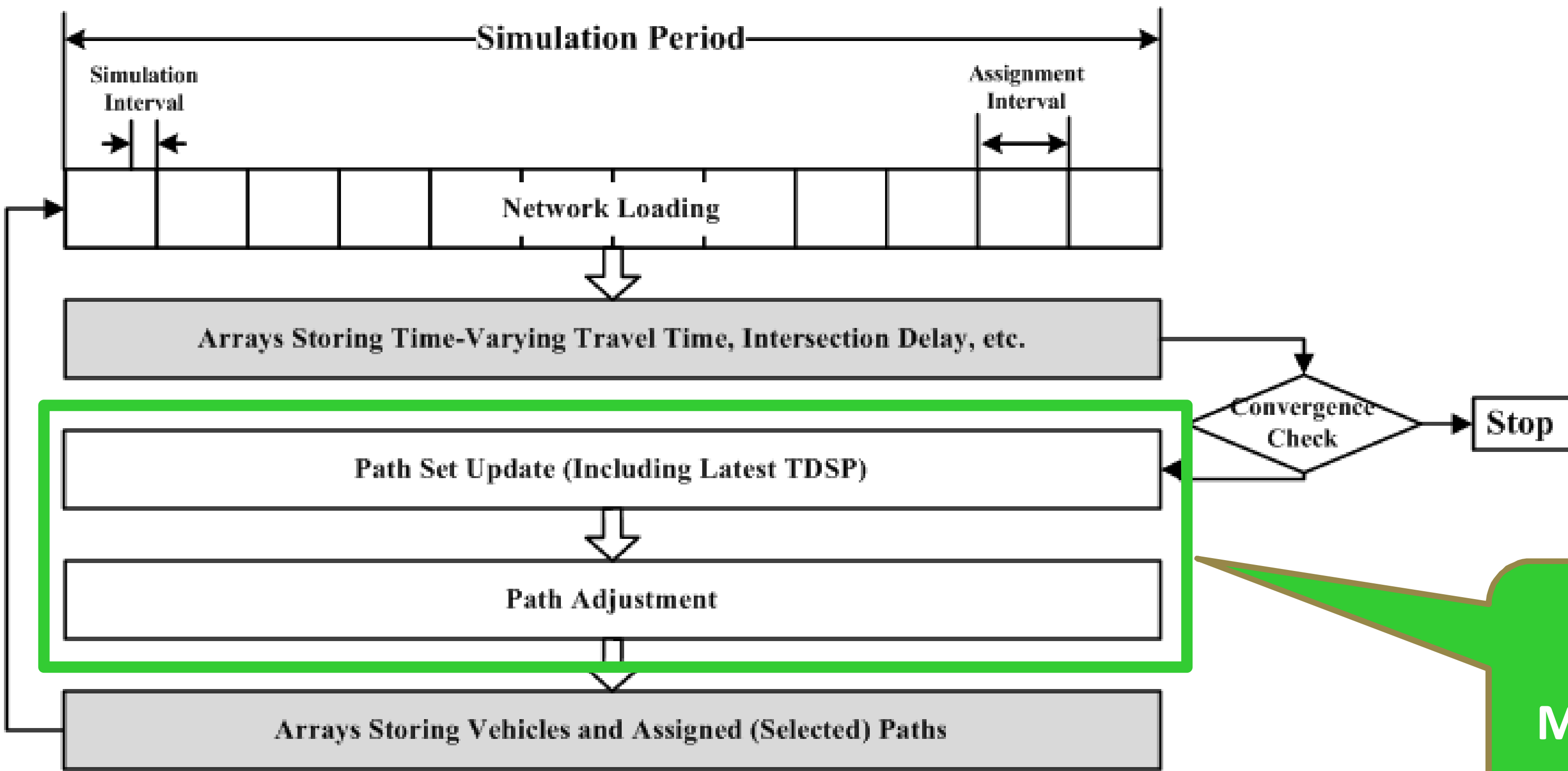
- The Method of Isochronal Vehicle Assignment (MIVA)
  - SBDTA Computational Scheme
  - Consistent with the GFV algorithmic structure
    - Vehicle-based approach
  - Computationally improvements
    - Memory requirement
    - Computational time

# Background

- Computational Management
  - SBDTA memory requirements
    - Spatially (tens of thousands of nodes/links)
    - Temporally (24hr – multiday simulation)
    - Loading scale (millions of vehicles)
  - Computation of the time-dependent shortest paths (TDSP)

# Background

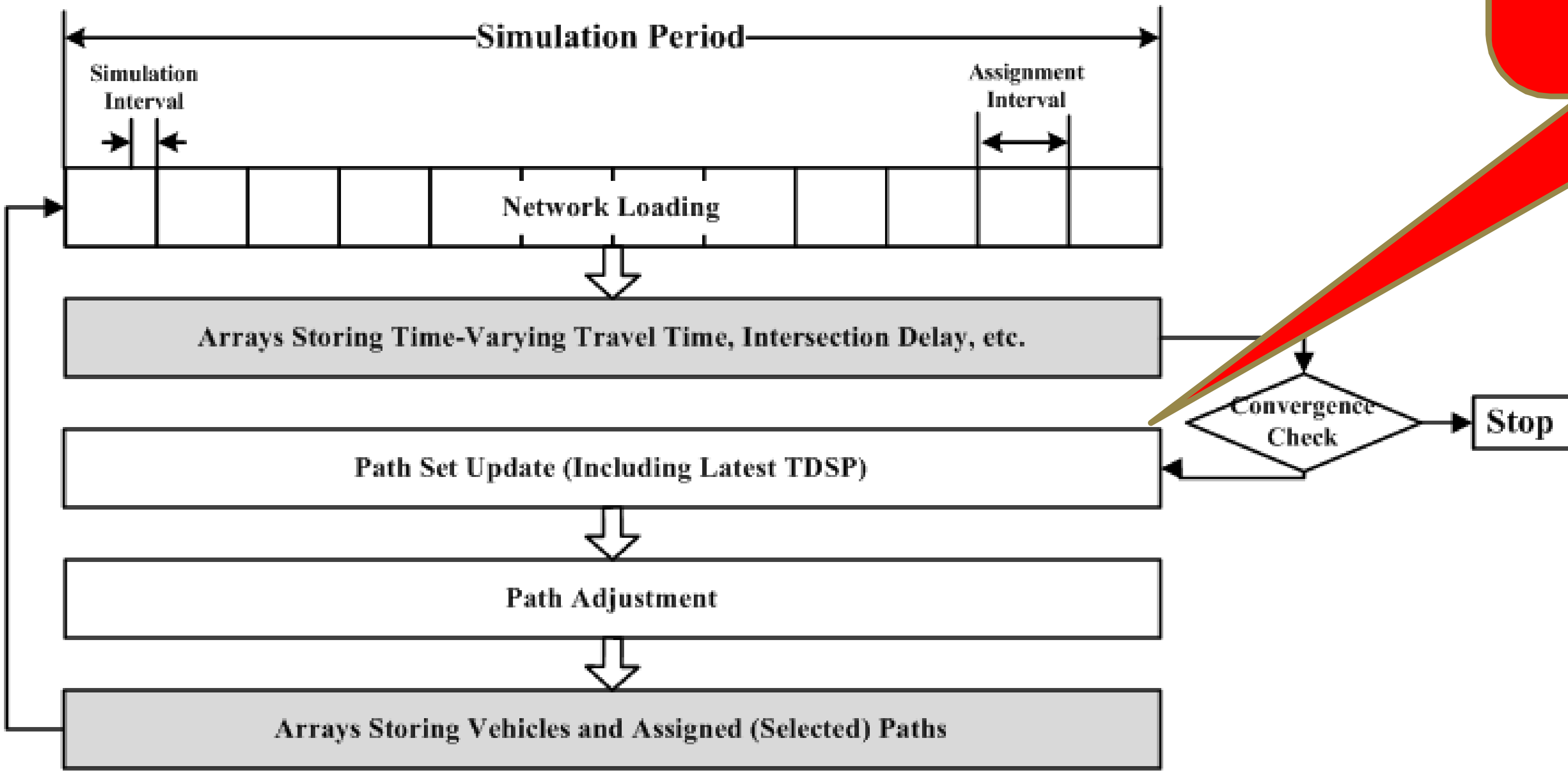
- Computational Management




Computational Management Scheme

# Background

- Computational Management




Management of memory requirement needed to feed TDSP and Vehicle Assignment

# MIVA Development

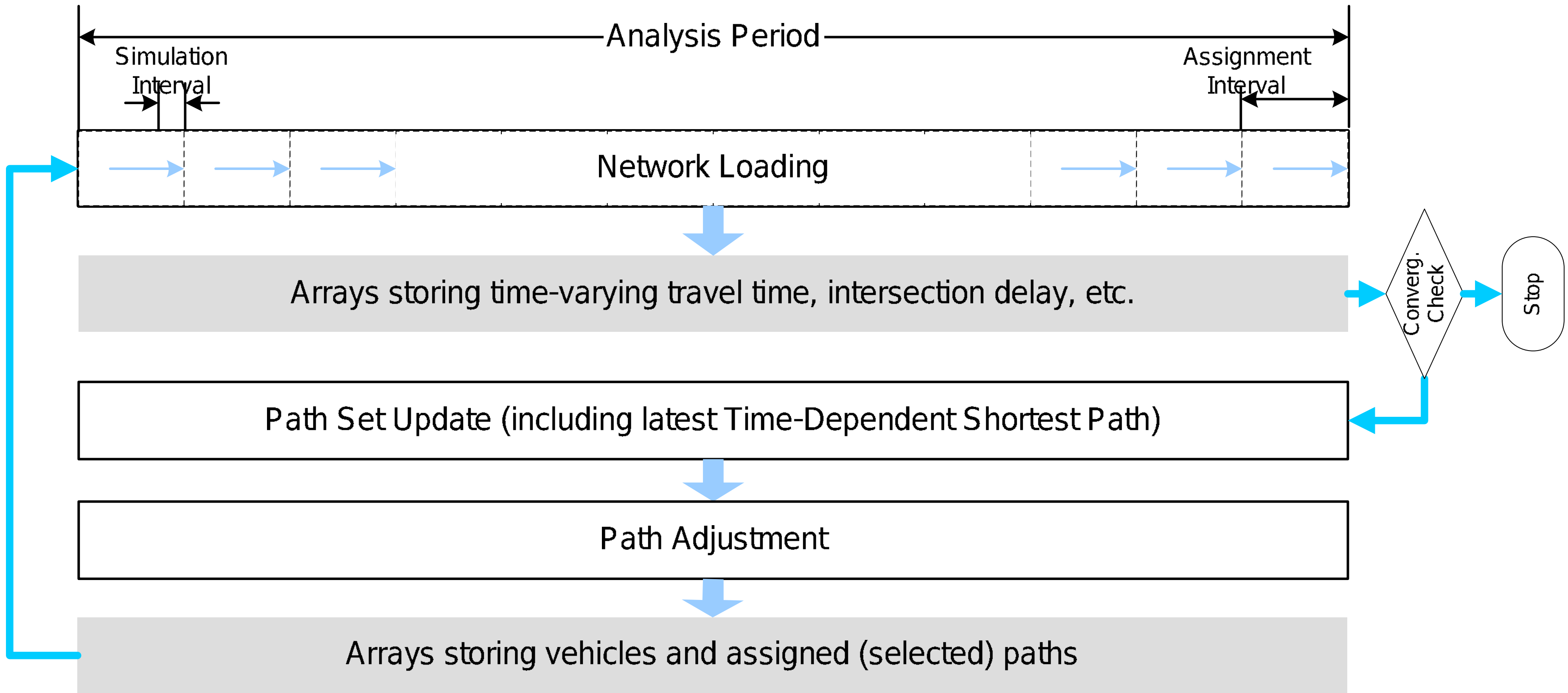
- The Method of Isochronal Vehicle Assignment (MIVA)
  - Time domain decoupling scheme of the between simulation and assignment procedures into sequential stages
  - Allows memory requirement for TDSP and assignment to be temporally bounded
    - Reduction in memory need
    - Ability to handle large-scale, long-term SBDTA applications

# MIVA Development

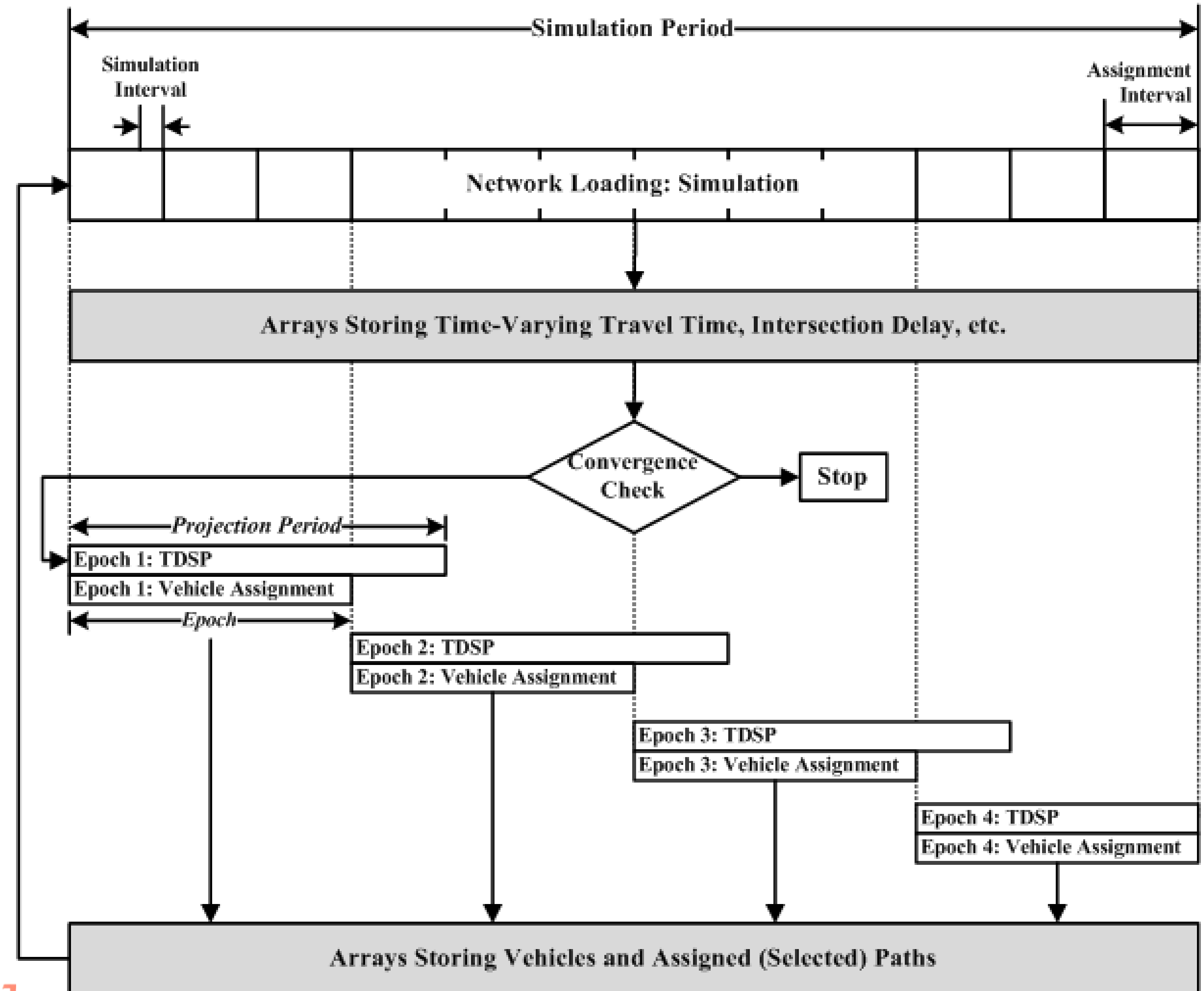
- Rolling Horizon
  - Sequential stages of the time domain is similar in concept to rolling horizon
  - Used  in real-time DTA applications
    - Forecasting future conditions
- Distinction between rolling horizon and  MIVA
  - Future condition is known
  - Used for staging assignment

# DTA Algorithmic Structure (simulation-based)

- Network loading
- Path set update
- Path flow adjustment

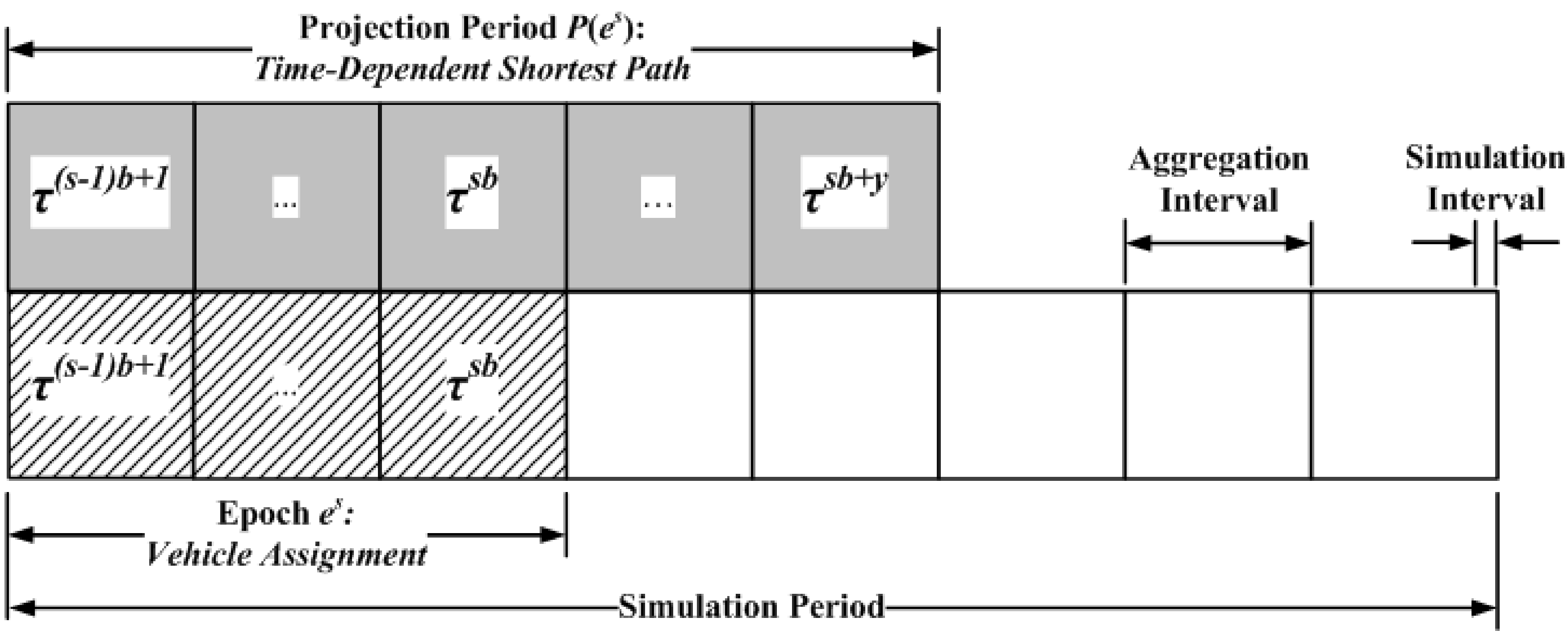


# MIVA Development



# Projection Period

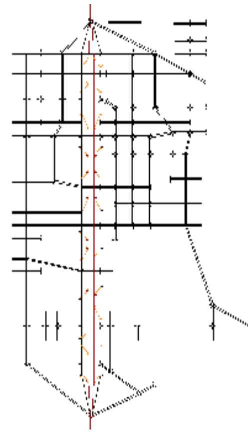
- Time period in which TDSP is updated:
  - Projection Period $P(e^s) = \{\tau^{(s-1)b+1}, \tau^{(s-1)b+2}, \dots, \tau^{sb}, \tau^{sb+1}, \dots, \tau^{sb+y}\}$
  - Projection Period length (percentile) $h \cdot \tau^{sb+y} \geq$ [illegible]; $0.0 \leq$ [illegible] $\leq 1.0$



# Numerical Analysis (MIVA)

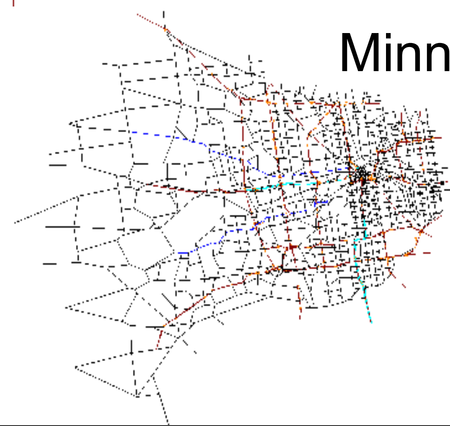
- Three real-world networks used for testing
- Three performance measures
  - Maintenance of solution quality
  - Peak memory usage
  - Computational time

Fort Worth



Guam

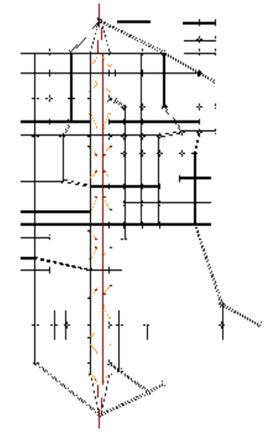
Minneapolis



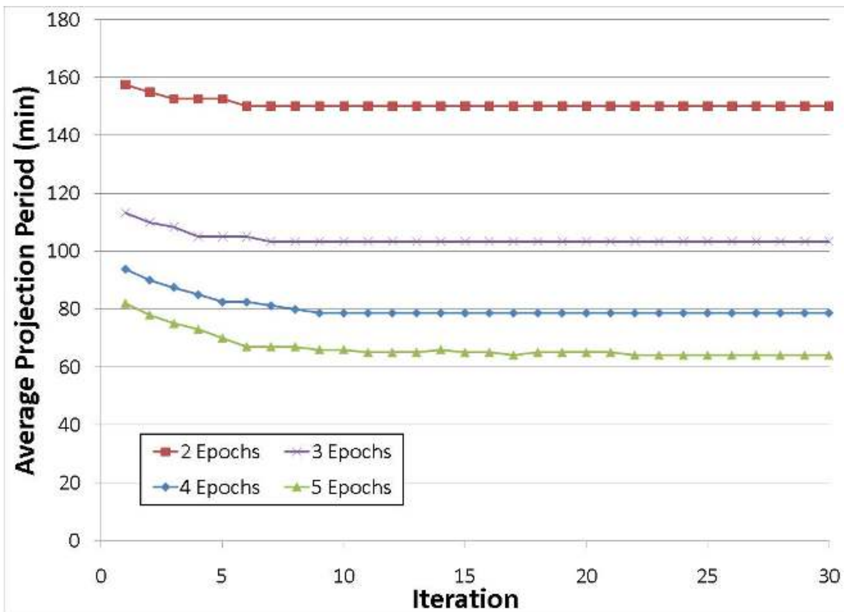
| Network | Zones | Nodes | Links | Agg. Int. | # Ite. | Sim. Period | #of Veh. |
|---|---|---|---|---|---|---|---|
| Fort Worth | 13 | 180 | 445 | 2 | 100 | 300 | 70,921 |
| Guam | 157 | 540 | 1183 | 5 | 50 | 120 | 70,088 |
| Minneapolis | 558 | 2837 | 6872 | 10 | 50 | 300 | 1,259,594 |

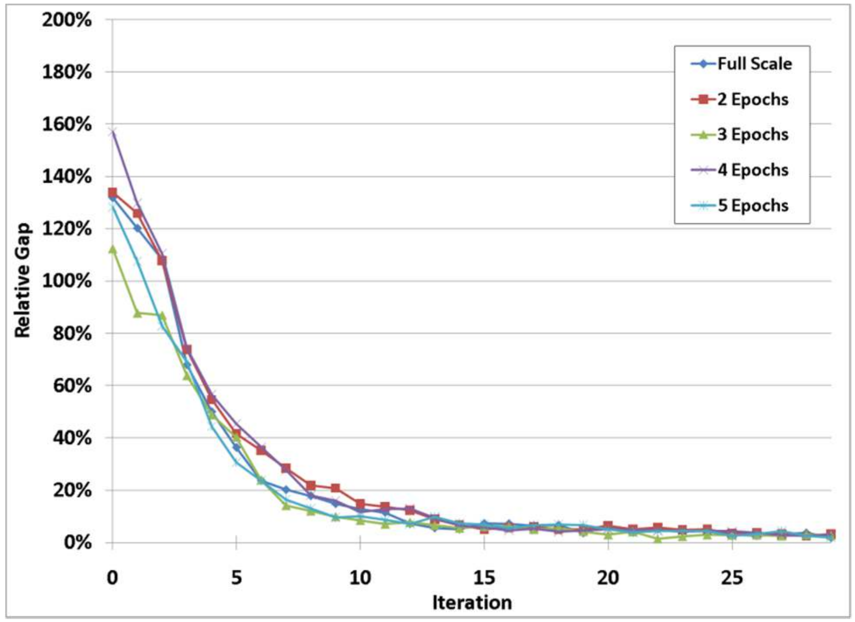
# Numerical Analysis (MIVA)

Fort Worth



- Maintenance of solution quality
  - Percentile = 0.90

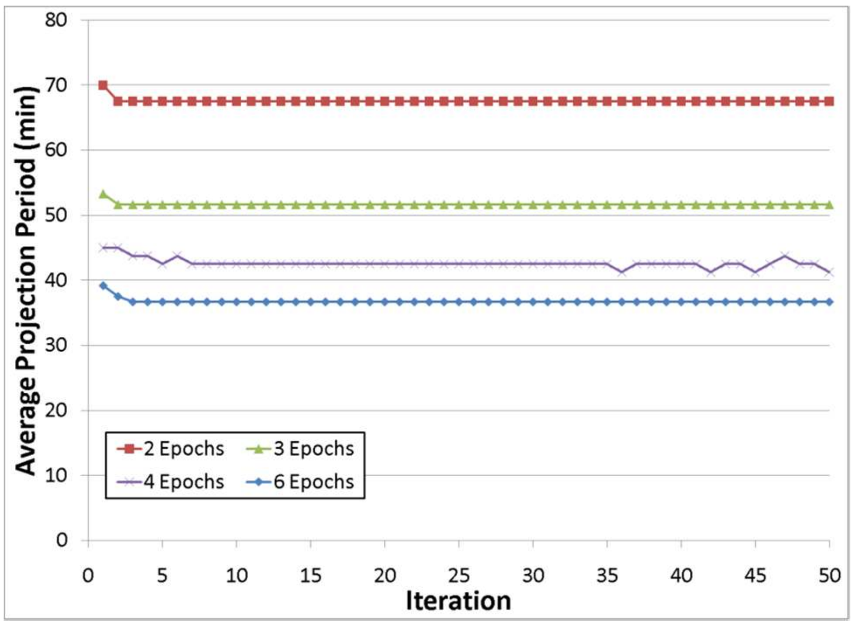


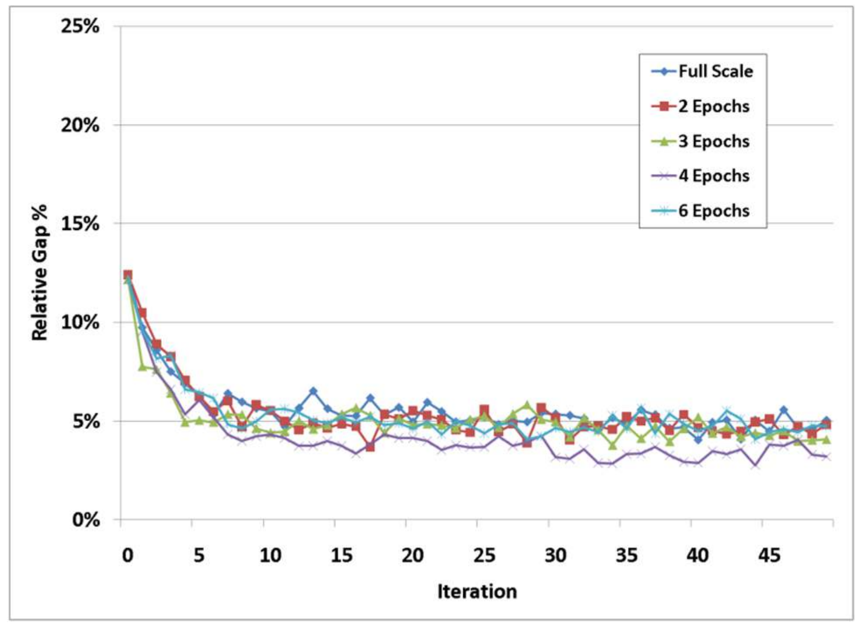



# Numerical Analysis (MIVA)

Guam

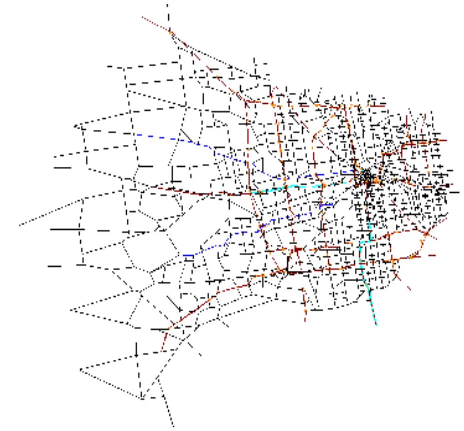
- Maintenance of solution quality
  - Percentile ??= 0.90



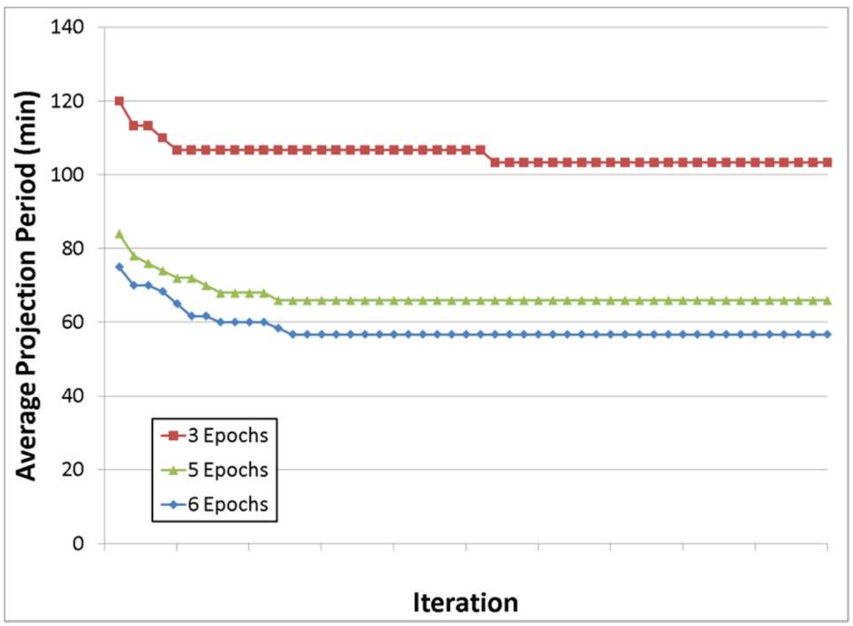



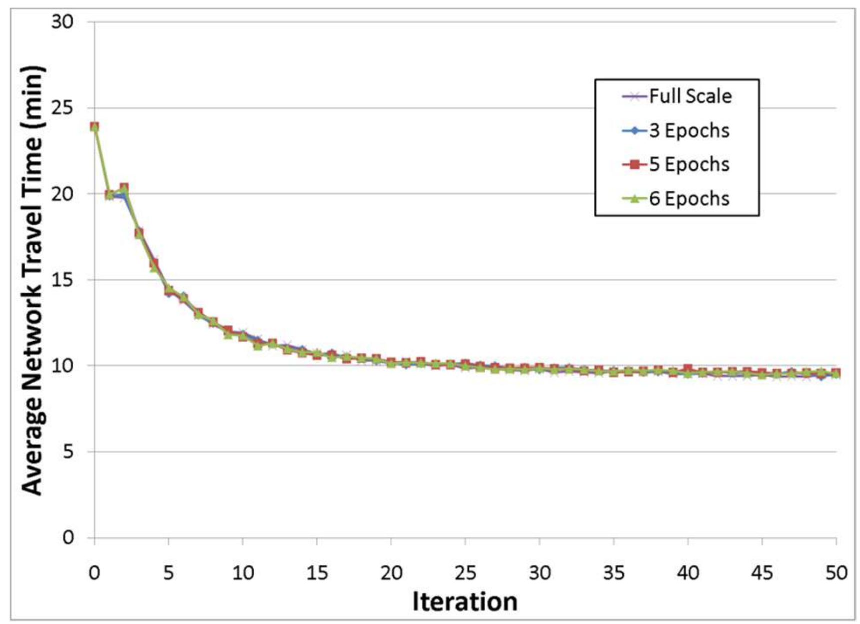
# Numerical Analysis (MIVA)

Minneapolis



- Maintenance of solution quality
  - Percentile [illegible]= 0.90



# Summary

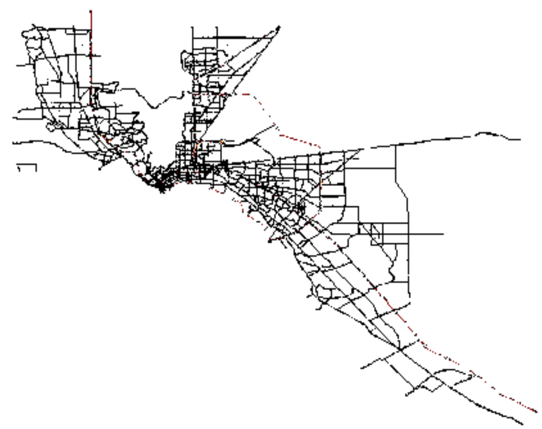
- Peak memory usage always decreases with increasing number of Epochs
- Degradation of computational time beyond certain point
  - Due to fixed overhead of each Epoch
  - There exists suitable Epoch value that outperforms in computational time
- Self-tuning mechanism to optimizes (on-line) in
  - Computational time
  - Memory requirements

# ST-MIVA Algorithm

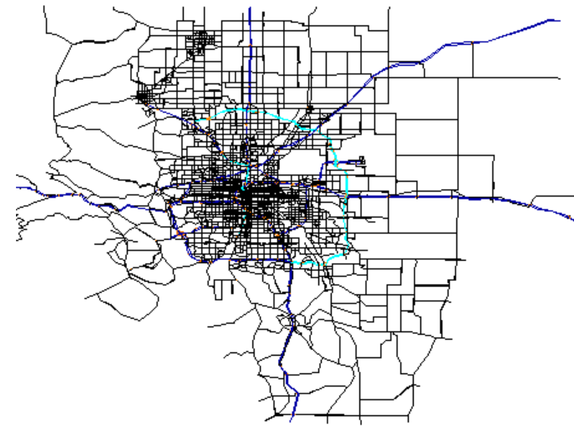
- Adaptive and robust on-line mechanism to determine time-optimal Epoch value
  - Iteratively evaluating the computational time of SBDTA execution based on different Epoch settings
  - “Bisection” search method
    - Iteratively downsizes the set of permissible Epochs by half

# Numerical Analysis (ST-MIVA)

- Two real-world networks used for testing
- Three performance measures
  - Peak memory usage
  - Computational time
  - Optimal epoch value



El Paso

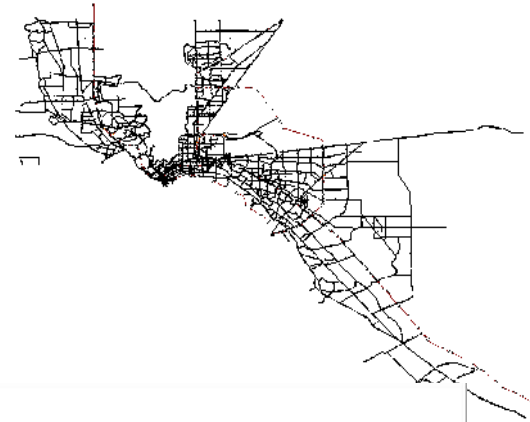


DRCOG

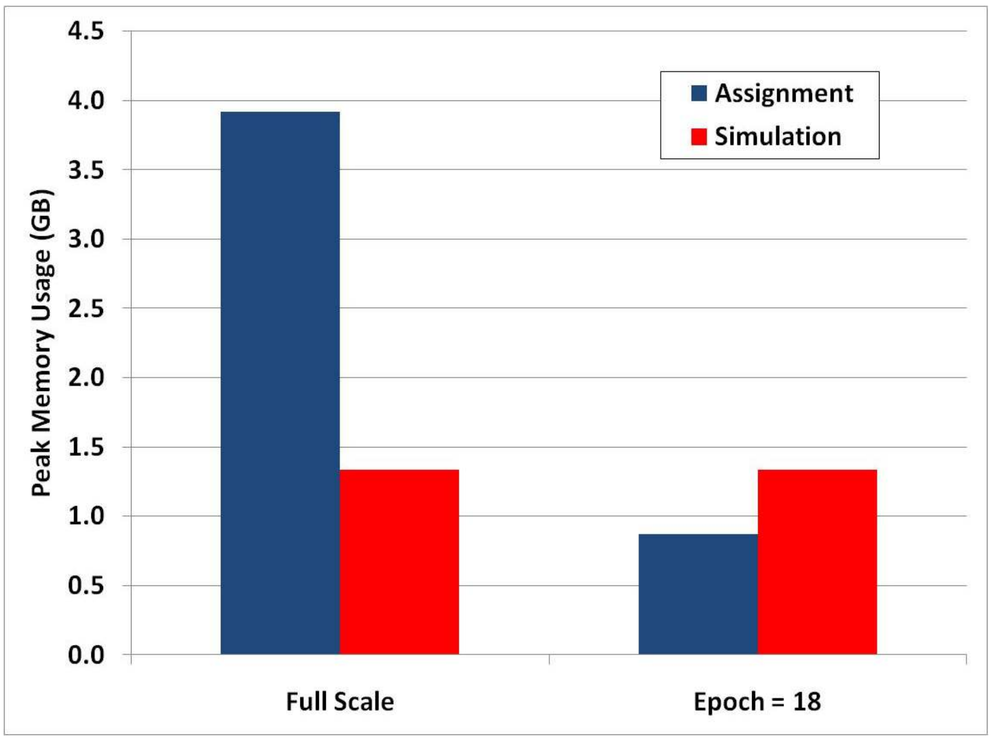
| Network | Zones | Nodes | Links | Agg. Int. | # Ite. | Sim. Period | #of Veh. |
|---|---|---|---|---|---|---|---|
| El Paso | 681 | 2,437 | 5,233 | 10 | 15 | 1440 | 2,171,006 |
| Guam | 2832 | 10,095 | 23,147 | 15 | 10 | 1440 | 6,814,589 |

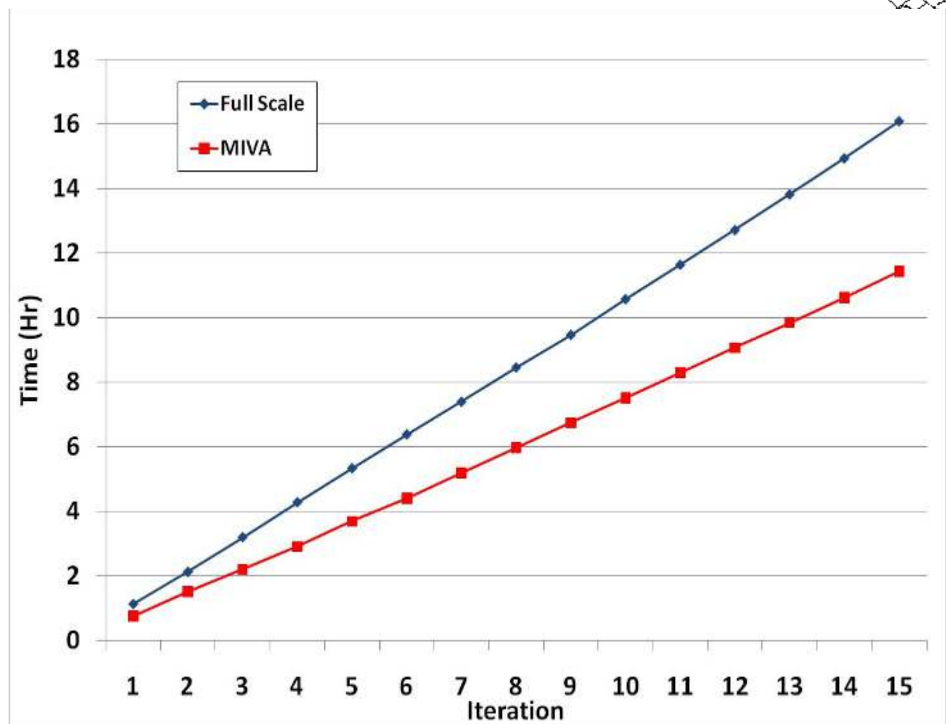
# Numerical Analysis (ST-MIVA)

El Paso



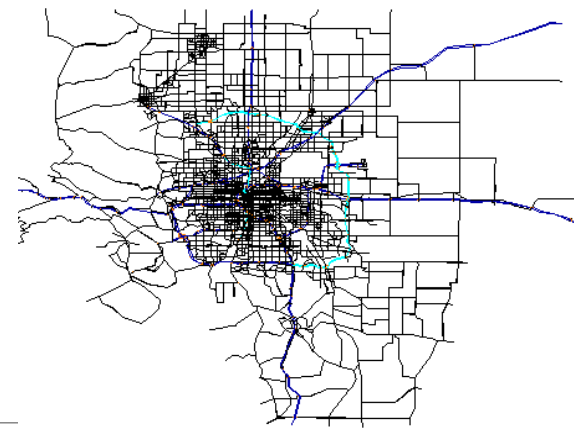
- Peak Memory Usage
  - At final Epoch value
- Computational Time



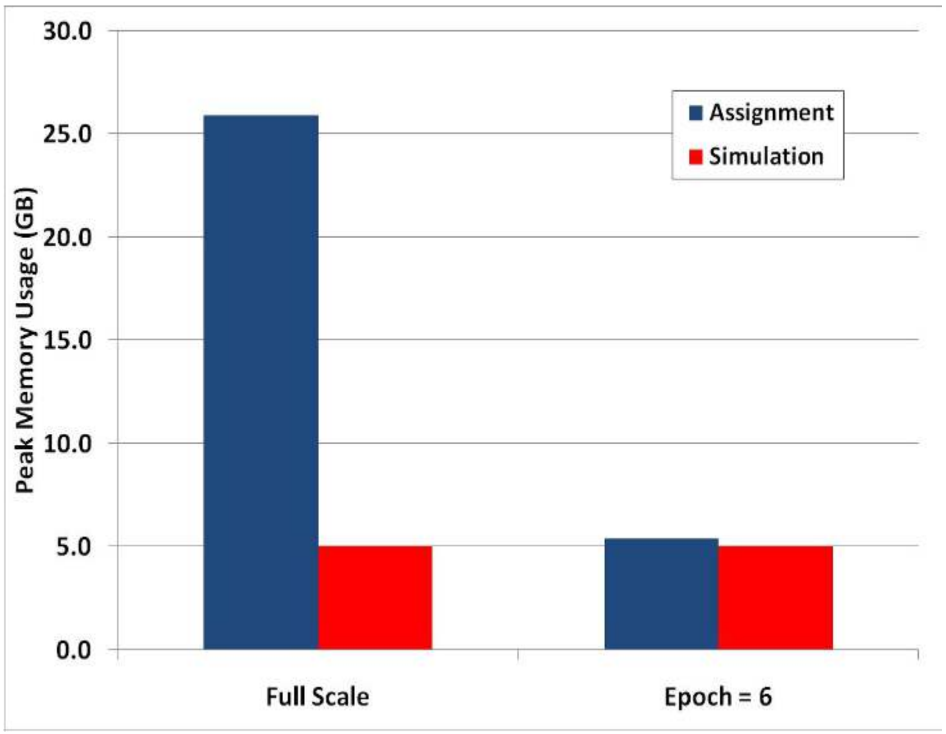



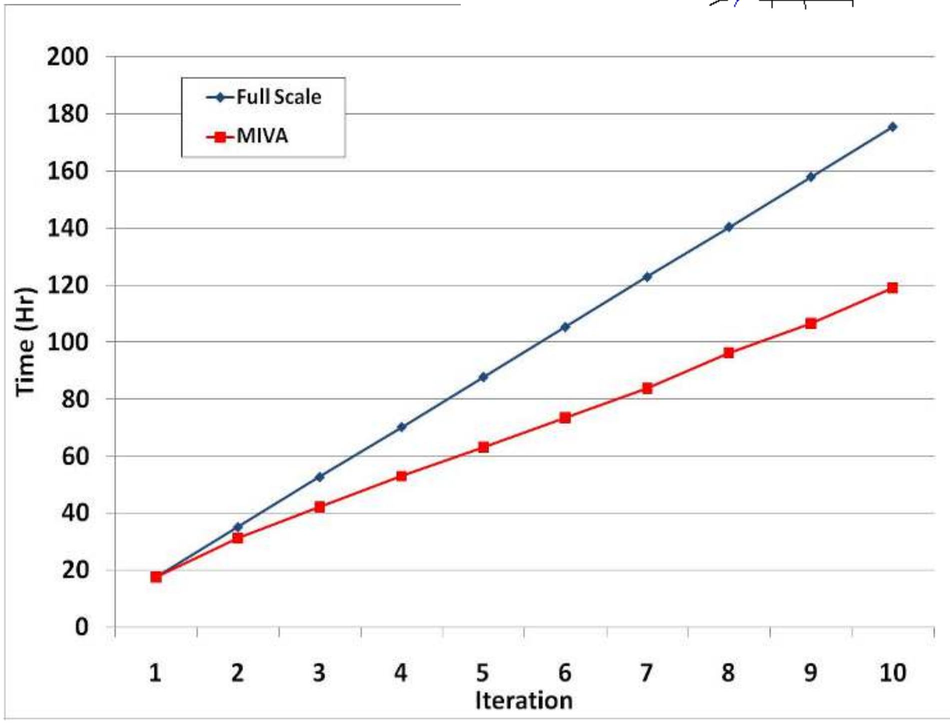
# Numerical Analysis (ST-MIVA)

DRCOG



- Peak Memory Usage
  - At final Epoch value
- Computational Time

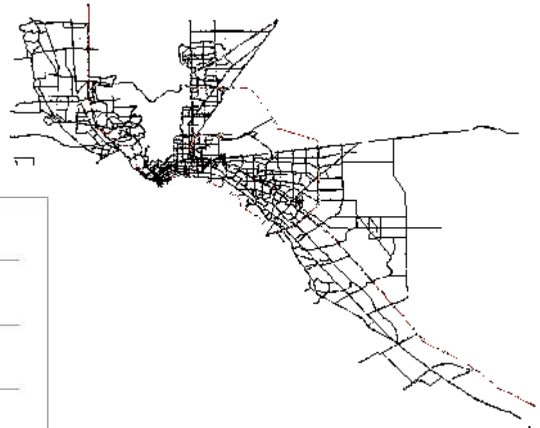


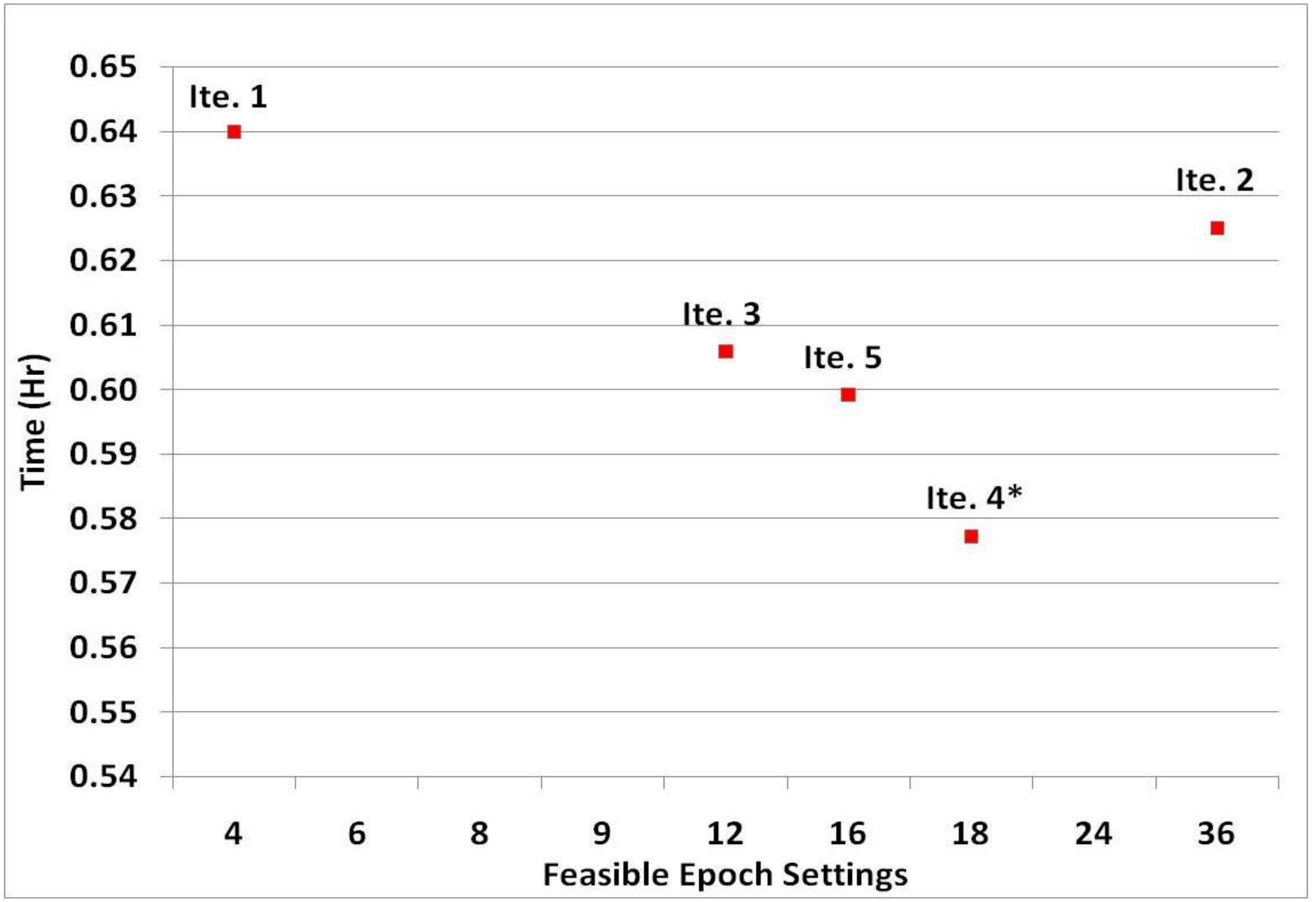



# Numerical Analysis (ST-MIVA)

- ST performance

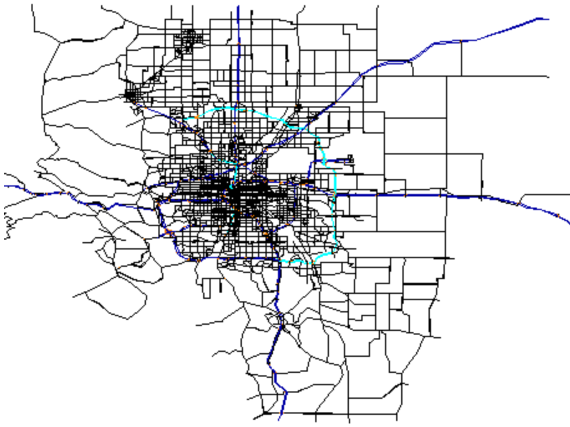
El Paso



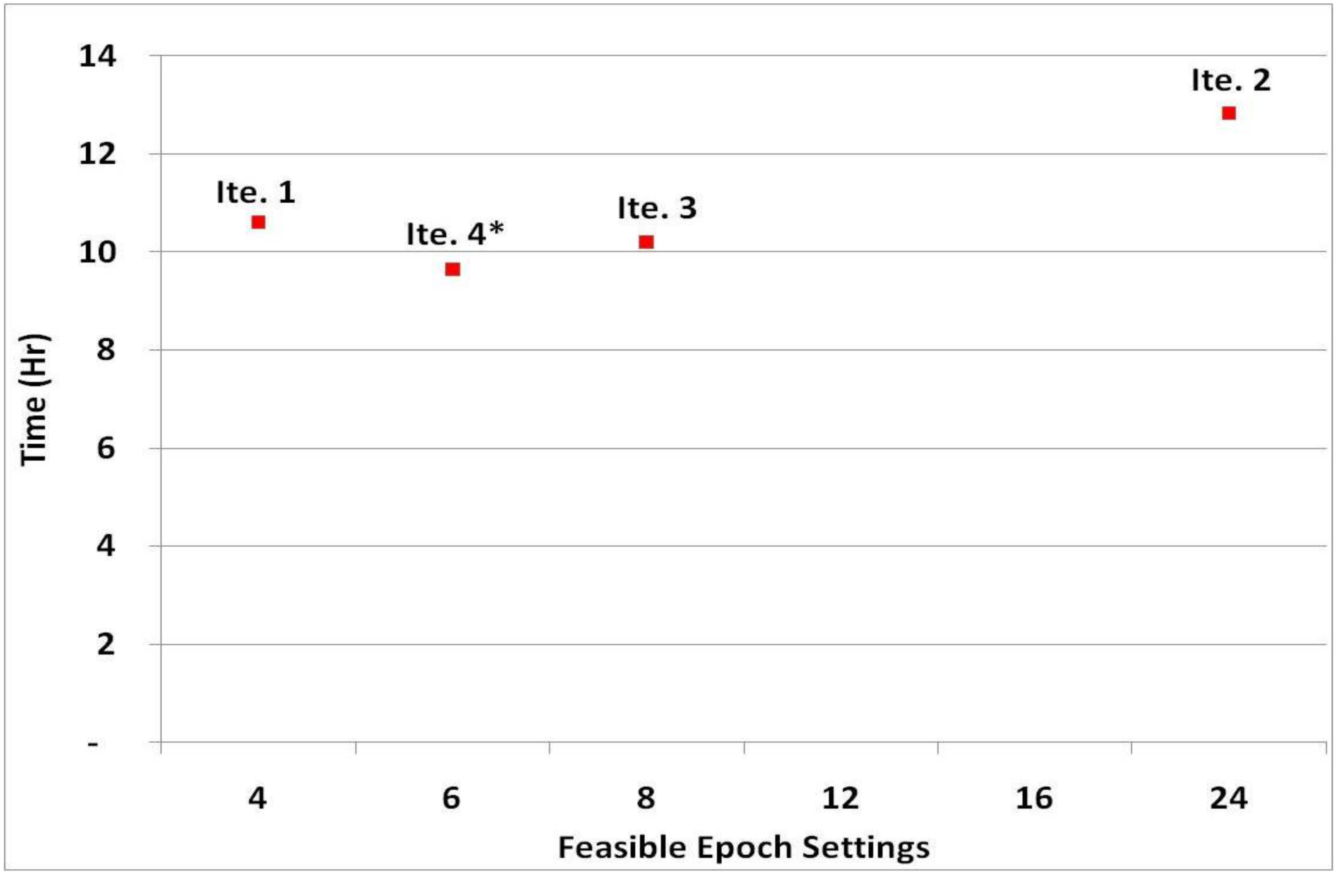


# Numerical Analysis (ST-MIVA)

DRCOG



- ST Performance



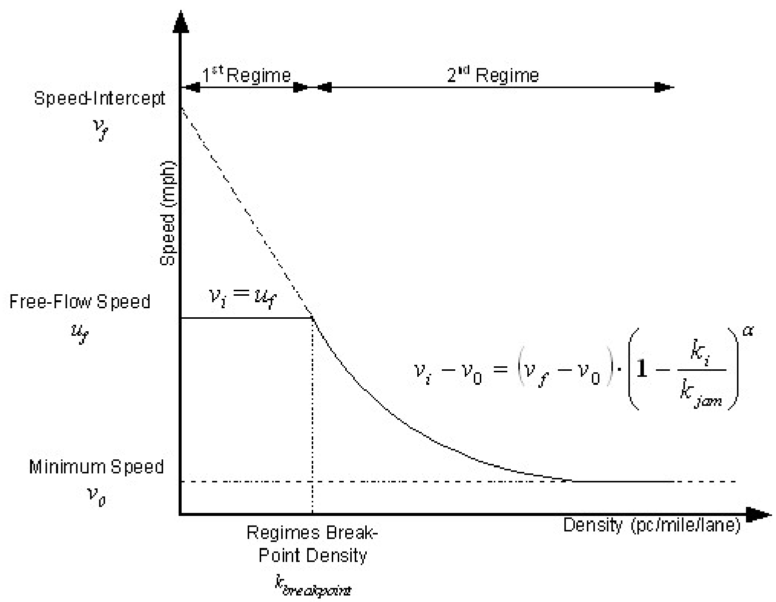
# MIVA Conclusions

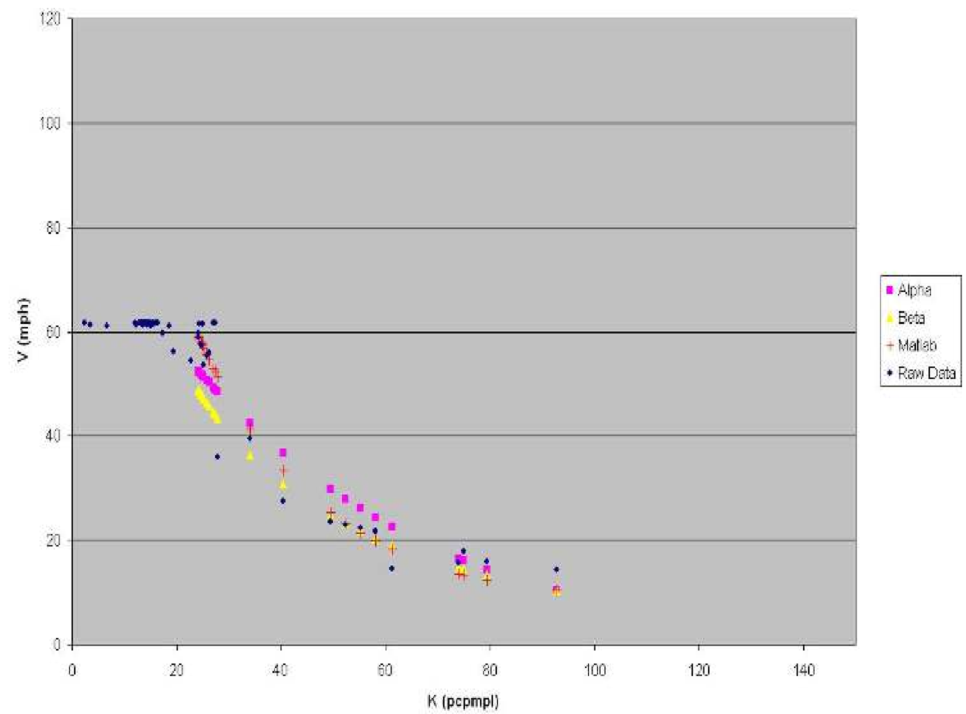
- MIVA computational scheme provides a robust treatment of the temporal domain issue in large-scale, long-period analysis
  - *Epoch*
  - *Projection Period*
- Self-Tuning on-line mechanism designed to determine optimal Epoch value
- Computational performance demonstrates desired memory efficiency and computational time

# Model Calibration – Traffic Flow and OD

# Model Calibration and Validation

- Calibration of traffic flow model
  - Multiple traffic flow models for categories of grade along corridor




**Source:**
http://ntl.bts.gov/lib/31000/31400/31419/14497_files/chap_6.htm

# Background

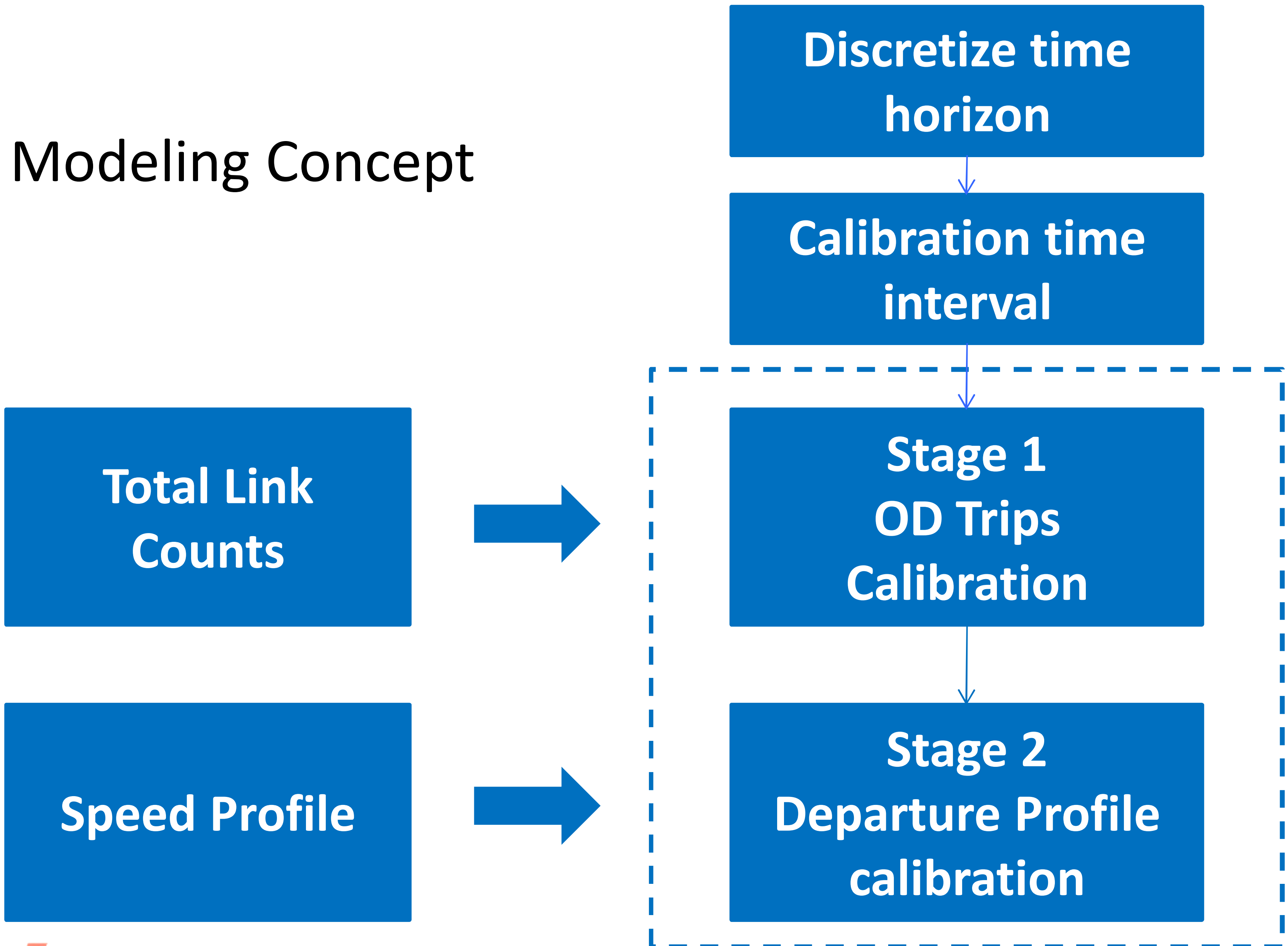
- Most OD calibration methods focus on matching link counts

  (Yang, Sasaki et al. 1992; Sherali, Arora et al. 1997; Sherali and Park 2001; Chiu, Zhou et al. 2007; Lundgren and Peterson 2008)

- OD calibration matching bottleneck (speed profile) has been limited
  - Manual and time consuming process
- A systematic approach is needed and motivated this research

# Two-Stage Dynamic Calibration Framework

Modeling Concept



# Modeling Concepts

- To ensure the simulated total counts matches with observed counts
  - Most of the existing approaches in literature
- To ensure the simulated speed profile matches with observed speeds
  - Innovative approaches proposed by this research is to match both counts and speed profile

# Stage 1: O/D Trips Calibration

- A bi-level formulation:

  classified by Lundgren and Peterson (2008)
- Upper level problem – minimizing link counts deviation
- Lower level problem – Dynamic User Equilibrium Traffic Assignment (DUE) problem

# Stage 1: O/D Trips Calibration (Original Formulation)

- Upper level one-norm formulation
- Can be transformed to a typical LP problem
- Computationally tractable for large problems (thousands of zones)

$$\text{Minimize } \sum_{m=1}^{|M|} \left\{ \left| \sum_{n=1}^{|N|} \left( \frac{d_{mn}^a}{r_n^a} x_n^a \right) - g_m^a \right| + \left| \sum_{n=1}^{|N|} \left( \frac{d_{mn}^c}{r_n^c} x_n^c \right) - g_m^c \right| \right\}$$

$$\text{Minimize } \sum_{m=1}^{|M|} (h_m^a + h_m^c)$$

$$\sum_{n=1}^{|N|} \left( \frac{d_{mn}^a}{r_n^a} x_n^a \right) - g_m^a \le h_m^a \quad \forall\ m = 1, \ldots, |M|$$

$$-\left[ \sum_{n=1}^{|N|} \left( \frac{d_{mn}^a}{r_n^a} x_n^a \right) - g_m^a \right] \le h_m^a \quad \forall\ m = 1, \ldots, |M|$$

$$\sum_{n=1}^{|N|} \left( \frac{d_{mn}^c}{r_n^c} x_n^c \right) - g_m^c \le h_m^c \quad \forall\ m = 1, \ldots, |M|$$

$$-\left[ \sum_{n=1}^{|N|} \left( \frac{d_{mn}^c}{r_n^c} x_n^c \right) - g_m^c \right] \le h_m^c \quad \forall\ m = 1, \ldots, |M|$$

# Stage 1: O/D Trips Calibration (Transformed Formulation) - Bi-level Formulation



$$\text{Minimize } \sum_{m=1}^{|M|}\left\{\left[\sum_{n=1}^{|N|}\left(\frac{d_{mn}^a}{r_n^a}x_n^a\right)-g_m^a+v_m^a\right]+\left[\sum_{n=1}^{|N|}\left(\frac{d_{mn}^c}{r_n^c}x_n^c\right)-g_m^c+v_m^c\right]\right\} \quad (12)$$

Upper level: min link counts deviation

Subject to:

$$-2\left[\sum_{n=1}^{|N|}\left(\frac{d_{mn}^a}{r_n^a}x_n^a\right)-g_m^a\right]-v_m^a \le 0 \quad \forall\ m=1,\dots,|M| \quad (13)$$

$$-2\left[\sum_{n=1}^{|N|}\left(\frac{d_{mn}^c}{r_n^c}x_n^c\right)-g_m^c\right]-v_m^c \le 0 \quad \forall\ m=1,\dots,|M| \quad (14)$$

$$(1-\alpha^a)r_n^a \le x_n^a \le (1+\alpha^a)r_n^a \quad \forall\ n=1,\dots,|N| \quad (15)$$

$$(1-\alpha^c)r_n^c \le x_n^c \le (1+\alpha^c)r_n^c \quad \forall\ n=1,\dots,|N| \quad (16)$$

$$(1-\beta^a)\sum_{n=1}^{|N|} r_n^a \le \sum_{n=1}^{|N|} x_n^a \le (1+\beta^a)\sum_{n=1}^{|N|} r_n^a \quad (17)$$

$$(1-\beta^c)\sum_{n=1}^{|N|} r_n^c \le \sum_{n=1}^{|N|} x_n^c \le (1+\beta^c)\sum_{n=1}^{|N|} r_n^c \quad (18)$$

$$x_n^a, x_n^c \ge 0 \quad \forall\ n=1,\dots,|N| \quad (19)$$

$$v_m^a, v_m^c \ge 0 \quad \forall\ m=1,\dots,|M| \quad (20)$$

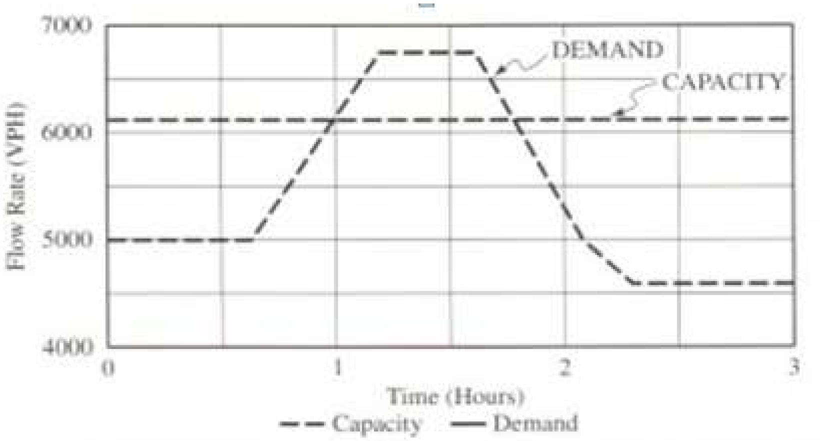
$$1.0 \ge \alpha \ge 0,\ 1.0 \ge \beta \ge 0 \quad (21)$$

$$G=\varphi(x_n^a, x_n^c, \forall\ n \in N) \quad (22)$$

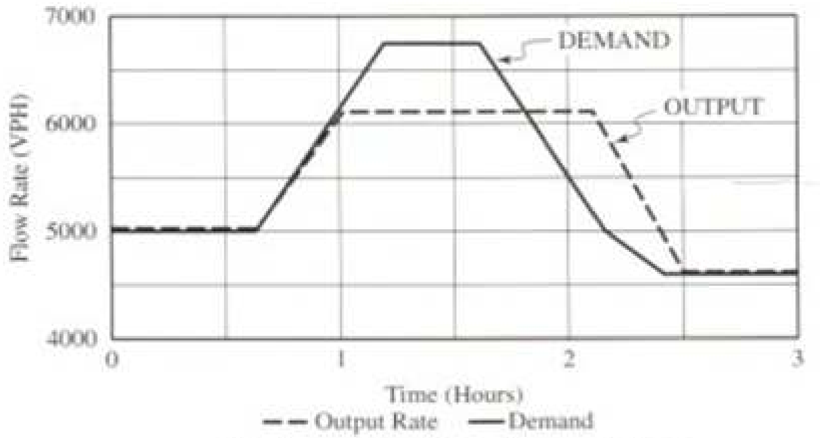
Lower level: DUE mapping

# Stage 2: Departure Profile Calibration - concept

- Flows and speeds are capacity constrained (observable)
- Speed reduction is caused by concentrated arriving flow subject to facility capacity
- The real goal is to re-estimate the departure profile (non observable) by using observable data




(a) Demand and capacity, as they would appear at the measurement point



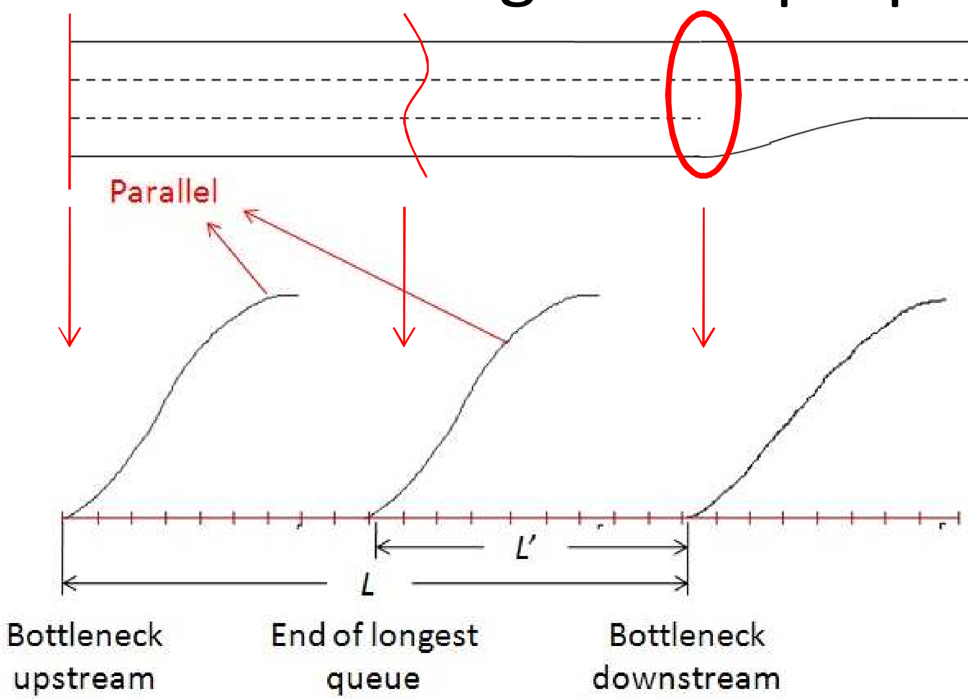

(b) Volume pattern distorted by capacity limit

# Stage 2: Departure Profile Calibration based on Speed Profile

- Stage 2.0 - Arrival Curve Construction
- Stage 2.1 - Arrival Curve Mapping to Departure Curve
  - Stage 2.1.1 - Arrival Curve Mapping to Departure Curve a SOSB case
  - Stage 2.1.2 - Arrival Curve Mapping to Departure Curve a MOSB case
- Stage 2.2 - An Algorithmic Procedure for Departure Curve Calibration Using Speed profile to find optimal mapping SOSB/MOSB case
- Stage 2.3 - Departure Profile Calibration Framework for SOSB/MOSB case
- Stage 2.4 - Departure Profile Calibration Framework for Network case

# Upstream and Downstream N-Curve of a Bottleneck

- Number of vehicles and travel time can be estimated from the two N-curves
- Downstream curve is subject to bottleneck capacity
- Upstream curve (not subject to queue spillover) represents the arriving demand at the bottleneck
- Back track to origin with proper time mapping



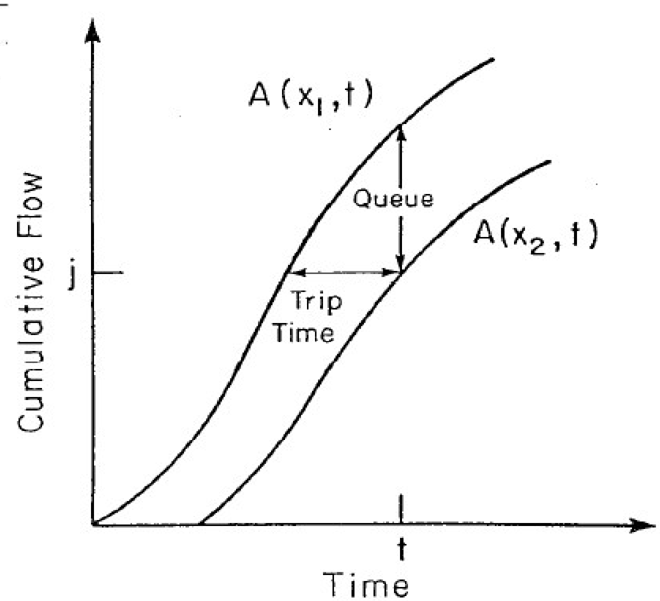
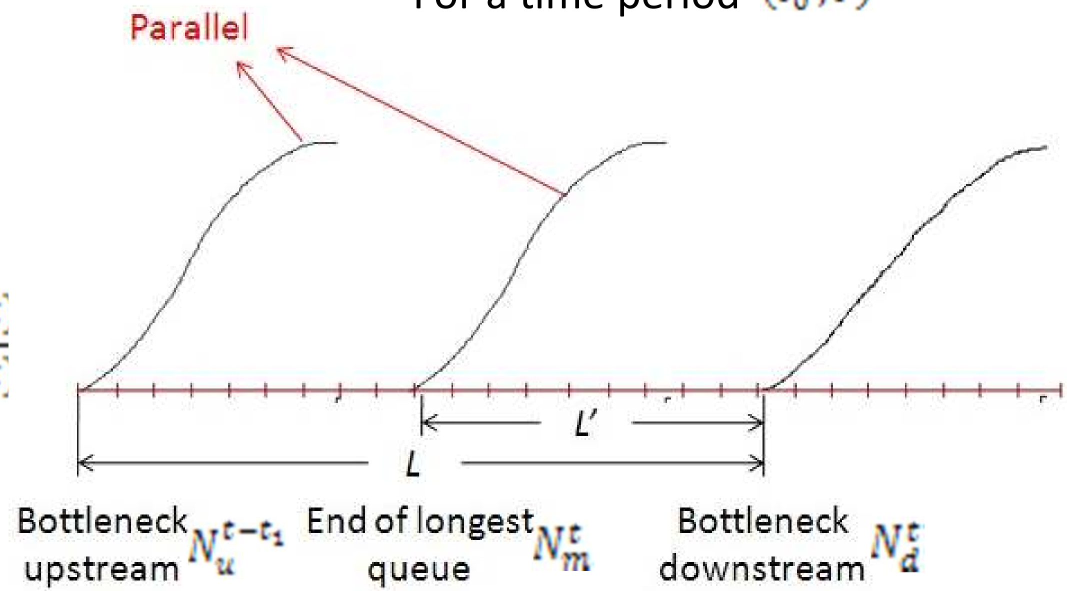




Fig. 1. Cumulative flow at two locations.

# Stage 2.0: Arrival Curve Construction

Assumption: Single-Origin Single-Bottleneck (SOSB)

For a time period $(t_0, T)$




$$N_u^{t-t_1} = N_m^t$$

$$N_m^t - N_d^t = k_a'(t)L' \approx k_a(t)L'$$

$$L' = \max_{\tau \in (t_0, T)}\{\int_{t_0}^{\tau} w_a(t)dt\} = \max_{\tau \in (t_0, T)}\{\int_{t_0}^{\tau} \frac{\Delta q_a(t}{\Delta k_a(t}$$

$$w_a(t) = \frac{\Delta q_a(t)}{\Delta k_a(t)} = \frac{q_a(t) - q_a(t_0)}{k_a(t) - k_a(t_0)}$$

$$N_u^{t-t_1} = N_m^t \approx N_d^t + k_a(t)\{max \int_{t_0}^{T} \frac{q_a(t) - q_a(t_0)}{k_a(t) - k_a(t_0)} dt\}$$

$t_1$: the constant average travel time from end of the longest queue to bottleneck upstream;

$k_a(t)$: the average density between bottleneck upstream and downstream;

$k_a'(t)$: the average density between end of the longest queue and bottleneck downstream;

$w_a(t)$: shock wave speed at time t

Assume that in heavy congestion situation,

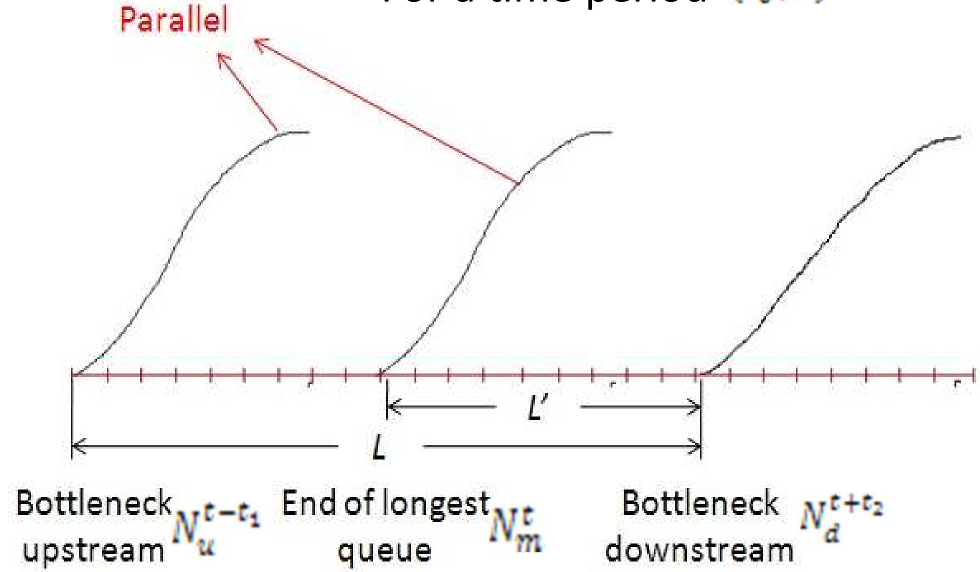
$$k_a'(t) \approx k_a(t)$$

# Stage 2.0: Arrival Curve Construction on a SOSB Case

For a time period $(t_0, T)$

In ideal situation, where flow is not constrained by capacity we would have :

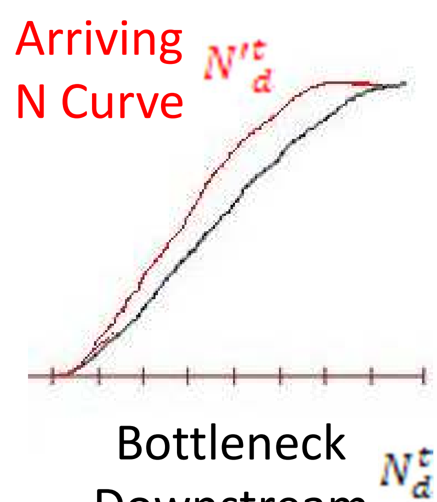
$$N_u^{t-t_1} = N_m^t = N_d^{t+t_2} \rightarrow$$ Arriving N Curve




$t_1$: the constant average travel time from end of the longest queue to bottleneck upstream;

$t_2$: the constant average travel time from end of the longest queue to bottleneck downstream;

Though, $L$ and $t_1$ are unknown, $L'$ and $t_2$ could be estimated from field data. Thus, we could construct the imaginary arriving N curve for bottleneck downstream.

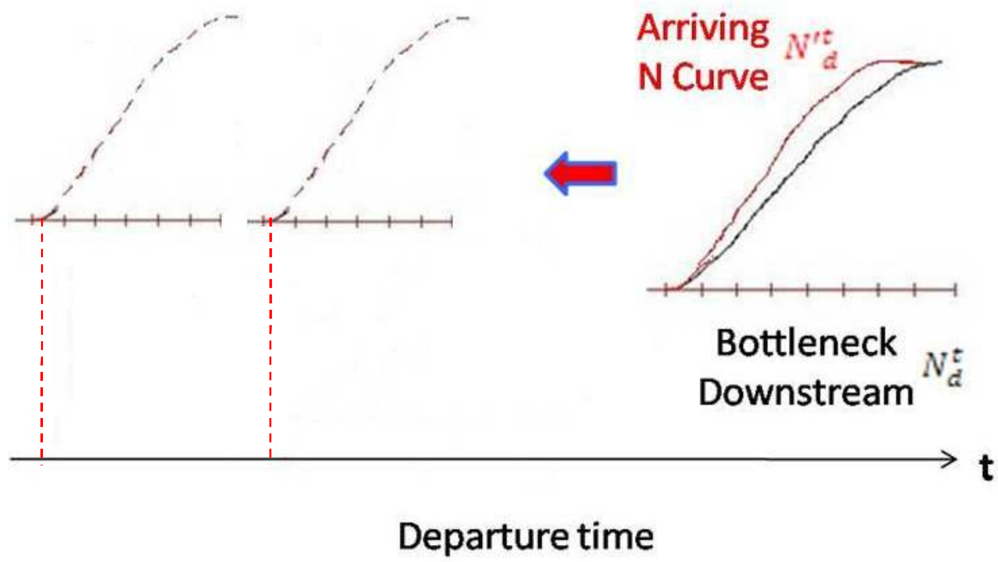



The next step is to find the appropriate origin, departure time and path mapping.

# Stage 2.1.1: Arrival Curve Mapping to Departure Curve a SOSB case

$$N(T) = \int_{t=0}^{T} x_l^t dt$$

$$x_l^t = dN(t)/dt$$




Demand to link flow: $d^{\tau,l,t} \xrightarrow[G(d^{\tau,l,t})]{\text{mapping}} x_l^t$

$$d^{\tau,l,t} = G^{-1}(x_l^t)$$

$$x_l^t = x_l \sum_{\tau \in (0,t)} \gamma_\tau$$

$$\gamma_\tau = G'^{-1}(x_l^t / x_l)$$

$d^{\tau,l,t}$: demand flow departures at time $\tau$ and reaches link $l$ at time $t$; $\tau \in (0,t)$

$x_l^t$: average flow of link $l$ at time $t$;

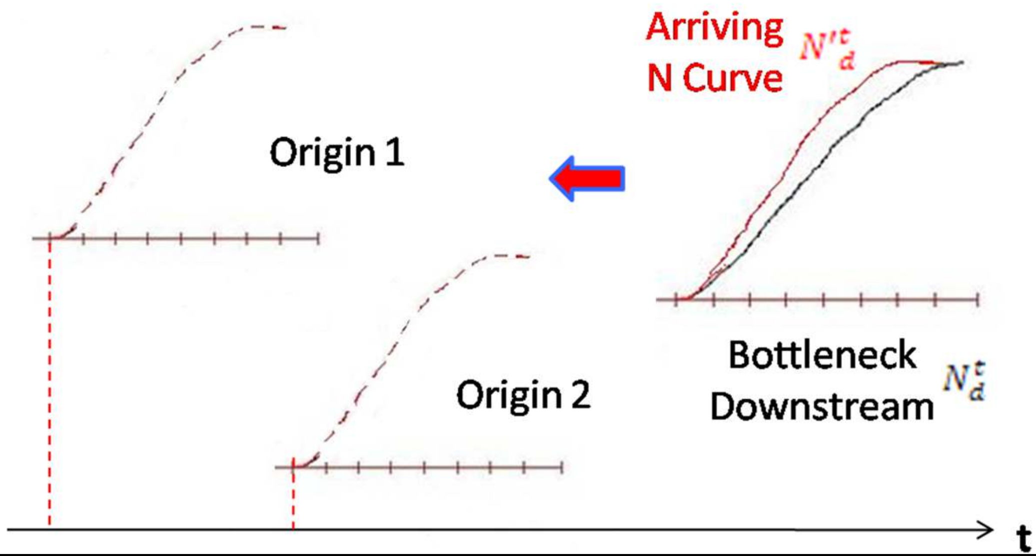
$x_l$: total link counts on link $l$, for a time period $[t_s, t_e]$;

$\gamma_\tau$: departure time proportion, $\tau \in [t_s, t_e]$

# Stage 2.1.2: Arrival Curve Mapping to Departure Curve a Multiple-Origin Single Bottleneck (MOSB) case

$$N(T) = \int_{t=0}^{T} x_l^t dt$$

$$x_l^t = dN(t)/dt$$




O/D table to link flow: $d_{rs}^{\tau,l,t} \xrightarrow[\text{}]{G(d_{rs}^{\tau,l,t})} x_l^t$ (mapping)

$$d_{rs}^{\tau,l,t} = G^{-1}(x_l^t)$$

$$d_{rs}^{\tau,l,t} = f_{n,\tau}^{l,t} = G^{-1}(x_l^t)$$

$$x_l^t = \sum_{\tau \in (0,t)} \sum_{n \in N} f_{n,\tau}^{l,t}$$

$$f_{n,\tau}^{l,t} = x_l \mu_\tau^{l,n,t}$$

$$\mu_\tau^{l,n,t} = \delta_l^n \sum_{\tau \in (0,t)} \gamma_\tau^n$$

$$\gamma_\tau^n = G'^{-1}(x_l^t / x_l, \delta_l^n)$$

$d_{rs}^{\tau,l,t}$ ($f_{n,\tau}^{l,t}$): demand flow from origin $r$ to destination $s$ (O/D pair $n$), departures at time $\tau$, reaches link $l$ at time $t$;

$x_l^t, v_l^t, k_l^t$: average flow, speed and density of link $l$ at time $t$;

$x_l$: total link counts on link $l$, for time period $[0,T]$;

$\delta_l^n$: O/D pair proportion, also $\sum_{n \in N} \delta_l^n = 1$;

$k'^t_l, v'^t_l$: estimated or observed average density, speed of link $l$ from field data at time $t$.

$\mu_\tau^{l,n,t}$: flow proportion, for O/D pair $n$, departures at time $\tau$, arrives at link $l$ at time $t$.

$\gamma_\tau^n$: departure time proportion, demand/departure flow of O/D pair $n$ departures at time $t$.

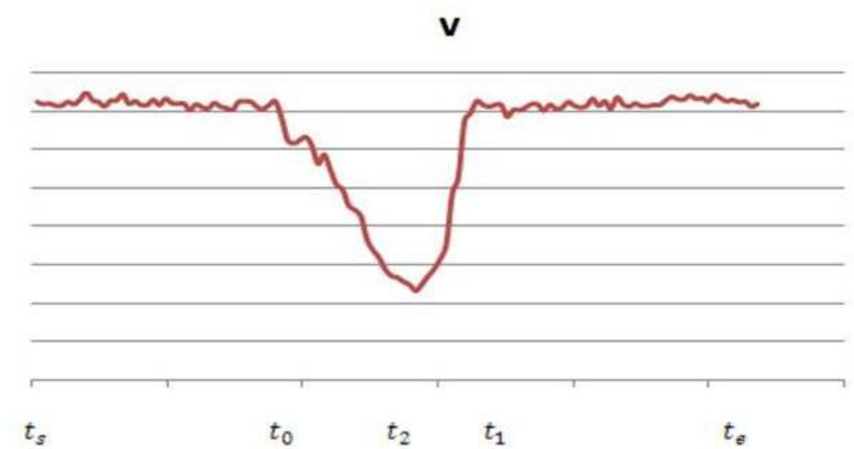
# Stage 2.2: An algorithmic procedure for Departure Curve Calibration Using Speed profile to find optimal mapping SOSB/MOSB case (1)

O/D table to link flow: $d_{rs}^{\tau,l,t} \xrightarrow[]{G(d_{rs}^{\tau,l,t})} x_l^t$ (mapping)

$$d_{rs}^{\tau,l,t} = G^{-1}(x_l^t)$$

$$x_l^t = x_l \sum_{n\in N} \delta_l^n \Big( \sum_{\tau\in(0,t)} \gamma_\tau^n \Big)$$

$$\gamma_\tau^n = G'^{-1}(x_l^t / x_l, \delta_l^n)$$




$$\min_{\gamma_\tau^n} \sum_{t\in[t_s,t_e]} |v_l^t(\gamma_\tau^n) - v'^t_l|$$

from simulation — from field data

Don't need to calibrate $\gamma_\tau^n$ blindly, there's an efficient way!

# Stage 2.2: An Algorithmic Procedure for Departure Curve Calibration Using Speed profile to find optimal mapping SOSB/MOSB case (2)

$$\gamma_\tau^n = G'^{-1}(x_l^t / x_l, \delta_l^n)$$

For each interval $[t_s, t_e]$,

*Step 1*: Get the current departure time mapping $\gamma'^n_\tau$ from simulation result:

*Step 2*: Identify speed drop and recover time period, denoted by $t_0$ and $t_1$. speed begins to recover at time $t_2$;

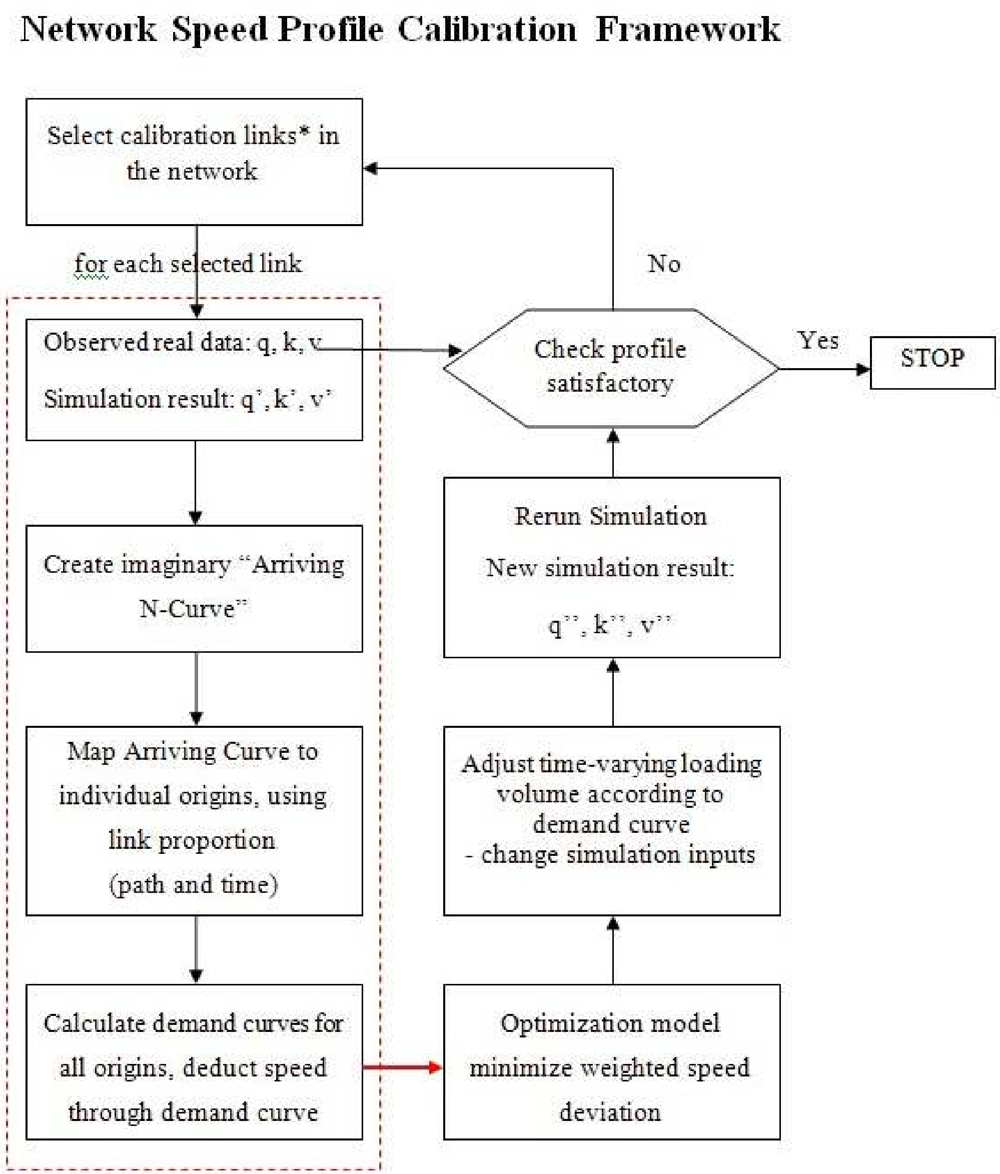
*Step 3*: Estimate average experienced travel time for each OD pair *n* at departure time $\tau \in [t_0, t_2]$ from field data, denoted by $t_n$;

*Step 4*: For each $\gamma_\tau^n$ and $\tau \in [t_0 - t_n, t_2 - t_n]$, increase it by $\Delta$, for each $\gamma_\tau^n$ and $\tau \in [t_2 - t_n, t_1 - t_n]$ decrease it by $\Delta$. ($\Delta$ is chosen to be very small, since $\gamma_\tau^n$ is a fraction between 0 and 1);

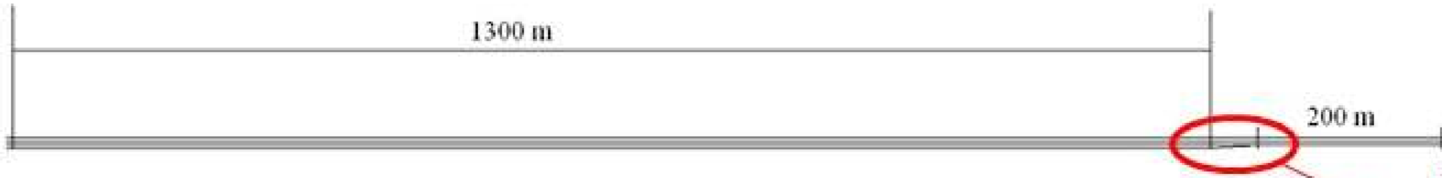
*Step 5*: Construct new set of $\gamma_\tau^n$, based on $\gamma'^n_\tau$, calculate departure flow, change simulation inputs;

*Step 6*: Rerun simulation and compare speed profile with field data, if reaches satisfactory stop, otherwise go to step 3.

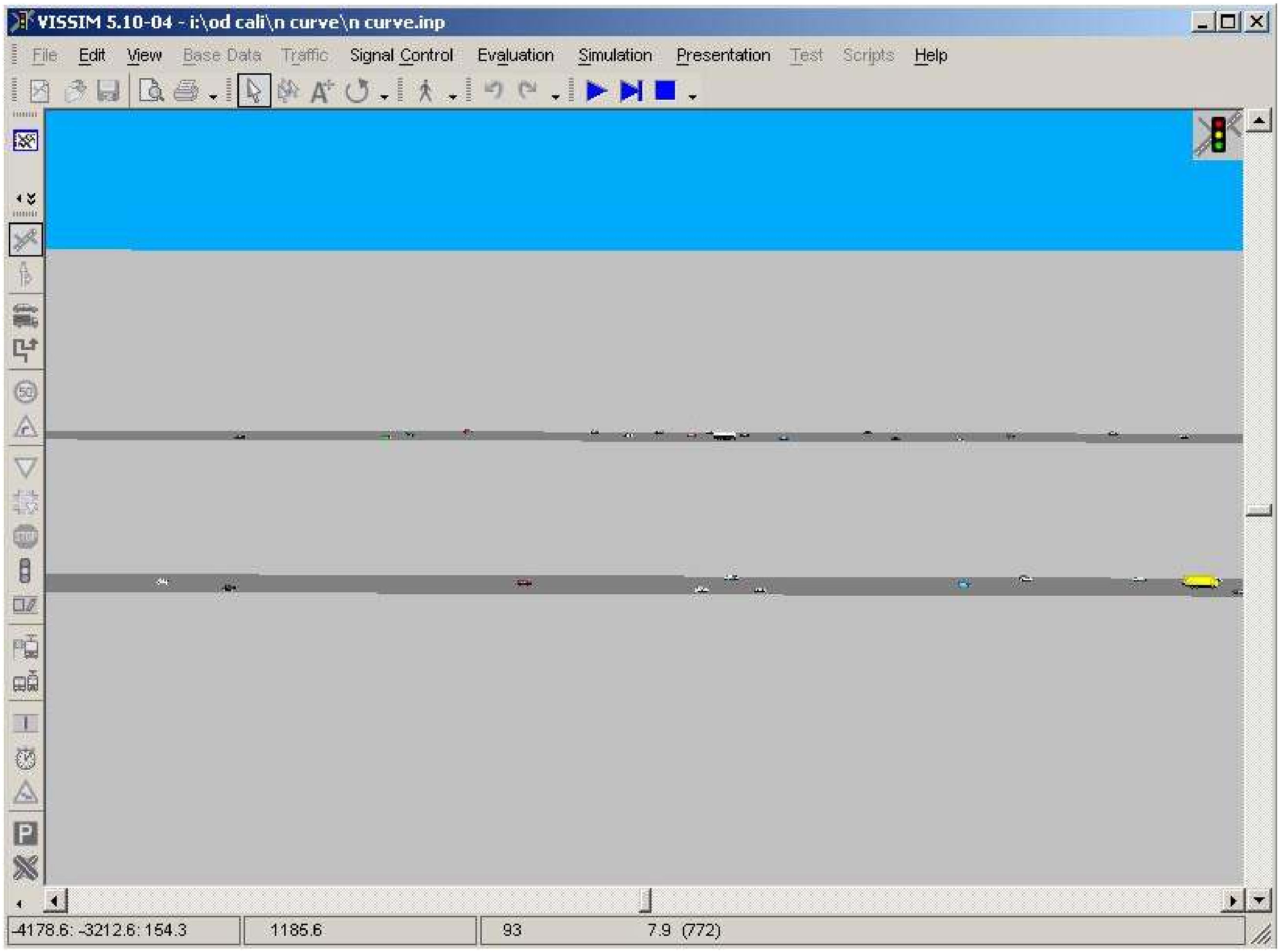
# Stage 2.4: Calibration Framework for network Case



# Numerical Example of the SOSB Case




Bottleneck
Lane drop (3 to 2)

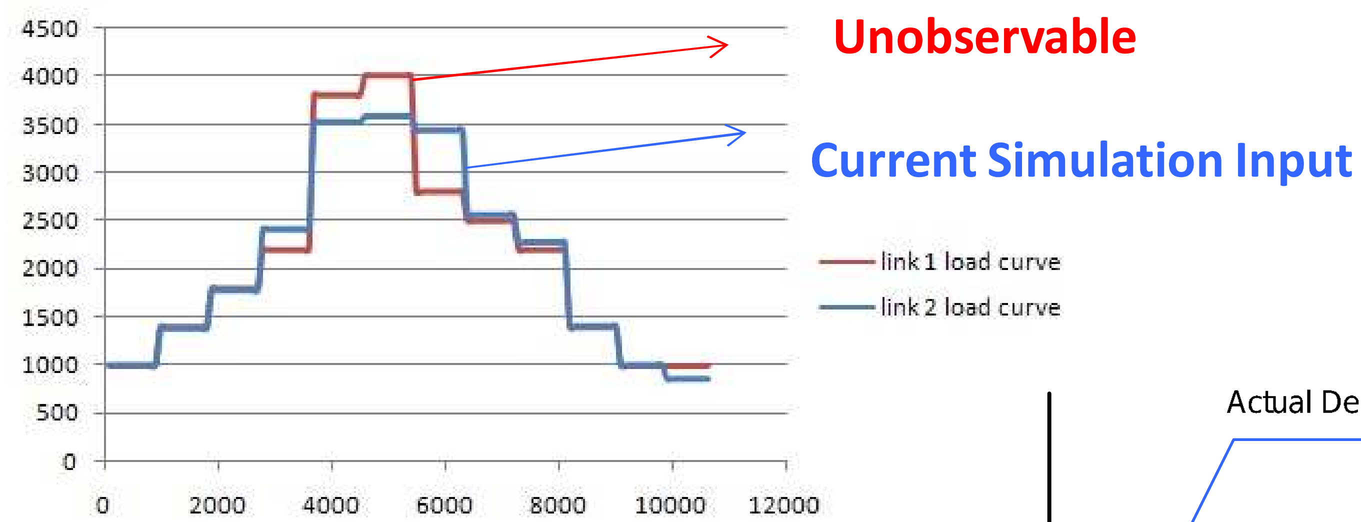


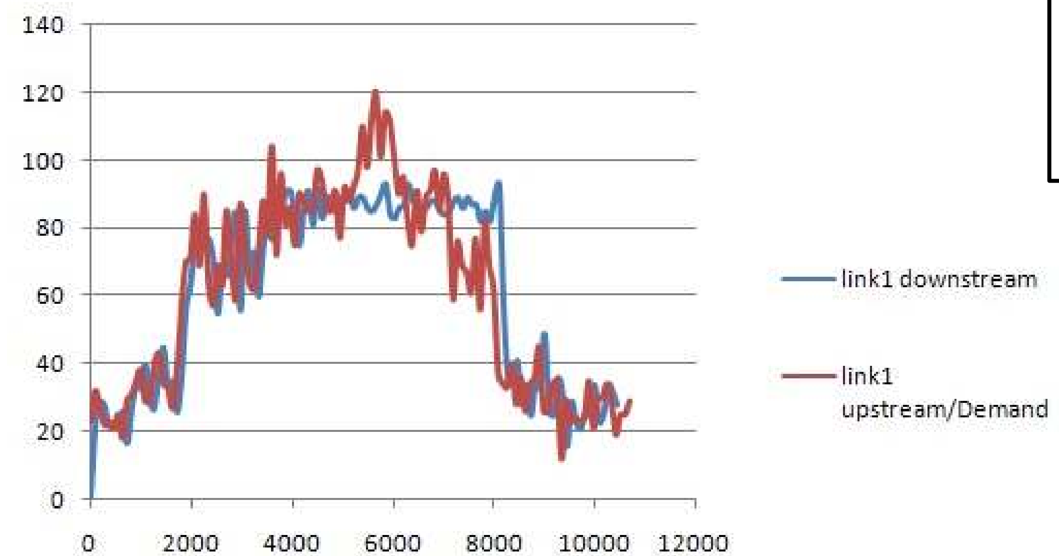

Real data "link1"

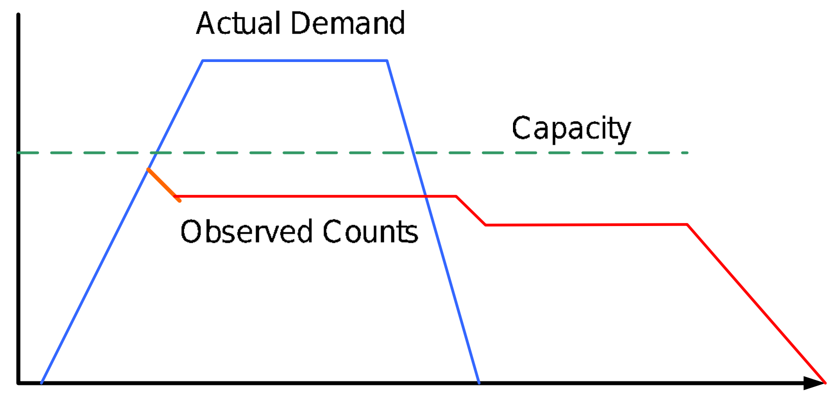
Simulation "link2"

# Numerical Example of the SOSB Case

Loading/Demand Curve



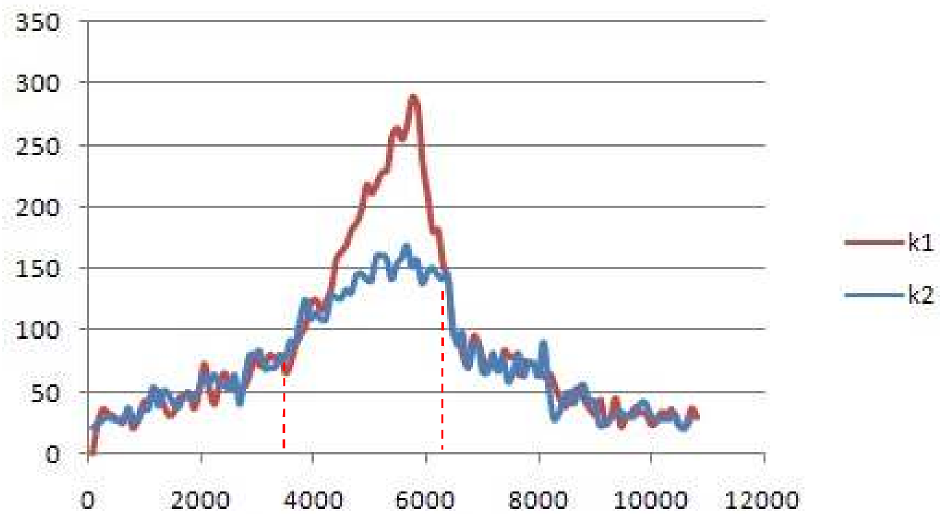



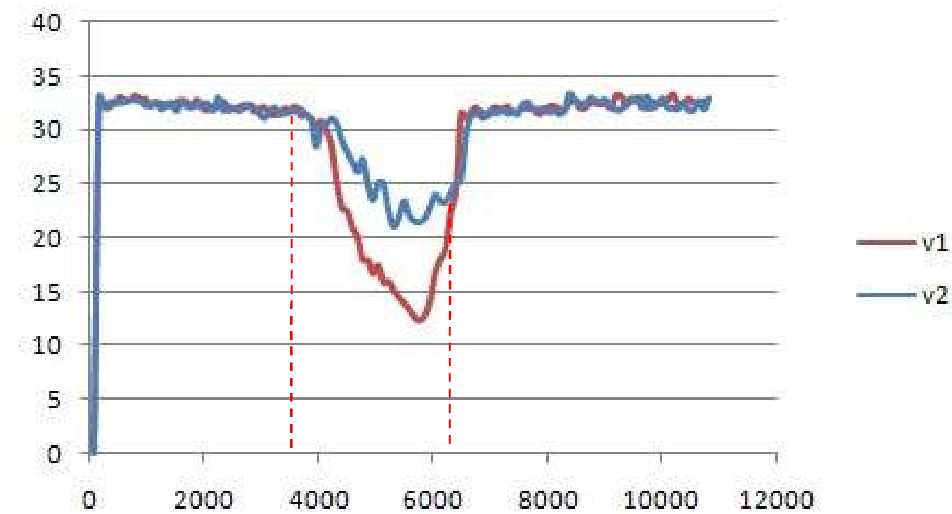

Actual demand vs Observed flow under capacity constraint

# Numerical Example of the SOSB Case

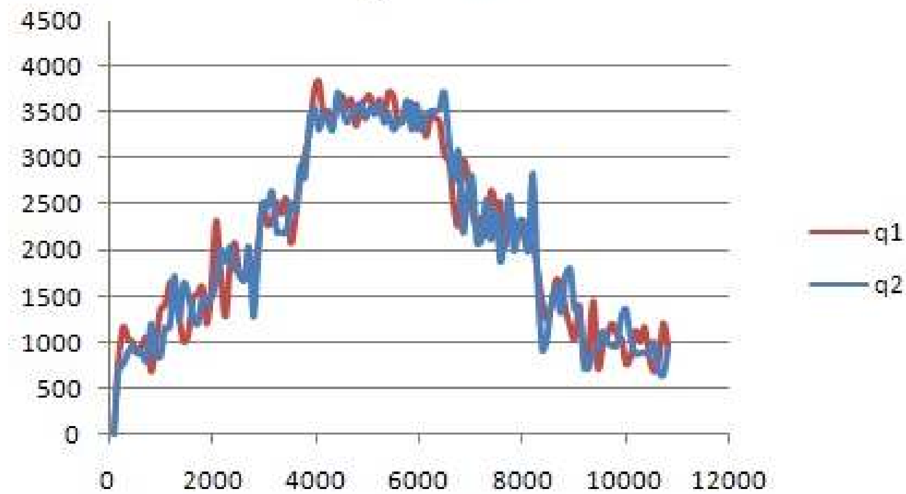
**Before calibration: q, k, v & N curves profile** $t_s = 3600 \quad t_e = 6300$



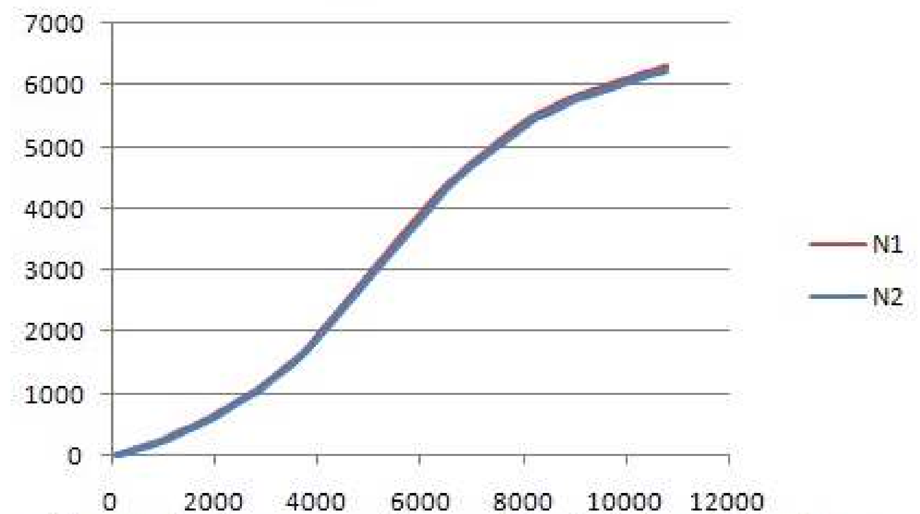

Density - time




Speed - time




Flow - time

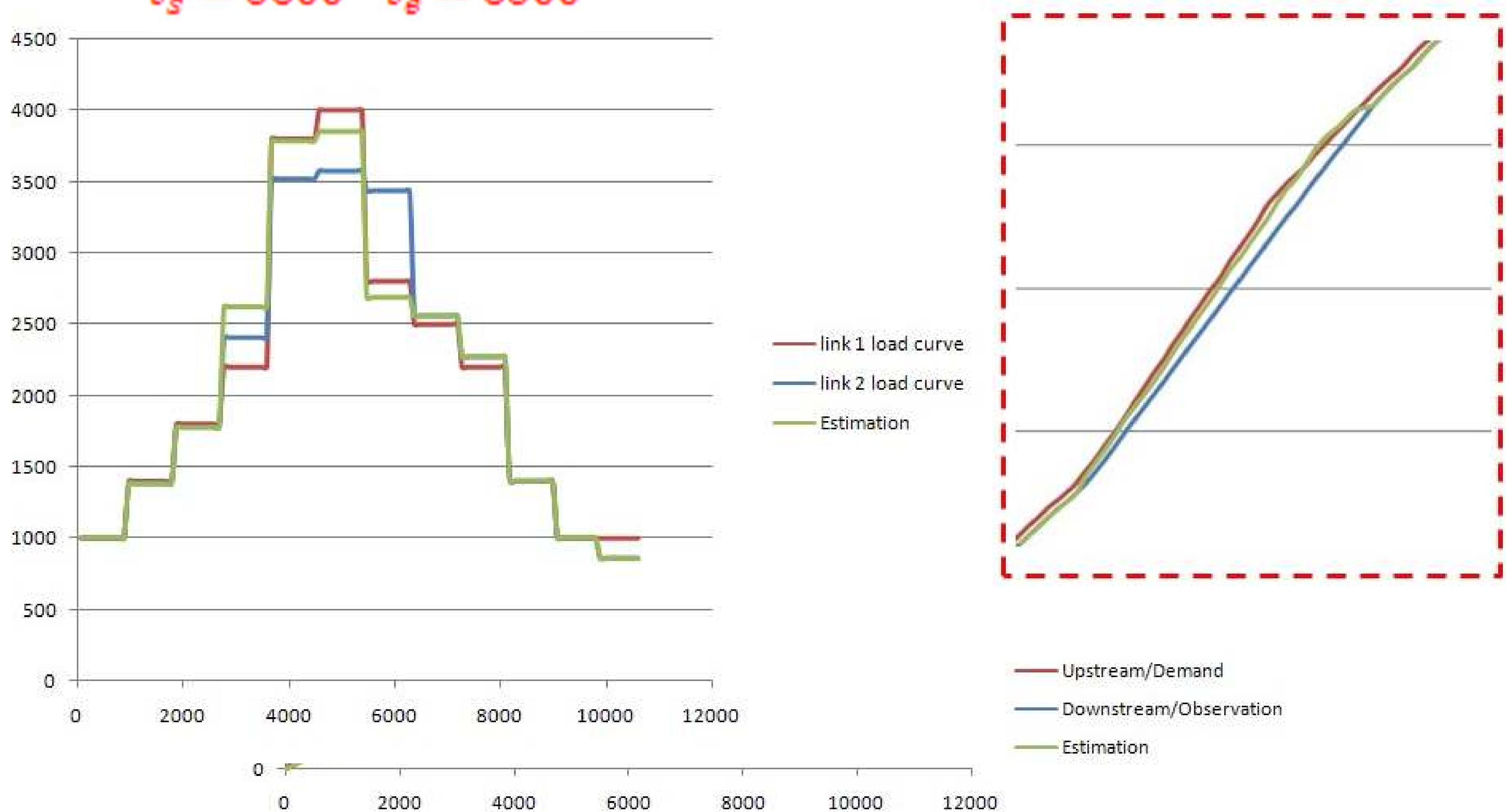



Cumulative number of vehicles N - time

# Numerical Example of the SOSB Case

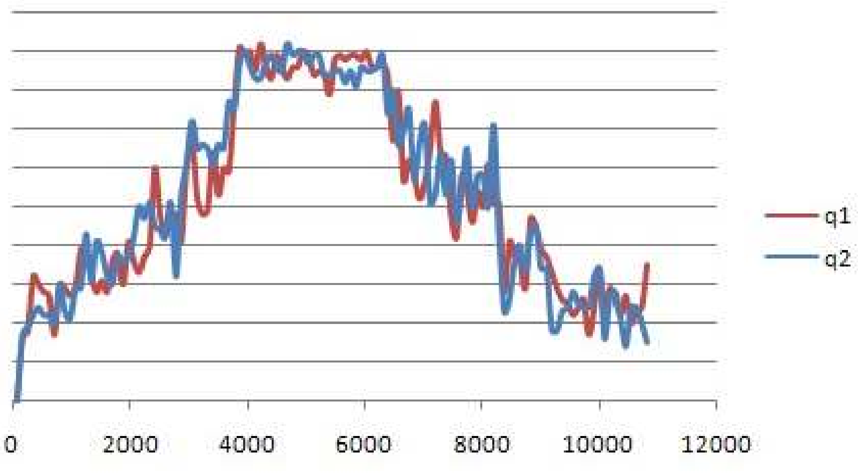
## Estimate Arriving N curves and map departure profile

$t_s = 3600 \quad t_e = 6300$

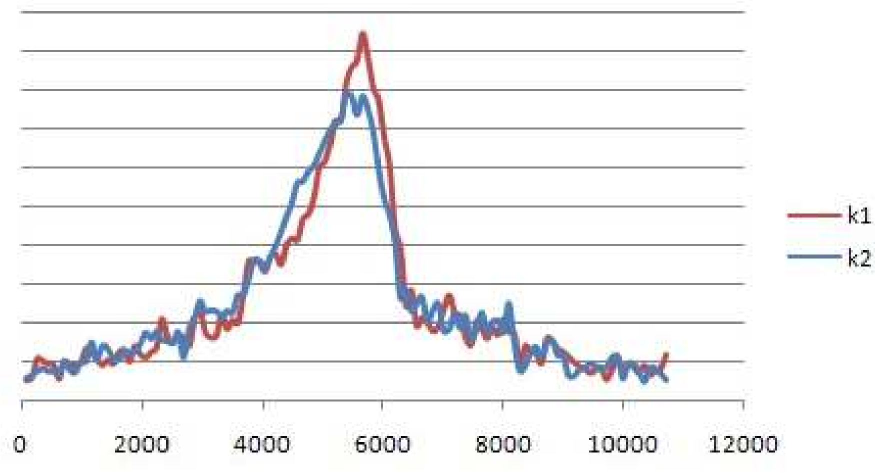


# Numerical Example of the SOSB Case

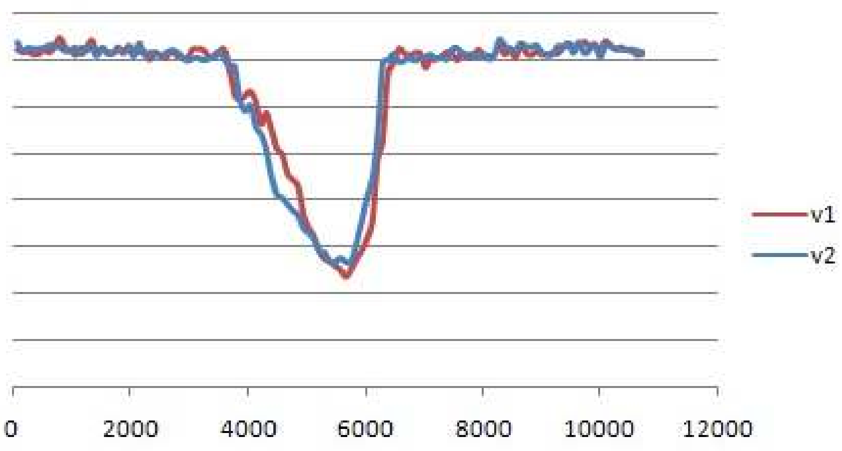
**After calibration: q, k, v & N curves profile**



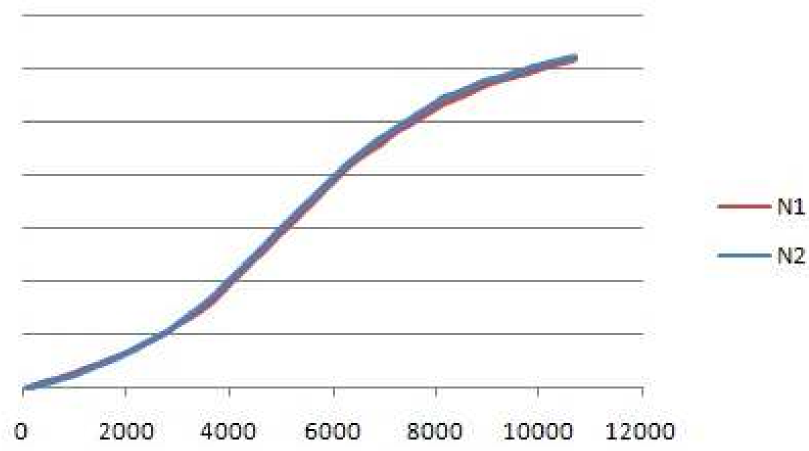

Flow- time




Density - time

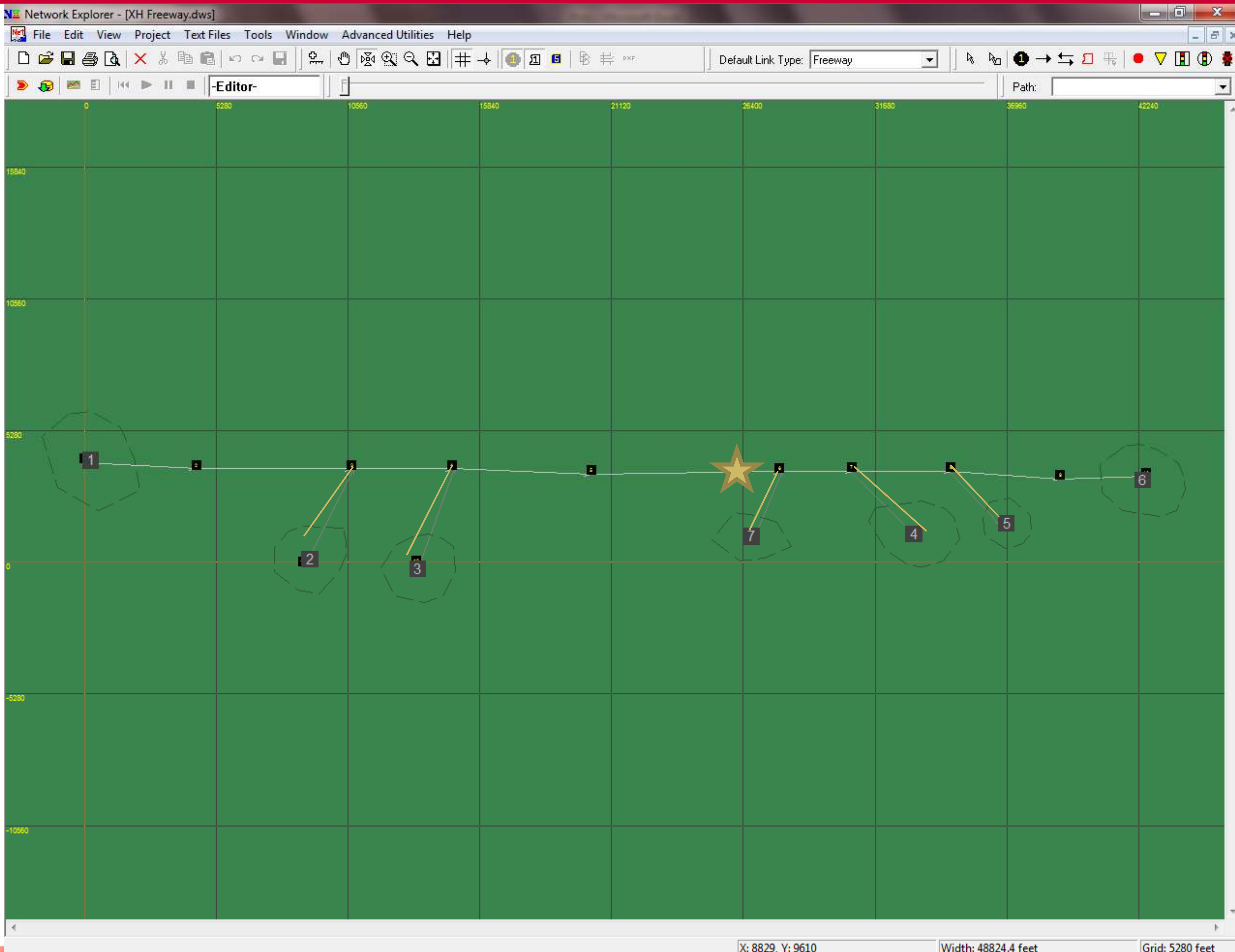


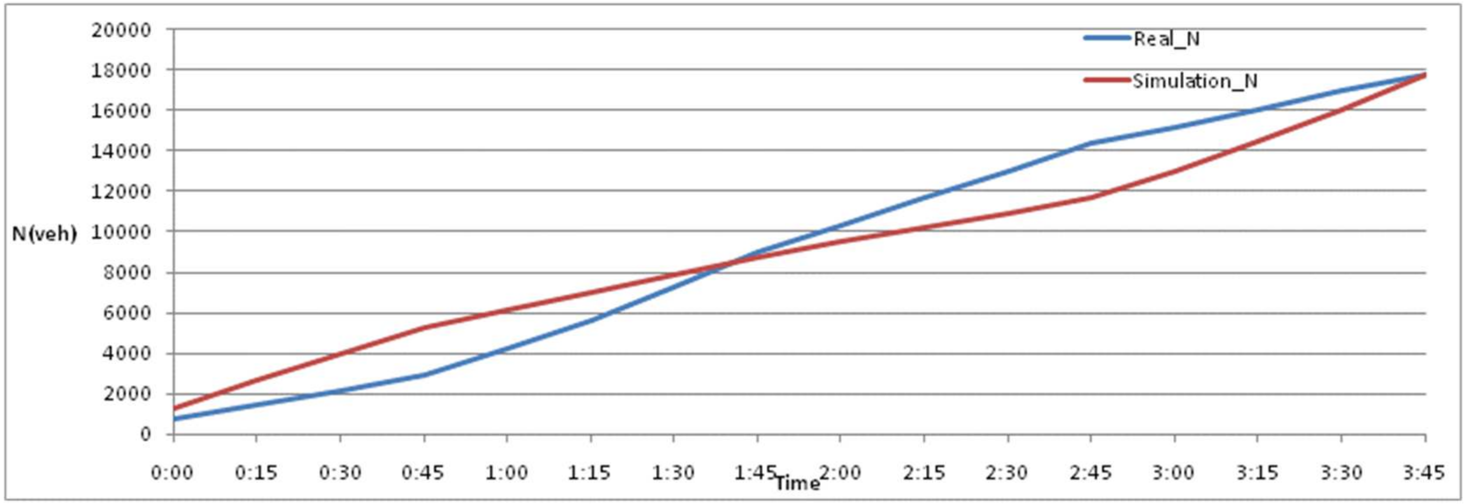

Speed - time

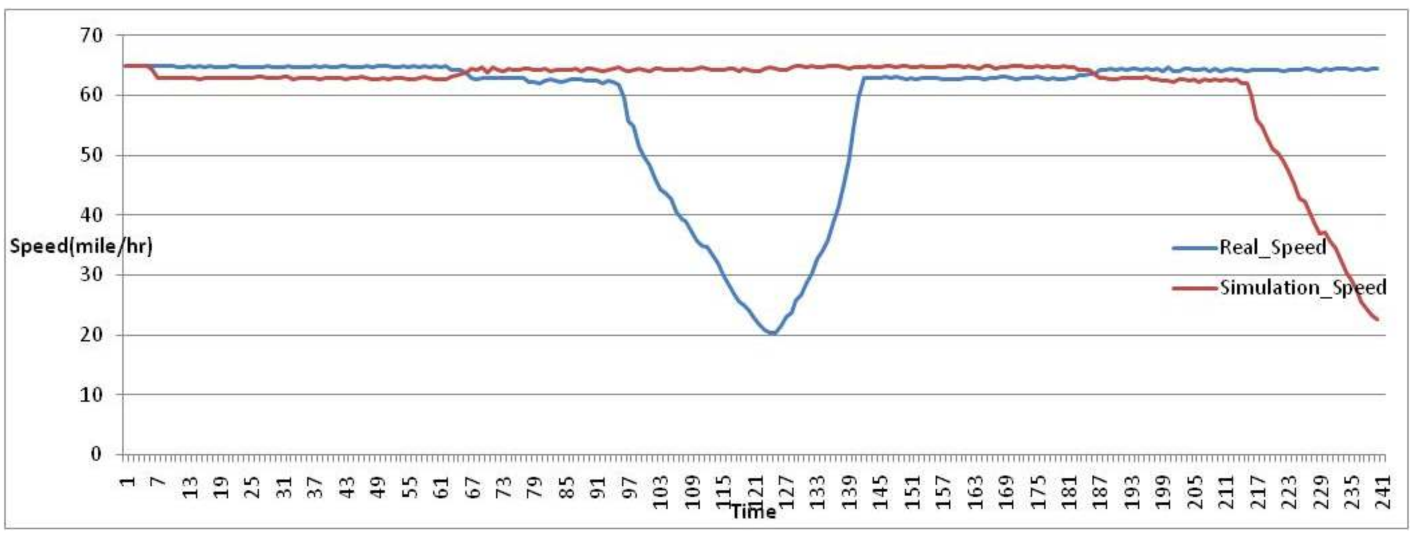


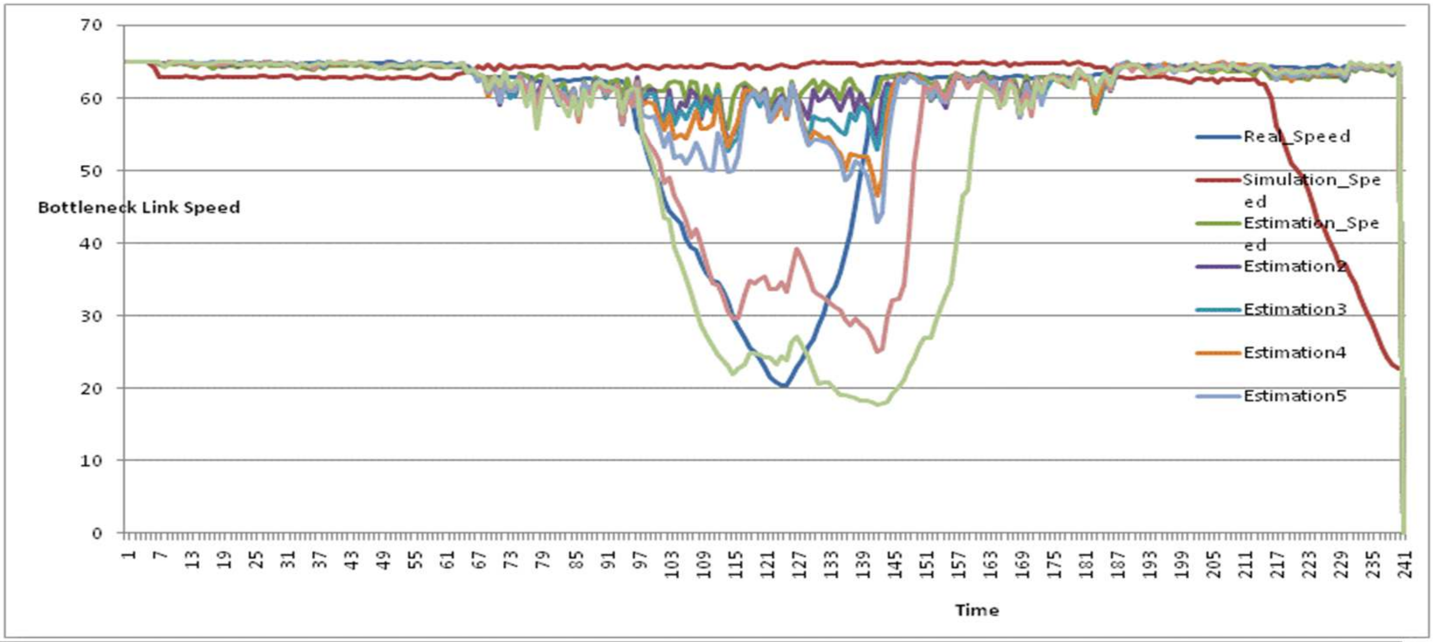

Cumulative number of vehicles N - time

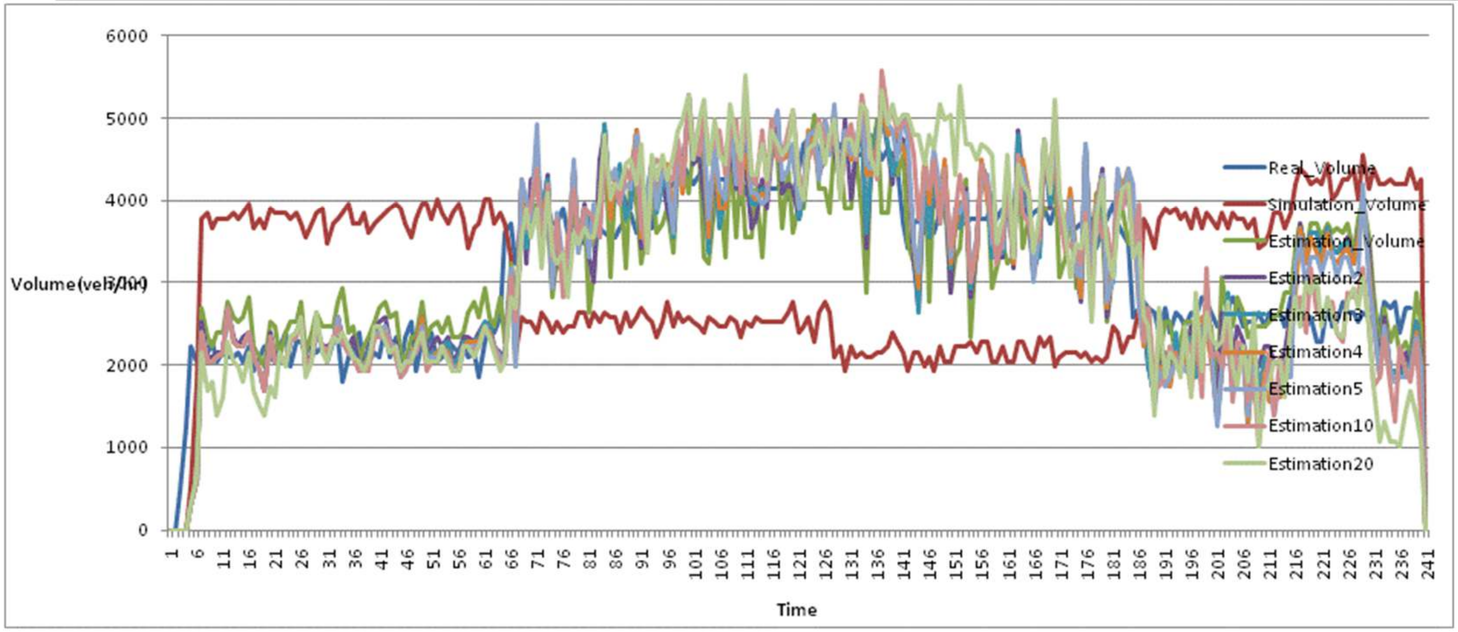
# MOSB Case (Large Initial Deviation)

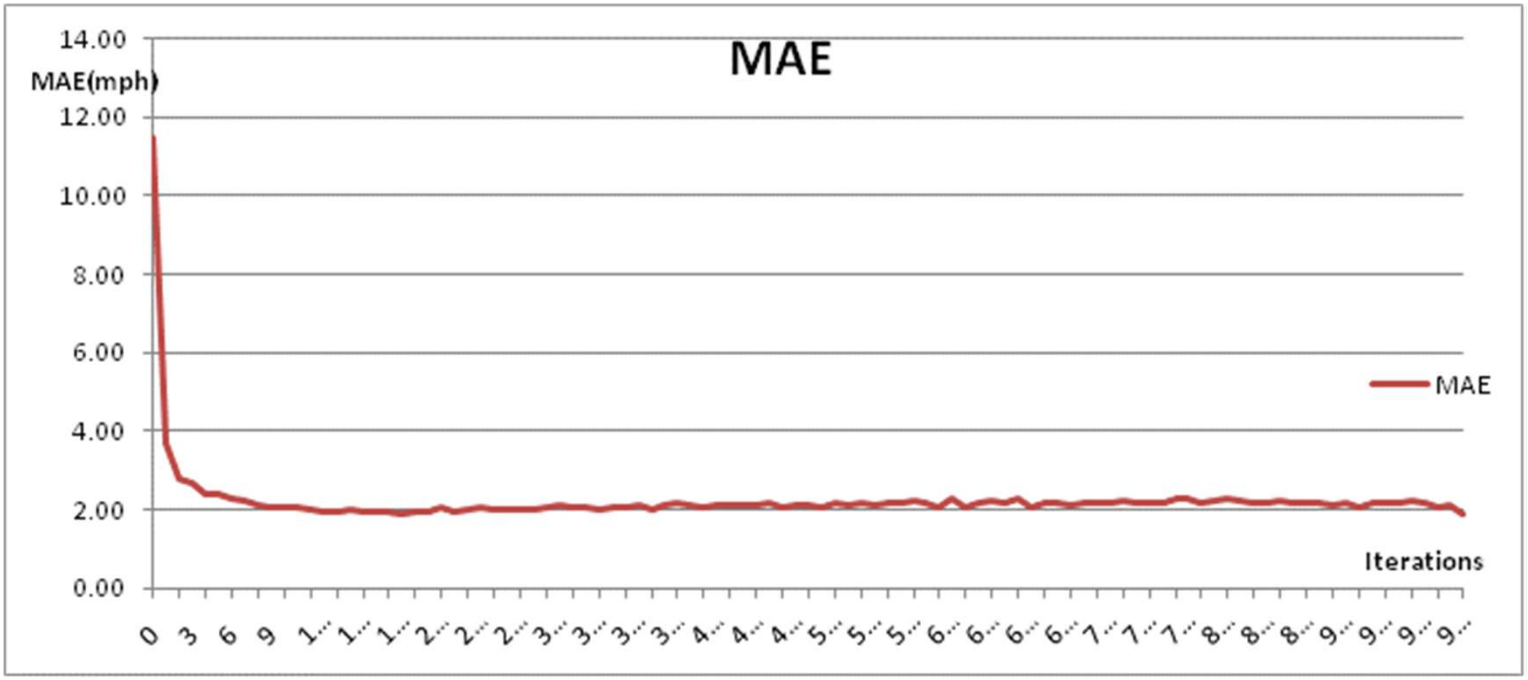



Real_N
Simulation_N
N(veh)
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
0:00
0:15
0:30
0:45
1:00
1:15
1:30
1:45
2:00
2:15
2:30
2:45
3:00
3:15
3:30
3:45
Time


Speed(mile/hr)
70
60
50
40
30
20
10
0
Real_Speed
Simulation_Speed
Time

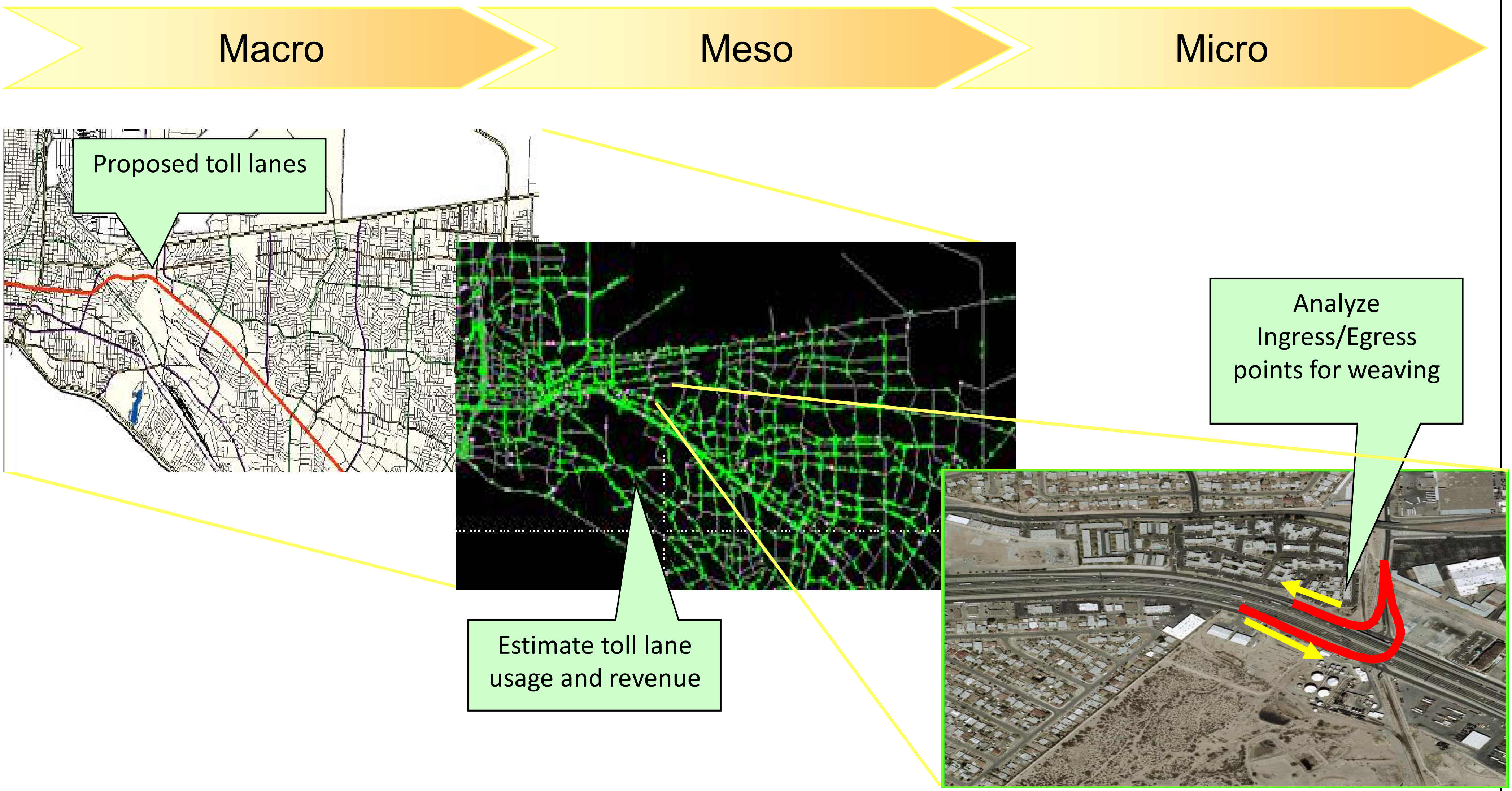

Bottleneck Link Speed
Time
Real_Speed
Simulation_Speed
Estimation_Speed
Estimation2
Estimation3
Estimation4
Estimation5


Volume(veh/hr)
Time
Real_Volume
Simulation_Volume
Estimation_Volume
Estimation2
Estimation3
Estimation4
Estimation5
Estimation10
Estimation20


MAE
MAE(mph)
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
MAE
Iterations

# Multi-Resolution Modeling (MRM)

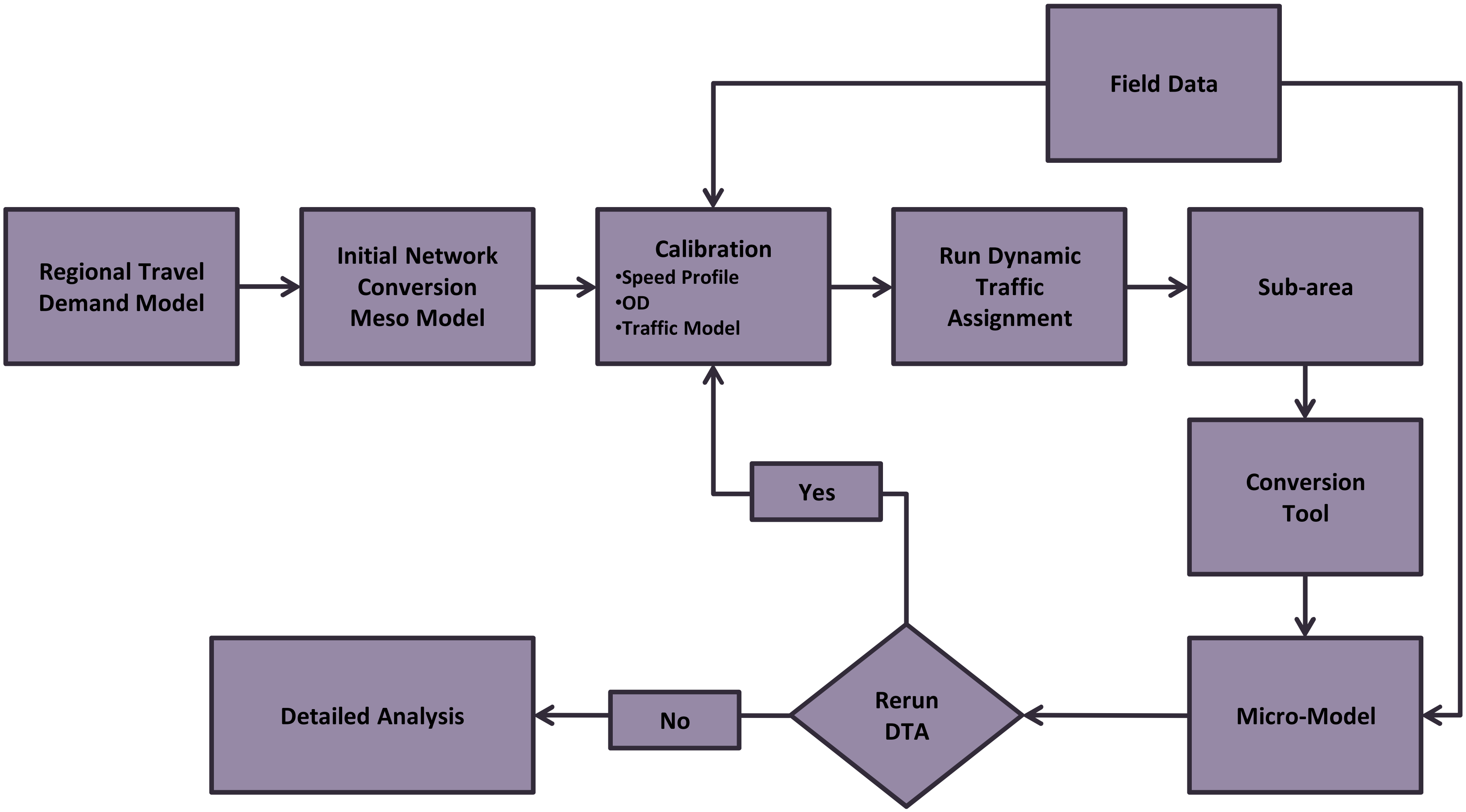
# Macro-Meso-Micro Integration



# Why is MRM Important?

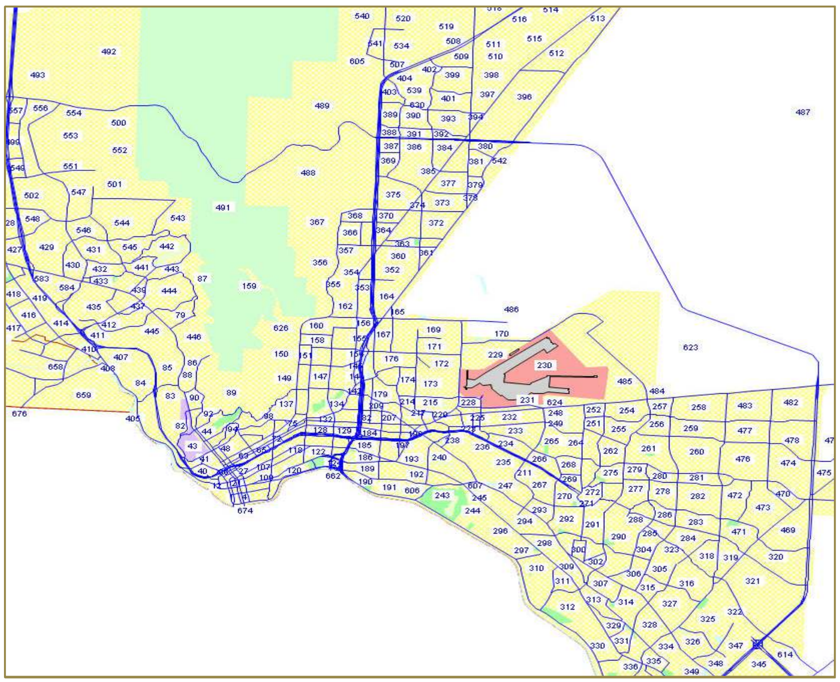
- Macro, meso and micro models are not mutually exclusive
- They are complimentary to one another and can accomplish optimal modeling capabilities
- Retain the best characteristics of each model
  - Incorporate multiple trip purposes
  - Realistic representation of regional traffic in baseline and future years
  - Provide realistic inputs to micro models
  - A wide range of visual representation of model outputs

# Network Conversion



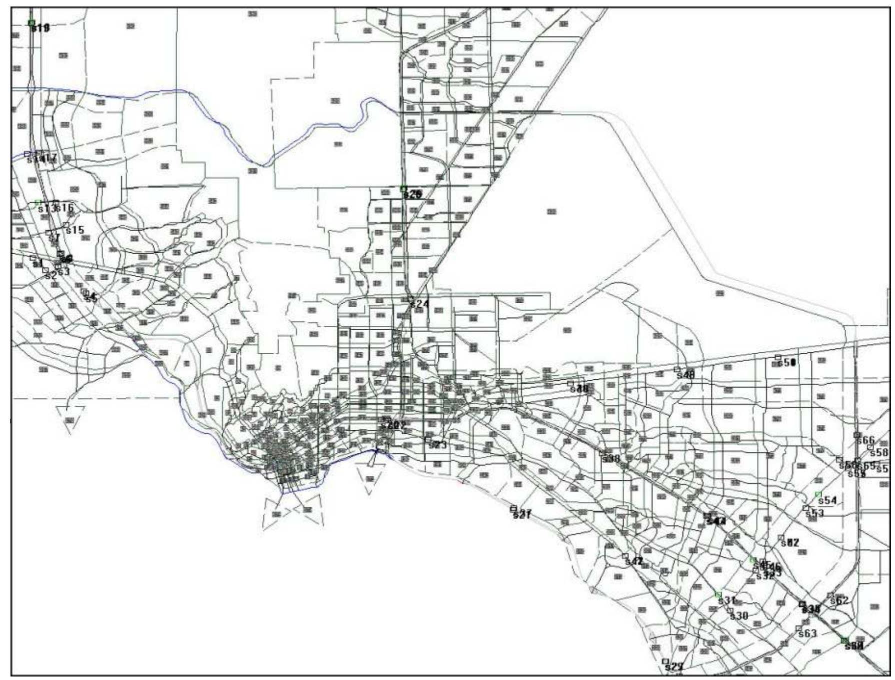

Macro –> Meso -> Micro

# Network Conversion



TDM

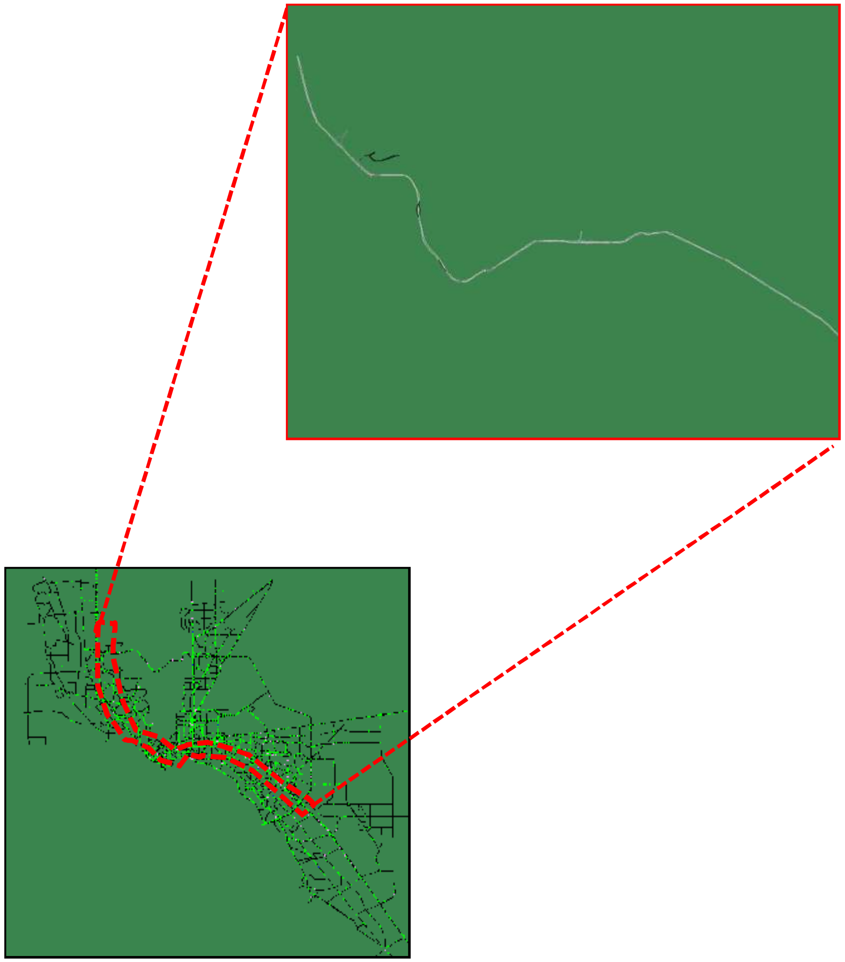
Links
Nodes
Zones



DTA model

# Network Conversion

- Network run to DUE
- Sub-area cut
  - **Remove unneeded sections of network**
  - **Renumbering of new zones, nodes and links**
  - **Retain paths and flows that travel through the sub-area**



# Network Conversion

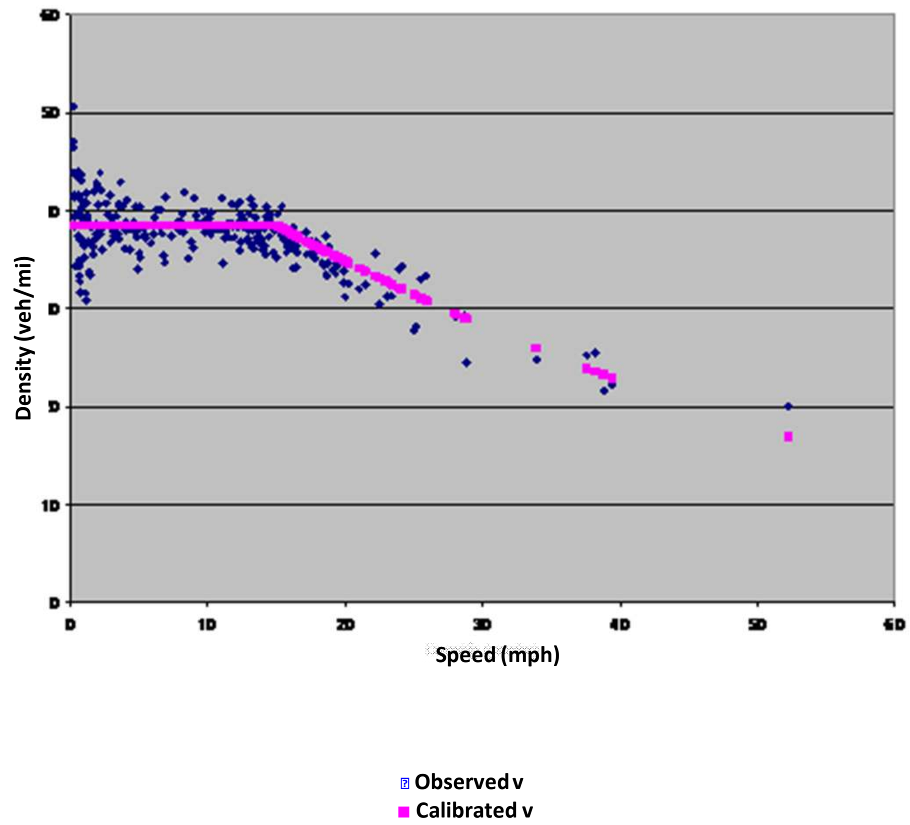
- Meso-Micro Converter
  - **Developed by researchers from TTI and UA**
  - **Converts roadway network to Macro network**
  - **Retains network geometry**
  - **Converts all time-dependent paths and flows**
  - **Creates separate transportation systems (car, truck)**

# Network Conversion

- Microscopic model
  - **Calibrate Micro model to reflect realistic roadway conditions**
  - **Perform detailed "fine-grained" analyses**
    - Speed profile for individual lanes
    - Lane-changing behaviors
    - Vehicle interactions at merge areas
  - **Create 3-D graphics for presentations**

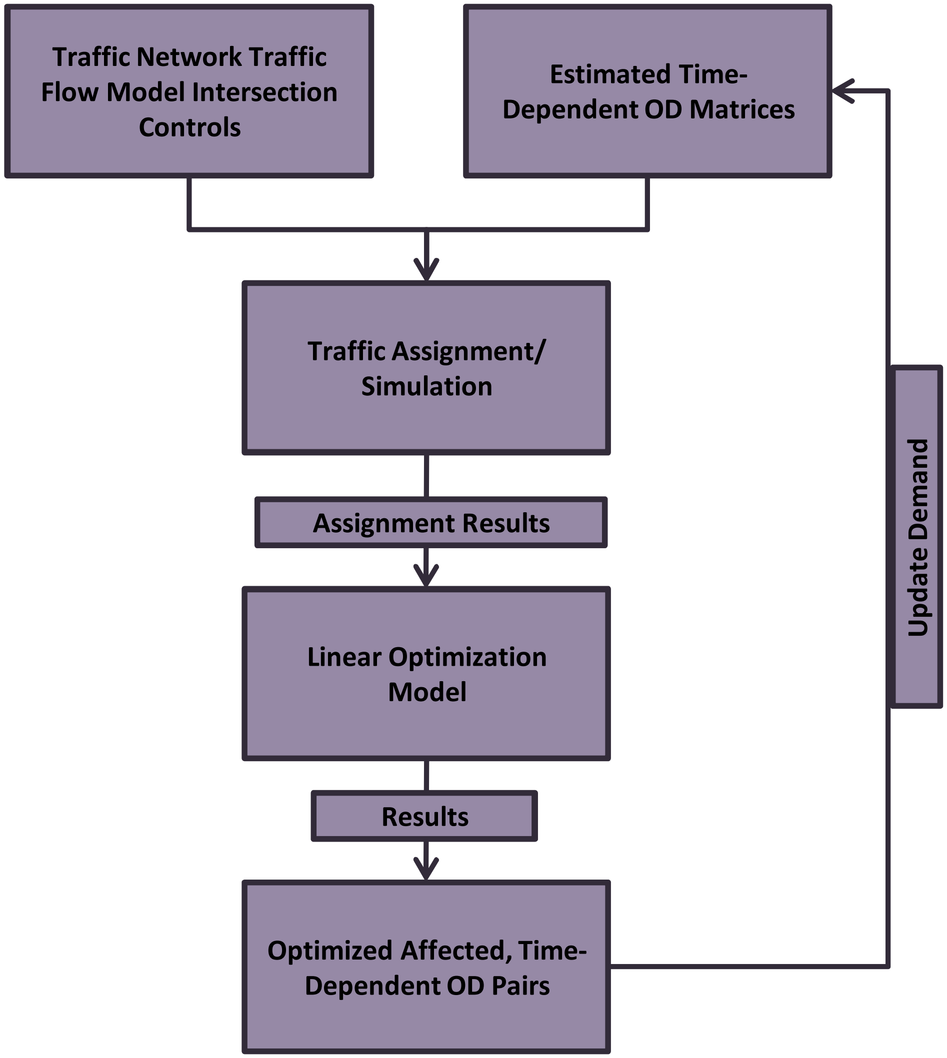
# Calibration

- Traffic flow model
  - **Traffic simulation in DynusT is based upon the Anisotropic Mesoscopic Simulation (AMS) model**
  - **Moves vehicle based upon speed-density (v-k) relationship**
  - **v-k relationship is derived from Greenshield's equation**



# Calibration

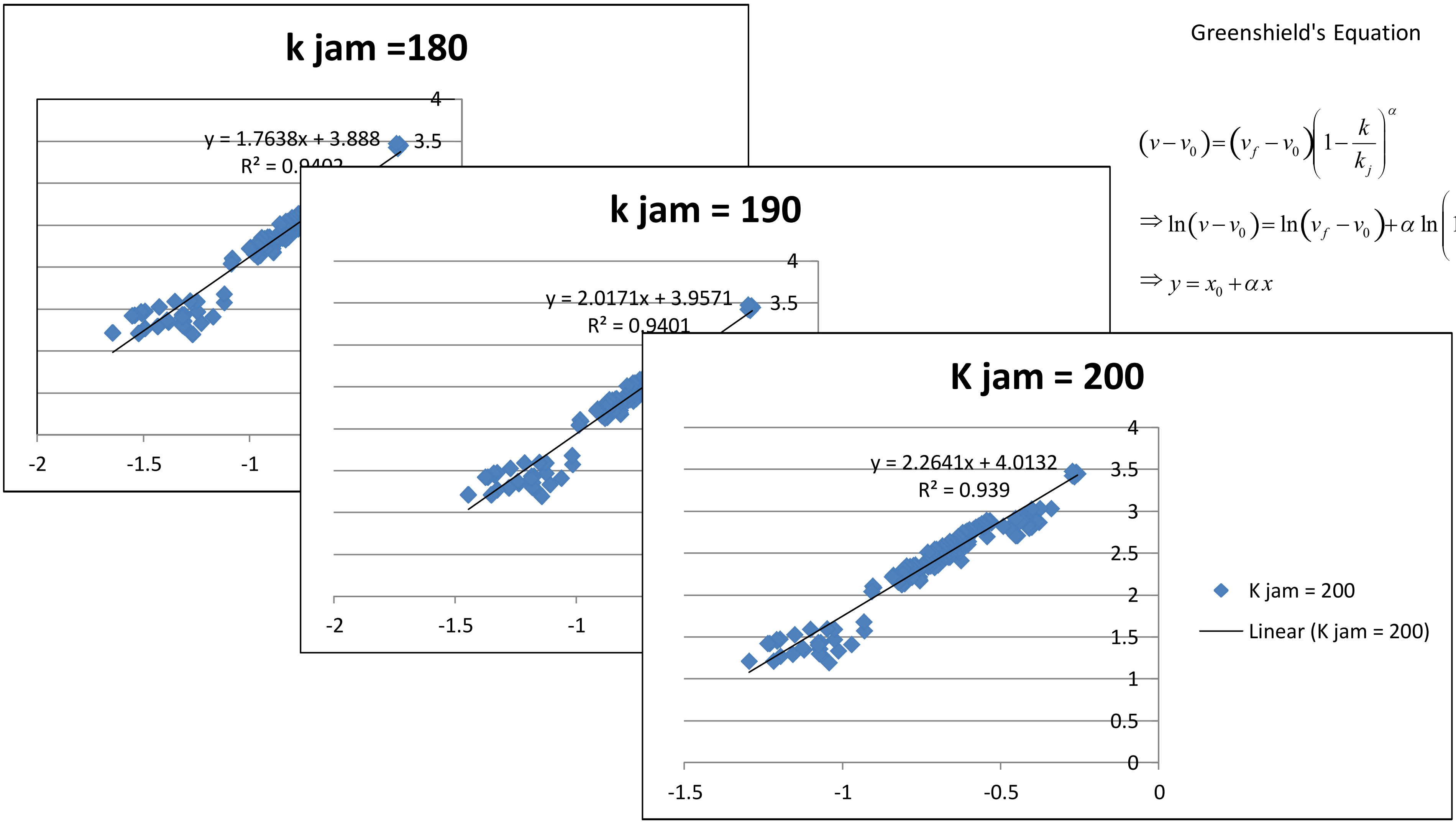
- Time-dependent OD
  - **Minimize the deviation between simulated and actual screen line counts & speed profile**
  - **Iterative process**
  - **Program solves linearized quadratic minimization problem**
  - **Results in updated OD matrices**



# Consistency

- Network
  - Lane configuration
  - Geometric design
- Paths and flows
  - Verify same origin/destination paths
  - Verify number of vehicles generated
- Speed profile
  - Perform field data collection to determine speed and vehicle counts
  - Obtain v-k curve from simulation output
  - Calibrate models with field data

# Consistency




Greenshield's Equation

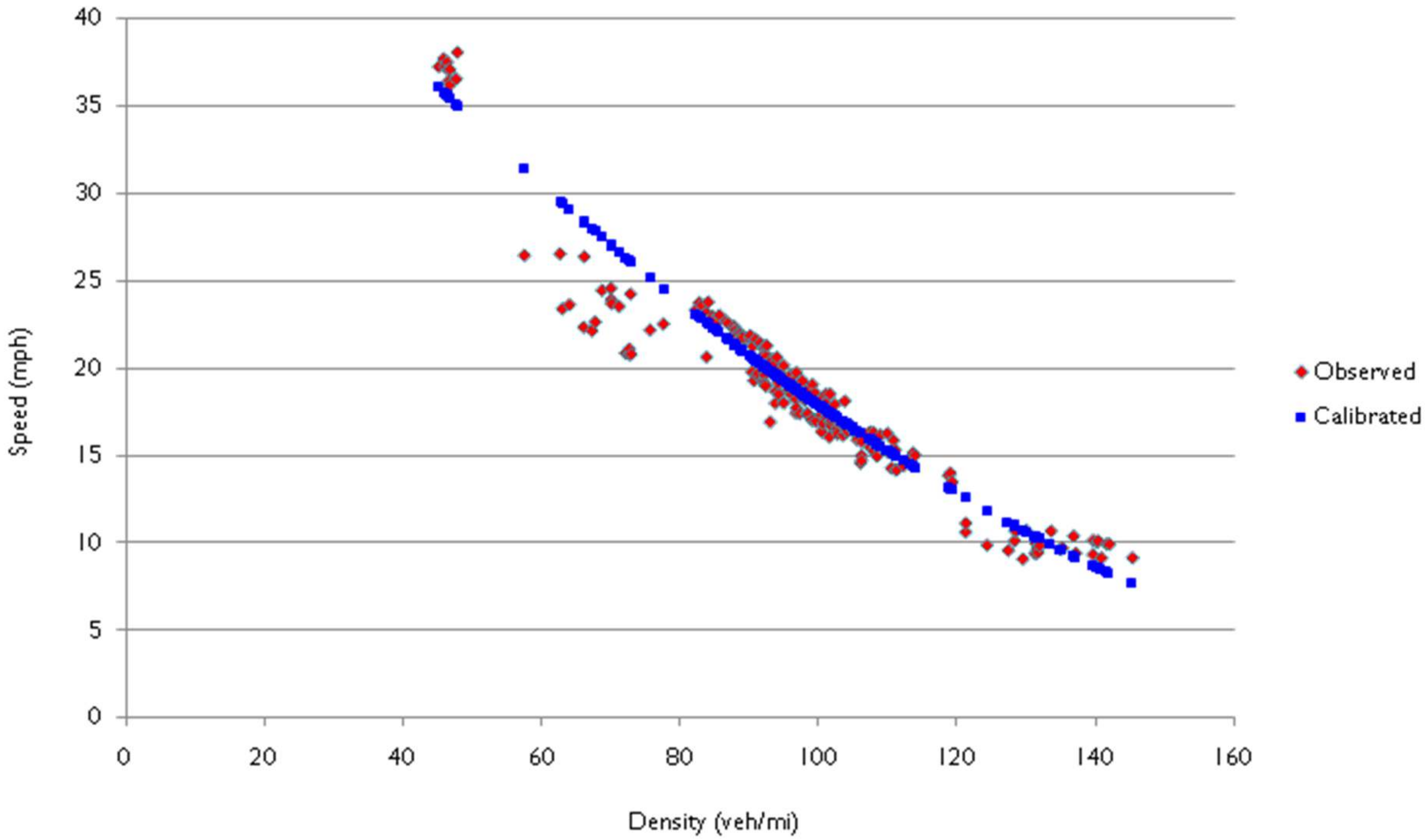
$$(v - v_0) = (v_f - v_0)\left(1 - \frac{k}{k_j}\right)^{\alpha}$$

$$\Rightarrow \ln(v - v_0) = \ln(v_f - v_0) + \alpha \ln\left(1 - \frac{k}{k_j}\right)$$

$$\Rightarrow y = x_0 + \alpha x$$

The density at which traffic stops

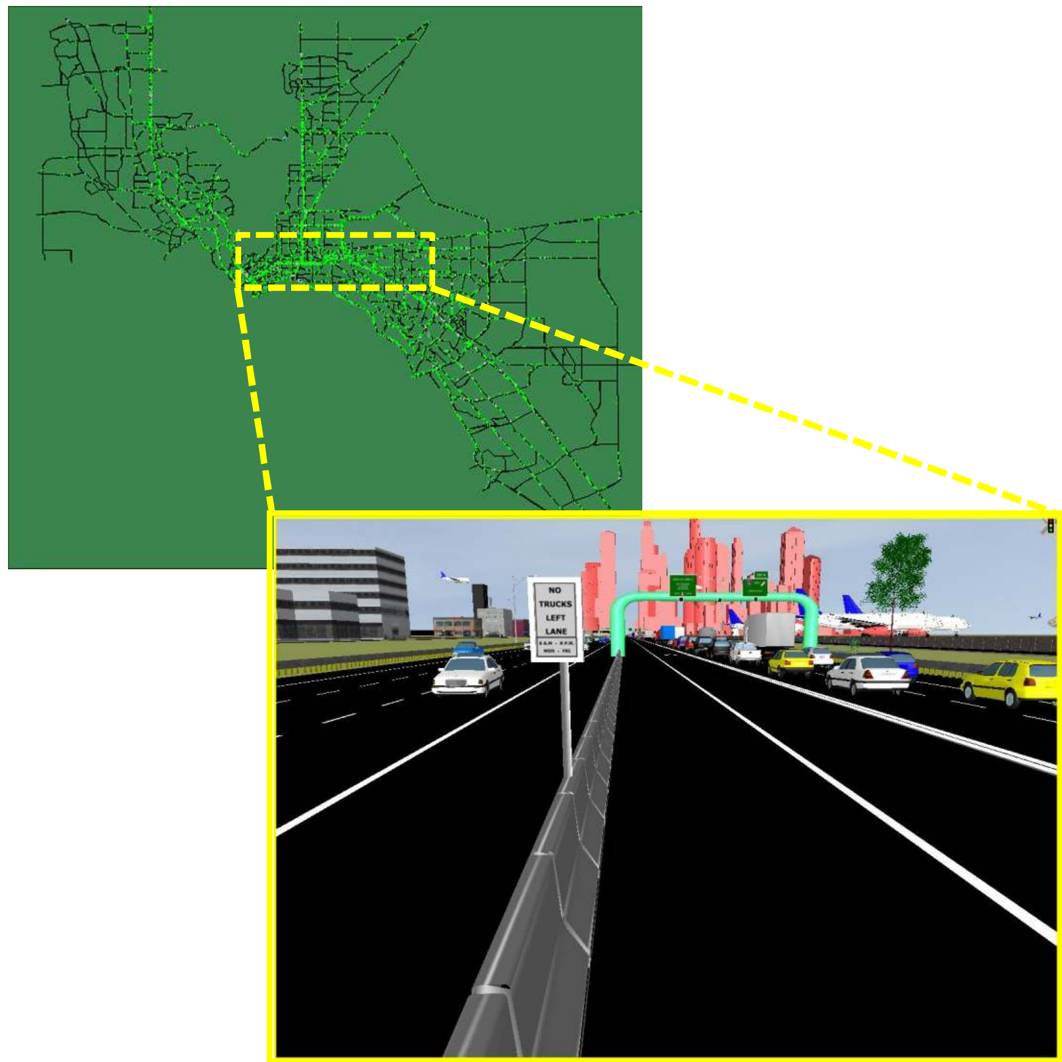
# Consistency




Speed profile calibrated with field data

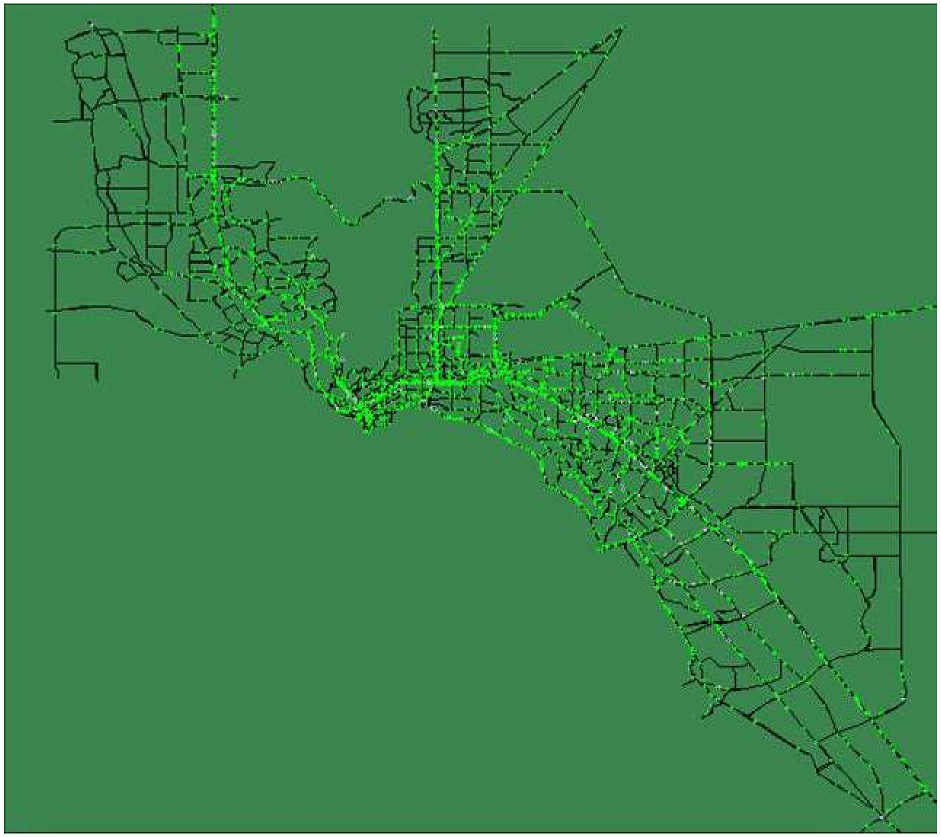
# Case Study 1 – Truck Restricted Lanes (TTI)

- DTA model estimates region-wide truck and car trajectories (time-dependent paths and flows)
- Micro model gives detailed I-10 truck lane operations with truck trajectories



# Case Study 1 – Truck Restricted Lanes (TTI)

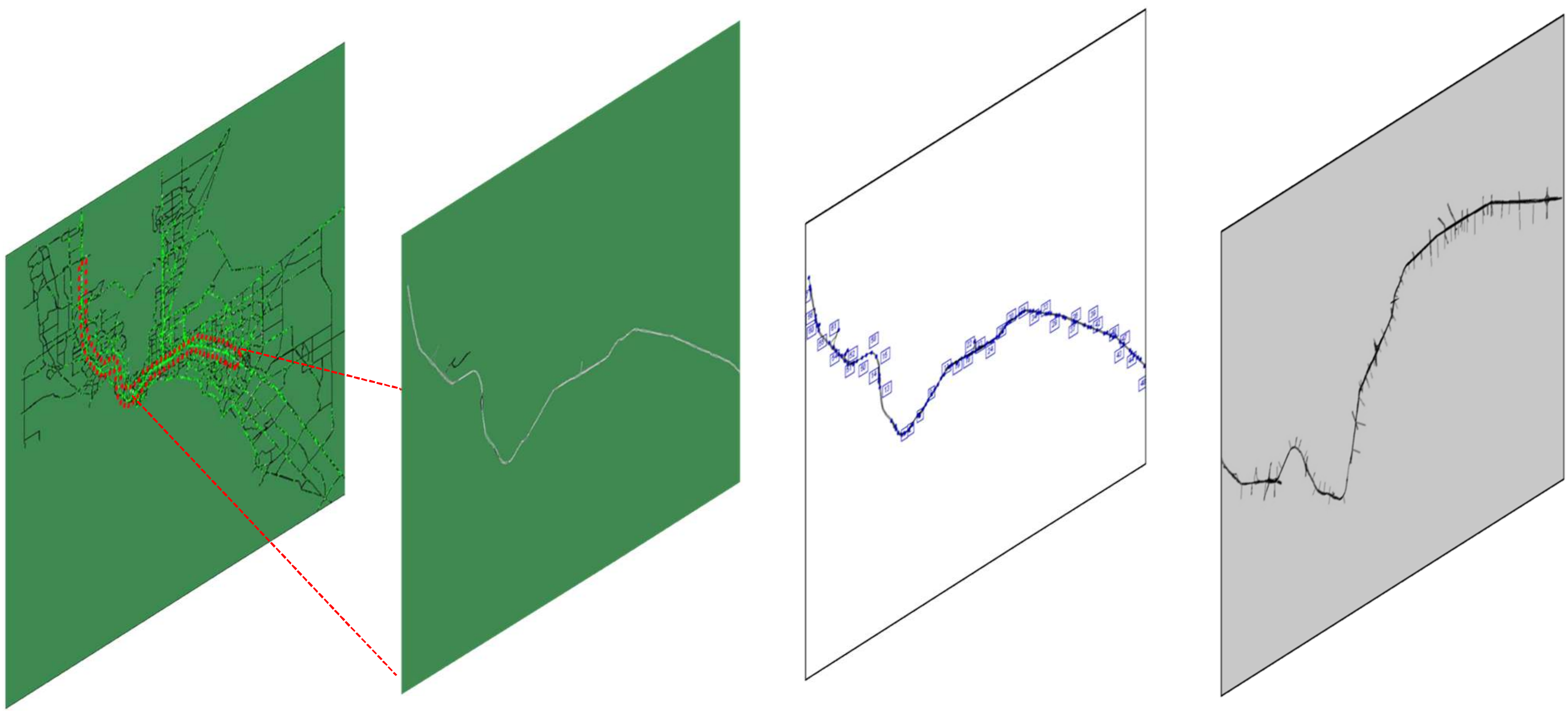
- Simulate entire El Paso network to equilibrium conditions
- Use separate demand matrices for auto & truck



# Case Study 1 – Truck Restricted Lanes (TTI)

- Sub-area cut of corridor was extracted
- Conversion tool was used to translate the roadway network, paths & flows to macro model
- Using macro models export capability, a microscopic simulation model was imported to microscopic format

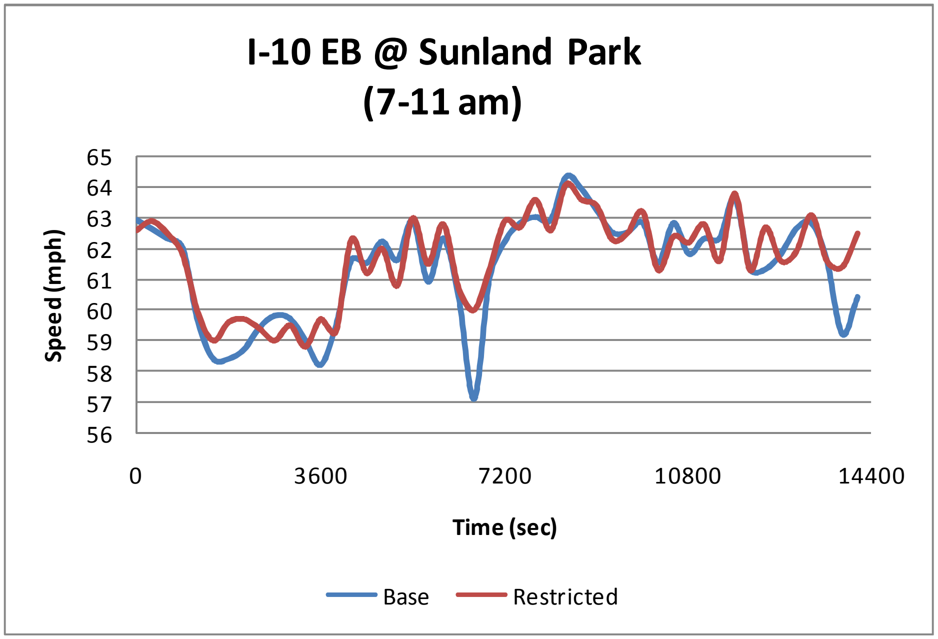
# Case Study 1 – Truck Restricted Lanes (TTI)

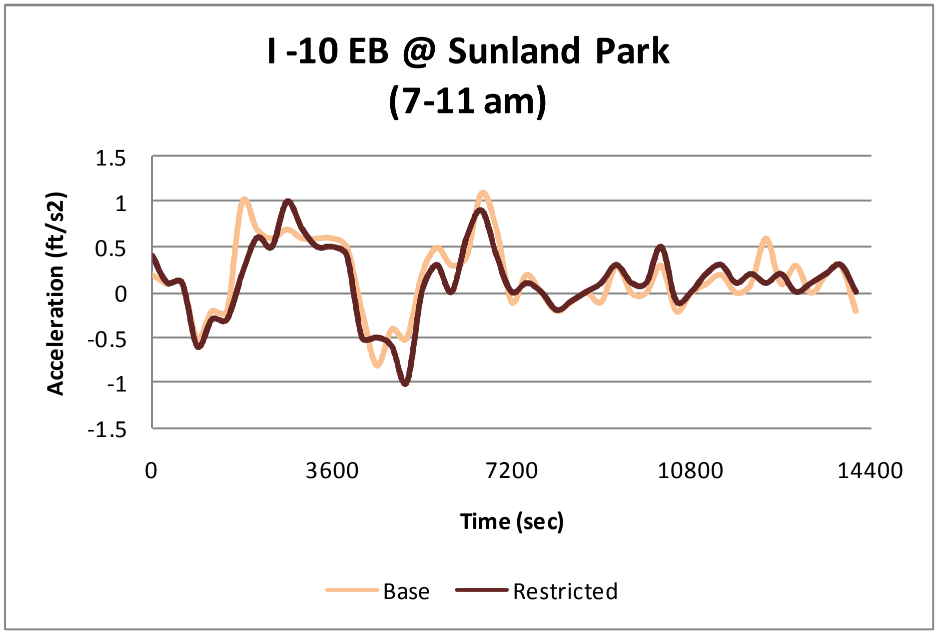


# Case Study 1 – Truck Restricted Lanes (TTI)

- If modifications in the micro model change driver behavior (alters routes), changes must be reflected in DTA model and conversion process begins again.
- If no additional changes are needed, micro model development begins

# Case Study 1 – Truck Restricted Lanes (TTI)



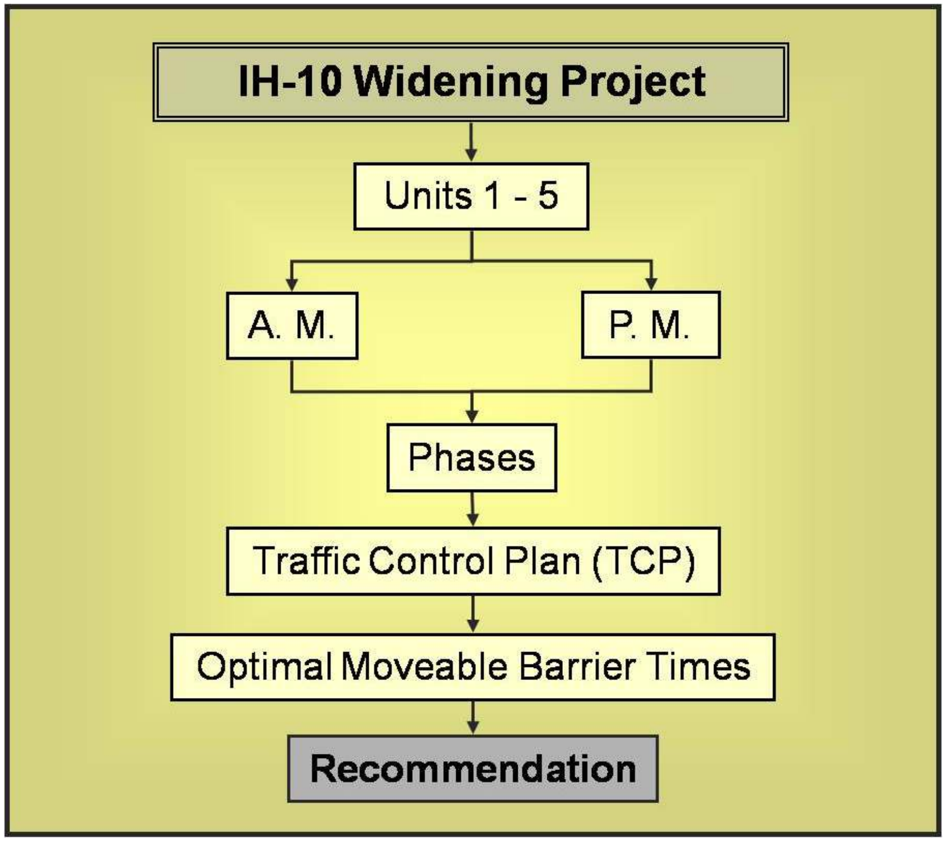

Speed

Accel/Decel

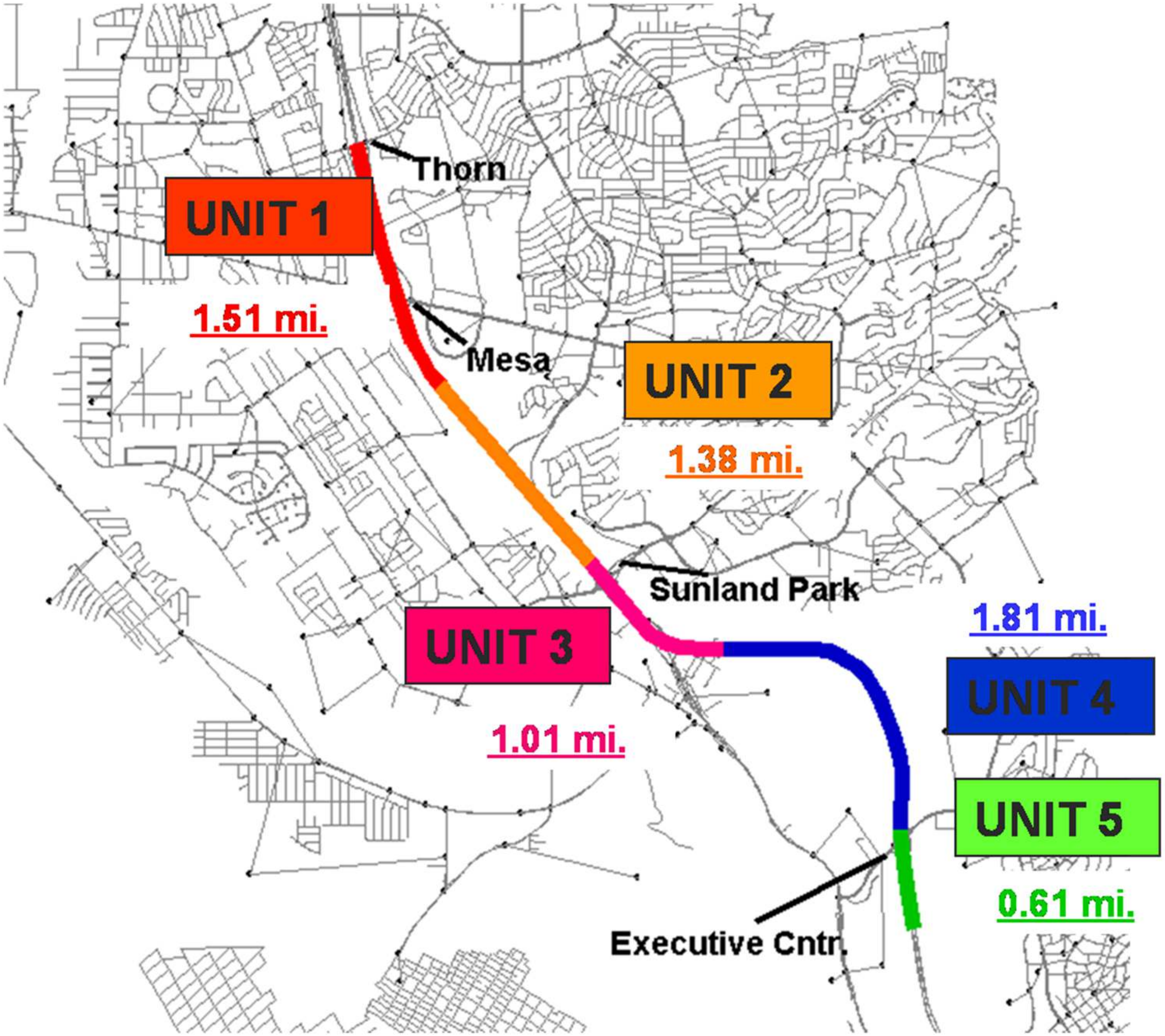
Speed profile calibrated with field data

# Case Study 3 – Work Zone Mobility

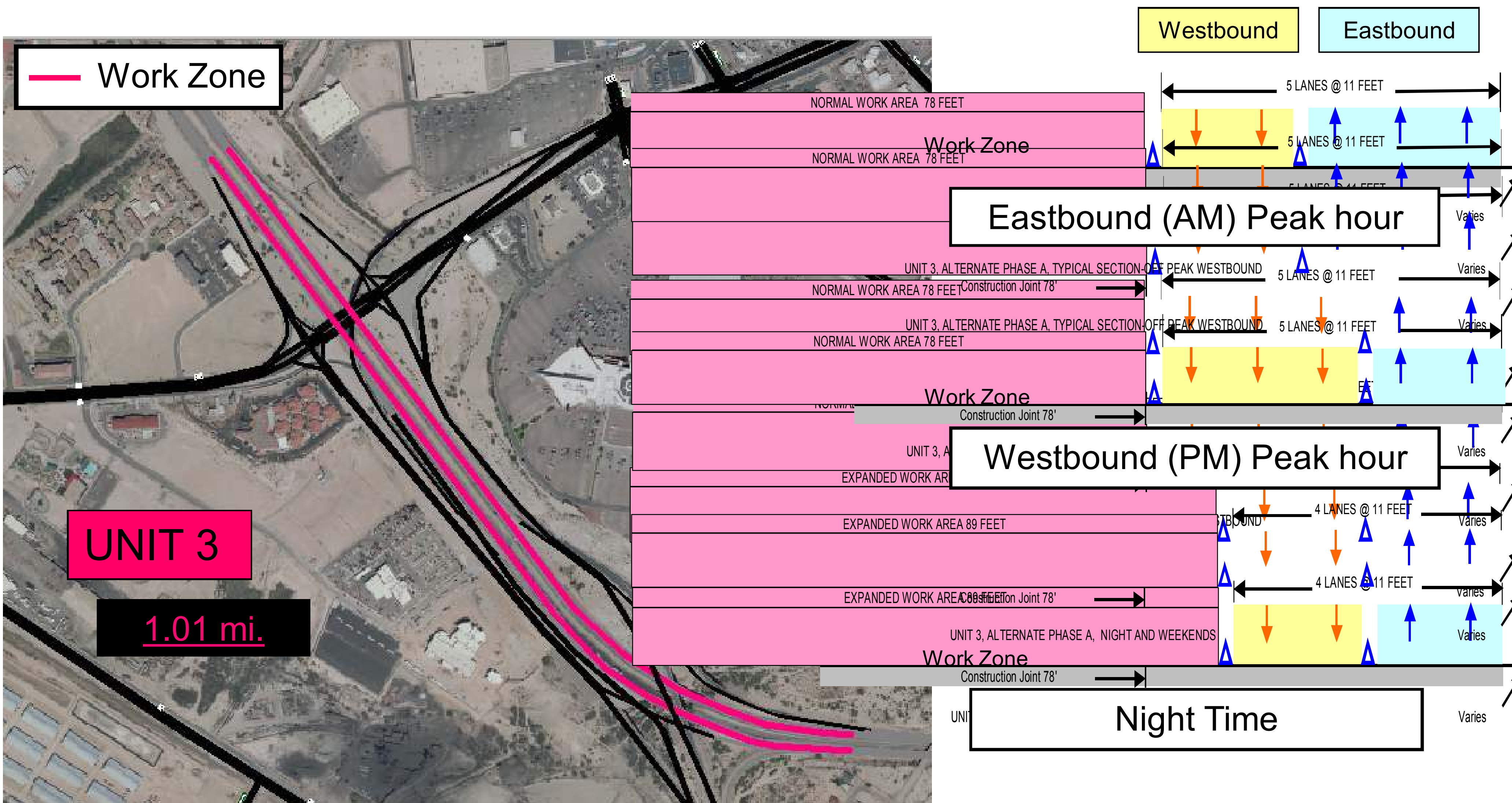
- Construction sequencing for addition of freeway lane
  - **TxDOT wants to widen section of I-10 in western portion of El Paso**
  - **Construction divided into 5 section areas**
  - **Determine optimal construction sequencing for TCP with moveable barriers**



# Case Study 3 – Work Zone Mobility



# Case Study 3 – Work Zone Mobility




**Determine optimal traffic flow in work zone during peak/non-peak hours using movable barriers**

# Incident Response Behavioral Routing (Evacuation)

# Incident Diversion Rules (Short-Term Reaction)

- Delay-Responsive Diversion
  - A traveler may switch to a different route by comparing his remaining trip time with his/her ***experience*** when no other information is available
  - Applicable to: all (100% Pre and Post ICM)
- Pre-trip information
  - A traveler has an experienced historical path, but checks for the current network condition at departure and selects the best available path if:
    - (1) his/her historical path is impacted by an incident
    - (2) estimated delay exceeds a threshold N(15,2)
  - Applicable to: a sub-set of travelers

# ICM Incident Diversion Rules

- En-Route Information
  - A traveler is equipped with a in-vehicle device, or is able to receive updated information to access travel time for the remaining trip of the original route and a new route (auto route only)
    - Information updated every 10 min
    - Switch if travel time saving on the new route exceeds a threshold (5 min)
  - Applicable to: a sub-set of travelers (5%)
- DMS Information
  - A certain percent of travelers passing through the sign will choose a new path, which is calculated based on either current or historical experienced travel time

# ICM Incident/Work Zone/Evacuation Diversion Rules

- Comparative Information
  - At each DMS location, if a traveler is willing to consider transit (5%), then
    - Assess total transit generalized time
      - Access time to boarding stop
      - Transit line-haul time
      - Access time to final destination from the alight stop
      - Fare
    - Switch if transit saving exceeds a threshold (10 min)
  - else
    - Apply en-route switch rule
  - Applicable to: en-route information travelers

# Ongoing Research Activities

# Travel Choices and Hetergeneous Attributes

- Congestion Pricing
  - Fixed toll
  - Time-of-Day Toll
  - Congestion Responsive Facility Best Toll

# Pricing Model

$$\max □ = \sum_{□\in □}\sum_{□\in □} □_{□}^{□}\, □(□_{□}^{□}) \qquad (1)$$

□□□□□□□□□□,

$$□(□_{□}^{□}) \geq □_{□}^{0}, \qquad \forall\, □\in □,\ □\in □ \qquad (2)$$

$$\frac{□_{□}}{□_{□}}\left(\frac{1}{□_{□}^{□}} - \frac{1}{□(□_{□}^{□})}\right) \leq □, \qquad \forall\, □\in □,\ □\in □ \qquad (3)$$

$$\frac{□_{□}}{□_{□}}\left(\frac{1}{□_{□}^{□}} - \frac{1}{□(□_{□}^{□})}\right) \geq □ - □, \qquad \forall\, □\in □,\ □\in □ \qquad (4)$$

□□□h □□□ □□□□□ □□□□□□□□□□□□□ (5)

Where,

- $□_{□}^{□}$ : density of CP segment □at time □
- $□_{□}^{□}(□)$ : speed of CP segment □at time □
- $□_{□}^{0}$ : required minimal operating speed inside HOT lane
- $□_{□}^{□}$ : average speed on the GP lane
- $□_{□}$ : distance of the CP segment □
- $□_{□}^{□}$ : toll rate for CP segment □at time □, this is the decision variable.
- $□_{□}$ : value of time for vehicle type □
- □ : threshold

# DUE Route Choice Model

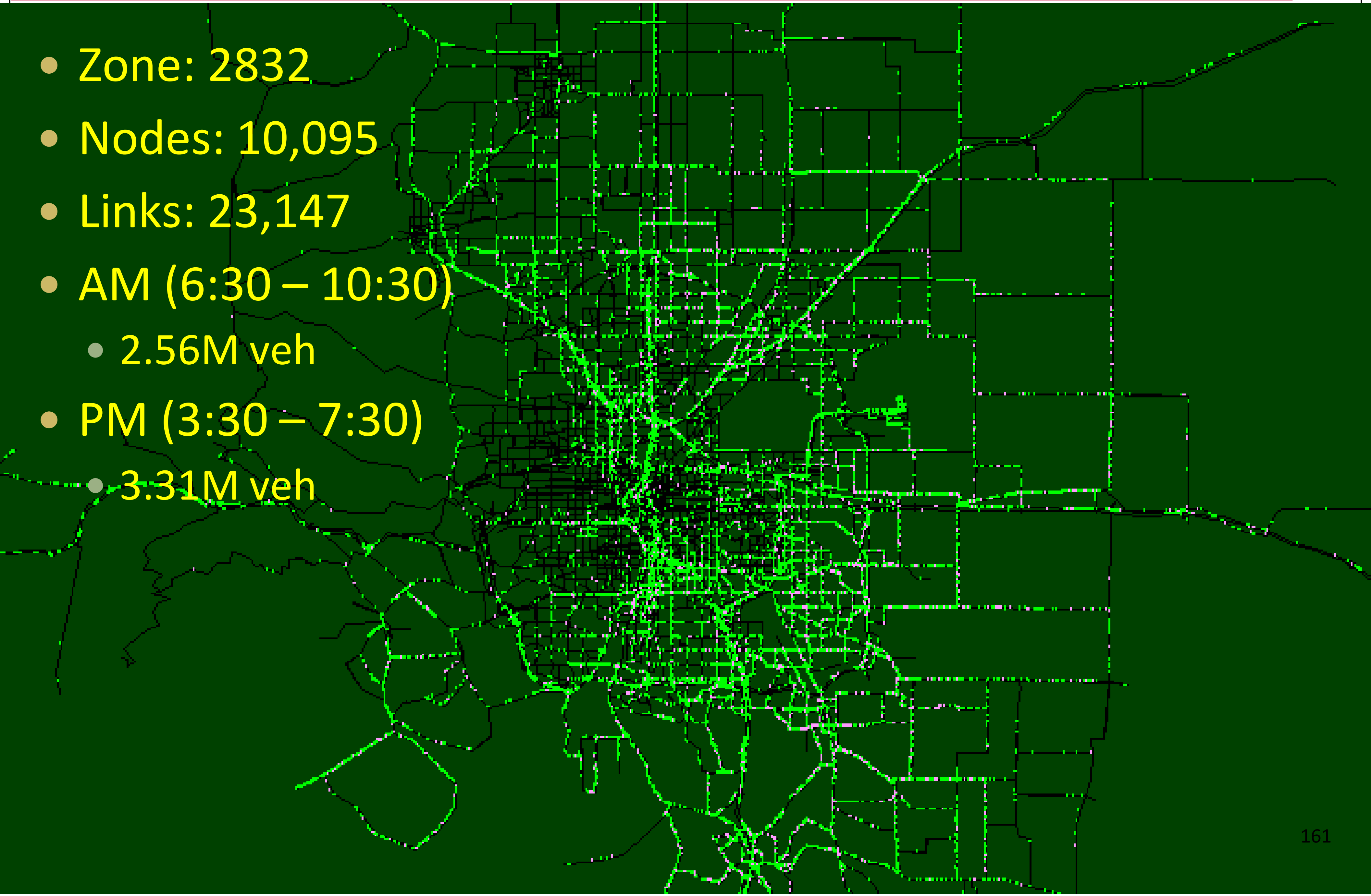
[illegible equation: generalized cost = travel time + toll rate / value of time]

Where,

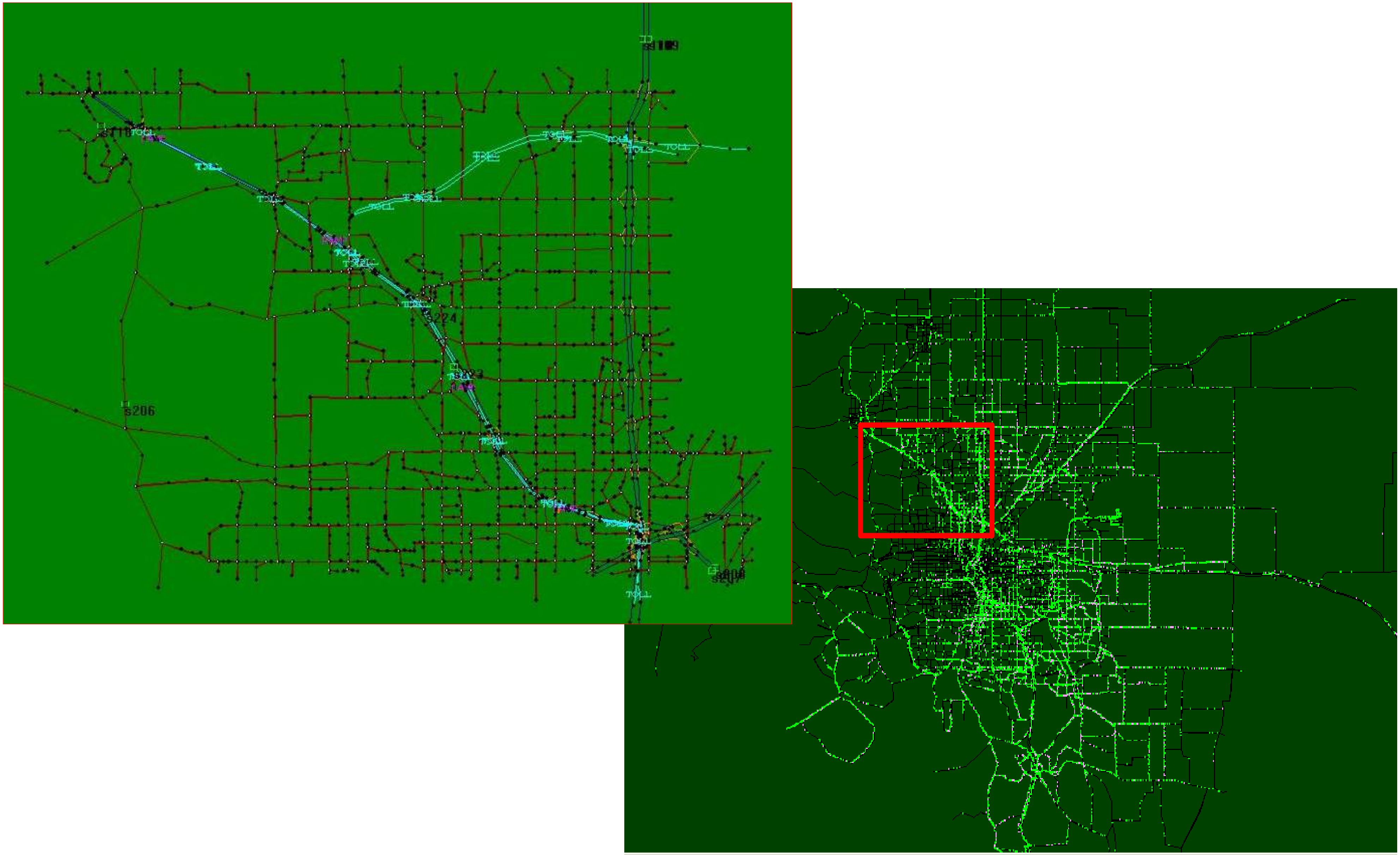
- [illegible] : generalized cost for link [illegible] at time [illegible]
- [illegible] : travel time link [illegible] at time [illegible]
- [illegible] : toll rate for link [illegible] at time [illegible] determined by the pricing model
- [illegible] : value of time for vehicle type [illegible]

# DRCOG Regional Model in DTA

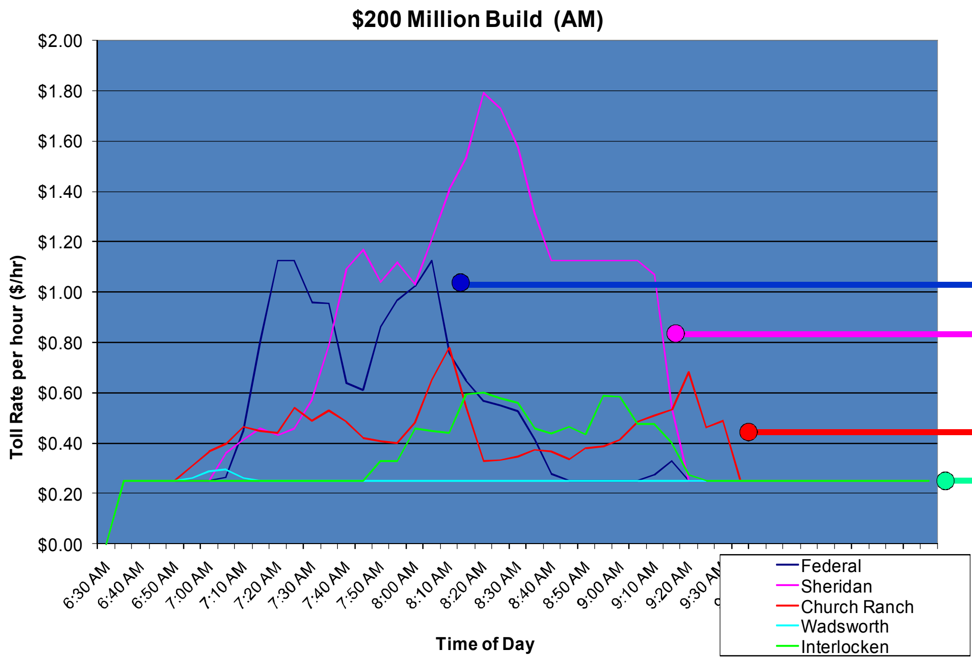
- Zone: 2832
- Nodes: 10,095
- Links: 23,147
- AM (6:30 – 10:30)
  - 2.56M veh
- PM (3:30 – 7:30)
  - 3.31M veh

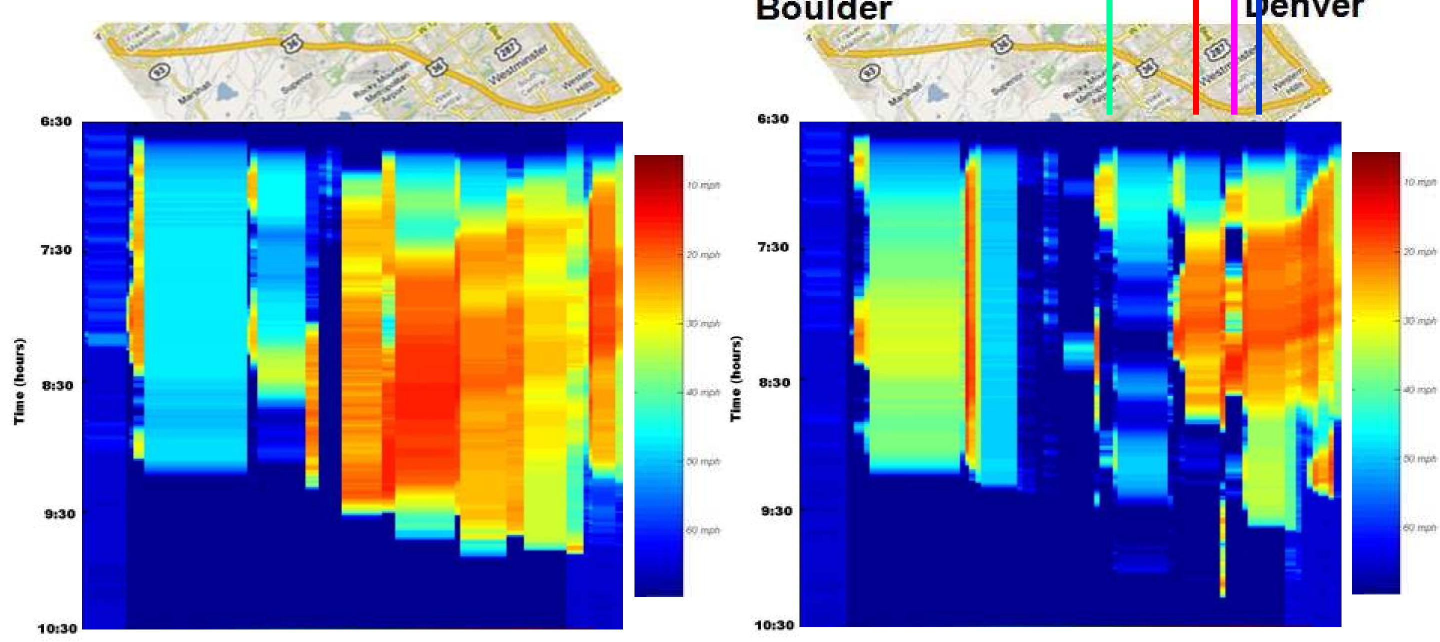


# US 36. Study Area Cut from Regional DTA



# GP Lane Congestion vs. HOT Price




No Build

$260 Million Build



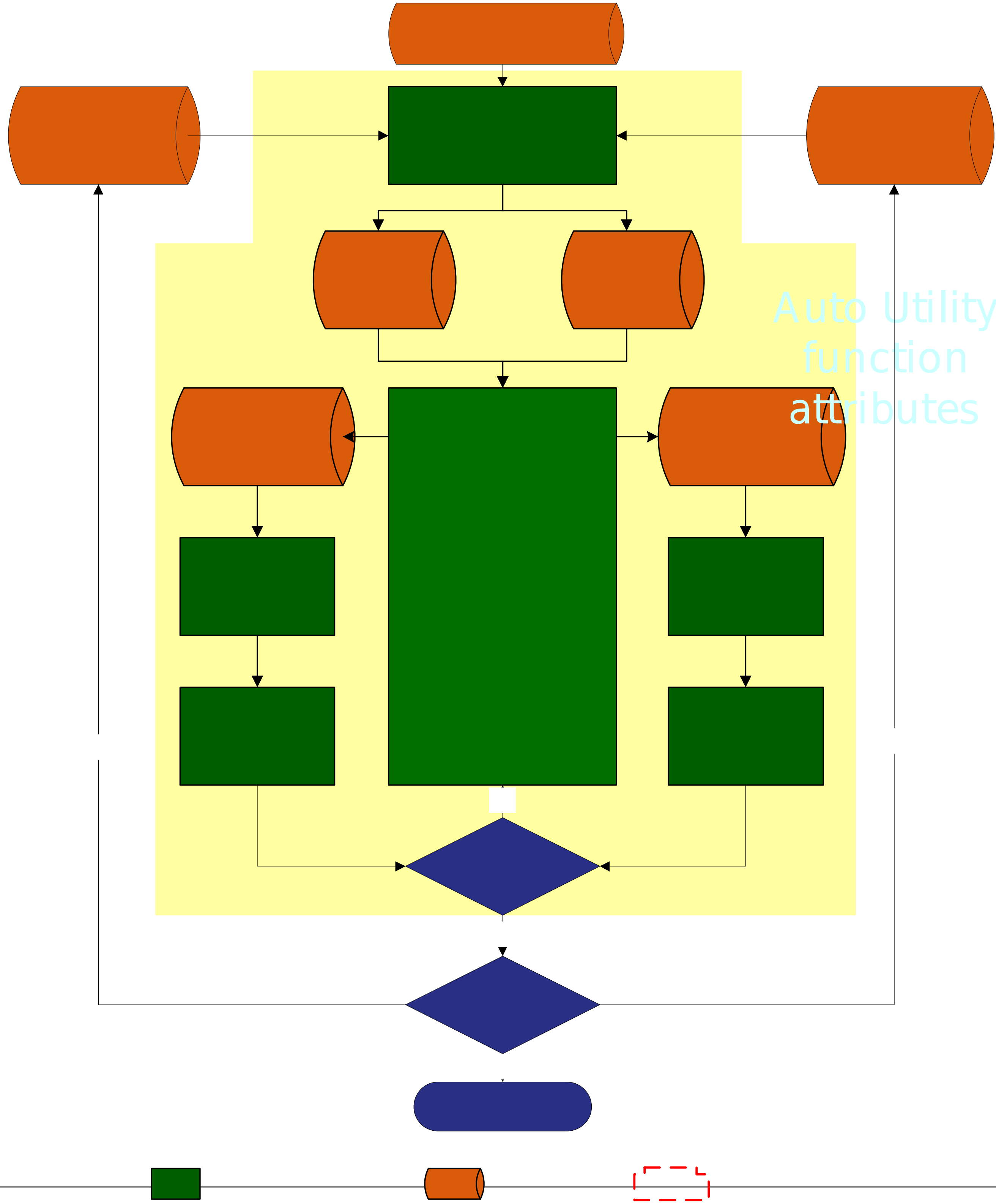
DynusT

atlas

# Transit Modeling Requirements

Need for a versatile simulation and assignment tool that:

- Captures operational dynamics for transit vehicles
- Captures traveler assignment and network loading in a multi-modal context
  - Transit assignment
  - Inter-modal assignment



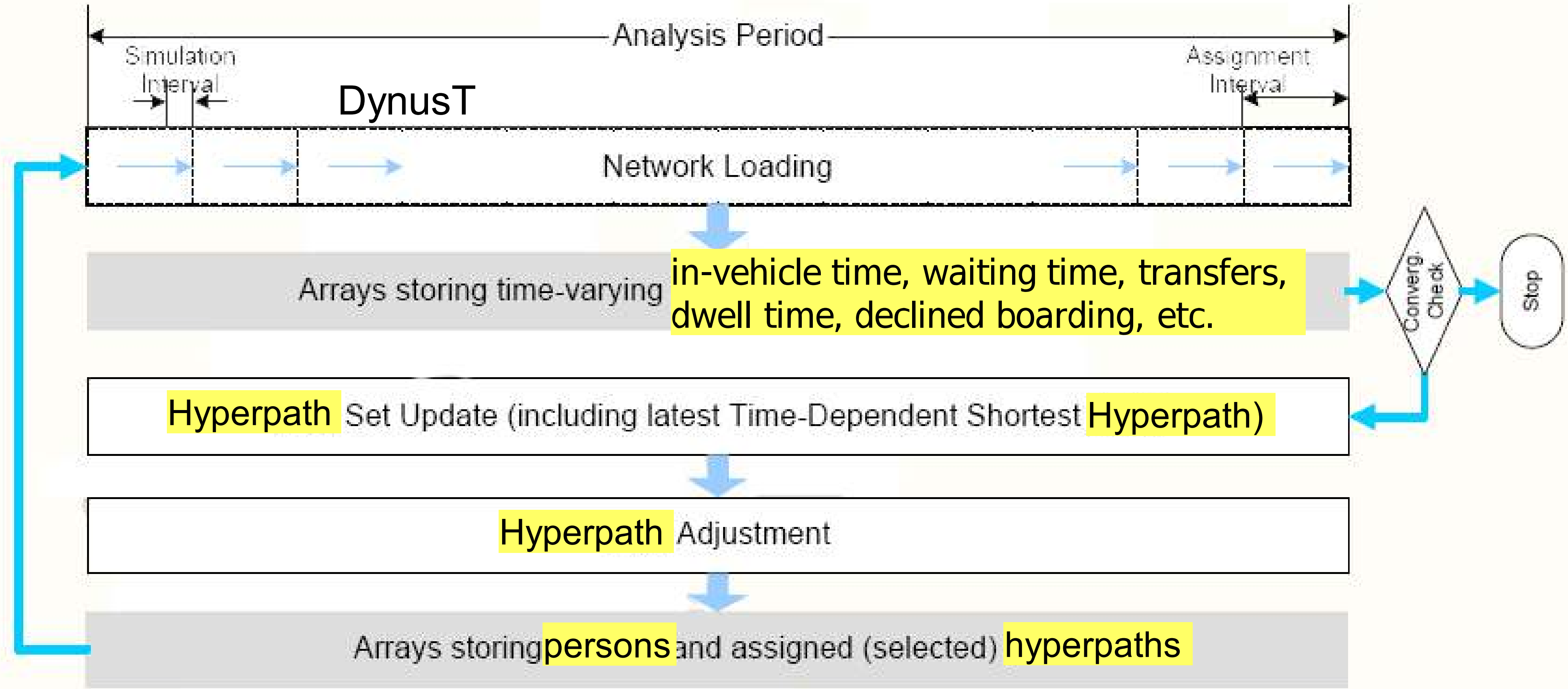

Networ
Performar
Statistics (
Specific

# Transit Operations in DynusT

- Routes are designated by specific paths for transit vehicles
- Transit vehicles leave terminals at designated scheduled times or at specific headways
- Transit vehicles move through the network
  - Mesoscopic flow characteristics while in the traffic stream
  - Specific modeling of stops, with dwell times:
    - Track number of passengers at specific stops
    - Incremental boarding and alighting time model is used

      Dwell time = $a$ + max $\{b_1 * B , b_2 * A \}$

# Transit Assignment vs. Dynamic Traffic Assignment

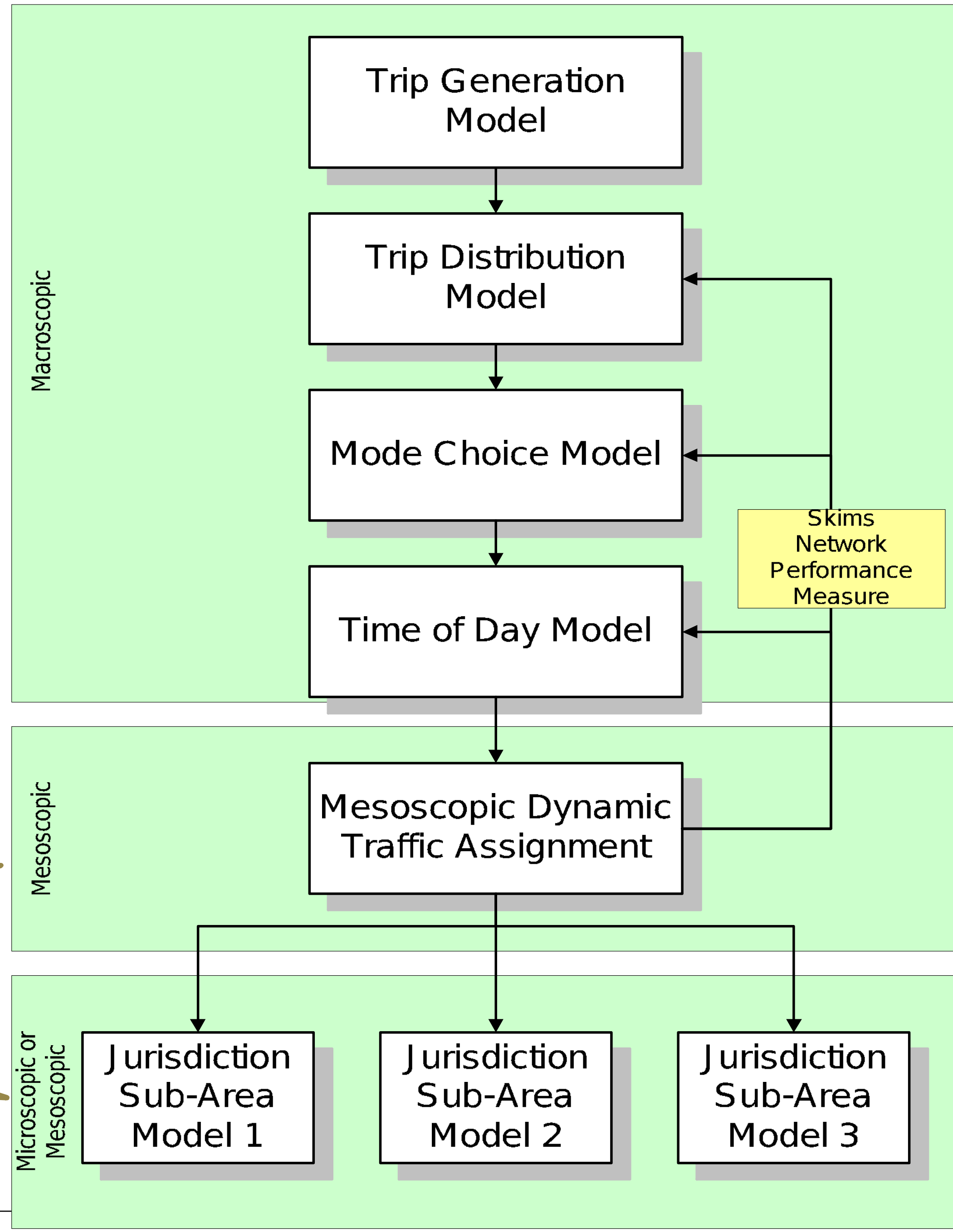


# Transit Loading and Assignment

- Operational dynamics through mesoscopic traffic simulation with transit-specific characteristics in the network loading
  - Dwell times, on-street vs. pull-out stop locations
- Dynamic transit assignment
  - Passenger stop choice
  - Passenger path choice / boarding decisions
    - Frequency-based and schedule-based assignment models
- Iterative convergence of an equilibrium assignment, if capacity constraints apply (heavily congested routes)
- Assignment models are calibrated using common data: transit networks, transit schedules, boarding and alighting data

# Compatibility with Existing Modeling Framework

- Trip-based framework

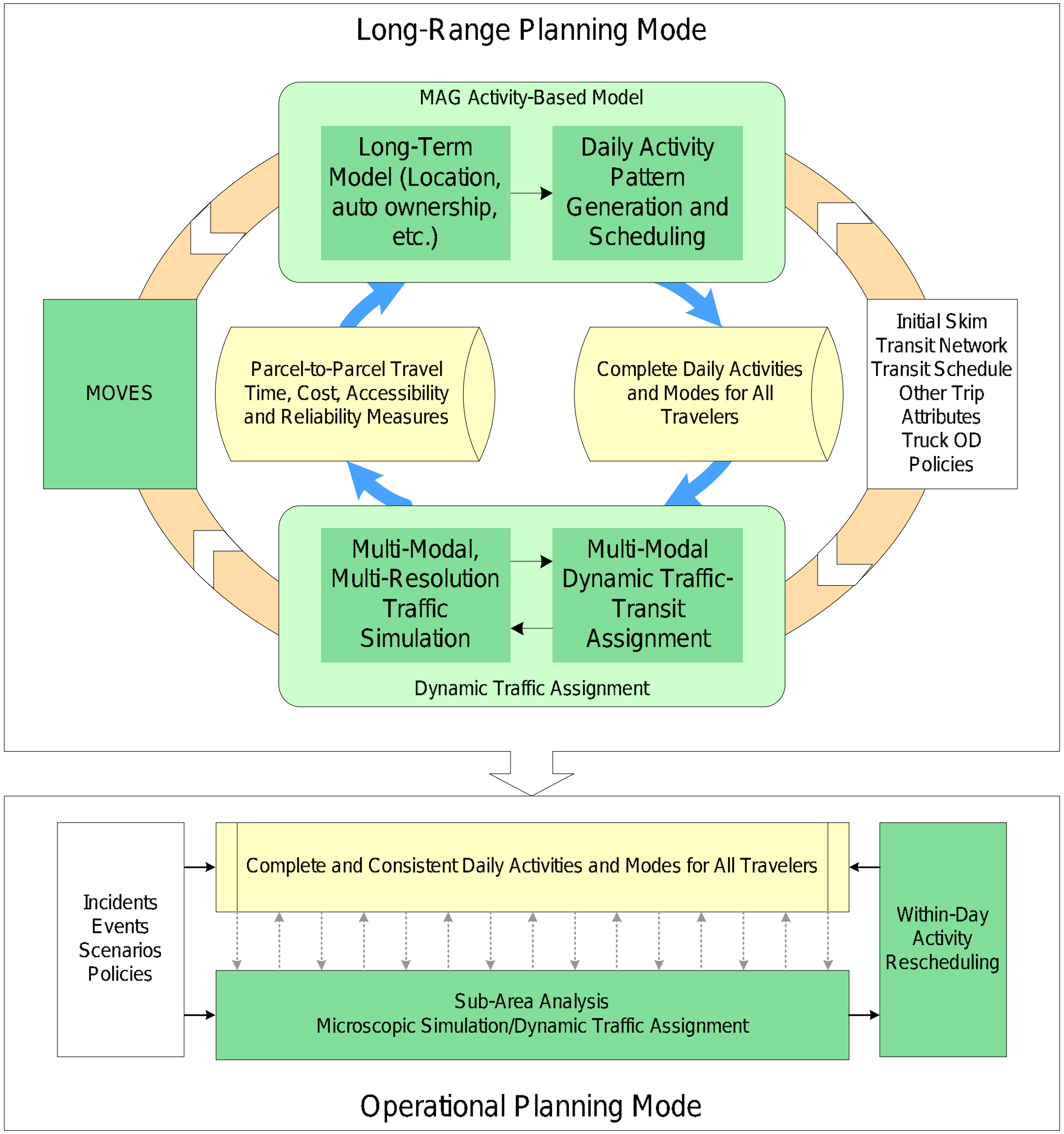



Strategic Modeling

Mission-Driven Modeling

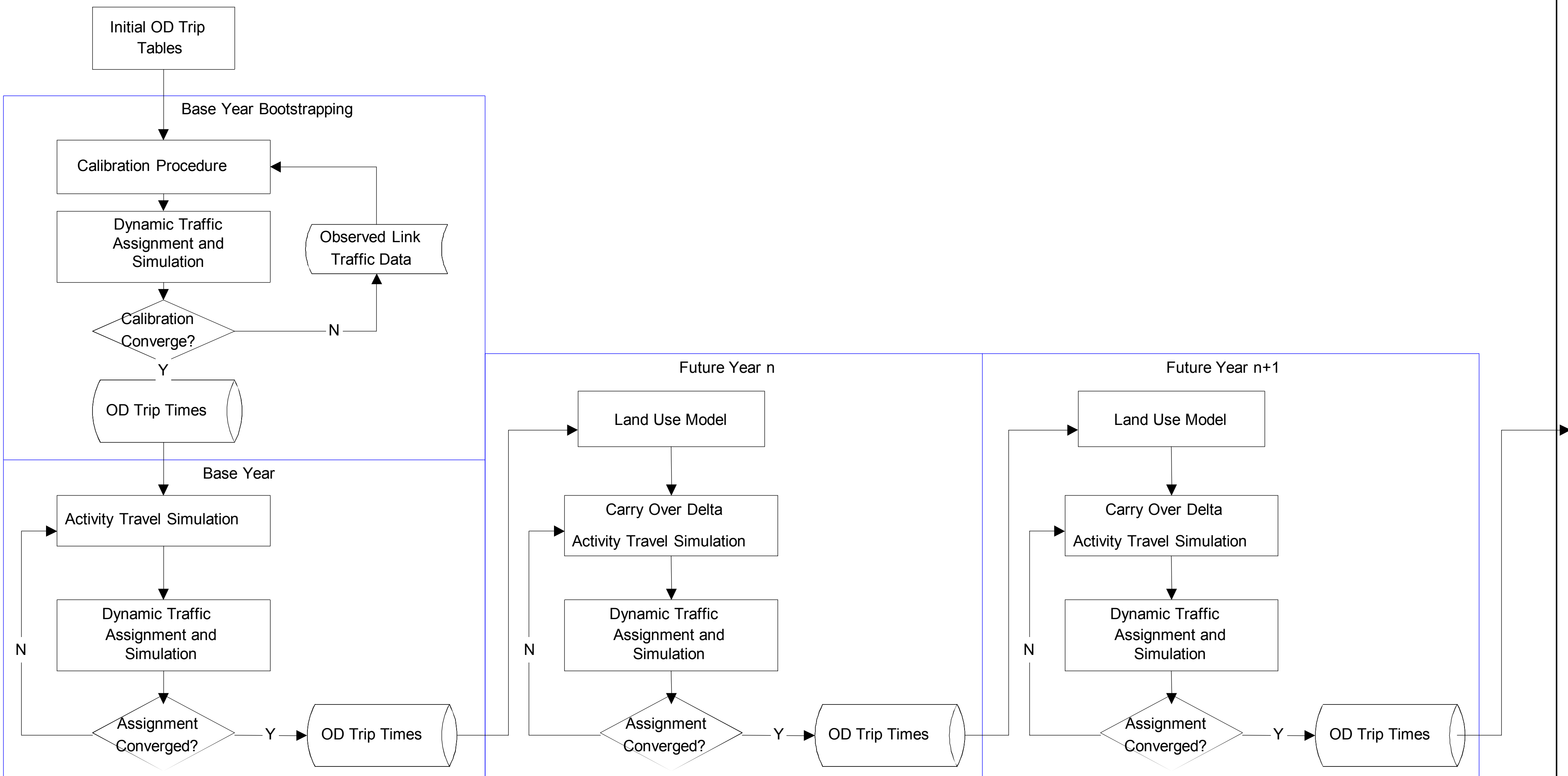
# Compatibility with Existing Modeling Framework

- Activity-Based Model



Civil Engineering and Engineering Mechanics

# UrbanSim-OpenAMOS-DynusT Integrated Model

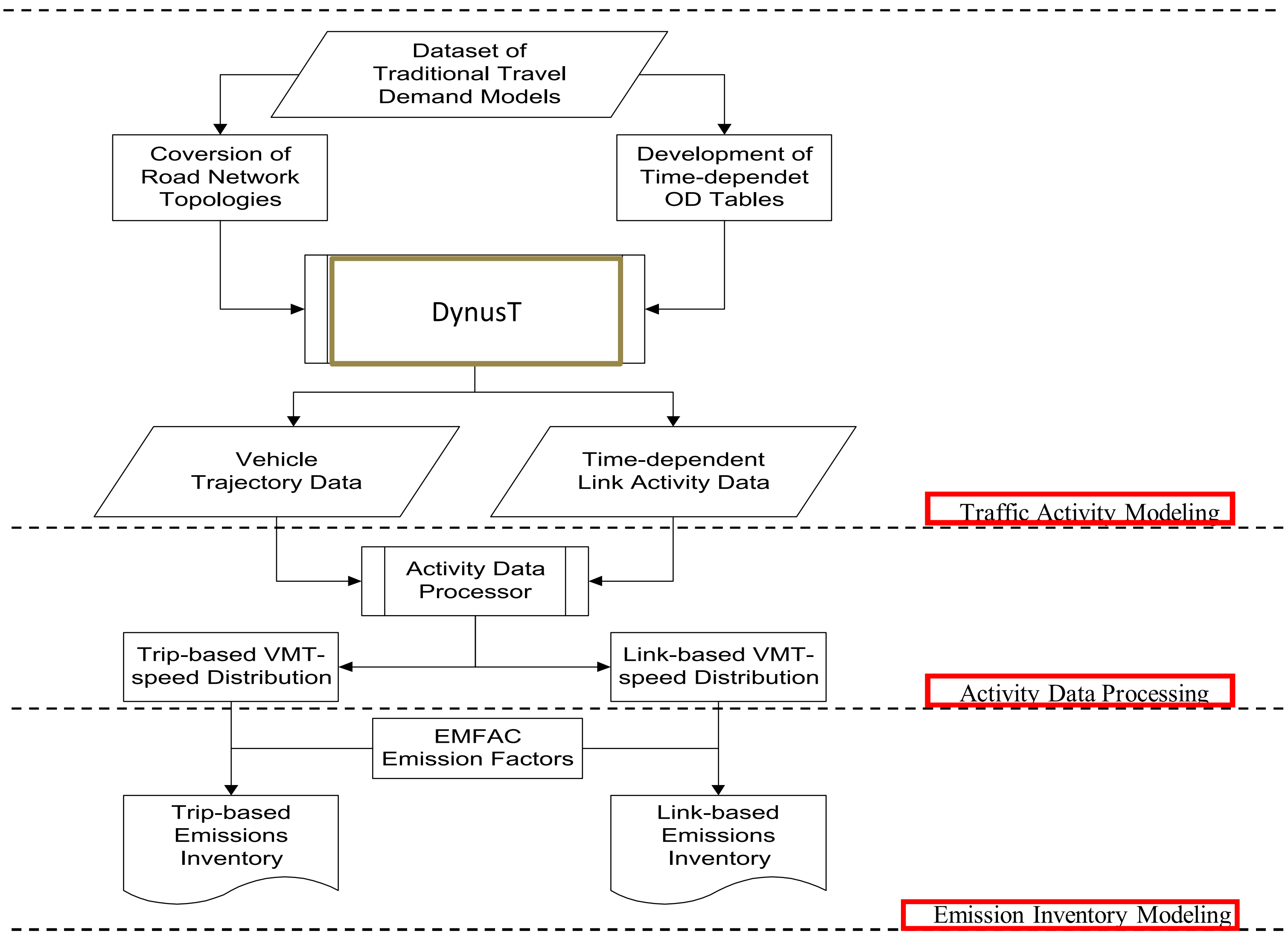



DynusT

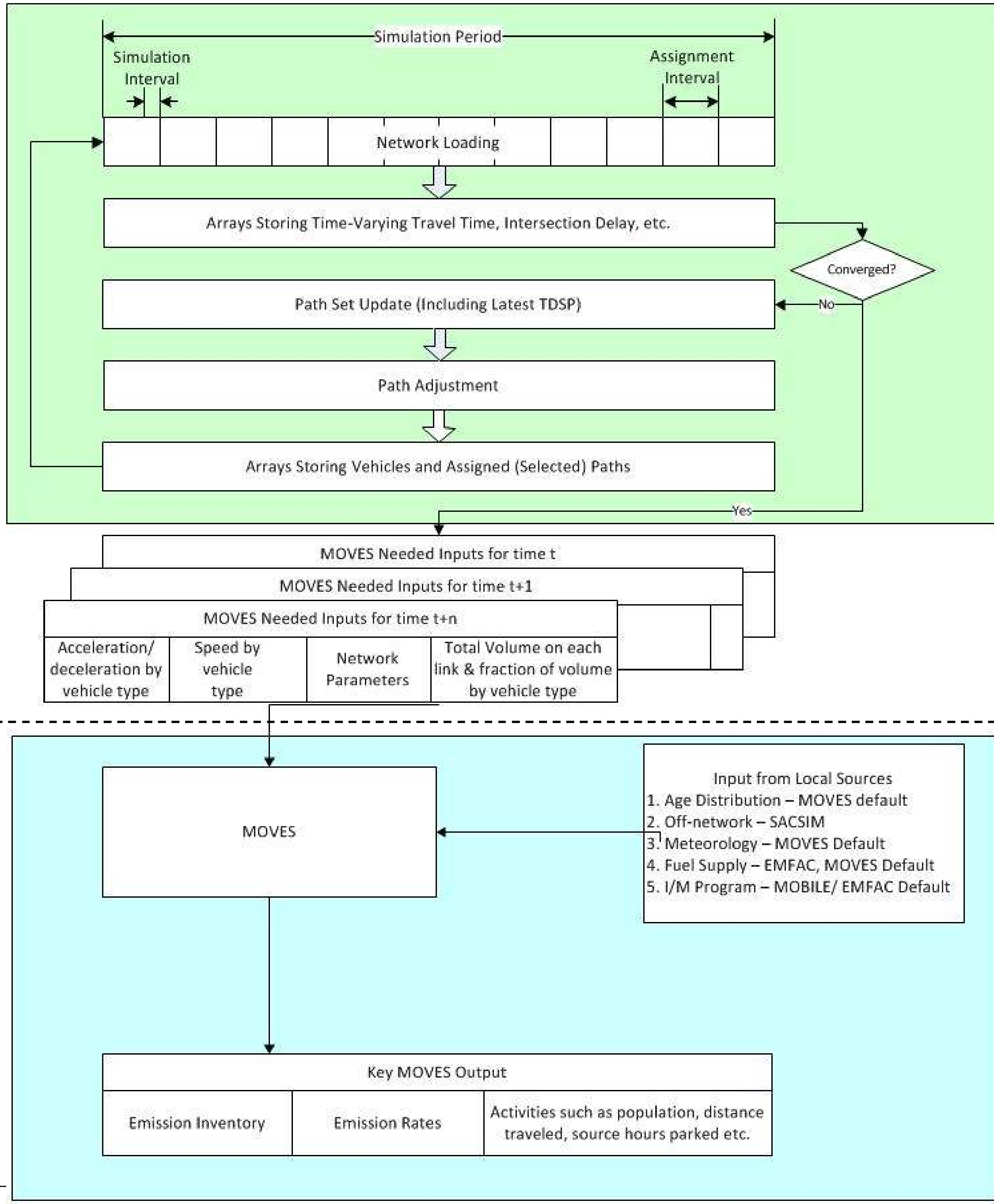


atlas

# EMFAC-DTA Integration



# DynusT-MOVES Integration




Simulation based Dynamic Traffic Assignment Model

Built-in Converter to Link by Link Operating Mode Distribution

MOVES

DynusT

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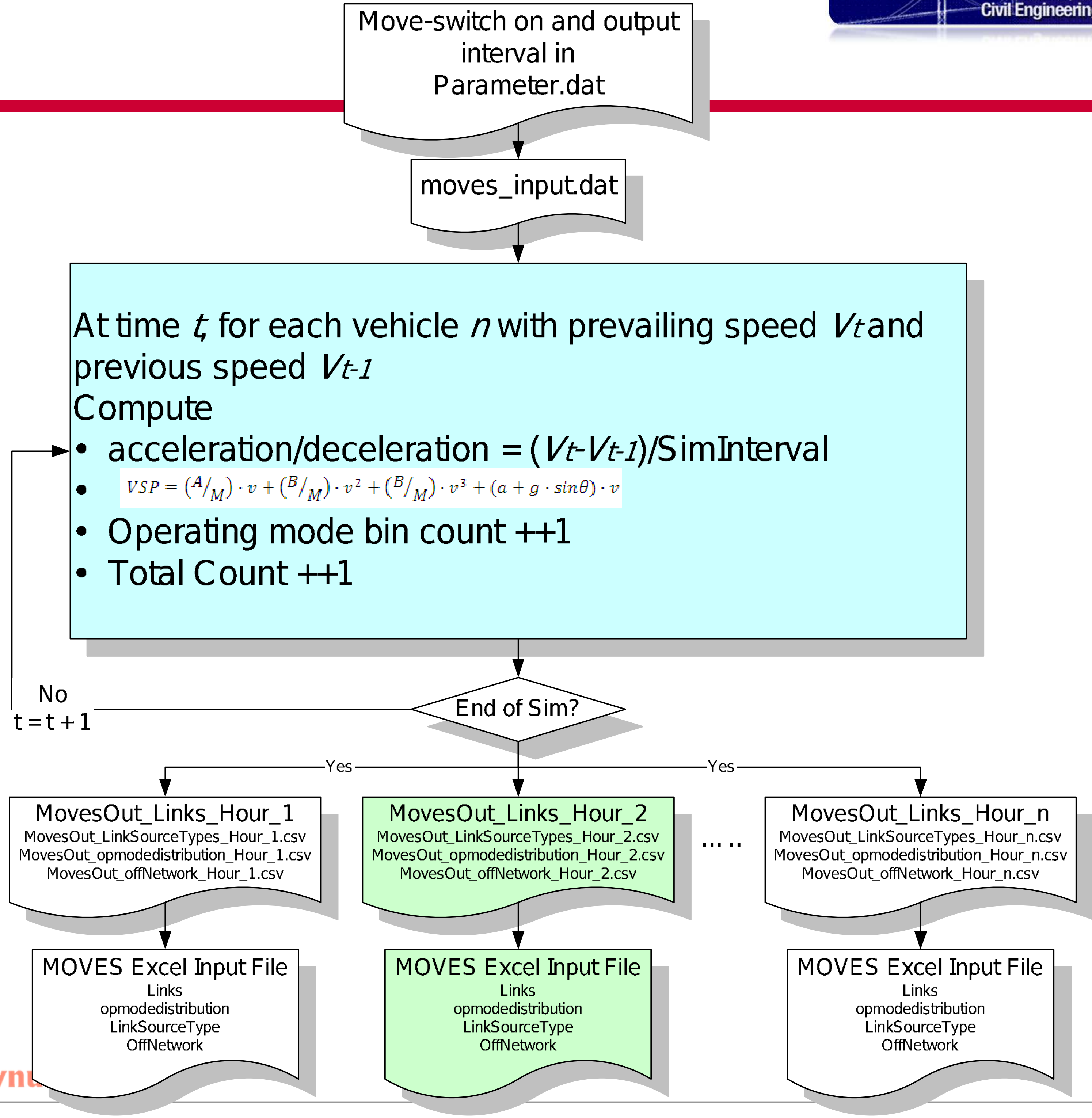
Move-switch on and output interval in Parameter.dat
moves_input.dat
At time t, for each vehicle n with prevailing speed Vt and previous speed Vt-1
Compute
• acceleration/deceleration = (Vt-Vt-1)/SimInterval
• $VSP = (A/M) \cdot v + (B/M) \cdot v^2 + (B/M) \cdot v^3 + (a + g \cdot sin\theta) \cdot v$
• Operating mode bin count ++1
• Total Count ++1
End of Sim?
No
t = t + 1
Yes
Yes
MovesOut_Links_Hour_1
MovesOut_LinkSourceTypes_Hour_1.csv
MovesOut_opmodedistribution_Hour_1.csv
MovesOut_offNetwork_Hour_1.csv
MovesOut_Links_Hour_2
MovesOut_LinkSourceTypes_Hour_2.csv
MovesOut_opmodedistribution_Hour_2.csv
MovesOut_offNetwork_Hour_2.csv
… ..
MovesOut_Links_Hour_n
MovesOut_LinkSourceTypes_Hour_n.csv
MovesOut_opmodedistribution_Hour_n.csv
MovesOut_offNetwork_Hour_n.csv
MOVES Excel Input File
Links
opmodedistribution
LinkSourceType
OffNetwork
MOVES Excel Input File
Links
opmodedistribution
LinkSourceType
OffNetwork
MOVES Excel Input File
Links
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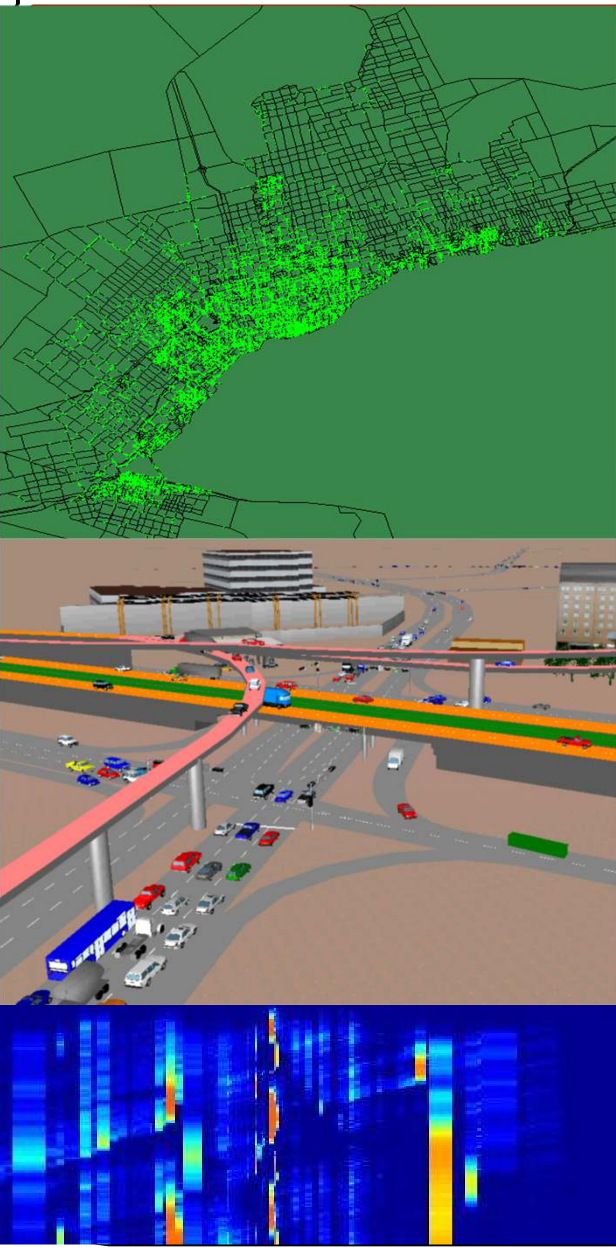
LinkSourceType
OffNetwork

# More Readings:
# "Google DynusT"
# http://dynust.net



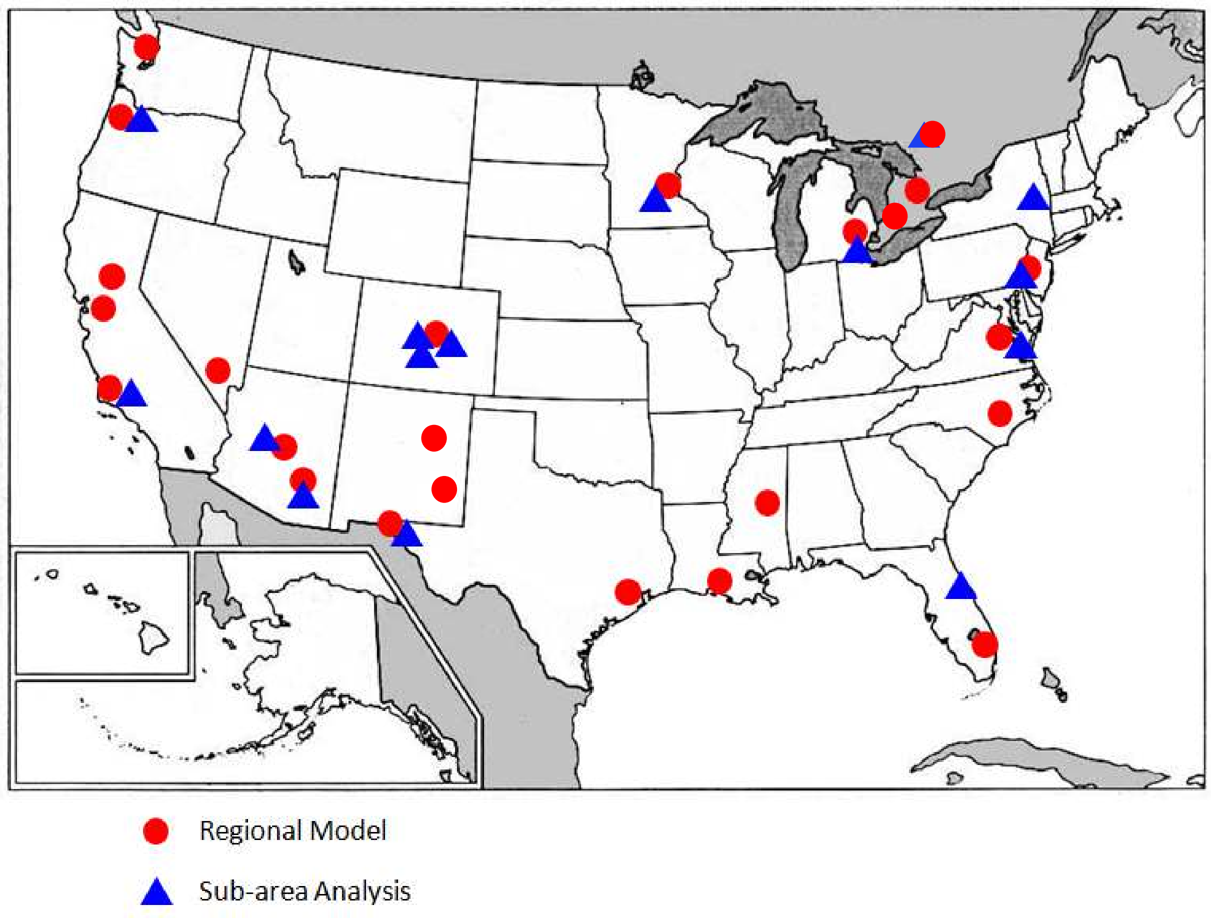
# Dynamic Traffic Assignment – DynusT Overview

Yi-Chang Chiu, Ph.D.
University of Arizona

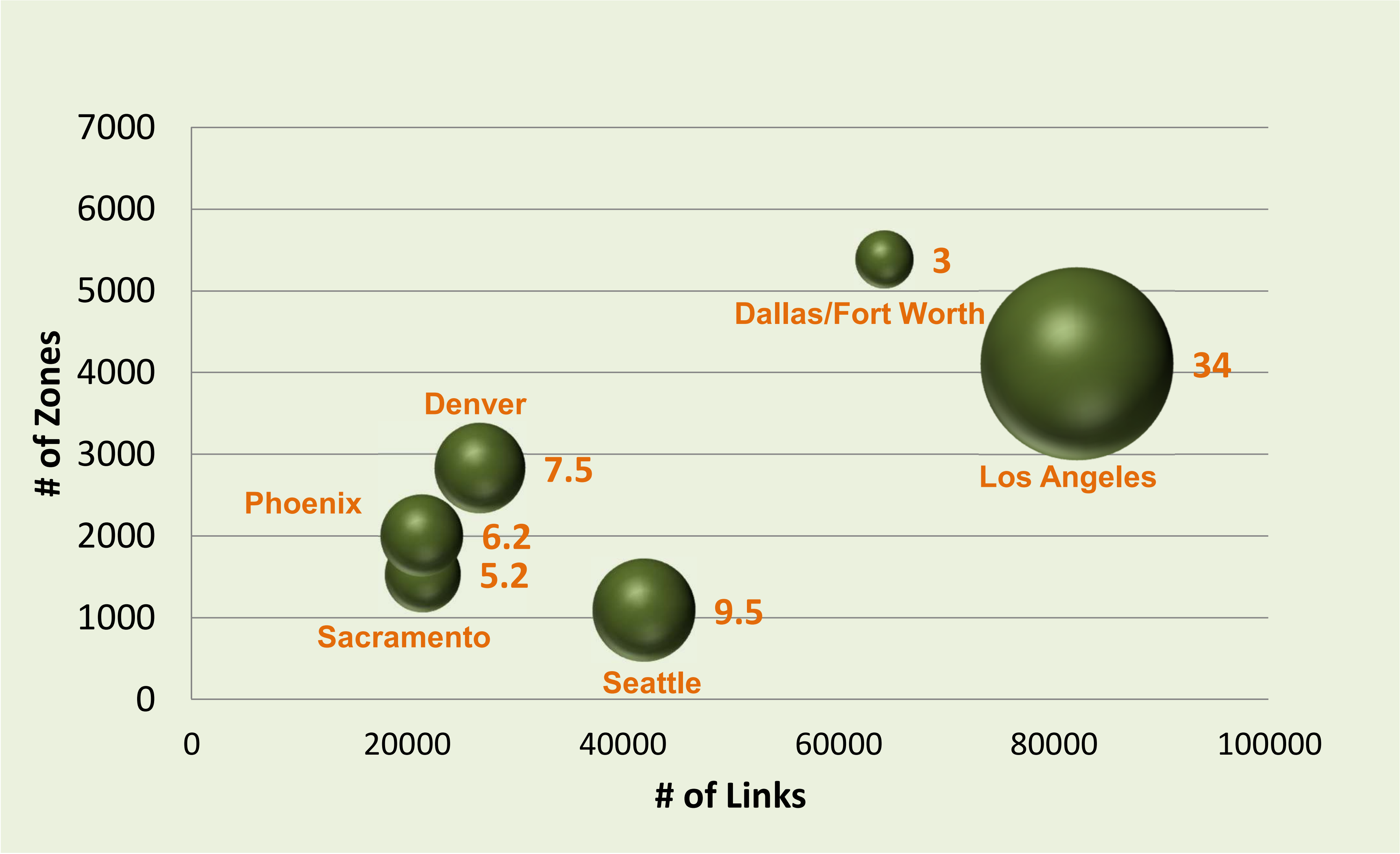
Present to SCAG
February 27-28, 2014

# ***DynusT*** (***Dyn***amic ***U***rban ***S***ystems for ***T***ransportation)

- **Simple**, **lean** and easy to **integrate** with macro and micro models.
- Developed since 2002, applied to 50+ regions since.
- 1000+ download world-wide since 2011.



# DynusT Daily Regional Models




DynusT

# Modeling Capabilities

- Capacity Improvement/restrictions where diversion is of concern:
  - Long-term: dynamic user equilibrium
- Congestion pricing (fixed pricing, time-of-day pricing, congestion responsive pricing, truck-only, truck restriction)
  - Dynamic user equilibrium
  - Generalized cost with heterogeneous individual attributes (e.g. value of time)
- Signal control (two, four-way stops, pre-time, actuated, coordinated)

DynusT

# Modeling Capabilities

- ITS Strategies (pre-trip, en-route, DMS information, ramp metering, incident)
- Active Traffic/Demand Management (dynamic hard running shoulder, dynamic reversible lanes, dynamic lane/ramp closure, peak spreading, etc.)
- Linking with ABM (DaySim, OpenAMOS)
- Linking with MOVES
- **Continued rapid development due to open source community**

DynusT

# Interoperability

- Import from all travel demand models
- Import from Synchro
- Export to VISSIM
- Skim feedback to other models
- DynusT - TRANSIMS
- DynusT – VISTA
- DynusT - DYNAMEQ

# Computational Efficiency (20 iterations)

| MPO | Zones | Nodes | Links | Sim Period | Veh(M) | Time(hr) | Peak Memory |
|---|---|---|---|---|---|---|---|
| PSRC | 1091 | 5288 | 15400 | 5 | 1.3 | 2 | 2 |
| MAG | 2006 | 9891 | 20506 | 10 | 2.8 | 5 | 5 |
| PSRC | 1091 | 5288 | 15400 | 24 | 6.4 | 11 | 7 |
| Virginia | 1240 | 5421 | 12506 | 7 | 6.7 | 12 | 10 |
| SCAG | 3025 | 17903 | 44773 | 6 | 12.8 | 25 | 15 |

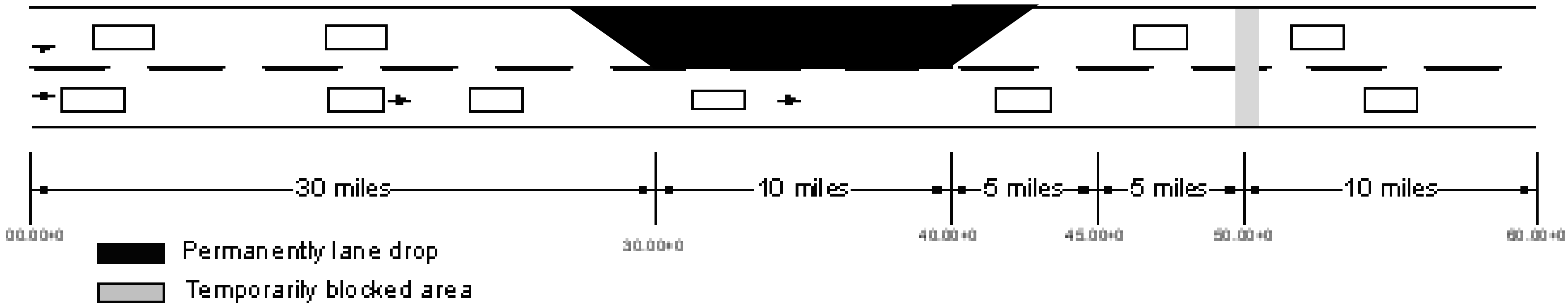
- Memory scalable for 24 hr simulation and assignment
- Highly linear to # of vehicles, regardless of network sizes, most efficient possible
  - 1.8 hours per 1M vehicles for 20 iterations ($R^2 = 0.99$)

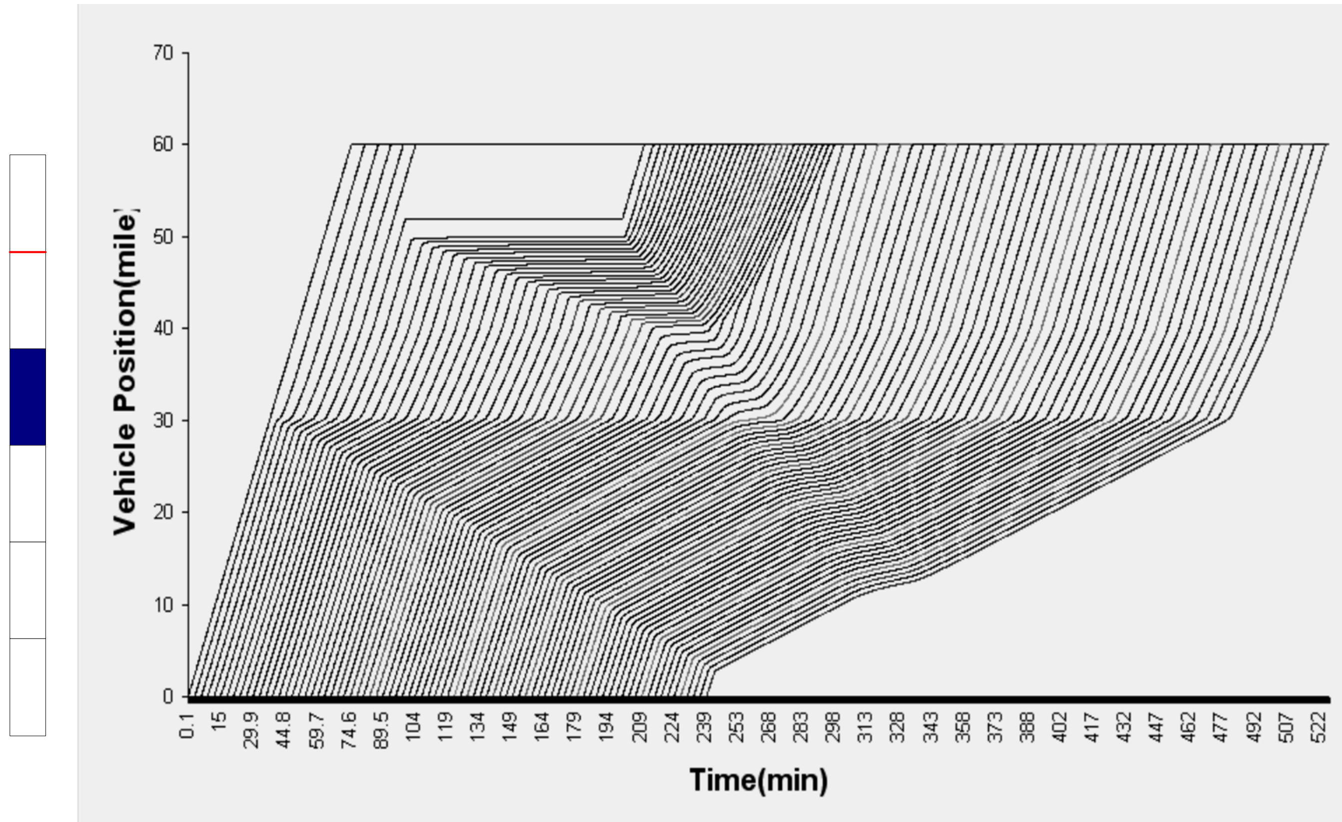
DynusT

# *DynusT* (*Dyn*amic *U*rban *S*ystems for *T*ransportation)

- Developed since 2002
  - Supported by various agencies including FHWA
- Memory efficient
  - Capable of large-Scale 24-hr simulation assignment
- Fast simulation/computation
  - Multi-threaded simulation and assignment
- Realistic, micro-like mesoscopic traffic simulation
  - Anisotropic Mesoscopic Simulation (AMS)
- Assignment
  - Method of Isochronal Vehicle Assignment

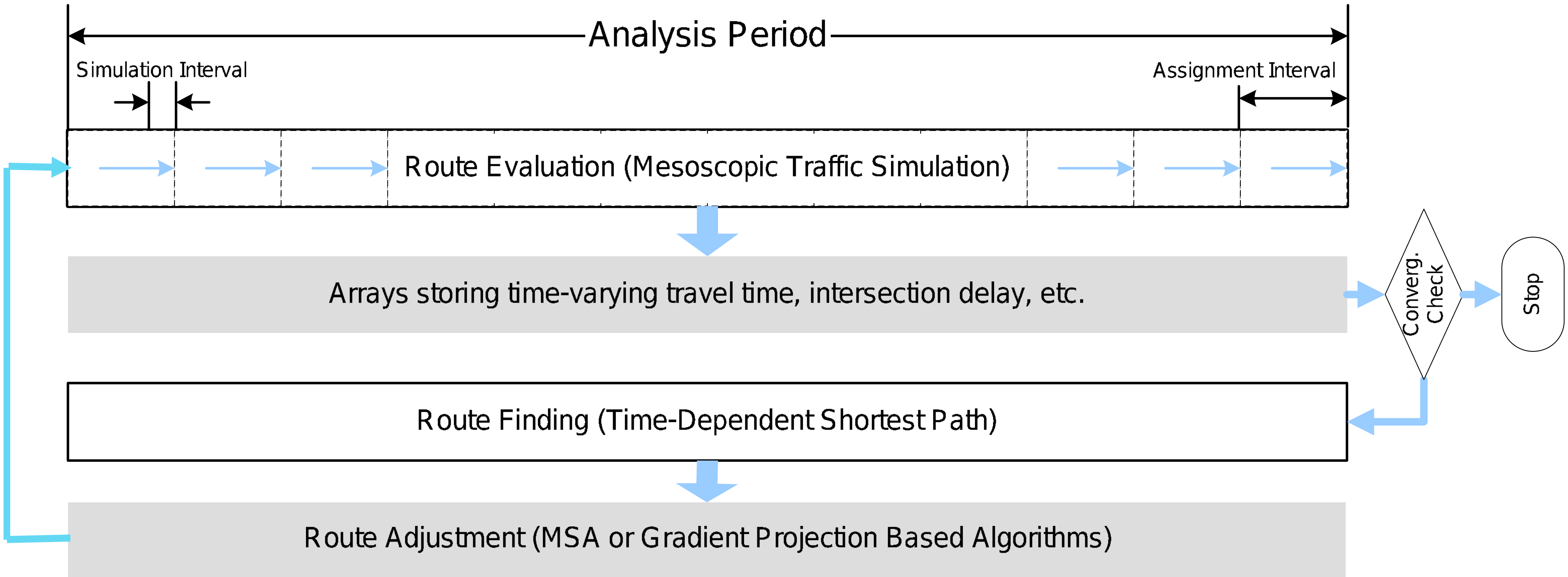
# Realistic Vehicle Trajectories



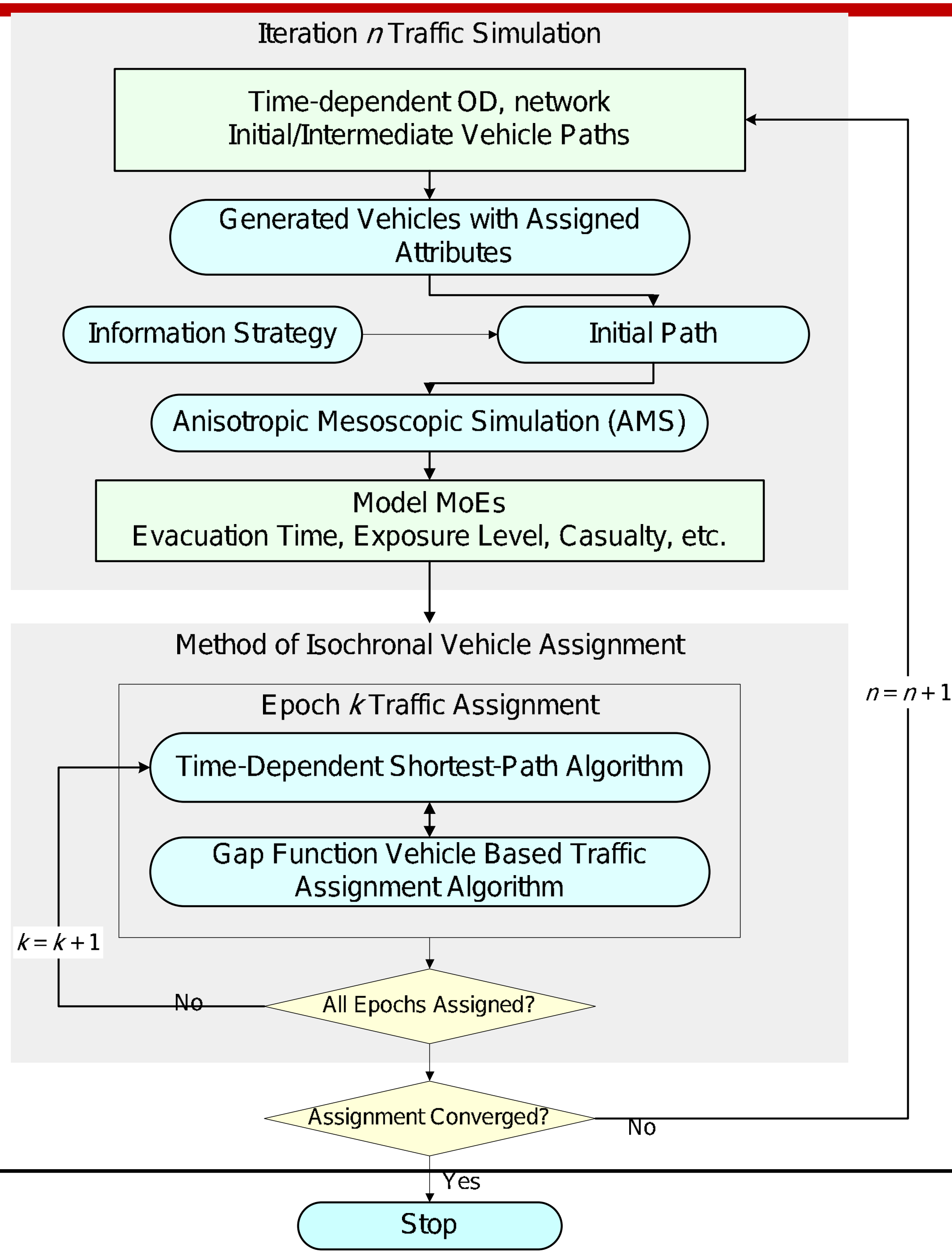



# DynusT Simulation-Based Dynamic Traffic Assignment

- Typical algorithmic structure



# DynusT Simulation Assignment Framework

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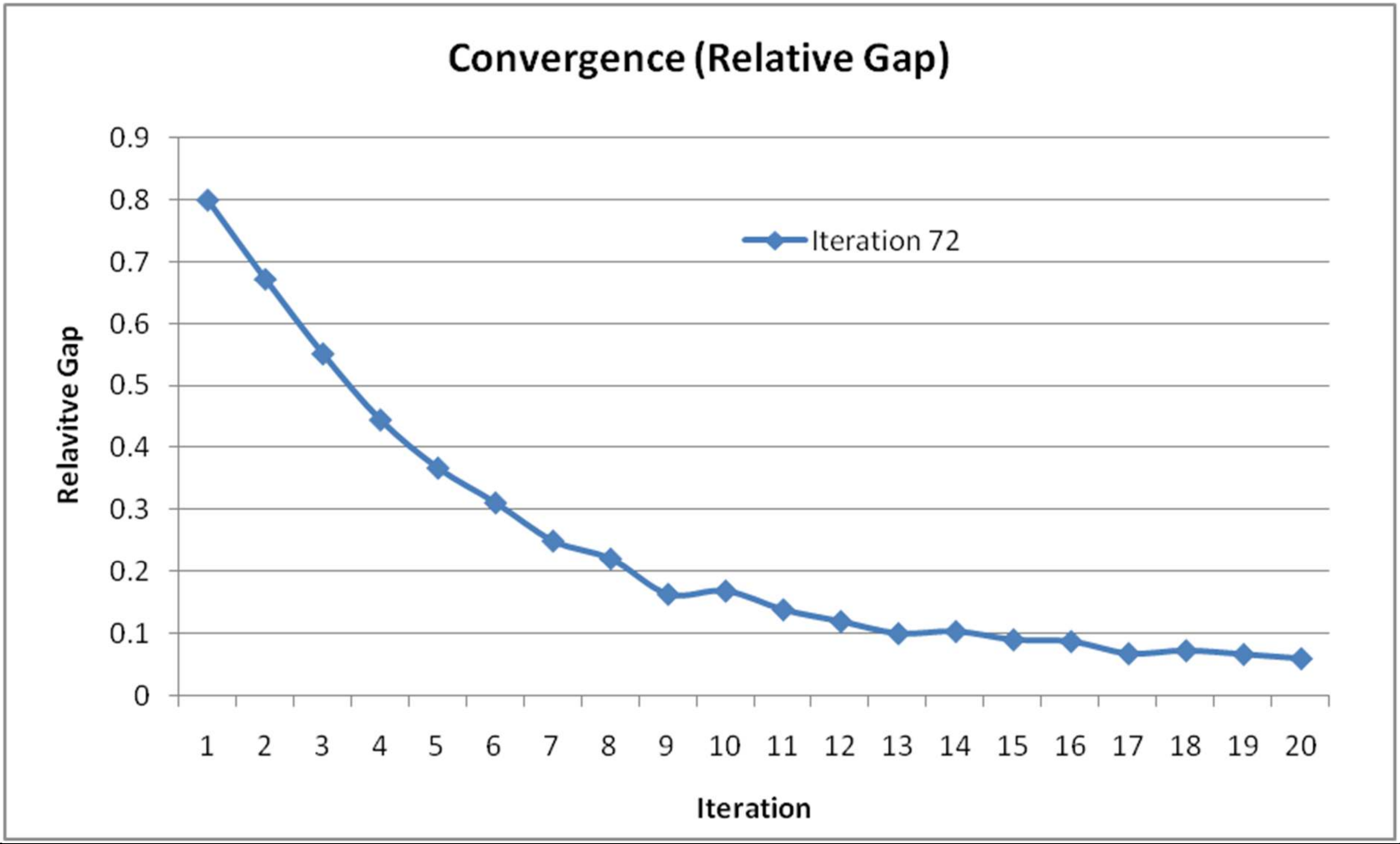
# Gap-Function Vehicle Based Assignment

- Driven by Gap Function

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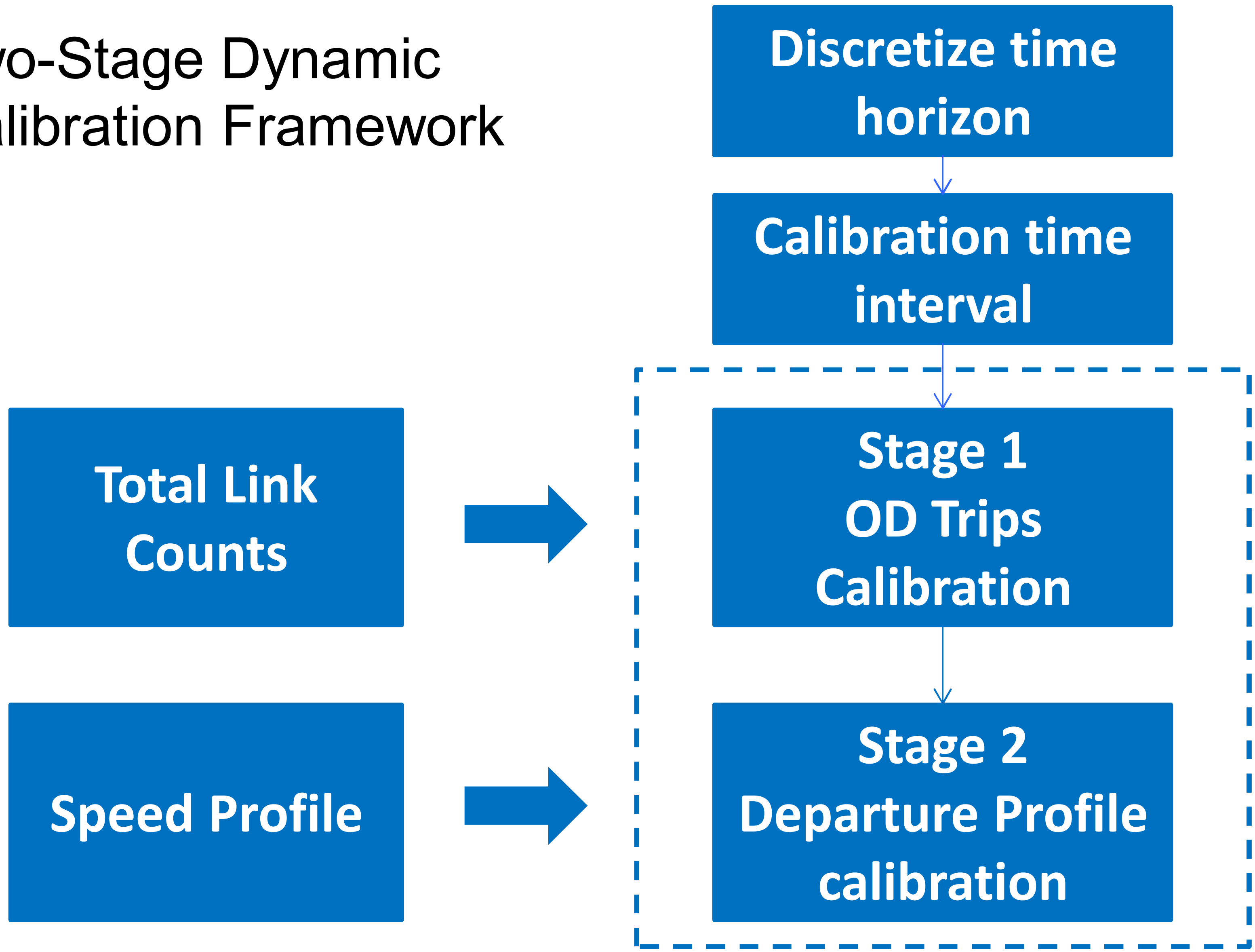
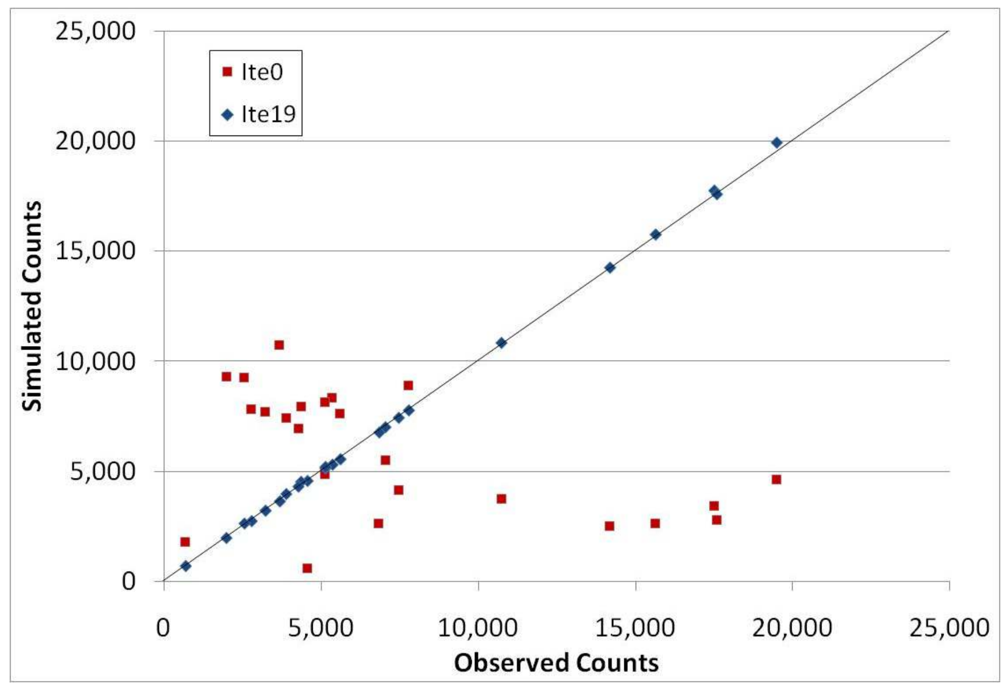
# Optimization Driven Model Calibration and Validation

Two-Stage Dynamic Calibration Framework



# Model Calibration and Validation

- OD calibration
  - Automatically match total traffic counts within time period at different locations along corridor with minimal change to original seed matrices

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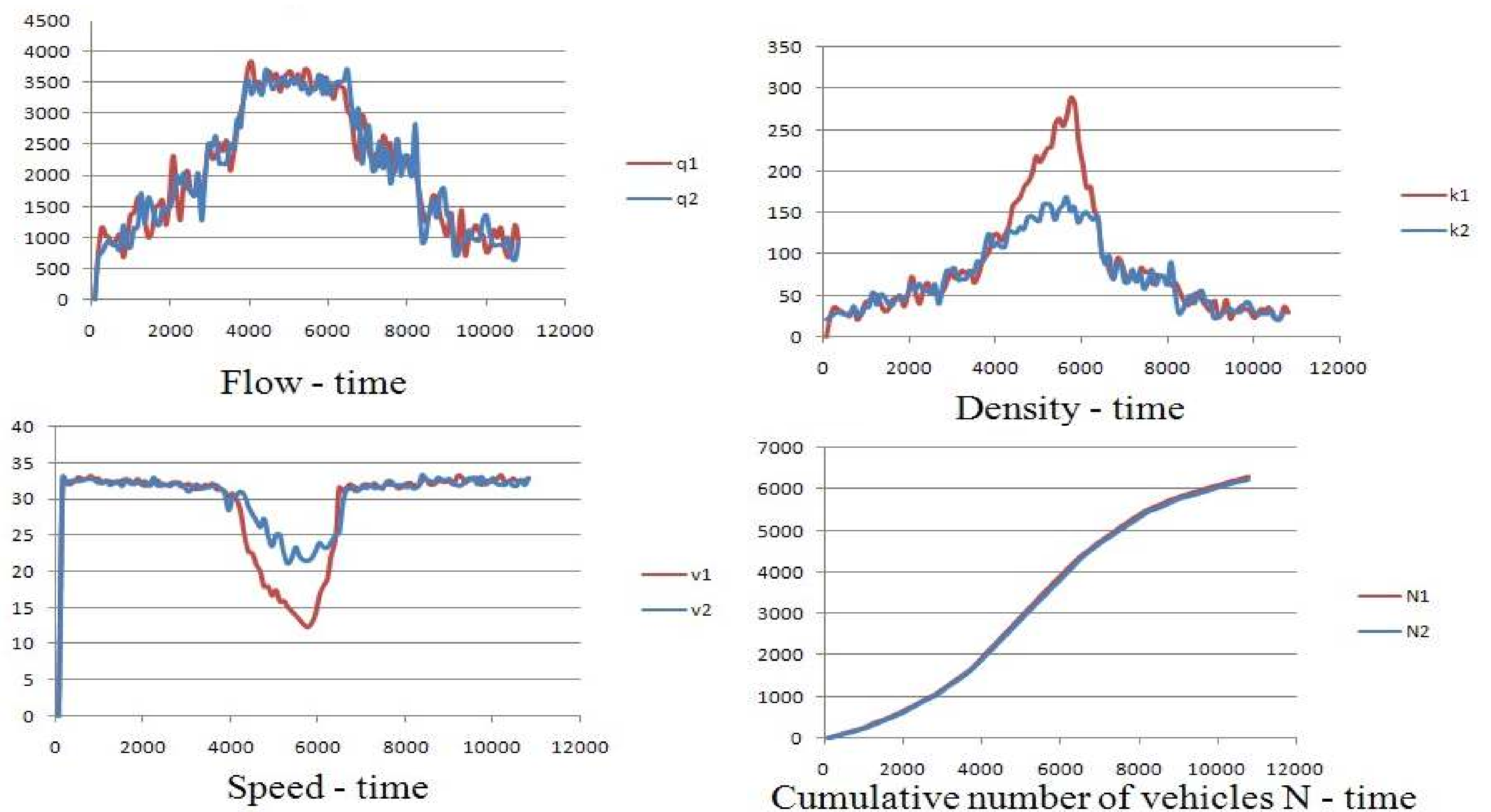
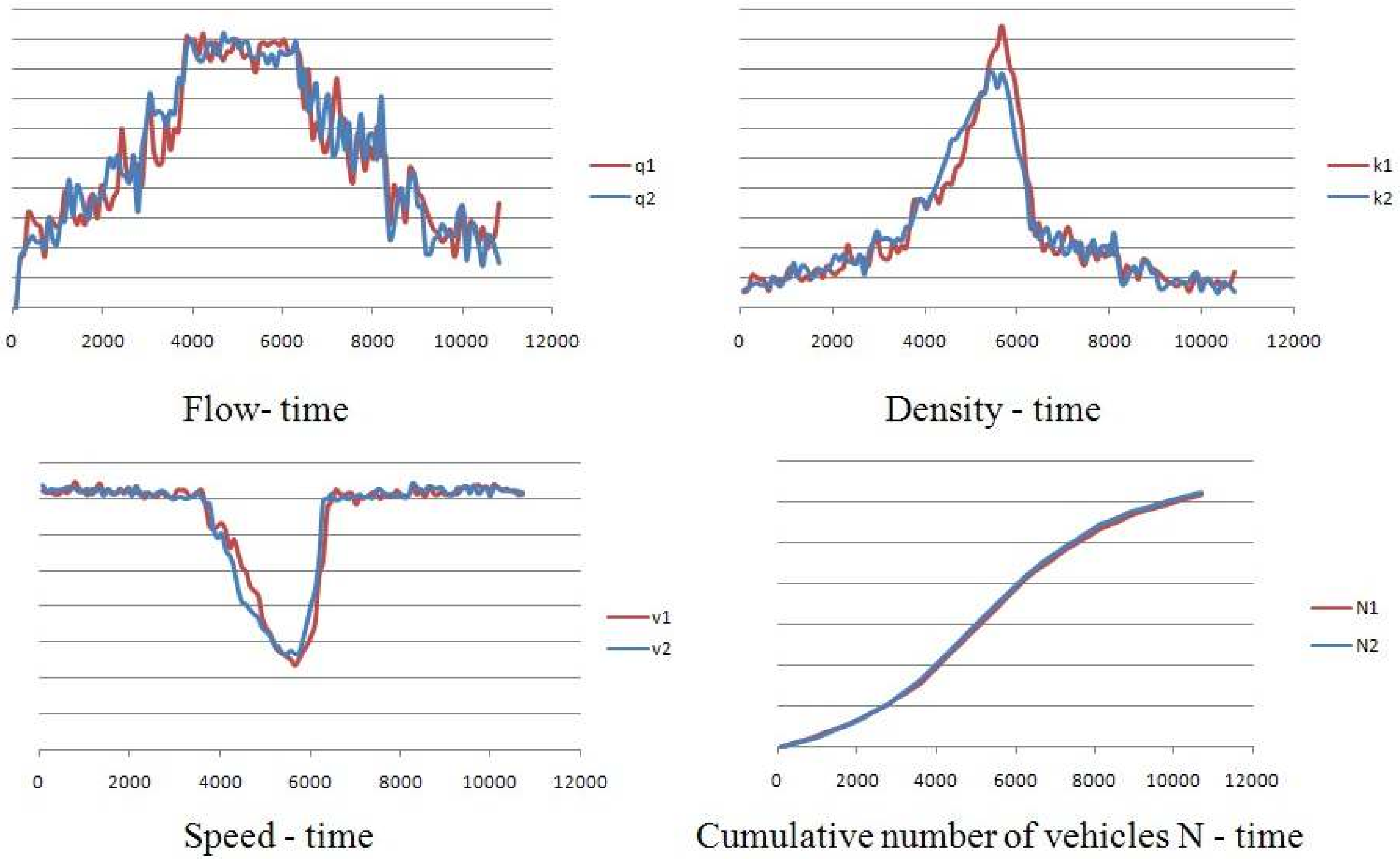
# Model Calibration and Validation

- Automatic Departure Curve Calibration to Match Speed Profile
  - Before Calibration: q, k, v & N curve profiles



# Model Calibration and Validation

- Automatic Departure Curve Calibration to Match Speed Profile
  - Before Calibration: q, k, v & N curve profiles

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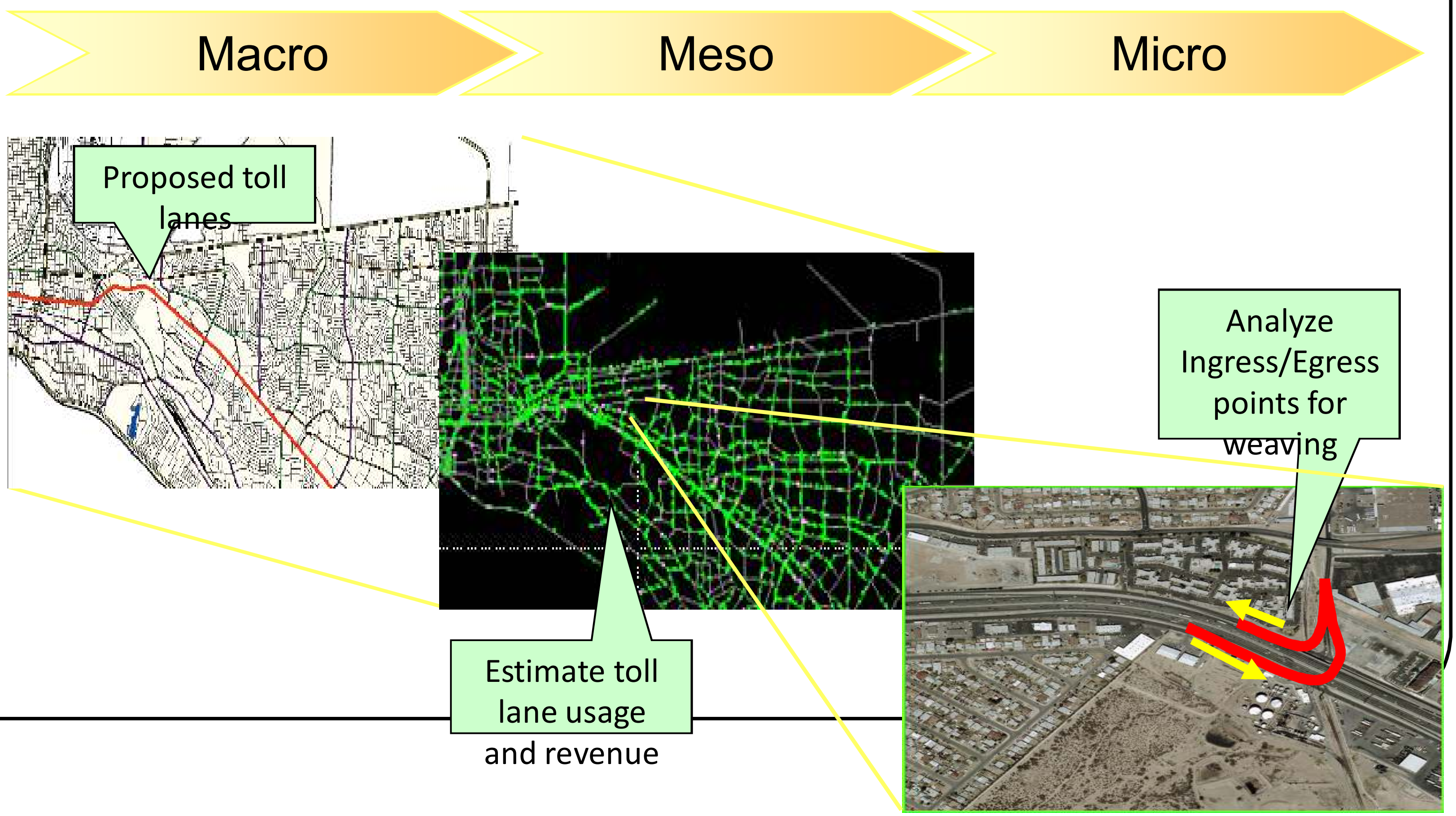
# Macro-Meso-Micro Integration

- Why
  - Inform sub-area micro model with accurate diverted route and flow info for scenarios.



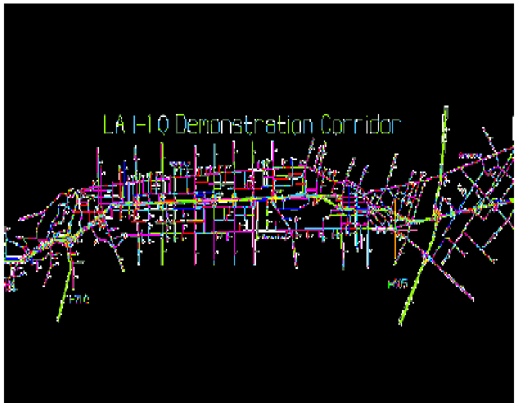

DynusT

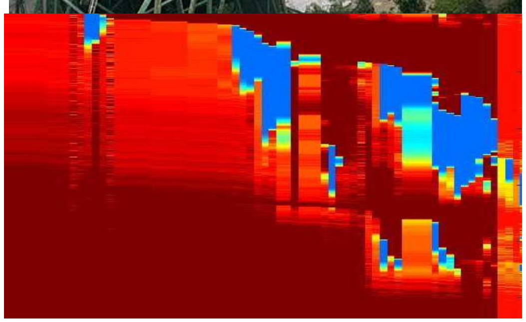
- Open source and free software download at http://dynust.net
  - 250+ international users
  - 1000+ software downloads
  - 200+ source codes downloads
  - Current release: 2011
  - New release 2012

# Community-Based Open Source (2011 or 2012)

- Existing Developers
  - Univ. of Utah(*)
    - Travel demand model importer
  - RST International
    - DynuStudio
  - Texas Transportation Institute
    - VISUM - DynusT interface (PTV)
    - DynusT - VISSIM interface
  - Parsons Brinckerhoff(*)
    - Synchro - DynusT importer
    - Google Earth displayer
    - DynusT - DYNAMEQ (PB)
    - DynusT - VISTA (PB)
  - Pima Associations of Governments(*)
    - Synchro - DynusT importer

# Ongoing Efforts to Support Users and Agencies



- **Work zone management** (**SHRP2 R11, ,** Kittleson**, ADOT;** TTI**, TxDOT;** PB**, MDOT,** Atkins**, CDOT;** UA**,DVRPC** )
- **Military deployment transportation improvement in Guam** (PB, **FHWA**)
- **Interstate highway corridor improvement** (TTI, **TxDOT**, **ELPMPO,** UA**, CDOT**)
- **Congestion pricing** (Atkins, **CDOT**;ORNL, **FHWA**; SRF, **Mn/DOT**, TTI, **TxDOT**, UA, **CDOT/DRCOG**)
- **Evacuation operational planning** (Virginia Tech U, **VDOT/VDEM**; TTI, **TxDOT**, UA, **ADOT**; LSU, **LDOT**; Noblis, **FHWA**; Univ. of Toronto, Cornell Univ. Jackson State Univ., **MDOT**, Univ. of Missouri, **MDOT**)
- **Integrated Corridor Management modeling** (CS, **FHWA**, **MAG**, NCSU, **NCDOT, MAG**)
- **Regional Strategic Model** (**Portland Metro, SCAG, DRCOG**)
- **Activity-based model integration** (UA, **SHRP2 C10**; UA, **DRCOG**; UA, **SCAG**; **FHWA EARP**)

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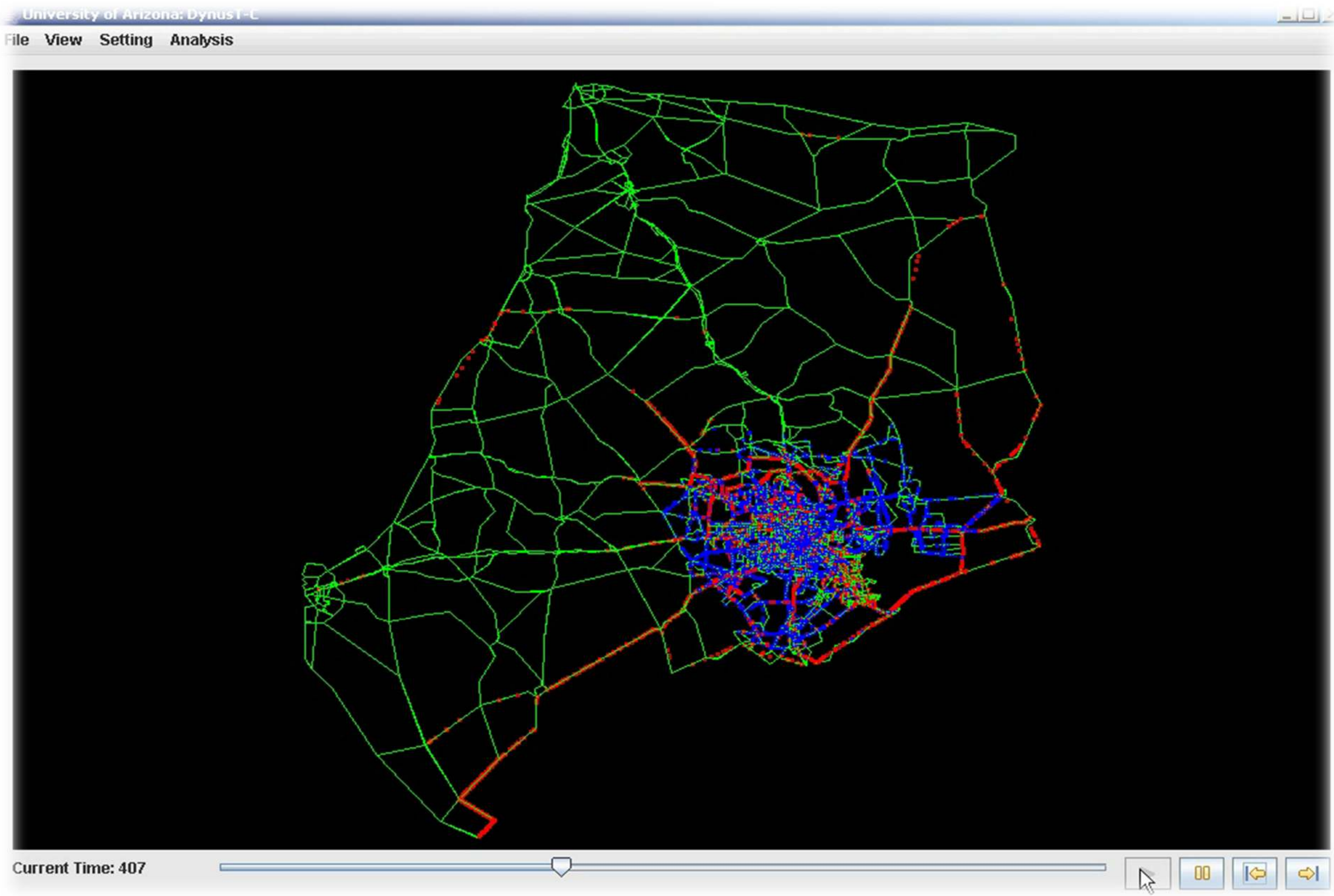
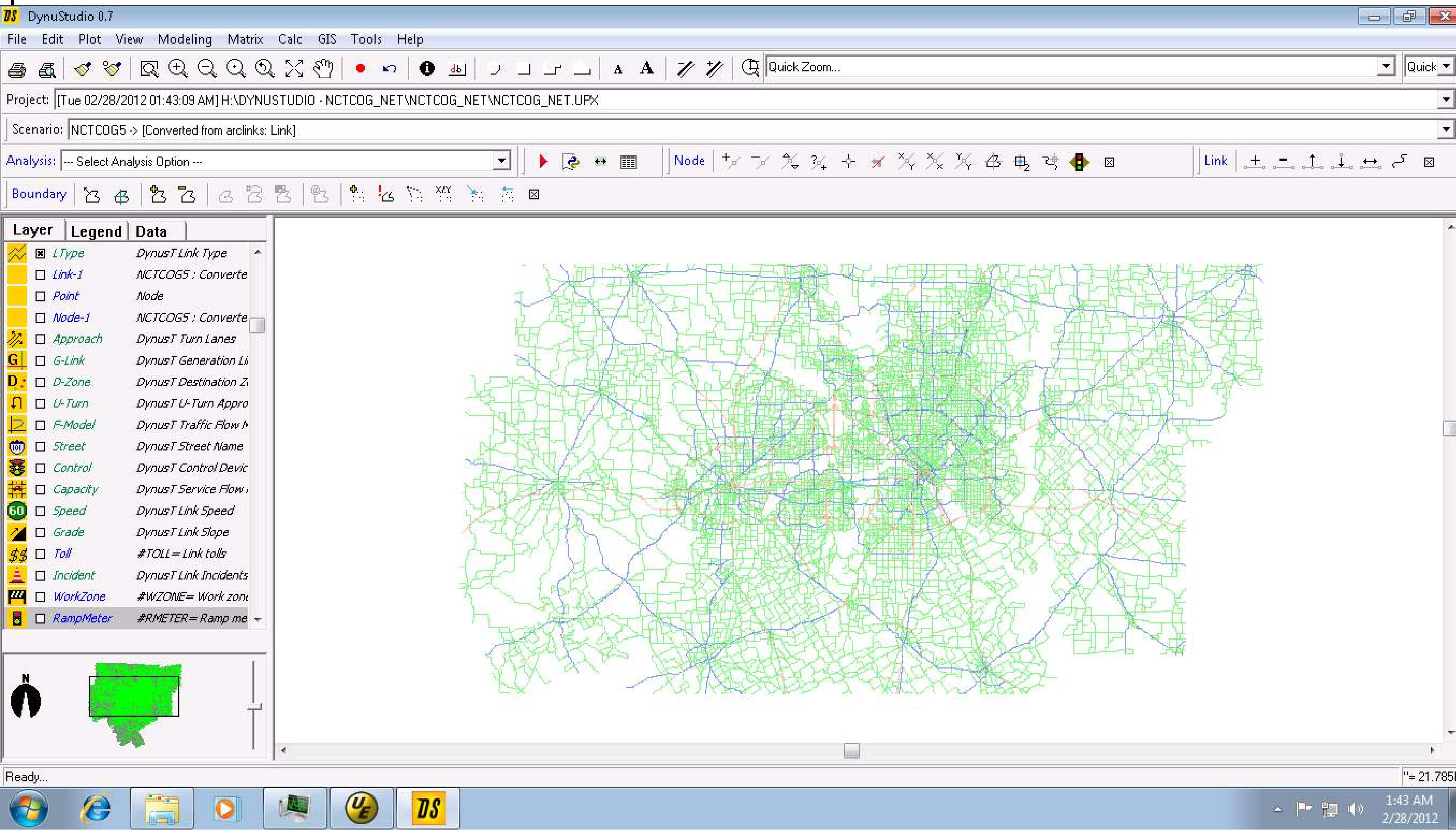
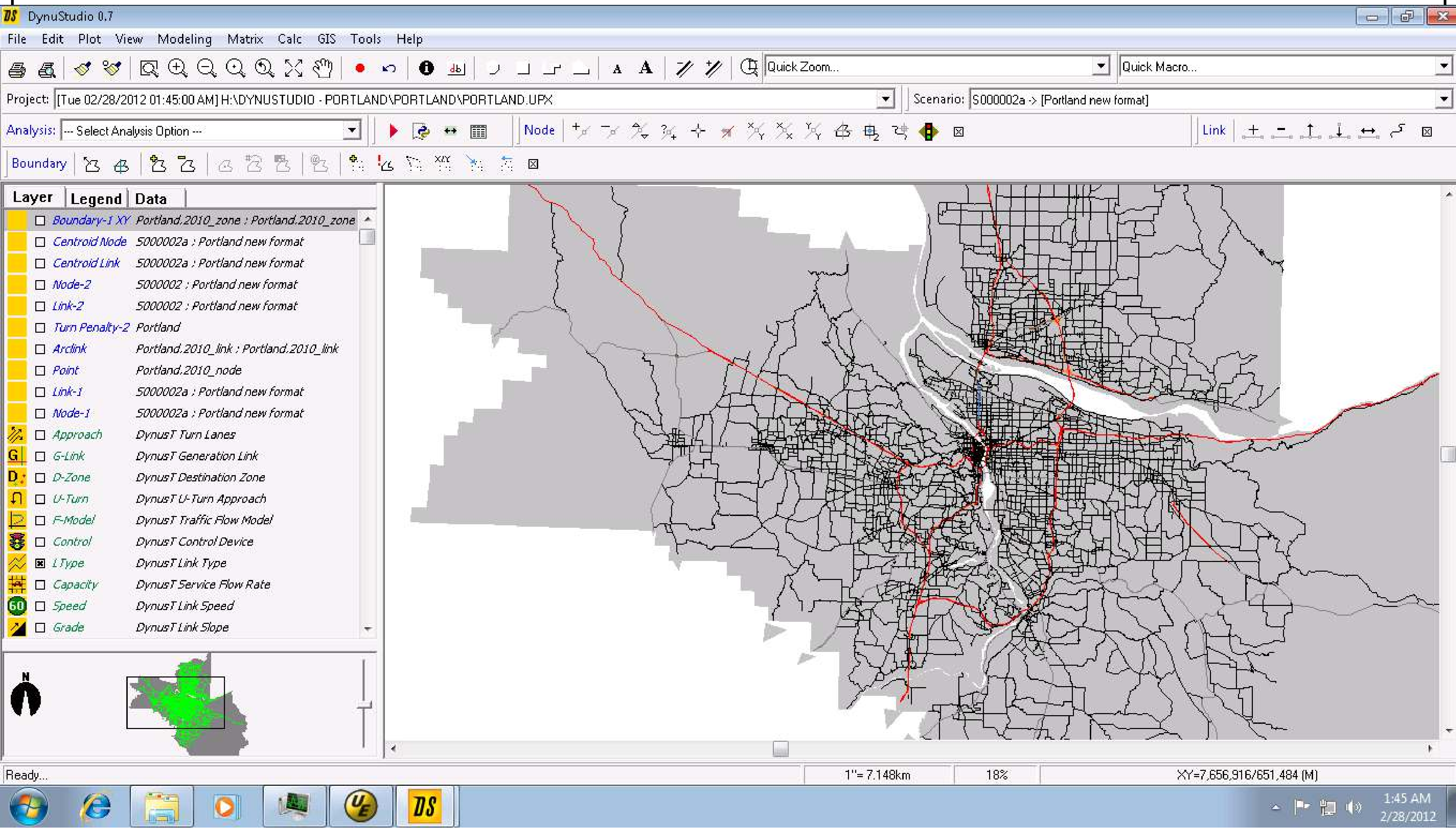
# Central Texas Evacuation Model



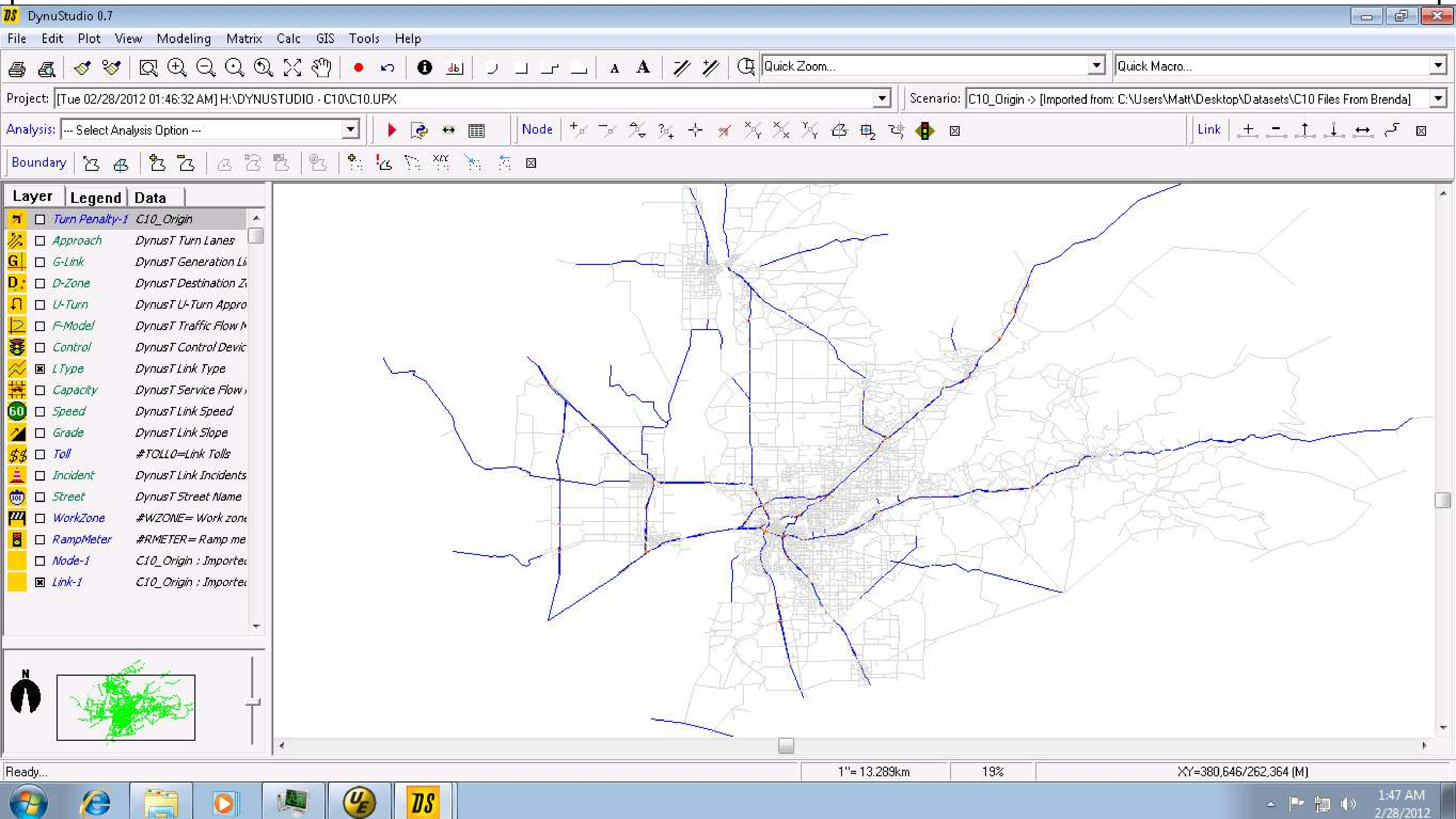
# NCTCOG DynusT Model



# Portland Metro DynusT Model



# SACOG DynusT Model

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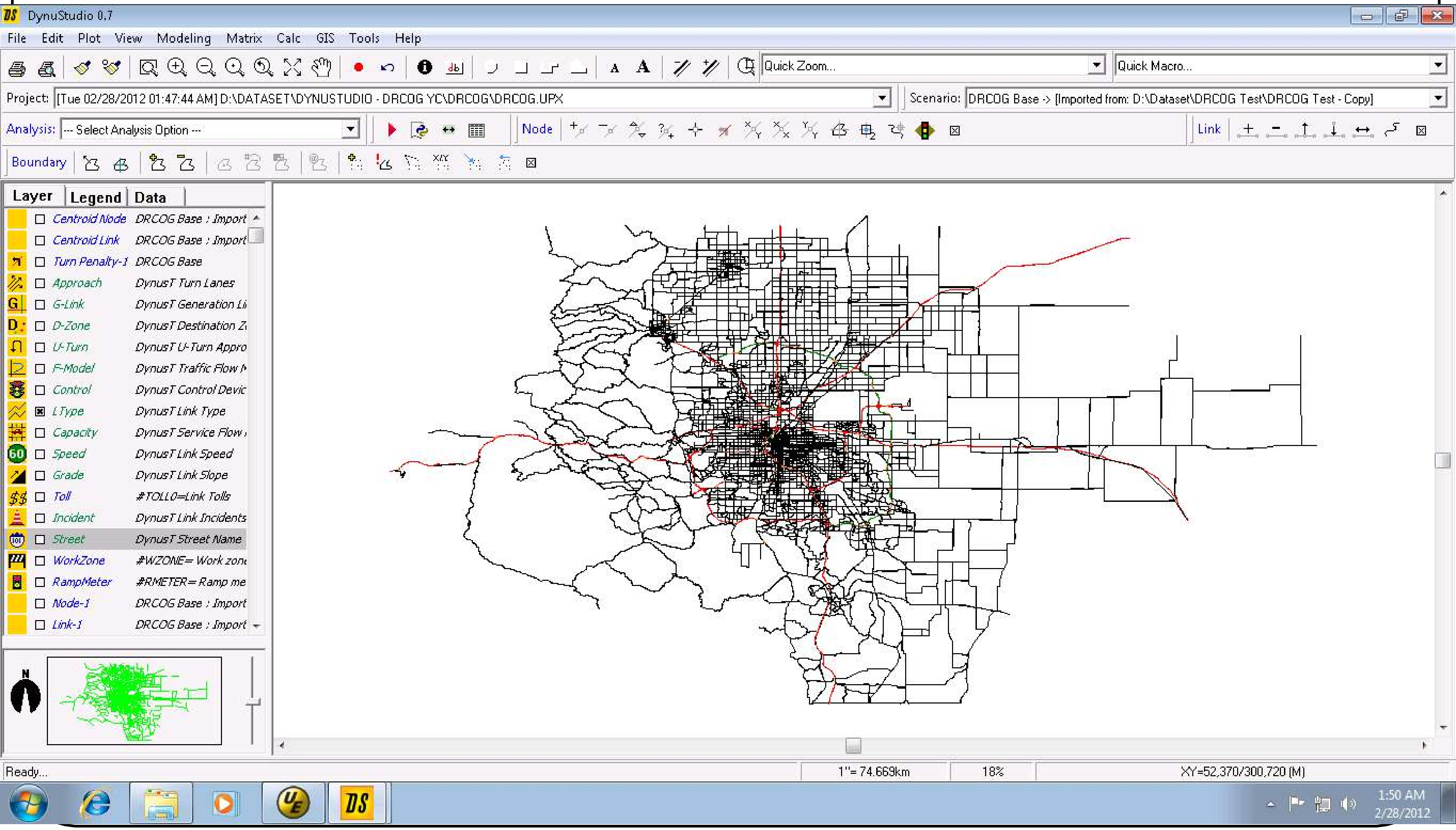
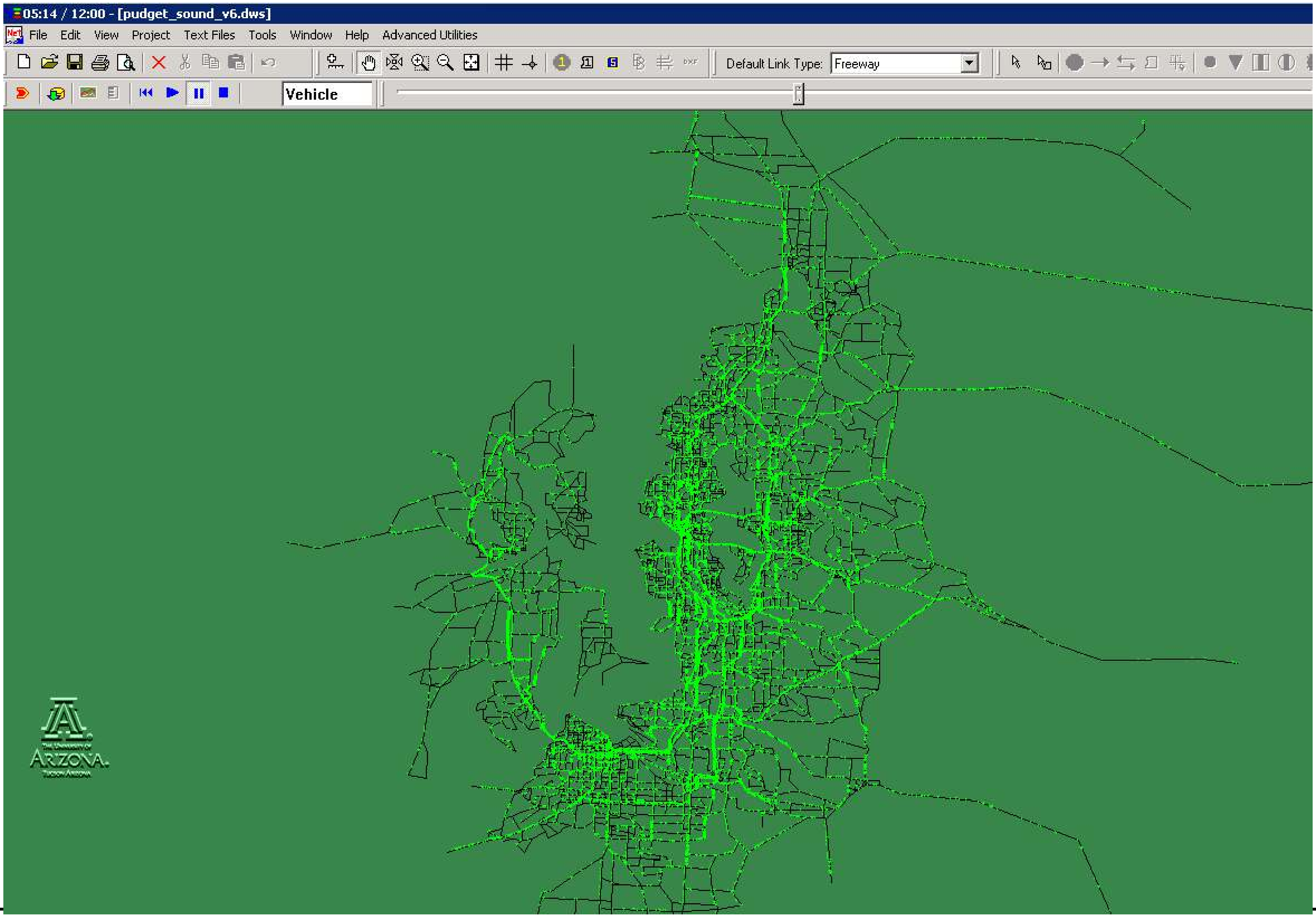
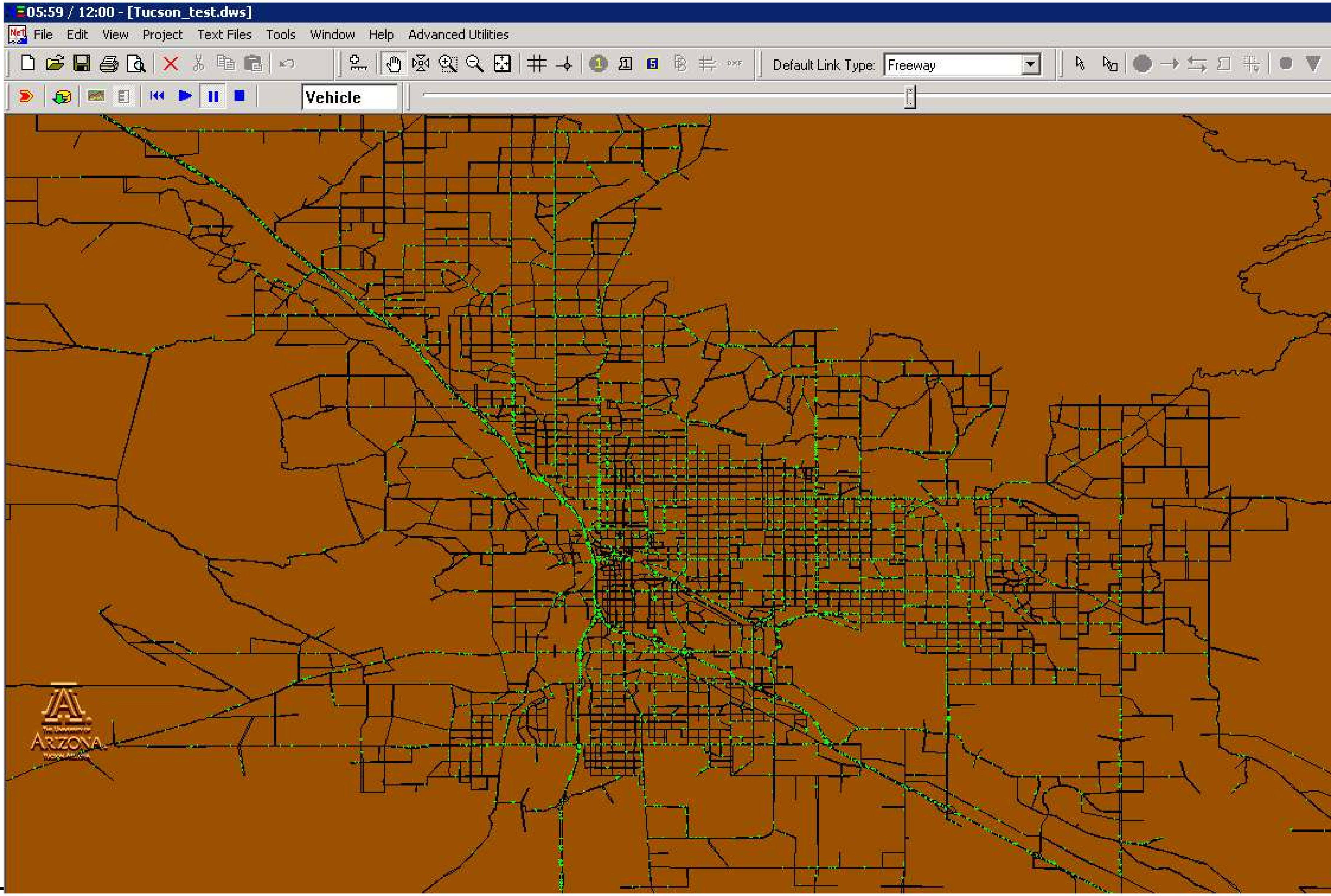
# DRCOG DynusT Model



# Puget Sound DynusT Model



# PAG DynusT Model

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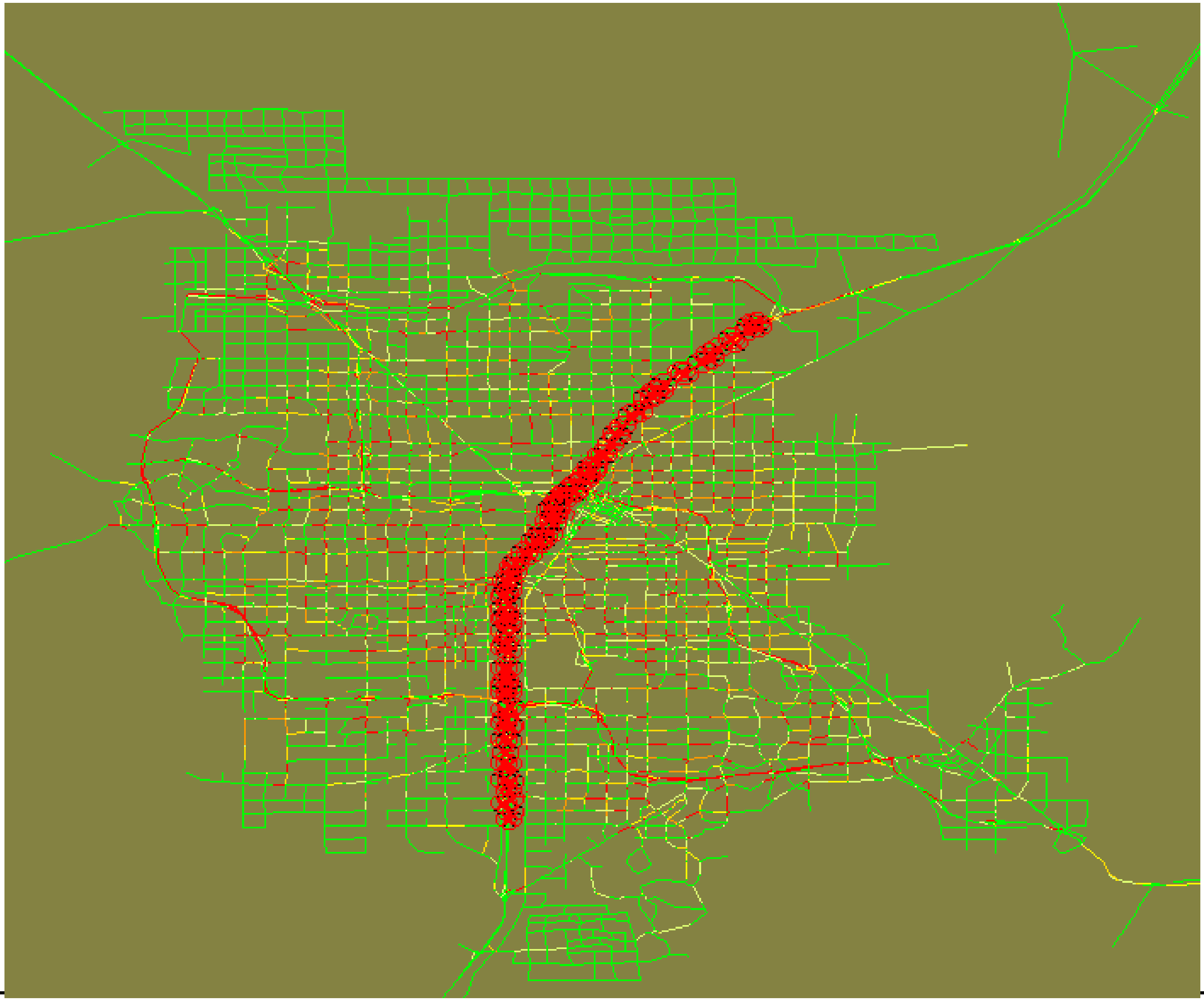
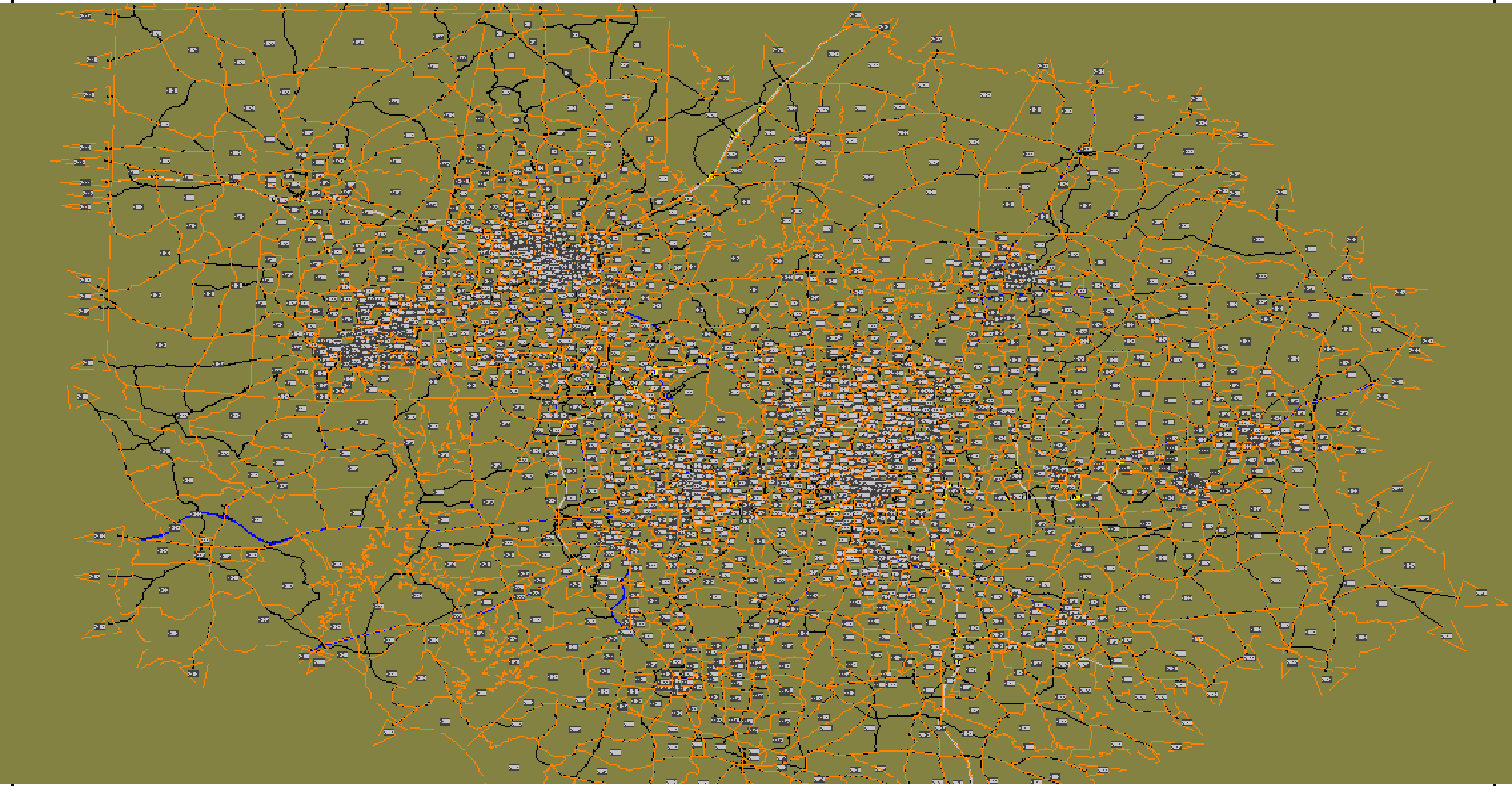
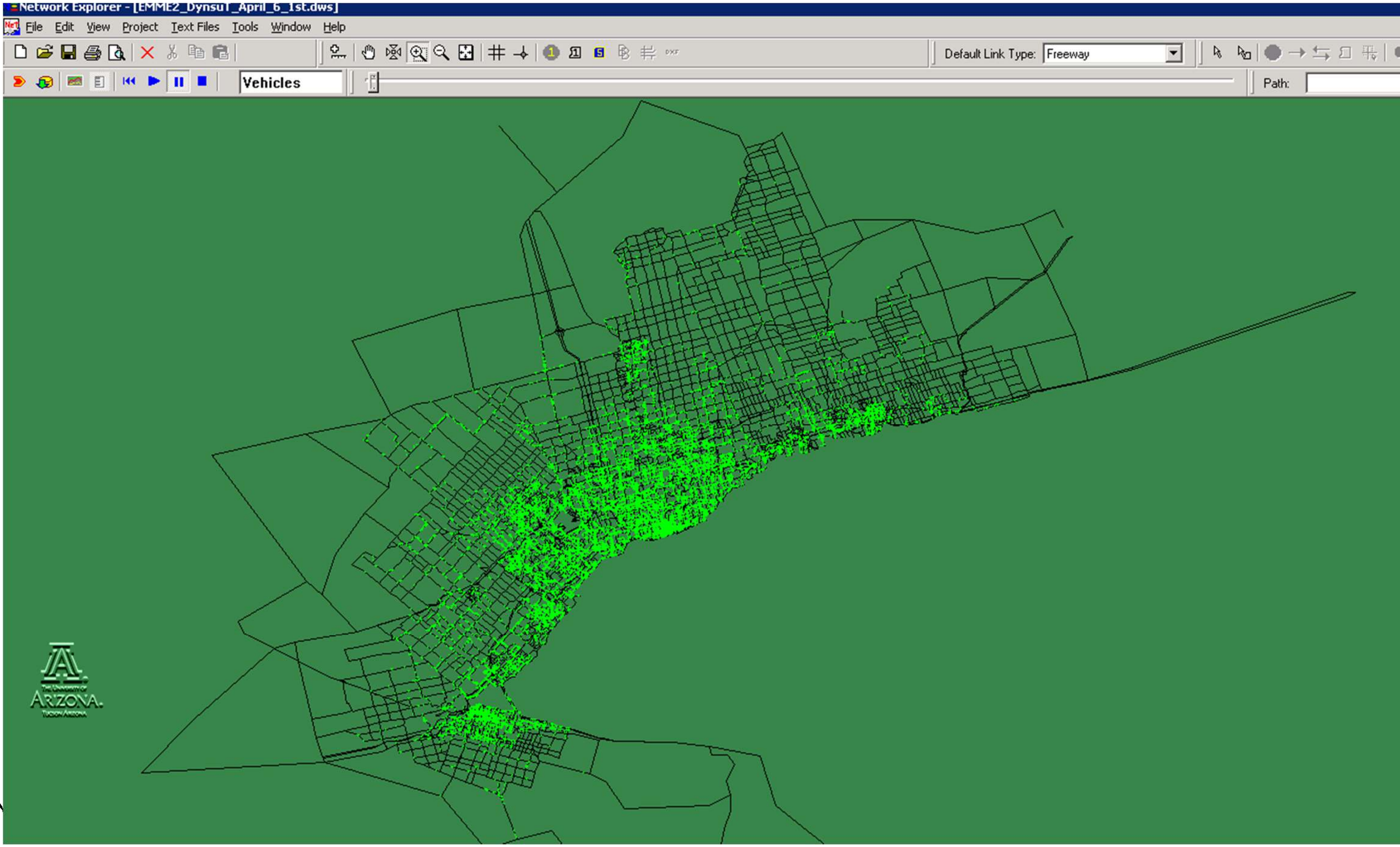
# Las Vegas DynusT Model



# Triangle, NC DynusT Model

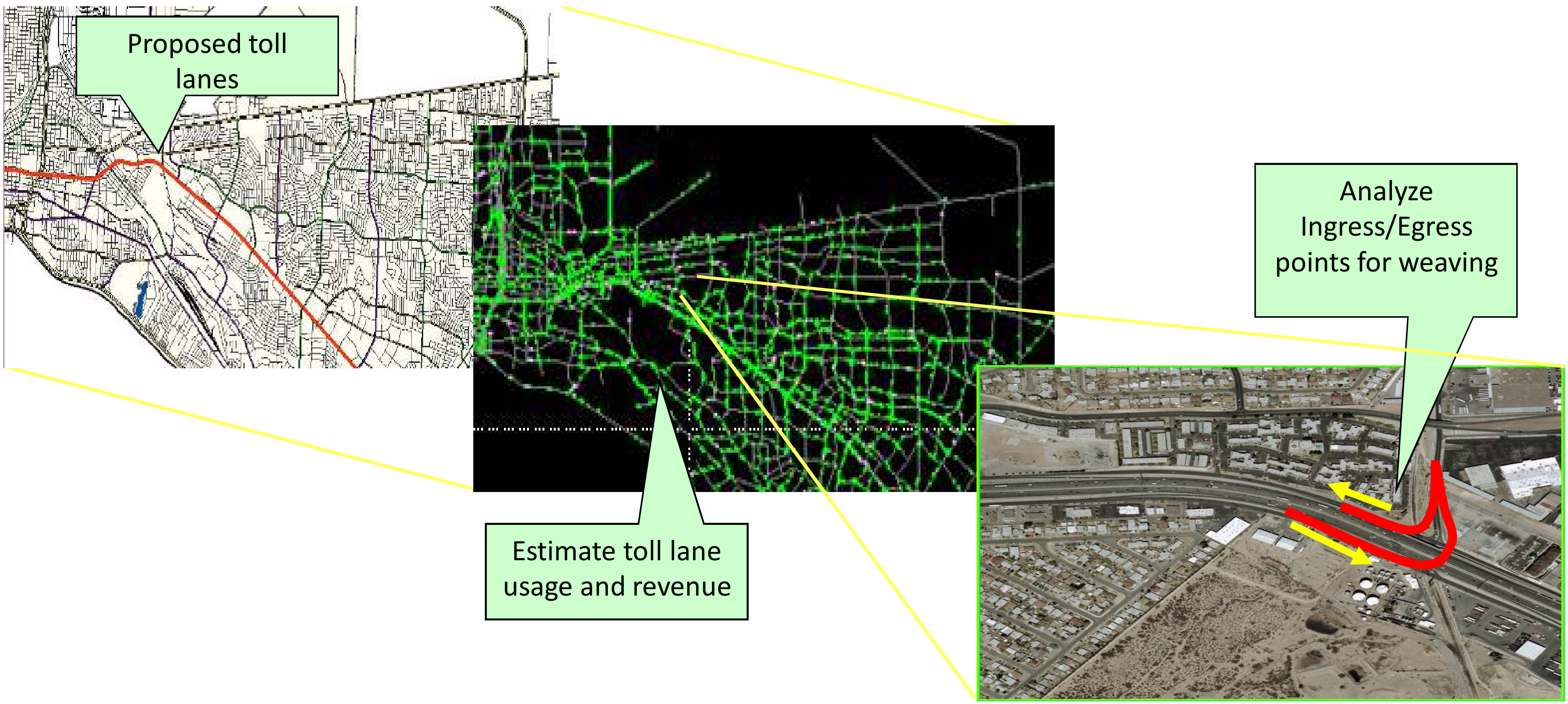


# Toronto, CAN DynusT Model

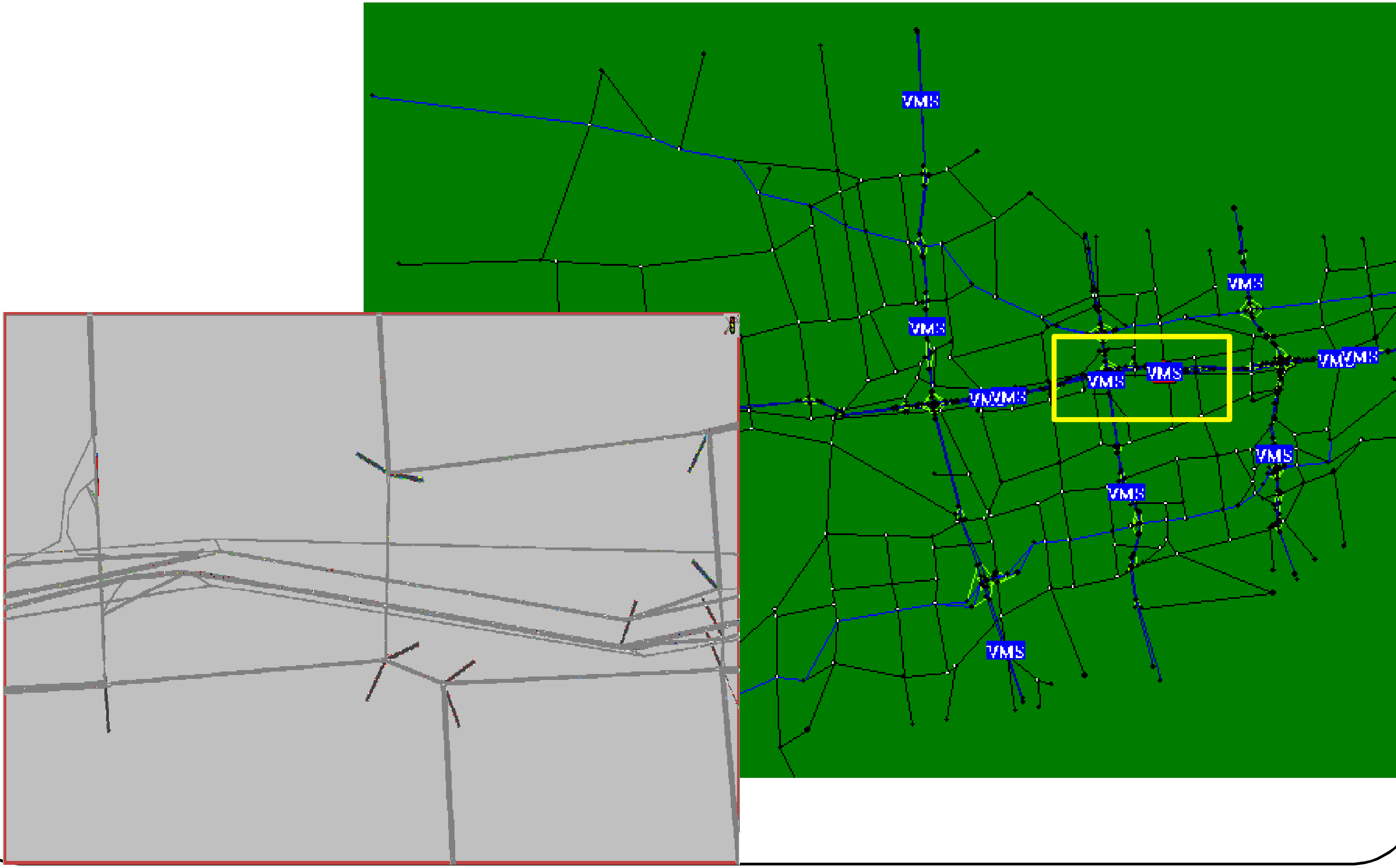


# Macro-Meso-Micro Integration

Macro → Meso → Micro



# DynusT-VISSIM Integration



# Recent Enhancements

- Computational Enhancements (*)
- Pricing analysis
  - Fixed
  - Time-of-day
  - Congestion responsive pricing
  - Heterogeneous attribute (VoT, trip purpose, etc.)
- Diurnal curve estimation (*)
- MOVES integration
- Skim retrieval
- Reliability measures
- Transit integration (*)

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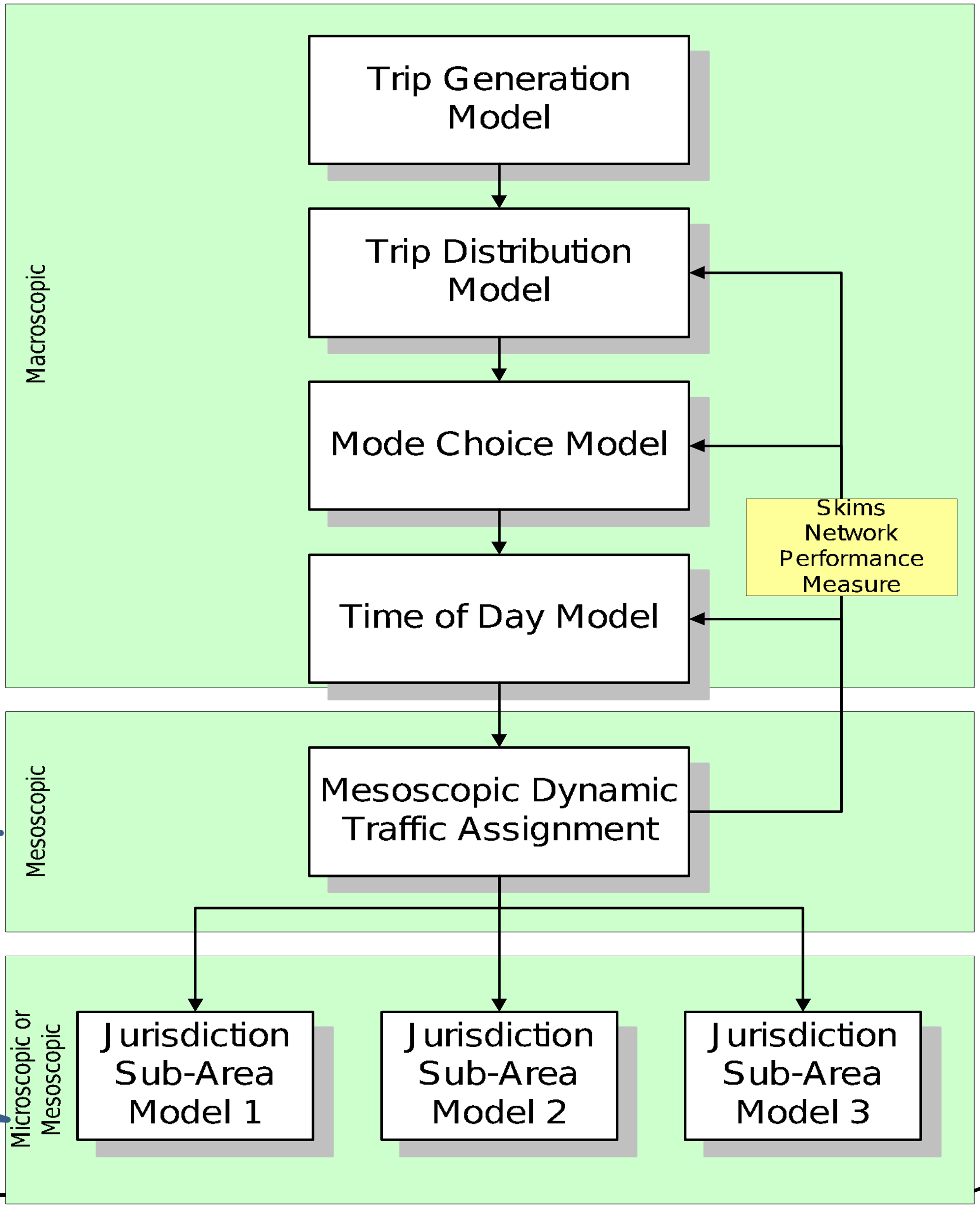
# Compatibility with Existing Modeling Framework

## Trip-based framework

Strategic Modeling

Mission-Driven Modeling

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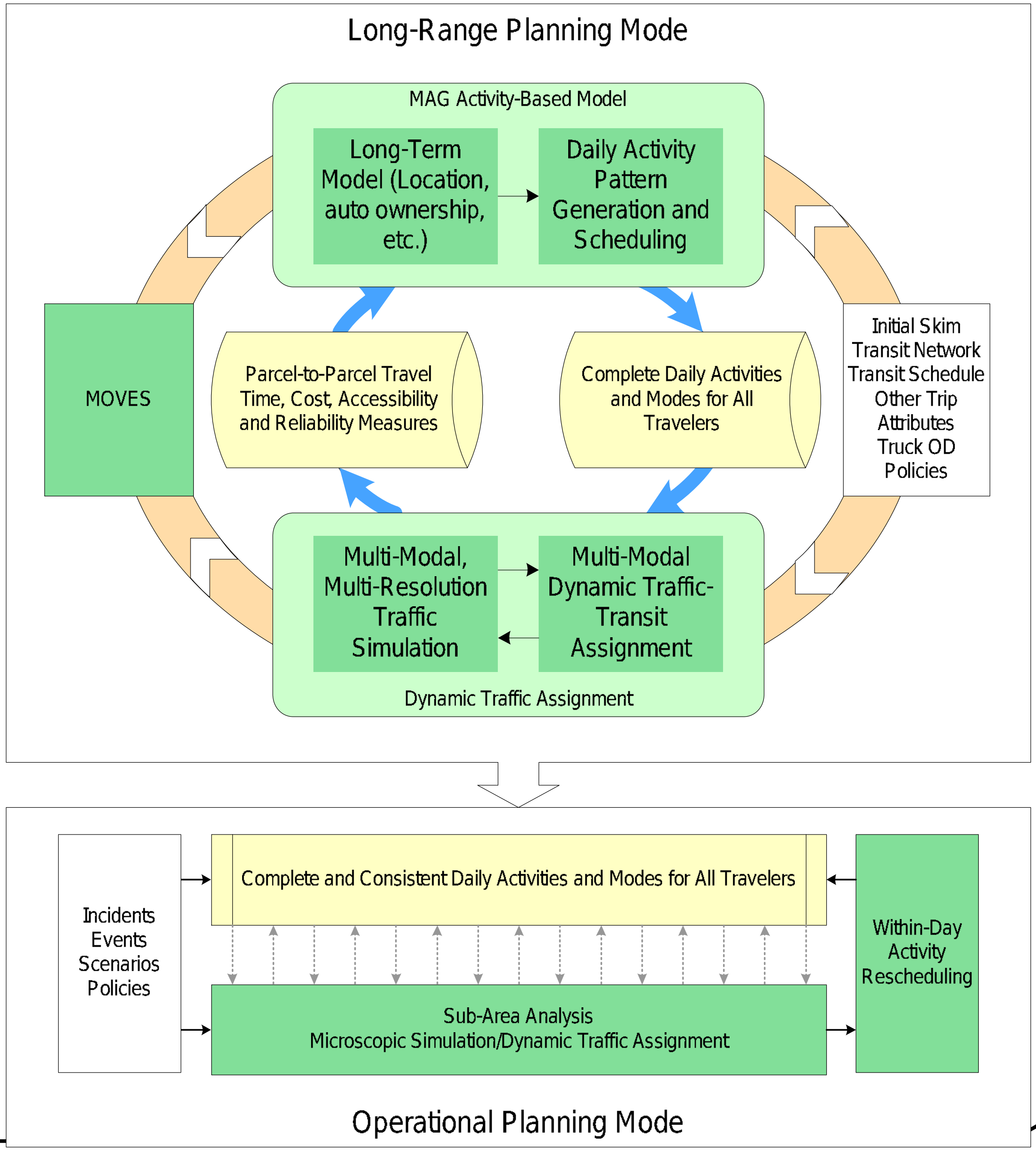
# Compatibility with Emerging Modeling Framework

## Activity-Based Model

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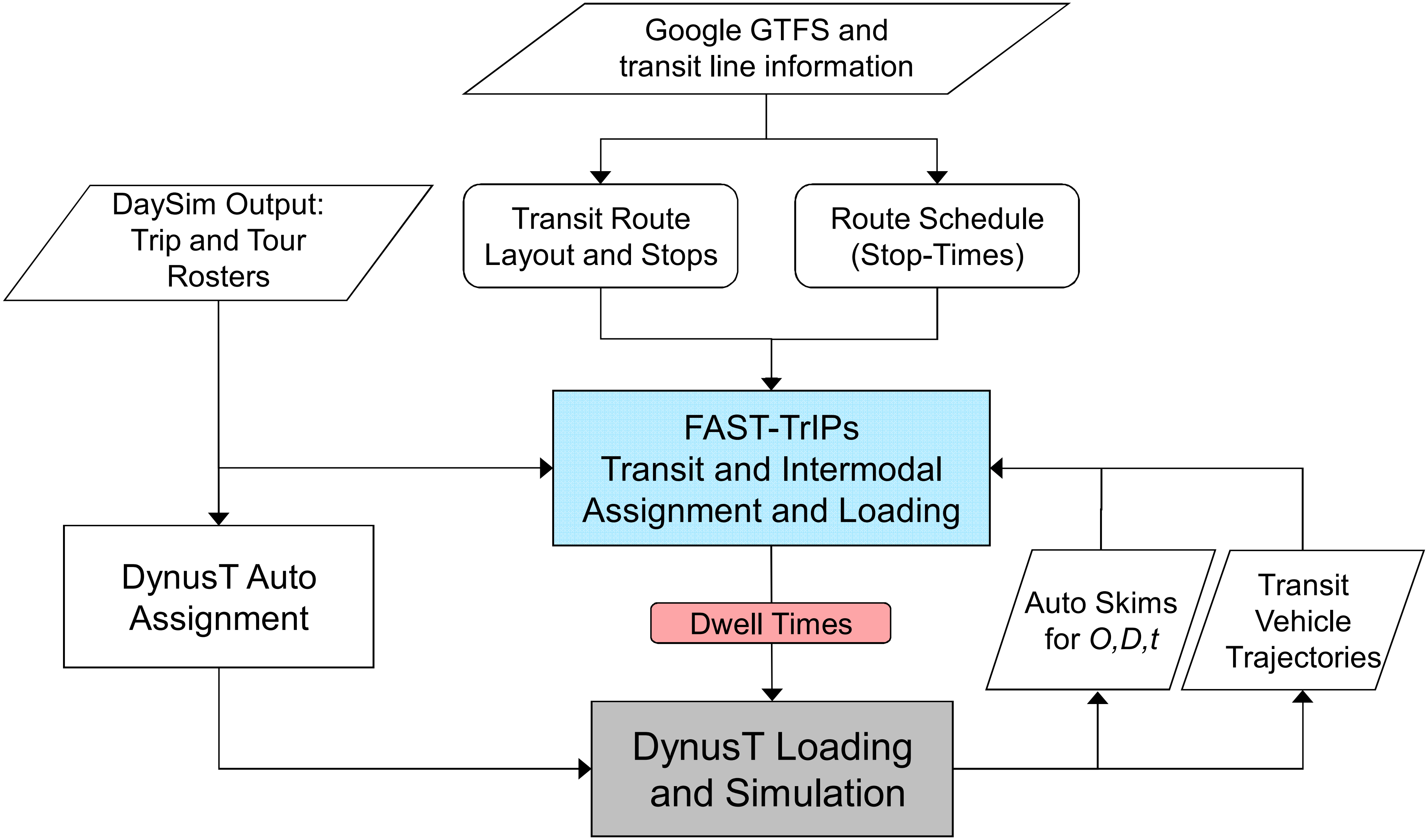
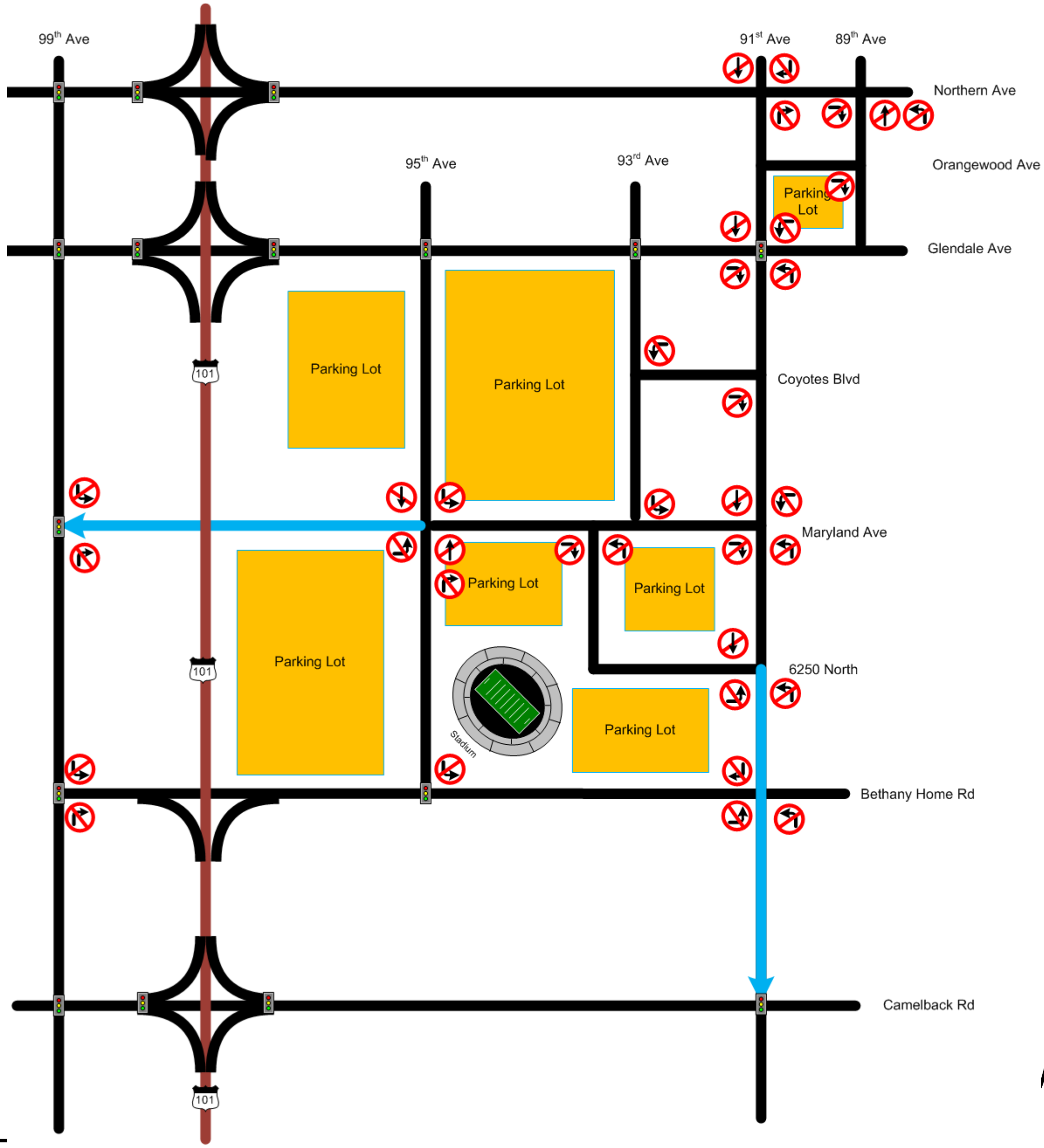
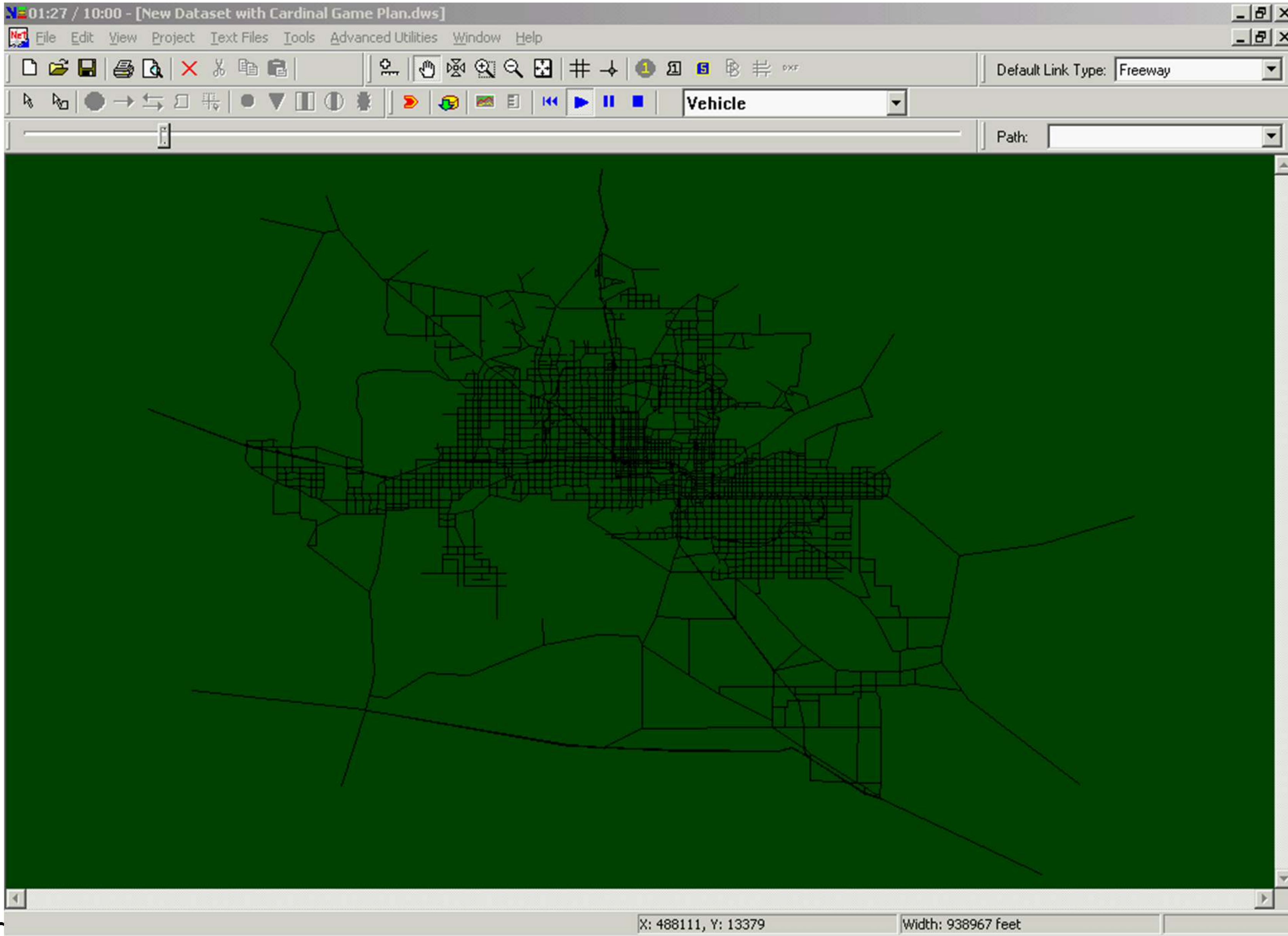
# DTA-Dynamic Transit Assignment



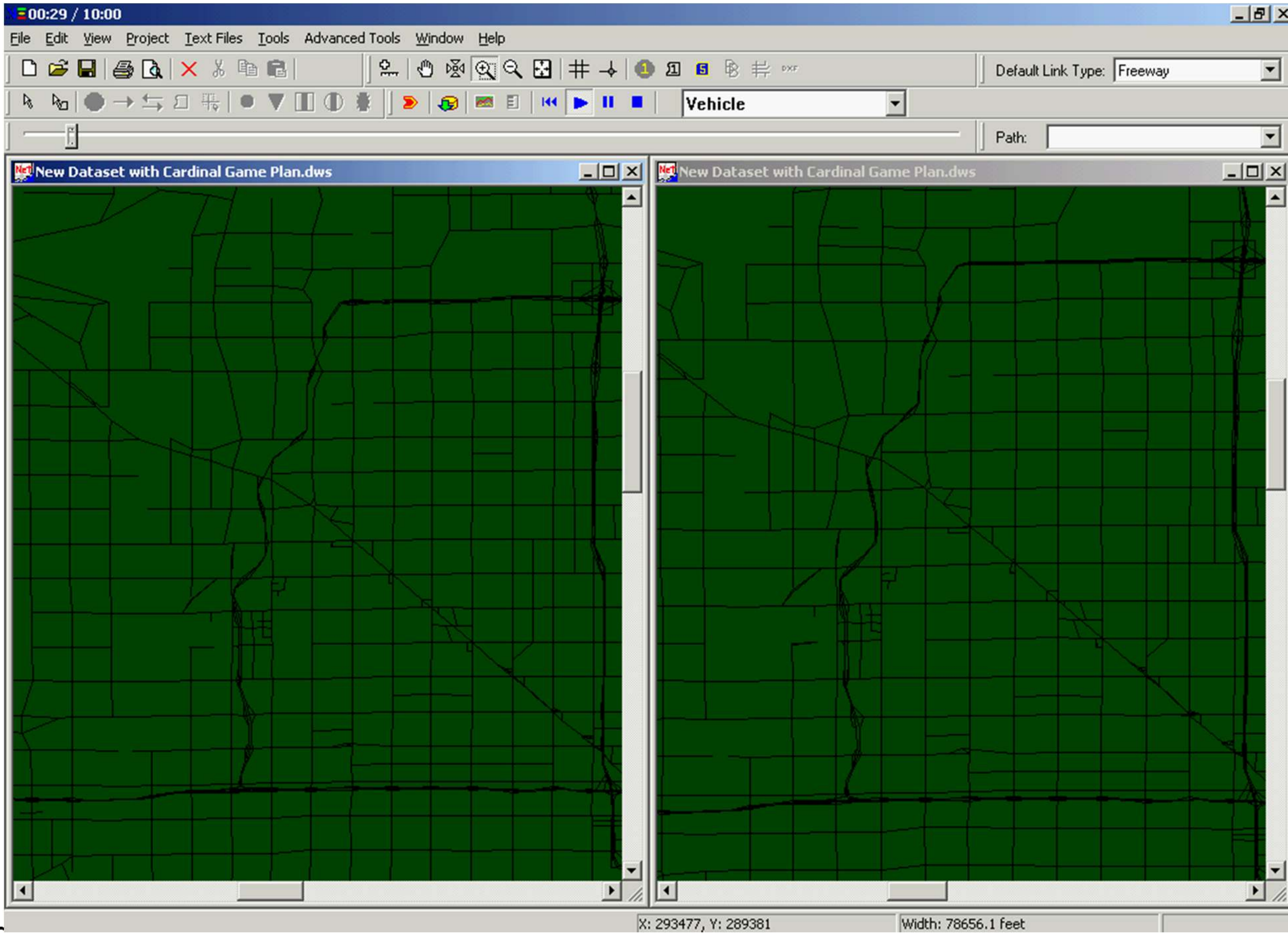
# Cardinal Game Scenario - No-notice Evacuation

- University of Phoenix Stadium
- Scenario
  - Game kick-off: 7:00 pm
  - Bomb threat: 7:30 pm
- 26,780 vehicles evacuated
- Baseline strategy: Glendale's 2007 traffic control plan




01:27 / 10:00 - [New Dataset with Cardinal Game Plan.dws]
File Edit View Project Text Files Tools Advanced Utilities Window Help
Default Link Type: Freeway
Vehicle
Path:
X: 488111, Y: 13379
Width: 938967 feet

# Game Evacuation – Scenario Comparison

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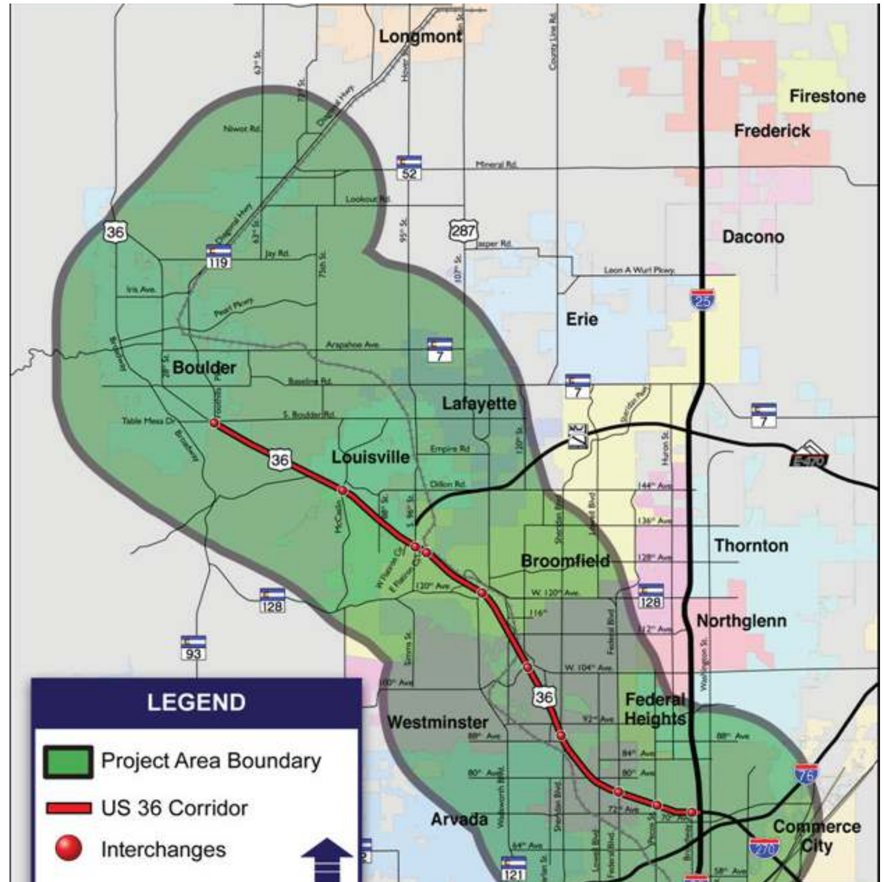
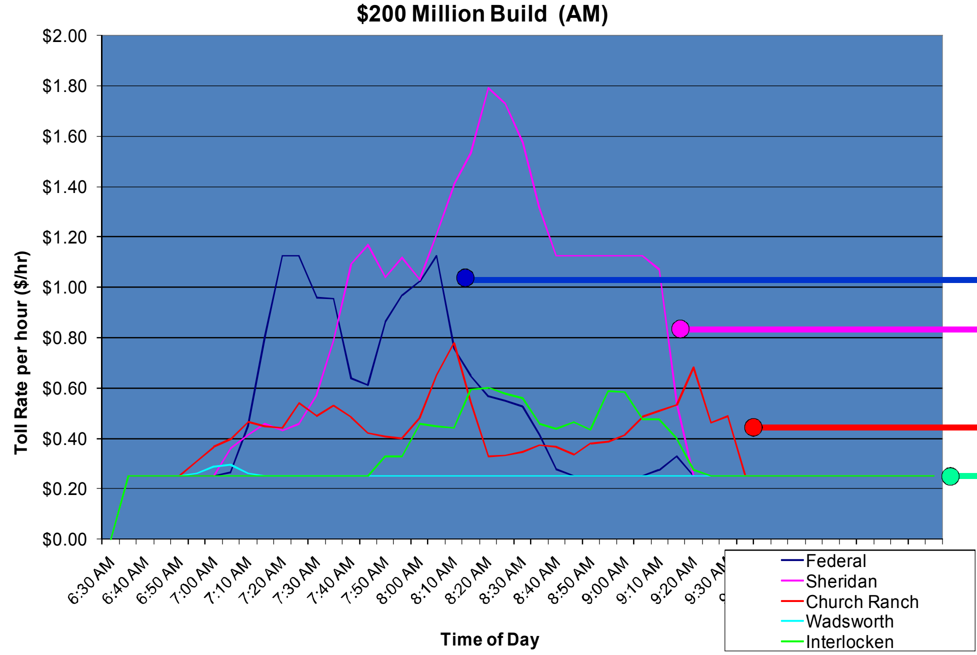
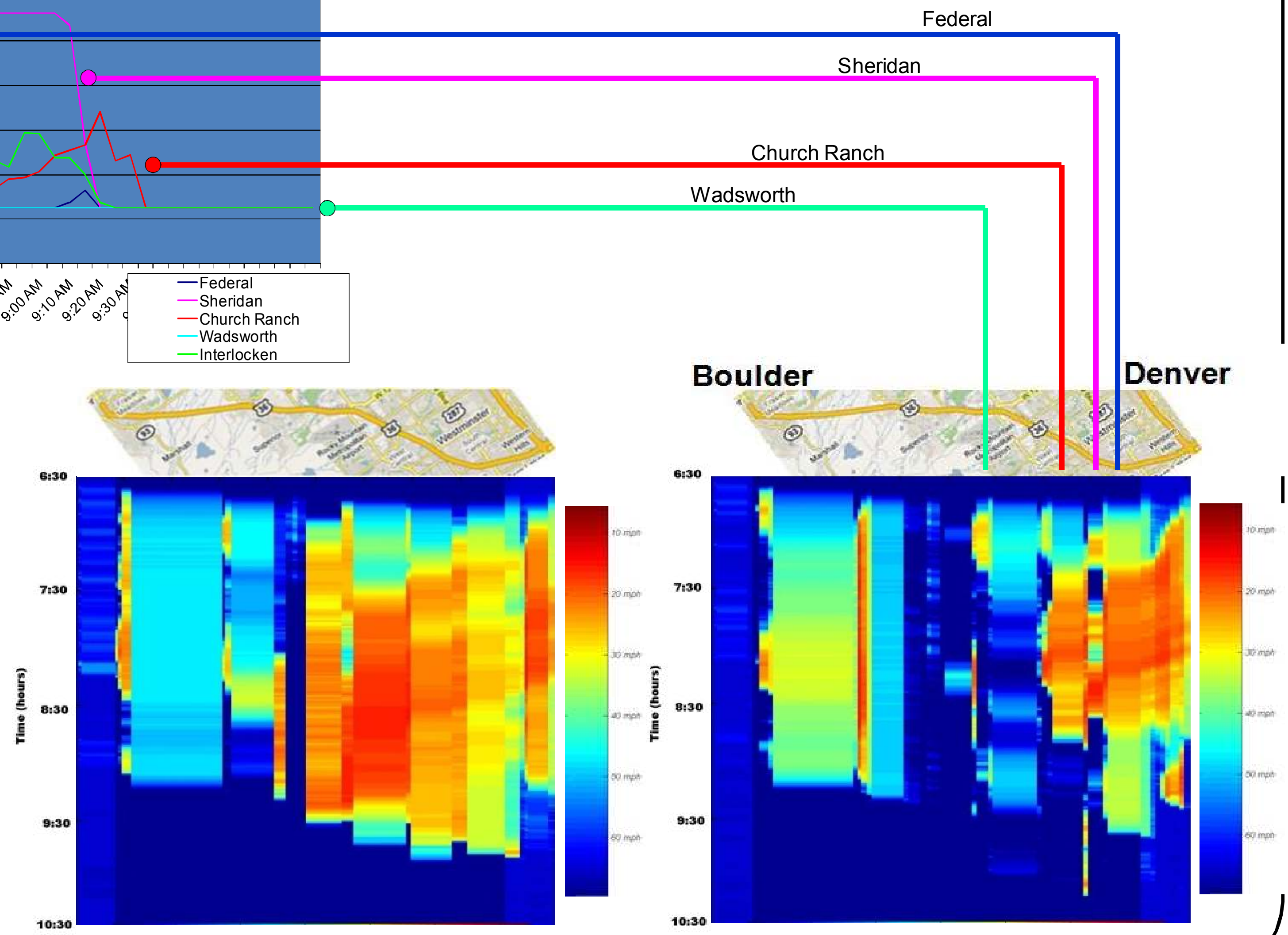
# Background

- Managed lane:
  - One buffer separated lane each direction
  - From I-25 Express Lanes in Denver to Interlocken Interchange
- Bus Rapid Transit
  - Connect cities along the corridor to Denver Union Station
- Bikeway, ITS & TDM Strategies
  - Integration of an 18-mi. commuter bikeway along U.S. 36, with BRT stations




# GP Lane Congestion vs. HOT Price




No Build

$260 Million Build

# The Problem

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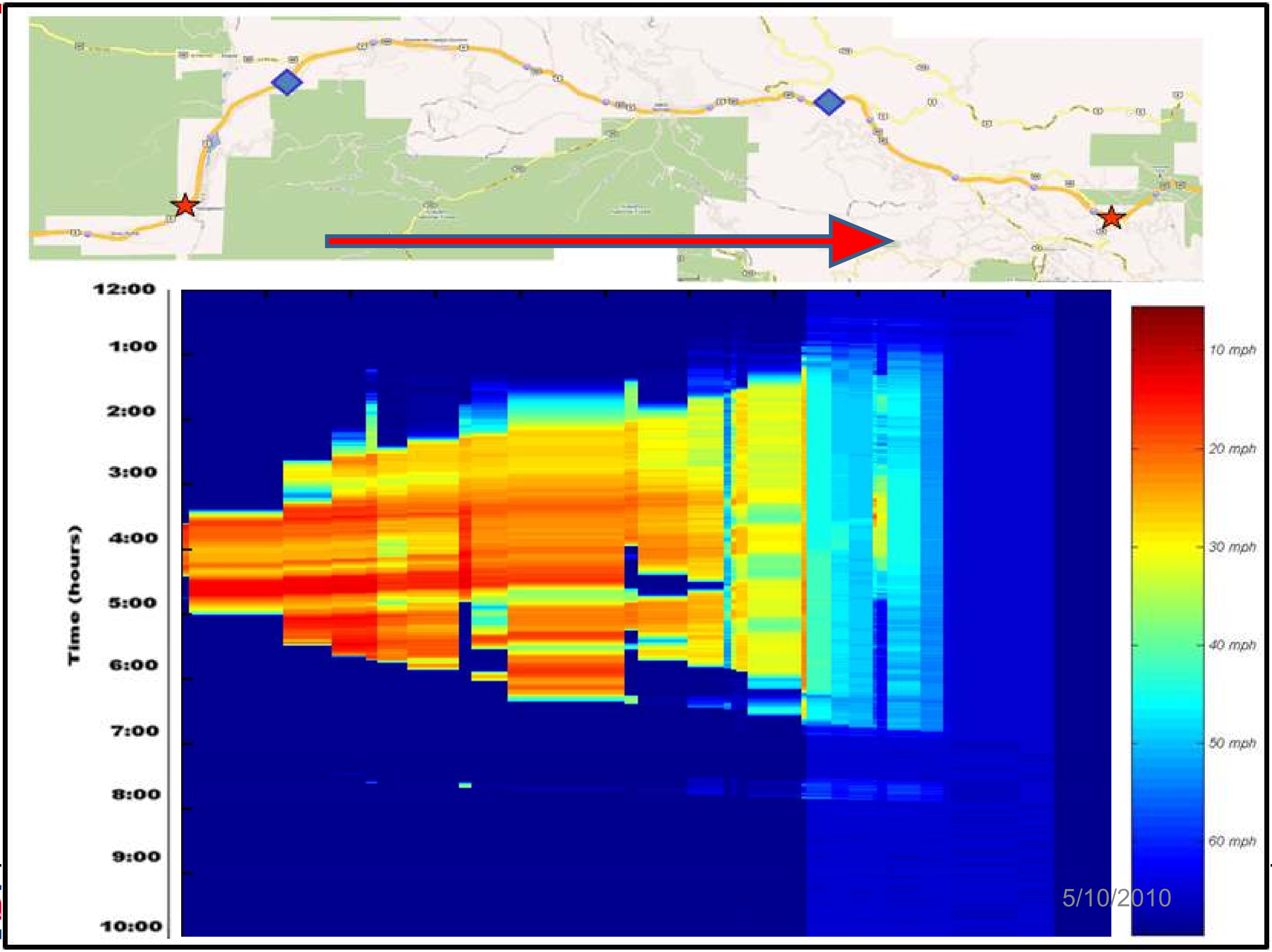
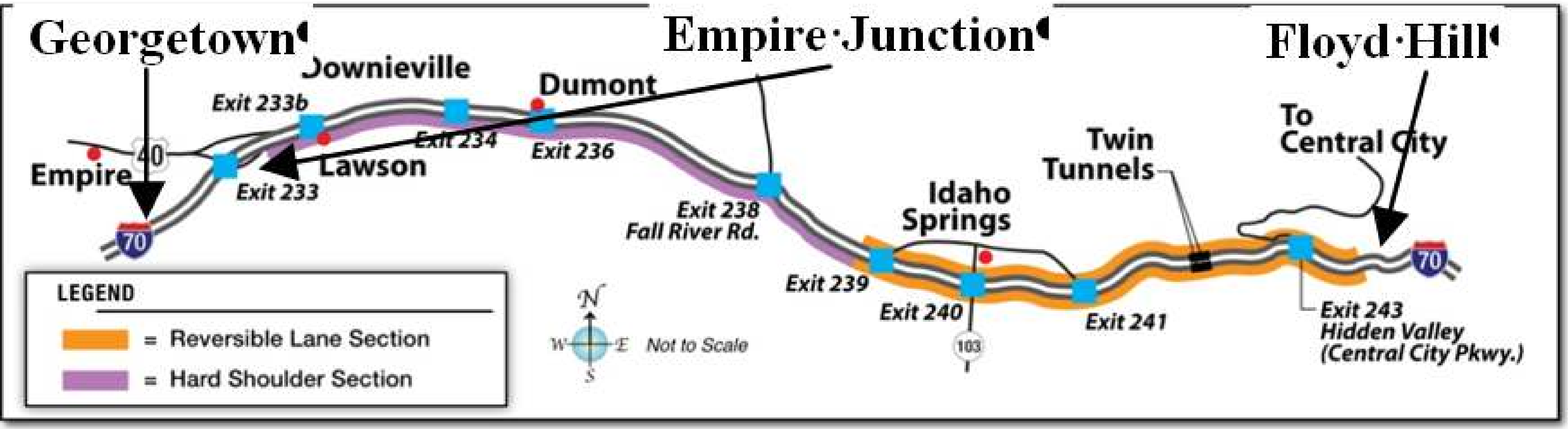
**Scenario 1:** Baseline (Existing Conditions)

**Direction:** EB Main Lanes



# Hard Shoulder Running



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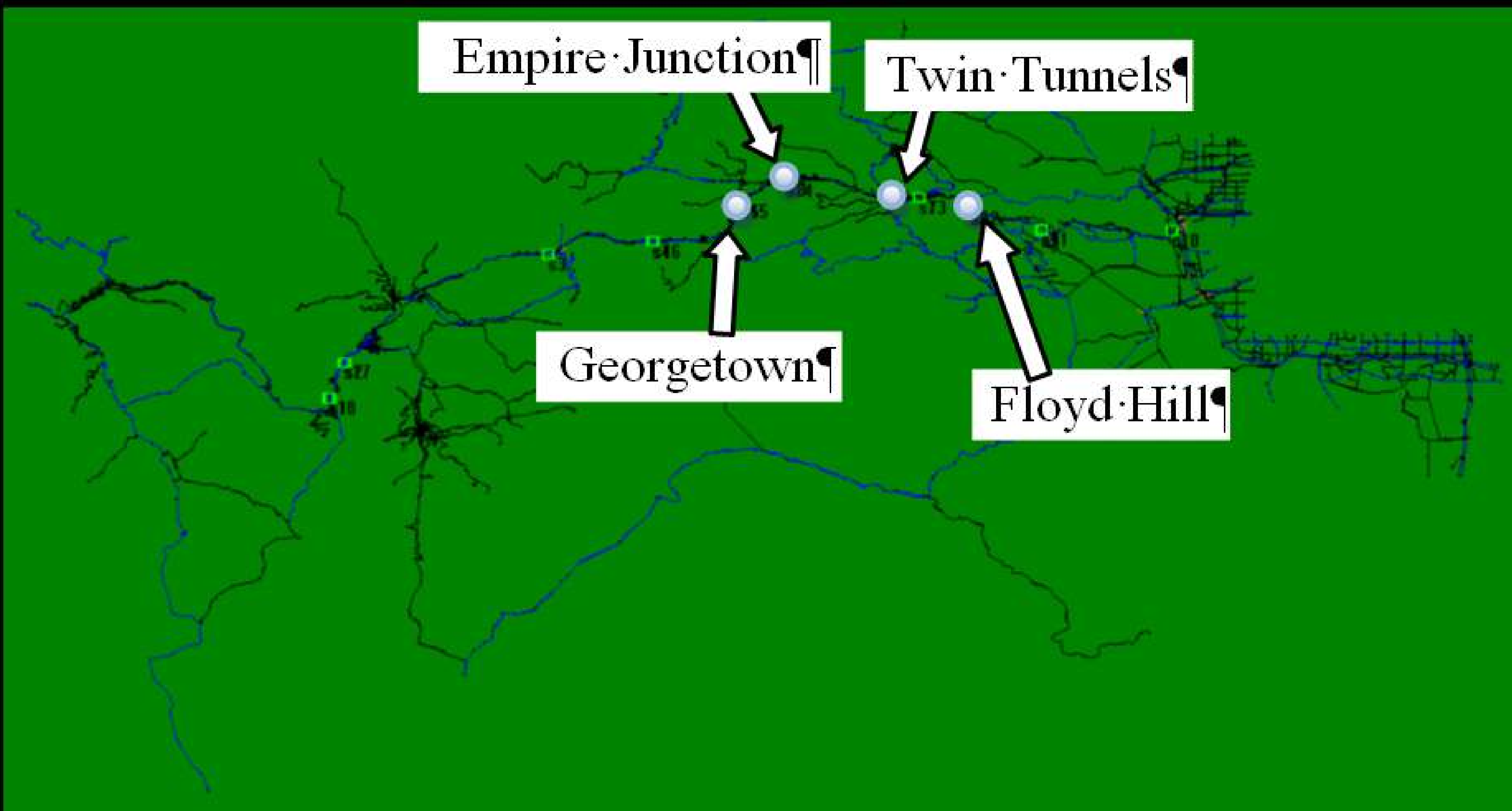
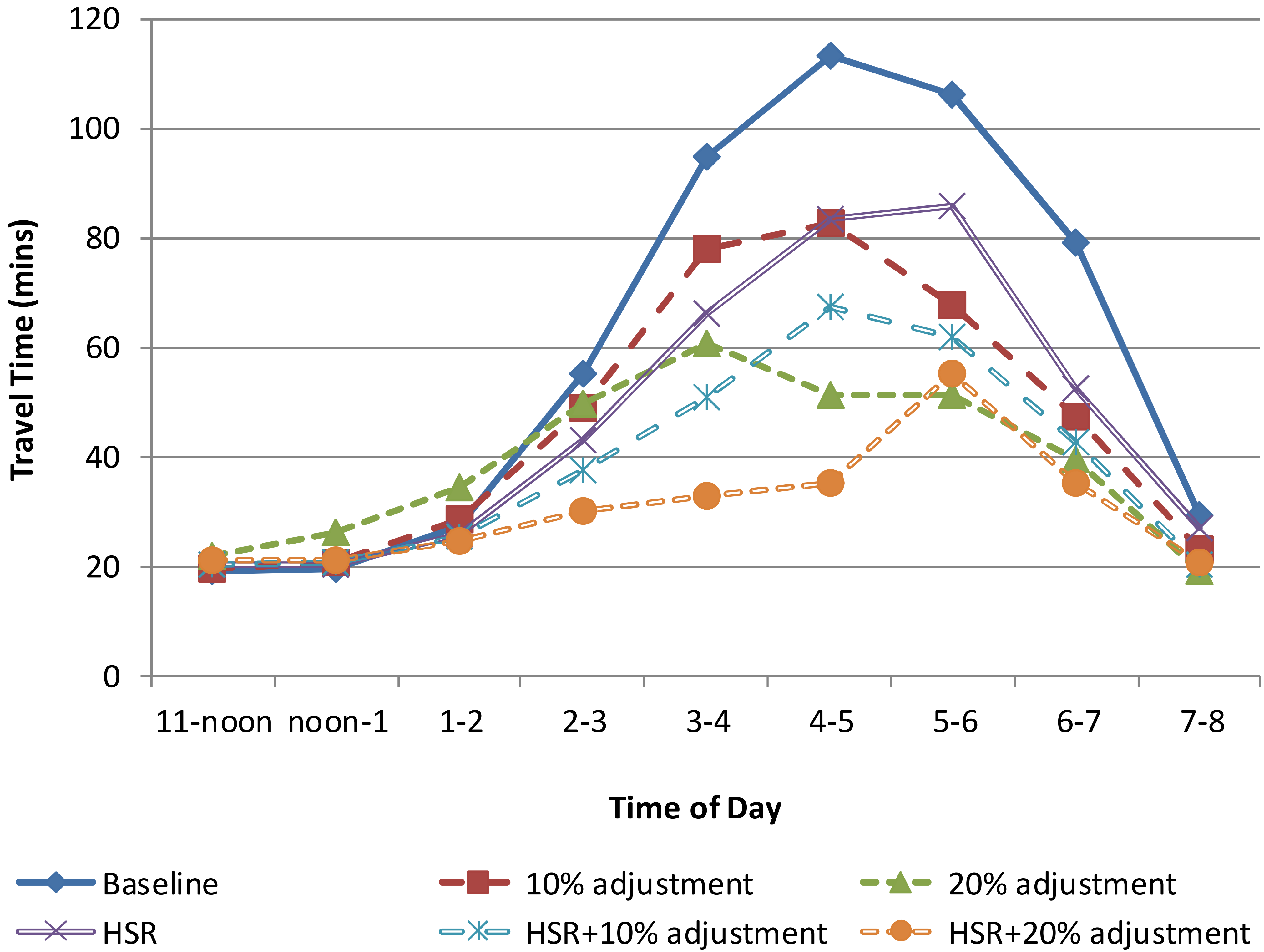
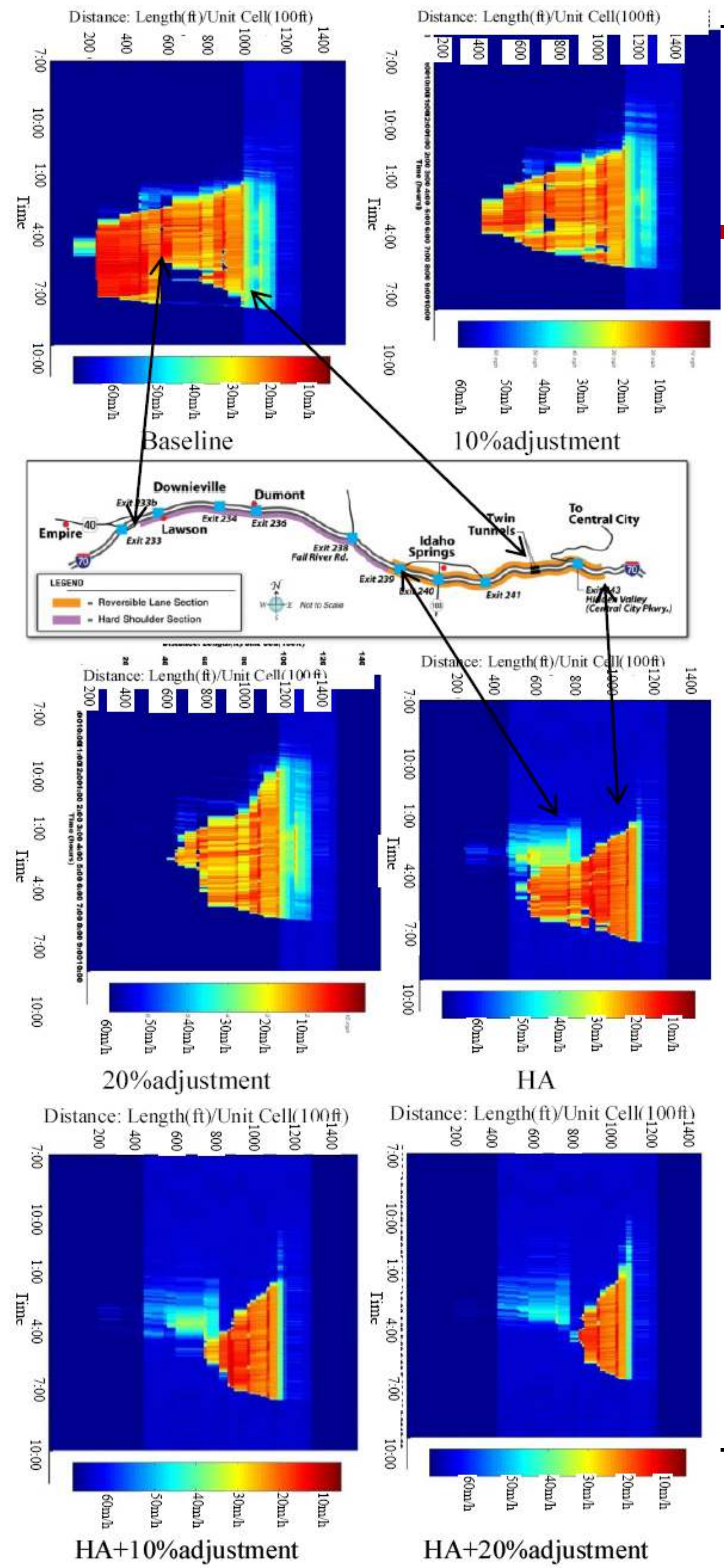
# Network





Travel Time (mins)
120
100
80
60
40
20
0
11-noon
noon-1
1-2
2-3
3-4
4-5
5-6
6-7
7-8
Time of Day
Baseline
10% adjustment
20% adjustment
HSR
HSR+10% adjustment
HSR+20% adjustment


Distance: Length(ft)/Unit Cell(100ft)
Time
60mi/h
50mi/h
40mi/h
30mi/h
20mi/h
10mi/h
Baseline
10%adjustment
Downieville
Dumont
Empire
Lawson
Exit 233
Exit 234
Exit 235
Exit 238 Fall River Rd.
Idaho Springs
Twin Tunnels
To Central City
Exit 239
Exit 240
Exit 241
Hidden Valley (Central City Pkwy.)
LEGEND
= Reversible Lane Section
= Hard Shoulder Section
Not to Scale
20%adjustment
HA
HA+10%adjustment
HA+20%adjustment

# THANK YOU