Open-Source Dynamic Traffic Assignment Package

DTALite/NEXTA Classic Edition

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Workshop Purpose and Objectives

Purpose

- Educate workshop attendees on Dynamic Traffic Assignment modeling through hands-on exercises using the open-source DTALite software tool

Learning Objectives

- Understand basic modeling approaches in DTALite
- Import data to code and modify a subarea network
- Evaluate simulation results using the visualization and reporting features in NeXTA

Outline

Module 1: Introduction to DTALite/NeXTA

Module 2: Introduction to DTA modelling principles

Module 3: Visualization Features in NeXTA

Module 4: Introduction to Workshop Exercises

Module 5: Traffic Flow Theory

Module 6: OD Matrix Estimation

Module 7: Signalized Intersections Modeling

Module 8: VRP program

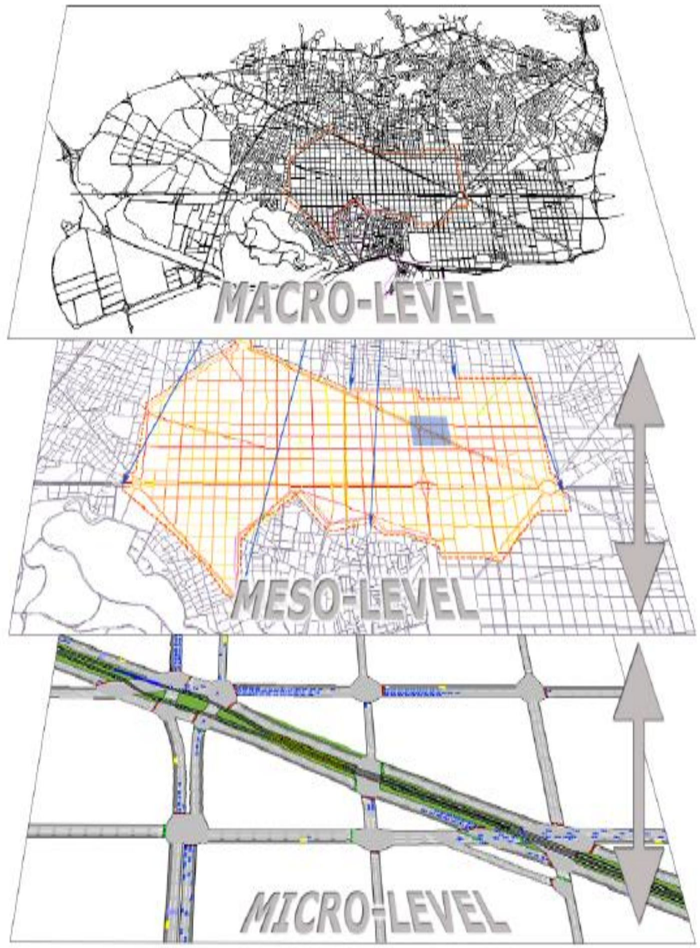
Module 1
Introduction to DTALite/NeXTA

1.1 Project Objective and Motivations

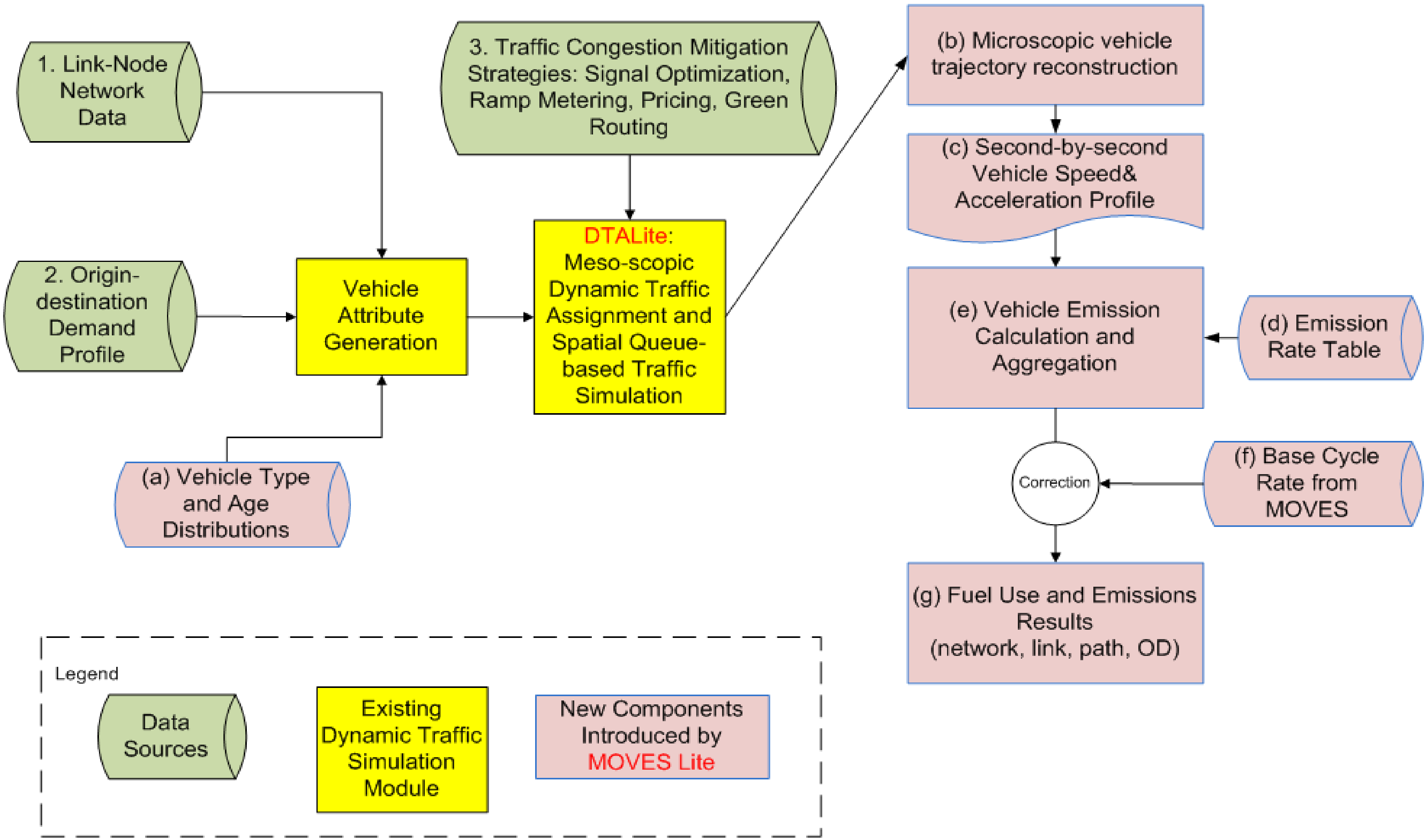
1.2 What NeXTA/DTALite Can Do

1.3 Open-source Free Software Package

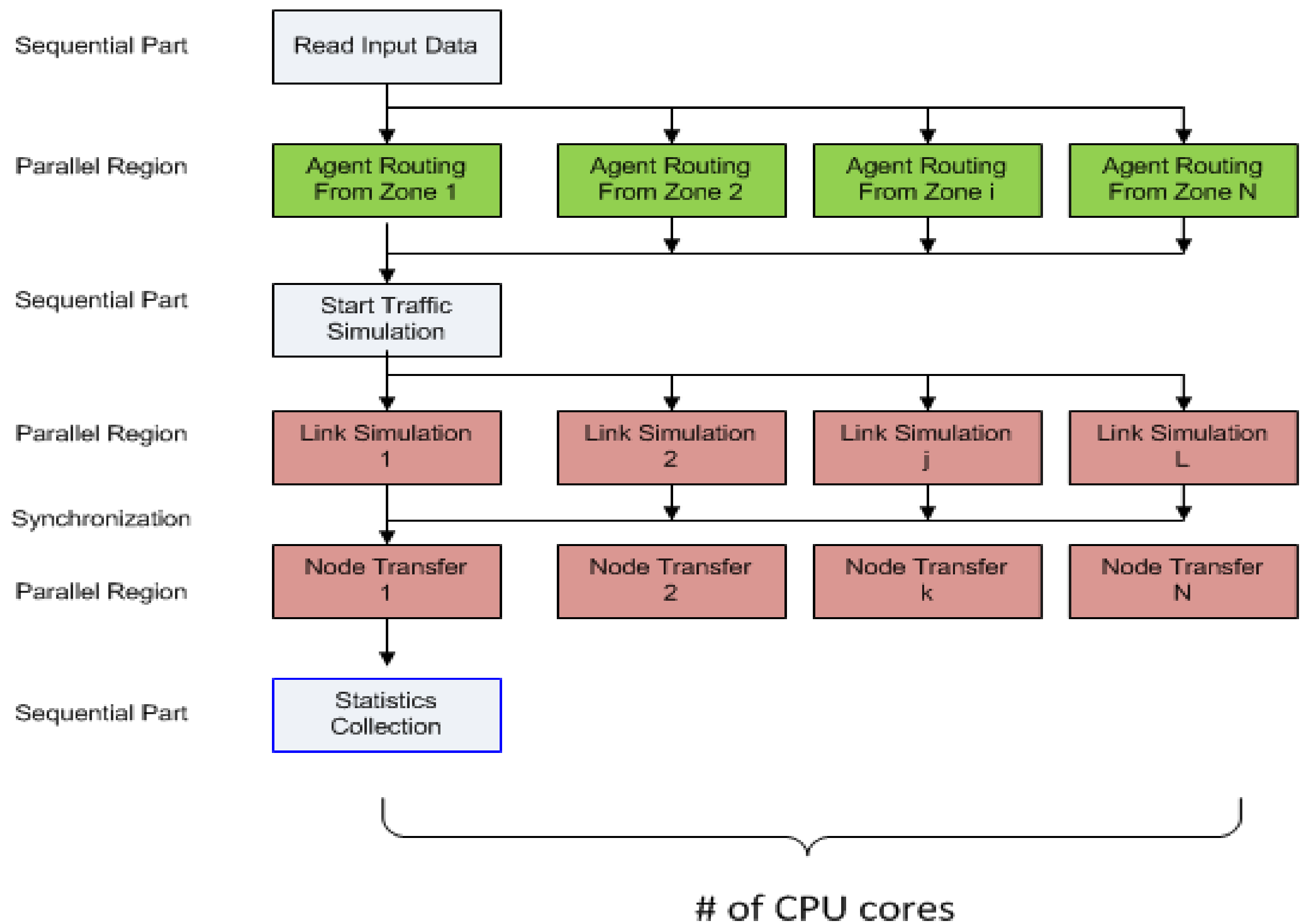
Mesoscopic Traffic Simulation



System Architecture and Data Flow



Computational Efficiency



1.0 Traffic Flow Theoretical Foundation: LWR Equations

- Hyperbolic system of conservation laws

$$\frac{\partial q}{\partial x} + \frac{\partial k}{\partial t} = g(x,t)$$

  where q, k are flow and density, respectively, and g(·) is the net vehicle generation rate.

- Traffic flow model
  - Speed (or flow) of traffic is a function of density only
  - E.g. Greenshields model: $V = V_{free} (1 - k/K_{jam})$

Numerical Calculation Scheme Based on Link Flow/Density (Used in CTM)

- Notation
  - Δt = length of simulation interval (e.g. 1 sec, 6 sec)
  - Δx = cell length (e.g. 0.5 mile)
  - $k_{i,t}$, $v_{i,t}$ =the prevailing density and mean speed in cell i during the t^{th} time step
  - $q_{i,t}$ = transfer flow rate from section i to cell i+1 during the t^{th} time interval [t, t+Δt].
- Computation Procedure
  - Step 1: Calculate prevailing speed $v_{i,t}$ according to a traffic flow model
  - Step 2: Calculate flow ready to move from cell i-1 to section i: $v_{i,t} \times k_{i,t}$
  - Step 3: Calculate transfer flow from section i to cell i+1

  $$q_{i,t} = \text{Min}\ \{ v_{i,t} \times k_{i,t}\ ,\ q_{max\ i+1,t} \}$$

  - Step 4: Update prevailing density at cell i

  $$k_{i,t+1} = k_{i,t} + (q_{i-1,t} - q_{i,t}) \times \Delta t / \Delta x$$

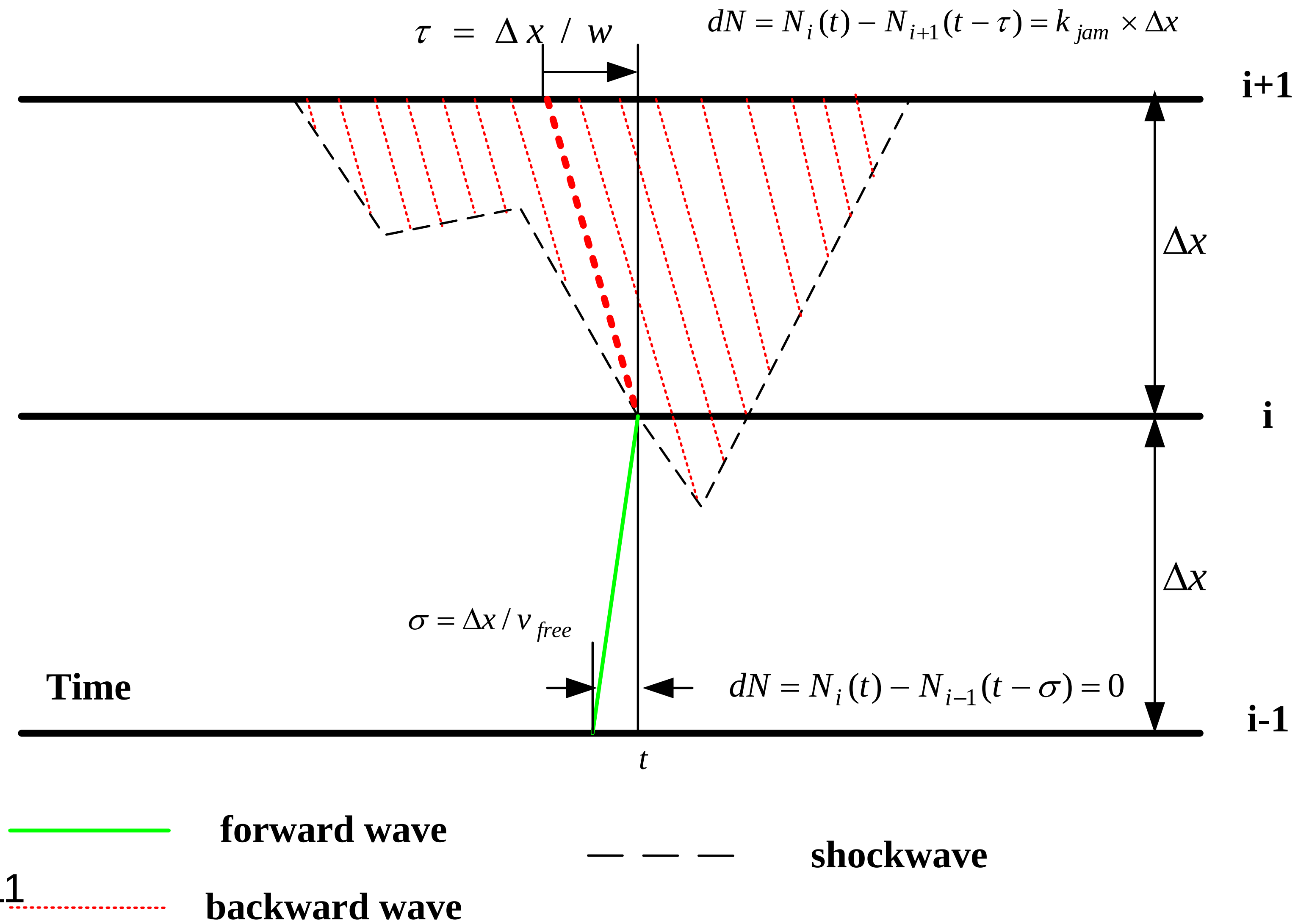
- Issue: transfer flow $q_{i,t}$ is an explicit function of the occupancy at the current cell, other than the downstream capacity
  - Transferred flow exceeds the spatial storage capacity at the next cell

Newell's N-Curve Approach (Used in DTALite)

- N_i (t): cumulative flow counts at location i at time t
  - $q=[N_i(t+1)-N_i(t)]/\Delta t$
  - $K=[N_{i+1}(t)-N_i(t)]/\Delta x$
- Focus on N-curve at transfer points
  - $N=\mathrm{Min}\ \{N_{upstream}, N_{downstream}\}$
- Focus on change of N along a characteristic line (wave) at sections
  - $dN = (\partial N/\partial x)dx + (\partial D/\partial t)dt = -\ kdx + qdt =$

    $(-k+ q \times \text{wave})dx$
  - if wave$=v_{free}$, $dN=(-k + k)\ dx=0$
  - if wave$=w$, $dN=-(k+qw)dx= -k_{jam}dx$

Illustration of N-Curve Computation For Tracking Queue Spillback



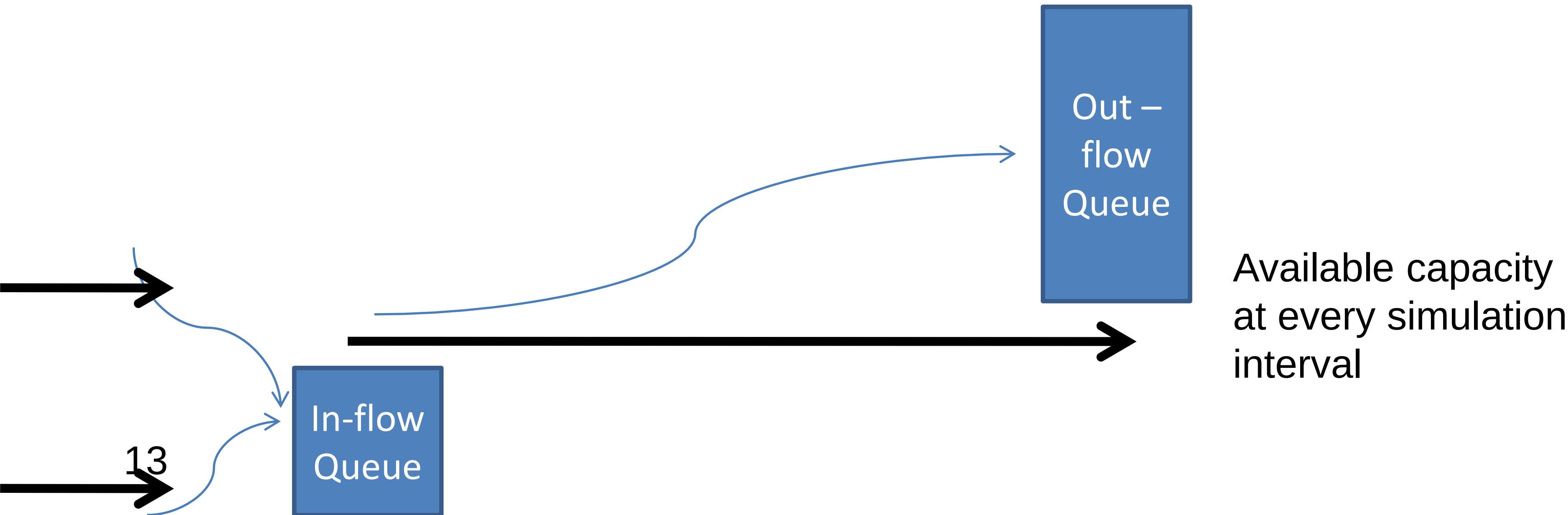
Summary of Comparison

- CTM’s variables are density, incoming and outgoing flows and speed

- Newell’s variables are incoming and outgoing cumulative flow counts, from which the density and flows can be derived.
  - We do not have direct speed measurements and link travel times are calculated from vehicle trajectories (with arrival times at upstream node and departure time at downstream node)

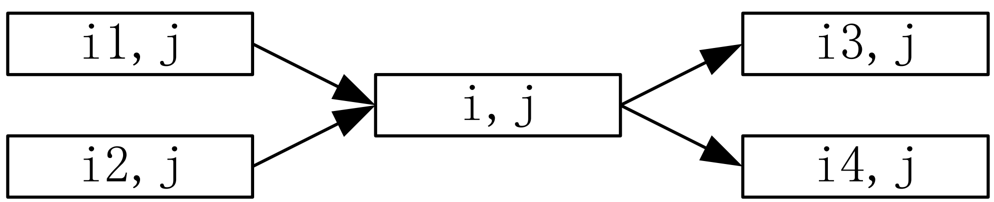
Simulation Logic as Simple Queue

- Can be viewed as pseudo event-based simulation and we do not simulate how a vehicle moves inside the link
- Vehicle is moved into an in-flow queue at time t_a
- Calculate time entering the out-flow queue as t_a+FFTT (free-flow travel time)
- If the current simulation time t equals to or is later than t_a+FFTT, if the link out capacity is still available, move this vehicle to the next link, otherwise stay in the out-flow queue



Network Traffic Flow Model

- Goal: define boundary conditions for each link
  - Downstream link capacity distribution at merges
  - Outflow distribution at diverges

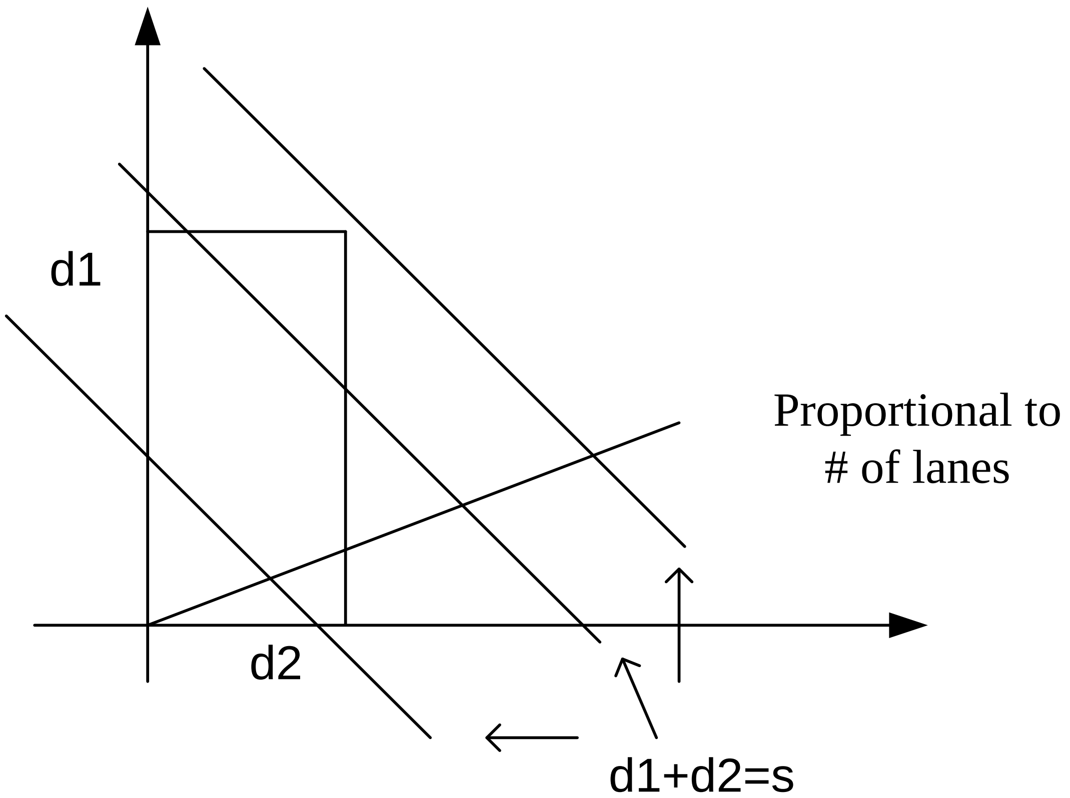


- Congestion from downstream link:

  q(i1→i)+q(i2→ i)<= $\mathbf{w \times (k_{jam} - k_{i,j}(t)) \times \Delta x}$

  or d1+d2<s
- Outflow distribution: q(i→i3)+q(i→ i4)=q(i)
  - OD flow pattern, turning percentages

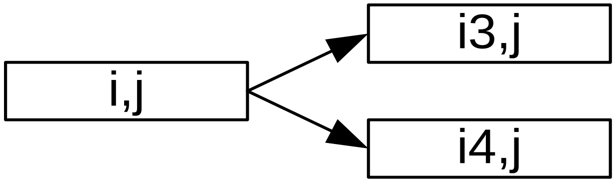
In-Flow Capacity Distribution Schemes at Merges with two ramps or two freeways



Flows are assumed to be proportional to # of lanes whenever supplies are not adequate,

Traffic Flow Model at Diverge

- As a meso-scopic model, DTALite moves vehicles with OD and path specific information instead of continuous flow
- Outflow distribution is dependent on
  - OD flow pattern, turning percentages

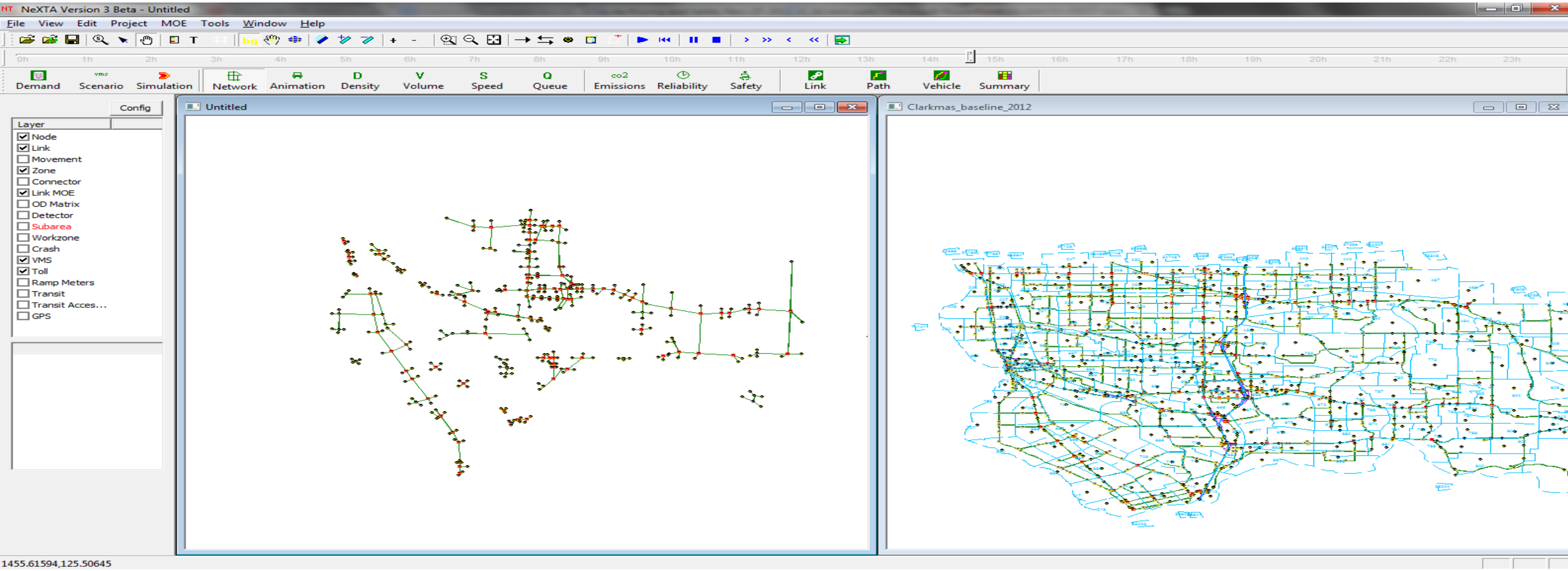


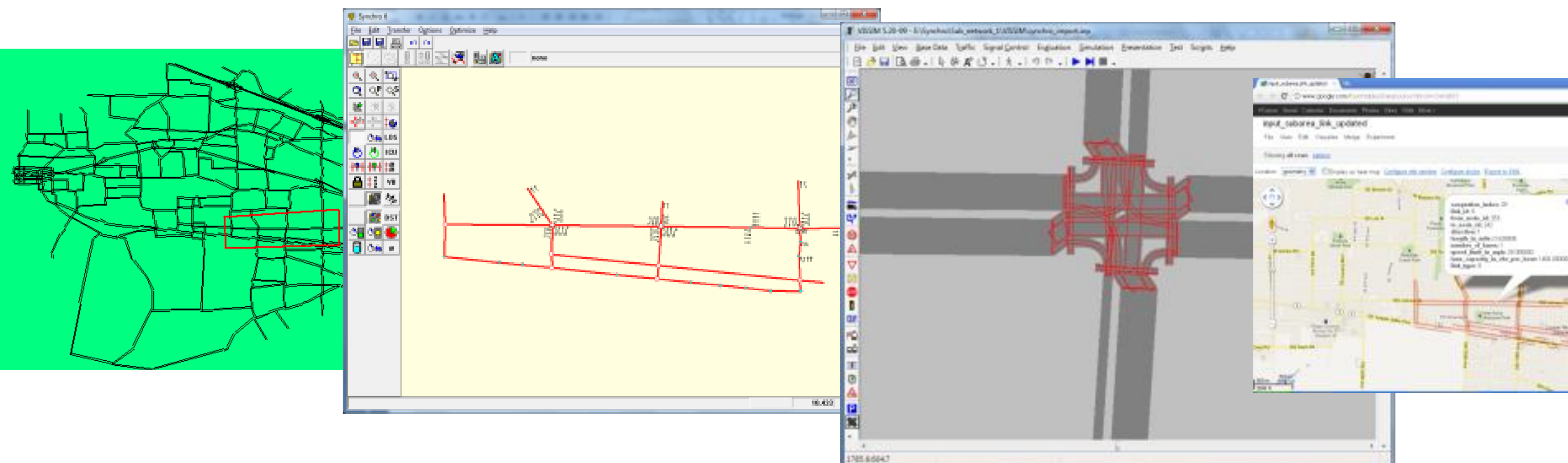
Time-Dependent Shortest Path Algorithm

- C++ implementation
    - Use standard template library (STL) for complicating data structure (e.g. multi-dimensional vector, list, map (hash table)
    - Customized efficient structure for shortest path algorithm
- Multiple processor-oriented
    - OpenMP technique for using multiple processors
- Shortest path algorithm
    - Label correcting with deque
    - Single departure time, origin-based.
        - The algorithm is called iteratively for each departure time to calculate shortest paths for all departure times

What NeXTA/DTALite Can Do

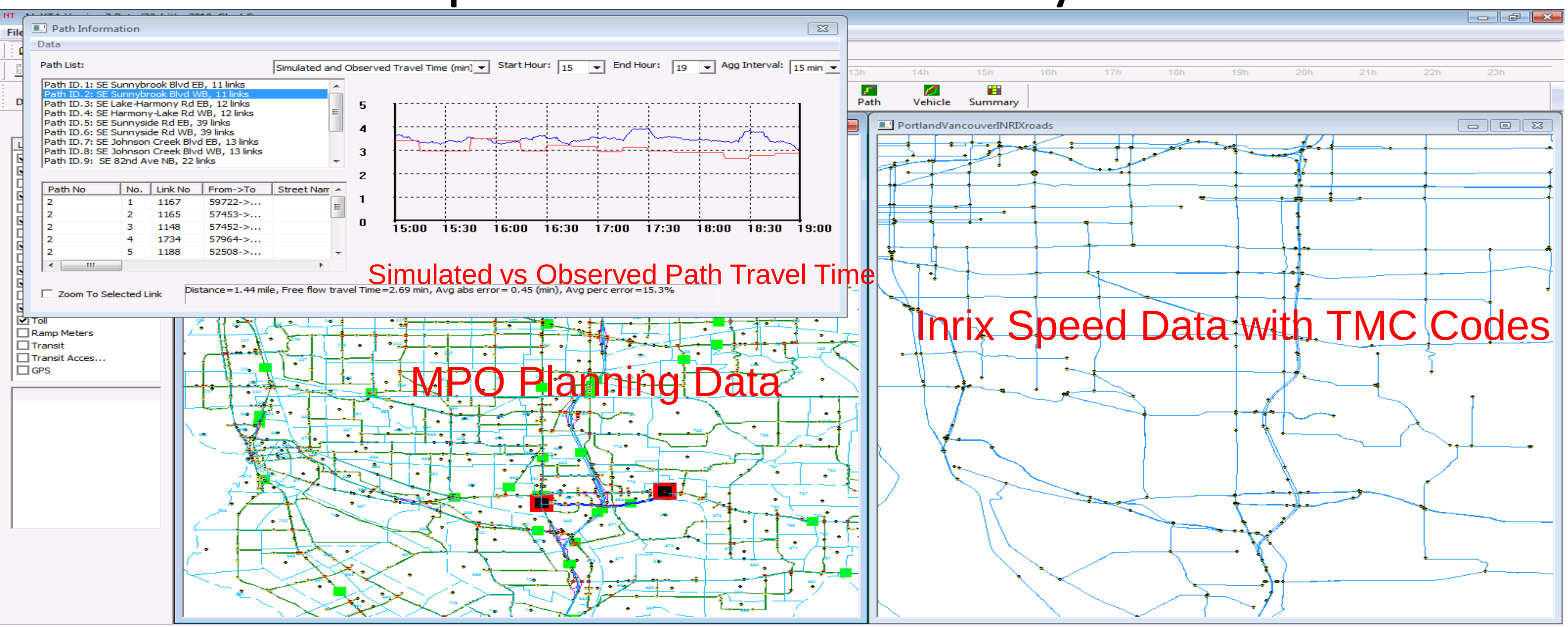
1. Open-source traffic simulation/modeling Data Hub
   - Integrated simulated and measured data management tools
   - Connection with Travel demand model, signal optimization tool (Synchro)
2. Large-scale dynamic traffic assignment
   - Typical network size: 2K~5K zones, 20K~50K links, 2~4 Million vehicles
3. Network scenario analysis
   - Rich outputs: various operational performance measures
   - Road pricing application: Consider time-dependent toll, Heterogeneous Value of times


NeXTA Version 3 Beta - Untitled
File View Edit Project MOE Tools Window Help
Demand Scenario Simulation
Network Animation Density Volume Speed Queue Emissions Reliability Safety
Link Path Vehicle Summary
Config
Layer
Node
Link
Movement
Zone
Connector
Link MOE
OD Matrix
Detector
Subarea
Workzone
Crash
VMS
Toll
Ramp Meters
Transit
Transit Acces...
GPS
Untitled
Clarkmas_baseline_2012
1455.61594,125.50645



Connection with Traffic Sensor Data

1. Import TMC GIS data directly to NEXTA
2. Match TMC links with planning links using two layers
3. Fetch speed data from Inrix layer to AMS data



1.1 Project Objective and Motivations

Project Objective

Enhance DTALite to provide a rigorous and computationally efficient tool to evaluate road pricing and crash-reduction strategies

The enhanced tool will enable practitioners to:

- Assess corridor and network-wide effects
- Conduct numerous alternatives analyses
- Evaluate recurring and non-recurring congestion
- Calculate performance measures that can be applied in investment-level planning and decision making

1.1 Project Objective and Motivations

Motivations

- Existing technical barriers (based on DTA user survey, TRB network modeling committee, 2009)
  - Require too many input data: 47%
  - Take too long to run: 35%
  - Model is unclear: 35%
- Our goals
  - Simplified data input from static traffic assignment
  - Use parallel computing capability, simplified routing and simulation
  - Open-source Visualization: Seeing is believing
  - Excel Tools: Start from basics

1.2 What NeXTA/DTALite Can Do

1. Open-source traffic simulation/modeling Data Hub

   (1) Connection with signal optimization (Synchro) or microscopic simulation (VISSIM)

   (2) Integrated simulated and measured data management tools

2. Large-scale dynamic traffic assignment

   (1) Typical network size: 2000 zones, 20K links,1-2 Million vehicles

3. Network scenario analysis

   (1) Road pricing application: Consider time-dependent toll, Heterogeneous Value of times

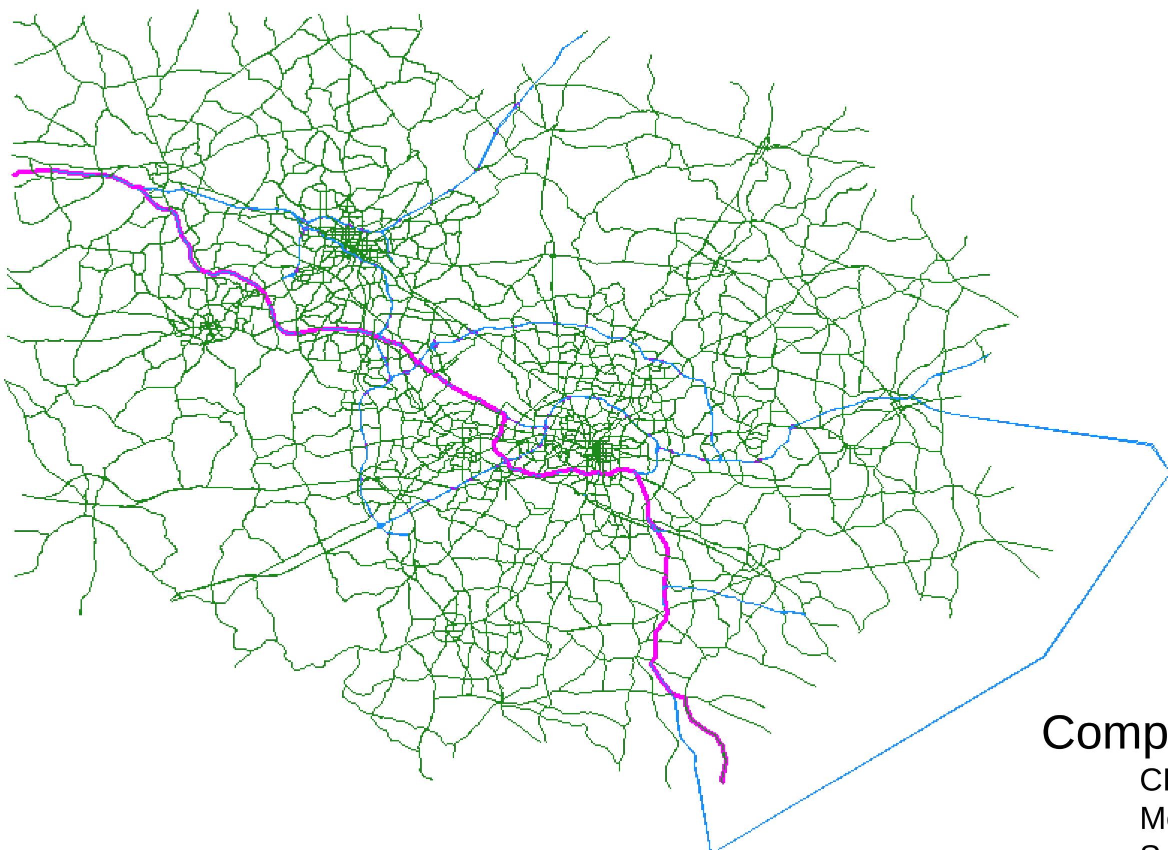
   (2) Emission study: Fast simulation for emission analysis (with MOVES Lite)

   (3) Safety planning: Predict annual crash rates based on link type and traffic volume

1.2 What NeXTA/DTALite Can Do

1) Fast Simulation

– A rigorous and computationally efficient tool to evaluate numerous alternatives analyses



Network Statistics

Triangle Corridor Network (NC, USA)

Zones = 2,389
Nodes = 9,528
Links = 20,258
Signals = 1,914
AM Trips = 1,064,703
Households = 490,000

2 min. 45 sec. / iteration
1hour for 20 iterations

Computer System Specification:

CPU: Intel i7-2960XM @ 2.70 GHz *8
Memory: 16.0 GB
System Type: 64-bit Windows 7

1.2 What NeXTA/DTALite Can Do

2) Rich Output

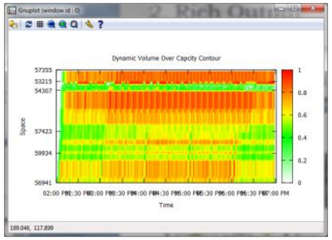
NeXTA

Large-scale Dynamic Traffic Assignment & Simulator

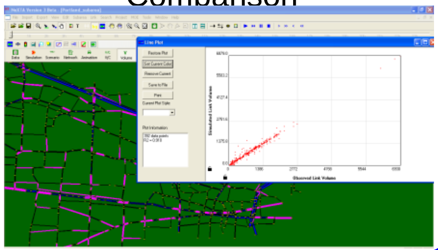
Google Earth/Maps

Other Visualization

Corridor-level VOC contour

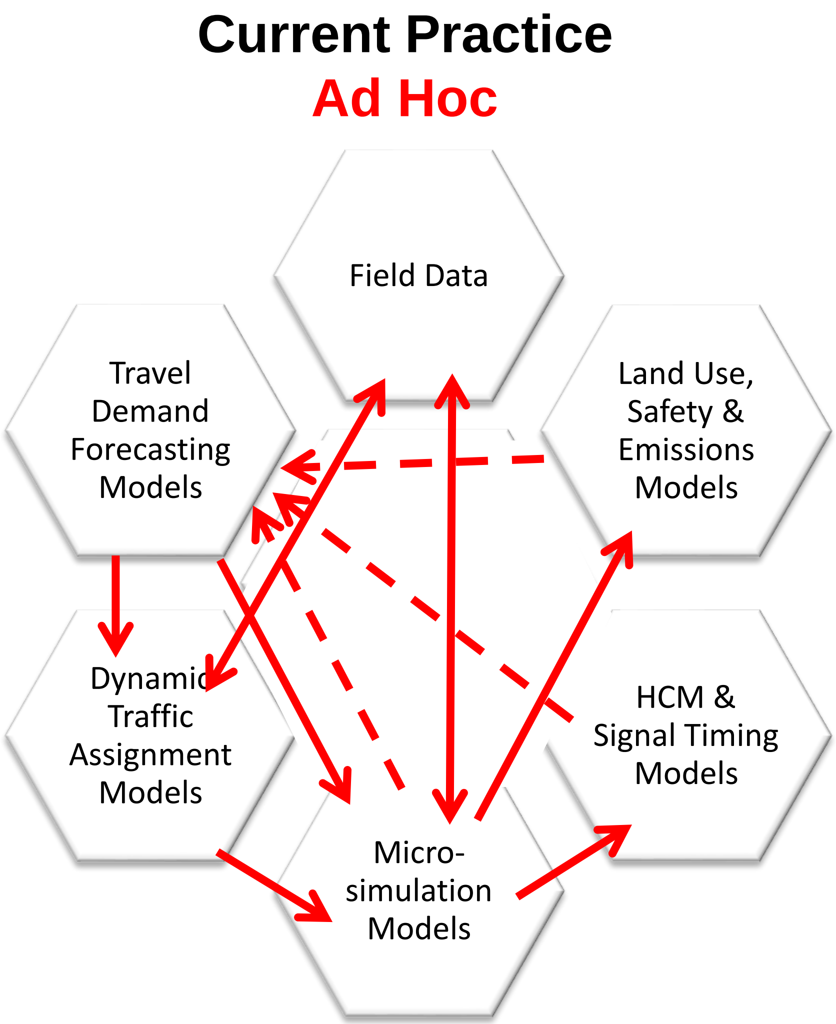


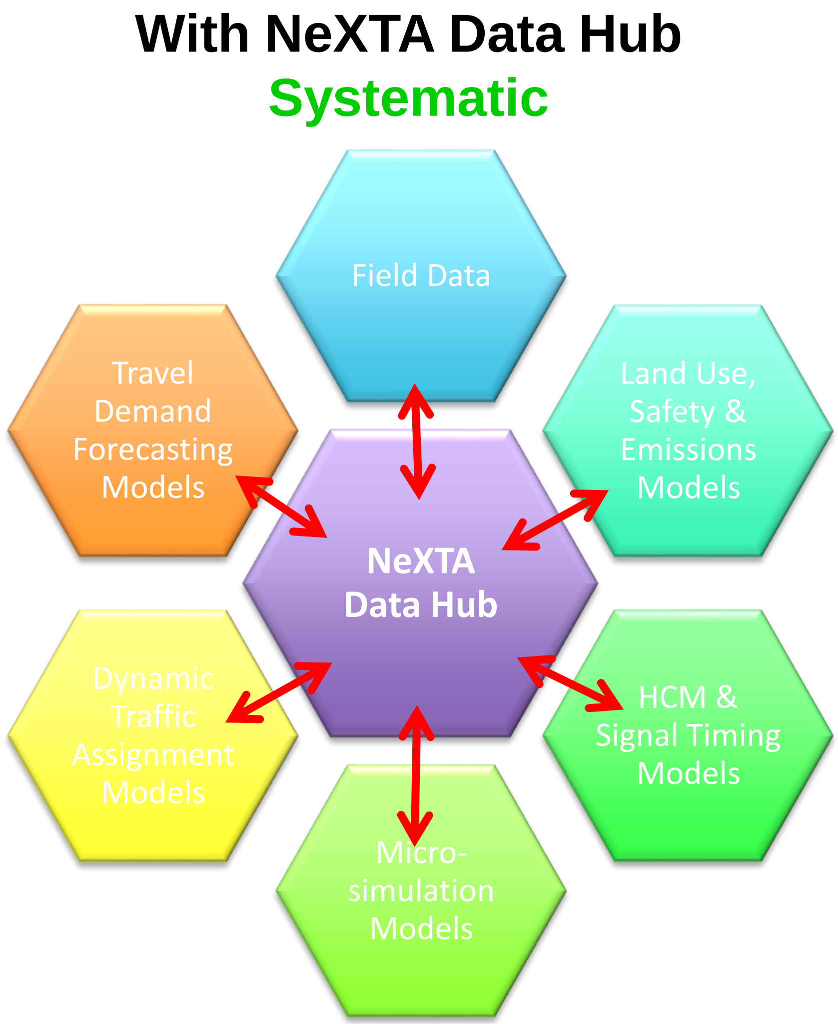
Simulation vs. Observation Comparison



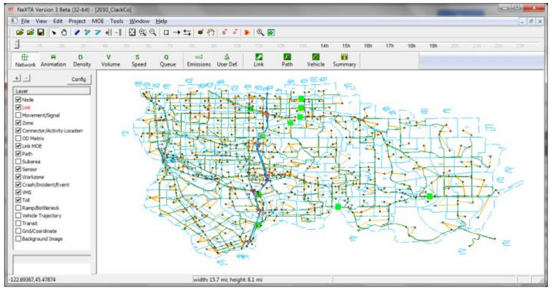
1.2 What NeXTA/DTALite Can Do

3) Integrated Modeling Practice

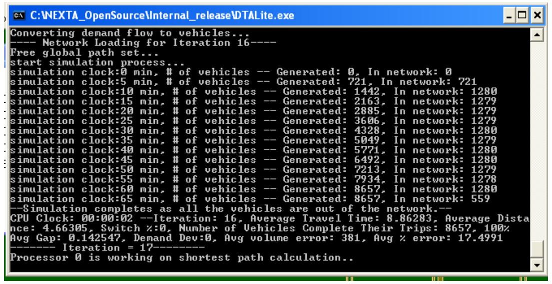




1.3 Open-source Free Software Package



- **NEXTA: front-end GUI (C++)**
  - Version 2: GUI for TRANSIMS and DYNASMART
  - Version 3: GNU Open-source data hub
    - Import
      - Other regional planning models (TransCAD, VISSUM, Cube)
      - GIS shape files (household data without node layer)
      - Traffic volume, speed, GPS data, Google Public Transit Feed
    - Export
      - Google Earth, Google fusion tables
      - Prepare network and signal data for Synchro and VISSIM (through QEM)



- **DTALite: Open-source computational engine (C++)**
  - Light-weight and agent-based DTA
  - Built-in OD demand matrix estimation (ODME) program

Useful Materials

- DTALite Software Release

  https://github.com/xzhou99/dtalite_software_release

- NeXTA/DTALite Training Materials

  https://github.com/xzhou99/learning-transportation/tree/master/lessons

- DTALite Source Codes
  - https://github.com/xzhou99/dtalite_beta_test

Useful Materials

- Installation required software packages
- Datasets and Learning documents
- User Guide

Dataset_1_West_Jordan
Dataset_2_3-corridor
Dataset_3_traffic_assignment
Dataset_4_GIS_import
Dataset_5_ODMatrixEstimation
Dataset_6_Emissions_MOVESLite
Dataset_7_Activity_based_Model
Dataset_8_TransitModel
Dataset_9_traffic_signal
Documents
Installation_required_software_packages
ToyNetworkToBeCreated
DTALite.exe
DTASettings.txt
Guidelines for DTALite_V1.3_20170526.docx
NEXTA.exe
NEXTA_Settings.ini

[1] DTALite A queue based mesoscopic traffic simulator for fast mo
[2] Workshop Handout.docx
[3] learning_document_GIS_importing.docx
[4] learning_document_equilibirum.docx
[5] learning_document_traffic_flow_theory.docx
[6] learning_document_traveler_information.docx
[7] learning_document_OD Estimation.pdf
[8] learning_document_ABM DTA Day_by_day Integration.pdf
[9] learning_document_DTA + ABM Integrated System .docx

Module 2
Introduction to DTA modelling principles

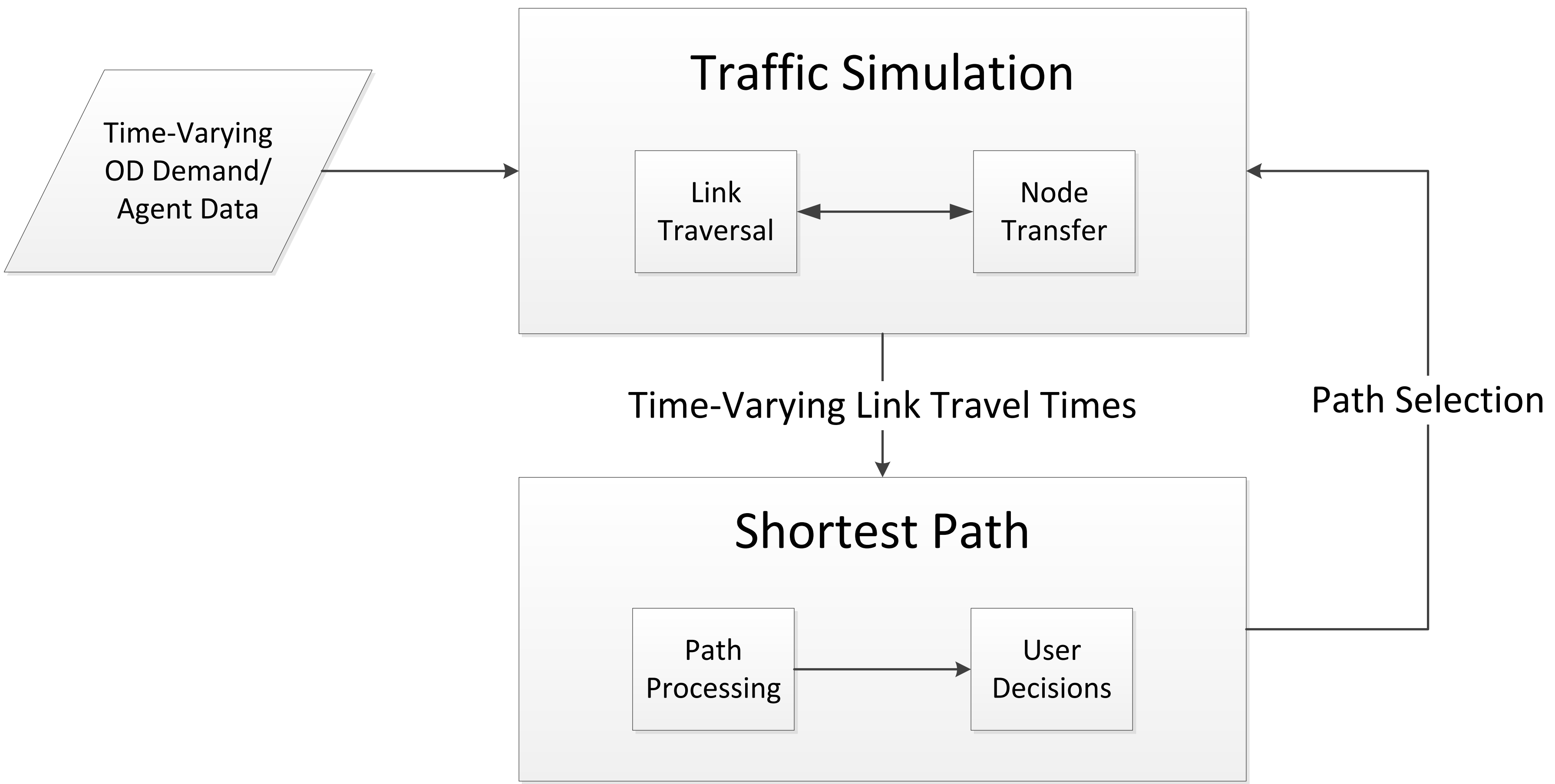
2.1 Dynamic Traffic Assignment Modelling Framework

2.2 Agent-based Routing

2.3 VOT Distribution

2.4 Multiple Traffic Simulation Models

2.1 DTA Modelling Framework



2.2 Agent-based Routing

Common Assignment Methods

(1) Traffic Analysis Zone (TAZ)-based

- From zone centroid to zone centroid
- The same value of time for each type of vehicles

(2) Agent-based

- From activity location to activity location
- Each vehicle has its own value of time, value of information
- Important for road tolling analysis, traveler information provision study

2.2 Agent-based Routing

- Routing performed for each individual agent
- Each agent has multiple dimensions of travel decisions
  - Origin, destination, departure time, path
  - Demand class (LOV, HOV, truck) or (HBW, HBO, NHB)
  - Information class (Historical, Pre-trip, En-route)

2.2 Agent-based Routing

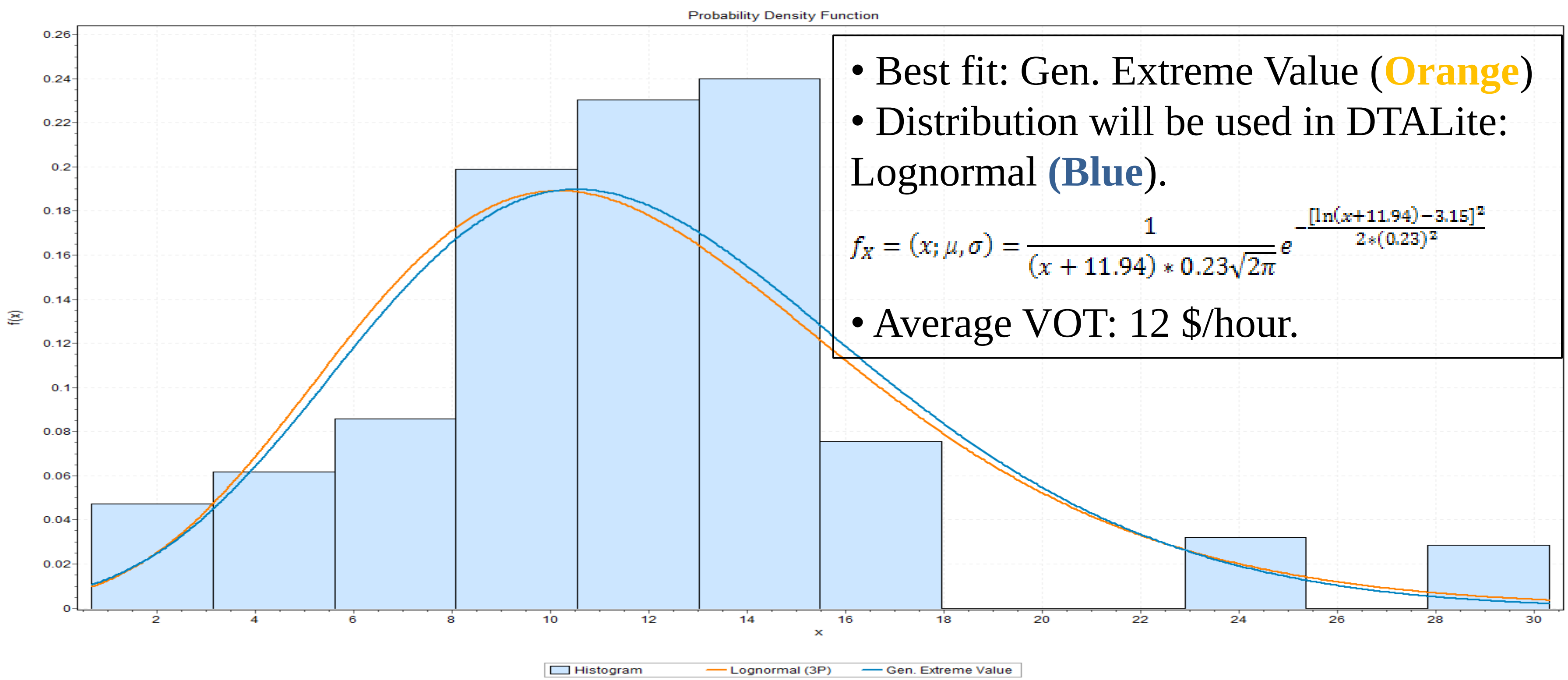
- Individual generalized cost function

$$Cost = Travel\,Time * VOT + Toll$$

  - Can consider multiple factors
    - Value of time, Value of reliability, Value of safety
  - Perform routing algorithm individually for each vehicle/agent
  - Can adjust origin/destination/departure time/path at each iteration (day)

2.3 VOT Distribution

- Assumption:
  - VOT : 50% of hourly rate (Concas and Kolpakov, 2009)



- Best fit: Gen. Extreme Value (**Orange**)
- Distribution will be used in DTALite: Lognormal (**Blue**).

$$f_X = (x;\mu,\sigma) = \frac{1}{(x+11.94)*0.23\sqrt{2\pi}}e^{-\frac{[\ln(x+11.94)-3.15]^2}{2*(0.23)^2}}$$

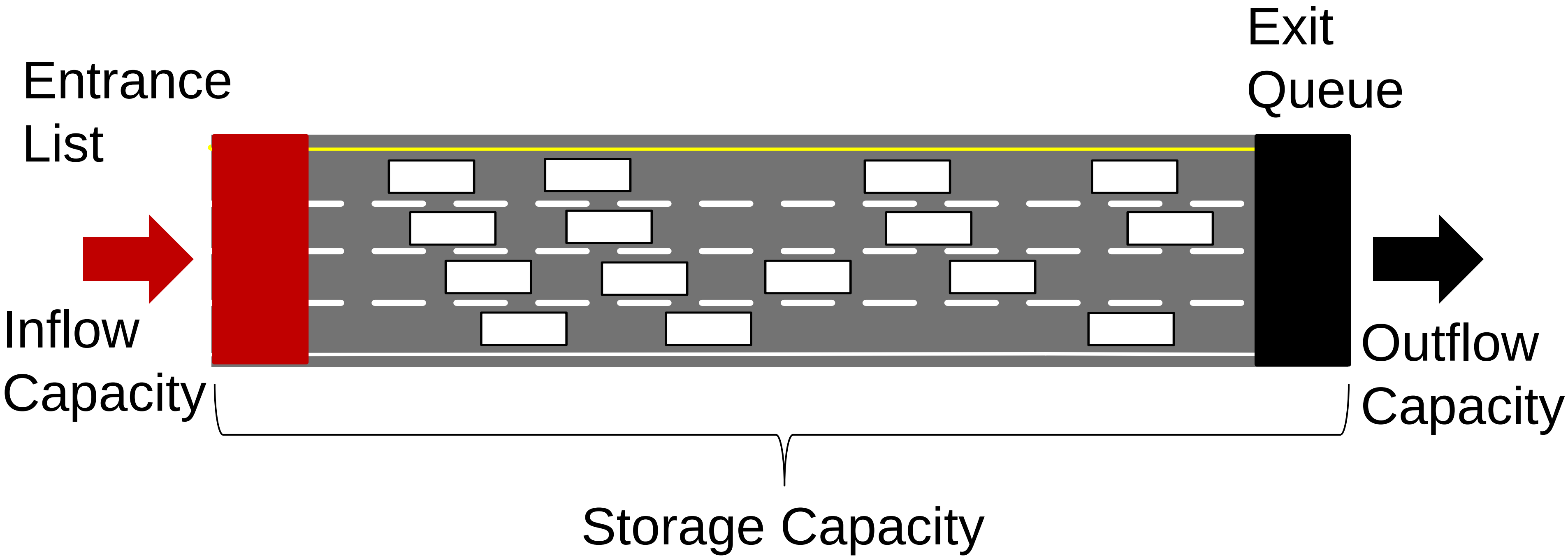
- Average VOT: 12 \$/hour.

2.4 Multiple Traffic Simulation Models

- BPR travel time functions
- Point queue (relaxed storage constraints)
- Spatial queue (similar to DYNASMART-P model)
- Newell’s model (similar to Cell Transmission Model)
  - Shockwave propagation

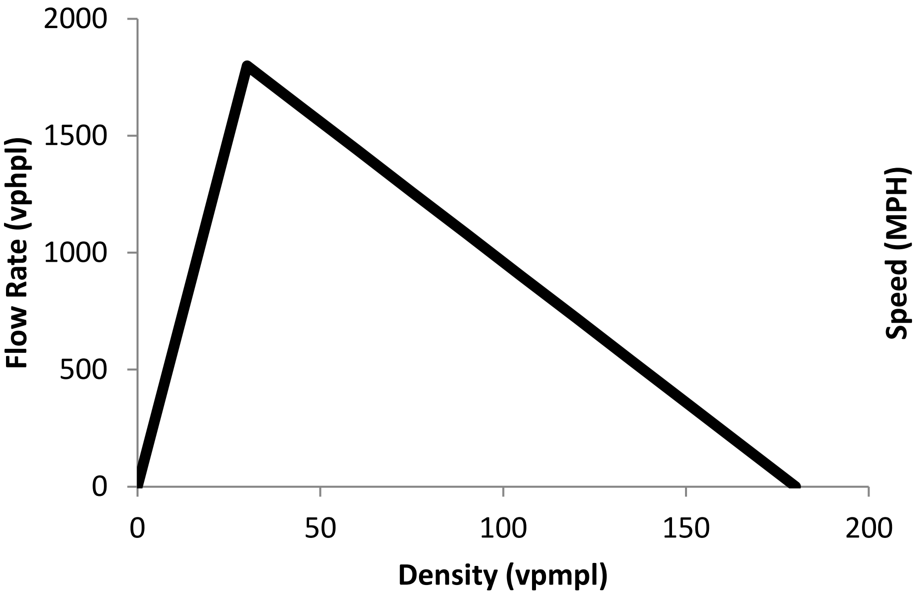
2.4 Multiple Traffic Simulation Models

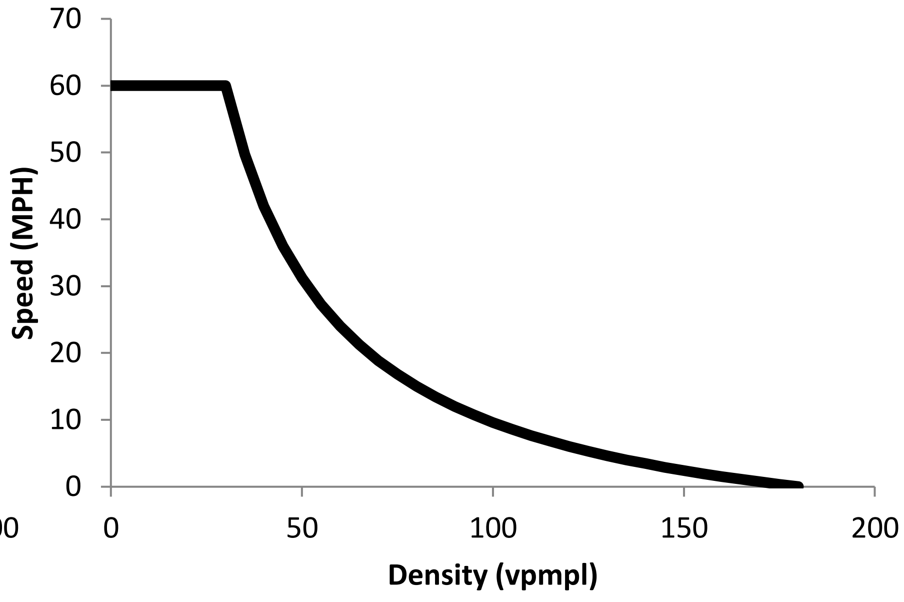
- **Newell’s simplified kinematic wave model**
  - Outflow capacity
  - Inflow capacity
  - Storage capacity



2.4 Multiple Traffic Simulation Models

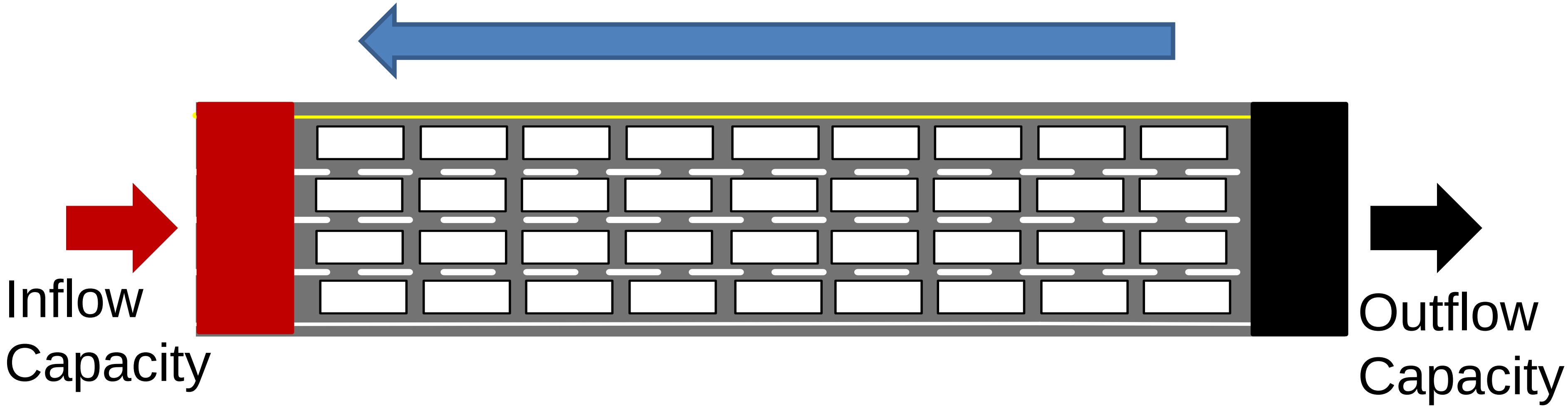
- **Newell's simplified kinematic wave model**
  – Triangular flow-density relationship
  – Free flow speed, jam density, backward wave speed





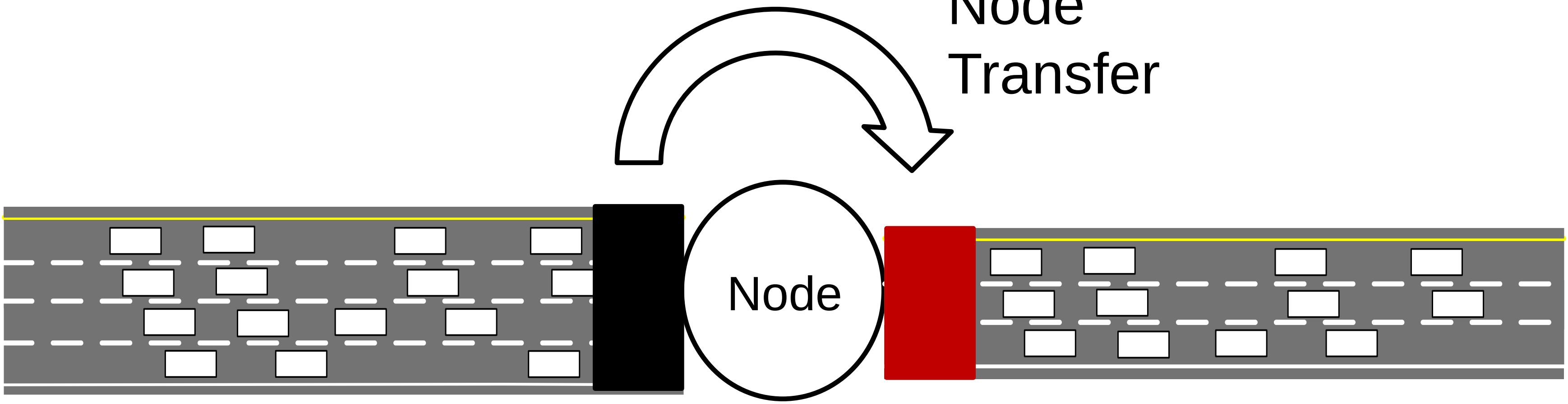
2.4 Multiple Traffic Simulation Models

- **Queue propagation**
  - Inflow capacity = outflow capacity



2.4 Multiple Traffic Simulation Models

- **Node transfer**

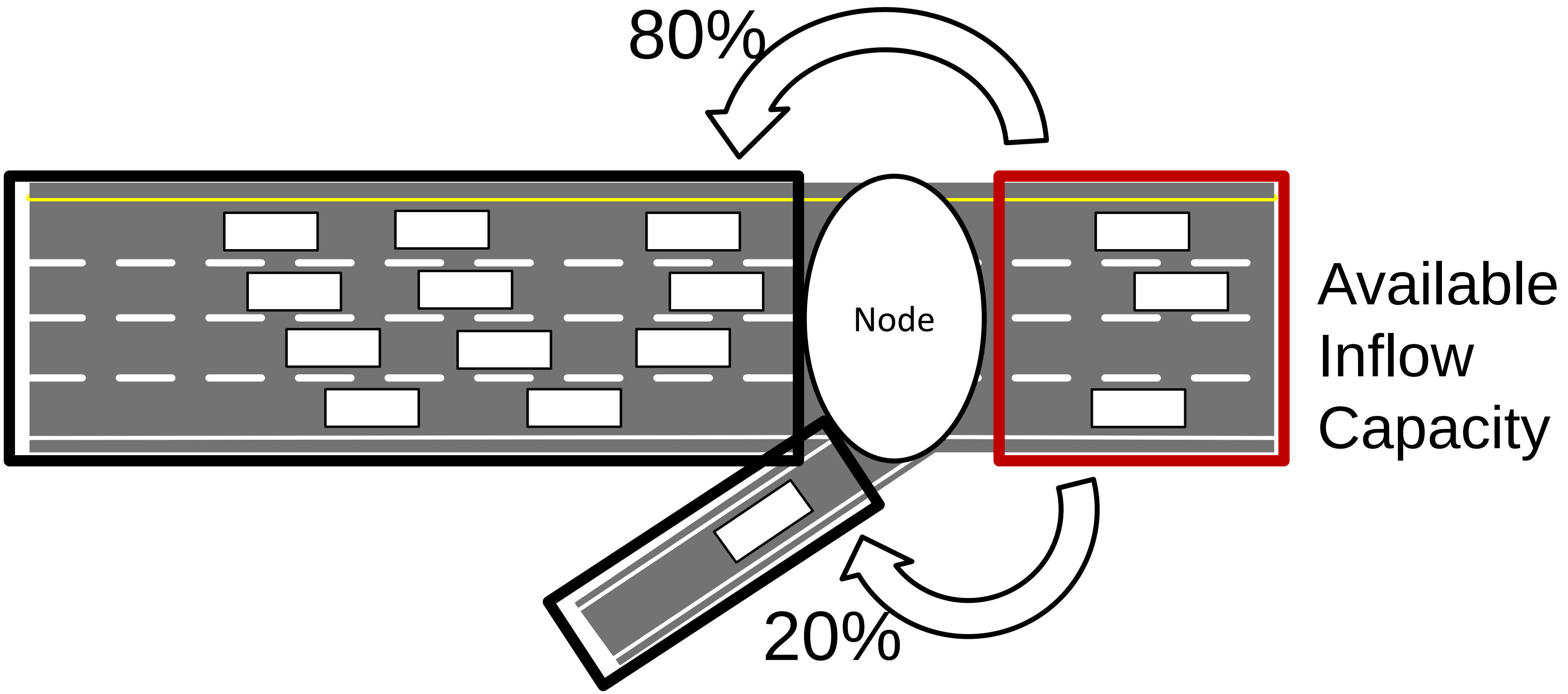


Check Outflow Capacity

Check Inflow Capacity
Check Storage Capacity

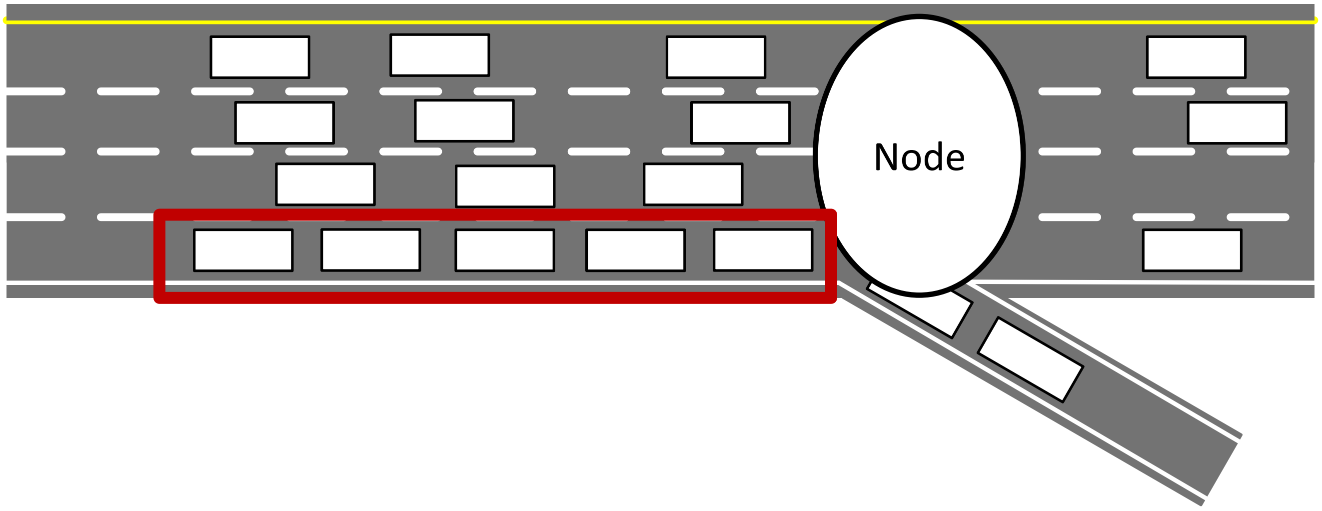
2.4 Multiple Traffic Simulation Models

- **Merge Models**
  - Distribute inflow capacity to upstream links
  - Lane & demand-based methods



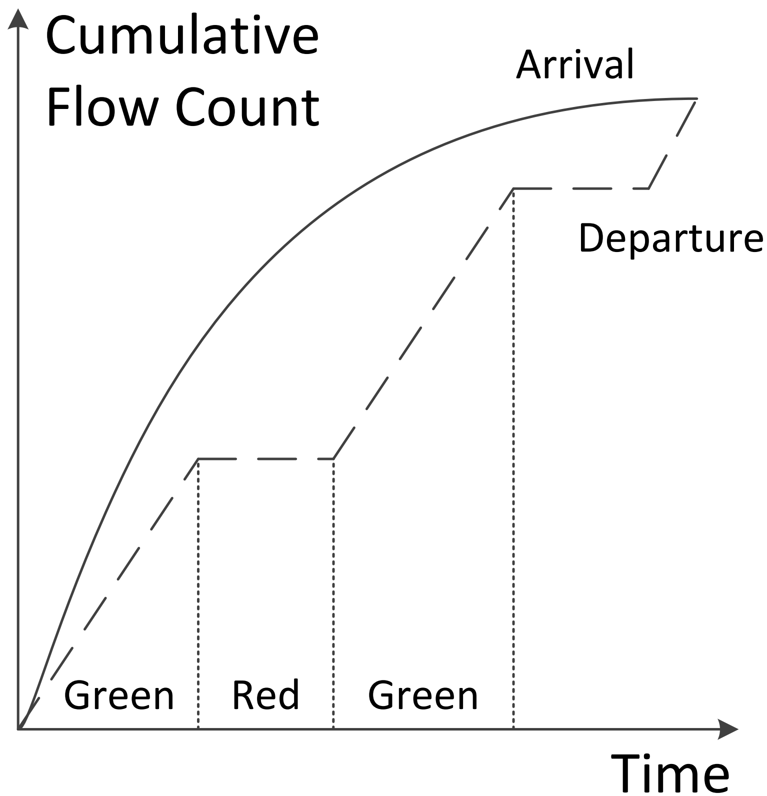
2.4 Multiple Traffic Simulation Models

- **Diverge Models**
  - Different conditions by lane
  - First-In-First-Out (FIFO) constraint
  - Relaxation to prevent extreme bottlenecks



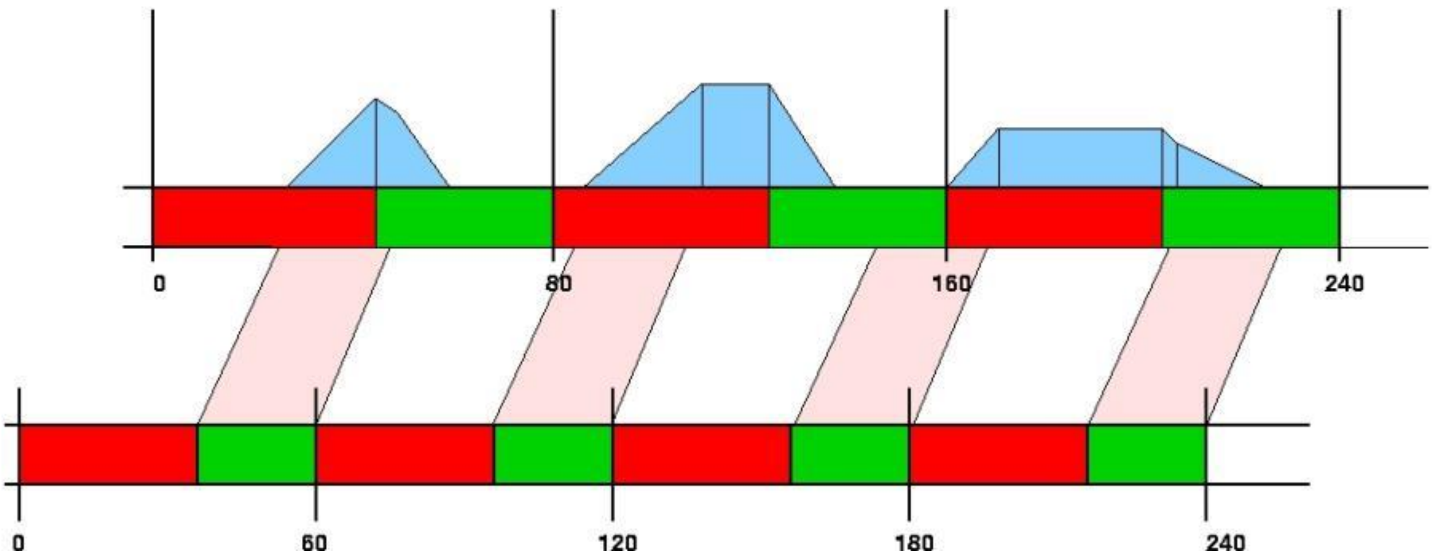
2.4 Multiple Traffic Simulation Models

- **Signalized Intersections**
  - Effective green time, saturation flow rate, movement-based capacity
  - Relaxed inflow constraints



2.4 Multiple Traffic Simulation Models

- **Signal Timing & Hourly Capacity**
  – Input: Average hourly capacity, cycle time, offset at node
  – Output: Effective green time per cycle(capacity/saturation flow rates)



Module 3
Visualization Features in NeXTA

3.1 Basic GUI features

3.2 View/Edit data files in NEXTA's "project" menu

3.3 Integration with assignment model

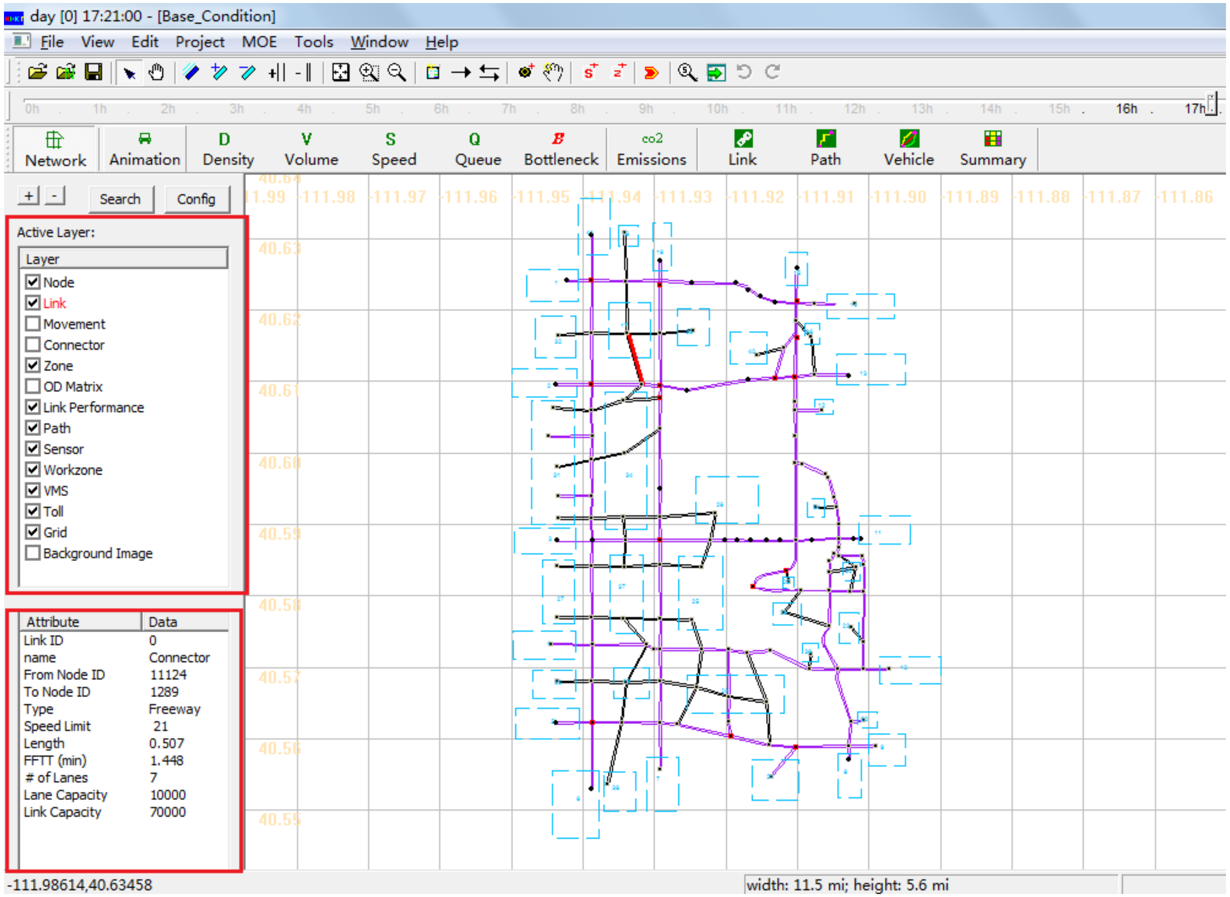
3.4 Advanced visualization functions of NEXTA

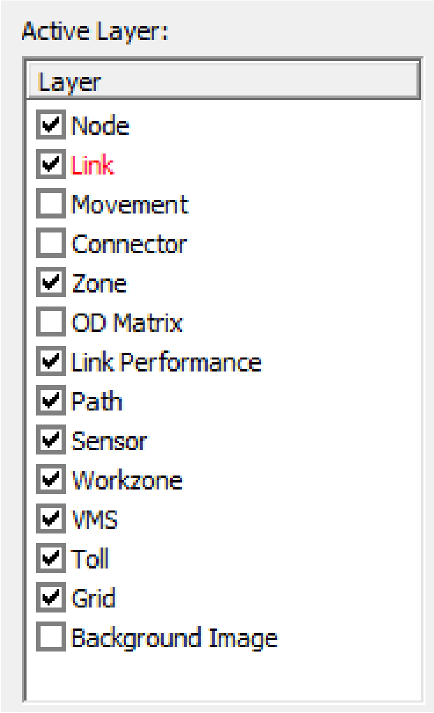
3.5 MOE related display

3.6 Data exporting to Google Earth /GIS package

3.1 Basic GUI features

- Turn on and off GIS layers; Move around, select node and links; Toolbars for editing networks
- Open project folder (CSV file format)





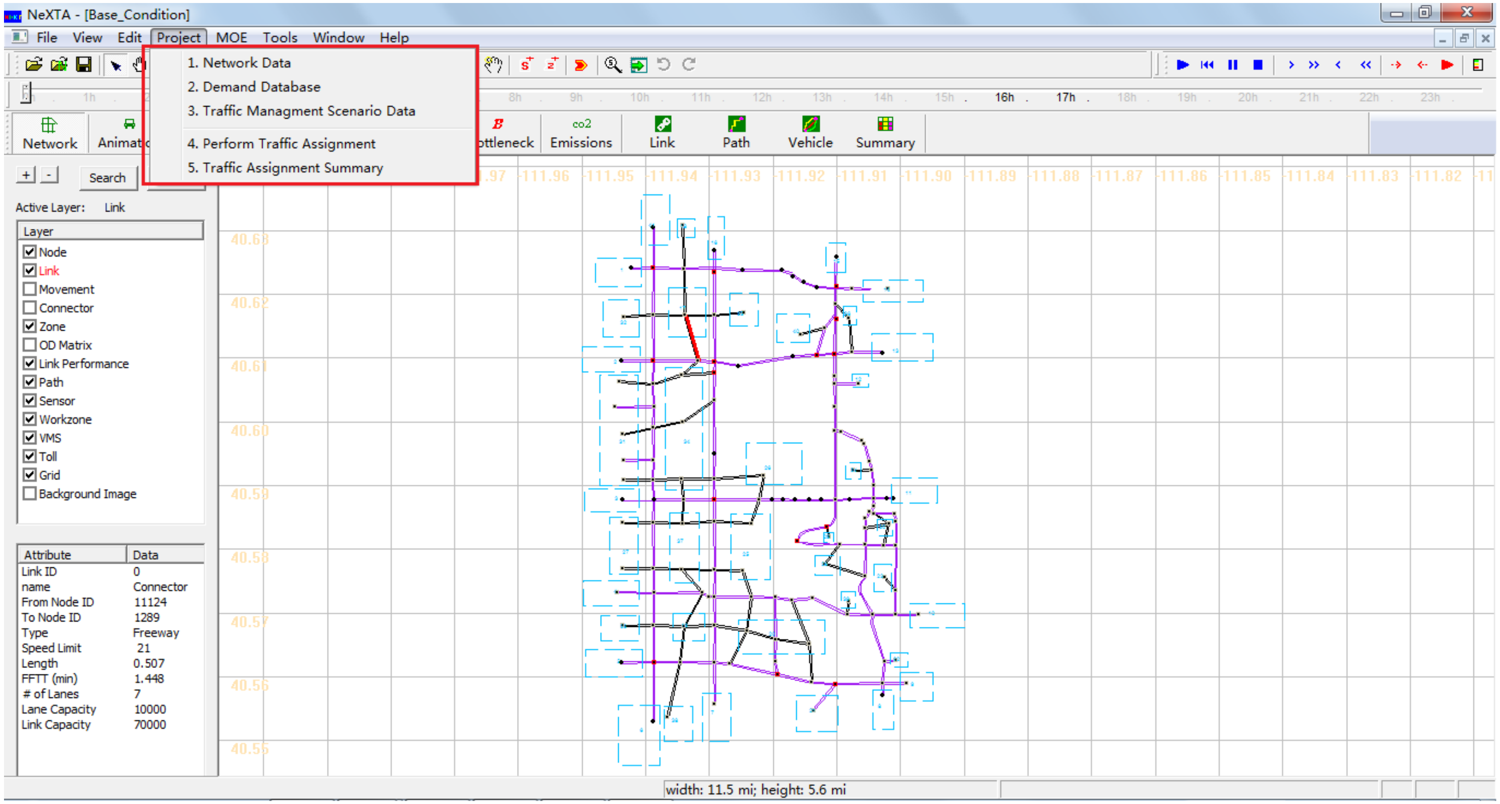
3.1 Basic GUI features

- Turn on and off GIS layers; Move around, select node and links; Toolbars for editing networks
- Open project folder (CSV file format)

input_activity_location.csv	1/22/2017 4:14 ...	Microsoft Excel ...	1 KB
input_demand.csv	1/11/2013 9:43 ...	Microsoft Excel ...	24 KB
input_demand_file_list.csv	1/23/2017 12:08...	Microsoft Excel ...	2 KB
input_demand_type.csv	6/30/2016 3:40 ...	Microsoft Excel ...	1 KB
input_link.csv	9/4/2017 3:53 PM	Microsoft Excel ...	65 KB
input_link_type.csv	1/22/2017 4:14 ...	Microsoft Excel ...	1 KB
input_movement.csv	1/22/2017 4:14 ...	Microsoft Excel ...	25 KB
input_node.csv	1/22/2017 4:14 ...	Microsoft Excel ...	17 KB
input_node_control_type.csv	1/22/2017 4:14 ...	Microsoft Excel ...	1 KB
input_scenario_settings.csv	5/25/2017 5:06 ...	Microsoft Excel ...	1 KB
input_zone.csv	1/22/2017 4:14 ...	Microsoft Excel ...	11 KB
ODME_link_based_log.csv	6/14/2017 10:54...	Microsoft Excel ...	1 KB
ODME_zone_based_log.csv	6/14/2017 10:54...	Microsoft Excel ...	0 KB
optional_MOE_settings.csv	3/22/2016 11:07...	Microsoft Excel ...	1 KB
optional_vehicle_type.csv	3/22/2016 10:54...	Microsoft Excel ...	1 KB
output_agent.csv	6/14/2017 10:54...	Microsoft Excel ...	0 KB
output_day_to_day_MOE.csv	6/14/2017 10:54...	Microsoft Excel ...	9 KB
output_LinkMOE.csv	6/14/2017 10:54...	Microsoft Excel ...	0 KB

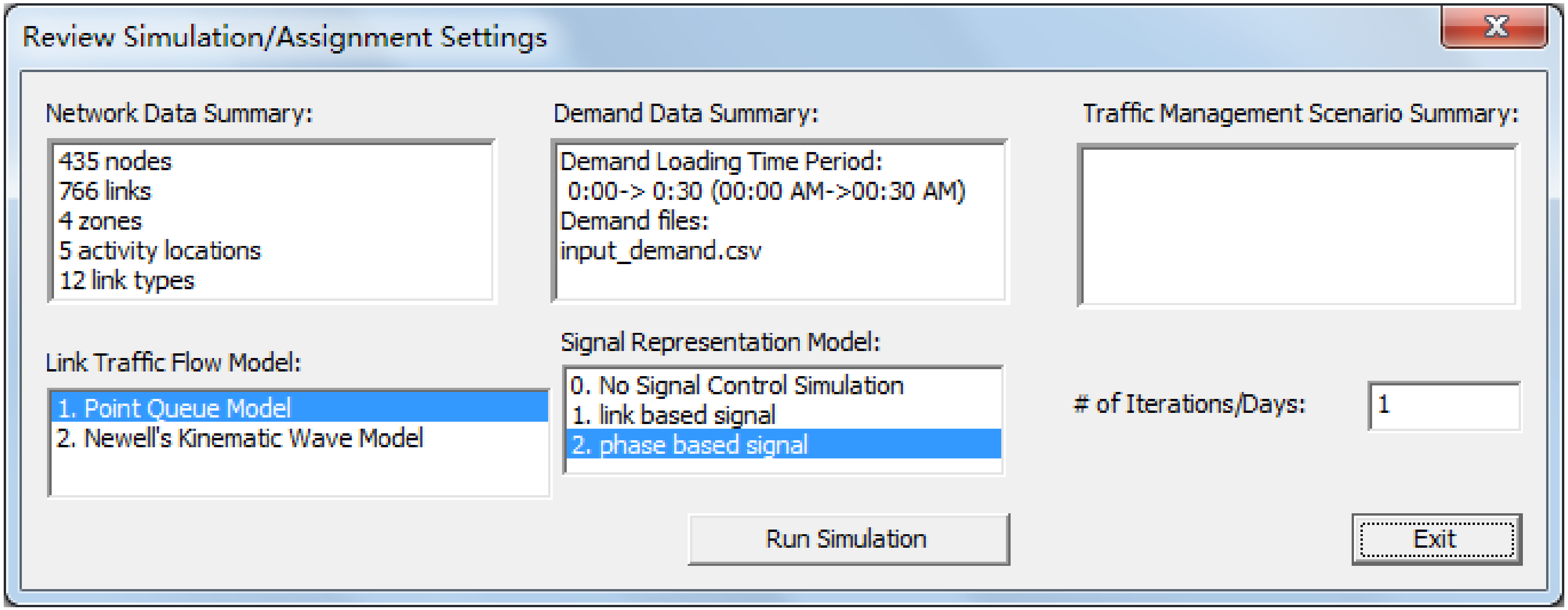
3.2 View/Edit data files in “project” menu

- Node/link/zone/activity location
- Demand meta database
- Scenario files



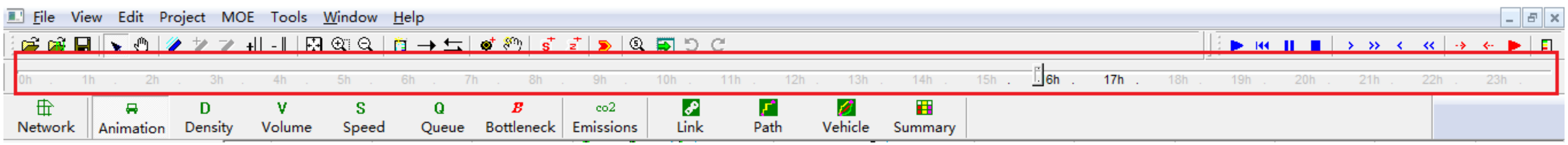
3.3 Integration with assignment model

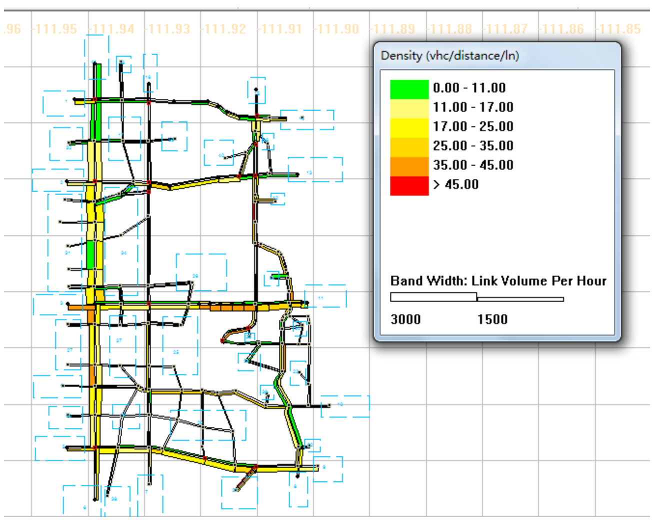
- Traffic flow model
- Traffic Assignment method

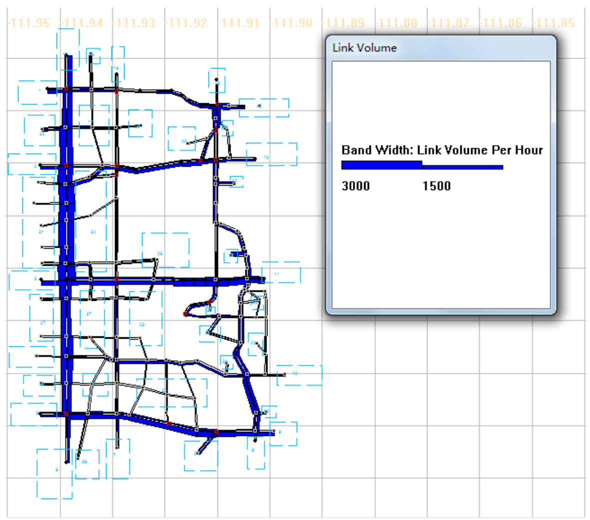


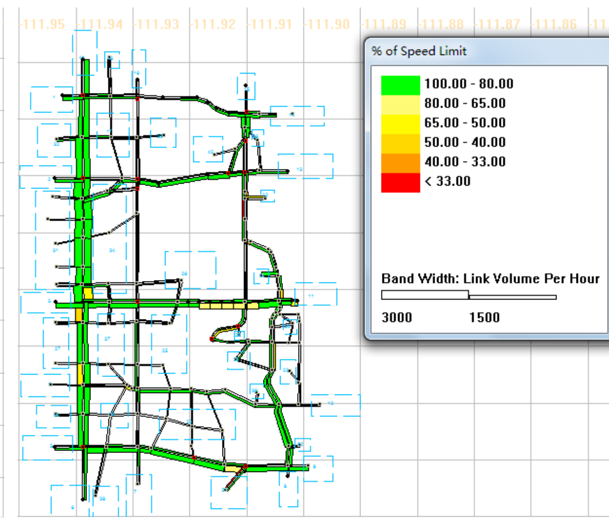
3.4 Advanced visualization functions of NeXTA

- 24-hour Time control/Clock bar
- Volume (bandwidth), density, speed
- Animation and queue: (turn off node layer and bandwidth)









3.4 Advanced visualization functions of NeXTA

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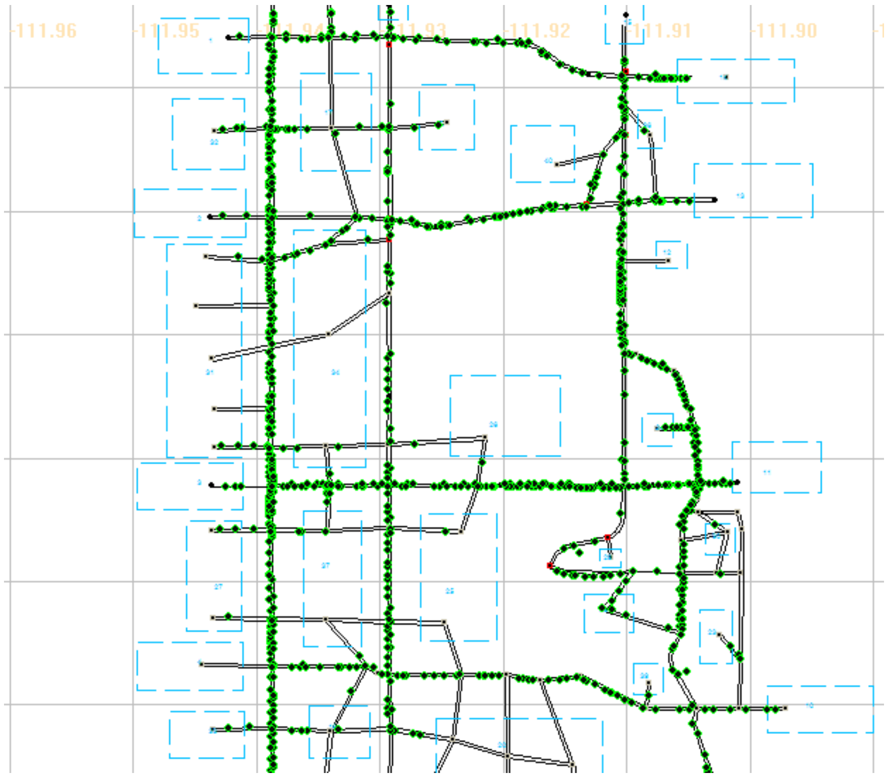
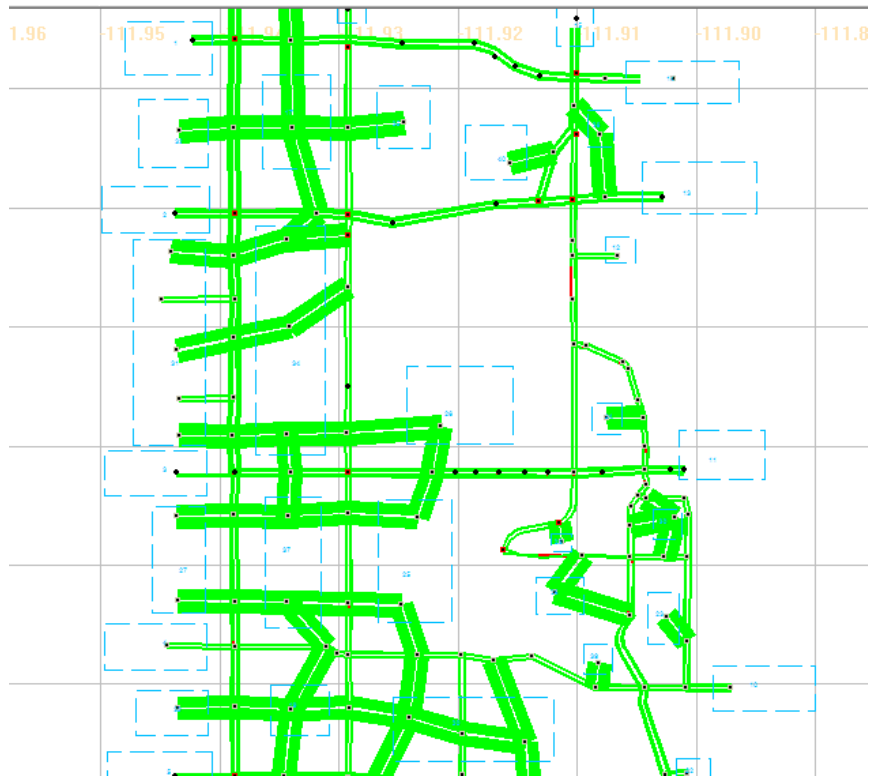
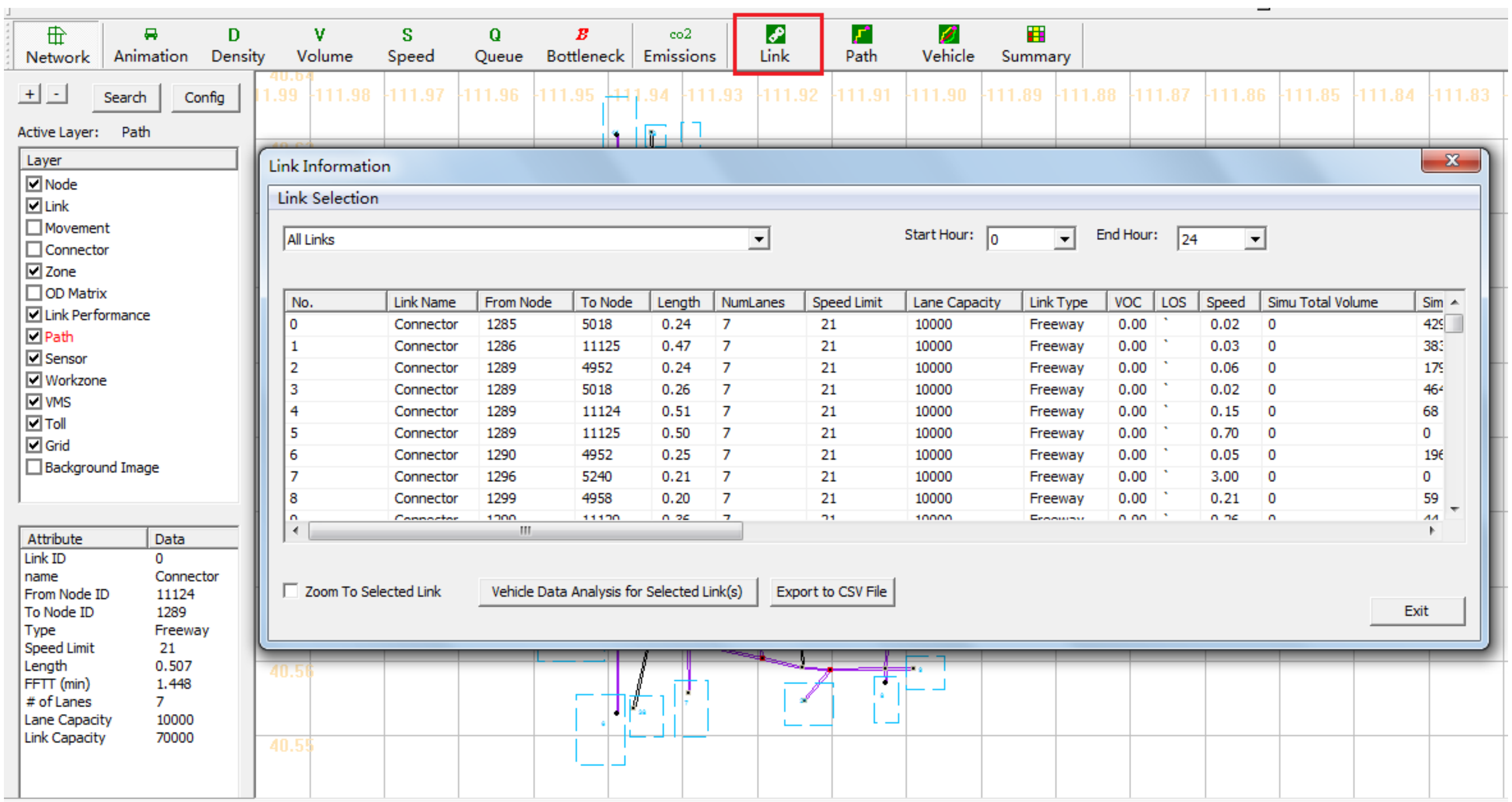




3.5 MOE related display

- Link-related display
- Path-related display
- Vehicle and Summary Charts



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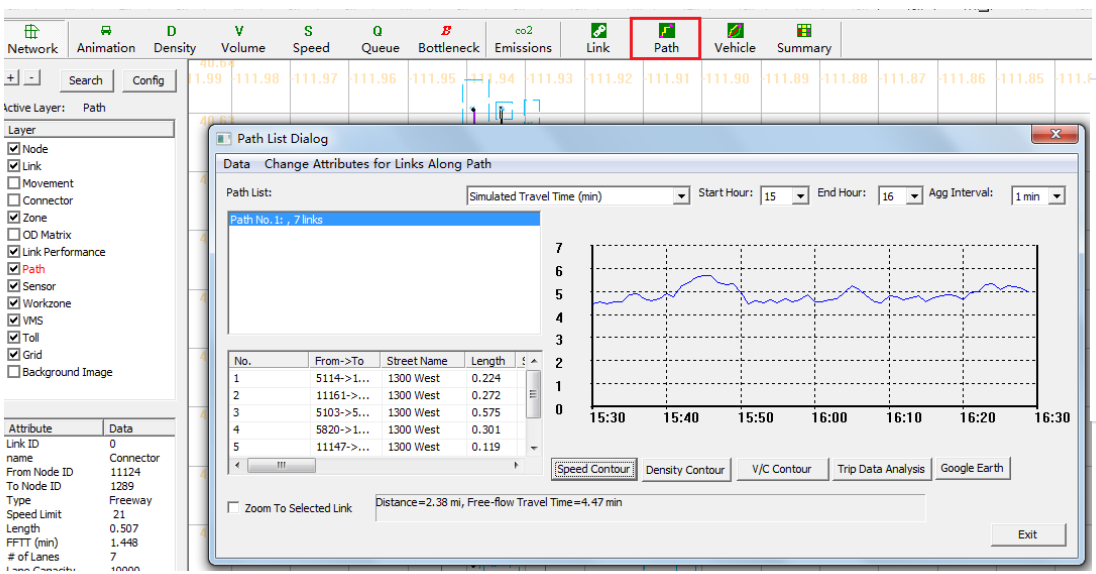
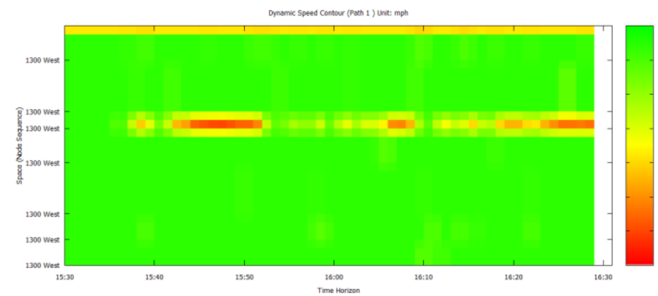
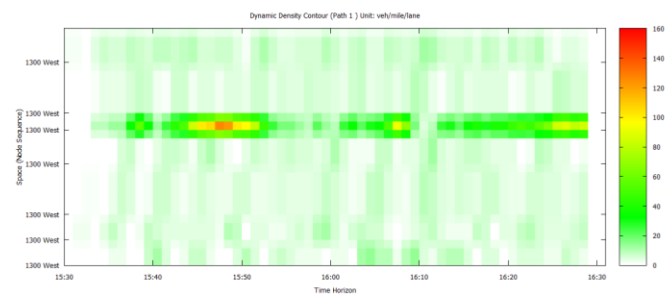
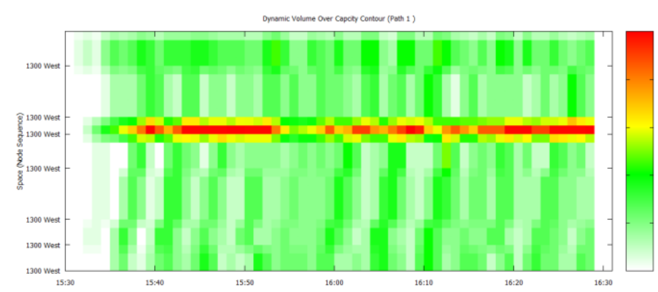
- Link-related display
- Path-related display
- Vehicle and Summary Charts



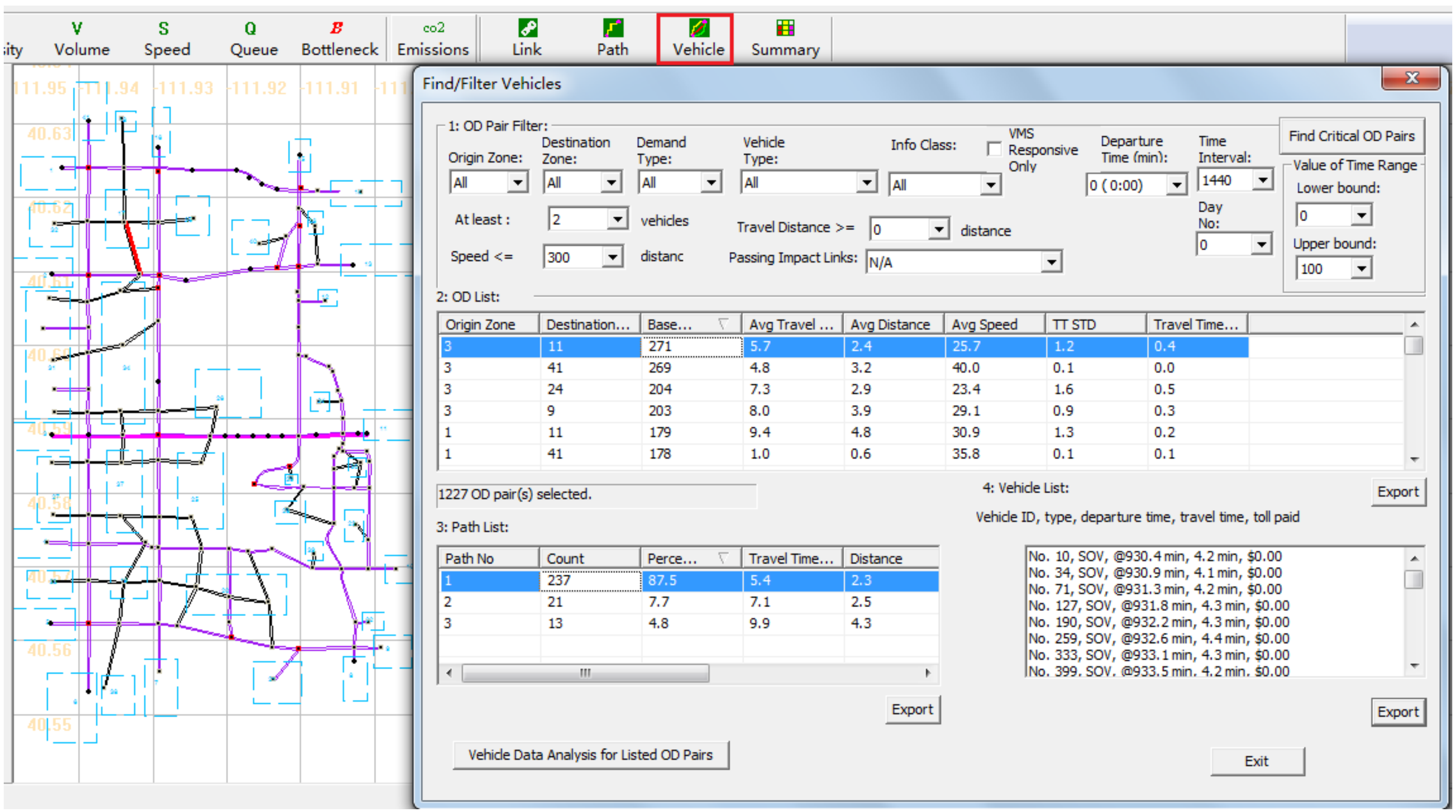






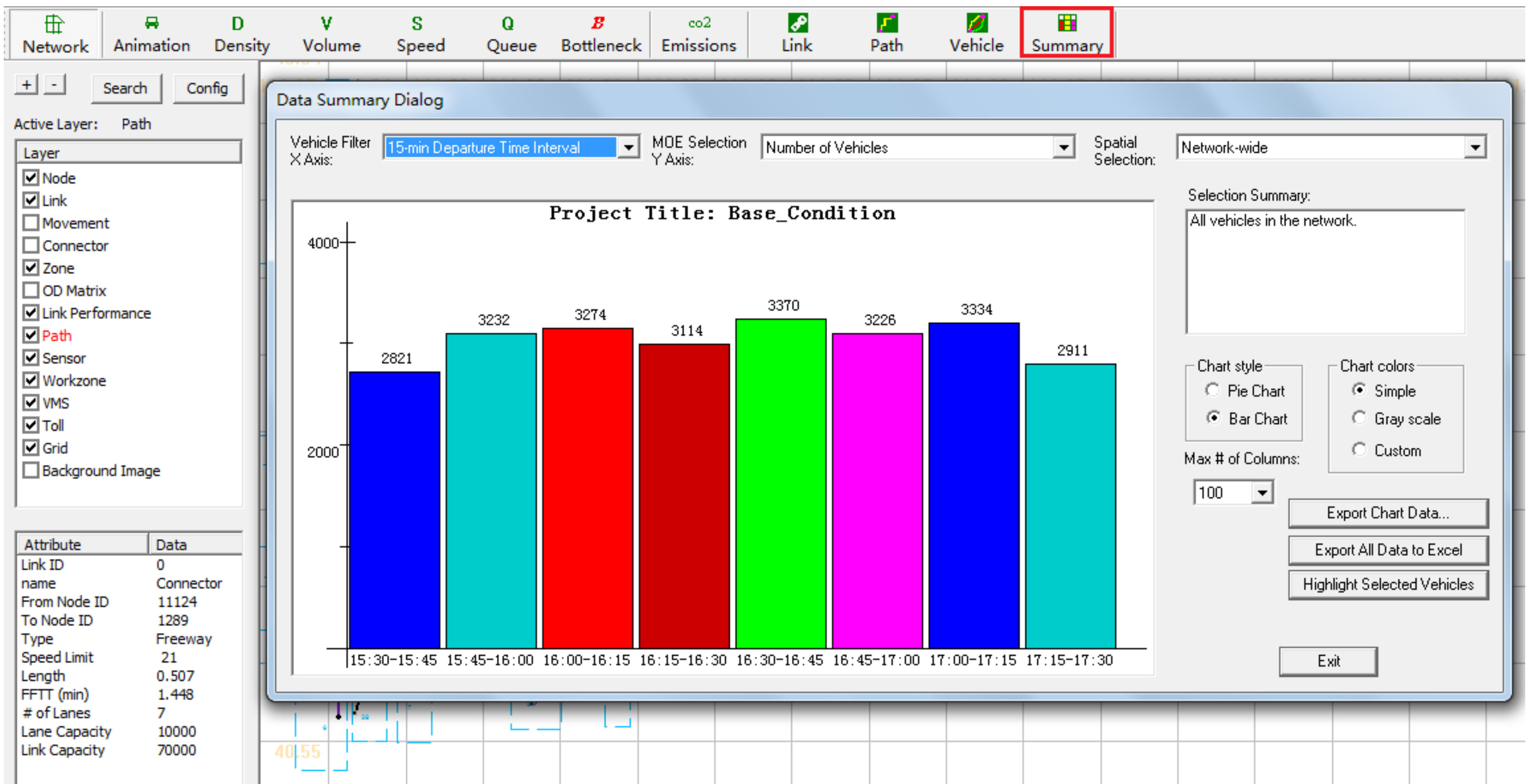
3.5 MOE related display

- Link-related display
- Path-related display
- Vehicle and Summary Charts



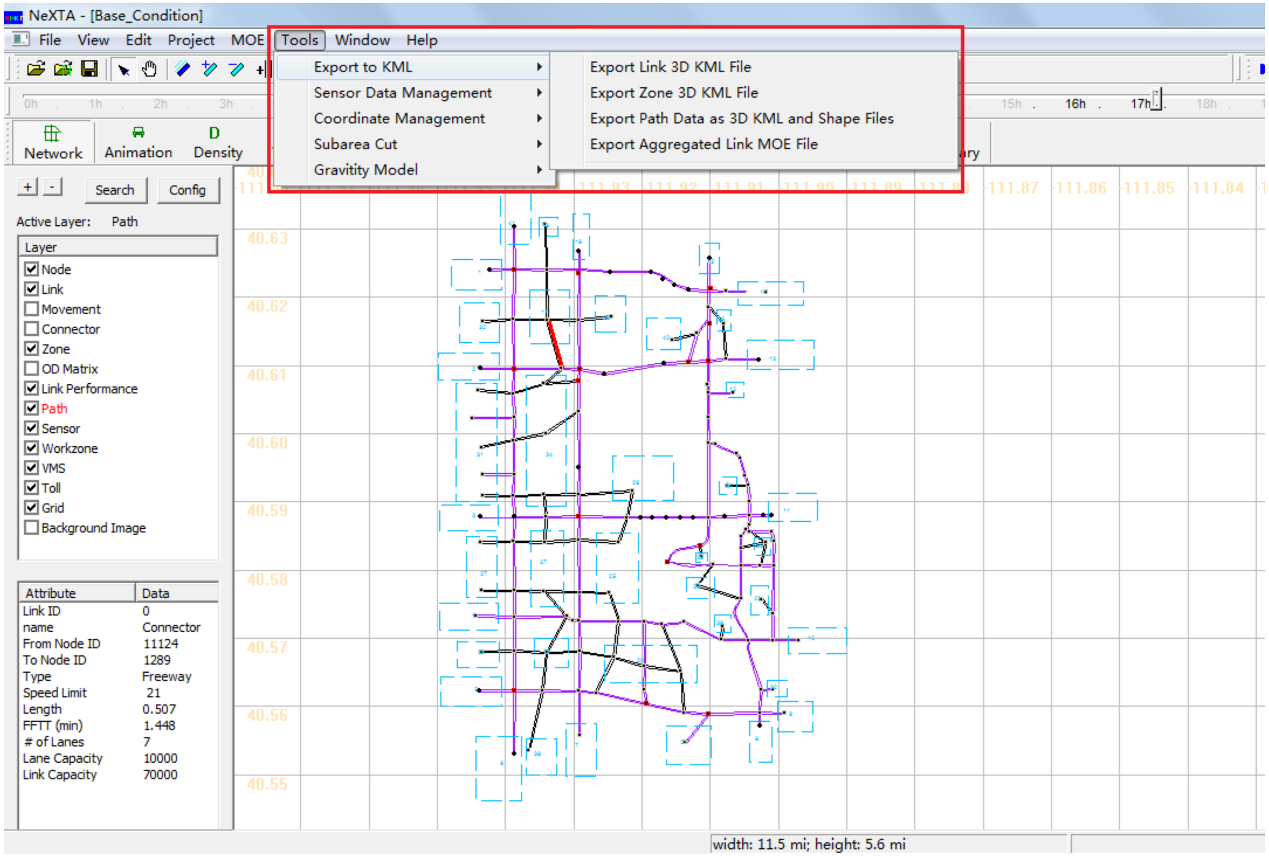
3.5 MOE-related display

- Link-related display
- Path-related display
- Vehicle and Summary Charts



3.6 Export Data to Google Earth/GIS package

- 2D KML, 3D KML, GIS shape files
- Google Earth visualization
- Zone level display: adjust height/color



Module 4
Introduction to Workshop Exercises

4.1 Data Preparation for Building A Regional Traffic Network

4.2 Clackamas Network Modeling(Calibration)

4.1 Data Preparation for Building A Regional Traffic Network

Data Block	File Name
GIS Shape Files	1a: node shape file
	1b: link shape file
	1c: zone shape file
GIS Importing Setting Files	2: input_GIS_setting.csv
Advanced Definition Files	3a: input_node_control_type.csv
	3b: input_link_type.csv
	3c: input_demand_type.csv
	3d: optional_vehicle_emission_rate.csv
Demand Files	4.Demand files
Simulation Configuration Files	5: input_demand_file_list.csv
	6. input_scenario_settings.csv
D: Scenario Files	7a: sensor_count.csv
	7b: sensor_speed.csv
	8: Scenario_Work_Zone.csv
	9: Scenario_Dynamic_Message_Sign.csv
	10: Scenario_Link_Based_Toll.csv

4.1 Data Preparation for Building A Regional Traffic Network

Step 1: Prepare Required Shape files

- node shape file (1a)
- link shape file (1b)
- zone shape file (1c) -- optional

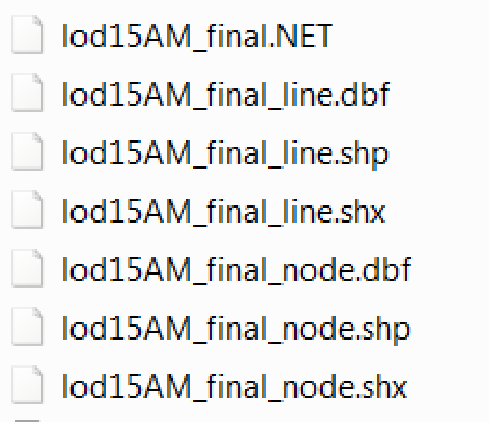
- e.g. given shape files for the Atlanta network:

- lod15AM_final_node.shp:

provide node ID and coordinate values;

- lod15AM_final_line.shp:

provide from node id, to node id, length of links, link type, number of lanes of link, ect.



4.1 Data Preparation for Building A Regional Traffic Network

Step 2: Extract GIS information from shape files – importing configuration

- The hub between shape files and NeXTA network data is import_GIS_settings.csv.(2)

- How to do the settings for import_GIS_settings.csv can be found at the learning document in “DTALite-NEXTA-Software-Package”

  [3] learning_document_GIS_importing.docx

key	value
node	lod15AM_final_node.shp
link	lod15AM_final_line.shp
zone	
centroid	
connector	
with_decimal_long_lat	yes
length_unit	mile
number_of_lanes_oneway_vs_twoway	oneway
lane_capacity_vs_link_capacity	lane
conversion_factor_for_obtaining_hourly_capacity	1
direction_0_as_oneway_vs_twoway	twoway
default_link_direction	oneway
node_number_threshold_as_centroid	5981
use_default_speed_limit_from_link_type	yes
use_default_lane_capacity_from_link_type	yes
use_default_number_of_lanes_from_link_type	no
identify_from_node_id_and_to_node_id_based_on_geometry	yes
create_connectors_for_isolated_nodes	no
identify_signal_intersection	no
minimum_speed_limit_for_signals	
maximum_speed_limit_for_signals	
default_cycle_length_in_second	
minimum_length_for_importing_links	0.00001
node_id	N
name	
TAZ	
control_type	
from_node_id	A
to_node_id	B

4.1 Data Preparation for Building A Regional Traffic Network

Step 3: Meta data files for building the network

- input_link_type.csv (3b)
- input_node_control_type.csv(3a) -- optional

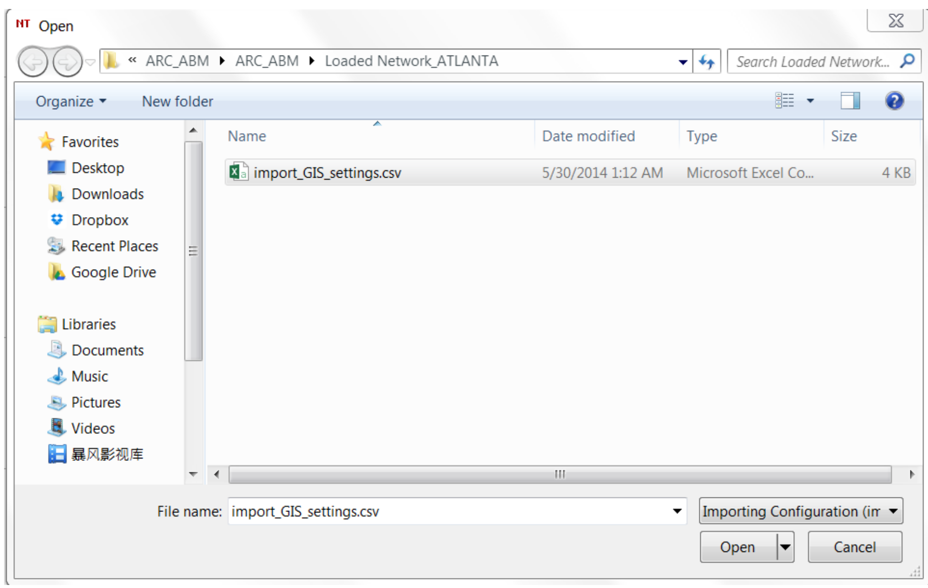
link_type	link_type_	type_code	default_la	default_sp	default_nu	capacity_a	travel_tim	approxima
0	centroid cc	c	10000	7	2	1	1	0
1	interstate/	f	1900	64	2	1	1	0
2	expresswa	h	1200	43	2	1	1	0
3	parkway	r	1150	41	2	1	1	0
4	freeway H	f	1900	66	2	1	1	0
5	freeway H	f	1900	66	2	1	1	0
6	freeway tr	f	1900	64	2	1	1	0
7	system to	r	1300	50	2	1	1	0
8	exit ramp	r	800	25	2	1	1	0
9	entrance r	r	900	25	2	1	1	0
10	principal a	a	1000	29	2	1	1	0
11	minor arte	a	900	26	2	1	1	0
12	arterial HC	a	1000	25	2	1	1	0

control_type_name	unknown_	no_contro	yield_sign	2way_stop	4way_stop	pretimed_	actuated_	roundabout
control_type	0	1	2	3	4	5	6	100

4.1 Data Preparation for Building A Regional Traffic Network

Step 4: Import GIS network to NeXTA

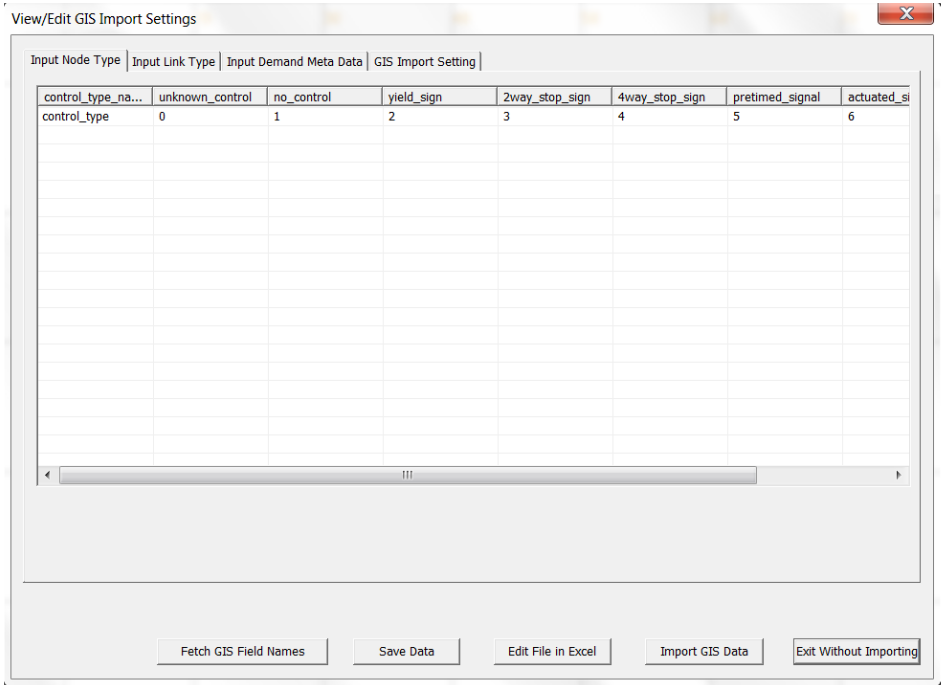
- Open NEXTA_GIS_Import.exe that is the only one program to generate traffic network;
- Click “File” ->“Import GIS Data Set”->“Next”. It will display the following dialogue.



4.1 Data Preparation for Building A Regional Traffic Network

Step 4: Import GIS network to NeXTA

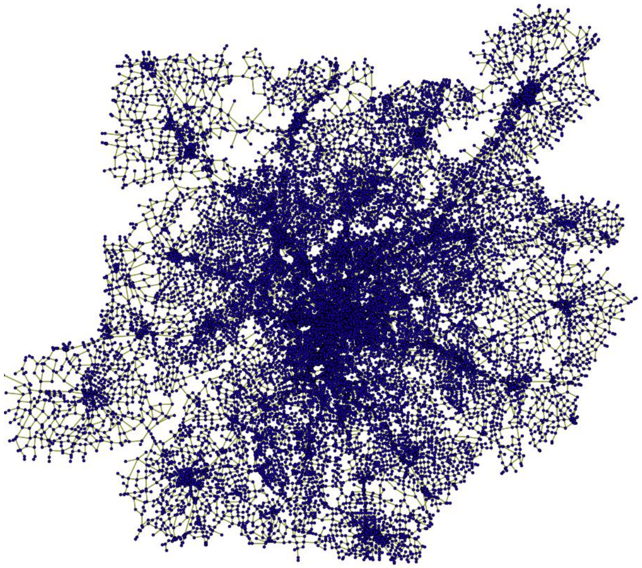
- Choose the import_GIS_setting.csv file and open it. It will display the right interface: those four csv files can be checked here.



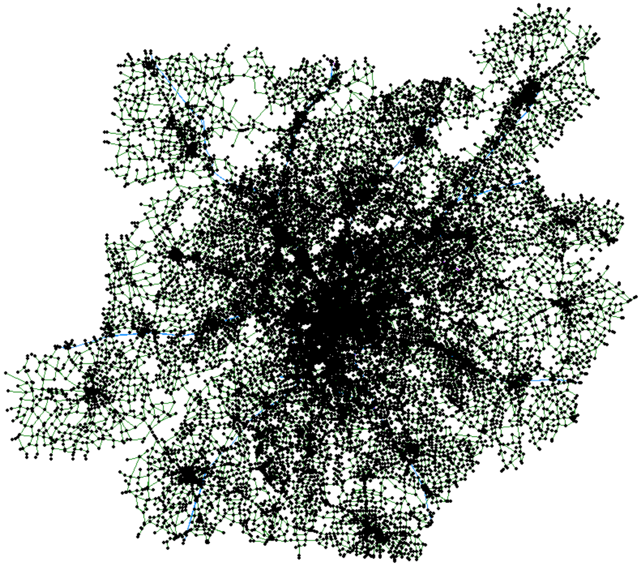
4.1 Data Preparation for Building A Regional Traffic Network

Step 4: Import GIS network to NeXTA

- Click “Import GIS Data” button. And the network will be generated.



GIS Shape files



NeXTA

4.1 Data Preparation for Building A Regional Traffic Network

Step 5: Prepare Demand files

- Demand file (4) is the source of dynamic traffic assignment. Generally, it is provided by users. And all types of demand should be defined in Input_demand_type(3c)

- NeXTA can accommodate various demand formats:
- column format from VISUM,
- matrix format,
- full matrix format,
- Dynasmart format,
- agent file,
- and so on.

4.1 Data Preparation for Building A Regional Traffic Network

Step 5: Prepare Demand files

- Input_demand_file_list.csv(5) is used to define the characteristics of demand data (4).

scenario_r	file_seque	file_name	format_ty	number_o	loading_m	start_time	end_time_	apply_add	subtotal_i	number_o	demand_t	demand_t	demand_t	demand_t
0	1	htkbypass_	full_matri	0	1	180	360	0	0	1	3	0	0	0
0	2	htkbypass_	full_matri	0	1	360	600	0	0	1	3	0	0	0
0	3	htkbypass_	full_matri	0	1	600	900	0	0	1	3	0	0	0
0	4	htkbypass_	full_matri	0	1	900	1140	0	0	1	3	0	0	0
0	5	mtk_EAMT	full_matri	0	1	180	360	0	0	1	3	0	0	0
0	6	mtk_AMM	full_matri	0	1	360	600	0	0	1	3	0	0	0
0	7	mtk_MDM	full_matri	0	1	600	900	0	0	1	3	0	0	0
0	8	mtk_PMM	full_matri	0	1	900	1140	0	0	1	3	0	0	0
0	9	TODEA15_	full_matri	0	1	180	360	0	0	1	2	0	0	0
0	10	TODEA15_	full_matri	0	1	180	360	0	0	1	2	0	0	0
0	11	TODEA15_	full_matri	0	1	180	360	0	0	1	2	0	0	0
0	12	TODEA15_	full_matri	0	1	180	360	0	0	1	2	0	0	0
0	13	TODEA15_	full_matri	0	1	180	360	0	0	1	1	0	0	0
0	14	TODEA15_	full_matri	0	1	180	360	0	0	1	1	0	0	0
0	15	TODAM15	full_matri	0	1	360	600	0	0	1	2	0	0	0
0	16	TODAM15	full_matri	0	1	360	600	0	0	1	2	0	0	0
0	17	TODAM15	full_matri	0	1	360	600	0	0	1	2	0	0	0
0	18	TODAM15	full_matri	0	1	360	600	0	0	1	2	0	0	0
0	19	TODAM15	full_matri	0	1	360	600	0	0	1	1	0	0	0

4.1 Data Preparation for Building A Regional Traffic Network

Step 6: Data required for OD Demand calibration

- sensor_count.csv (7a)
- link_count , matched_link_from_node_id, matched_link_to_node_id;

count_sen	day_no	start_time	end_time_	direction	link_count	derived_la	matched_l	matched_link_from_node_id	matched_link_to_node_id	matched_l
25008_2	16	375	390	2	186	248	626	553	Major arterial	3
24002_2	16	435	450	2	589	785.3333	594	599	Major arterial	3
41009_2	16	450	465	2	526	526	691	694	Major arterial	4
3051_2	16	480	495	2	771	1028	2310	2253	RR 3&4	3
24003_2	16	360	375	2	252	336	590	593	Major arterial	3
41001_2	16	405	420	2	935	1246.667	1860	1897	Urban Express	3
4032_2	16	495	510	2	1579	1579	357	314	RR 3&4	4
41005_2	16	375	390	2	325	433.3333	1936	1901	Urban Express	3
4032_2	16	405	420	2	1238	1238	357	314	RR 3&4	4
3046_2	16	435	450	2	1631	2174.667	1888	1812	RR 3&4	3
3046_2	16	405	420	2	1665	2220	1888	1812	RR 3&4	3
4039_2	16	510	525	2	1151	1151	660	640	RR 3&4	4
3046_2	16	525	540	2	1632	2176	1888	1812	RR 3&4	3
25006_2	16	420	435	2	638	850.6667	2521	2484	Major arterial	3
2050_2	16	360	375	2	1032	1032	1653	1616	RR 2nd	4
3046_2	16	495	510	2	1611	2148	1888	1812	RR 3&4	3
3051_1	16	390	405	1	625	833.3333	2243	2304	RR 3&4	3
3055_1	16	495	510	1	1068	1424	2353	2379	RR 3&4	3

Sensor_count.csv

- sensor_speed.csv(7b)
- speed_sensor_id , speed, population_count;

day_no	start_time	end_time_	speed_sen	speed	probe_cou	population_count
16	360	375	14988	33.3459	4	40
16	360	375	32655	46.33333	1	10
16	360	375	7185	56.52771	2	20
16	360	375	125928	31.29616	2	20
16	360	375	24497	71.30745	1	10
16	360	375	22459	73.44187	1	10
16	360	375	39107	51.83703	1	10
16	360	375	28241	64.96103	2	20
16	360	375	17696	49.60911	7	70
16	360	375	46810	42.01696	5	50

sensor_speed.csv

4.1 Data Preparation for Building A Regional Traffic Network

Step 7: Work zone evaluation

- The setting file for work zone simulation is
- Scenario_Work_Zone.csv (8)

A	B	C	D	E	F	G	H
Link	Scenario No	Start Day	End Day	Start Time in Min	End Time in min	Capacity Reduction Percentage (%)	Speed Limit (mph)
1	1	1	30	420	540	20	40

Scenario_Work_Zone.csv

4.1 Data Preparation for Building A Regional Traffic Network

Step 8: VMS evaluation

- Scenario_Dynamic_Message_Sign.csv(9) is used to define the location and characteristics of variable message signs in the simulation

A	B	C	D	E	F	G	H	
Link	Scenar	Start Day	End Day N	Start Tim	End Time i	Number of	Detour Route 1	De
[270387,242201]	0	10	10	450	510	1	10;242201;242202;233800;244347;244346;236589;270393;266159;266160;283899;0.80	

Scenario_Message_Sign.csv

4.1 Data Preparation for Building A Regional Traffic Network

Step 9: Tolling evaluation

- Scenario_Link_Based_Toll.csv (10)
- Since the toll for different demand types is represented by money, the data Value of Time in input_demand_type.csv is important.

Link	Scenario No	Start Day	End Day	Start Time in Min	End Time in min	Charge for LOV ($)	Charge for HOV ($)	Charge for Truck ($)	Charge for Intermodal ($)
1	1	1	30	420	540	0.5	0.2	0.2	0.3
2	1	1	30	420	540	0.5	0.2	0.2	0.3
3	1	1	30	420	540	0.5	0.2	0.2	0.3
4	1	1	30	420	540	0.5	0.2	0.2	0.3
5	1	1	30	420	540	0.5	0.2	0.2	0.3

Scenario_Link_Based_Toll.csv

4.1 Data Preparation for Building A Regional Traffic Network

Step 10: Emission evaluation(9a)

- optional_vehicle_emission_rate.csv (3d)

vehicle_ty	OpModeID	meanBase	meanBase	meanBase	meanBase	meanBase	age
1	0	49206.3	3536.293	0.05385	2.36609	0.039171	0
1	1	45521.4	3271.471	0.008979	4.05557	0.000418	0
1	11	71581.4	5144.317	0.146868	6.52187	0.022892	0
1	12	98841	7103.373	0.155233	2.82379	0.02085	0
1	13	137367	9872.108	0.363034	9.76815	0.052262	0
1	14	173571	12473.97	0.657844	14.2137	0.072532	0
1	15	206979	14874.89	1.18797	20.8813	0.103686	0
1	16	249989	17965.88	2.5348	35.9857	0.171948	0
1	21	97382.5	6998.556	0.254133	5.8165	0.038721	0

optional_vehicle_emission_rate.csv

4.1 Data Preparation for Building A Regional Traffic Network

Step 11: Run Simulation

- Input_scenario_setting.csv (6)

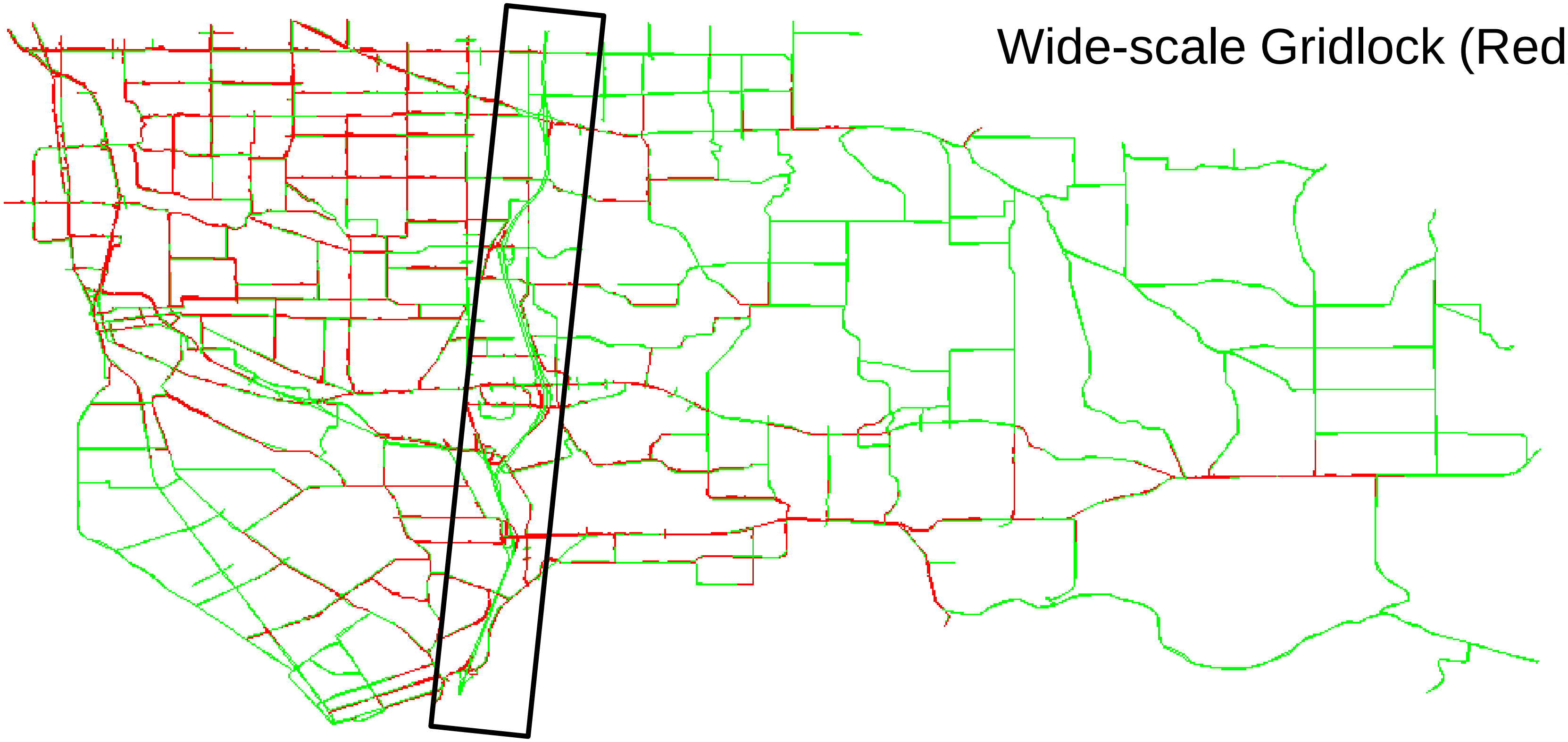
A	B	C	D	E	F	G	H	I	J	K	L
scenario_	scenario_na	number_of_ite	traffic_f	signal_repr	traffic_ana	random_seed	ODME_star	ODME_max_	ODME_step	calibrati	calibratio
1	test1	3	1	0	0	100	20	50	0.15	990	1050

Input_scenario_setting.csv

4.2 Clackamas Network Modeling(Calibration)

Converting from Macroscopioc Model to Mesoscopic Model

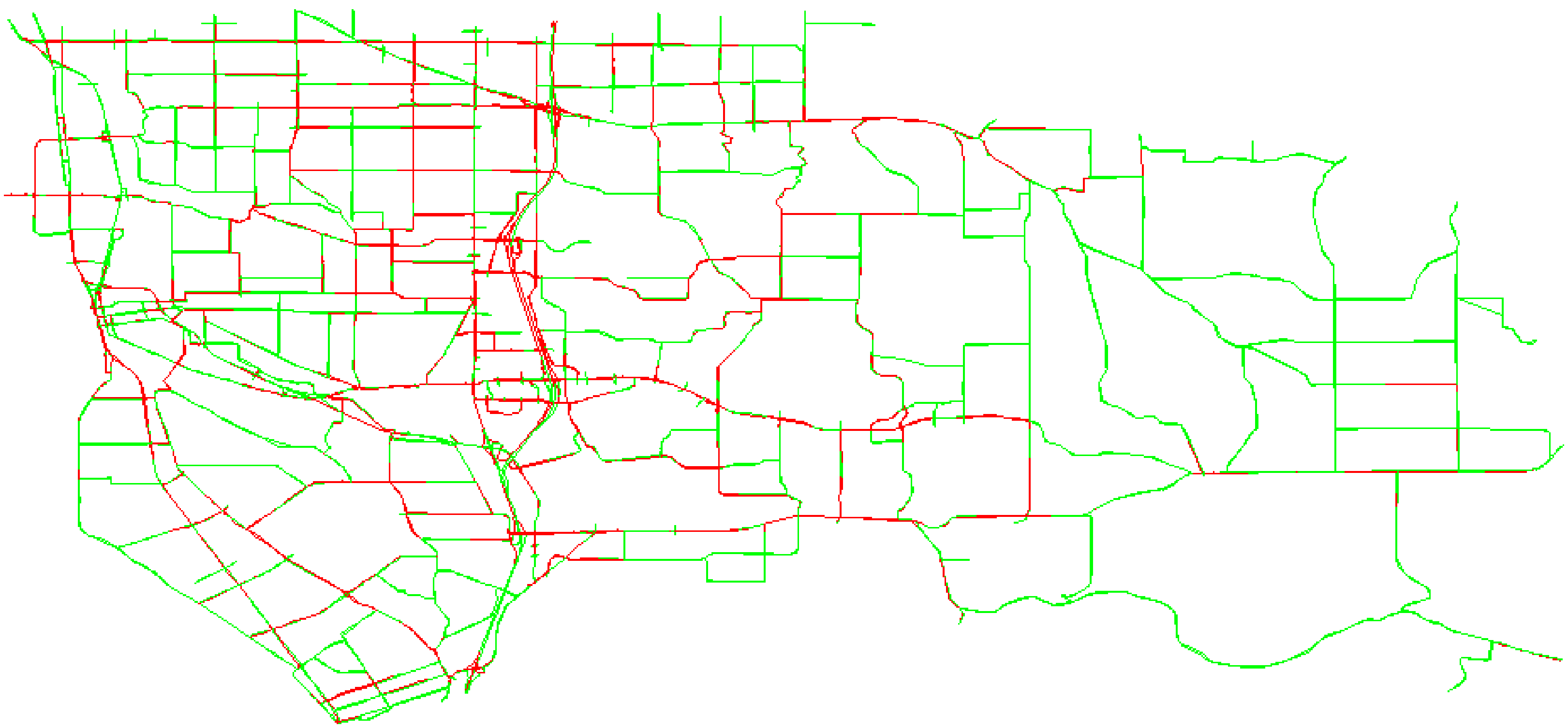
- Directly import important network attributes: Capacity, speed, number of lanes, etc.
- First Simulation Run:



4.2 Clackamas Network Modeling(Calibration)

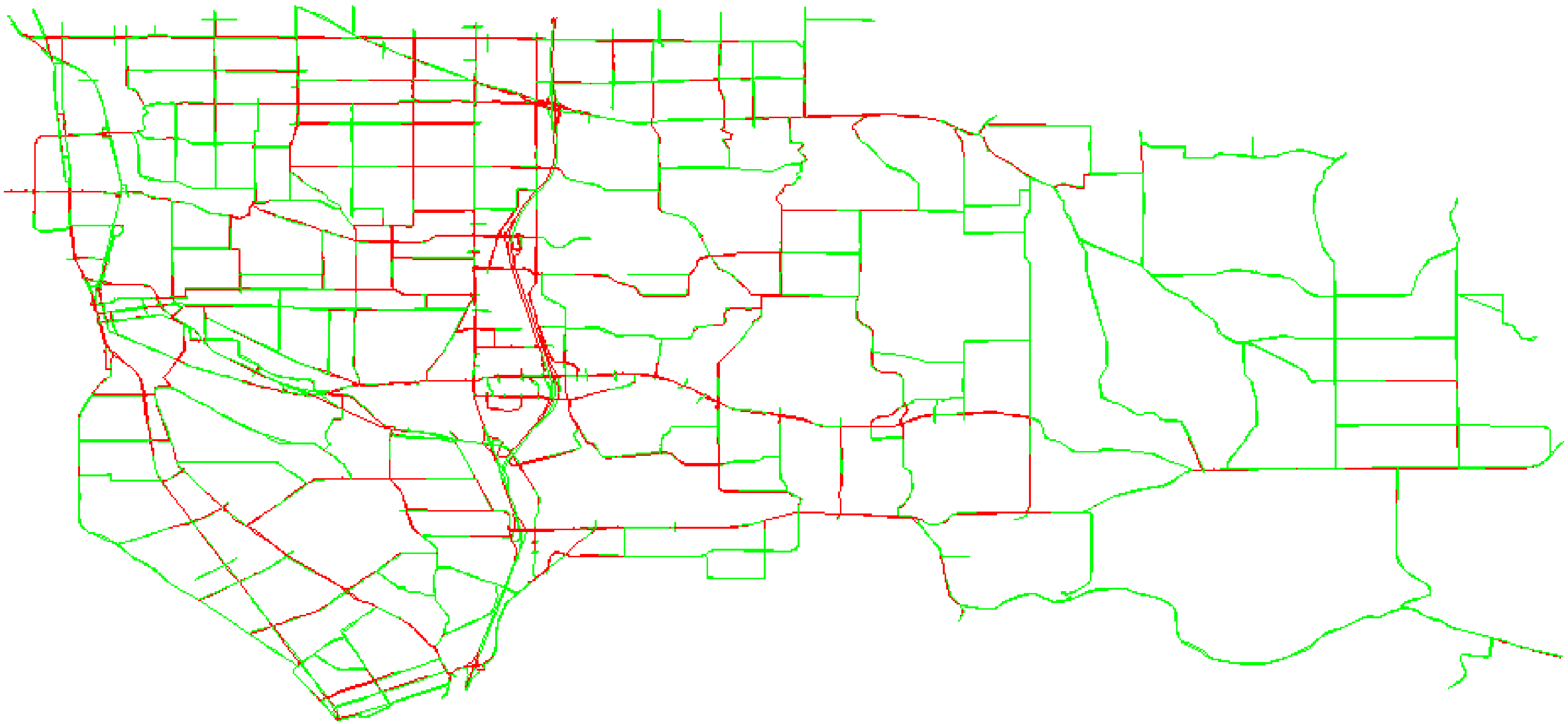
Second Attempt

- Increased ramp outflow capacity
  - Still experiencing significant queuing



4.2 Clackamas Network Modeling(Calibration)

Inflow/Storage Capacity?



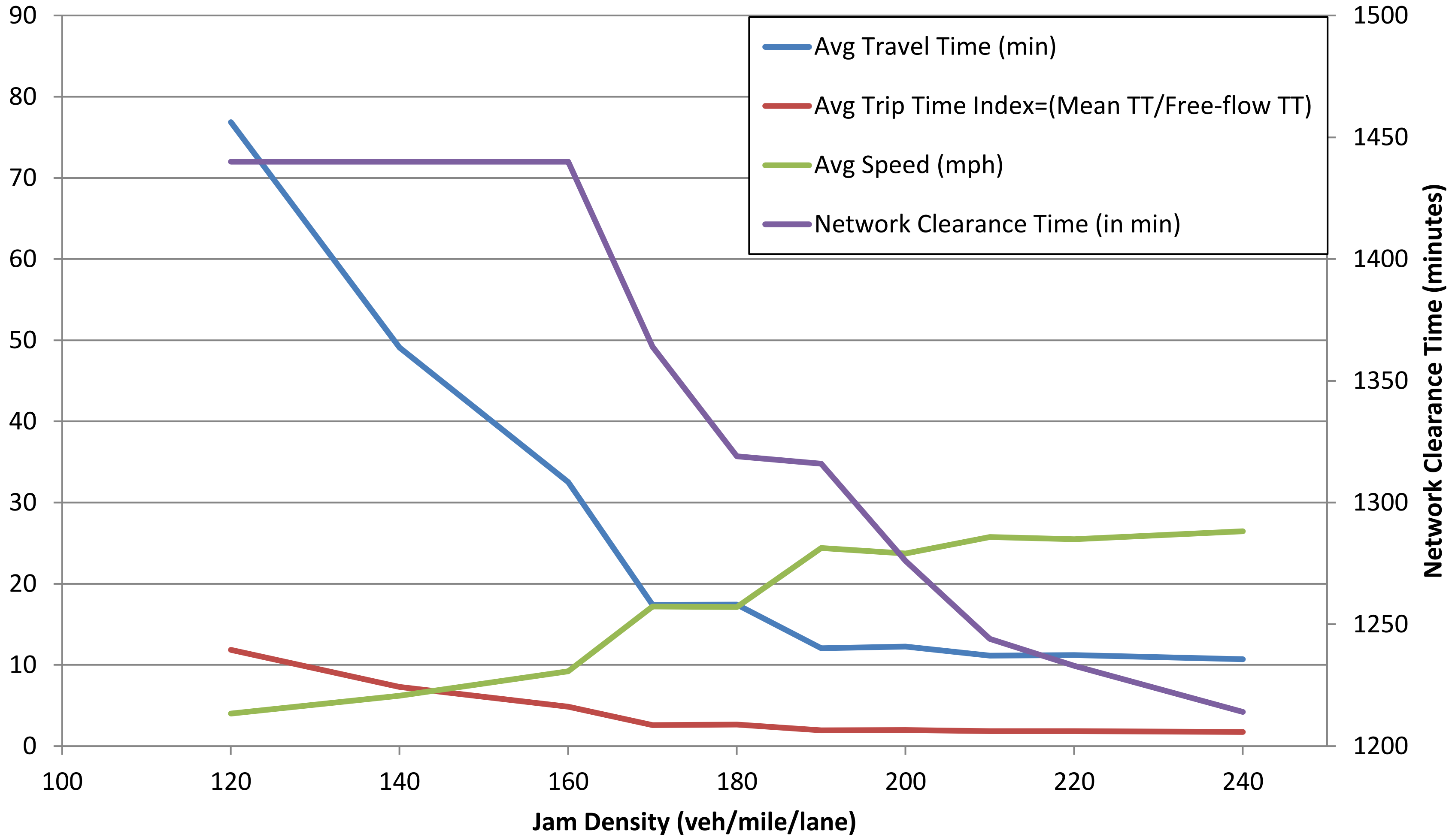
4.2 Clackamas Network Modeling(Calibration)

Geometry Details

- Two-lane ramp, coded with one lane
  - Reasonable outflow capacity
  - Potential issues
- Underestimated inflow capacity
  - Underestimated storage capacity

4.2 Clackamas Network Modeling(Calibration)

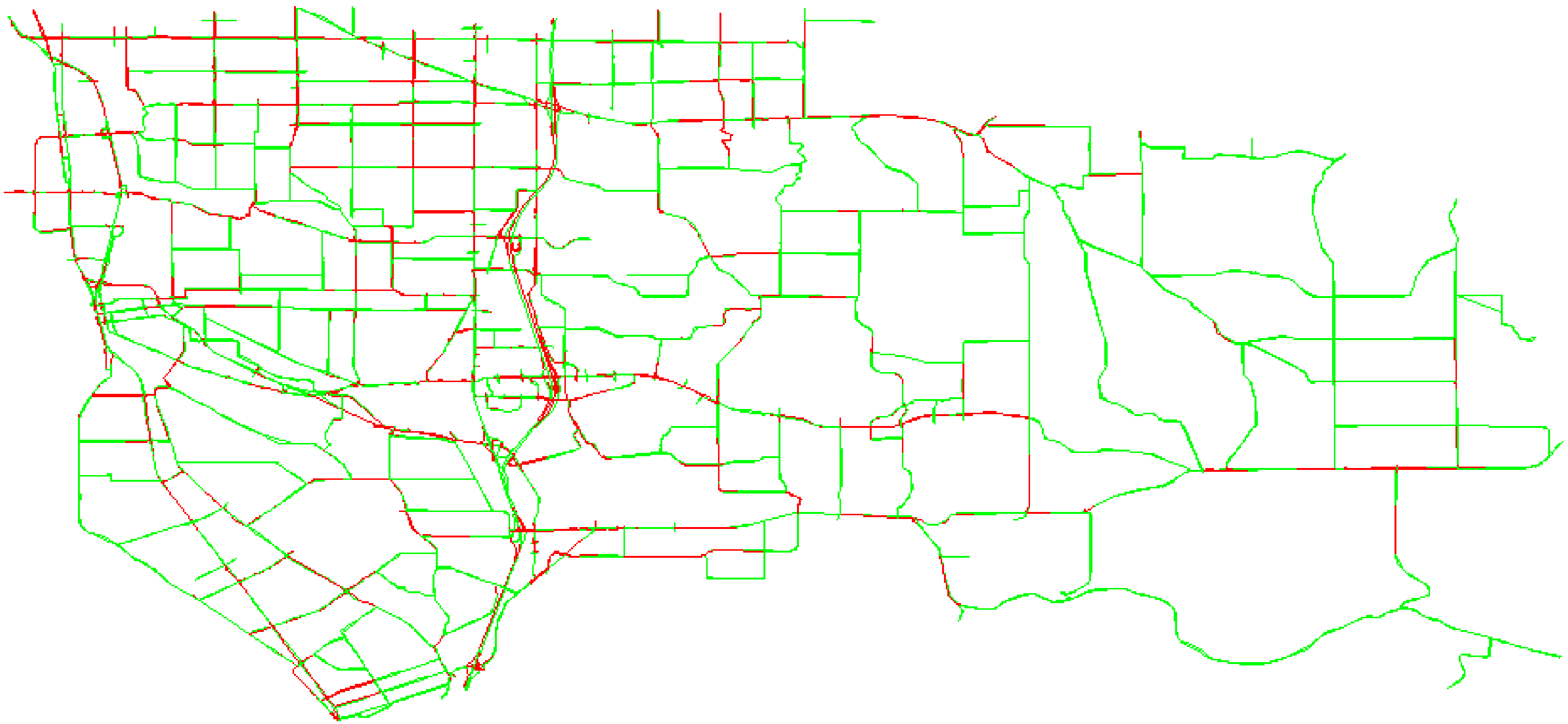
Traffic Flow Model Sensitivity



4.2 Clackamas Network Modeling(Calibration)

Third Attempt

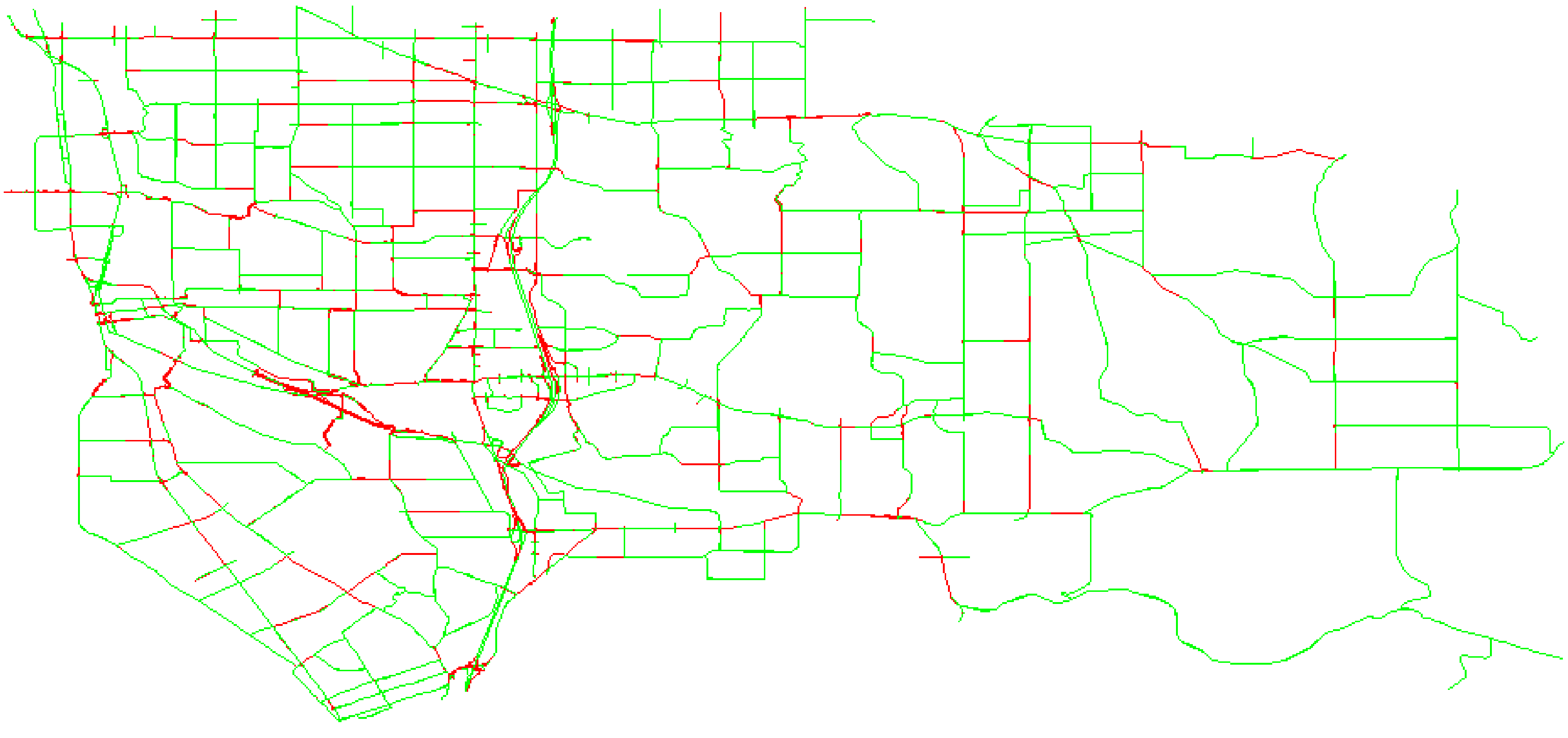
- Reset outflow capacity, adjusted inflow & storage capacity



4.2 Clackamas Network Modeling(Calibration)

Combined Modifications

- Combination of adjusting outflow and storage capacity appears more reasonable



4.2 Clackamas Network Modeling(Calibration)

Recommended Diagnostic Procedures

- Macroscopic capacity may not be appropriate for mesoscopic capacity constraints
- Understand the traffic flow model
  - Understand limitations, special cases
- Adjust capacity before OD demand, path flow
- Start with fewer capacity constraints to remove possible unrealistic bottlenecks
  - Point queue → Spatial queue → Shock wave → Speed-density relationships

Outline

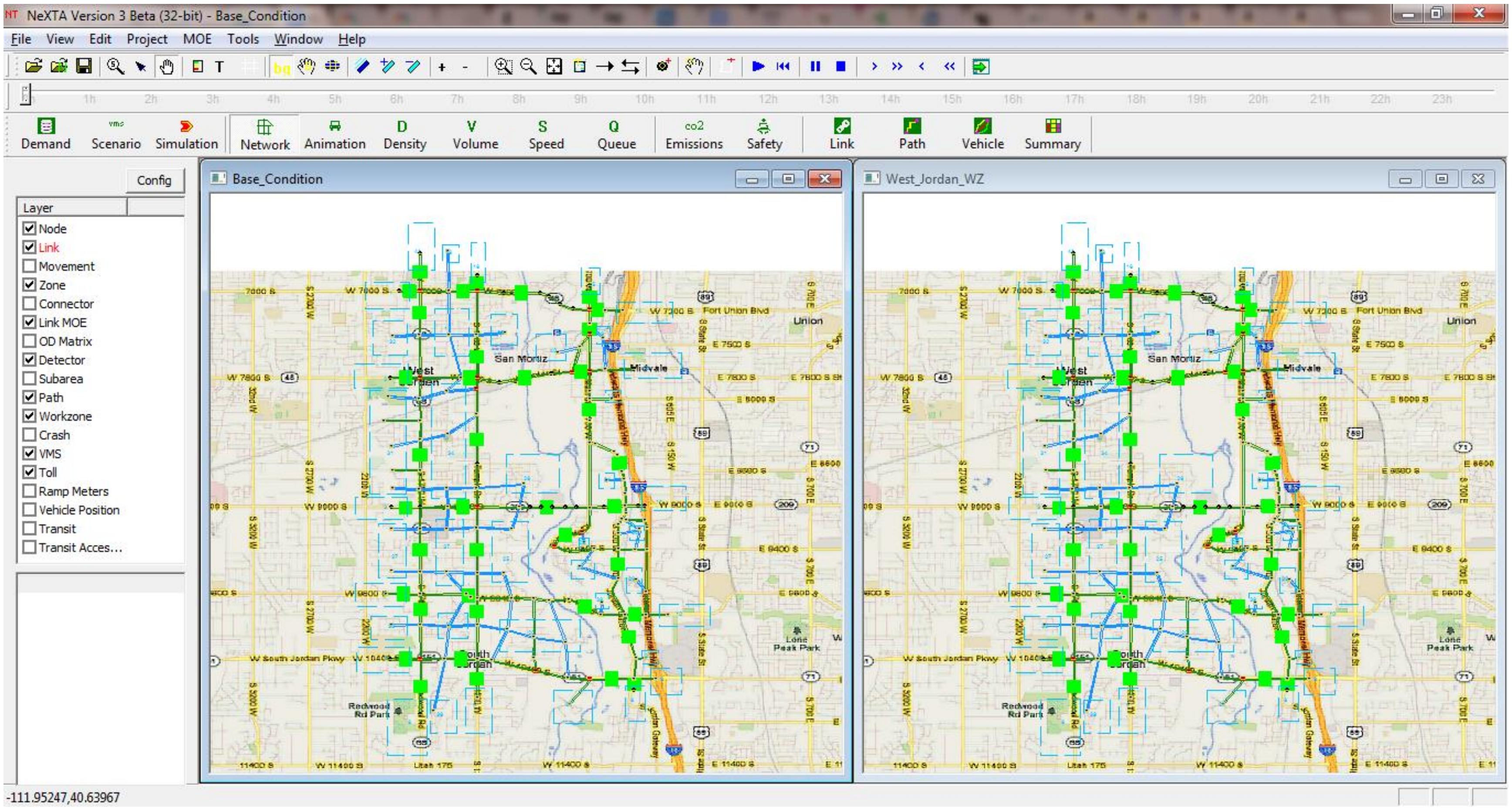
Module 5: Traffic Flow Theory

Module 6: OD Matrix Estimation

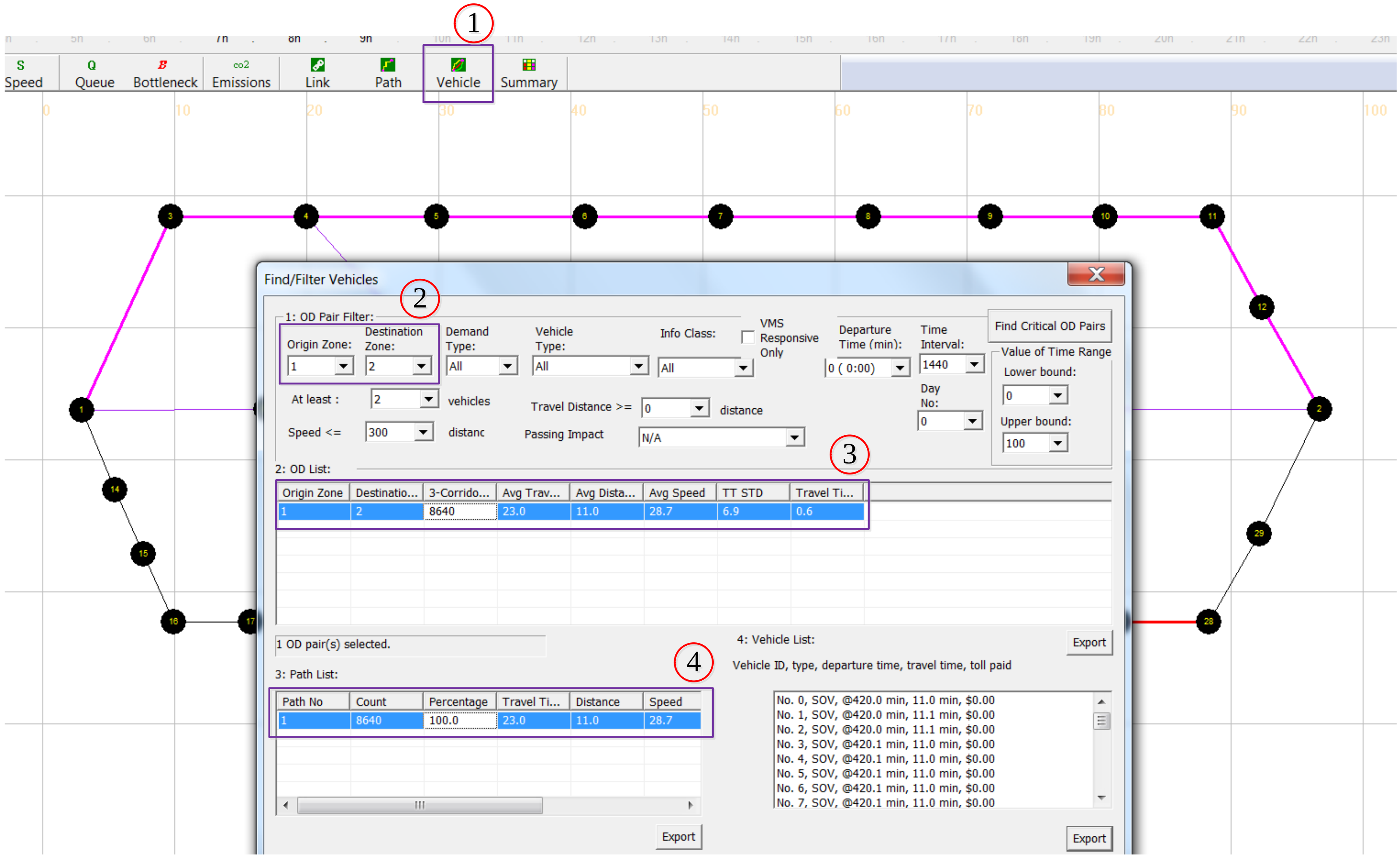
Module 7: Signalized Intersections Modeling

Module 8: VRP code

• Synchronized display in NeXTA



Vehicle Analysis Dialog



Module 3: Modeling Approach

Module 5
Traffic Flow Theory

5.1 Traffic Congestion Propagation: Understanding Theoretical Basics of Dynamic Traffic Network Assignment and Simulation

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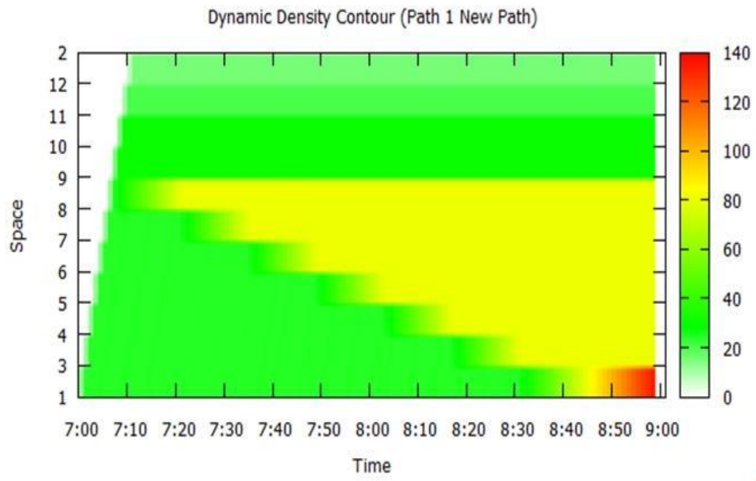
https://scholar.google.com/citations?user=VLP4r4MAAAAJ&hl=en

5.2 Understand Network Equilibrium Model: Braess' Paradox

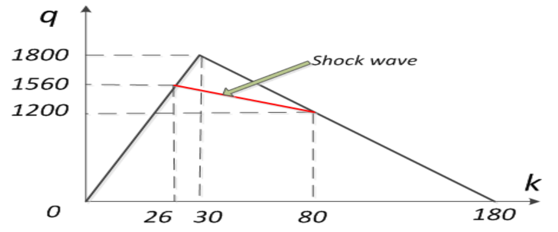
Contributing Author: Tie Shi

5.1 Traffic Congestion Propagation



Learning Objectives

- (1) Understand major input and output data for a dynamic network loading program;
- (2) Identify bottlenecks and model congestion propagation;
- (3) Calculate traffic states through different computational approaches.

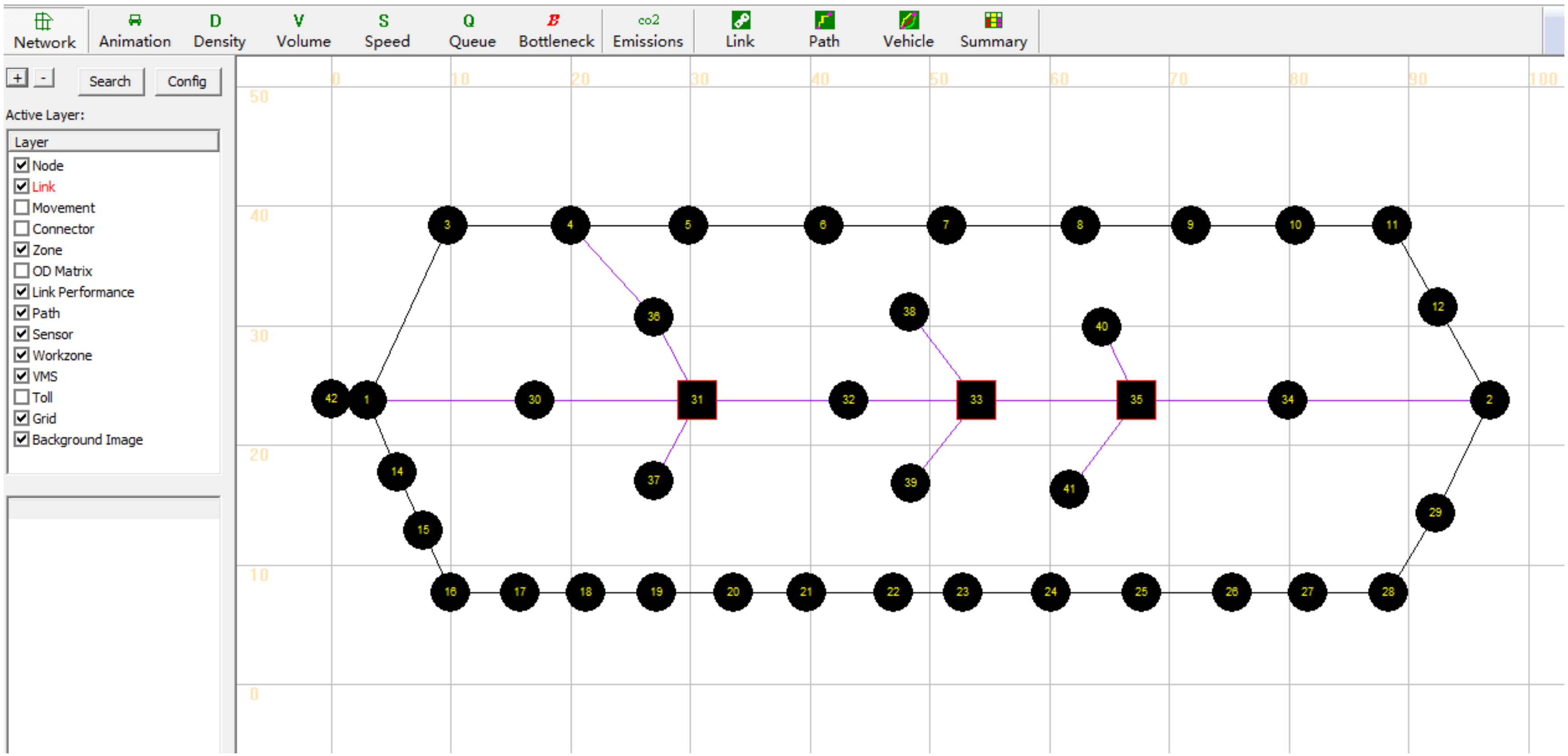


Data Set

https://github.com/xzhou99/learning-transportation/tree/master/Lessons/Lesson%202/Data%20Set

5.1 Traffic Congestion Propagation

Sample Case: 3-corridor Network



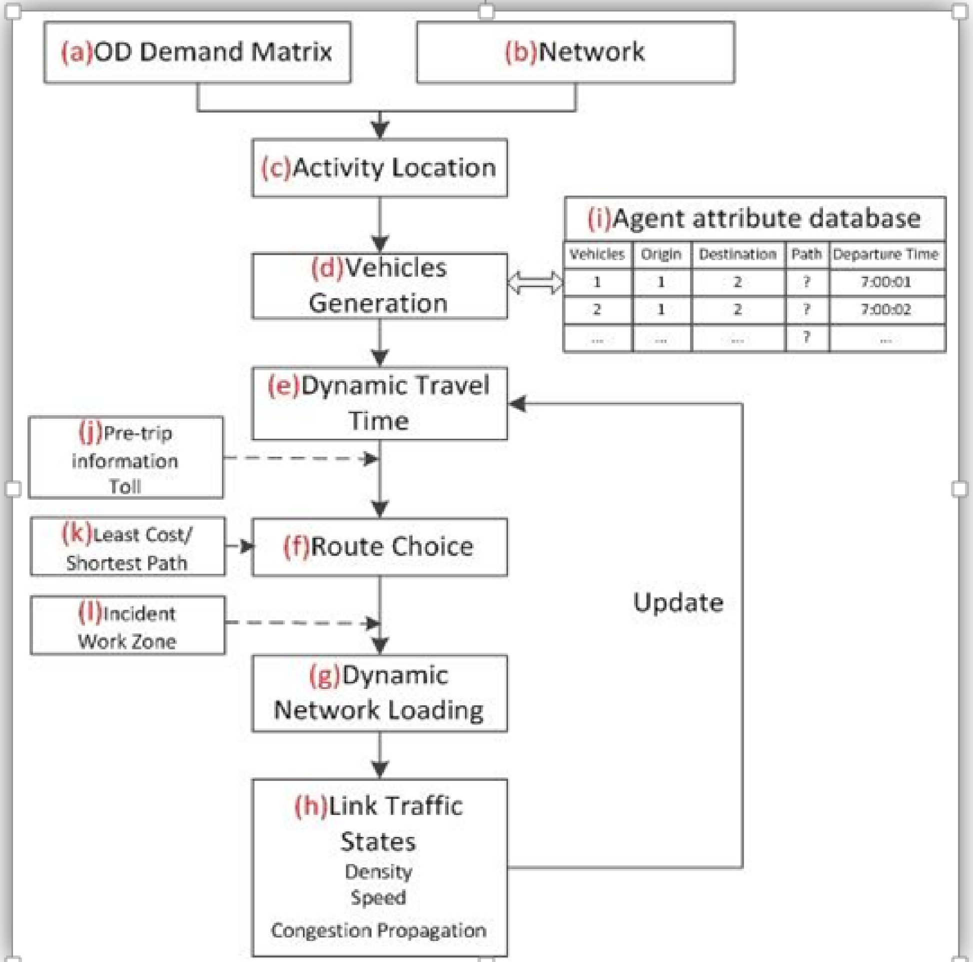


Fig.1. The process of dynamic network loading

1. The **basic data input** for a dynamic network loading program (g) includes time-dependent origin-destination demand (a) and the traffic network (b) with road capacity constraints on links and nodes.

2. **Activity locations** (c) describe a zone-to-node mapping between OD demand matrix (a) and the traffic network (b). The vehicles generation process (d) determines specific origin, destination, and departure time of agents/vehicles, which leads to an agent attribute database (i), to be iteratively updated throughout the simulation process.

3. Through calculating the **dynamic travel time** of all links (free-flow travel time is used at first iteration), corresponding to element (e), the **route choice model** (f) embeds a standard time-dependent least-cost path algorithm (k) to generate paths for all agents.

4. The core **dynamic network loading program** (g) loads previously generated agents on the traffic network for the entire planning horizon, which produces traffic data output (h) that describes time-varying traffic states at the link level, including traffic flow volume, traffic density, speed, travel time. The link-based traffic states (h) can be further processed to represent traffic congestion and propagation at the aggregated path level, as well as update the time-dependent travel time database (e).

Table 1. Properties of traffic network

File No.	GIS Layer	Associated Data File	Associated Menu for Data Editing	Important Attributes
1	Node	input_node.csv	Project->Network Data-> Node	node coordinate, control type
2	Link	input_link.csv	Project->Network Data-> Link	from node, to node, speed limit -> free-flow travel time, capacity, number of lanes
3	Zone	input_zone.csv	Project->Network Data-> Zone	zone definition for OD demand
4	Activity Location (similar to centroid)	input_activity_location.csv	Project->Network Data-> Activity Location	mapping from zone number to nodes as origin or destination
5	OD demand matrix	input_demand_file_list.csv input_demand.csv	Project-> Demand Database	# of trips from zone i to zone j
6	Traffic simulation setup	input_scenario_settings.csv	Project-> Perform Traffic Assignment	# of iterations, traffic models, traffic assignment method…
7	Generated Vehicle Data	output_agent.csv	---	Agent ID, Arrival time, departure time…
8	Traffic States	output_LinkTDMOE.csv	---	Travel time, speed, density…

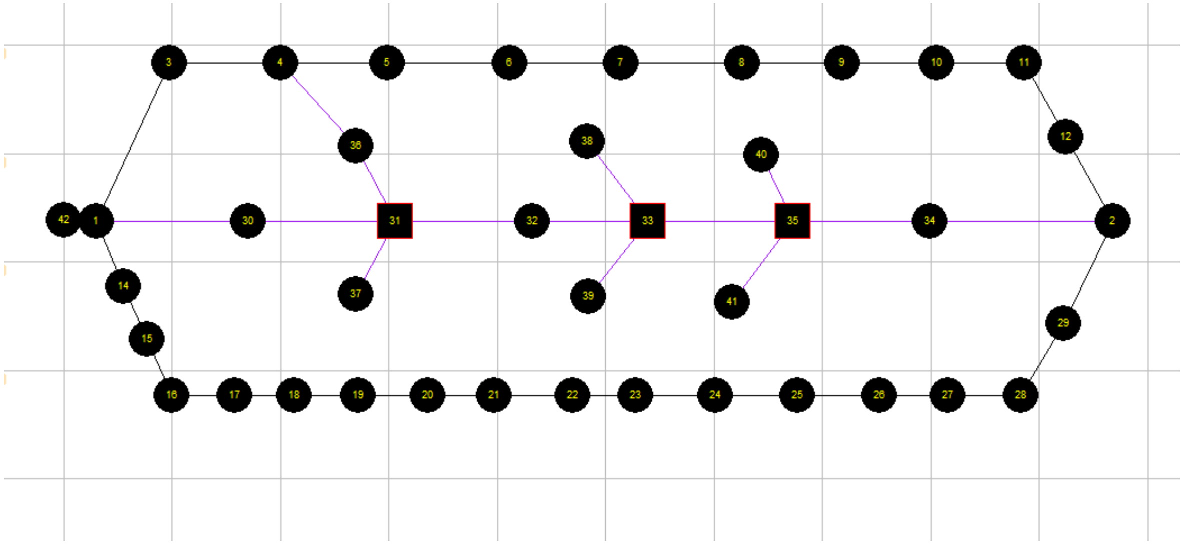


Table 2. Link attributes for calculating the travel time of path 1

No.	Link (From node->to Node)	Distance (mile)	Free-flow travel time(min)	Link capacity (veh/h)
1	1->3	1	1	5700
2	3->4	1	1	5400
3	4->5	1	1	5400
4	5->6	1	1	5400
5	6->7	1	1	5400
6	7->8	1	1	5400

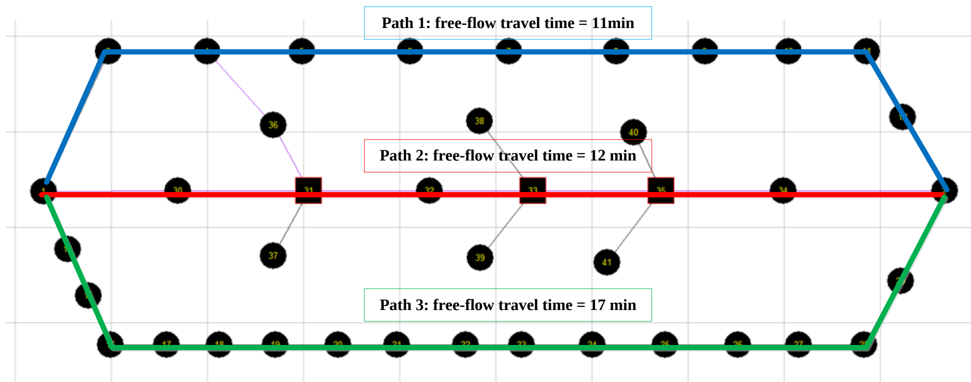


Table 3. Travel time and travel distance of three paths

Path	**Node sequence**	**# of links**	**Travel time (min)**	**Travel Distance (mile)**	**Bottleneck**
Path 1 (Major Freeway)	1->3->4...-> 12->2	11	11	11	Link 9->10, Link 10->11
Path 2 (Alternative Arterial corridor)	1->30->31...-> 34->2	7	12	8	
Path 3 (Alternative Freeway)	1->14->15...-> 29->2	17	17	17	

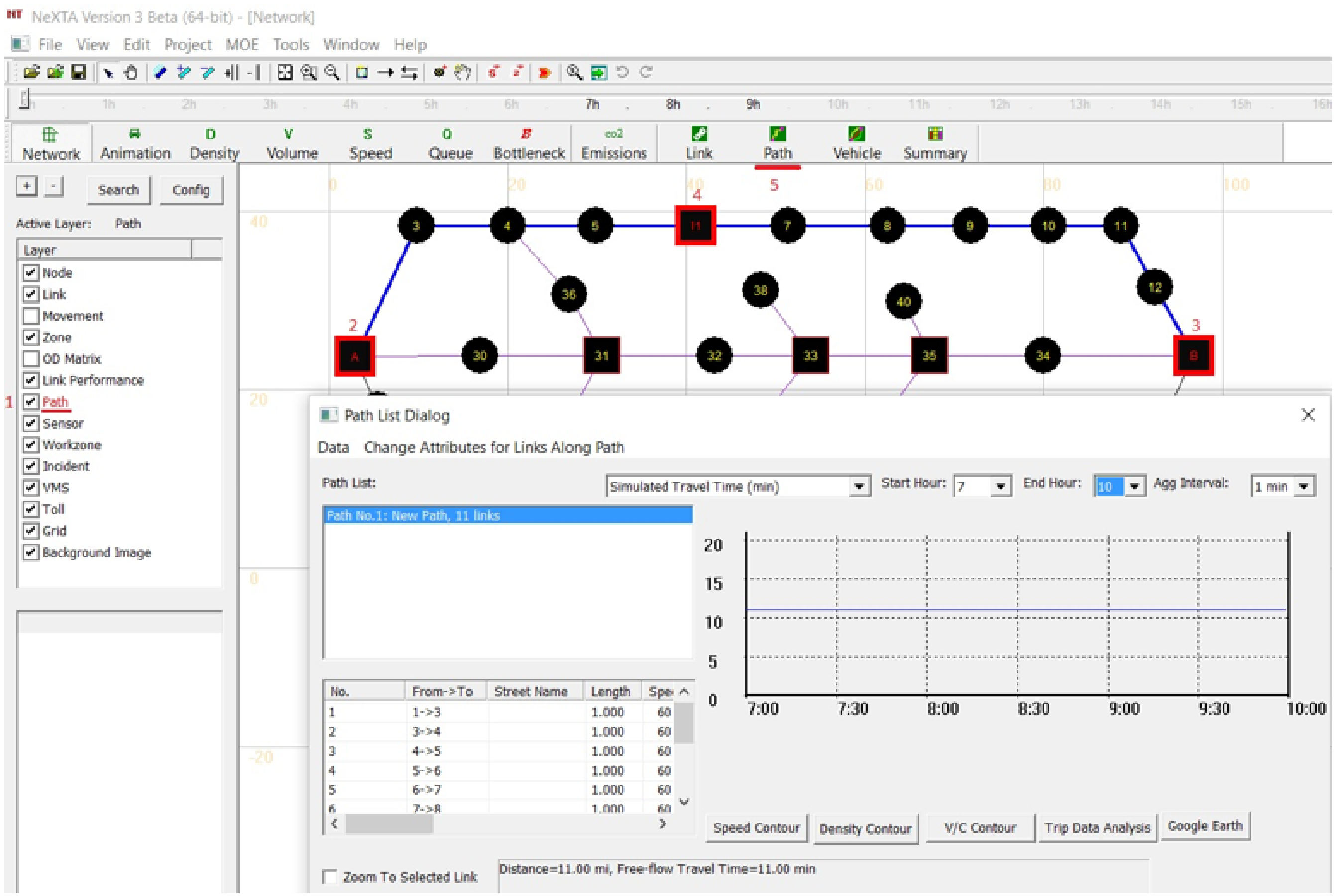


Fig.6. Path list dialog

STEPS

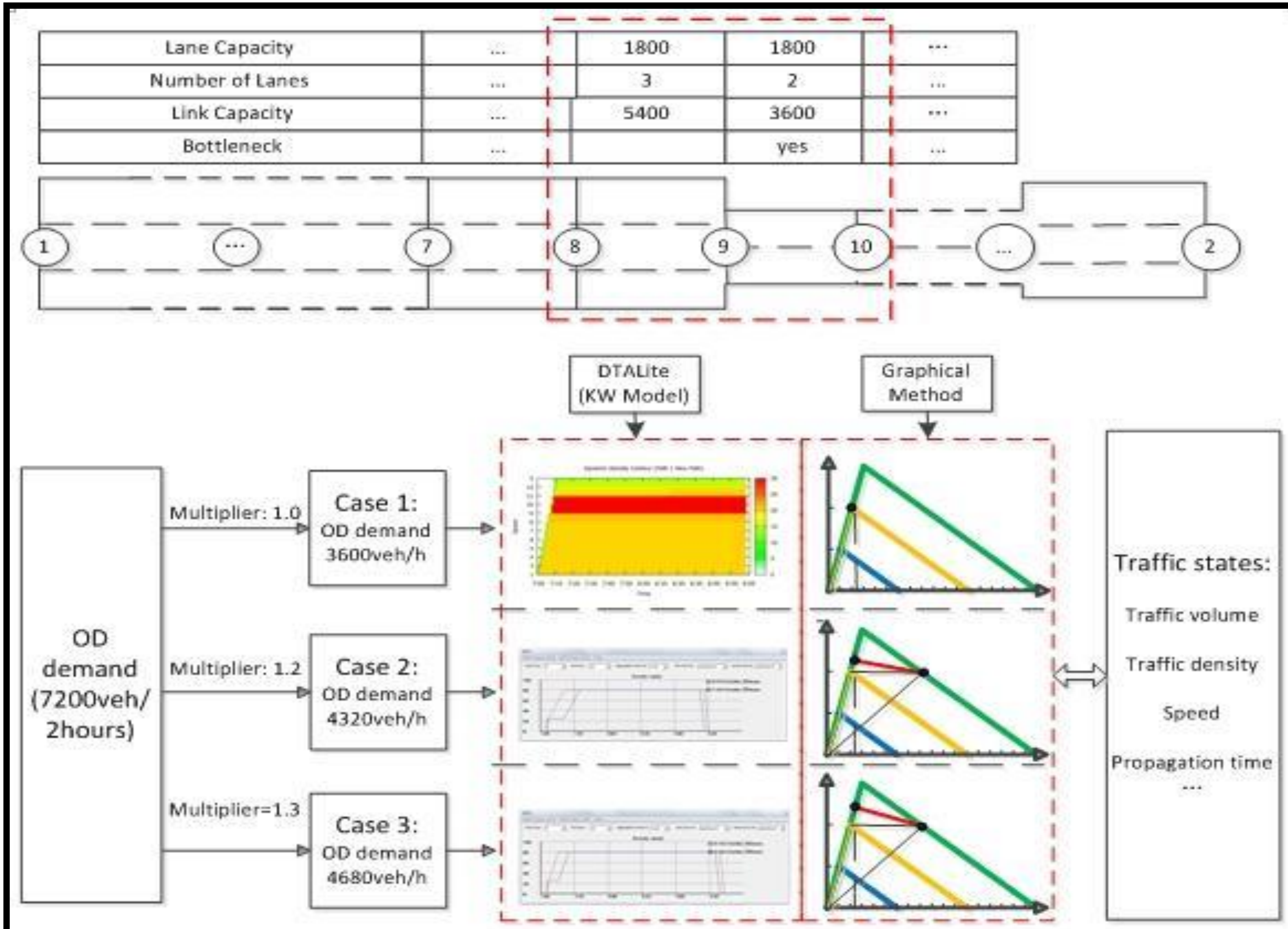
Step 1: Select the "path" layer in the GIS layers panel

Step 2: Click on node 1-> right click menu to choose "Direction from here"

Step 3: Click node 2-> right click menu to choose "Direction to here"

Step 4: Select any node (e.g. node 6) of the path 1-> right click to choose "Add Intermediate Destination here".

Step 5: To view the traffic states of selected path, click on the "Path" button in the MOE bar

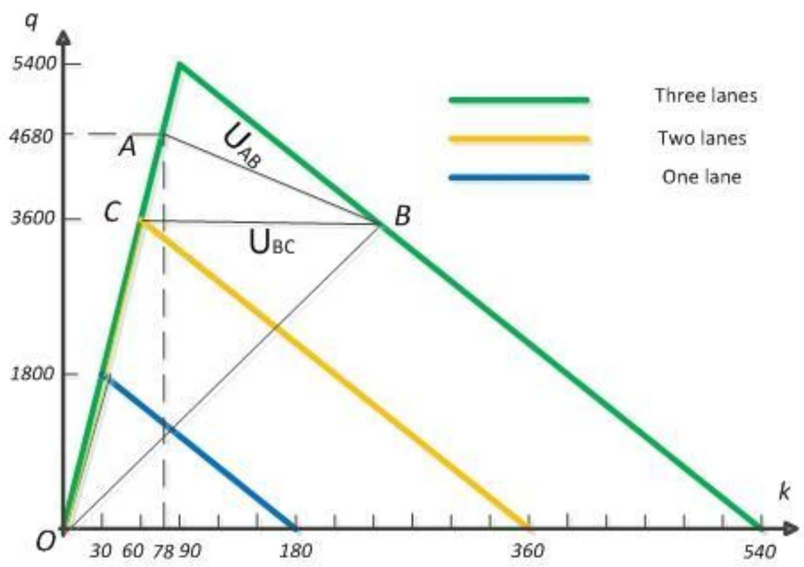


Lane Capacity
...
1800
1800
...
Number of Lanes
...
3
2
...
Link Capacity
...
5400
3600
...
Bottleneck
...
yes
...
1
...
7
8
9
10
...
2
DTALite (KW Model)
Graphical Method
OD demand (7200veh/ 2hours)
Multiplier: 1.0
Multiplier: 1.2
Multiplier=1.3
Case 1: OD demand 3600veh/h
Case 2: OD demand 4320veh/h
Case 3: OD demand 4680veh/h
Traffic states:
Traffic volume
Traffic density
Speed
Propagation time
...

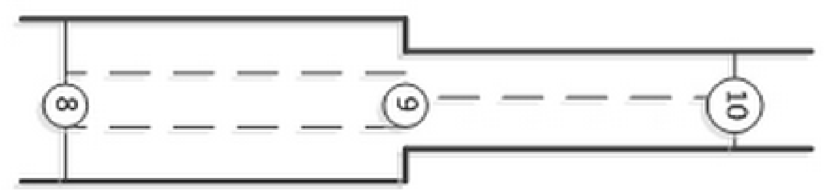
5.1 Traffic Congestion Propagation

Case 1: demand = supply (multiplier = 1.0)

Graphical Method



The flow-density relationship for different states of links



- U: interface between two different traffic states.
- State O: there is no traffic flow
- State A: the demand traffic enter the link 8->9
- State C: the steady traffic state of link 9->10

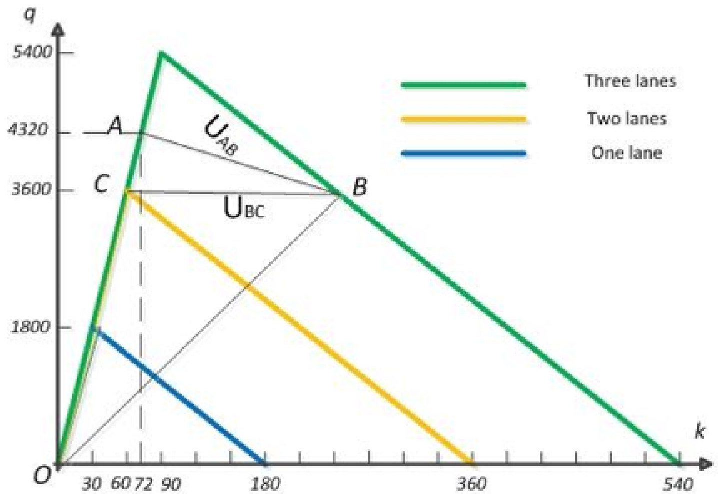
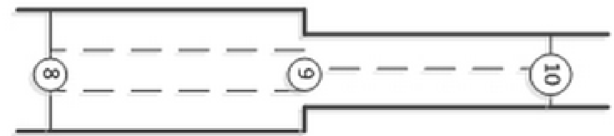


Fig.29. The flow-density relationship for different states of links



U: interface between two different traffic states.

State O: there is no traffic flow

State A: the demand traffic enters the link 8->9

State B: the steady traffic state of link 8->9

State C: the steady traffic state of link 9->10

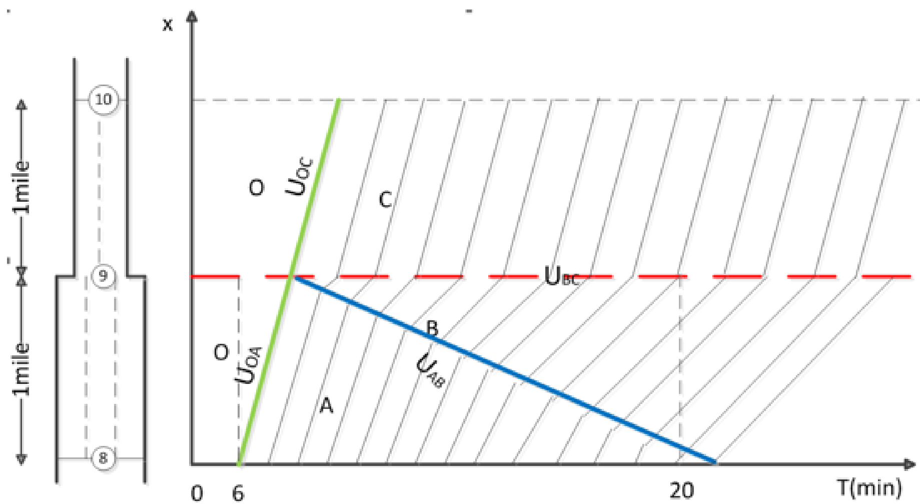


Fig.30. Vehicles' trajectory in time-space diagram

Speed: for link 8->9, at state A, its speed is 60 mph; at state B, due to the limitation of capacity, its speed is 15 mph. For link 9->10, the vehicles will drive at a speed based on the capacity, state C, whose speed is 60 mph;

Density: for link 8->9, at the state A, its density is 72 vpmpl(link). After the propagation time, it is at the state B, whose density is 240 vpmpl(link). Meanwhile, the link 9->10 is always at the state C, whose density is 60 vpmpl(link). In addition, the method of calculating the density of each lane is the same as case 1.

Propagation time: 14 min.

5.1 Traffic Congestion Propagation

Case 1: demand = supply (multiplier = 1.0)

Step 1: Check the value of traffic demand

- When Demand multiplier is 1.0, the hourly OD demand is 0.5*7200*1 = 3600 vehicles.
- The limit capacity of the path 1 is 3600, so now the demand is equal to the path capacity.

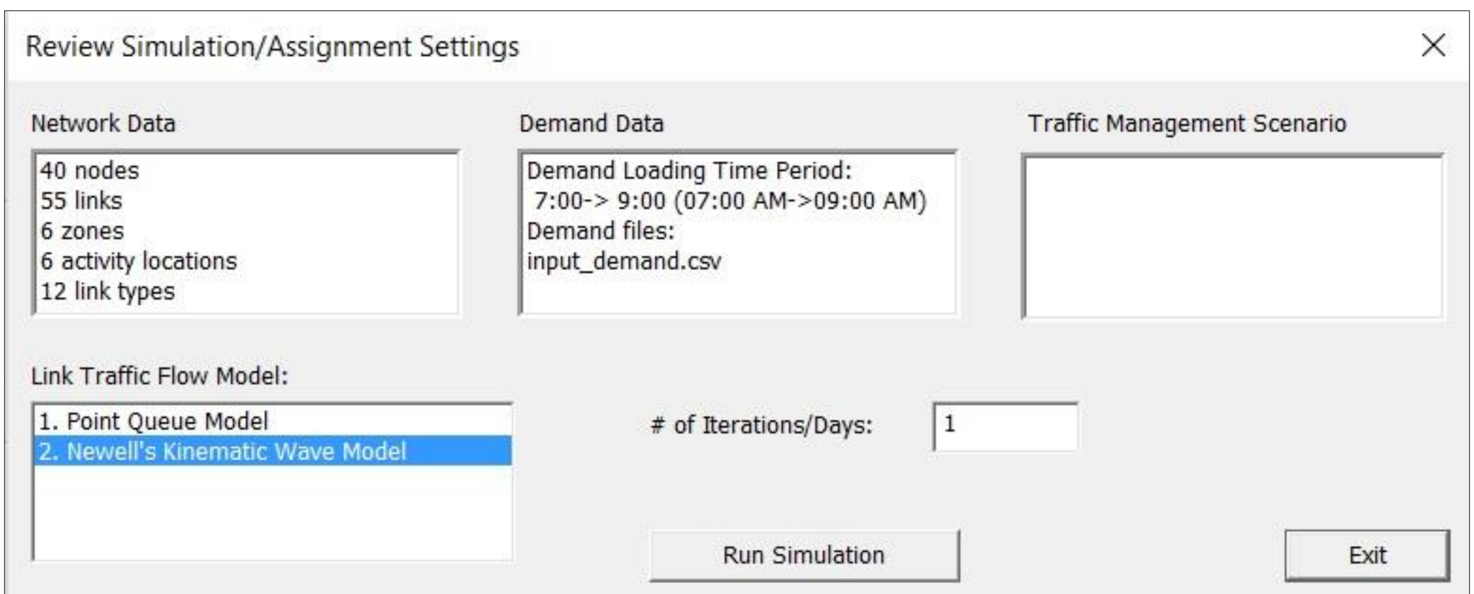
- The traffic demand from origin zone 1 to destination zone 2 is 7200 vehicles in two hours. You can check value of traffic demand from “input_demand.csv” in the project folder.

5.1 Traffic Congestion Propagation

Case 1: demand = supply (multiplier = 1.0)

Step 2: Setup simulation settings

- Please use the following simulation settings shown in the flowing figure, and run simulation
- Link Traffic Flow Model: “Newell’s Kinematic Wave Model”
- # of Iterations/Days: 1



5.1 Traffic Congestion Propagation

Case 1: demand = supply (multiplier = 1.0)

Step 3: View the result of simulation and analyze traffic states

- View the simulation result: "Total Volume over Capacity Ratio" in the file output_summary.csv

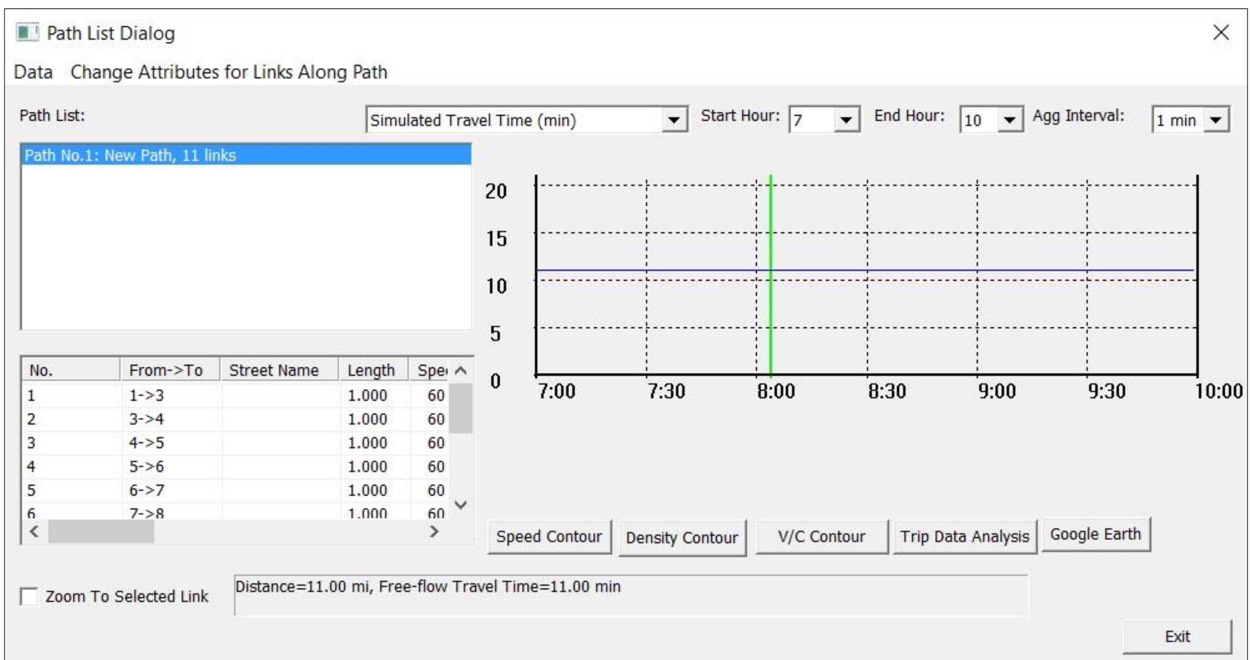
from_node_id	to_node_id	type_code	link_type	link_length	start_time_in_min	end_time_in_min	total_link_volume	lane_capacity_in_vhc_per_hour	link_capacity_in_vhc_per_hour	volume_over_capacity_ratio
1	3	f	Freeway	1	420	540	7200	1900	5700	**0.6316**
3	4	f	Freeway	1	420	540	7200	1800	5400	**0.6667**
4	5	f	Freeway	1	420	540	7200	1800	5400	**0.6667**
5	6	f	Freeway	1	420	540	7200	1800	5400	**0.6667**
6	7	f	Freeway	1	420	540	7200	1800	5400	**0.6667**
7	8	f	Freeway	1	420	540	7200	1800	5400	**0.6667**
8	9	f	Freeway	1	420	540	7200	1800	5400	**0.6667**
10	11	f	Freeway	1	420	540	7200	1800	3600	**1**
11	12	f	Freeway	1	420	540	7200	1800	5400	**0.6667**
9	10	f	Freeway	1	420	540	7200	1800	3600	**1**
12	2	f	Freeway	1	420	540	7200	1800	7200	**0.5**

5.1 Traffic Congestion Propagation

Case 1: demand = supply (multiplier = 1.0)

Step 3: View the traffic states of one path

- Choose a path in the network
- Click on the “Density Contour”, “Speed Contour”, and “V/C Contour” to analyze the details of this traffic assignment.

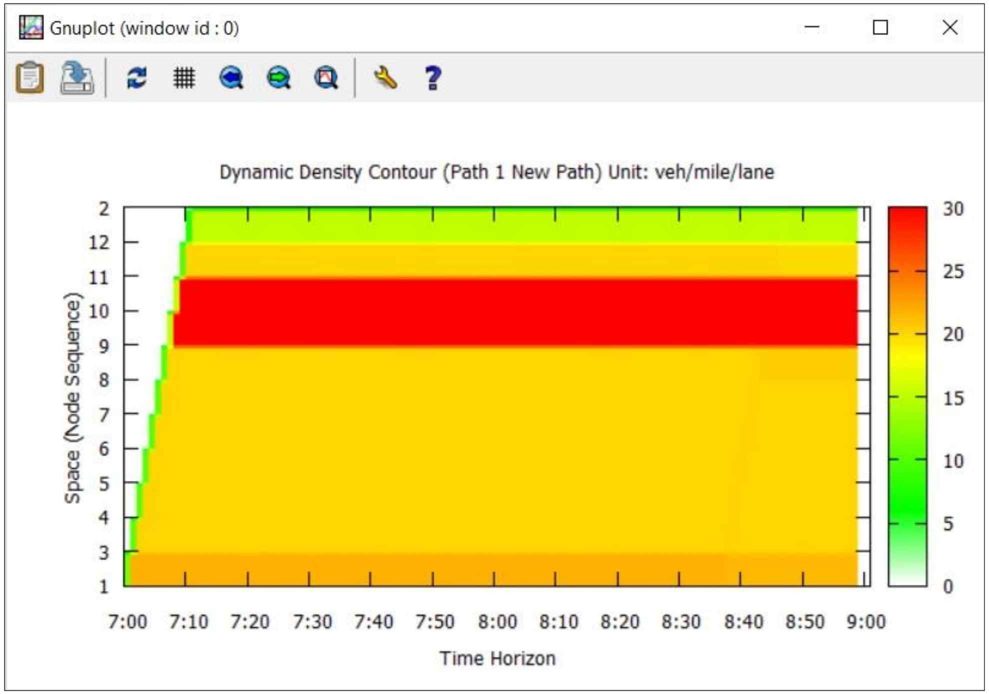


5.1 Traffic Congestion Propagation

Case 1: demand = supply (multiplier = 1.0)

Step 3: View the traffic states of one path

- Similarly, other analyses can also be displayed easily.
- link 9->10 and link 10->11 has a high density, which is consistent with the above “Total Volume over Capacity Ratio”.

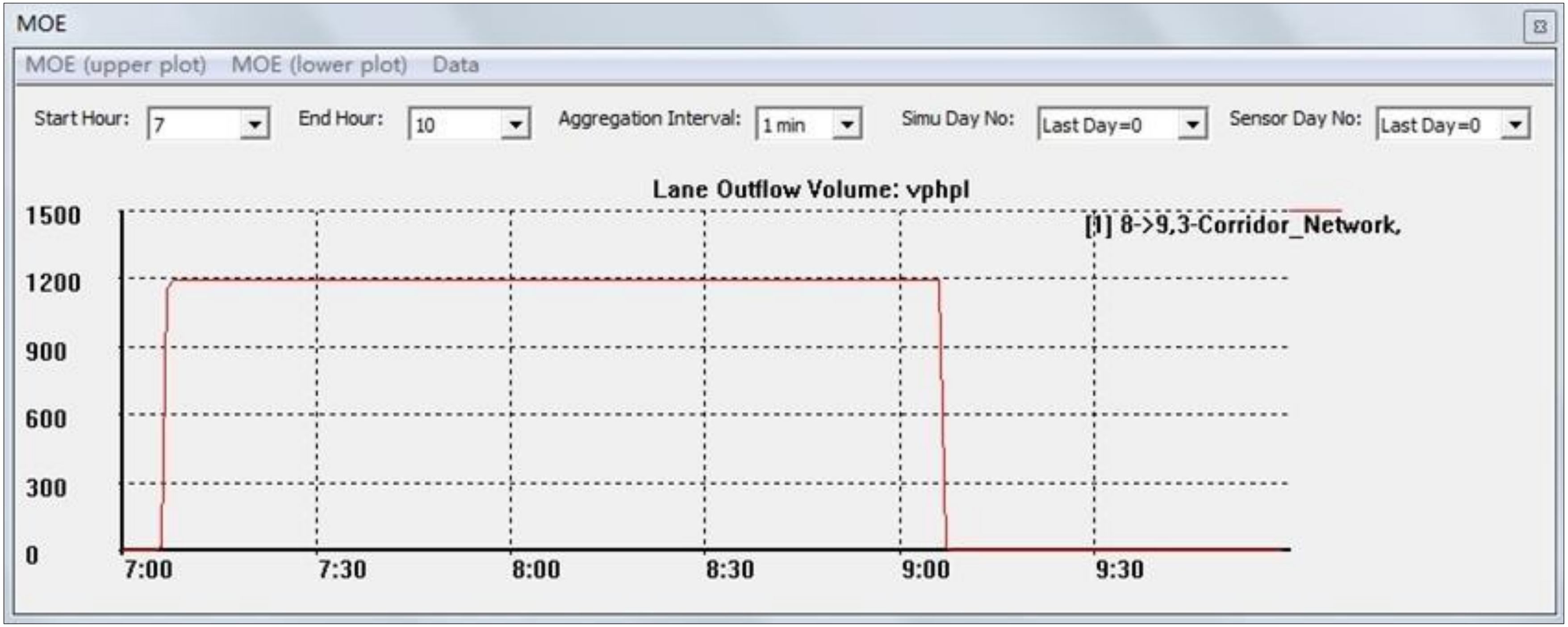


5.1 Traffic Congestion Propagation

Case 1: demand = supply (multiplier = 1.0)

Step 4: View link MOE of bottleneck links

- Simulated lane volume of link 8->9

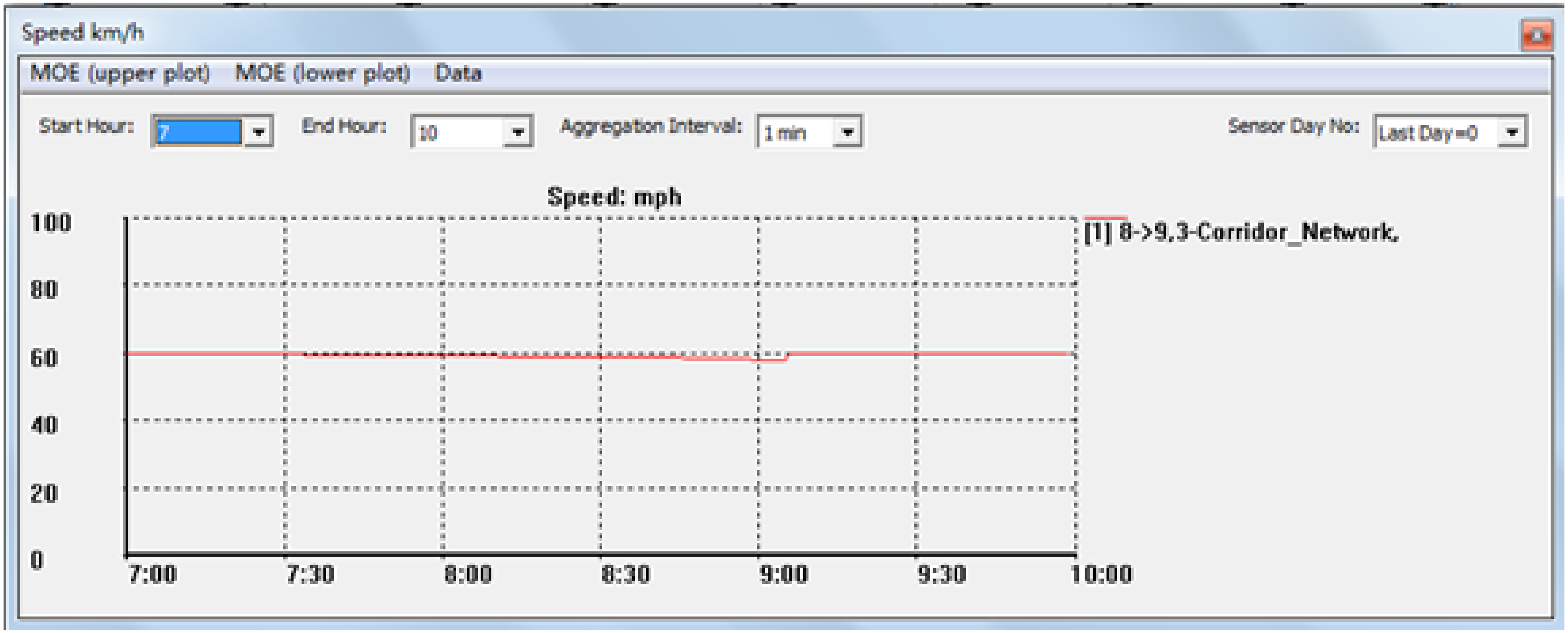


5.1 Traffic Congestion Propagation

Case 1: demand = supply (multiplier = 1.0)

Step 4: View link MOE of bottleneck links

- Simulated speed of link 8->9

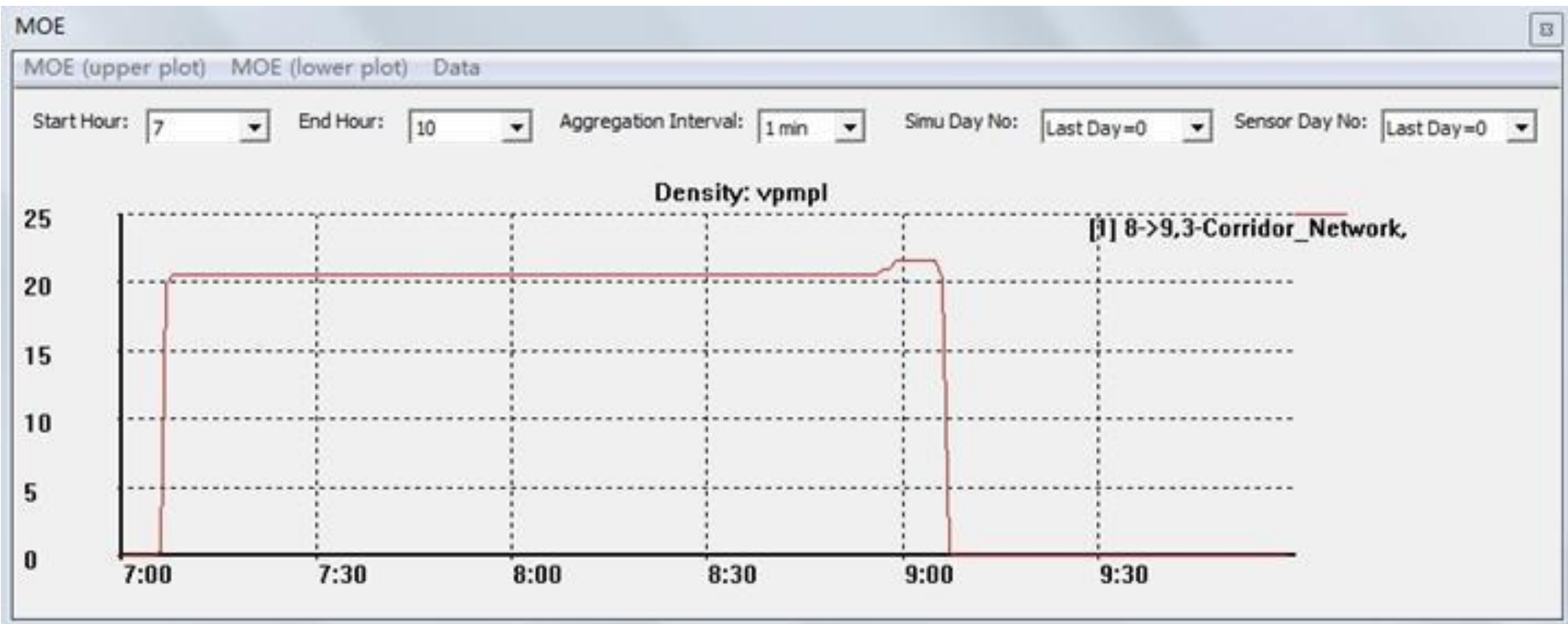


5.1 Traffic Congestion Propagation

Case 1: demand = supply (multiplier = 1.0)

Step 4: View link MOE of bottleneck links

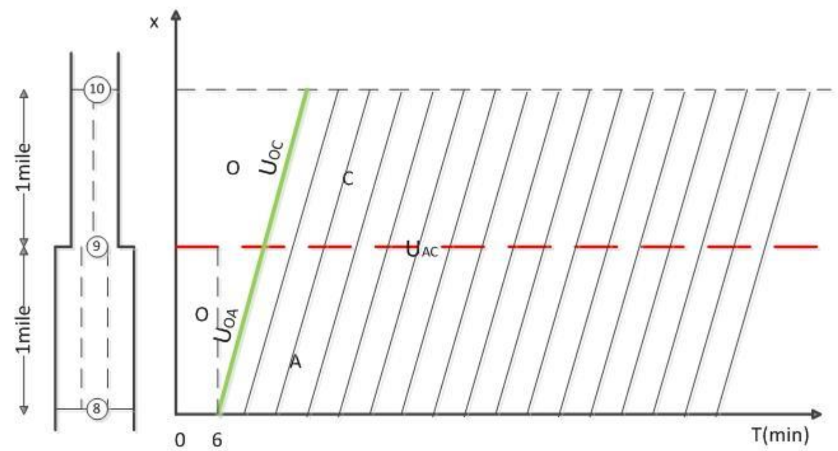
- Simulated density of link 8->9



5.1 Traffic Congestion Propagation

Case 1: demand = supply (multiplier = 1.0)

Graphical Method



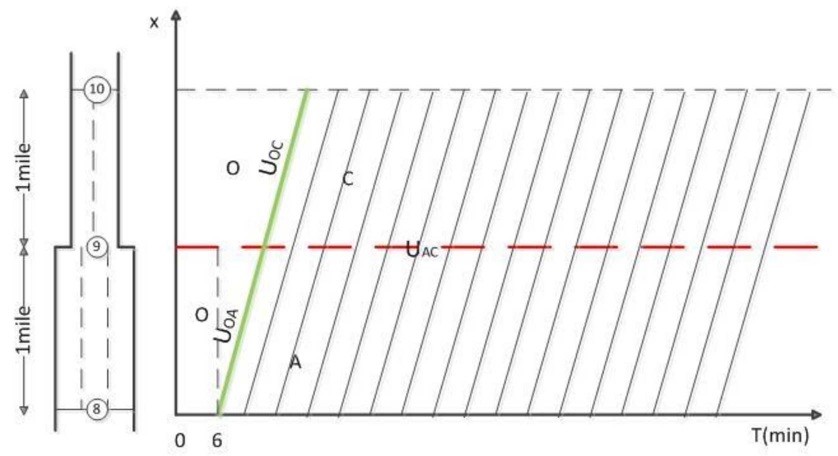
Vehicles' trajectory in time-space diagram

- Speed
- The speed of link 8->9 and link 9->10 is the free flow speed, 60 mph, because the demand is equal to the capacity for the two links.

5.1 Traffic Congestion Propagation

Case 1: demand = supply (multiplier = 1.0)

Graphical Method



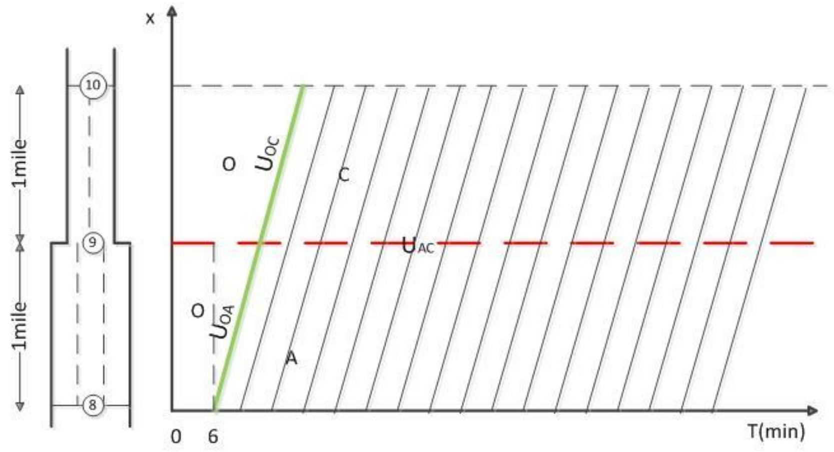
Vehicles' trajectory in time-space diagram

- Density
- Link 8->9 is always at the state A and link 9->10 is at the state C, so its density is 60 vpmpl(link) for the both links.
- Meanwhile, about the density of each lane, link 8->9 is 20 vpmpl(lane) and link 9->10 is 30 vpmpl(lane).

5.1 Traffic Congestion Propagation

Case 1: demand = supply (multiplier = 1.0)

Graphical Method



Vehicles' trajectory in time-space diagram

- Propagation time: N/A

5.1 Traffic Congestion Propagation

Case 2: demand > supply (multiplier = 1.2)

Step 1: Check the value of traffic demand

- When the demand multiplier is 1.2, the hourly OD demand is 0.5*7200*1.2 (4320).
- The limit capacity of the path 1 is 3600, so now the demand is slightly higher than the path capacity.
- As a result, a traffic congestion is formed and further propagated to the upstream corridor.

5.1 Traffic Congestion Propagation

Case 2: demand > supply (multiplier = 1.2)

Step 2: Setup simulation settings

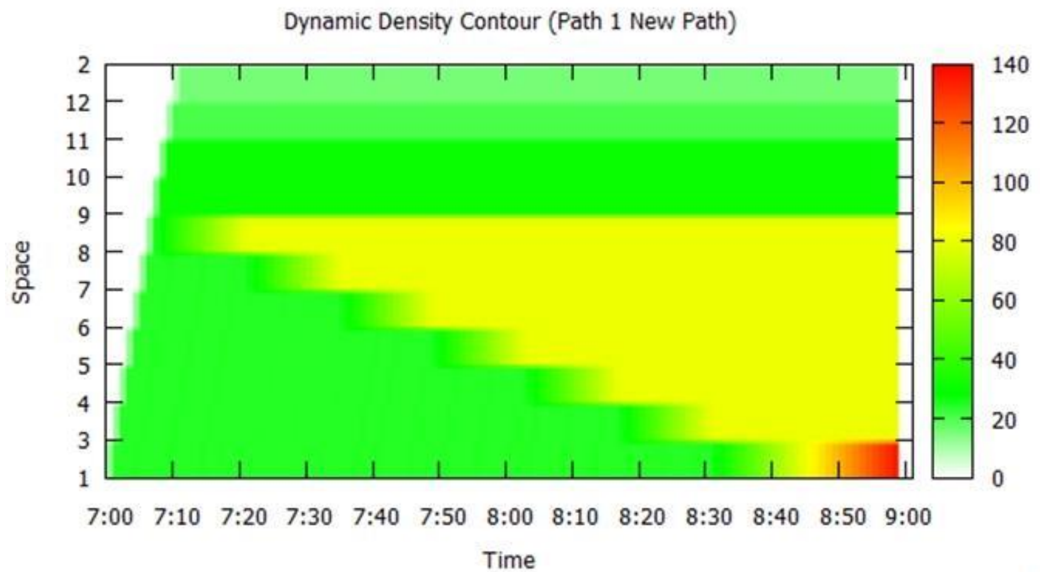
- Go to input_demad_file_list.csv
- Change the loading multiplier to 1.2 in the excel sheet
- Run the simulation for 1 iteration.

5.1 Traffic Congestion Propagation

Case 2: demand > supply (multiplier = 1.2)

Step 3: View link MOE of path 1

- traffic congestion starts from link 8->9, and then propagates back to upstream links
- Then the traffic jam reaches the starting link 1->3 (without further space to accommodate the congestion), leading to continuously increasing density

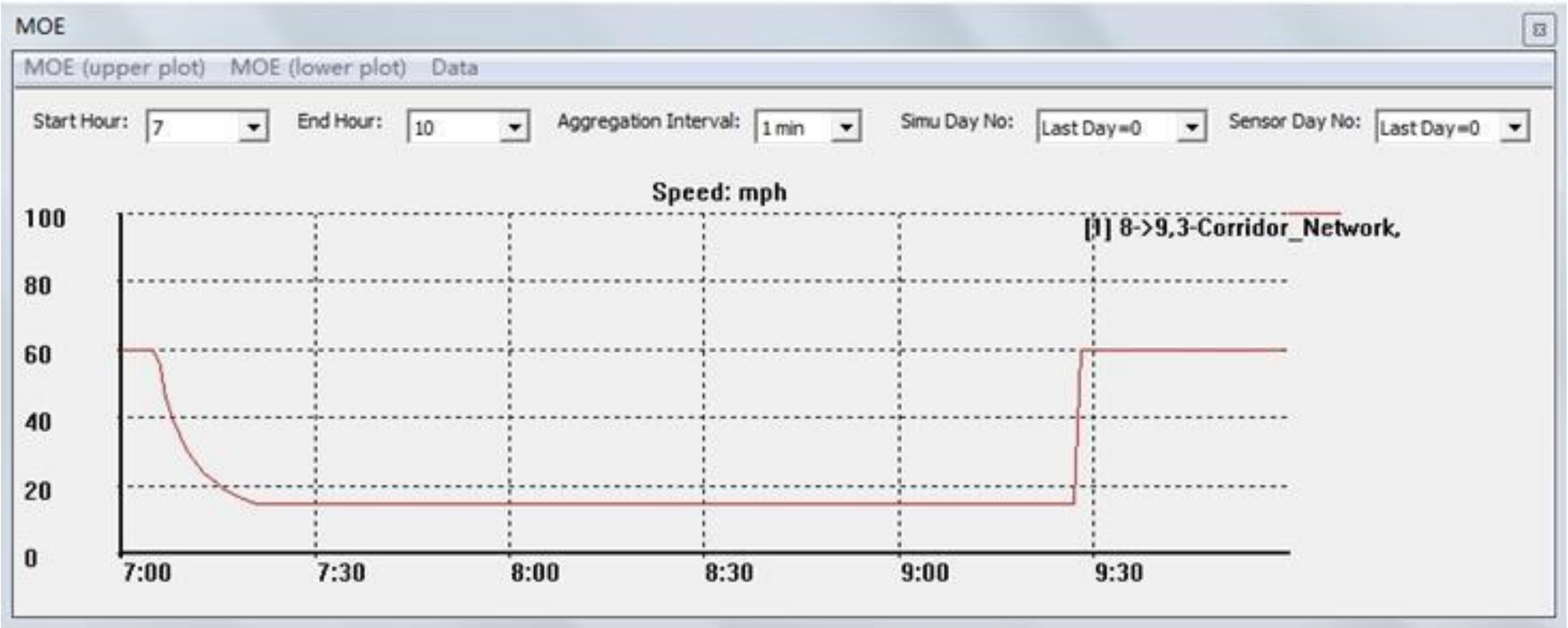


5.1 Traffic Congestion Propagation

Case 2: demand > supply (multiplier = 1.2)

Step 4: View link MOE of bottleneck links

- Simulated speed of link 8->9

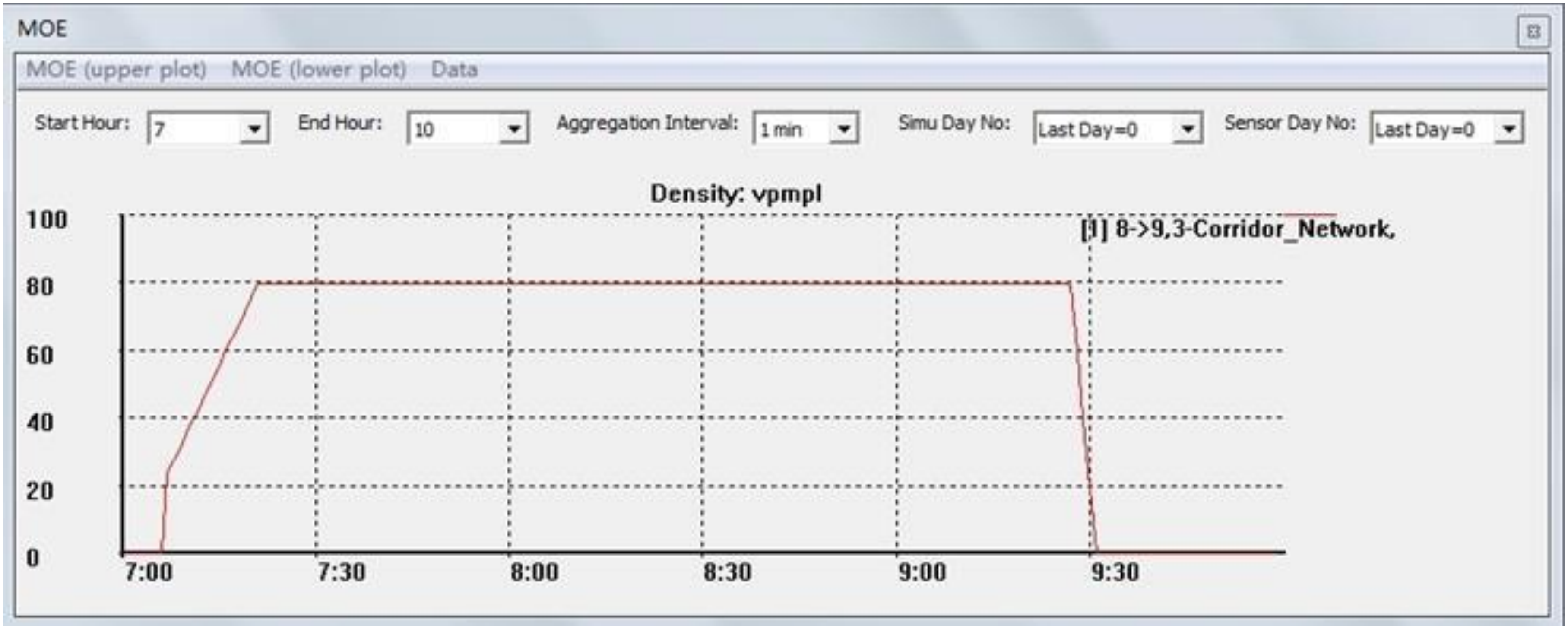


5.1 Traffic Congestion Propagation

Case 2: demand > supply (multiplier = 1.2)

Step 4: View link MOE of bottleneck links

- Simulated density of link 8->9



5.1 Traffic Congestion Propagation

Case 2: demand > supply (multiplier = 1.2)

Step 5: Describe traffic speed and density evolutions on links 7->8 and 8->9, Calculate the traffic congestion speed

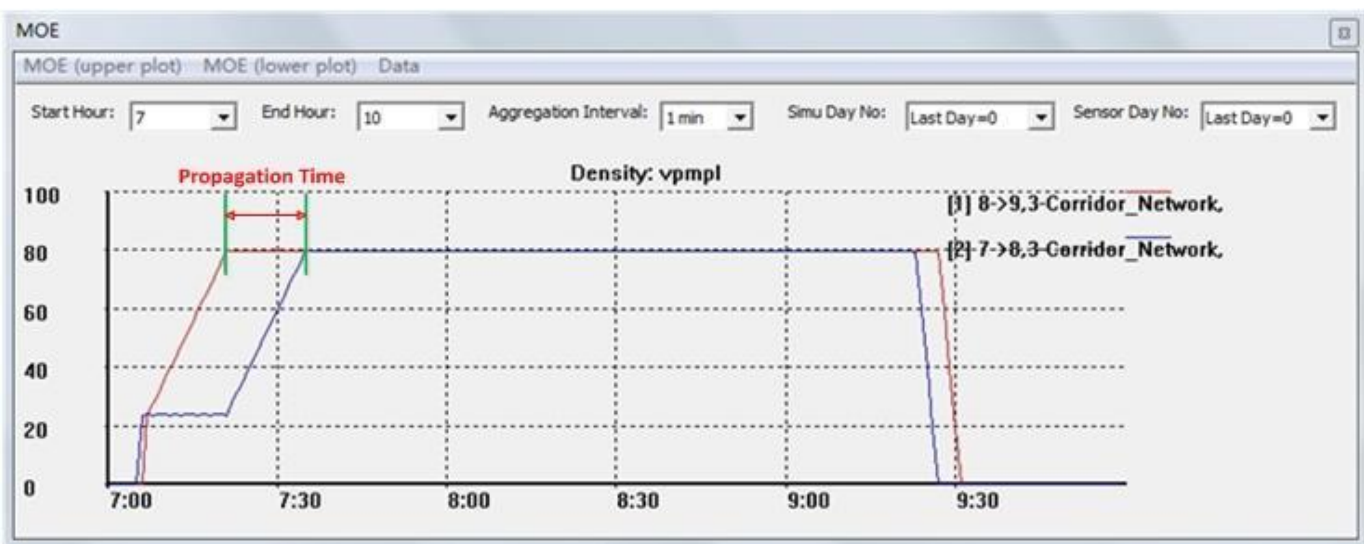
- The speed of link 8->9 changes from 60 mph to 15 mph in the first 20 min, and its density increases from 24 vpmpl to 80 vpmpl.
- To calculate traffic congestion propagation speed, we need to measure the propagation time and link length (1 mile)

5.1 Traffic Congestion Propagation

Case 2: demand > supply (multiplier = 1.2)

Step 5: Describe traffic speed and density evolutions on links 7->8 and 8->9, Calculate the traffic congestion speed

- Select two links simultaneously, link 8->9 and link 7->8.
- Using key combination “ctrl +mouse click”, we can obtain the link MOE plot and then measure the queue propagation time.



5.1 Traffic Congestion Propagation

Case 2: demand > supply (multiplier = 1.2)

Step 5: Describe traffic speed and density evolutions on links 7->8 and 8->9, Calculate the traffic congestion speed

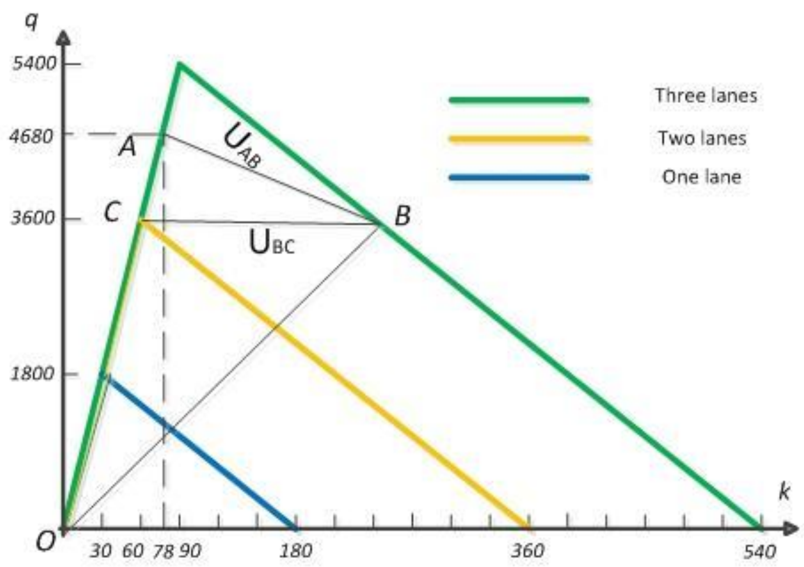
- One can also precisely measure the exact propagation time duration using exported link MOE csv file.

- When the density (link 8->9) becomes 80, the corresponding time is 441min.
- When the density (link 7->8) becomes 80, the corresponding time is 455 min.
- Thus, the propagation time duration is 14 min.

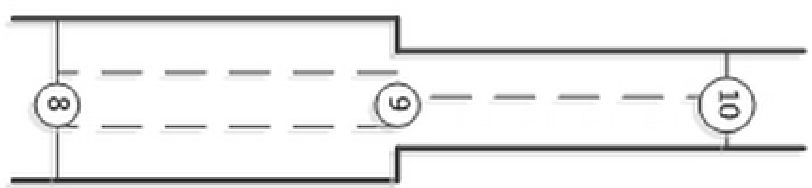
5.1 Traffic Congestion Propagation

Case 2: demand > supply (multiplier = 1.2)

Graphical Method



The flow-density relationship for different states of links

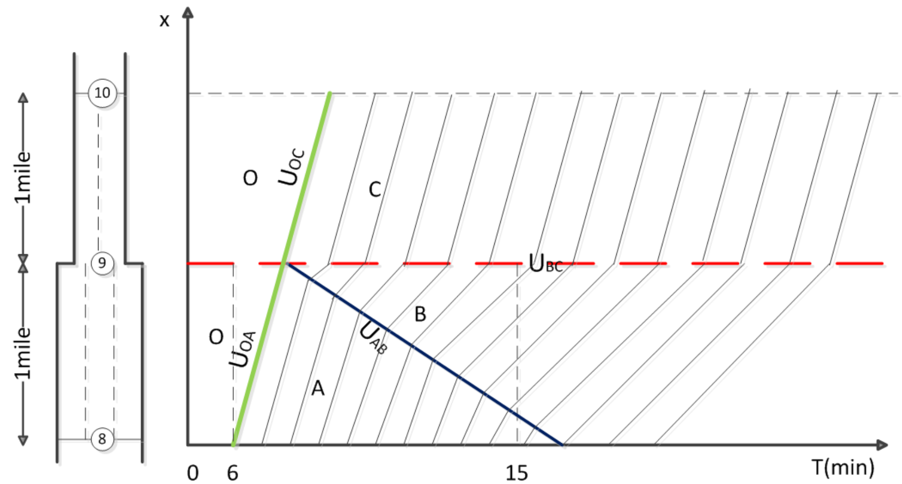


- U: interface between two different traffic states.
- State O: there is no traffic flow
- State A: the demand traffic enter the link 8->9
- State B: the steady traffic state of link 8->9
- State C: the steady traffic state of link 9->10

5.1 Traffic Congestion Propagation

Case 2: demand > supply (multiplier = 1.2)

Graphical Method



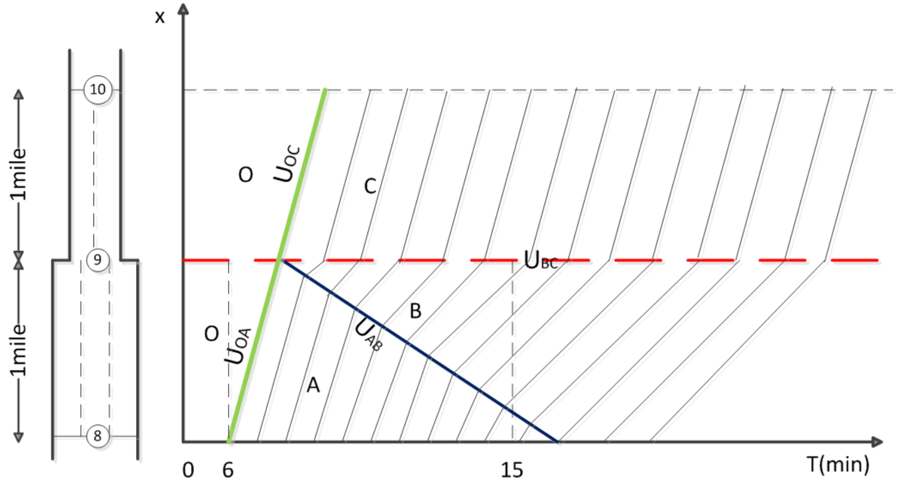
Vehicles' trajectory in time-space diagram

- Speed
- for link 8->9, at state A, its speed is 60 mph; at state B, due to the limitation of capacity, its speed is 15 mph.
- For link 9->10, the vehicles will drive at a speed based on the capacity, state C, whose speed is 60 mph;

5.1 Traffic Congestion Propagation

Case 2: demand > supply (multiplier = 1.2)

Graphical Method



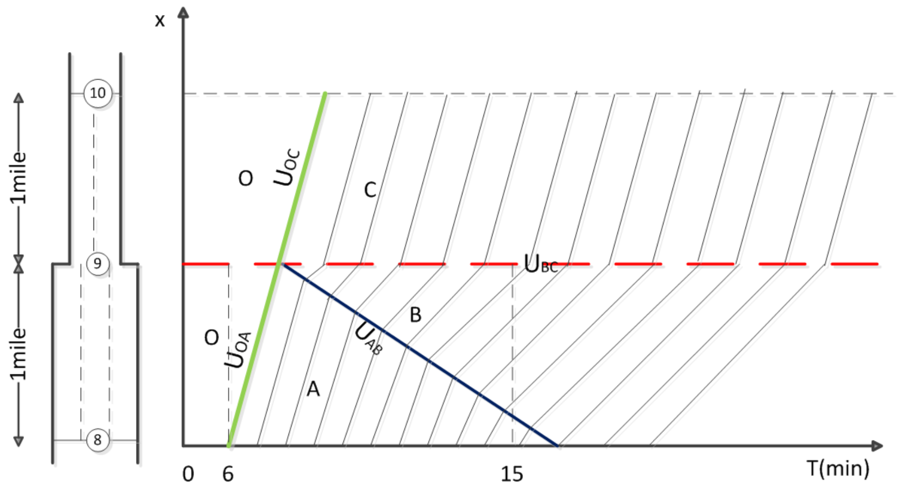
Vehicles' trajectory in time-space diagram

- Density
- for link 8->9, at the state A, its density is 72 vpmpl(link). After the propagation time, it is at the state B, whose density is 240 vpmpl(link).
- Meanwhile, the link 9->10 is always at the state C, whose density is 60 vpmpl(link).

5.1 Traffic Congestion Propagation

Case 2: demand > supply (multiplier = 1.2)

Graphical Method



Vehicles' trajectory in time-space diagram

- Propagation time: 14 min.

5.1 Traffic Congestion Propagation

Case 3: demand > supply (multiplier = 1.3)

Step 1: Check the value of traffic demand

- In this case, the demand OD is still 7200 from 7am to 9am,
- the multiplier is 1.3. so now the demand is much higher than the path capacity.
- The analysis process is the same as case 2 (0.5*7200*1.3 = 4680 vehicles).

5.1 Traffic Congestion Propagation

Case 3: demand > supply (multiplier = 1.3)

Step 2: Setup simulation settings

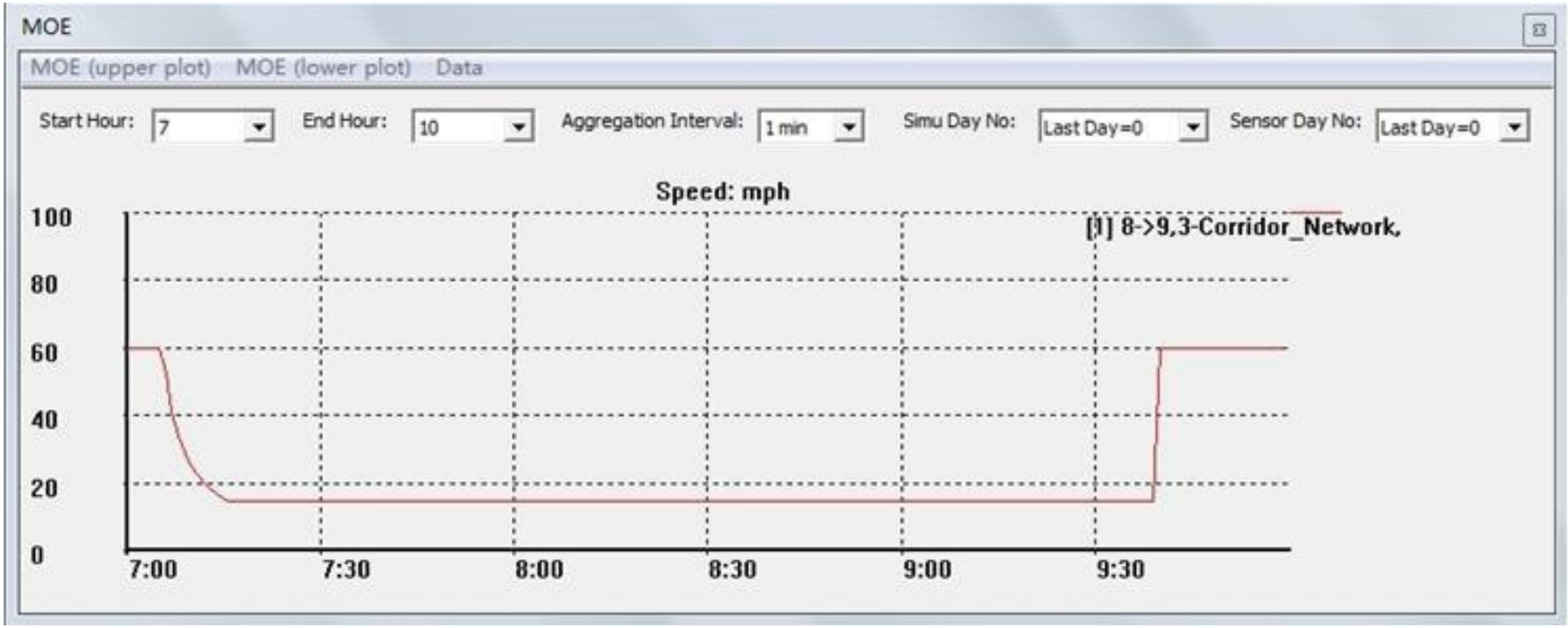
- Go to input_demad_file_list.csv
- Change the loading multiplier to 1.3 in the excel sheet
- Run the simulation for 1 iteration.

5.1 Traffic Congestion Propagation

Case 3: demand > supply (multiplier = 1.3)

Step 3: View link MOE of bottleneck links

- Simulated speed of link 8->9

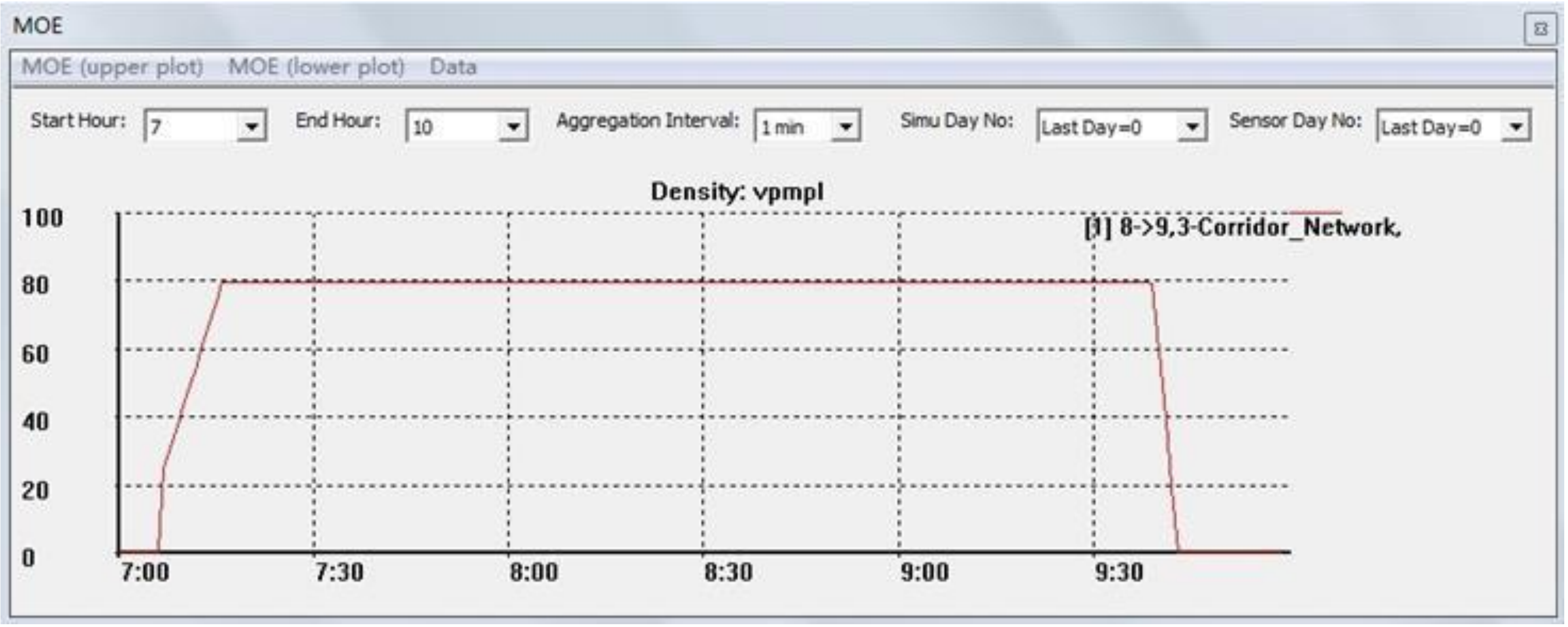


5.1 Traffic Congestion Propagation

Case 3: demand > supply (multiplier = 1.3)

Step 3: View link MOE of bottleneck links

- Simulated density of link 8->9

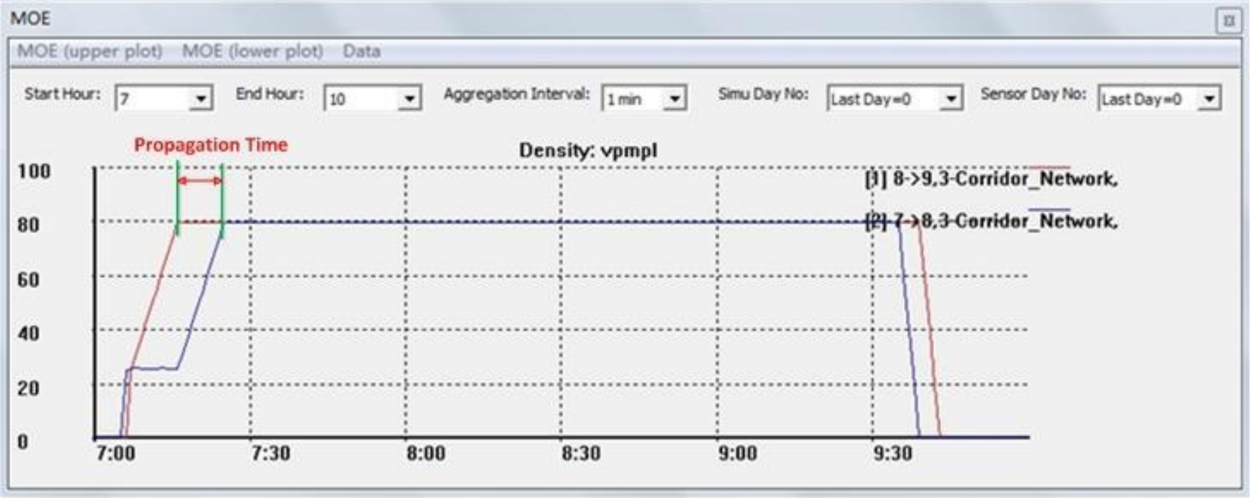


5.1 Traffic Congestion Propagation

Case 3: demand > supply (multiplier = 1.3)

Step 4: Describe traffic speed and density evolutions on links 7->8 and 8->9, Calculate the traffic congestion speed

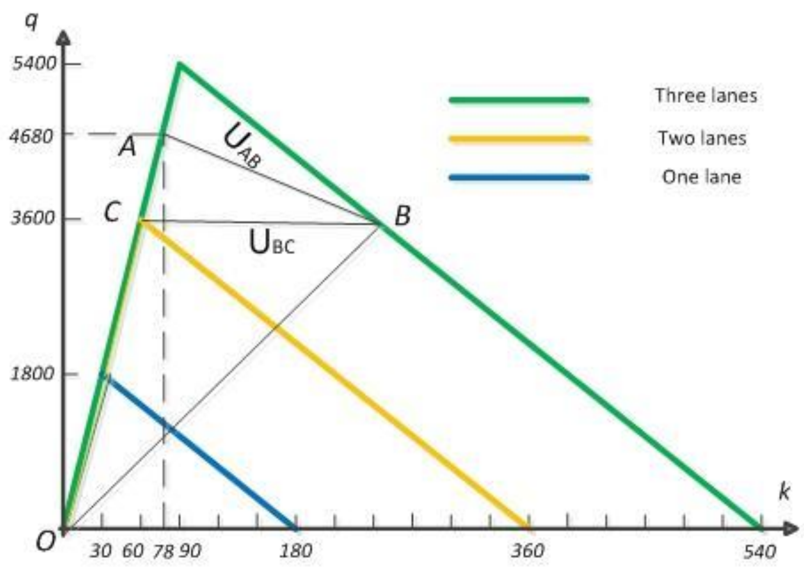
- The speed of link 8->9 changes from 60 mph to 15 mph, and its density of one lane increases from 26 vpmpl to 80 vpmpl.
- A traffic congestion propagation time of 9 min can be observed in the following figure.



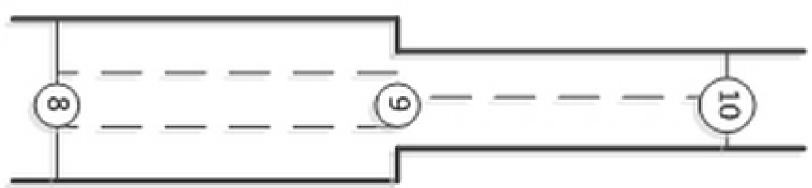
5.1 Traffic Congestion Propagation

Case 3: demand > supply (multiplier = 1.3)

Graphical Method



The flow-density relationship for different states of links

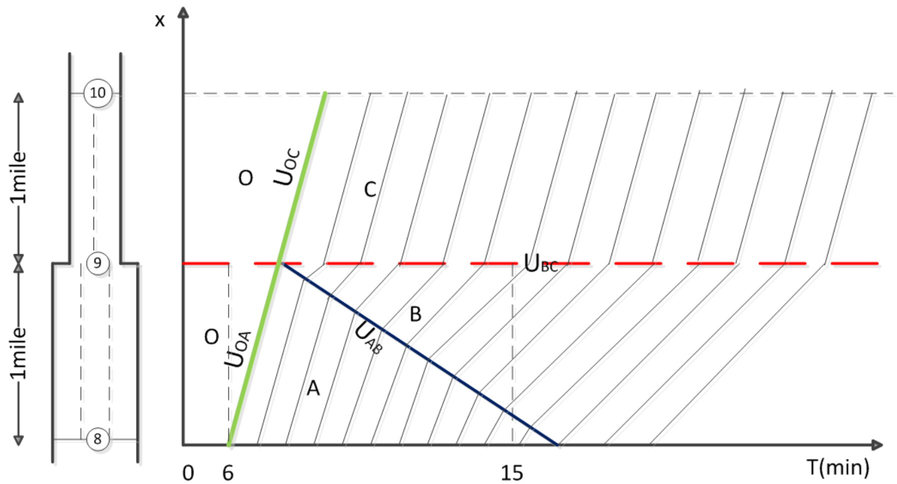


- U: interface between two different traffic states.
- State O: there is no traffic flow
- State A: the demand traffic enter the link 8->9
- State B: the steady traffic state of link 8->9
- State C: the steady traffic state of link 9->10

5.1 Traffic Congestion Propagation

Case 3: demand > supply (multiplier = 1.3)

Graphical Method



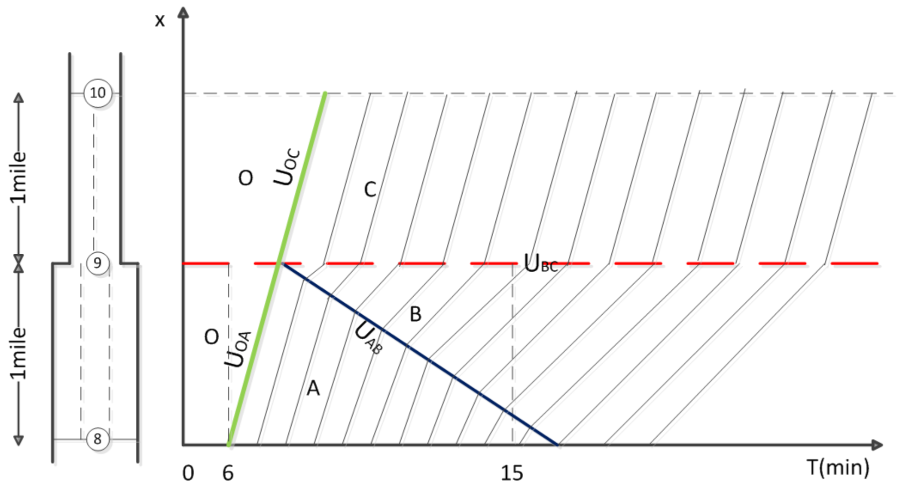
Vehicles' trajectory in time-space diagram

- Speed
- For link 8->9, at state A, its speed is 60 mph; at state B, due to the limitation of capacity, its speed is 15 mph.
- For link 9->10, the vehicles will drive in a speed based on the capacity, state C, whose speed is 60 mph;

5.1 Traffic Congestion Propagation

Case 3: demand > supply (multiplier = 1.3)

Graphical Method



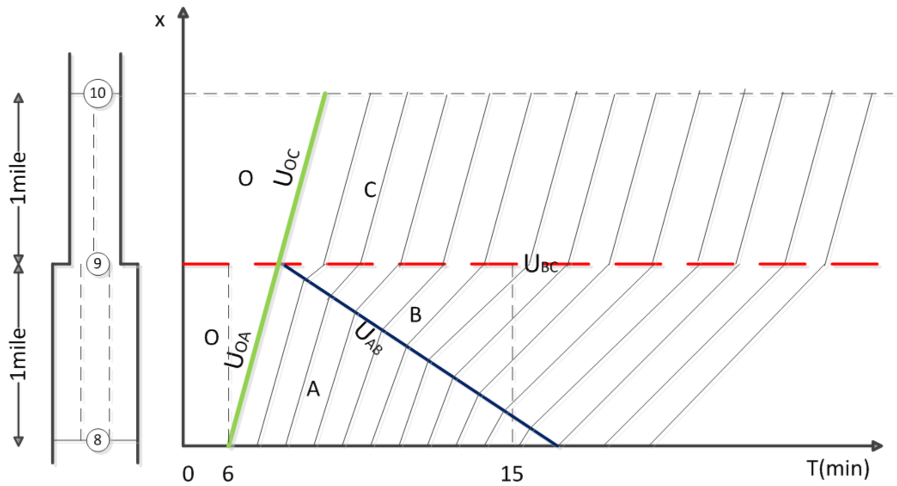
Vehicles' trajectory in time-space diagram

- Density
- For link 8->9, at state A, its density is 78 vpmpl(link). After the propagation time, at state B, its density is 240 vpmpl.
- Meanwhile, the link 9->10 is always at the state C, whose density is 60 vpmpl(link). In addition, the method of calculating the density of each lane is the same as case 1.

5.1 Traffic Congestion Propagation

Case 3: demand > supply (multiplier = 1.3)

Graphical Method

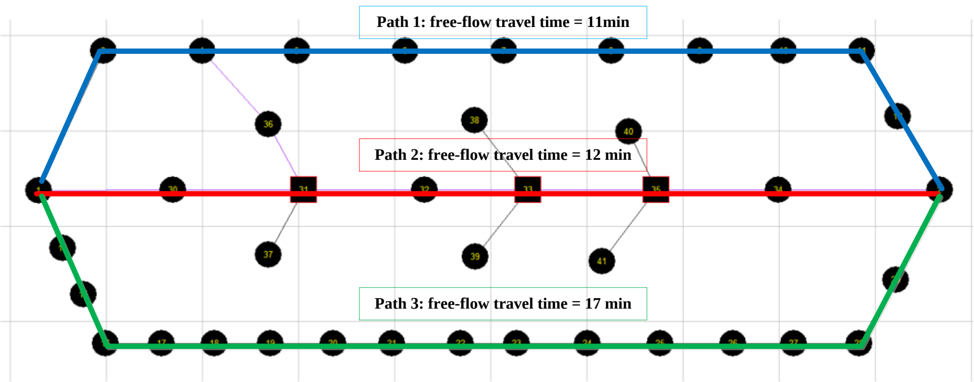


Vehicles' trajectory in time-space diagram

- Propagation time: 9 min.

5.2 Traffic States as a result of demand-supply interactions

- **Base case without toll settings**



- Input_demand_type
- Scenario_Link_Based_Toll.csv

Table. 5. Average VOT of demand type SOV in the file input_demand_type.csv

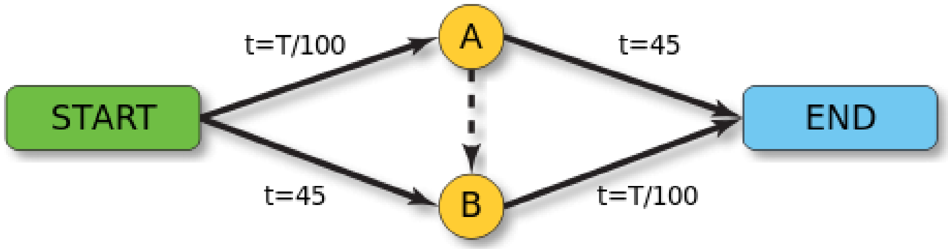
demand_type	demand_type_name	avg_VOT
1	SOV	**10**

The specific toll settings are input in Scenario_Link_Based_Toll.csv.

Link	Scenario No	Start Day	End Day	Start Time in Min	End Time in min	Toll for Demand Type 1
[4,5]	0	0	100	420	540	0.2

One toll value of \$0.2 is collected on link (4, 5). The generalized link travel time can be formulated as $GC_{i,j} = t_{i,j} + \frac{toll_{i,j}}{VOT}$, so the link with toll values will have the generalized travel time value of $(11 + \frac{0.2}{10/60})$ min, which means that path 1 will have 1.2 min more generalized travel time.

5.2 Equilibrium Model: Braess' Paradox



Learning Objectives

- Understand modeling principles of user equilibrium
- Know how to setup BPR function parameters for special link types
- Understand the impact of adding a link and analyze the performance at link, path and network levels
- The impact of different levels of demand on Braess' paradox
- Understand the impact of road pricing on Braess paradox and how to resolve Braess' Paradox

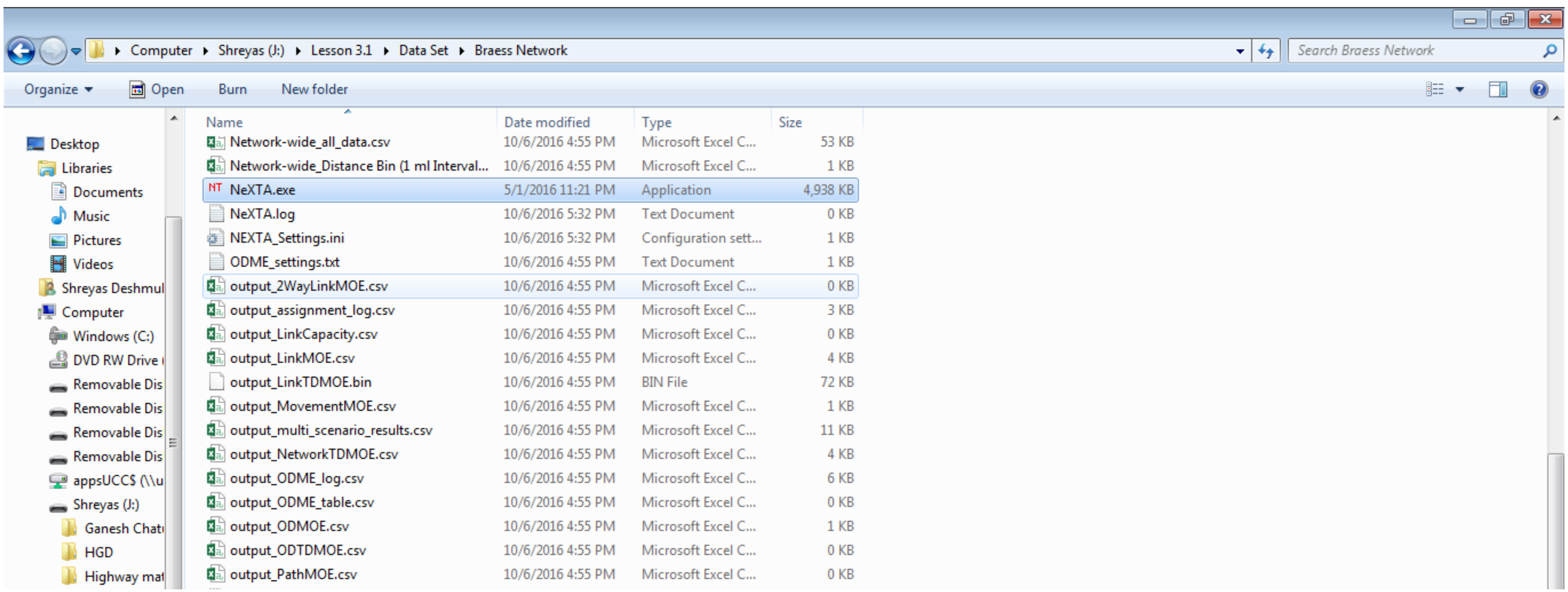
Source of Braess' Paradox:

http://en.wikipedia.org/wiki/Braess%27s_paradox

5.2 Equilibrium Model: Braess' Paradox

Task 1: Build a network for static traffic assignment, and configure BPR parameters

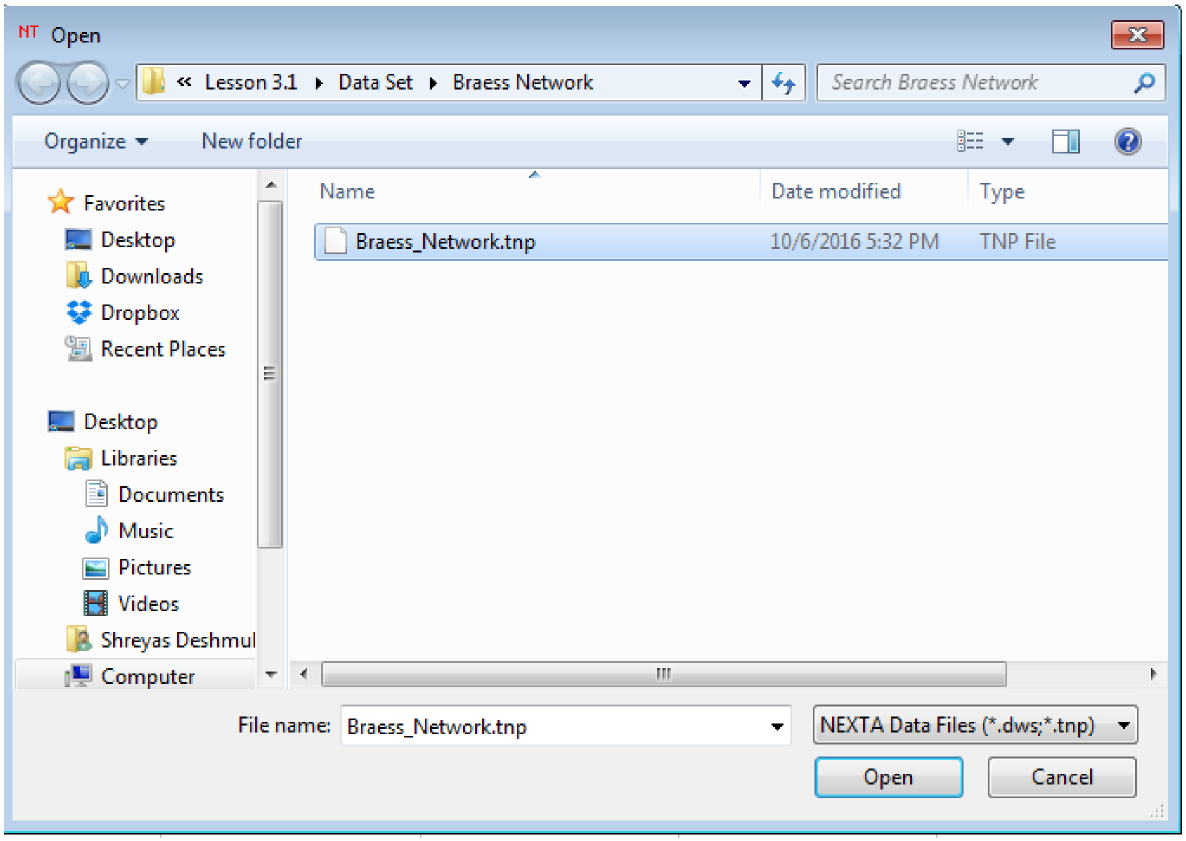
Step 1: Locate a file called "NeXTA.exe " from the Braess Network Data Set and open the application.



5.2 Equilibrium Model: Braess' Paradox

Task 1: Build a network for static traffic assignment, and configure BPR parameters

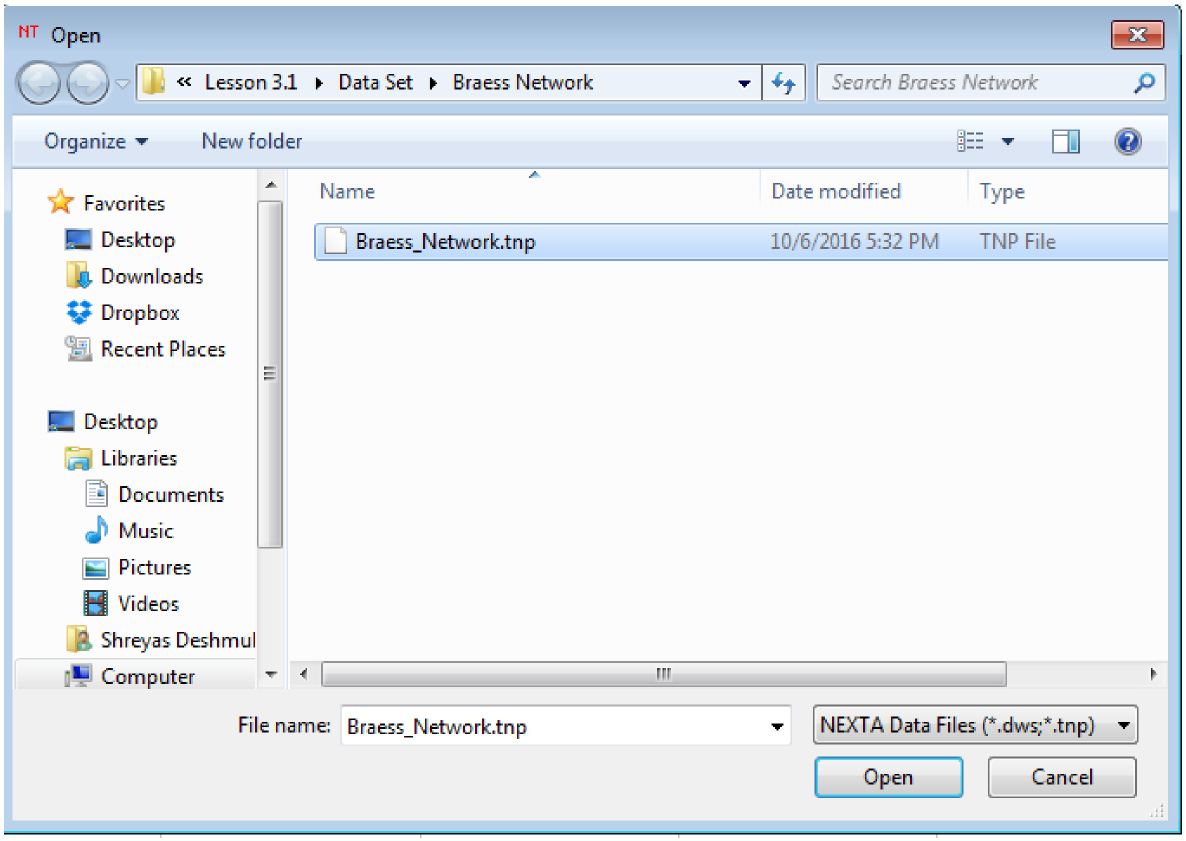
Step 2: in NeXTA, open the Braess_Network.tnp from the Braess Network Data Set.



5.2 Equilibrium Model: Braess' Paradox

Task 1: Build a network for static traffic assignment, and configure BPR parameters

Step 2: in NeXTA, open the Braess_Network.tnp from the Braess Network Data Set.

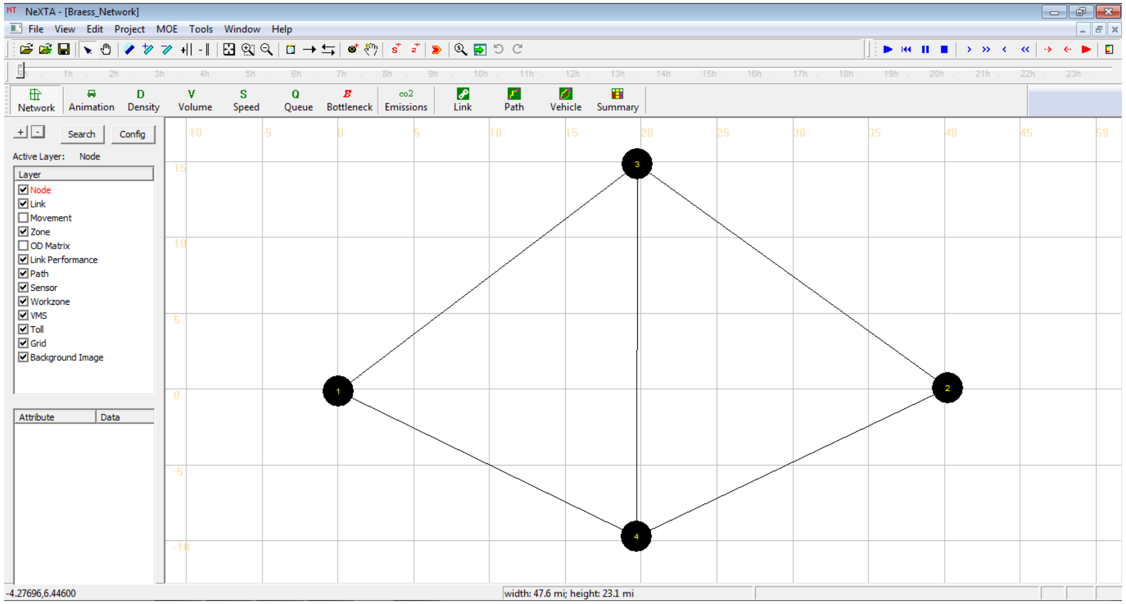


5.2 Equilibrium Model: Braess' Paradox

Task 1: Build a network for static traffic assignment, and configure BPR parameters

Step 2: in NeXTA, open the Braess_Network.tnp from the Braess Network Data Set.

- The following network file will be loaded into NeXTA, which has 4 nodes and 5 links.

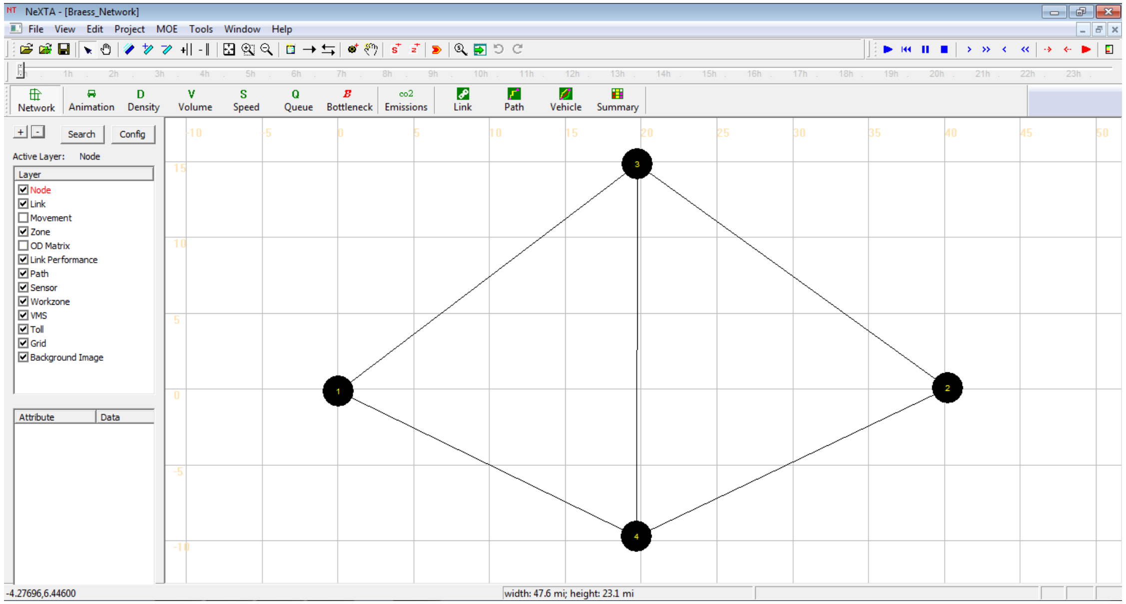


5.2 Equilibrium Model: Braess' Paradox

Task 1: Build a network for static traffic assignment, and configure BPR parameters

Step 2: in NeXTA, open the Braess_Network.tnp from the Braess Network Data Set.

- For notational convenience, the following discussion denote link1->3; 4->2; 1->4; 3->2; 3->4 as a, b, c, d, e, respectively.



5.2 Equilibrium Model: Braess' Paradox

Task 2: Run simulation for the Braess network to carry out traffic assignment

Step 1: run simulation and view this data table by right-clicking and selecting 'View Link Data Table' in link layer

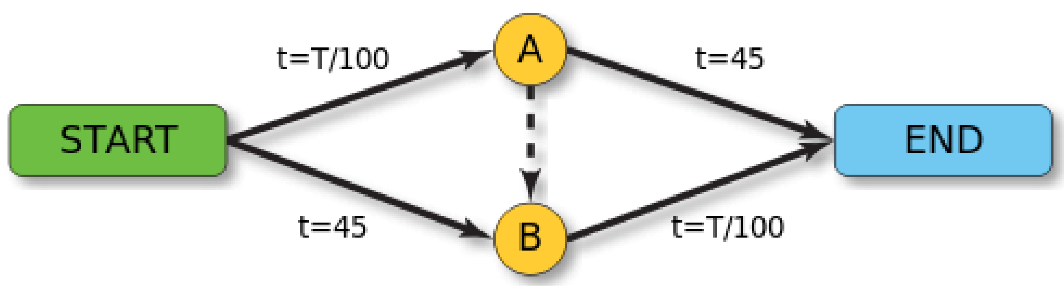
	Travel time function	Link Length	Lane capacity	# of lanes	BPR_alpha	BPR_beta
Links a, b	(v/100)	0.01	1714	1	100	1
Links c, d	45 min	45	1900	3	0	1

5.2 Equilibrium Model: Braess' Paradox

Task 2: Run simulation for the Braess network to carry out traffic assignment

Step 1: run simulation and view this data table by right-clicking and selecting 'View Link Data Table' in link layer

- How do we specify the α and β for the links in Braess Network?



$$TT = FFTT[1 + \alpha(v/c)^{\beta}]$$

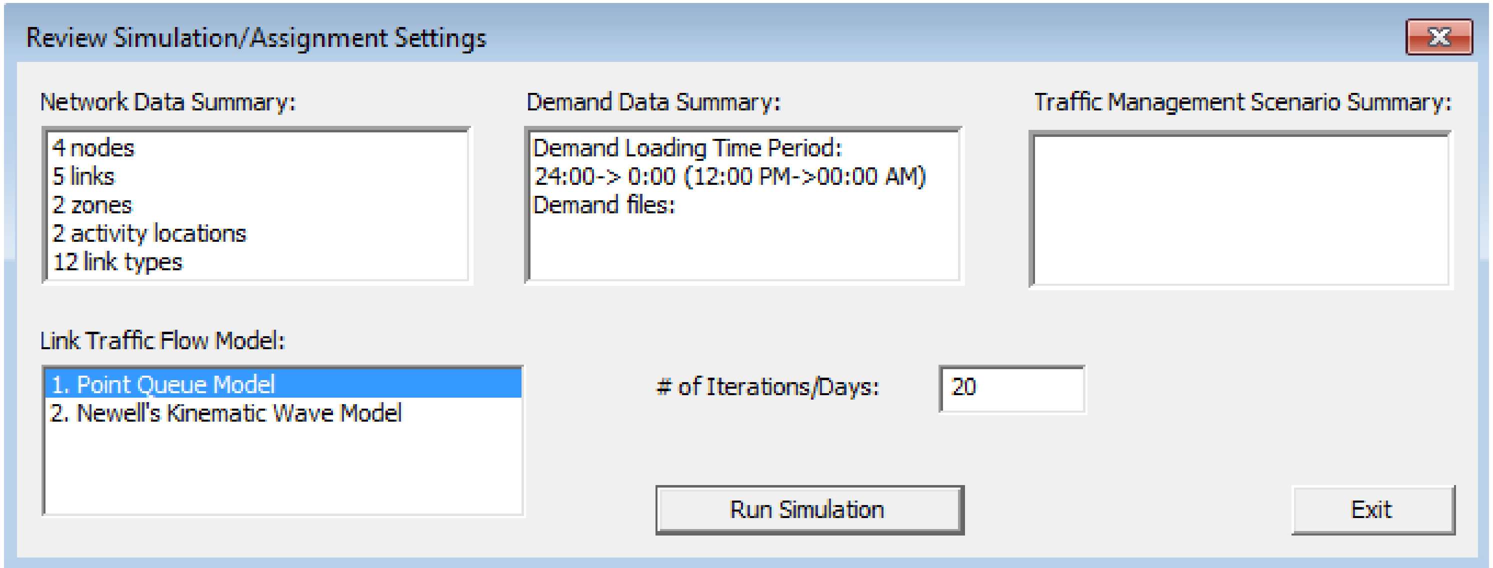
- t=T/100 is re-expressed as t=v/100 --> FFTT = 0.01; α = 100; c = 100; β=1. so that the reconstructed function is 0.01*(1+100v/100) = 0.01+ v/100, which is close to v/100.

5.2 Equilibrium Model: Braess' Paradox

Task 2: Run simulation for the Braess network to carry out traffic assignment

Step 2: Select a traffic flow model and Traffic Assignment Method.

- Choose the option 'Point Queue Model' and 20 iterations.
- Run simulation



5.2 Equilibrium Model: Braess' Paradox

Task 2: Run simulation for the Braess network to carry out traffic assignment

Step 3: Review summary statistics

	A	B	C	D	E	F	G	H	I	J	K	L
1	DTALite:											
2	A Fast Open Source DTA Engine											
3	Software V	1.1.0										
4	Release Dat	May 4 2016										
5	Simulation I	year: 2016	month:10	day:13	hour:23	min: 1						
6	----------------------test1----------------------											
7	Signal Conti	Continuous Flow with Link Capacity Constraint										
8	Traffic Flow	Point Queue Model										
9	Assignment	MSA										
10												
11												
12	User Define	32										
13												
14	# of Nodes=	4										
15	# of Link Ty	12										
16	# of Links=	5										
17	# of Prohibi	0										
18	# of Pretime	0										
19	# of Actuate	0										
20	# of Zones=	2										
21	# of Activity	2										
22	# of Vehicle	5										
23	# of Deman	4										

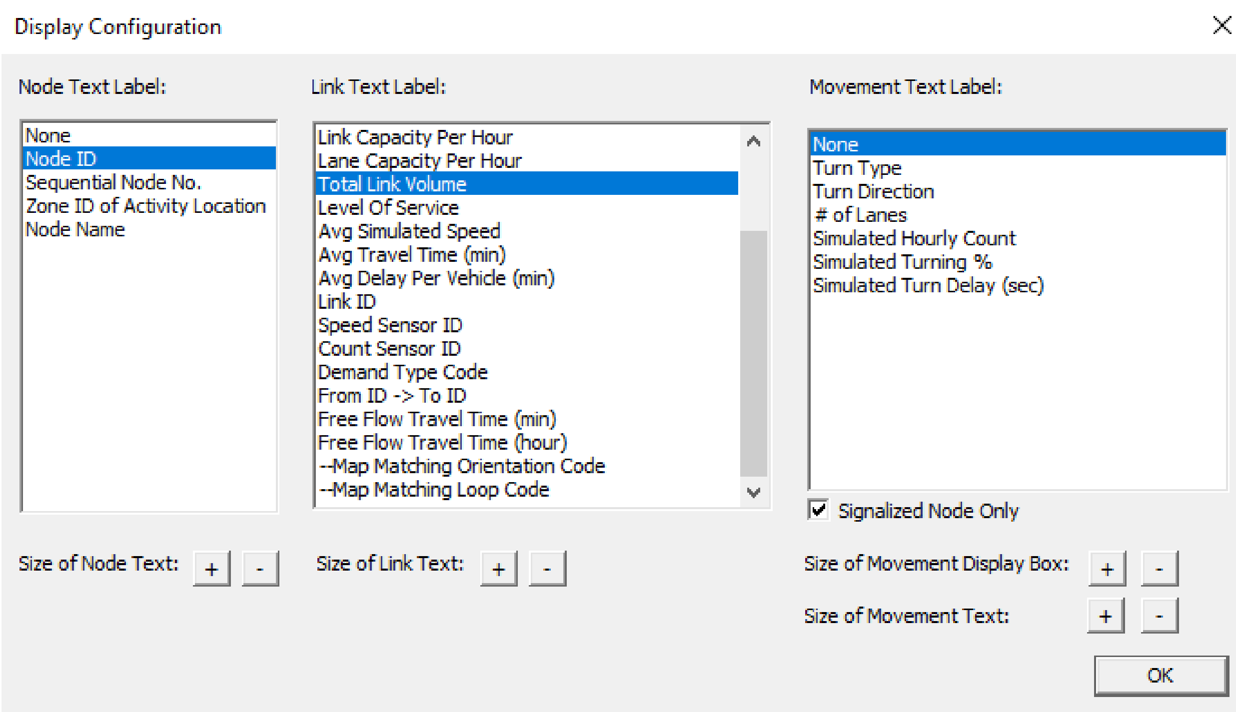
output_summary

5.2 Equilibrium Model: Braess' Paradox

Task 2: Run simulation for the Braess network to carry out traffic assignment

Step 4: Display the link volume.

- First, click "config" (the button to the extreme left in NEXTA), which opens up a dialog box titled "Display Configuration".



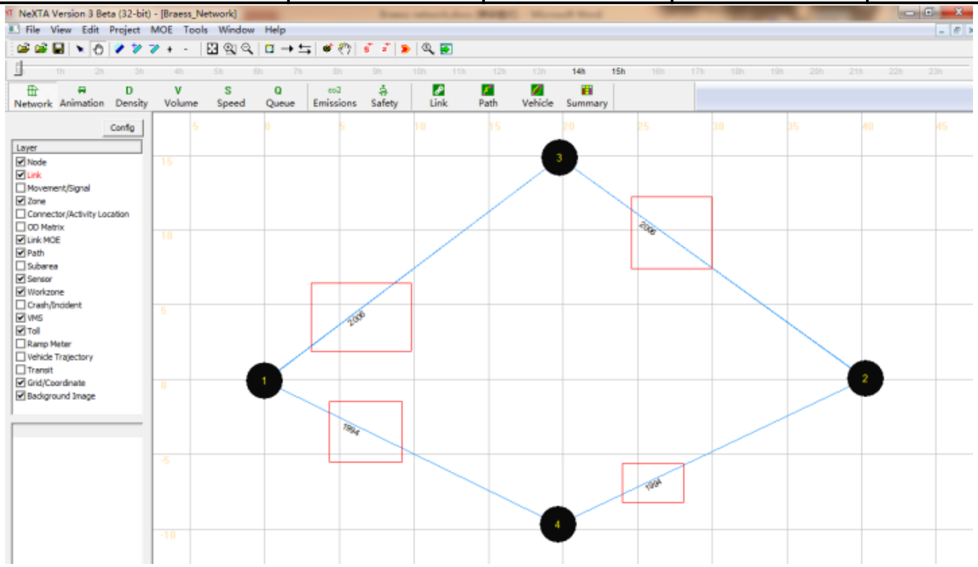
5.2 Equilibrium Model: Braess' Paradox

Task 2: Run simulation for the Braess network to carry out traffic assignment

Step 4: Display the link volume.

- The volume values on each link are shown in the map as shown below.

link	a	b	c	d
Total Link Volume (vhc)	2006	1994	1994	2006

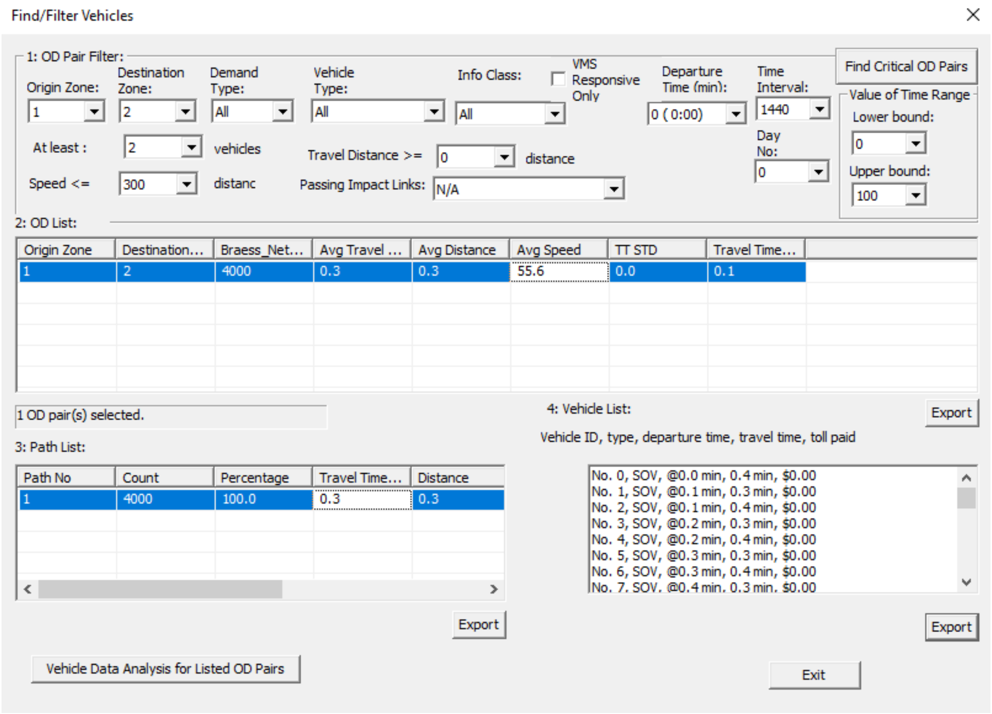


5.2 Equilibrium Model: Braess' Paradox

Task 2: Run simulation for the Braess network to carry out traffic assignment

Step 5: Prepare statistics for the base case scenario.

- Use the "vehicle" button to verify the path selection information

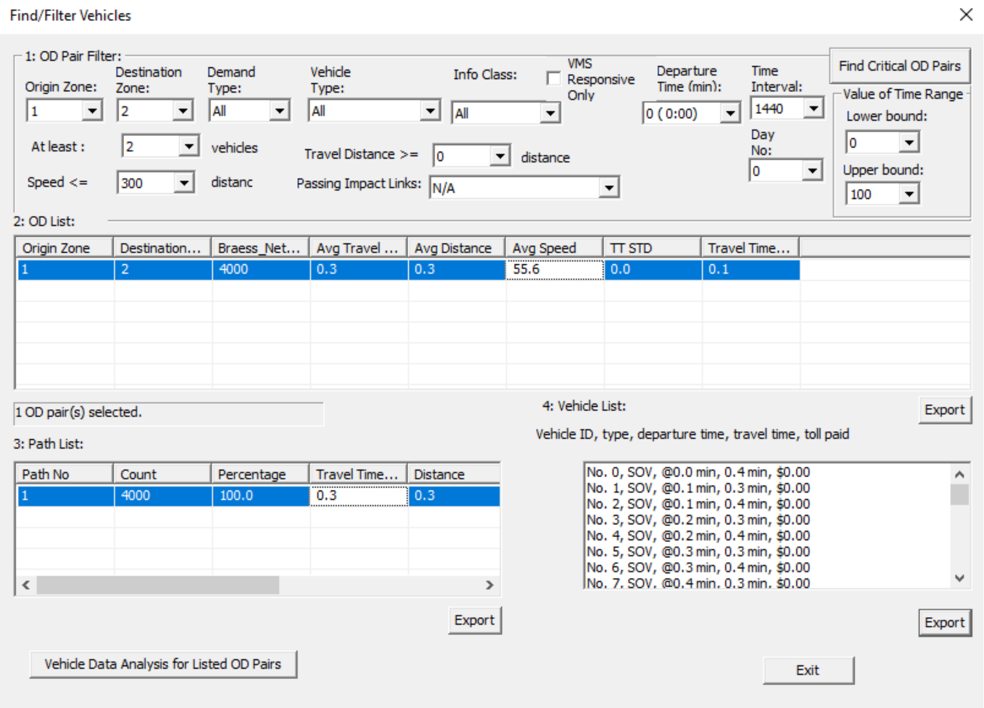


5.2 Equilibrium Model: Braess' Paradox

Task 2: Run simulation for the Braess network to carry out traffic assignment

Step 5: Prepare statistics for the base case scenario.

- Select "1" under the tab "Origin Zone" and "2" under "Destination Zone",

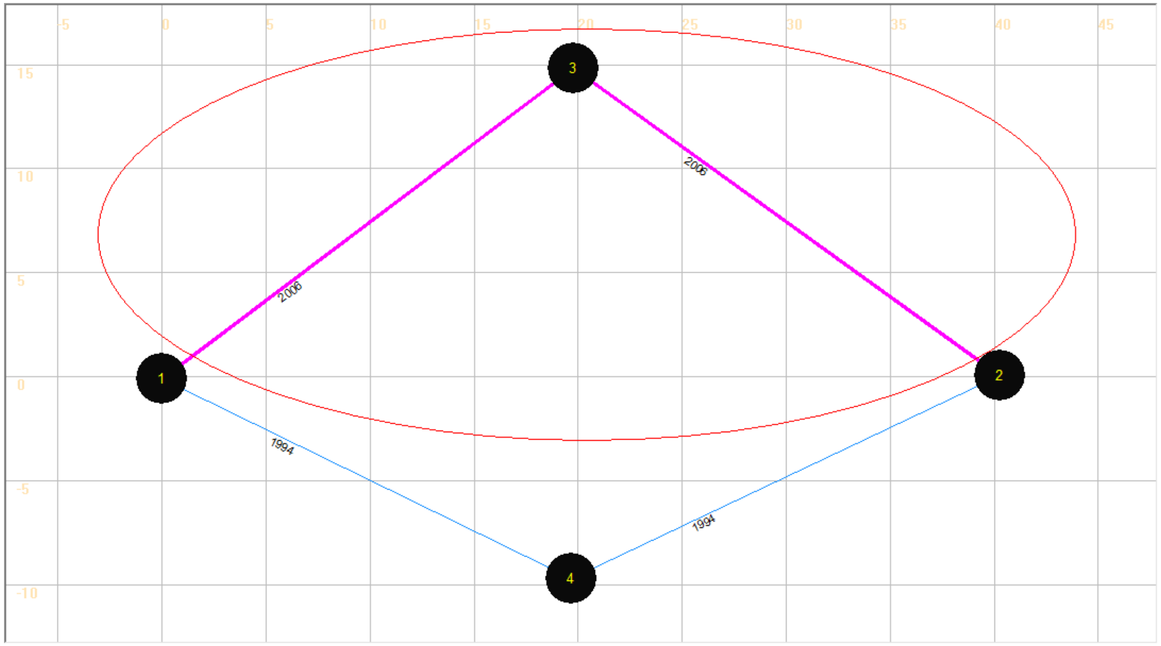


5.2 Equilibrium Model: Braess' Paradox

Task 2: Run simulation for the Braess network to carry out traffic assignment

Step 5: Prepare statistics for the base case scenario.

- Click on the OD list populated, and then we can see the path list related to the demand, travel time at path 1.

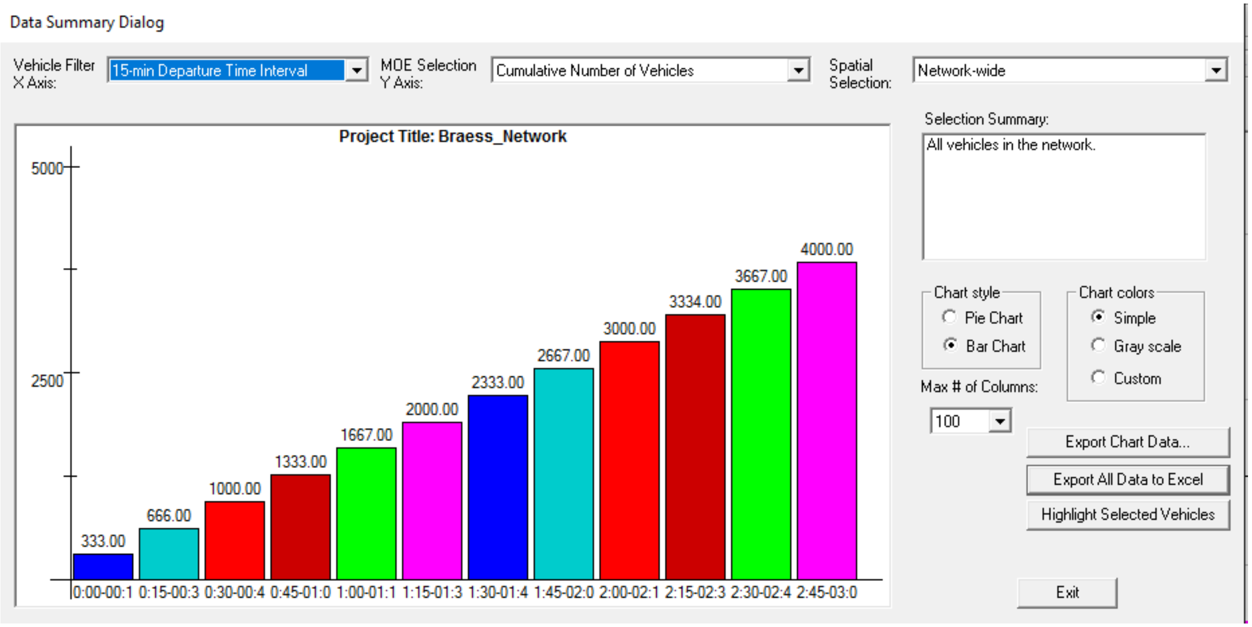


5.2 Equilibrium Model: Braess' Paradox

Task 2: Run simulation for the Braess network to carry out traffic assignment

Step 6: Use the "summary" button to verify the overall network performance.

- Select the item "Avg Travel Time (min)" under the Y Axis drop-down list to show the average travel time in the network.

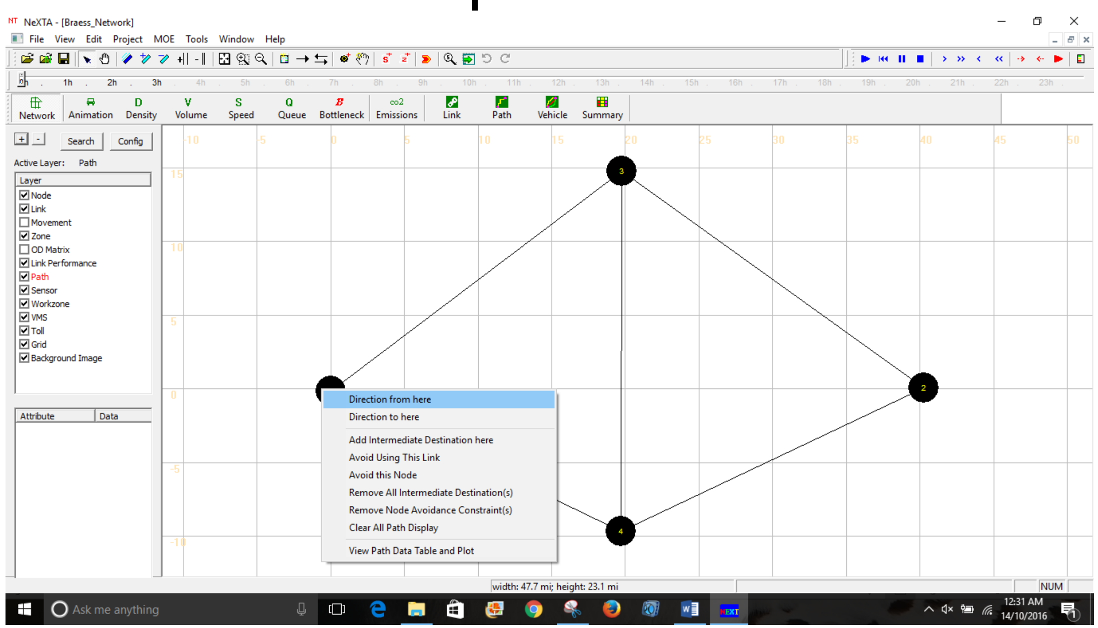


5.2 Equilibrium Model: Braess' Paradox

Task 3: Using NEXTA to display the shortest path in Braess network.

Step 1: Click "Path" on the GIS Layer Panel Menu on the left side of your screen

- Right click on Node 1 to choose the option "Direction from here". Node 1 becomes a red highlighted box, 'A', indicating the start point of the shortest path

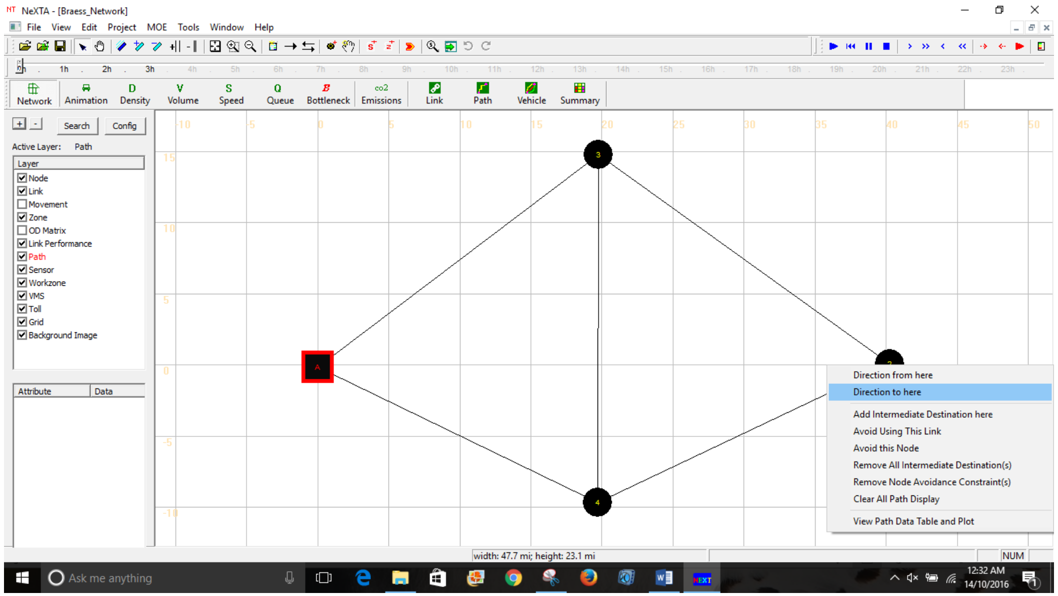


5.2 Equilibrium Model: Braess' Paradox

Task 3: Using NEXTA to display the shortest path in Braess network.

Step 1: Click "Path" on the GIS Layer Panel Menu on the left side of your screen

- Then right click on Node 2 to choose the option "Direction to here" and it becomes a red highlighted box, 'B'.

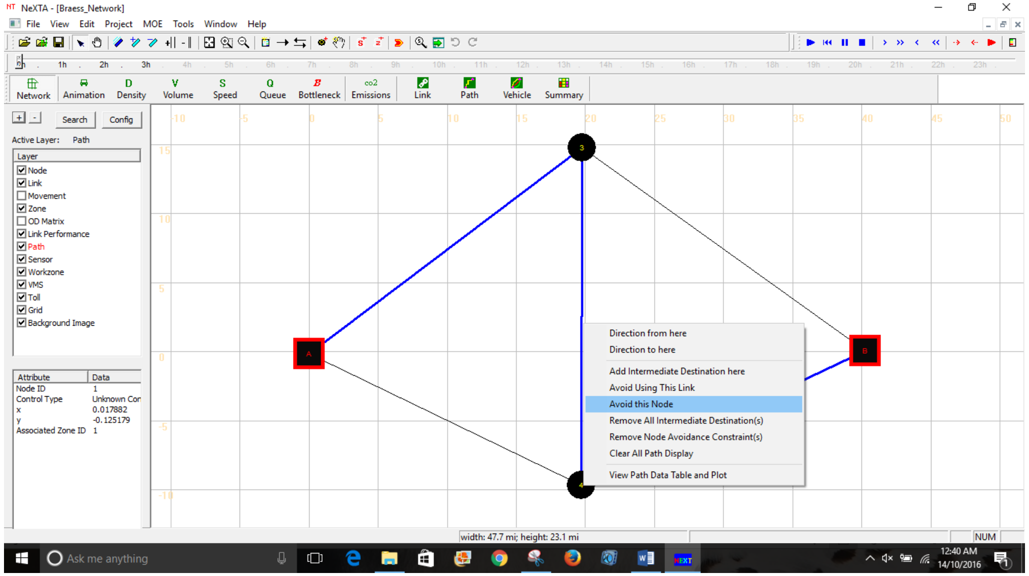


5.2 Equilibrium Model: Braess' Paradox

Task 3: Using NEXTA to display the shortest path in Braess network.

Step 2: Right click on node 4, click on the "avoid this node" menu

- The shortest path from Node 1 to Node 2 is highlighted in the map as shown below.



5.2 Equilibrium Model: Braess' Paradox

Task 3: Using NEXTA to display the shortest path in Braess network.

Step 2: Right click on node 4, click on the "avoid this node" menu

- The path from node 1 to node 2 is now changed and no vehicle uses node 4 as it has been prevented.

	Travel time	**Flow**
Path 1	Link a(40.01) + Link d(45) = 85.01 min	0
Path 2	Link c(45) + Link b(40.01) = 85.01 min	0
Path 3	Link a(40.01)+ Link e(0.001)+ Link b(40.01) = 80.02 min	4000

5.2 Equilibrium Model: Braess' Paradox

Task 4: Compare System-wide Performance Differences between Two Networks.

- The Braess paradox is a User Equilibrium (UE) system that is not necessarily System Optimal (SO).
- Under the UE principle, the users are assumed to be greedy and rational to choose their own route with minimum cost, and users are familiar with the system.

	Without adding link e	Adding link e
Total number of vehicles	4000	4000
System-wide total travel time	260040.7	320083.8
Average travel time for each vehicles	65.01	80.02
Volume on link a	2006	4000
Volume on link c	1994	0
Path 1 travel time	**65.07**	**85.01**
Path 1 volume	2006	0
Path 2 travel time	64.95	85.01
Path 2 Volume	1994	0
Path 3 travel time	——	80.02
Path 3 Volume	0	4000

5.2 Equilibrium Model: Braess' Paradox

Task 4: Compare System-wide Performance Differences between Two Networks.

- **Remarks:**
- Comparing the average travel times before and after the addition of link e
- it is interesting that the average travel time increases from 65.01-min to 80.02-min, due to the addition of link e.
- After adding link e into the Braess Network, all the vehicles travel through link e, and the system-wide total travel time increases significantly.

5.2 Equilibrium Model: Braess' Paradox

Task 4: Compare System-wide Performance Differences between Two Networks.

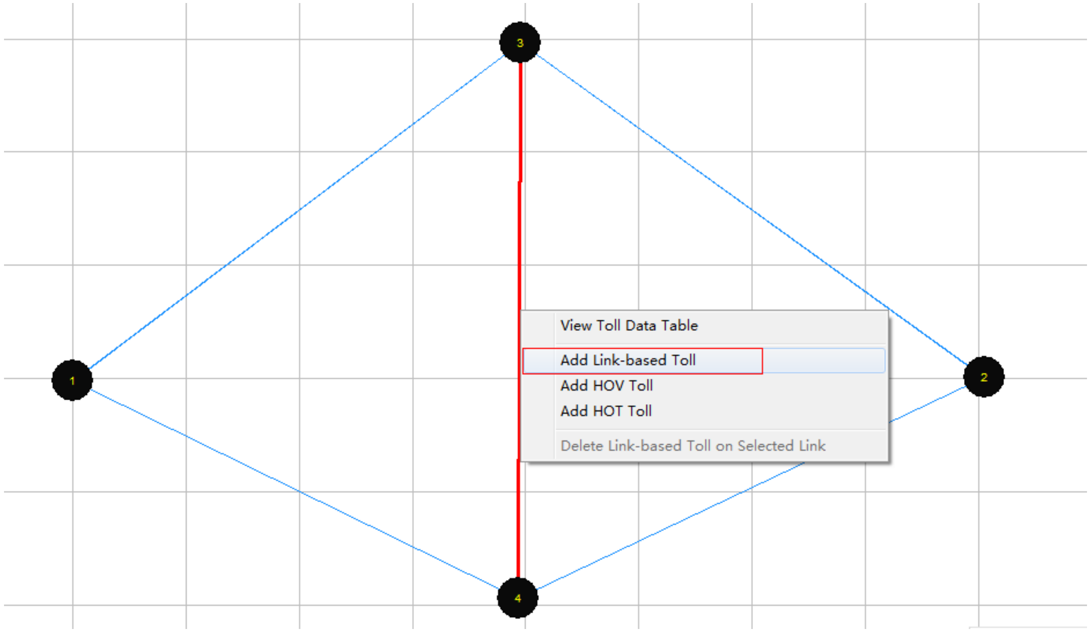
- **Remarks:**
- However, for one single vehicle, the driver does not have an incentive to switch his route, as the travel times for the other two paths (Path 1 and Path 2) are 85.01 minutes when all the other vehicles travel through link e (except for that one vehicle).
- Therefore, there is a paradox on Braess network under reasonable assumptions, necessary and sufficient conditions in a general transportation network.
- It should be noted that the length of link e must be short enough to ensure that the travel time on path 3 is less than the travel times on both path 1 and 2.

5.2 Equilibrium Model: Braess' Paradox

Task 5: Add a Link Toll and Run Static Simulation

Step 1: Click "Toll" on the GIS Layer Panel, and then click to select link e.

- Set link e as a Toll link by clicking "Add Link-based Toll" in the right click drop-down list.

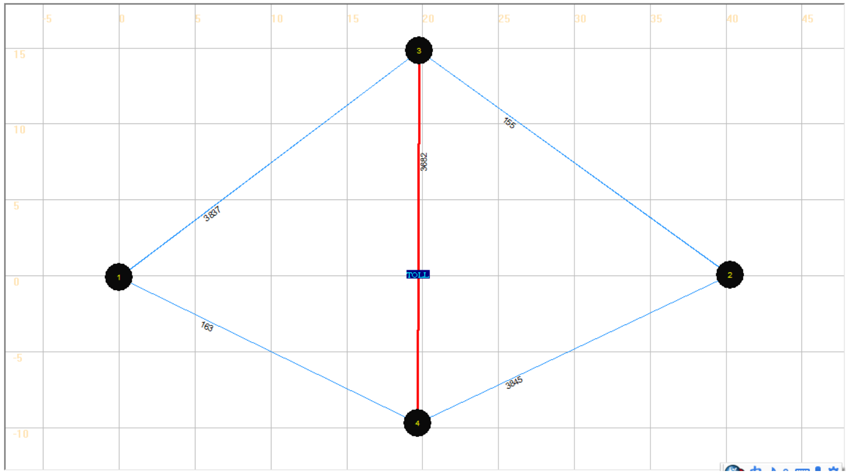


5.2 Equilibrium Model: Braess' Paradox

Task 5: Add a Link Toll and Run Static Simulation

Step 3: Run simulation on the new network and display the volumes on the map.

- We can see some vehicles shifting from Path 3 to Path 1 and Path 2 because of introducing the toll on path 3.



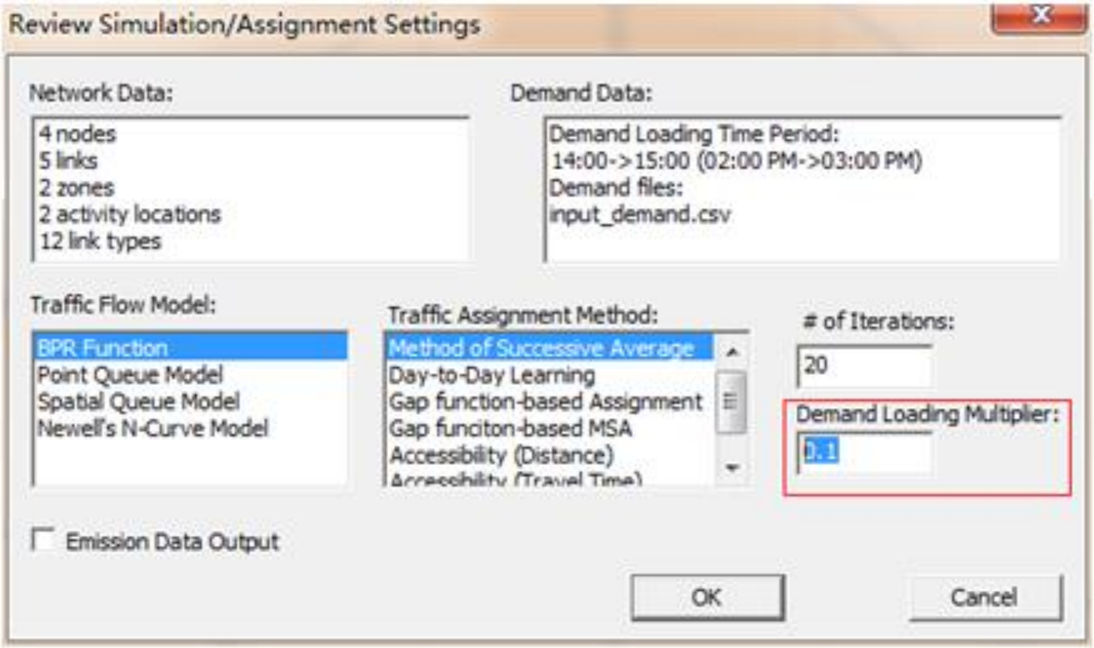
	a	b	c	d	e
Total Link Volume(vhc)	3837	3845	163	155	3682

5.2 Equilibrium Model: Braess' Paradox

Task 6: Sensitivity analysis using different demand levels

Step 1: Analysis of low demand on Braess Network

- change the value of "Demand Loading Multiplier" at 0.1.
- Then, the demand will change into 4000*0.1=400 (the original demand is 4000).

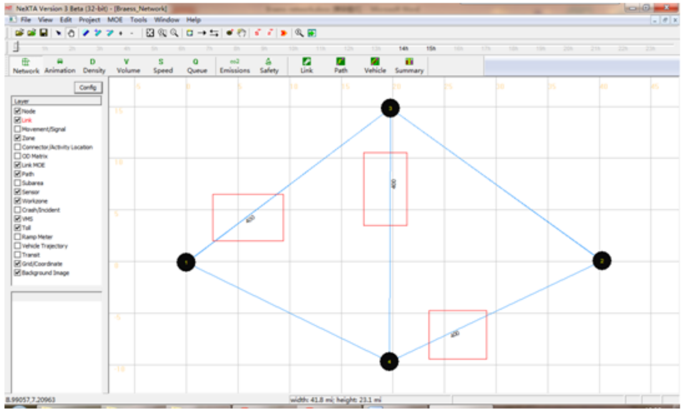


5.2 Equilibrium Model: Braess' Paradox

Task 6: Sensitivity analysis using different demand levels

Step 1: Analysis of low demand on Braess Network

- Run simulation using "BPR Function" as "Traffic Flow Model"
- "Method of Successive Average" as "Traffic Assignment Method" on Braess network
- display the volume value on the network.



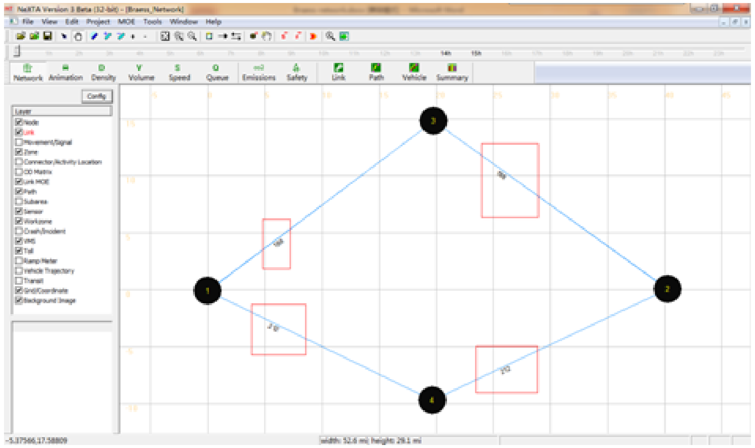
	a	b	c	d	e
Total Link Volume(vhc)	400	400	0	0	400

5.2 Equilibrium Model: Braess' Paradox

Task 6: Sensitivity analysis using different demand levels

Step 1: Analysis of low demand on Braess Network

- Keep the "Demand Loading Multiplier" at 0.1.
- Use BPR Function to run simulation and display the volume values on each link.



	a	b	c	d	e
Total Link Volume(vhc)	188	212	212	188	400

5.2 Equilibrium Model: Braess' Paradox

Task 6: Sensitivity analysis using different demand levels

Step 1: Analysis of low demand on Braess Network

- Compare and analysis the system performance between two networks under low demand.

	Without adding link e	Adding link e
System-wide travel time	18806.88	3208.37
Volume on link a	188	400
Volume on link c	212	0
Path 1 travel time	46.89	49.01
Path 1 volume	188	0
Path 2 travel time	47.13	49.01
Path 2 volume	212	0
Path 3 travel time	——	8.02
Path 3 volume	0	400

5.2 Equilibrium Model: Braess' Paradox

Task 6: Sensitivity analysis using different demand levels

Step 1: Analysis of low demand on Braess Network

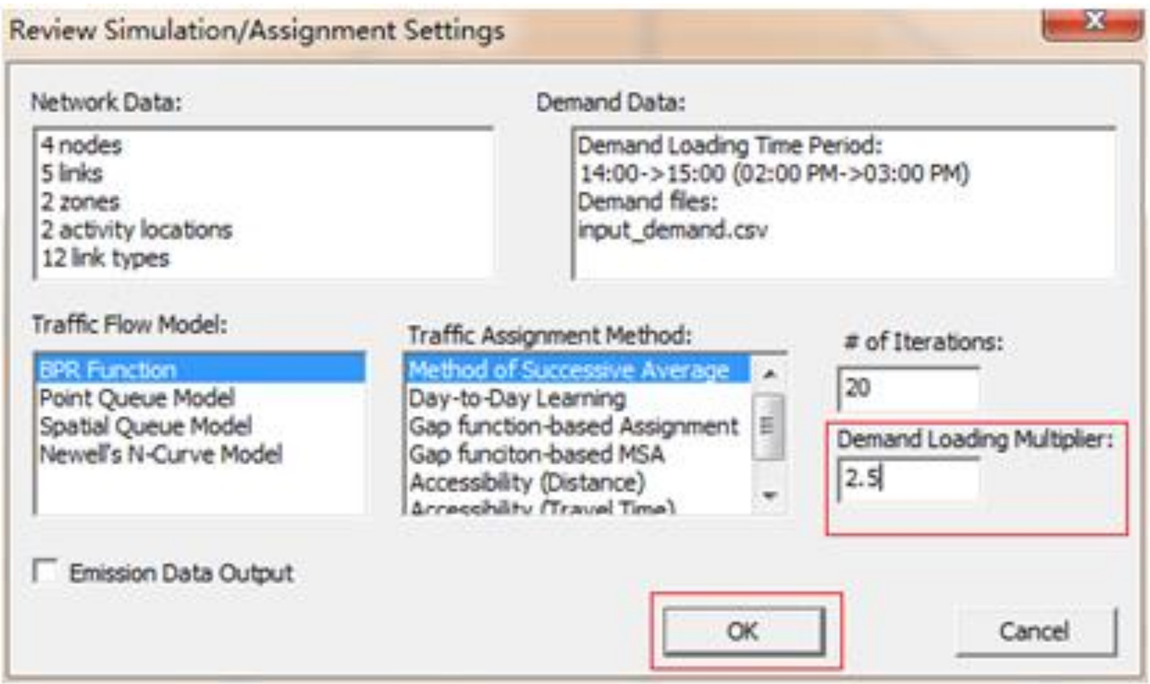
- From the statistics above, the system performance of the Braess network with link e is much better than the other's.
- The travel time for a single vehicle or whole system decrease because of link e. Thus, no paradox occurs.

5.2 Equilibrium Model: Braess' Paradox

Task 6: Sensitivity analysis using different demand levels

Step 2: Analysis of high demand on Braess Network

- change the value of "Demand Loading Multiplier" at 2.5.
- Then, the demand will change into 4000*2.5=10000 (the original demand is 4000).

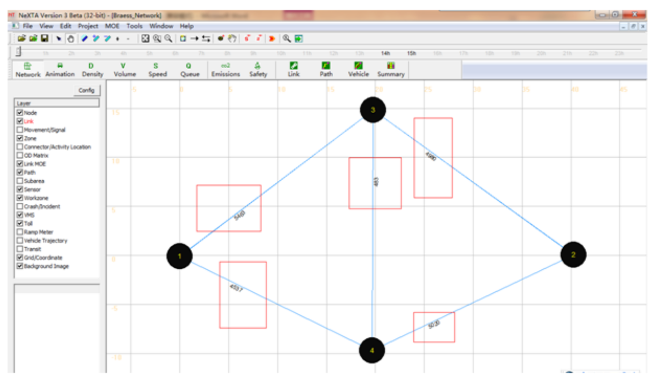


5.2 Equilibrium Model: Braess' Paradox

Task 6: Sensitivity analysis using different demand levels

Step 2: Analysis of high demand on Braess Network

- Choose "BPR Function" in "Traffic Flow Model" list
- "Method of Successive Average" in "Traffic Assignment Method" list on Braess network
- then click OK to start simulation. Display the volume values on the map.



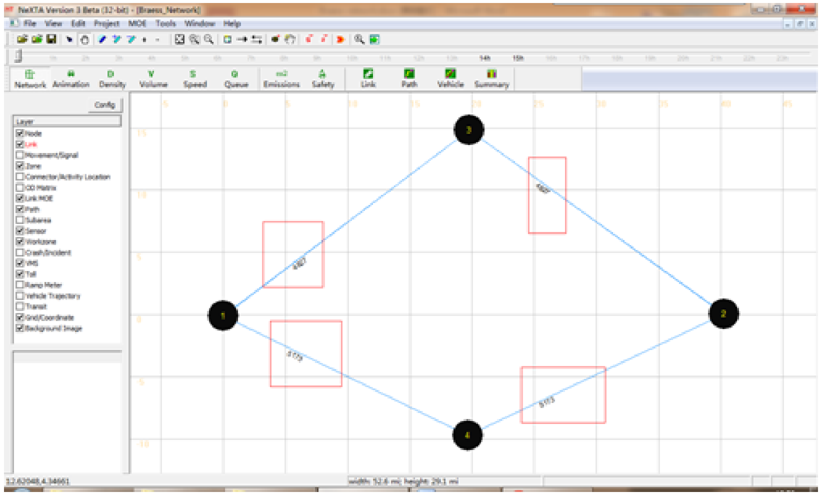
	a	b	c	d	e
Total Link Volume(vhc)	5463	5020	4537	4980	483

5.2 Equilibrium Model: Braess' Paradox

Task 6: Sensitivity analysis using different demand levels

Step 2: Analysis of high demand on Braess Network

- Keep "Demand Loading Multiplier" at 2.5
- Run the simulation using BPR Function to obtain the volume values on each link.



	a	b	c	d
Total Link Volume(vhc)	4827	5173	5173	4827

5.2 Equilibrium Model: Braess' Paradox

Task 6: Sensitivity analysis using different demand levels

Step 2: Analysis of high demand on Braess Network

- Compare and analysis the system performance between two networks under high demand.

	Without adding link e	Adding link e
System-wide travel time	950698.6	978817.97
Volume on link a	4827	5463
Volume on link c	5173	4537
Path 1 travel time	93.28	99.64
Path 1 volume	4827	4980
Path 2 travel time	96.74	95.21
Path 2 volume	5173	4537
Path 3 travel time	——	104.85
Path 3 volume	0	483

5.2 Equilibrium Model: Braess' Paradox

Task 6: Sensitivity analysis using different demand levels

Step 2: Analysis of high demand on Braess Network

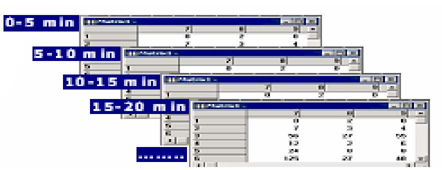
- From the statistics above, not all vehicles take the path 3 because of link capacity limitation.
- And the travel time on path 3 is a little longer than other two paths'.
- Neither does paradox occur under high demand in Braess network.

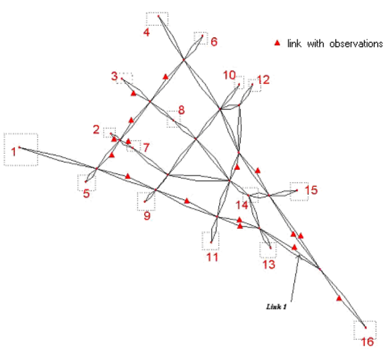
Module 6
Origin Demand Matrix Estimation

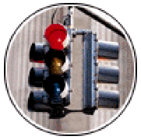
6.0 Background information

Why is OD Demand Estimation Important?

- Essential input for traffic assignment systems to support transportation network planning and operational decisions







OD Demand

Network

Capacity, Traffic Control

Traffic Assignment

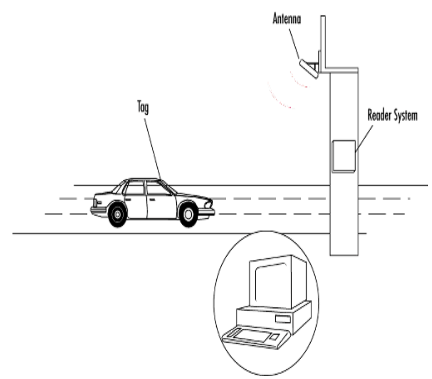
Performance Measures

Why do We Need to Utilize Different Data Sources?

- Advanced sensor technologies offer more reliable and less costly channels to provide real-time traffic flow measurements

Survey Data   Point Sensor   Point-to-point Sensor

Loop Detector



Automatic Vehicle Identification

How has OD Matrix Estimation been Done?

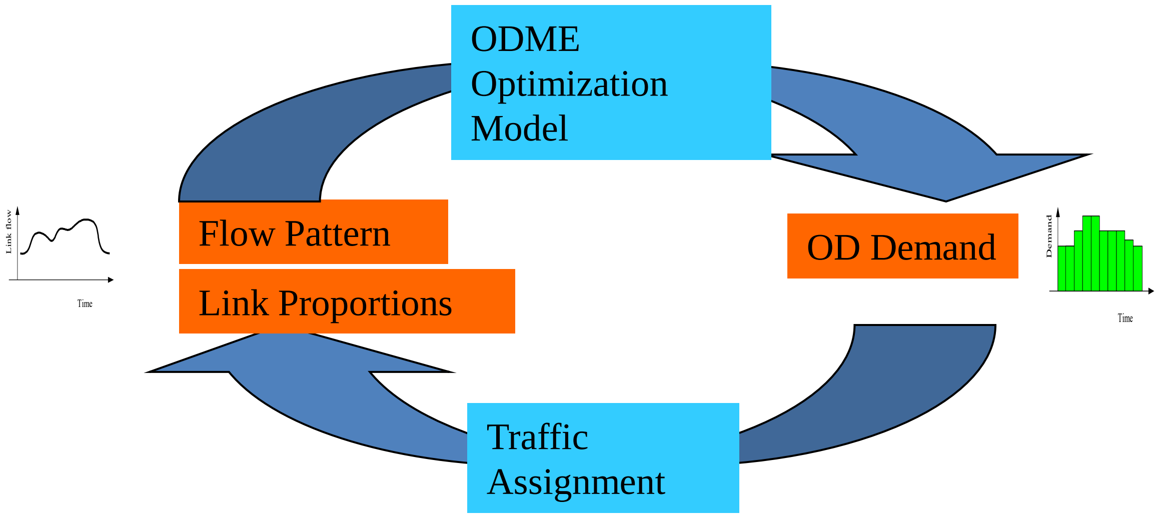
Upper level:

Constrained ordinary least-squares problem

$$\min Z = \sum_{l \in L_{lc}, t} \Big[\sum_{o,d,\tau} \hat{p}_{(l,t),(o,d,\tau)} \cdot D_{(o,d,\tau)} - c_{(l,t)} \Big]^2$$

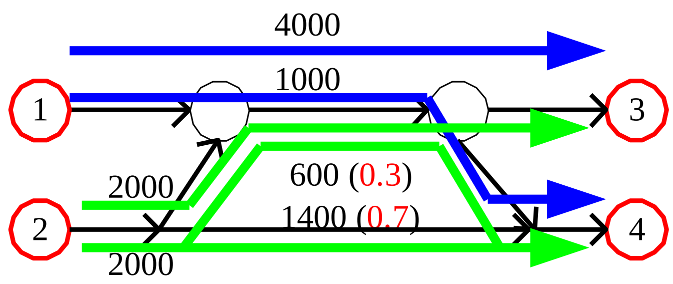
Lower level:

– Link flow proportion $\hat{p}_{(l,h),(o,d,\tau)}$ Traffic assignment ($D_{(o,d,\tau)}$



What is Link-Flow Proportion?

Path Flow Structure

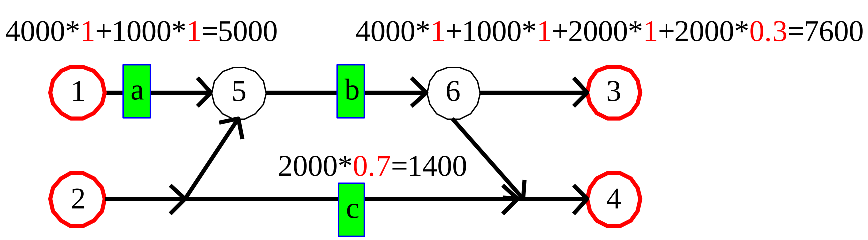


<u>Link Proportions (*Assignment matrix*)</u>

Fraction of vehicular demand flow from **OD pair(*i, j*)** contributing to the flow on **link *l***

$$p_{l,(o,d)} = \frac{c_{(o,d),l}}{D_{o,d}}$$

OD pair	1->3	1->4	2->3	2->4
Link a	1	1	0	0
Link b	1	1	1	0.3
Link c	0	0	0	0.7



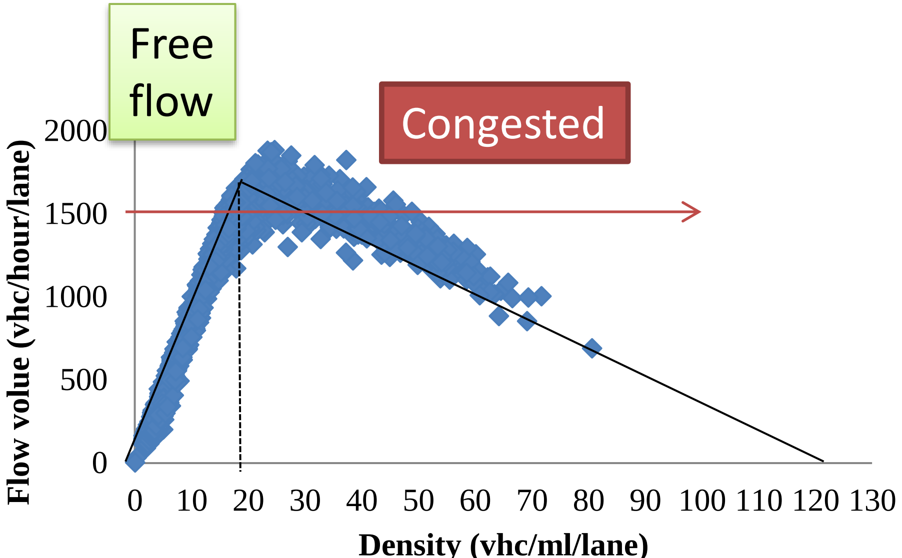
Two Common Questions…

1. Travel time IS NOT the only factor in travel route choice utility function.
   - A long list of additional route choice factors: Highway bias, distance consideration, # of signals, inherence preferences
   - Do we need to reach the "perfect" travel-time-based UE in ODME?

2. Can we combine/integrate traffic assignment and OD demand estimation? (Both aim to adjust flows in a network)

What is the Difficulty of Dynamic ODME under Congested Conditions?

Single value of flow volume observation could correspond to free-flow and congested states



No linear link proportions available for density and travel time measurements

Our Proposed Approaches

1. Path Flow Adjustment
    - Combine OD estimation/adjustment with traffic assignment
    - Final solution is a set of path flow patterns satisfying "tolled user equilibrium"

2. Approximate Gradient Method
    – Use spatial queue model to calculate link flow/density change due to incoming path flow change

Objective Function: Minimize

(1) Deviation between measured and estimated traffic states

(2) Deviation between aggregated path flows and target OD flows

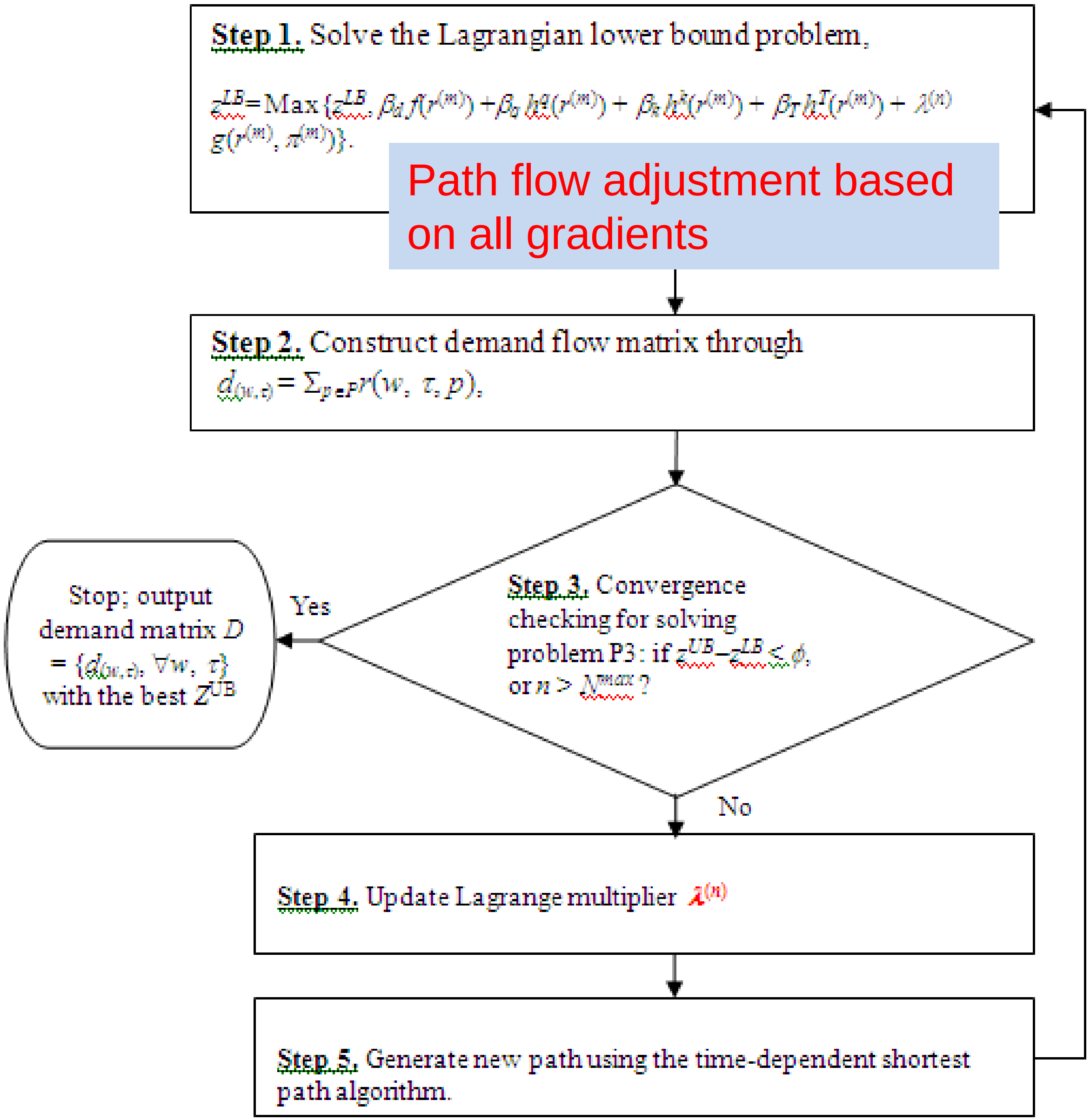
$$\sum_{o\in O}\sum_{d\in D}\sum_{\tau\in T}\left[D_{od}^{\tau}-\overline{D}_{od}^{\tau}\right]=\sum_{o\in O}\sum_{d\in D}\sum_{\tau\in T}\left[\sum_{p\in P(o,d,\tau)} r_{odp}^{\tau}-\overline{D}_{od}^{\tau}\right]$$

Demand flow   target demand   path flow   target demand

(3) Gap Function to Quantify User Equilibrium Conditions

$$Gap(r,\pi)=\sum_{o\in O}\sum_{d\in D}\sum_{\tau\in T}\sum_{p\in P(o,d,\tau)} r_{odp}^{\tau}[T_{odp}^{\tau}(r)-\pi_{od}^{\tau}]$$

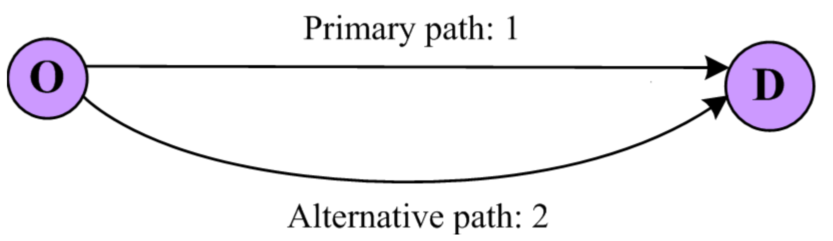
Flow Chart of Algorithm



Example 1

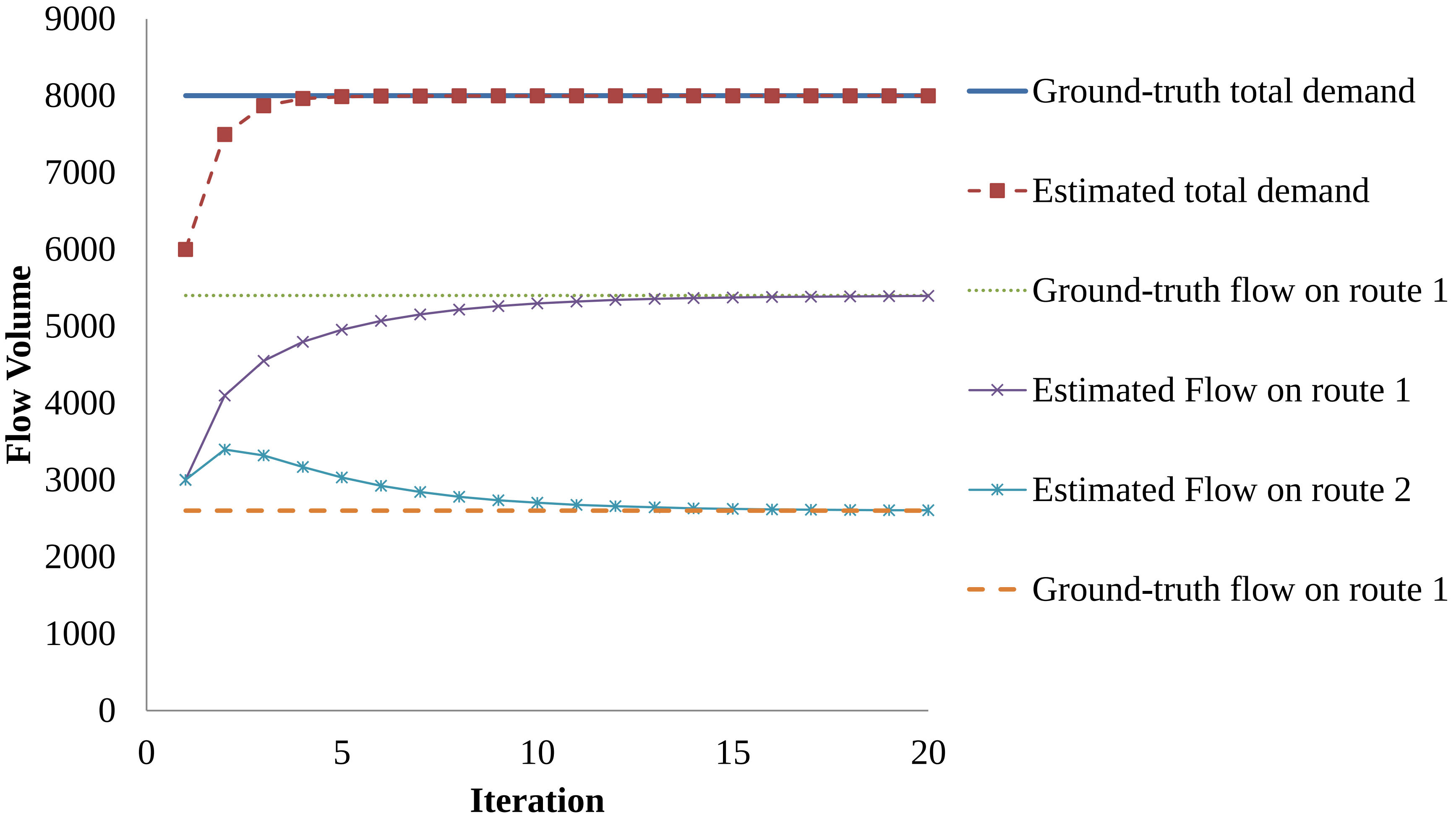
Congested two-link Corridor:

Total demand = 8000 veh/hour

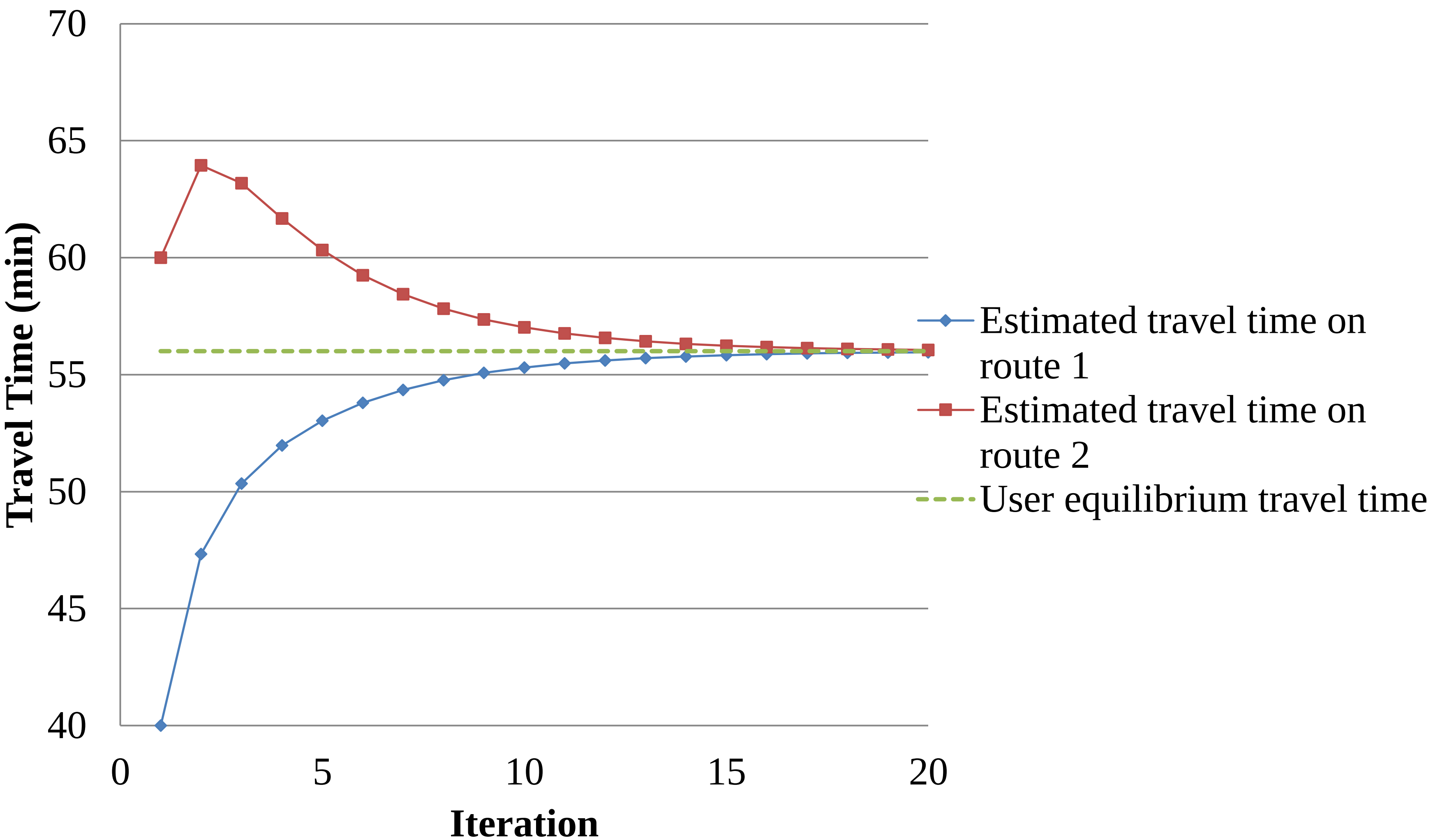


Path	FFTT (min)	Capacity (veh/hr)	Assigned Flow (veh/hr)	Travel Time (min)
Path 1	20	3000	5400	56
Path 2	30	3000	2600	56

Path Flow Volume Convergence Pattern



Path Travel Time Convergence Pattern

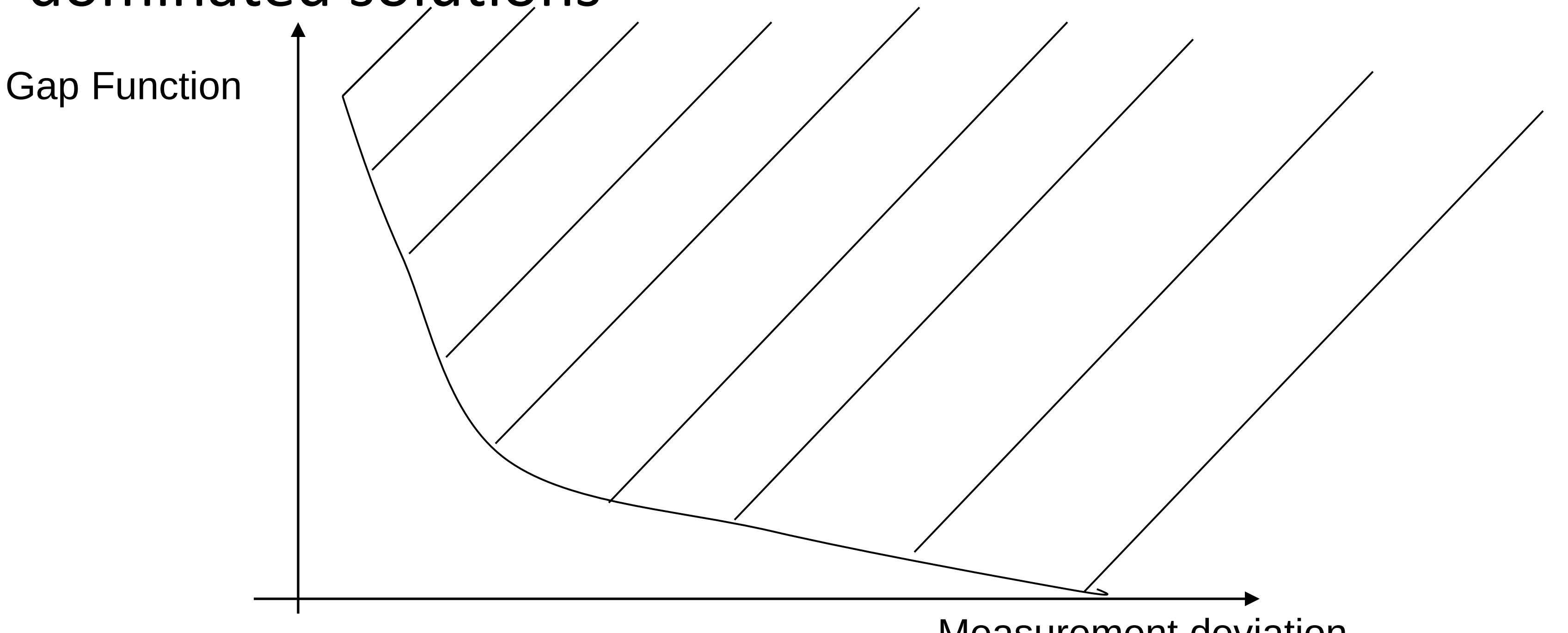


Algorithm Performance under Different Input Conditions

Information Availability				Estimation Result			
Volume observations on path 1 only	Volume observations on path 2 only	Error-free target demand, 8000vhc/hr	Error-free travel time on path 1	Flow on path 1	Flow on path 2	Total estimated demand	Equilibrium travel time (min)
X				5051.7	2367.8	**7419.5**	**53.7**
	X			4967.7	2311.8	**7279.4**	**53.1**
X	X			5011.8	2341.2	**7353.0**	**53.4**
X	X	X		5387.9	2592.0	**7979.9**	**55.9**
X	X	X	X	5401.1	2600.7	**8001.8**	**56.0**

Multi-objective Programming Perspective

- Gap Function: Degree of deviation from the original user equilibrium solutions
- Vary penalty on path cost to generate non-dominated solutions

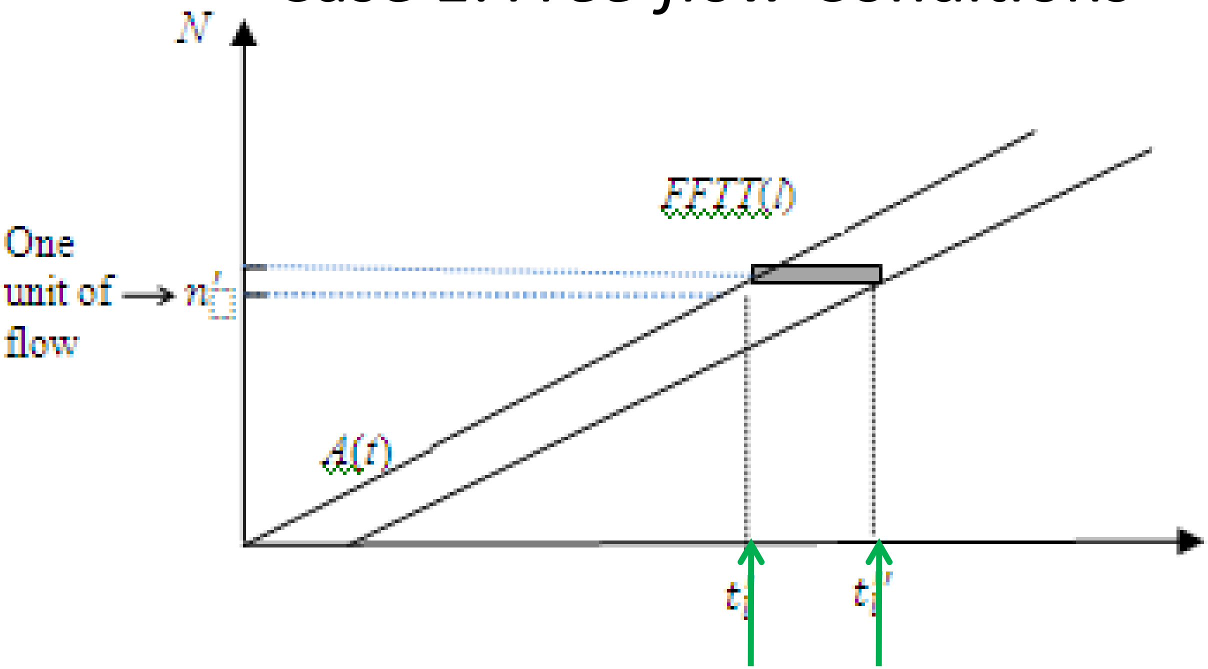


Sensitivity-Analysis and Gradient Information

- Approximate the derivatives through simulation for each OD pair and each time interval in every iteration (Tavana, 2001)
- Gradient approximation methods
  - Simultaneous Perturbation Stochastic Approximation (SPSA) framework by Balakrishna et al. (2008); Cipriani et al. (2011)

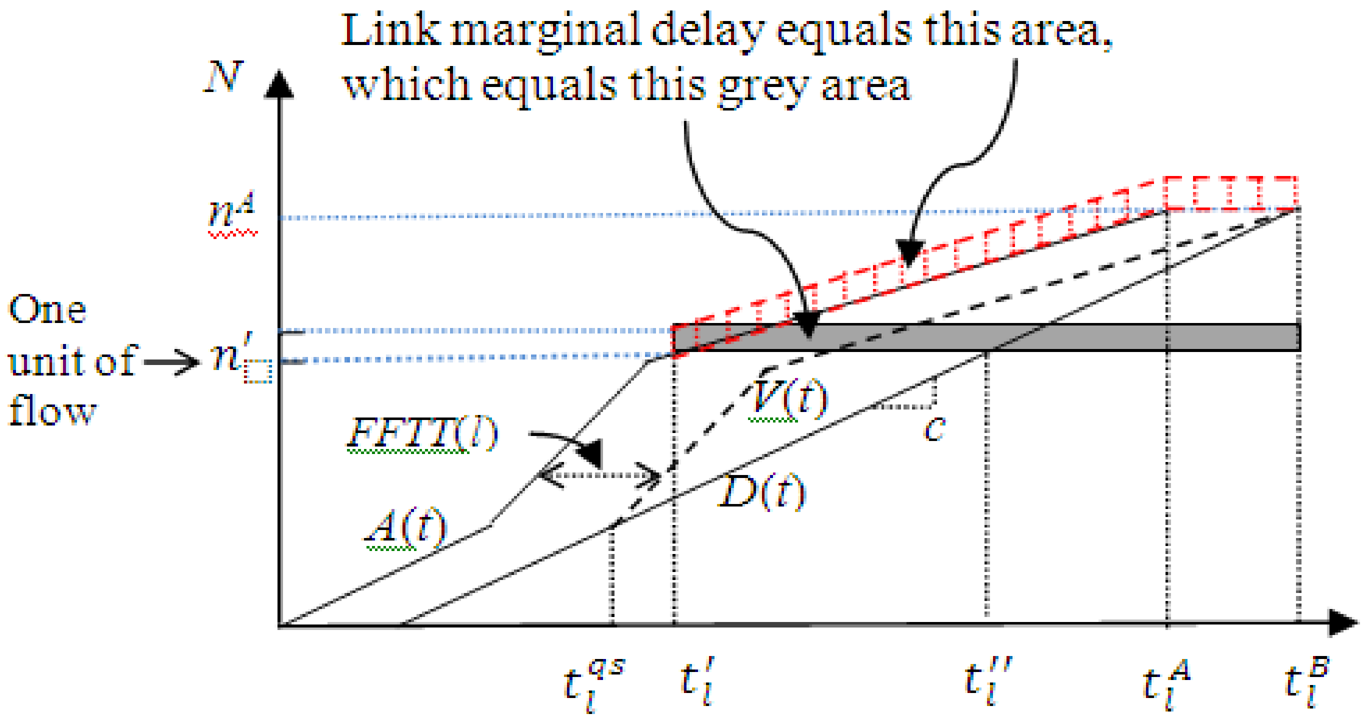
How to Use Spatial Queue Model to Evaluate Partial Derivatives with respect to Path Flow Perturbation?

Case 1: *Free-flow* Conditions



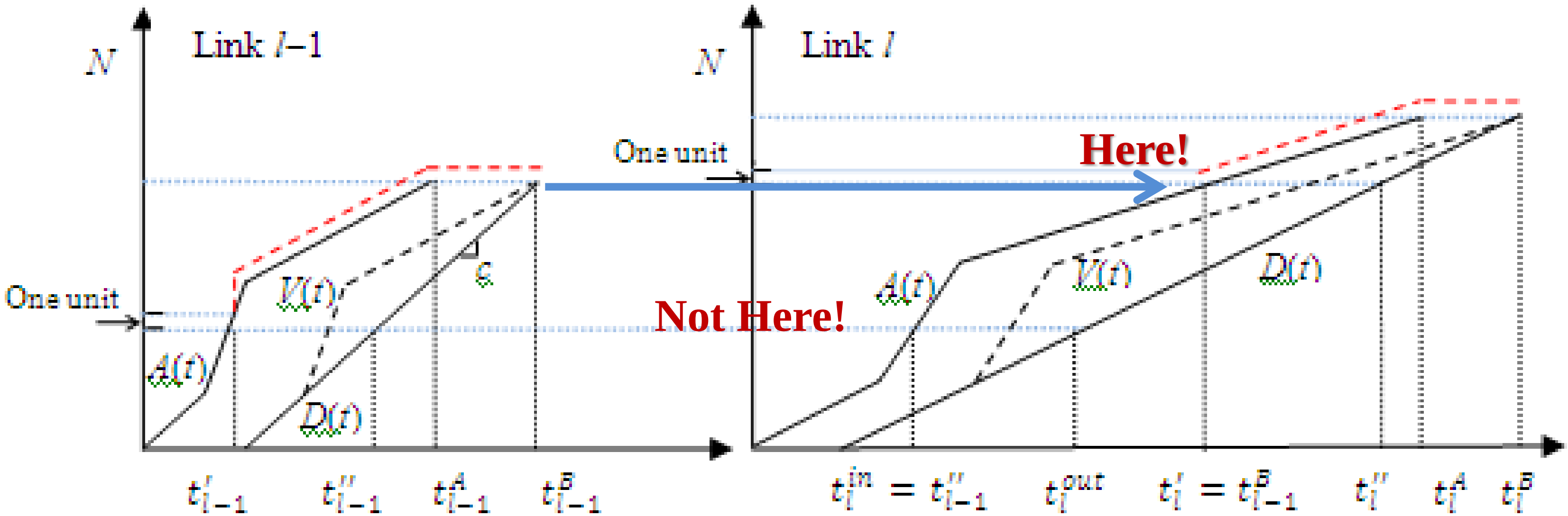
Link inflow and outflow increase by 1 at entering time and leaving time, respectively.

Case 2: Congested Condition



Inspired by study by Ghali and Smith (1995)

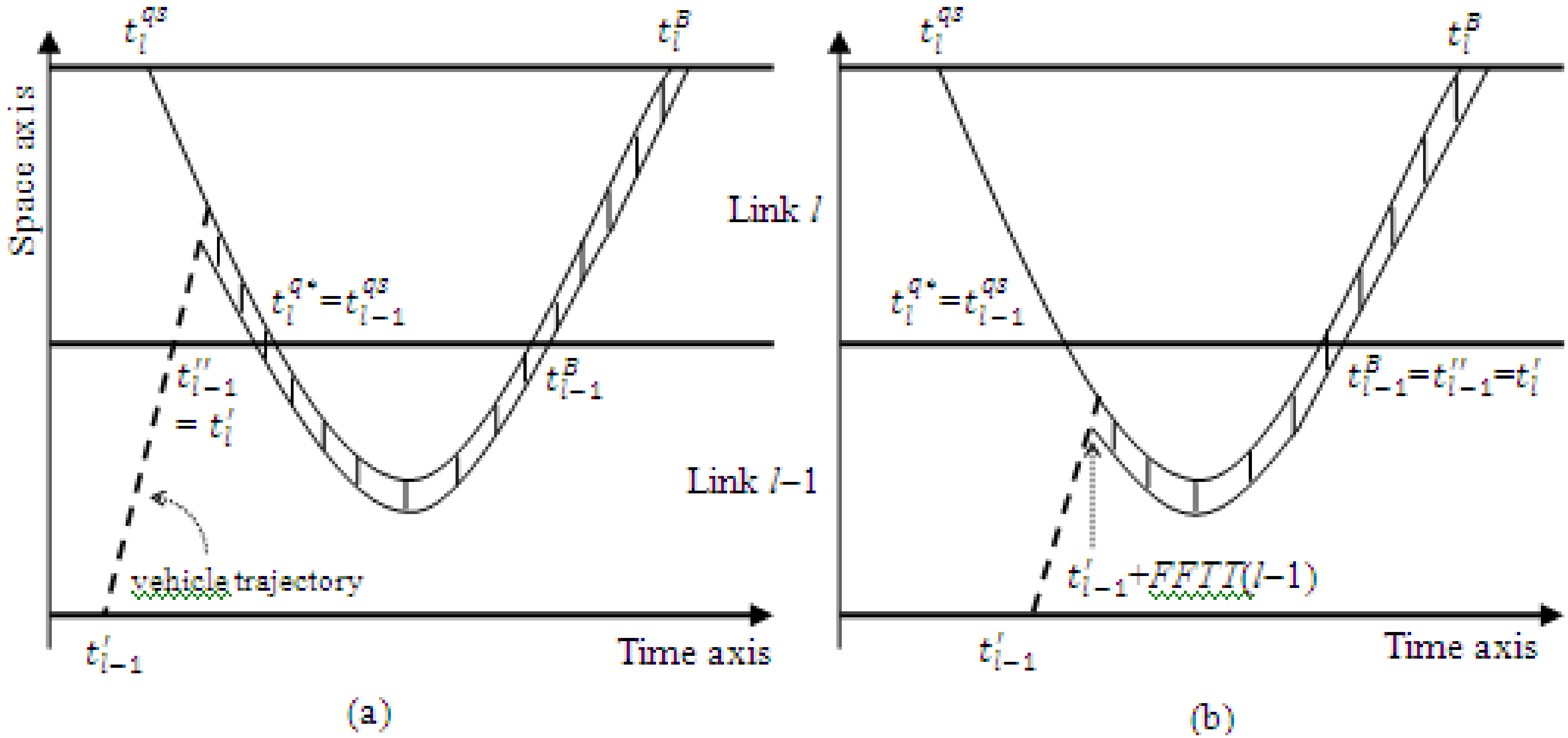
Case 3: Two Partially Congested Links



The perturbation flow on the second link starts at the end of queue duration of the first link; rather than the vehicle entering time on second link

Similar work by Shen, Nie and Zhang (2007) for path marginal cost analysis

Case 4: Queue Spillback



Individual extra delay depends on when the vehicle/perturbation flow joins in the queue.

Summary

1. Integrated path-based OD demand estimation formulation

2. Gradient-based path flow adjustment process

3. Derive theoretically sound partial derivatives of link flow, density and travel time with respect to path flow perturbations

Mathematical Details: Gradient Based Formulation

Adjust path flow on each path based on generalized gradient/Cost

$$r_{(w,\tau,p)}^{(m+1)} = \max\Big\{0, r_{(w,\tau,p)}^{(m)} - \gamma^{(m)}\Big[\beta_d \nabla f(r)\big|_{r=r^{(m)}} + \beta_q \nabla h^q(r)\big|_{r=r^{(m)}} + \beta_k \nabla h^q(r)\big|_{r=r^{(m)}} + \nabla h^T(r)\big|_{r=r^{(m)}} + \lambda^{(n)} g(r,\pi)\big|_{r=r^{(m)}}\Big]\Big\}$$

Individual gradients with respect to path flow adjustment

$$\nabla f(r) = \frac{\partial f(r)}{\partial r_{(w,\tau,p)}} = 2\Big(\sum_{\tau\in H_d}\sum_{p\in P} r_{(w,\tau,p)} - \bar{d}_{(w)}\Big)$$

$$\nabla h^q(r) = \frac{\partial h^q(r)}{\partial r_{(w,\tau,p)}} = 2\sum_{t\in H_o}\sum_{a\in S}\Big\{\big[q_{(a,t)}(r) - \bar{q}_{(a,t)}\big] \times \frac{\partial q_{(a,t)}(r)}{\partial r_{(w,\tau,p)}}\Big\}$$

$$\nabla h^k(r) = \frac{\partial h^k(r)}{\partial r_{(w,\tau,p)}} = 2\sum_{t\in H_o}\sum_{a\in S}\Big\{\big[k_{(a,t)}(r) - \bar{k}_{(a,t)}\big] \times \frac{\partial k_{(a,t)}(r)}{\partial r_{(w,\tau,p)}}\Big\}$$

$$\nabla h^T(r) = \frac{\partial h^T(r)}{\partial r_{(w,\tau,p)}} = 2\sum_{t\in H_o}\sum_{a\in S}\Big\{\big[T_{(a,t)}(r) - \bar{T}_{(a,t)}\big] \times \frac{\partial T_{(a,t)}(r)}{\partial r_{(w,\tau,p)}}\Big\}$$

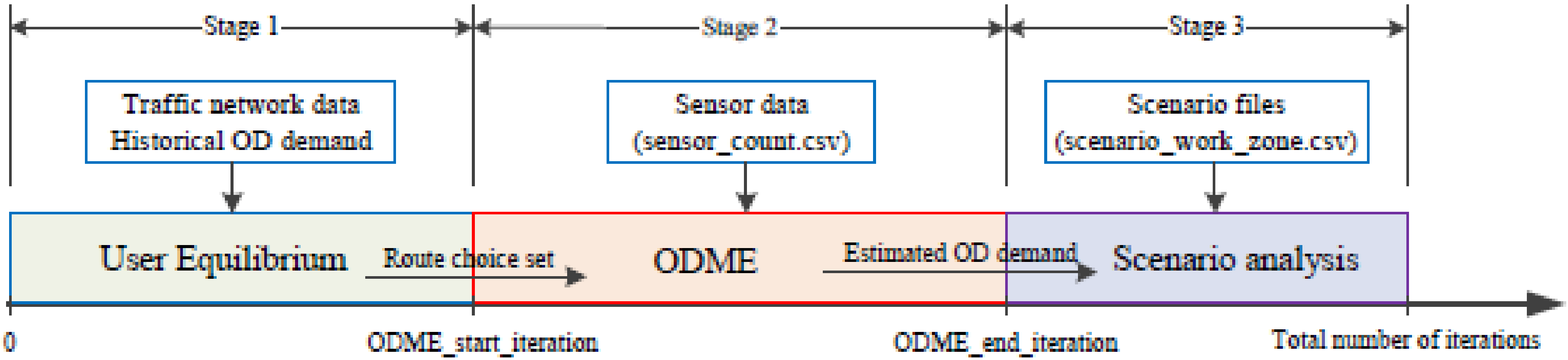
$$\nabla g(r,\pi) = \frac{\partial g(r,\pi)}{\partial r_{(w,\tau,p)}} = c_{(w,\tau,p)}(r) - \pi_{(w,\tau)} + r_{(w,\tau,p)}\frac{\partial c_{(w,\tau,p)}(r)}{\partial r_{(w,\tau,p)}}$$

Calculated based on the spatial queue model

6.1 OD Matrix Estimation Scenario

The process of one simulation for scenario analysis using estimated OD demand

- For performing scenario analysis, such as work zone, incident, ramp metering, etc., the travel demand should be calibrated in advance.
- In this section, the integration of the two parts above is realized in DTALite through just one simulation, the process of which can be illustrated in the following Figure



6.1 OD Matrix Estimation Scenario

Step 1: Build a Basic Network and Prepare Necessary Input Files for Basic Scenario

- Input_link.csv file

- Set count sensor ID to “origin node -> destination node”
- Set speed sensor ID to “origin node -> destination node”

B	C	D	E	F	G	O	P
link_id	from_node_id	to_node_id	direction	length	number_of_lanes	count_sensor_id	speed_sensor_id
1285	1285	5018	1	0.2384	7	1285->5018	1285->5018
1286	1286	11125	1	0.466	7	1286->11125	1286->11125
1289	1289	4952	1	0.2427	7	1289->4952	1289->4952
1289	1289	5018	1	0.2621	7	1289->5018	1289->5018
1289	1289	11124	1	0.5069	7	1289->11124	1289->11124
1289	1289	11125	1	0.5047	7	1289->11125	1289->11125
1290	1290	4952	1	0.2516	7	1290->4952	1290->4952
1296	1296	5240	1	0.2056	7	1296->5240	1296->5240
1299	1299	4958	1	0.1988	7	1299->4958	1299->4958
1299	1299	11129	1	0.3637	7	1299->11129	1299->11129
1314	1314	11146	1	0.2758	7	1314->11146	1314->11146
1316	1316	11148	1	0.2608	7	1316->11148	1316->11148
1318	1318	11160	1	0.2384	7	1318->11160	1318->11160
1319	1319	11124	1	0.2054	7	1319->11124	1319->11124
1320	1320	5820	1	0.3445	7	1320->5820	1320->5820
1320	1320	11148	1	0.2527	7	1320->11148	1320->11148
1322	1322	5589	1	0.2229	7	1322->5589	1322->5589
1322	1322	11161	1	0.267	7	1322->11161	1322->11161
1323	1323	5592	1	0.2697	7	1323->5592	1323->5592

6.1 OD Matrix Estimation Scenario

Step 1: Build a Basic Network and Prepare Necessary Input Files for Basic Scenario

- Input_scenario_setting.csv file
- so at least 30 iterations are required for the path flow adjustment for ODME
- Specify traffic assignment method to “3>ODME”

E	F	G
traffic_flow_model	signal_representation_model	traffic_assignment_method
1	0	3

6.1 OD Matrix Estimation Scenario

Step 1: Build a Basic Network and Prepare Necessary Input Files for Basic Scenario

- Input_scenario_setting.csv file
- Specify start and end iteration of ODME (the iteration number indicate that ODME will begin at the 21th iteration and end at the 50th iteration)

H	I	J	K
demand_multiplier	random_seed	ODME_start_iteration	ODME_end_iteration
1	100	20	50

6.1 OD Matrix Estimation Scenario

Step 2: Prepare Specific Input File for Signal Scenario

- Sensor_count.csv file
- Specify count sensor ID, origin node ID and destination node ID of observed links
- Specify observation time period of observed links

A	B	C	D	E	F	G
count_sensor_id	from_node_id	to_node_id	day_no	start_time_in_min	end_time_in_min	link_count
5010->4958	5010	4958	1	990	1050	49.5
4958->5010	4958	5010	1	990	1050	74.5
4952->5022	4952	5022	1	990	1050	221.5
5022->4952	5022	4952	1	990	1050	147.5
5018->5436	5018	5436	1	990	1050	634
5436->5018	5436	5018	1	990	1050	951
4804->5109	4804	5109	1	990	1050	107
5109->4804	5109	4804	1	990	1050	160.5

6.1 OD Matrix Estimation Scenario

Step 2: Prepare Specific Input File for Signal Scenario

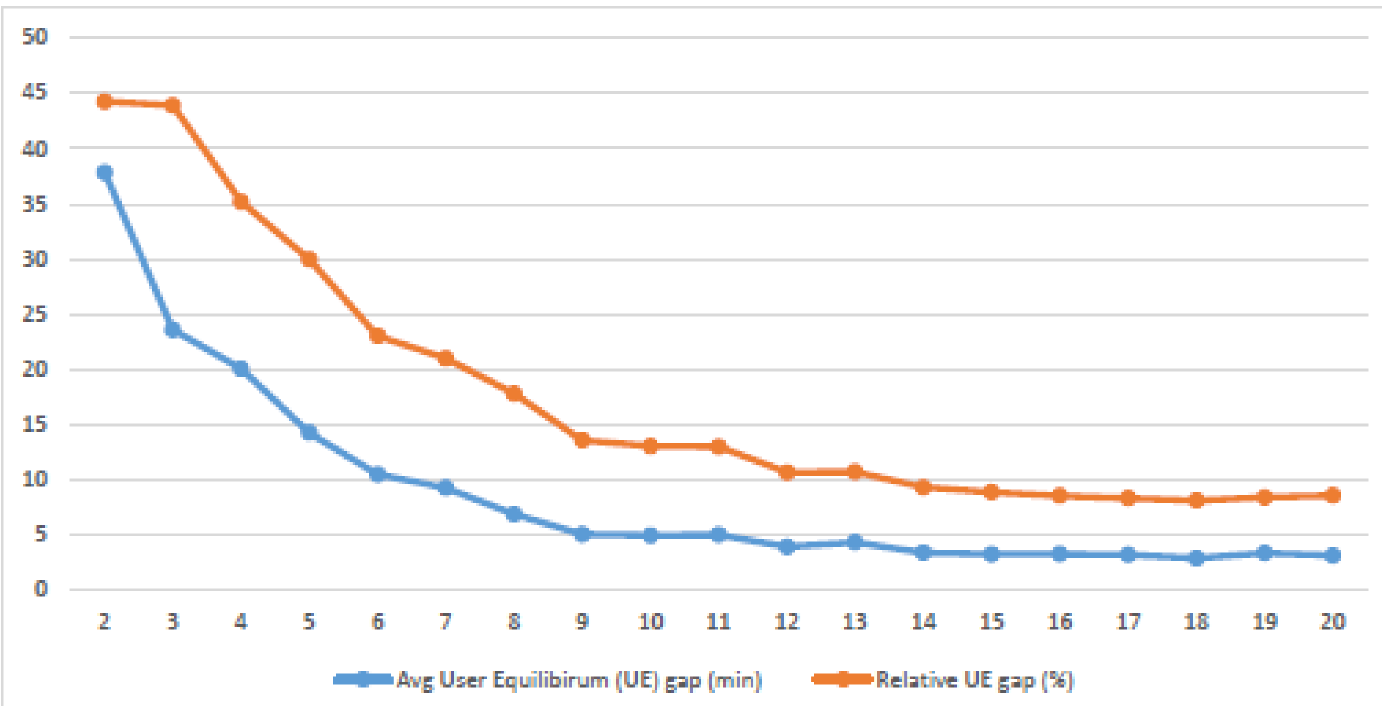
- Sensor_speed.csv file
- Specify count sensor ID, origin node ID and destination node ID of observed links
- Specify observation speed of observed links

A	B	C	D	E	F	G
speed_sensor_id	from_node_id	to_node_id	day_no	start_time_in_min	end_time_in_min	speed
5010->4958	5010	4958	1	990	1050	60
4958->5010	4958	5010	1	990	1050	60
4952->5022	4952	5022	1	990	1050	60
5022->4952	5022	4952	1	990	1050	60
5018->5436	5018	5436	1	990	1050	60
5436->5018	5436	5018	1	990	1050	60
4804->5109	4804	5109	1	990	1050	60
5109->4804	5109	4804	1	990	1050	60
6270->6273	6270	6273	1	990	1050	60
6273->6270	6273	6270	1	990	1050	60
5103->5820	5103	5820	1	990	1050	60
5820->5103	5820	5103	1	990	1050	60
5113->11148	5113	11148	1	990	1050	60
11148->5113	11148	5113	1	990	1050	60
6185->8172	6185	8172	1	990	1050	60

6.1 OD Matrix Estimation Scenario

Step 3: Run Simulation and Perform Analysis

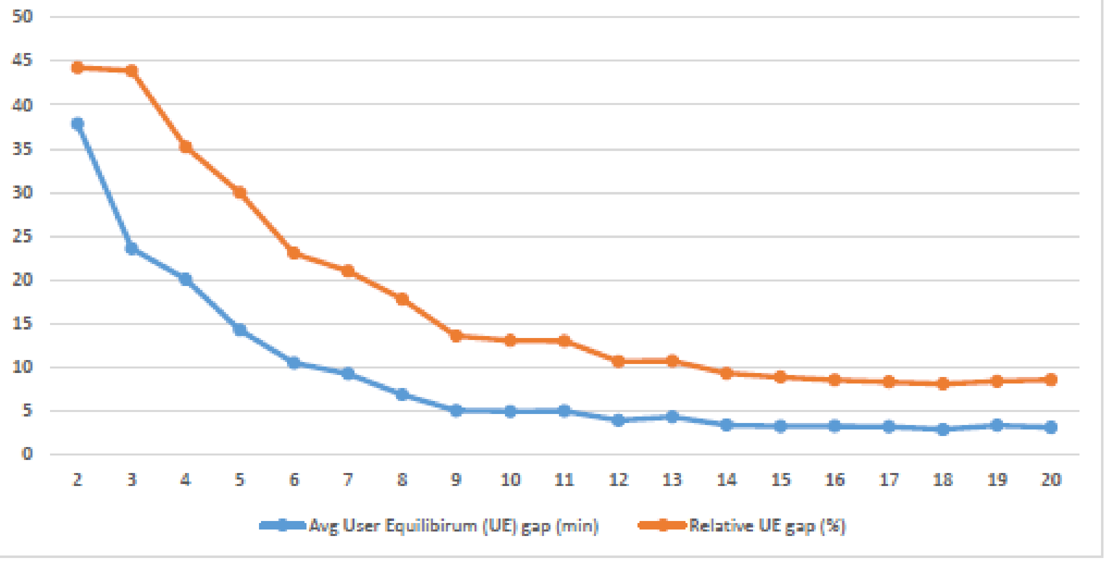
- checking output_summary.csv file, users can better understand the process of ODME in DTALite.



6.1 OD Matrix Estimation Scenario

Step 3: Run Simulation and Perform Analysis

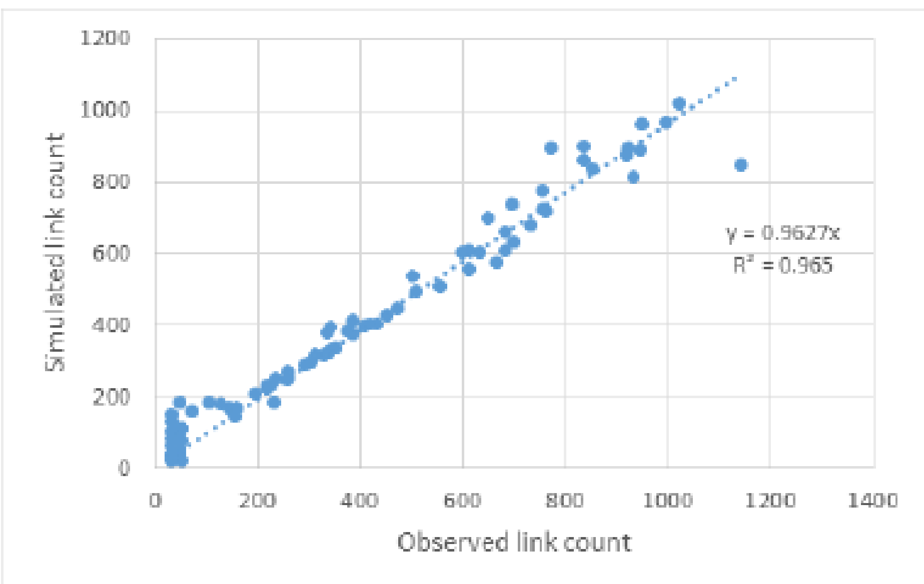
- For the first 20 iterations, a standard dynamic user equilibrium method, MAS, is used.
- It is expected to see the UE gap (Avg User Equilibirum (UE) gap (min) and Relative UE gap (%)) dramatically decreases and finally reach a stable state,



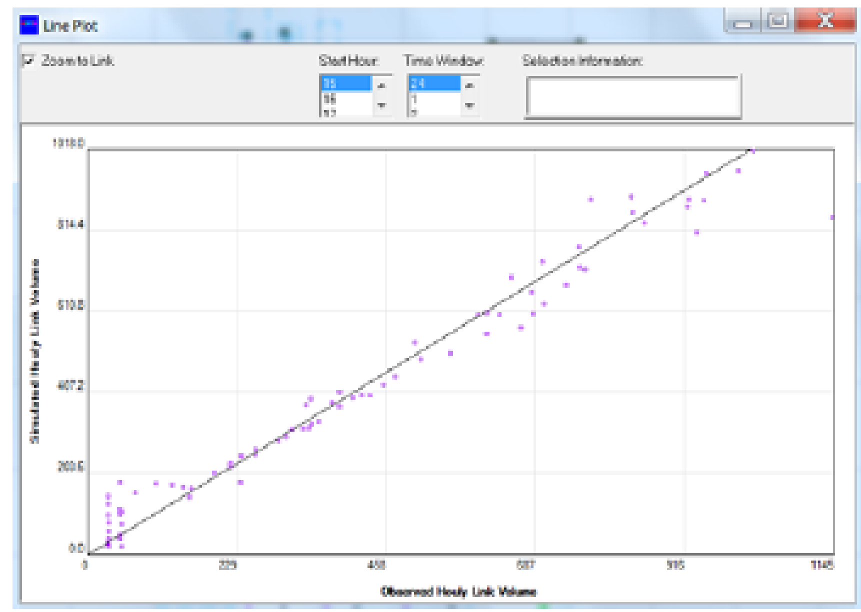
6.1 OD Matrix Estimation Scenario

Step 3: Run Simulation and Perform Analysis

- Comparison result between observed link count and simulated link count after ODME



(a) comparison result in Excel



(b) comparison result in NeXTA

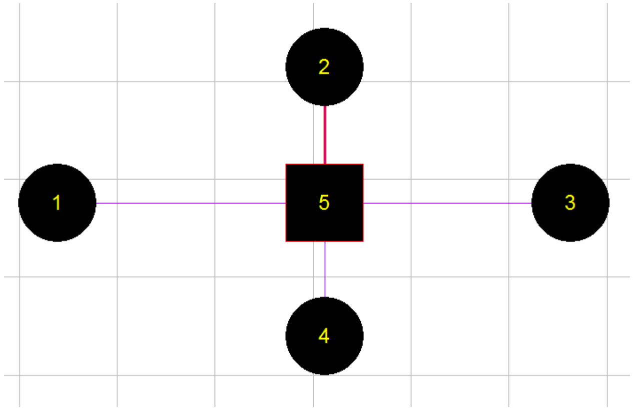
Module 7
Signalized Intersections Modeling

7.1 Link Based Signal Representation Model
7.2 Phase Based Signal Representation Model
7.3 Importing data from Synchro to DTALite
7.4. QEM (Signal Quick Estimation Method) Application to Generate signal timing data

7.1 Link Based Signal Representation Model

Step 1: Build a Basic Network and Prepare Necessary Input Files for Basic Scenario

- Input_node.csv
- Set the control type of signal intersections to signalized type
- (e.g., the control type of node 5 is set to “pretimed signal” in this case)

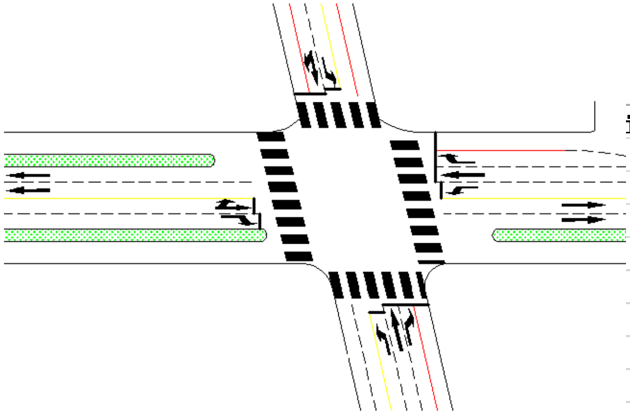


B	C	D	E	F	G
node_id	control_type	control_type_name	x	y	geometry
1	0	unknown_control	16.97894	23.79017	<Point><coordinate
5	5	pretimed_signal	30.58159	23.79017	<Point><coordinate
3	0	unknown_control	43.16913	23.79017	<Point><coordinate
2	0	unknown_control	30.58159	30.69301	<Point><coordinate
4	0	unknown_control	30.58159	16.98884	<Point><coordinate

7.1 Link Based Signal Representation Model

Step 1: Build a Basic Network and Prepare Necessary Input Files for Basic Scenario

- Input_link.csv
- Specify the number of left-turn lanes (including separated left-turn lanes and shared left-turn lanes)



B	C	D	E	F	G	H
ink_id	from_node	to_node_i	directior	length	number_of_lanes	number_of_leftturn_lanes
1	1	5	1	0.625	2	1
2	5	3	1	0.625	2	
3	2	5	1	0.625	2	1
4	5	2	1	0.625	1	
5	5	4	1	0.625	1	
6	4	5	1	0.625	3	1
7	3	5	1	0.625	3	1
8	5	1	1	0.625	2	

7.1 Link Based Signal Representation Model

Step 1: Build a Basic Network and Prepare Necessary Input Files for Basic Scenario

- Input_scenario_setting.csv
- Set traffic flow model to “2> Spatial Queue Model”
- Set signal representation model to “1> link based signal

A	B	C	D	E	F
scenario	scenari	number_of_iterations	traffic_flow_model	signal_representation_model	traffic_analysis_method
1	test1	1	2	1	0

7.1 Link Based Signal Representation Model

Step 2: Prepare Specific Input File for Signal Scenario

- Input_movement.csv
- Specify left-turn type movements and through-type movements which are required

node_id	up_node_id	dest_node_id	name	turn_type	prohibited_flag
5	1	2		Left	0
5	2	3		Left	0
5	3	4		Left	0
5	4	1		Left	0
5	1	3		Through	0
5	2	4		Through	0
5	3	1		Through	0
5	4	2		Through	0
5	1	4		Right	0
5	2	1		Right	0
5	3	2		Right	0
5	4	3		Right	0

7.1 Link Based Signal Representation Model

Step 2: Prepare Specific Input File for Signal Scenario

- Input_signal.csv
- the number of phase plan
- starting time(in seconds), ending time(in seconds), cycle length(in seconds) and offset (in seconds) of each signal plan

A	B	C	D	E	F	G
from_node	to_node	plan_no	plan_startime_in_sec	plan_endtime_in_sec	to_node_cycle_in_sec	to_node_offset_in_sec
1	5	1	1	1200	190	0
2	5	1	1	1200	190	0
3	5	1	1	1200	190	0
4	5	1	1	1200	190	0
1	5	2	1200	864000	120	0
2	5	2	1200	864000	120	0
3	5	2	1200	864000	120	0
4	5	2	1200	864000	120	0

7.1 Link Based Signal Representation Model

Step 2: Prepare Specific Input File for Signal Scenario

- Input_signal.csv
- saturation flow(per hour per lane), start time(in seconds) and end time(in seconds) for through-type movement and left-turned movement

A	B	C	D	E	F	G
from_node	to_node	plan_no	plan_startime_in_sec	plan_endtime_in_sec	to_node_cycle_in_sec	to_node_offset_in_sec
1	5	1	1	1200	190	0
2	5	1	1	1200	190	0
3	5	1	1	1200	190	0
4	5	1	1	1200	190	0
1	5	2	1200	864000	120	0
2	5	2	1200	864000	120	0
3	5	2	1200	864000	120	0
4	5	2	1200	864000	120	0

Step 3: Run Simulation

7.2 Phase Based Signal Representation Model

Step 1: Build a Basic Network and Prepare Necessary Input Files for Basic Scenario

- Input_node.csv
- Input_link.csv
- Setup data in these two files the same as “7.1 Link Based Signal Representation Model”

7.2 Phase Based Signal Representation Model

Step 2: Parameter settings in key simulation configuration files

- Input_movement.csv
- Movement id
- turn direction

movement_id	node_id	up_node_id	dest_node_id	name	turn_type	turn_direction	prohibited_flag
1-5-2-L	5	1	2	WBL	Left	WBL	0
1-5-3-T	5	1	3	WBT	Through	WBT	0
1-5-4-R	5	1	4	WBR	Right	WBR	0
2-5-3-L	5	2	3	NBL	Left	NBL	0
2-5-4-T	5	2	4	NBT	Through	NBT	0
2-5-1-R	5	2	1	NBR	Right	NBR	0
3-5-4-L	5	3	4	EBL	Left	EBL	0
3-5-1-T	5	3	1	EBT	Through	EBT	0
3-5-2-R	5	3	2	EBR	Right	EBR	0
4-5-1-L	5	4	1	SBL	Left	SBL	0
4-5-2-T	5	4	2	SBT	Through	SBT	0
4-5-3-R	5	4	3	SBR	Right	SBR	0

7.2 Phase Based Signal Representation Model

Step 2: Parameter settings in key simulation configuration files

- input_signal_timing_plan.csv
- Intersection id
- Timing plan number
- Start time and end time of timing plan
- Starting phase
- Offset

[TOD]	int_id	timing_plan_no	from_time	to_time	starting_phase	off_set
	5	1	0	86400	1	11

7.2 Phase Based Signal Representation Model

Step 2: Parameter settings in key simulation configuration files

- input_timing.csv
- Intersection id
- Timing plan number
- Number of phase
- green duration, movement string and movement direction string of phase

[Signal]	int_id	timing_plan_no	phase_id	next_phase	green_duration	movement_str	movement_dir_str
	5	1	1	2	120	1_3_T; 1_2_L; 3_1_T; 3_4_L	WBT; WBL; EBT; EBL;
	5	1	2	1	70	2_4_T; 2_3_L; 4_2_T; 4_1_L	SBT; SBL; NBT; NBL;

7.2 Phase Based Signal Representation Model

Step 3: generate the input_timing_status.csv file with timing_generator.exe
(Contributed by Prof. Pengfei Taylor Li, Currently maintained by the University of Maryland Prof. Lei Zhang's Group)

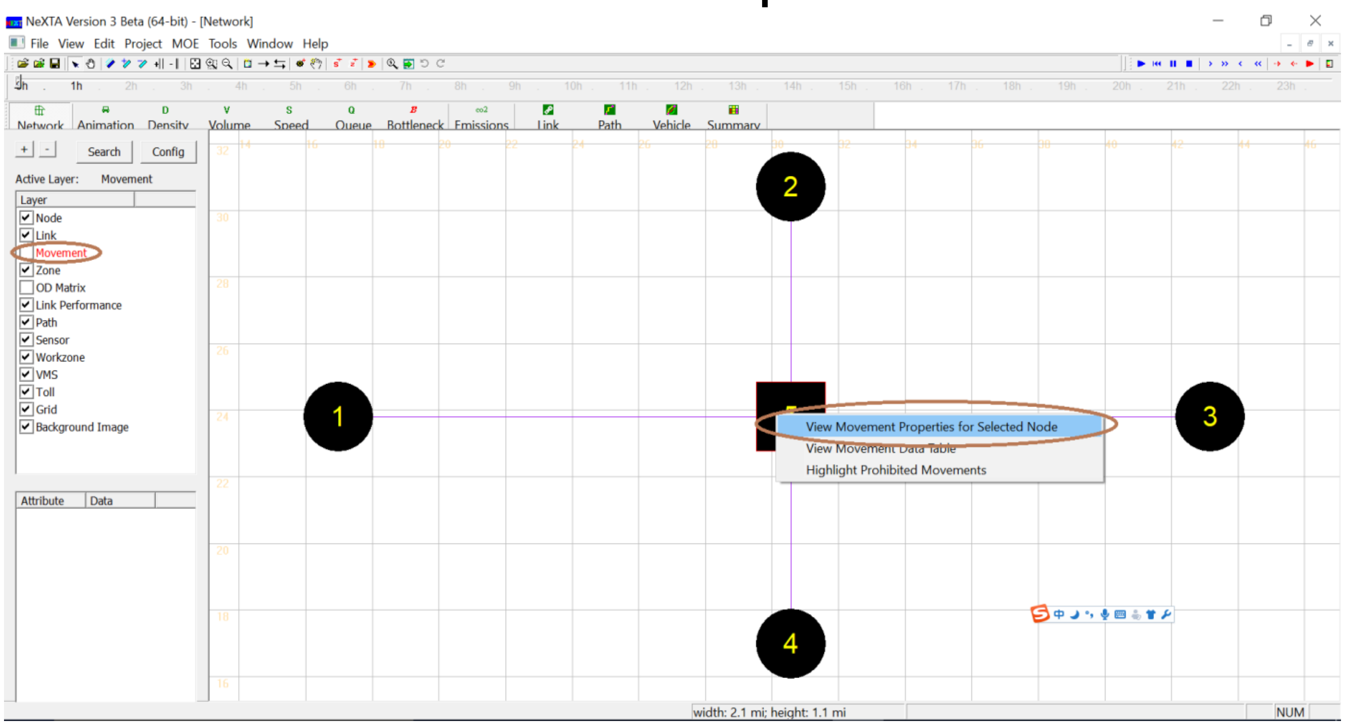
- Required files include input_timing.csv file and input_signal_timing_plan.csv file

movement_str	start_time_in_sec	end_time_in_sec	signal_status	from_node_id	to_node_id	turn_type
1_3_T	0	119	1	1	5	T
1_2_L	0	119	1	1	5	L
3_1_T	0	119	1	3	5	T
3_4_L	0	119	1	3	5	L
2_4_T	120	189	1	2	5	T
2_3_L	120	189	1	2	5	L
4_2_T	120	189	1	4	5	T
4_1_L	120	189	1	4	5	L
…	…	…	…	…	…	…

7.2 Phase Based Signal Representation Model

Step 3: NEXTA GUI instruction

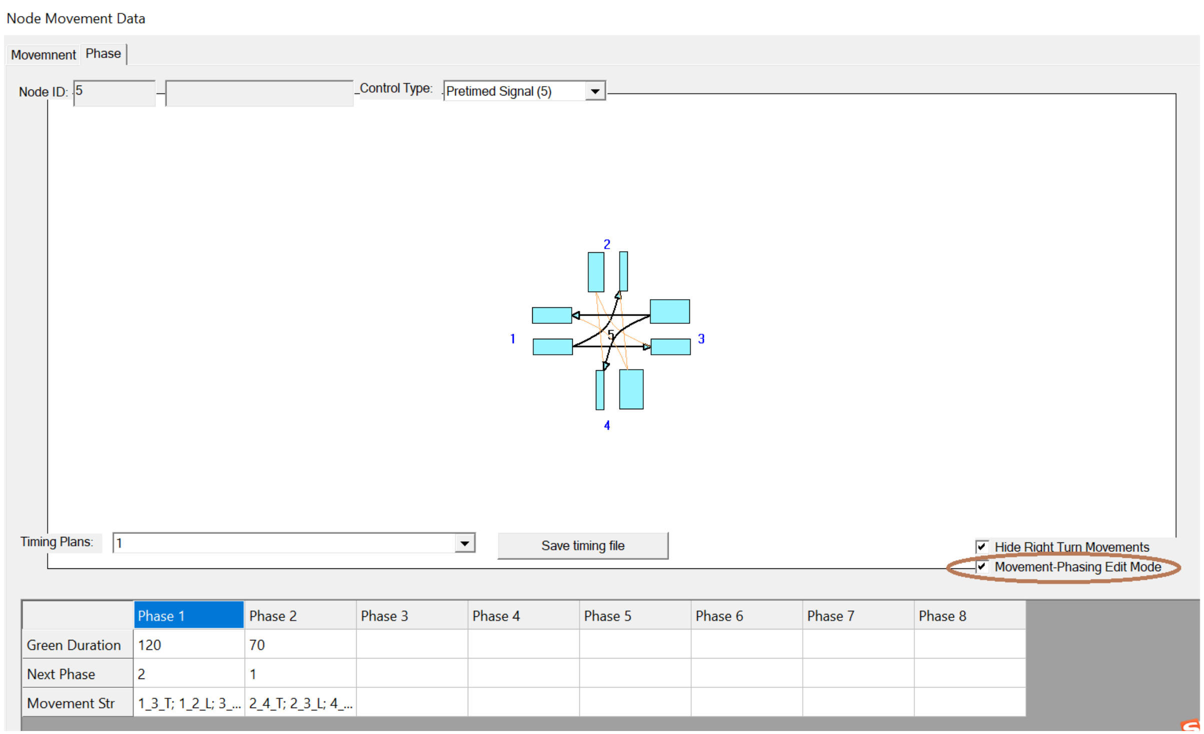
- Load the example project
- Choose the Movement layer -> right click the intersection node -> View Movement Properties for Selected Node.



7.2 Phase Based Signal Representation Model

Step 3: NEXTA GUI instruction

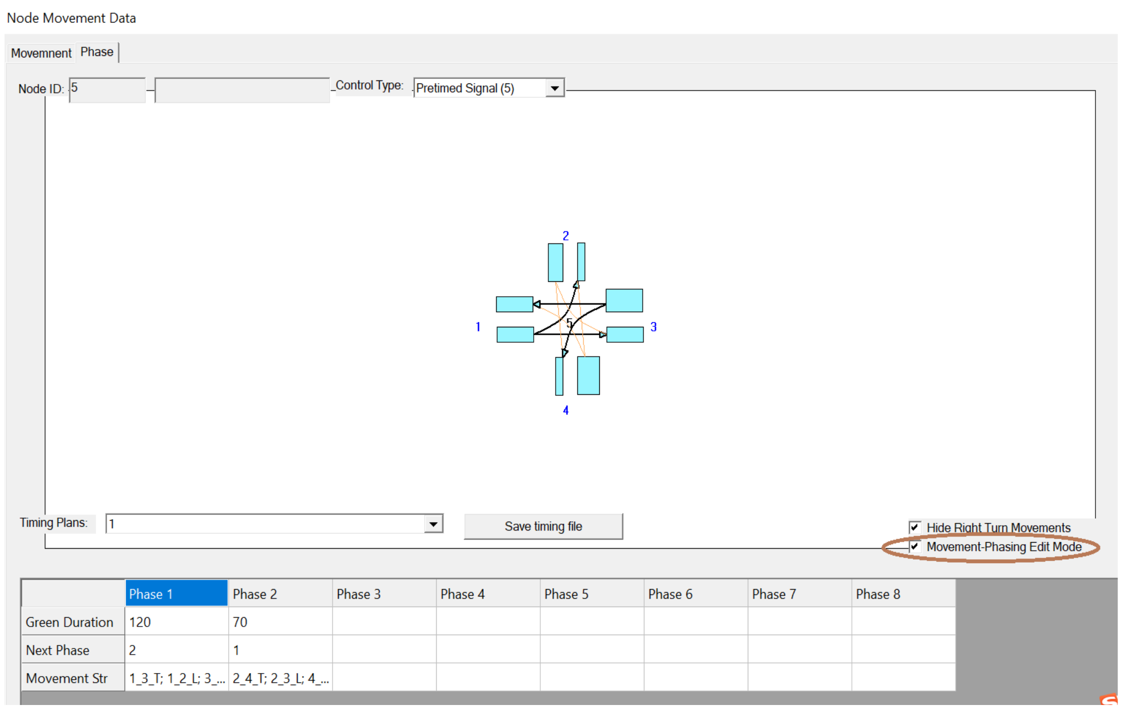
- If this section has the phase plan before, thus we could display them in NEXTA.



7.2 Phase Based Signal Representation Model

Step 4: Add/delete a phase in current phase

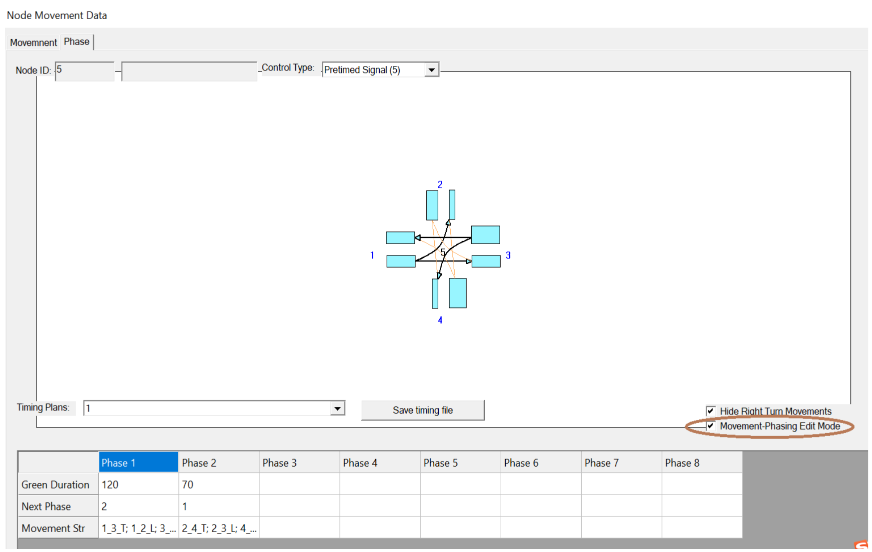
- Add/delete a phase in current phase:
- Check the box before Movement-Phasing Edit Mode
- Double click the phase that you want to add/delete



7.2 Phase Based Signal Representation Model

Step 4: Add/delete a phase in current phase

- then the corresponding movement_str will be changed in the table below
- Click save timing file button, the input_timing file will be updated in the folder.



7.2 Phase Based Signal Representation Model

Step 5: Run Simulation and Perform Analysis

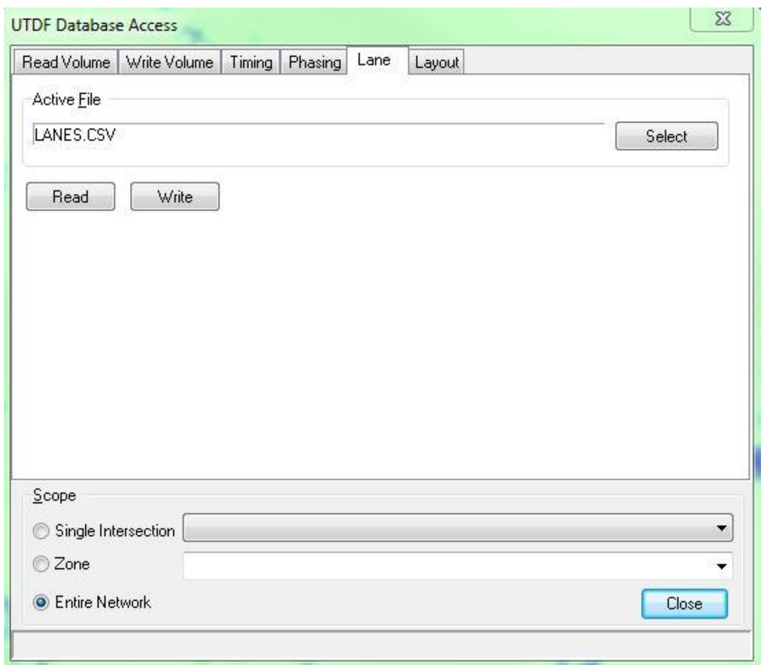
- Input_scenario_setting.csv
- Set traffic flow model to “2> Spatial Queue Model”
- Set signal representation model to “2> phase based signal”

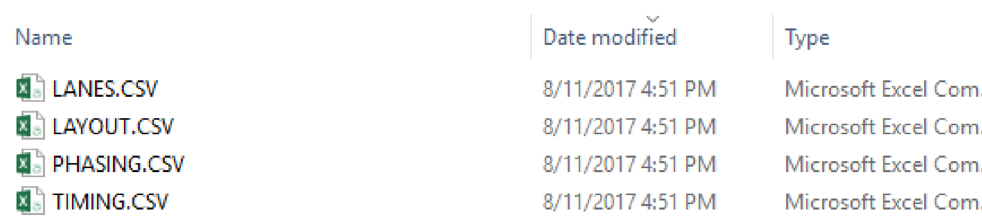
A	B	C	D	E	F
scenario_	scenari	number_of_iterations	traffic_flow_model	signal_representation_model	traffic_analysis_method
1	test1	1	2	2	0

7.3 Importing data from synchro to DTALite

Step 1: Prepare the Synchro dataset

- Export to LANES.cvs, LAYOUT.csv, PHASING.csv and TIMING.CSV (UTDF format).

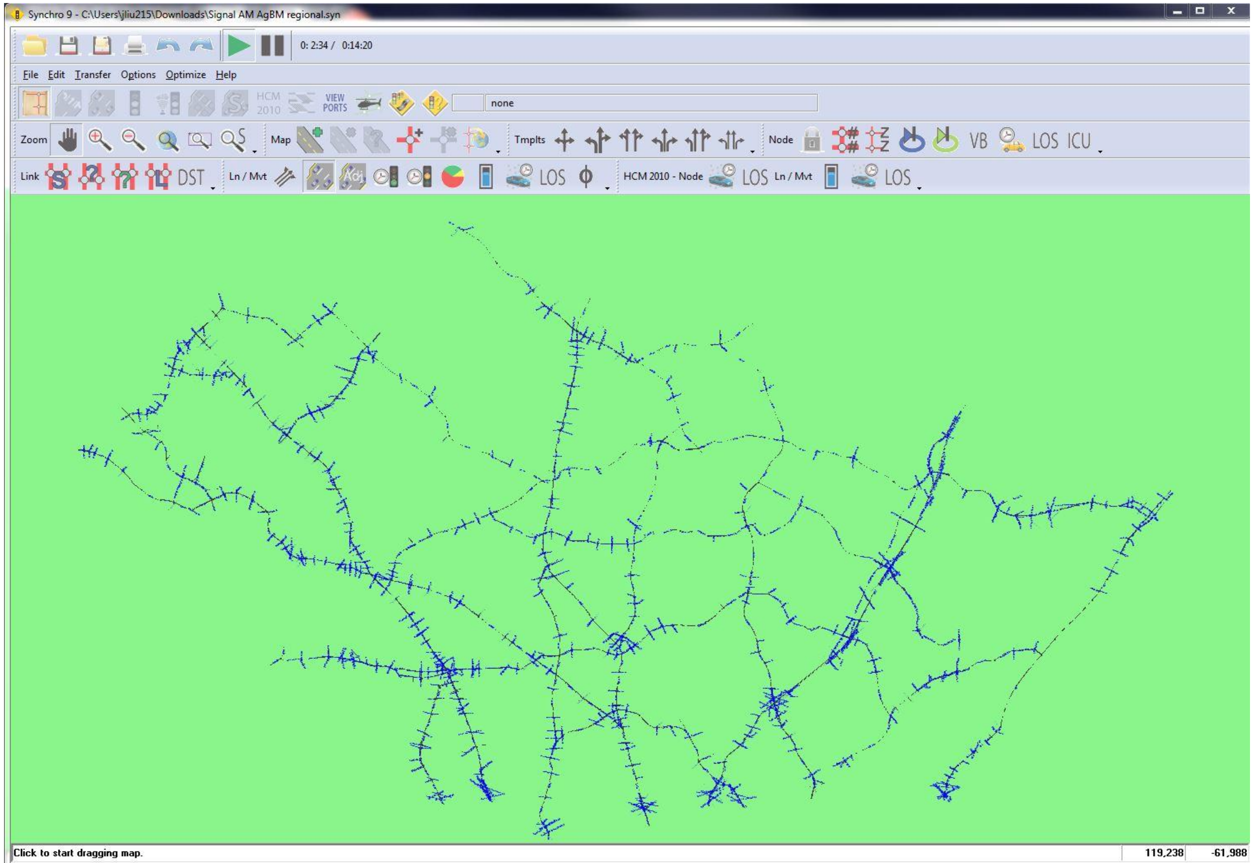




7.3 Importing data from synchro to DTALite

Step 1: Prepare the Synchro dataset

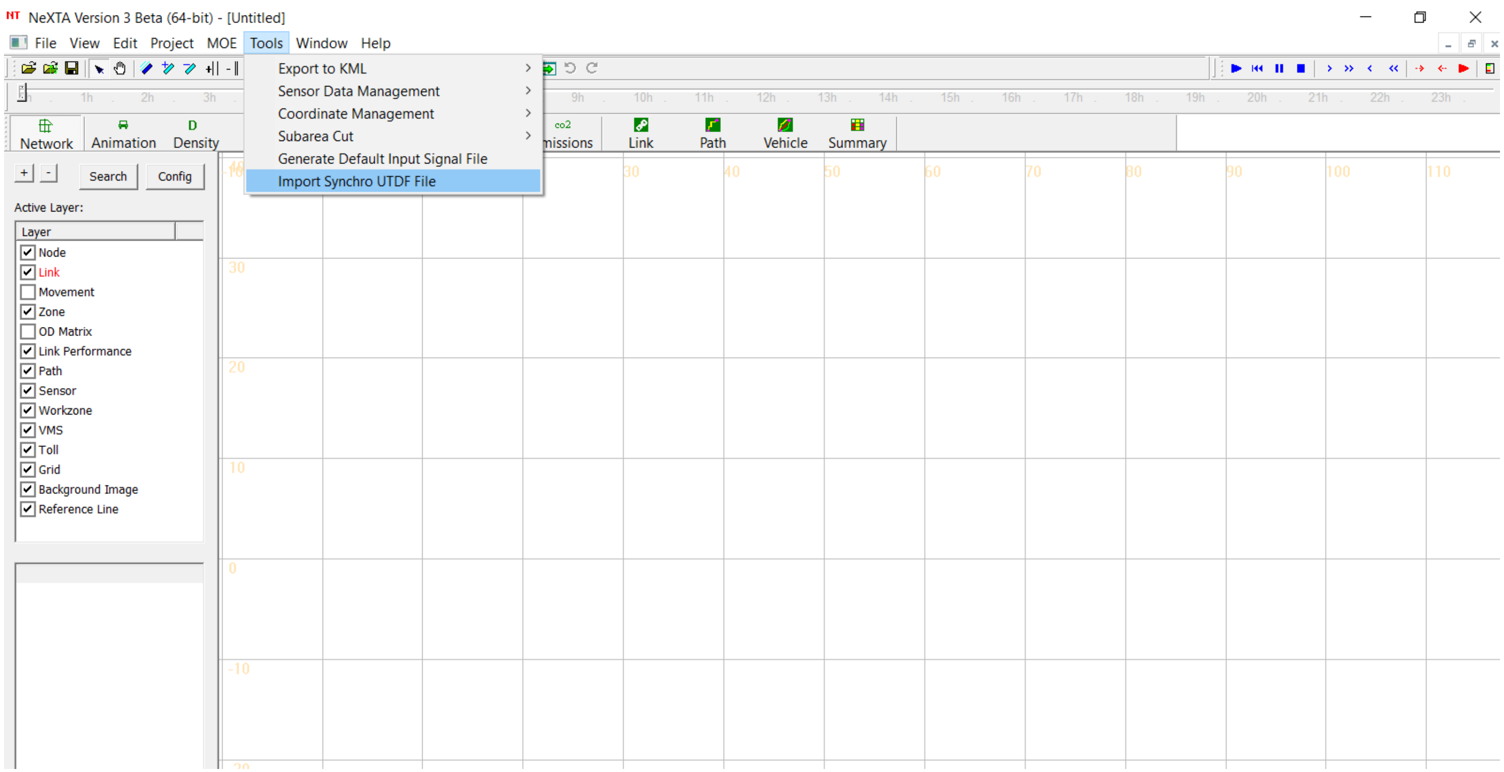
- Export to LANES.cvs, LAYOUT.csv, PHASING.csv and TIMING.CSV (UTDF format).



7.3 Importing data from synchro to DTALite

Step 2: Use nexta to import the synchro UTDF format.

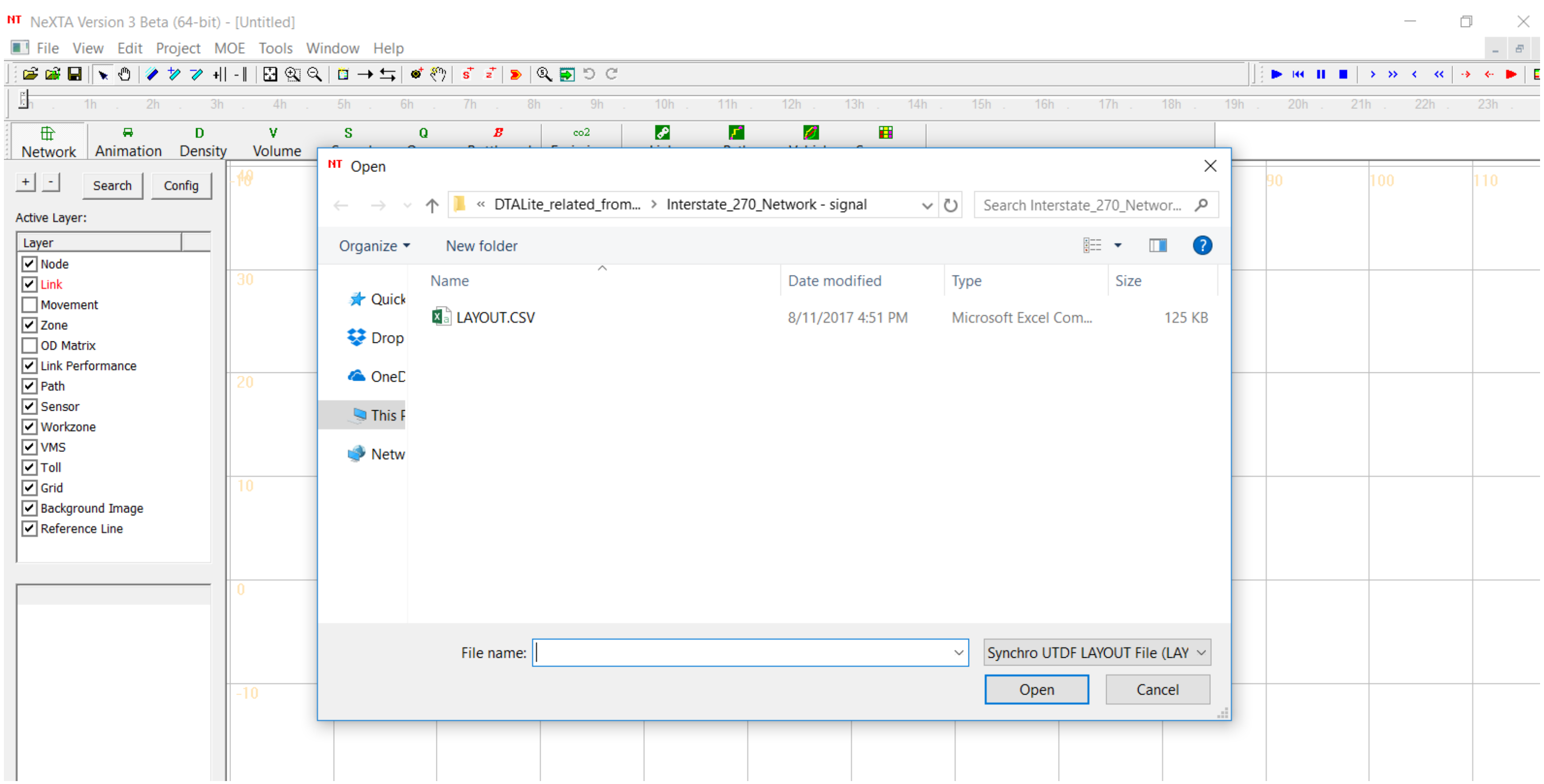
- Open NEXTA, click tools -> Import Synchro UTDF File:



7.3 Importing data from synchro to DTALite

Step 2: Use nexta to import the synchro UTDF format.

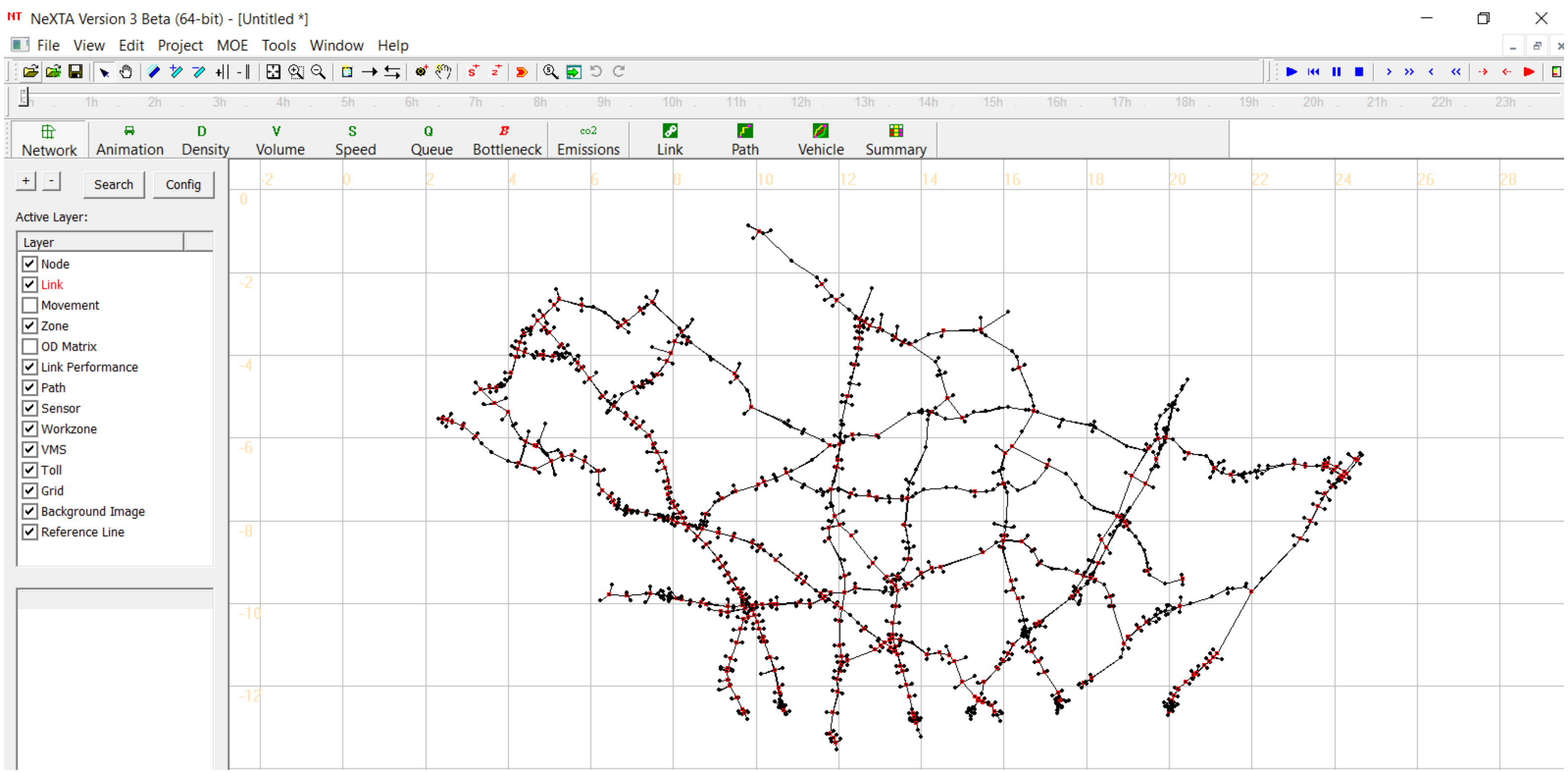
- Open LAYOUT.csv File



7.3 Importing data from synchro to DTALite

Step 2: Use nexta to import the synchro UTDF format.

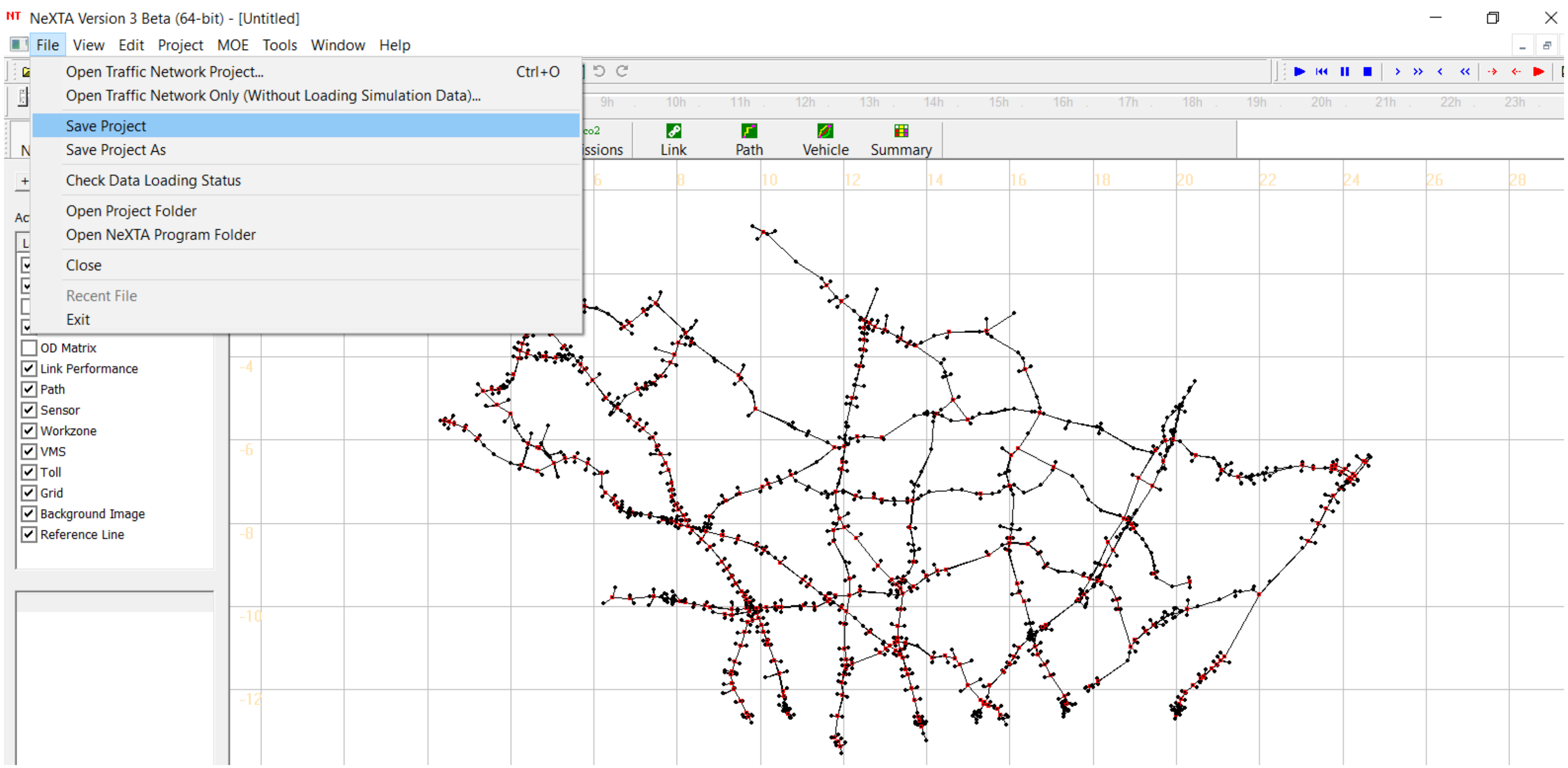
- The synchro data will be imported to NEXTA.



7.3 Importing data from synchro to DTALite

Step 2: Use nexta to import the synchro UTDF format.

- Save the project in the same folder



7.3 Importing data from synchro to DTALite

Step 2: Use nexta to import the synchro UTDF format.

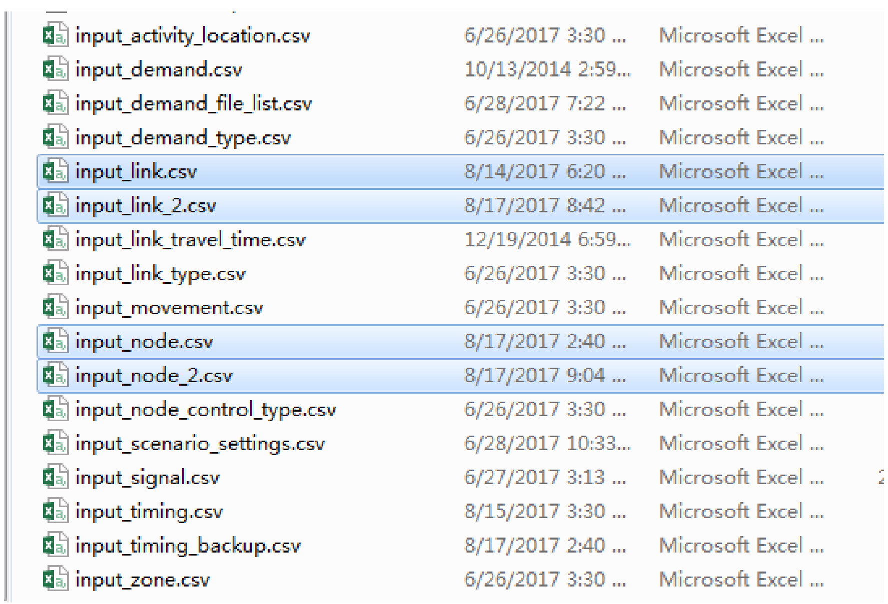
- The network and the signal data will be automatically saved into the folder.

Name	Date modified	Type	Size
input_activity_location.csv	8/13/2017 9:30 PM	Microsoft Excel Com...	1 KB
input_demand_type.csv	8/13/2017 9:30 PM	Microsoft Excel Com...	1 KB
input_link_type.csv	8/13/2017 9:30 PM	Microsoft Excel Com...	1 KB
input_timing_backup.csv	8/13/2017 9:30 PM	Microsoft Excel Com...	76 KB
input_zone.csv	8/13/2017 9:30 PM	Microsoft Excel Com...	1 KB
output_zone.csv	8/13/2017 9:30 PM	Microsoft Excel Com...	1 KB
Scenario_Dynamic_Message_Sign.csv	8/13/2017 9:30 PM	Microsoft Excel Com...	1 KB
Scenario_Link_Based_Toll.csv	8/13/2017 9:30 PM	Microsoft Excel Com...	1 KB
Scenario_Work_Zone.csv	8/13/2017 9:30 PM	Microsoft Excel Com...	1 KB
synchro_270.tnp	8/13/2017 9:30 PM	TNP File	1 KB
input_link.csv	8/13/2017 9:30 PM	Microsoft Excel Com...	827 KB
input_movement.csv	8/13/2017 9:30 PM	Microsoft Excel Com...	306 KB
input_node.csv	8/13/2017 9:30 PM	Microsoft Excel Com...	167 KB
input_node_control_type.csv	8/13/2017 9:30 PM	Microsoft Excel Com...	1 KB
LANES.CSV	8/11/2017 4:51 PM	Microsoft Excel Com...	1,816 KB
LAYOUT.CSV	8/11/2017 4:51 PM	Microsoft Excel Com...	125 KB
PHASING.CSV	8/11/2017 4:51 PM	Microsoft Excel Com...	335 KB
TIMING.CSV	8/11/2017 4:51 PM	Microsoft Excel Com...	17 KB
output_LinkMOE.csv	7/10/2017 2:34 PM	Microsoft Excel Com...	538 KB
output_LinkTDMOE.bin	7/10/2017 2:34 PM	BIN File	44,958 KB
agent.bin	7/10/2017 2:34 PM	BIN File	75,380 KB
input_scenario_settings.csv	6/28/2017 10:33 AM	Microsoft Excel Com...	1 KB
demand.dat	10/13/2014 2:59 AM	DAT File	189 KB
demand_HOV.dat	10/13/2014 2:59 AM	DAT File	189 KB
demand_truck.dat	10/13/2014 2:59 AM	DAT File	189 KB

7.3 Importing data from synchro to DTALite

Step 3: Mapping two networks

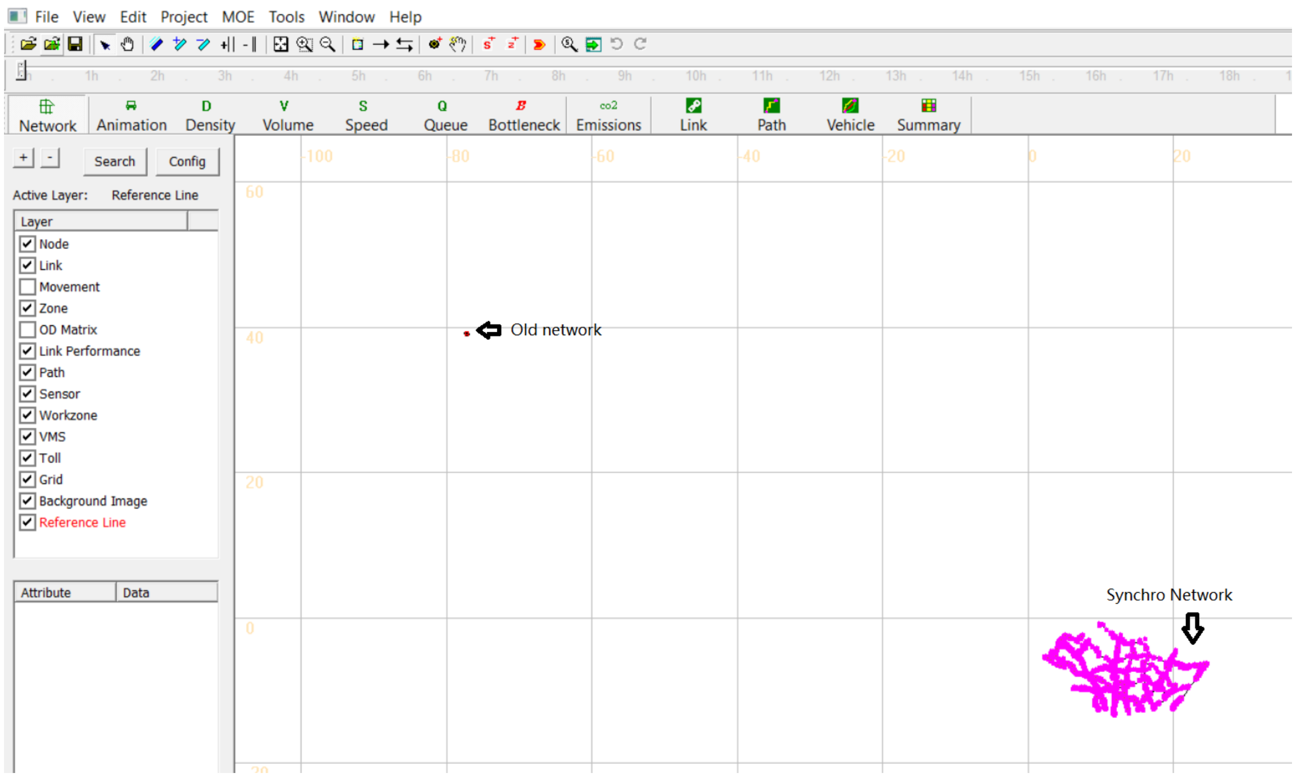
- In this step, we have two networks (a) DTALite main network (b) the imported synchro network in DTALite format.
- Rename the input_node.csv and input_link.csv to input_node_2.csv and input_link_2.csv and copy to our old DTALite network.



7.3 Importing data from synchro to DTALite

Step 3: Mapping two networks

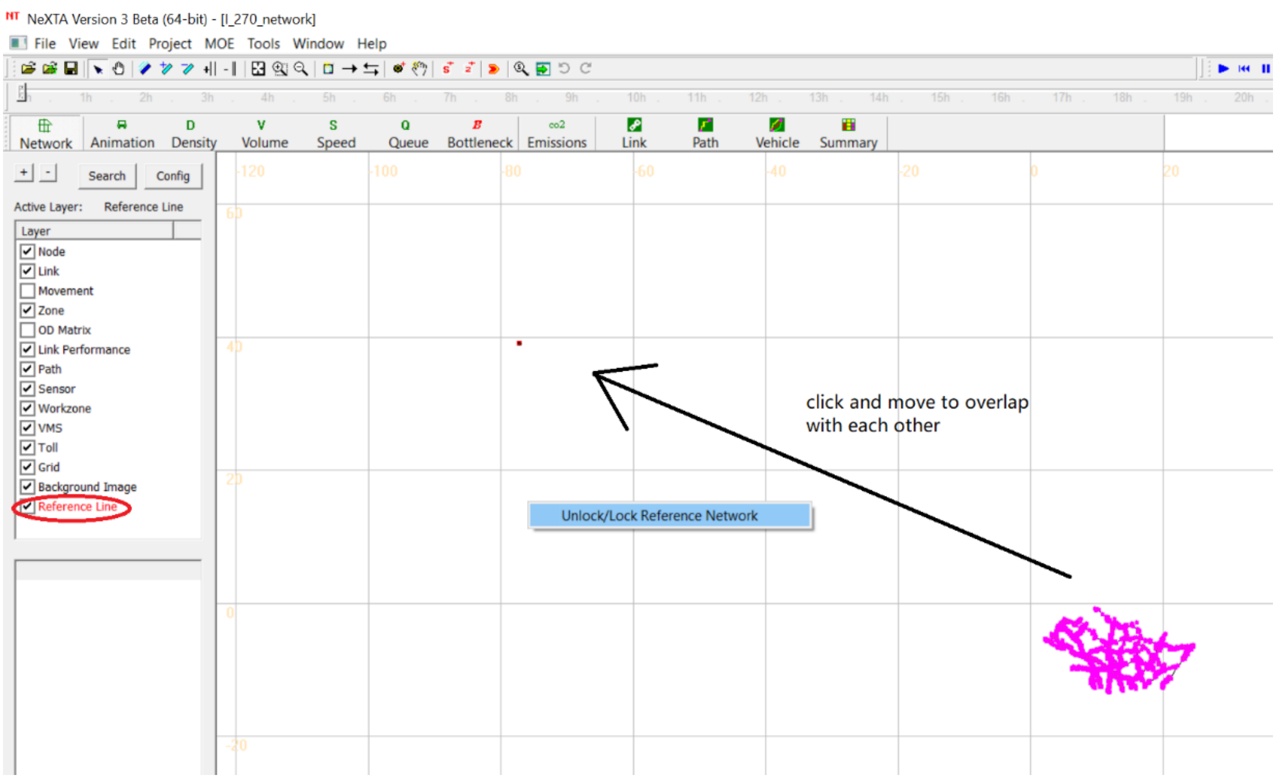
- Then, open the new project in NEXTA.



7.3 Importing data from synchro to DTALite

Step 3: Mapping two networks

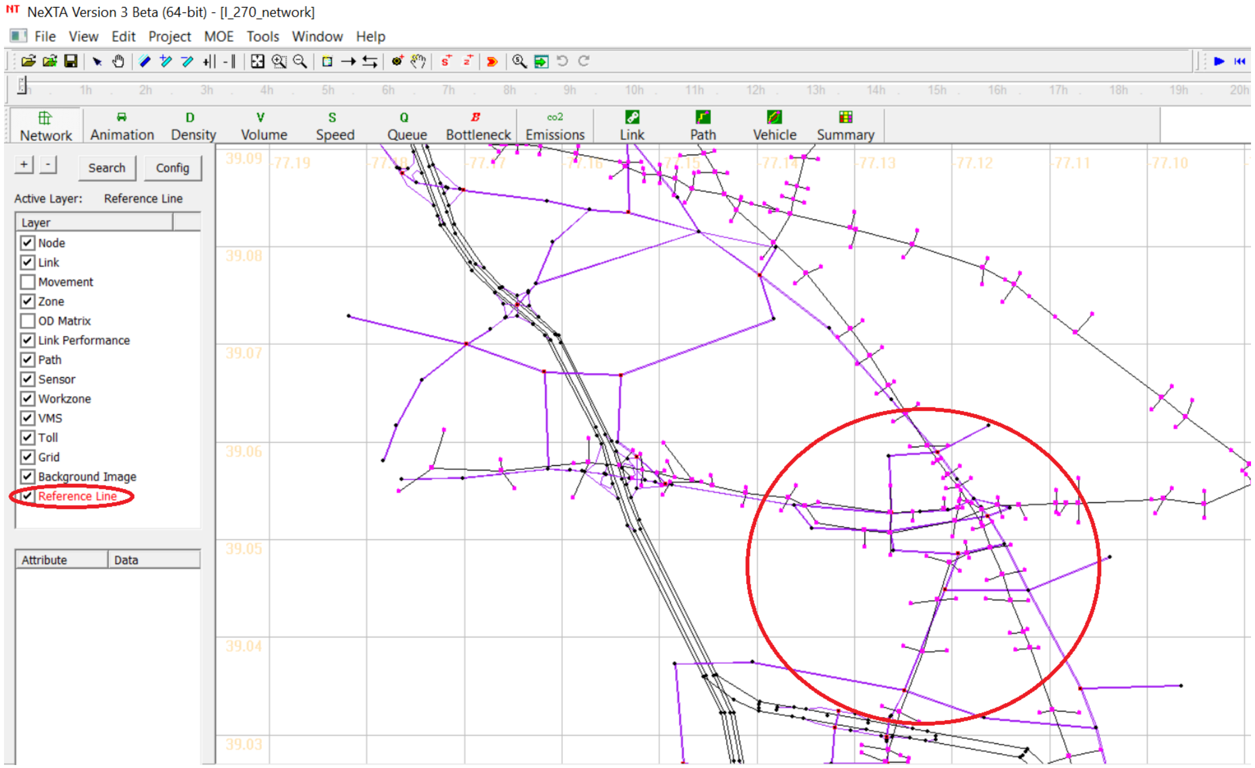
- Use lock/unlock reference network tool in reference line layer



7.3 Importing data from synchro to DTALite

Step 3: Mapping two networks

- Move, zoom in and zoom out imported synchro network



7.3 Importing data from synchro to DTALite

Step 3: Mapping two networks

- But now the node and Link ID of the two networks are different, we need to map them with our old DTALite Network.
- Based on this, we could have the input_node_mapping.csv table generated by ourselves manually.
- (e.g., Node_id_1 is the node id from the old DTALite network, node_id_2 is the mapping node from synchro exported network.)

node_id_1	**node_id_2**
3346	251
3335	1208
3338	1505
…	…

7.3 Importing data from synchro to DTALite

Step 3: Mapping two networks

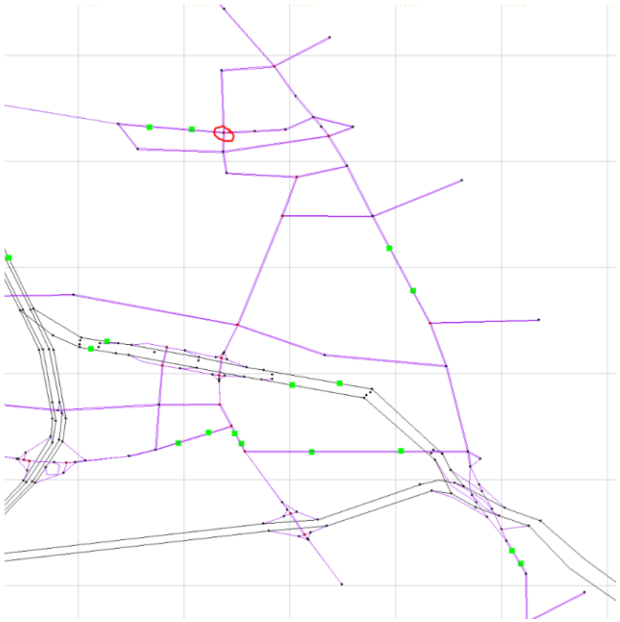
- Get input_node_mapping.csv file in the last step
- Copy the input_timing_2.csv from the Synchro to the new folder.
- Then we could run the simulation of timing_movement_generater.exe and get the result of input_timing_mapping.csv:

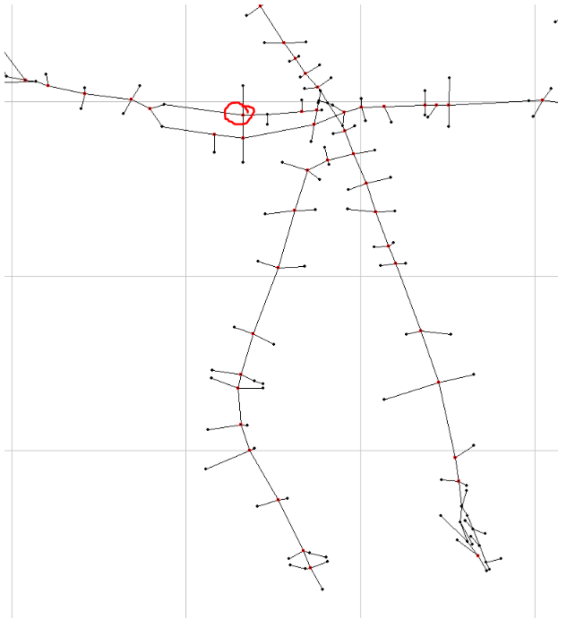
input_node_mapping.csv	8/17/2017 6:12 PM	Microsoft Excel Co...	1 KB
input_timing.csv	8/19/2017 3:55 PM	Microsoft Excel Co...	1 KB
input_timing_2.csv	8/13/2017 9:30 PM	Microsoft Excel Co...	76 KB
input_timing_mapping.csv	8/19/2017 4:04 PM	Microsoft Excel Co...	1 KB

7.3 Importing data from synchro to DTALite

Step 3: Mapping two networks

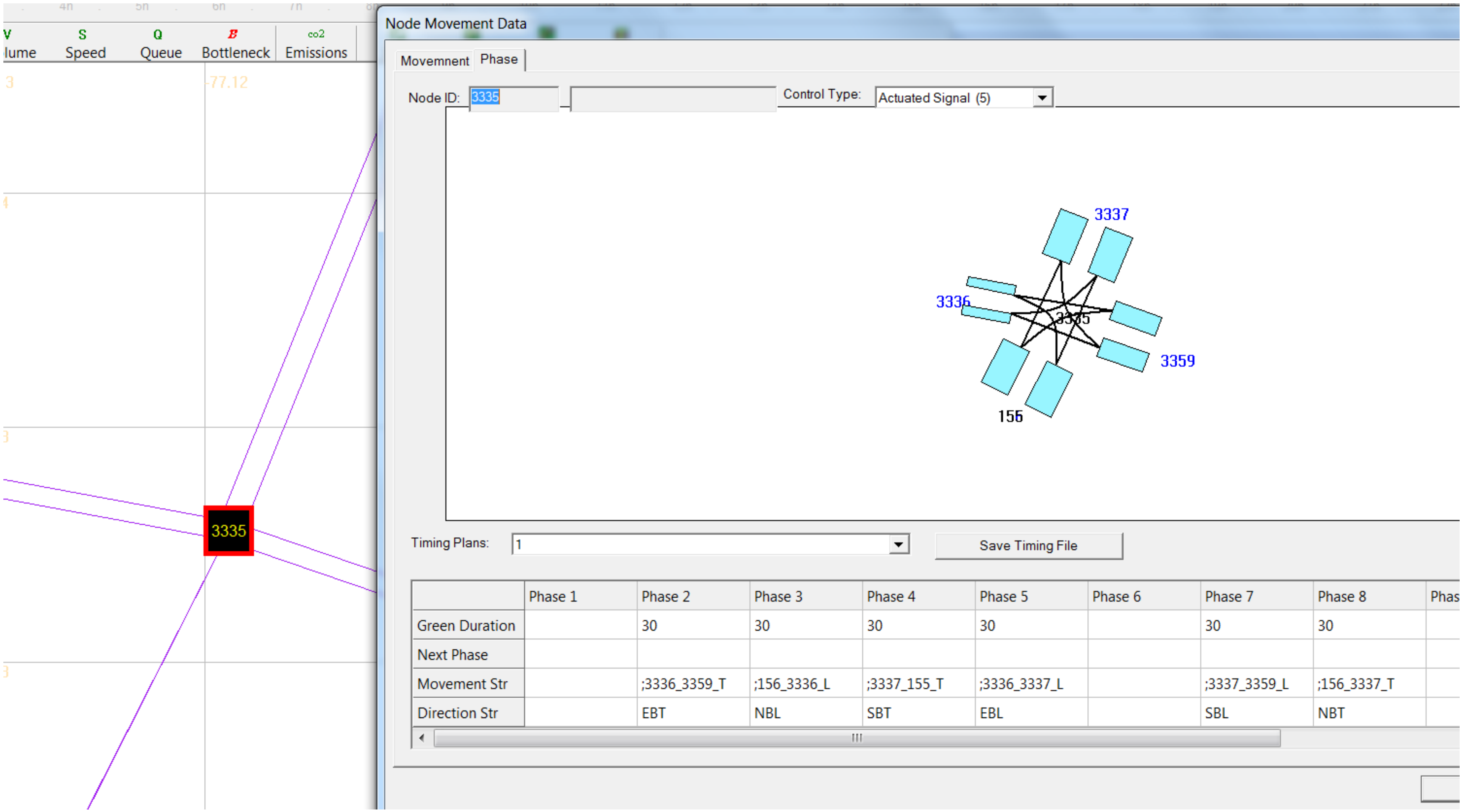
- Verify the input phasing results and add required next phase number. in main DTA network
- Make sure the imported phasing data are correctly display in NEXTA.



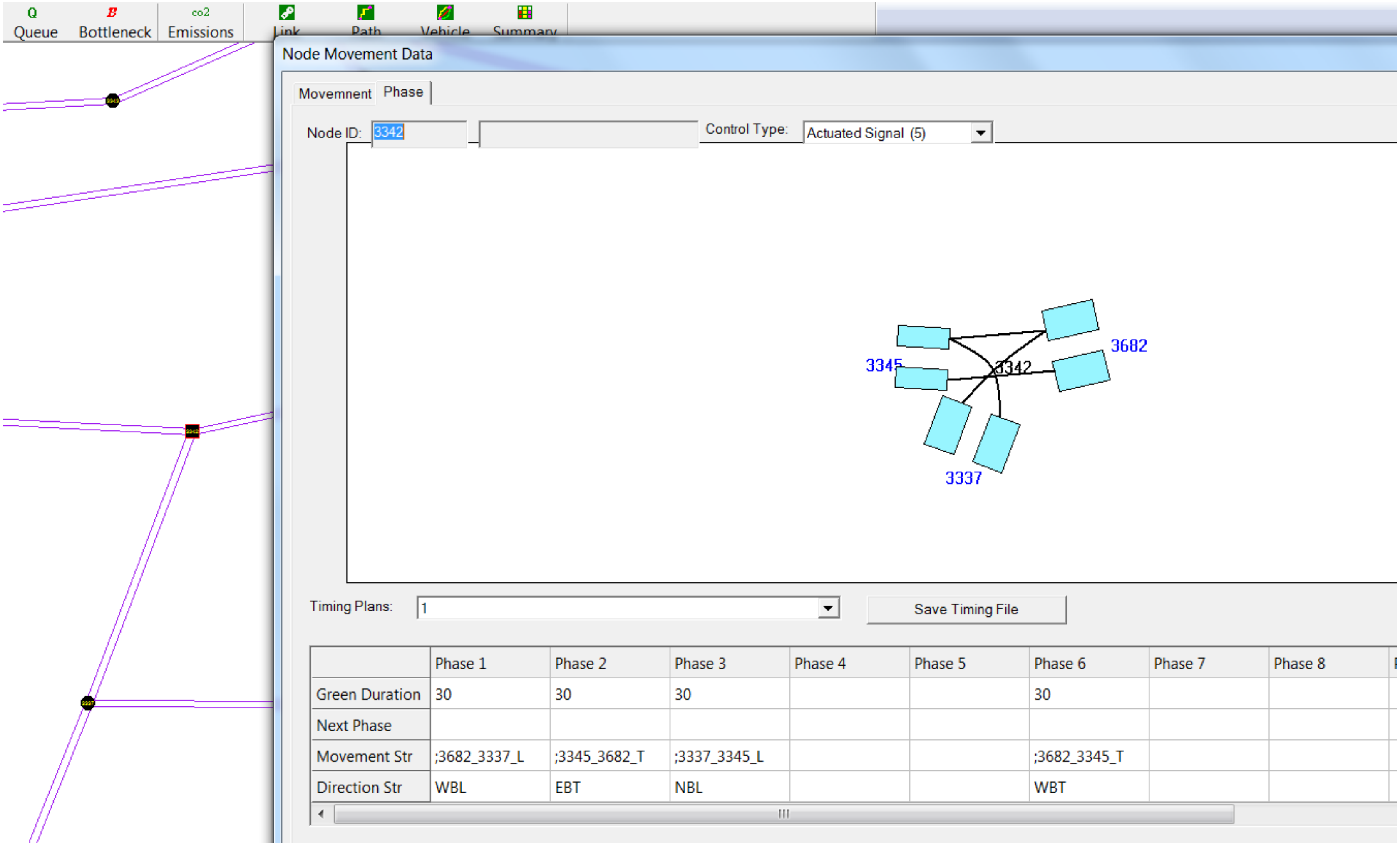


Generate default NEMA phasing for a signalized intersection

- If a node is designated as a pretimed signal, and there is no input timing information provided, then NeXTA can generate the default NEMA phasing

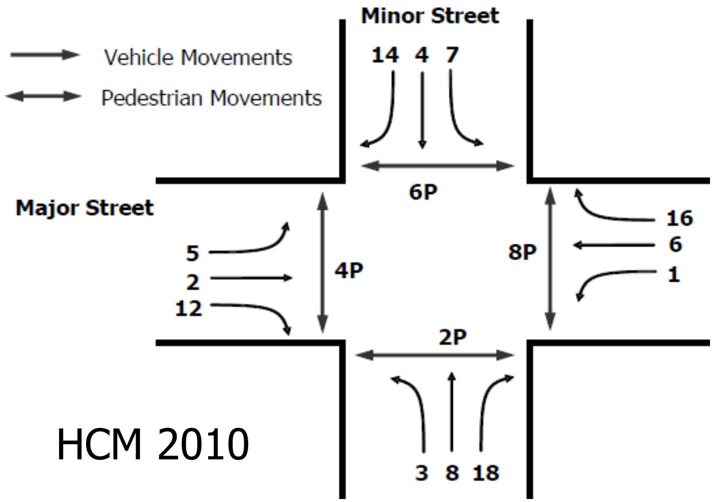


lume
Speed
Queue
Bottleneck
Emissions
3335
Node Movement Data
Movemnent
Phase
Node ID: 3335
Control Type: Actuated Signal (5)
3337
3336
3335
3359
156
Timing Plans: 1
Save Timing File
Phase 1 | Phase 2 | Phase 3 | Phase 4 | Phase 5 | Phase 6 | Phase 7 | Phase 8
Green Duration | 30 | 30 | 30 | 30 | 30 | 30
Next Phase
Movement Str | ;3336_3359_T | ;156_3336_L | ;3337_155_T | ;3336_3337_L | ;3337_3359_L | ;156_3337_T
Direction Str | EBT | NBL | SBT | EBL | SBL | NBT

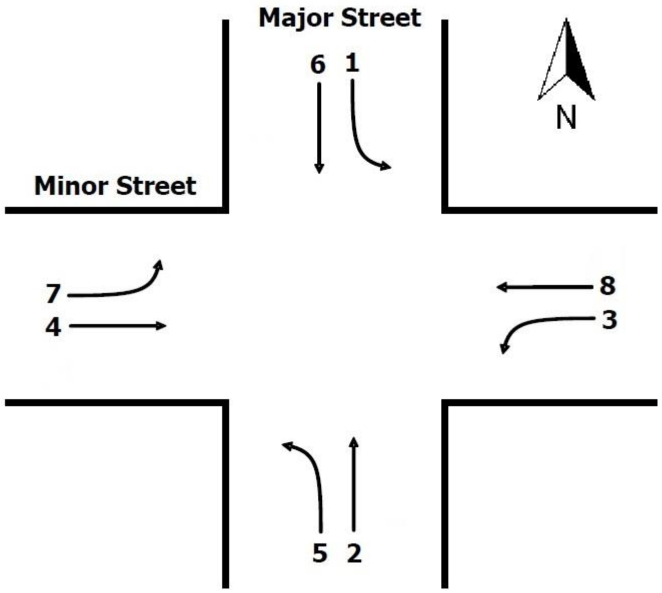


	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5	Phase 6	Phase 7	Phase 8
Green Duration	30	30	30			30		
Next Phase								
Movement Str	;3682_3337_L	;3345_3682_T	;3337_3345_L			;3682_3345_T		
Direction Str	WBL	EBT	NBL			WBT		

Movement & Phase Numbering



HCM 2010



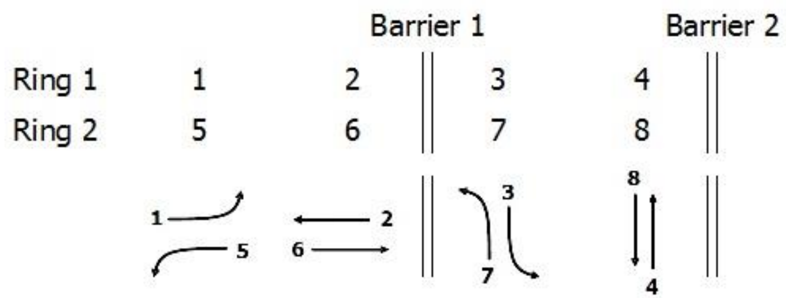
Through Φ: even numbers (2,4,6,8)
Left turn Φ: odd numbers (1,3,5,7)
3-legged intersection LT can be even #

Φ 2 & 6 denote major street
Right turn Φ concurrent w/ through in most cases (no special RT Φ)

Contributing Author:
Dr. Milan Zlatkovic

Ring-Barrier Phase Structure

- Ring-barrier diagram – graphical representation of phases within sets of rings & barriers (NEMA standard, all traffic controllers)
- Ring – phases that operate in sequence (cannot time simultaneously)
- Barrier - separation of intersecting movements to prevent operating conflicting phases at same time



Split summations:

Φ 1+2+3+4 = C $\quad$ Φ 1+2 = Φ 5+6

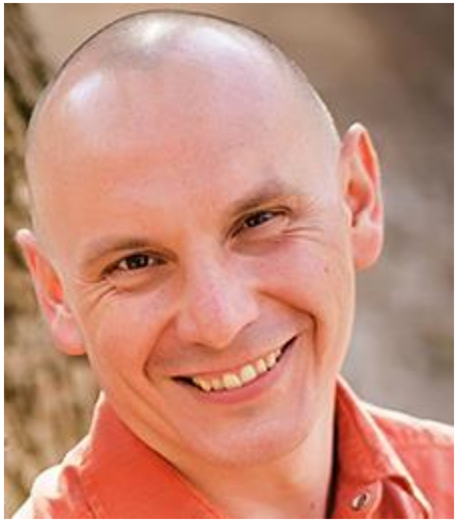
Φ 5+6+7+8 = C $\quad$ Φ 3+4 = Φ 7+8

Exceptions?

Contributing Author:
Dr. Milan Zlatkovic

7.4

QEM (Signal Quick Estimation Method) Application



Contributing Author:

Dr. Milan Zlatkovic

Assistant Professor, University of Wyoming

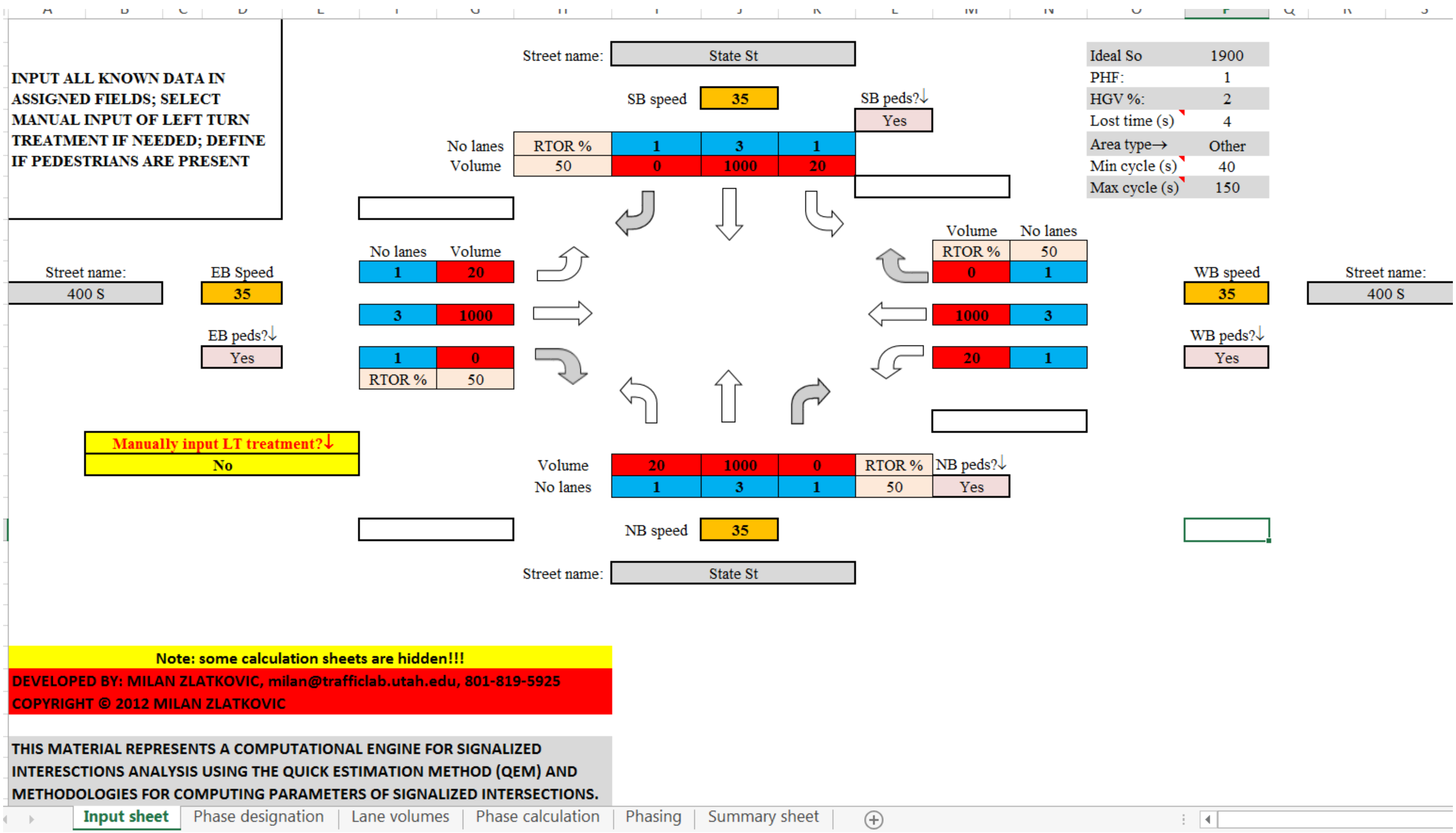
http://www.uwyo.edu/civil/faculty_staff/faculty/milan-zlatkovic/index.html

Reference:

Integration of signal timing estimation model and dynamic traffic assignment in feedback loops: system design and case study

Milan Zlatkovic, Xuesong Zhou

Journal of Advanced Transportation 49 (6), 683-699, 2015


INPUT ALL KNOWN DATA IN ASSIGNED FIELDS; SELECT MANUAL INPUT OF LEFT TURN TREATMENT IF NEEDED; DEFINE IF PEDESTRIANS ARE PRESENT
Street name: State St
SB speed 35
SB peds?↓ Yes
No lanes
Volume
RTOR % 50
1 3 1
0 1000 20
Ideal So 1900
PHF: 1
HGV %: 2
Lost time (s) 4
Area type→ Other
Min cycle (s) 40
Max cycle (s) 150
Street name: 400 S
EB Speed 35
EB peds?↓ Yes
No lanes Volume
1 20
3 1000
1 0
RTOR % 50
Volume No lanes
RTOR % 50
0 1
1000 3
20 1
WB speed 35
Street name: 400 S
WB peds?↓ Yes
Manually input LT treatment?↓
No
Volume 20 1000 0
No lanes 1 3 1
RTOR % 50
NB peds?↓ Yes
NB speed 35
Street name: State St
Note: some calculation sheets are hidden!!!
DEVELOPED BY: MILAN ZLATKOVIC, milan@trafficlab.utah.edu, 801-819-5925
COPYRIGHT © 2012 MILAN ZLATKOVIC
THIS MATERIAL REPRESENTS A COMPUTATIONAL ENGINE FOR SIGNALIZED INTERESCTIONS ANALYSIS USING THE QUICK ESTIMATION METHOD (QEM) AND METHODOLOGIES FOR COMPUTING PARAMETERS OF SIGNALIZED INTERSECTIONS.
Input sheet
Phase designation
Lane volumes
Phase calculation
Phasing
Summary sheet

QEM Application: Overview

- Challenges for Planners:
  - How to obtain signal data? Especially for future year with dramatically changed traffic pattern??
  - How do we obtain movement-specific capacity under prevailing traffic condition (e.g. different turning percentage) for a large number (100-500) of intersections?

- The QEM_SIG Excel spreadsheet that accompanies NeXTA represents a computational engine for estimating signalized intersections operation
- It relies on HCM 2010 and additional methodologies for computing parameters of signalized intersections
- Can be used as a stand-alone application, or integrated with NeXTA
- It is an open-source Excel application with friendly GUI for data input and viewing results

QEM Application: Sections

- Sheet 1 – input/output sheet for communication with NeXTA
- Input sheet – data input section; this is the only section where the user needs to input intersection data
- Phase designation – assigns phases to intersection movements, determines left turn treatment and defines ring-barrier structure
- Lane volumes – calculation of lane volumes (HCM 2010 Chapter 31)
- Phase calculation – calculation of the cycle length, green time (splits) allocations, movement capacities, V/C ratios, and Levels of Service (LOS)
- Phasing – calculates phasing data for correct export to Synchro
- Summary sheet – output sheet with calculation results

QEM Application: Input Sheet 1/2

- Street names – optional
- Intersection lane configuration – required for stand-alone application; not needed for use with NeXTA
- Turning volumes for each movement – required for stand-alone application; not needed for use with NeXTA
- Approach through speeds – important if the speeds are greater than 45 mph; not needed for use with NeXTA
- Presence of pedestrians – should be enabled for urban intersections
- Manual selection of left turn treatment – optional for stand-alone application; not needed for use with NeXTA
- Right Turn on Red (RTOR %) – 50-75% for exclusive right turn lanes, < 10% for shared

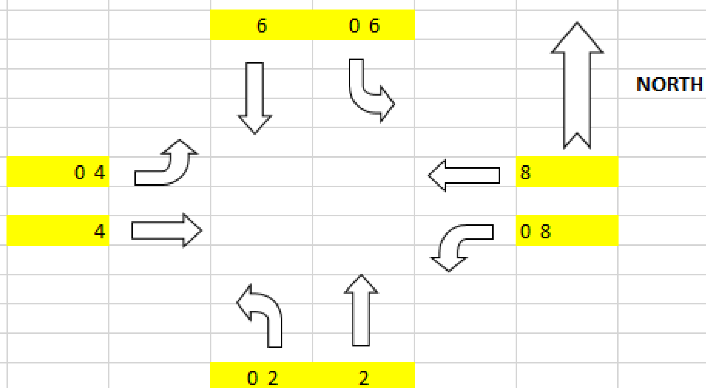
QEM Application: Input Sheet 2/2

- Ideal saturation flow rate (Ideal So) – default value = 1900 vphpl; can be changed to reflect local conditions
- Peak Hour Factor (PHF) – should be entered if known; otherwise, a default value of 0.9 can be used
- Percentage of heavy vehicles (HGV %) – should be entered for local conditions; otherwise, a default value of 3% can be used
- Lost Time (s) per phase – 4 seconds by default; can be changed to reflect local conditions
- Area Type selection – “CBD” (Central business district) and “Other”; should be selected for the analyzed network
- Minimum and maximum desired cycle lengths – by default, the cycle length is between 40 s (minimum) and 150 s (maximum)

InitPhase No.	7	4	3	8	5	2	1	6
3-leg?	7	4	3	8	5	2	1	6
No Lanes	1	3	1	3	1	3	1	3
Shared	0	0	0	0	0	0	0	0
ThruSpeedLimit		35		35		35		35

Criteria:	EBL	WBL	NBL	SBL	
LT lanes	0	0	0	0	Prot criteria
OppThruLanes	0	0	0	0	
OppThruSpeed	0	0	0	0	
LT volume	0	0	0	0	
Vlt*Vo for prot	0	0	0	0	
Protected decision	0	0	0	0	
Vlt*Vo	2	2	2	2	perm vs. p
ShareLanes	0	0	0	0	Split phase
3-leg?	0	0	0	0	
Initial Decision	2	2	2	2	
Final Decision	2	2	2	2	
	Permitted	Permitted	Permitted	Permitted	

Movement	**EBL**	**EBT**	**WBL**	**WBT**	**NBL**	**NBT**	**SBL**	**SBT**
Protected Phase	**0**	**4**	**0**	**8**	**0**	**2**	**0**	**6**
Permitted Phase	**4**		**8**		**2**		**6**	



Final Ring-Barrier Structure		
	b	
Ring 1	2	4
Ring 2	6	8

Input sheet | **Phase designation** | Lane volumes | Phase calculation | Phasing | Summary shee some calculation cells are hidden!

EB APPROACH

RIGHT TURNS	Exclusive RT lar	Shared RT lane	
RT volume, Vr (vph)	0	0	
No of excl. RT lanes, Nrt	1	1	
RT adj factor, frt	0.85	0.85	
RT vol per lane, Vrt (vphpl)	0	0	
LEFT TURNS			
LT volume, Vl (vph)	20		
Opposing mainline vol, Vo (vph)	1000		
No of excl. LT lanes, Nlt	1		
LT adj factor, flt	0.95	0	
LT vol per lane Vlt (vphpl)	Permitted LT	Protected LT	Not Opposed LT
	0	0	0
		21	
single lane, regular intersection	0.95		
>=2 lanes, regular int.	0		
single lane, 1-way or 3-leg int.	0		
>=2 lanes, 1-way or 3-leg int.	0		
THROUGH MOVEMENT	Permitted LT	Protected LT	Not Opposed LT
Through volume, Vt (vph)	1000	0	0
Parking adjustment factor, fp	1	1	1
Number of through lanes, Nth	3	3	3
Total approach volume, Vtot (vph)	1000	0	0
THROUGH MOVEMENT WITH EXCLUSIVE LT LANE	Permitted LT	Protected LT	Not Opposed LT
Through volume per lane, Vth (vph	333	0	0
Critical lane volume,Vcl (vph) Max[Vlt, Vrt (exclusive), Vth]	333	0	0
THROUGH MOVEMENT WITH SHARED LT LANE	Permitted LT	Protected LT	Not Opposed LT
Proportion of left turns, Plt	1	0	0
Equivalence factor, El1	4	0	0
Shared lane LT adjustment factor, f	1	1	1
Through volume per lane, Vth (vph	0	0	0
Critical lane volume,Vcl (vph) Max[Vrt (exclusive), Vth]	0	0	0

WB APPROACH

RIGHT TURNS	Exclusive RT lar	Shared RT lane	
RT volume, Vr (vph)	0	0	
No of excl. RT lanes, Nrt	1	1	
RT adj factor, frt	0.85	0.85	
RT vol per lane, Vrt (vphpl)	0	0	
LEFT TURNS			
LT volume, Vl (vph)	20		
Opposing mainline vol, Vo (vph)	1000		
No of excl. LT lanes, Nlt	1		
LT adj factor, flt	0.95	0	
LT vol per lane Vlt (vphpl)	Permitted LT	Protected LT	Not Opposed LT
	0	0	0
		21	
single lane, regular intersection	0.95		
>=2 lanes, regular int.	0		
single lane, 1-way or 3-leg int.	0		
>=2 lanes, 1-way or 3-leg int.	0		
THROUGH MOVEMENT	Permitted LT	Protected LT	Not Opposed LT
Through volume, Vt (vph)	1000	0	0
Parking adjustment factor, fp	1	1	1
Number of through lanes, Nth	3	3	3
Total approach volume, Vtot (vph)	1000	0	0
THROUGH MOVEMENT WITH EXCLUSIVE LT LANE	Permitted LT	Protected LT	Not Opposed LT
Through volume per lane, Vth (vphp	333	0	0
Critical lane volume,Vcl (vph) Max[Vlt, Vrt (exclusive), Vth]	333	0	0
THROUGH MOVEMENT WITH SHARED LT LANE	Permitted LT	Protected LT	Not Opposed LT
Proportion of left turns, Plt	1	0	0
Equivalence factor, El1	4	0	0
Shared lane LT adjustment factor, f	1	1	1
Through volume per lane, Vth (vphp	0	0	0
Critical lane volume,Vcl (vph) Max[Vrt (exclusive), Vth]	0	0	0

RIGHT TURNS
RT volume, Vr (vph)
No of excl. RT lanes, N
RT adj factor, frt
RT vol per lane, Vrt (vp
LEFT TURNS
LT volume, Vl (vph)
Opposing mainline vol
No of excl. LT lanes, Nl
LT adj factor, flt
LT vol per lane Vlt
single lane, regular inte
>=2 lanes, regular int.
single lane, 1-way or 3-l
>=2 lanes, 1-way or 3-le
THROUGH MOVEM
Through volume, Vt (v
Parking adjustment fac
Number of through lan
Total approach volume
THROUGH MOVEM WITH EXCLUSIVE
Through volume per la
Critical lane volume,Vc Max[Vlt, Vrt (exclusive)
THROUGH MOVEM WITH SHARED L
Proportion of left turns,
Equivalence factor, El1
Shared lane LT adjustr
Through volume per la
Critical lane volume,Vc Max[Vrt (exclusive), Vt

some calculation cells are hidden!

Movement	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
TurnVol	20	1000	0	21	1000	0	20	1000	0	21	1000	0
PhF	1	1	1	1	1	1	1	1	1	1	1	1
CompVol	20	1000	0	21	1000	0	20	1000	0	21	1000	0
NoLanes	1	3	1	1	3	1	1	3	1	1	3	1
RTORreduction			0			0			0			0
LaneGroupFlow	20	1000	0	21	1000	0	20	1000	0	21	1000	0
Flu	1	0.908		1	0.908		1	0.908		1	0.908	
SatFlowRateProt	0	4590	1530	0	4590	1530	0	4590	1530	0	4590	1530
SatFlowRatePerm	561	4590	1530	561	4590	1530	561	4590	1530	561	4590	1530
LaneVolume	0	333	0	0	333	0	0	333	0	0	333	0
Prot Phase	0	4		0	8		0	2		0	6	
Perm phase	4	0	4	8	0	4	2	0	2	6	0	6
Lost time	4	4	4	4	4	4	4	4	4	4	4	4

Sum of Lost Time	**8**		
Cycle Calculated	**14.2**	**Min Cycle**	**70**
Cycle Adopted	**70**		

Movement	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Phase	0	4	4	0	8	8	0	2	2	0	6	6
CalcSplit	0	35	35	0	35	35	0	35	35	0	35	35
Yellow	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6
AllRed	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1
DispGreen	29.3	29.3	29.3	29.3	29.3	29.3	29.3	29.3	29.3	29.3	29.3	29.3
EffectiveGren	31	31	31	31	31	31	31	31	31	31	31	31
Green Ratio (g/c)	0.00	0.50	0.50	0.00	0.50	0.50	0.00	0.50	0.50	0.00	0.50	0.50
V/C	0.17	0.49	0.00	0.17	0.49	0.00	0.17	0.49	0.00	0.17	0.49	0.00
Cap (vph)	121	2033	678	121	2033	678	121	2033	678	121	2033	678
ControlDelay (s)	14.8	14.7	0.0	14.8	14.7	0.0	14.8	14.7	0.0	14.8	14.7	0.0
LOS	B	B	N/A	B	B	N/A	B	B	N/A	B	B	N/A
Approach Delay (s)		14.7			14.7			14.7			14.7	
Approach LOS		B			B			B			B	

LOS	Color
A	
B	
C	
D	
E	
F	

Intersection Delay (s)	**14.7**
Intersection LOS	**B**
Intersection V/C	**0.44**
Intersection Status	**Under Capacity**

		b			C check	B1 check	B2 check
Ring 1	**0**	**35**	**0**	**35**	**70**	**35**	**35**
Ring 2	**0**	**35**	**0**	**35**	**70**	**35**	**35**

QEM Application: Summary Sheet

- Turning volumes (vph)
- Phase designations
- Number of lanes
- Split durations (s)
- Movement capacities (vph)
- V/C ratios
- Control delays (s)
- Intersection LOS
- Phase data table

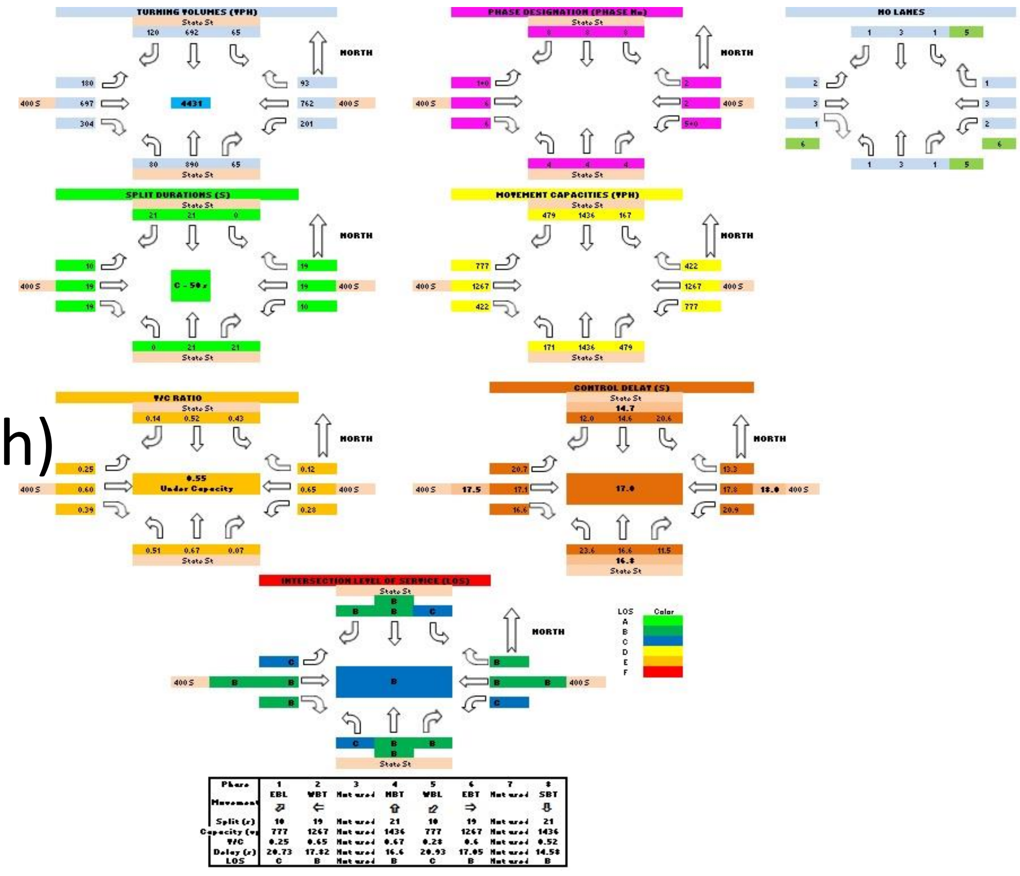


Fig. 20 QEM Summary Sheet

Module 8: VRP Code

Source code link:

https://github.com/xzhou99/Agent-Plus/blob/master/cpp_source_code_v2_VRP/AgentPlus_VRP/AgentPlus/AgentPlus.cpp

Lagrangian Relaxation Model

Lagarangian Relaxation

Lagarangian Multipliers mean passengers' profit

$$L = \sum_{v \in (V \cup V^*)} \sum_{(i,j,t,s,w,w') \in B_v} c(v,i,j,t,s,w,w') y(v,i,j,t,s,w,w') + \boxed{\boxed{\sum_{p \in P} \lambda(p)} \left[\sum_{v \in (V \cup V^*)} \sum_{(i,j,t,s,w,w') \in \Psi_{p,v}} y(v,i,j,t,s,w,w') - 1 \right]} \tag{7}$$

Therefore, the new relaxed problem can be written as follows:

$$\text{Min } L \tag{8}$$

s.t.

$$\sum_{(i,j,t,s,w,w') \in B_v} y(v,i,j,t,s,w,w') = 1 \quad i = o'_v,\ t = e_v,\ w = w' = w_0,\ \forall v \in (V \cup V^*) \tag{9}$$

$$\sum_{(i,j,t,s,w,w') \in B_v} y(v,i,j,t,s,w,w') = 1 \quad j = d'_v, s = l_v,\ w = w' = w_0,\ \forall v \in (V \cup V^*) \tag{10}$$

$$\sum_{(j,s,w'')} y(v,i,j,t,s,w,w'') - \sum_{(j',s',w')} y(v,j',i,s',t,w',w) = 0 \quad (i,t,w) \notin \left\{ (o'_v, e_v, w_0), (d'_v, l_v, w_0) \right\},\ \forall v \in (V \cup V^*) \tag{11}$$

$$y(v,i,j,t,s,w,w') \in \{0, 1\} \quad \forall (i,j,t,s,w,w') \in B_v, \quad \forall v \in (V \cup V^*) \tag{12}$$

If we further simplify function L, the problem will become a time-dependent least-cost path problem in the constructed state–space–time network. The simplified Lagrangian function L can be written in the following form:

$$L = \sum_{v \in (V \cup V^*)} \sum_{(i,j,t,s,w,w') \in B_v} \xi(v,i,j,t,s,w,w') y(v,i,j,t,s,w,w') - \sum_{p \in P} \lambda(p) \tag{13}$$

Input Data

Output Data

Initial profit of passengers

Input_node

node_id	node_type	passenger_id	timestamp	baseprofit	x	y	placetime
1001	1	1	32	20	61.671	71.431	
2002	2	2	36		62.22	69.113	3
2003	1	2	26	20	60.451	70.882	2
1004	2	1	41		60.939	68.198	
5000					62.83	66.063	
6000					58.194	69.967	
500							
501							
600							

Input_link

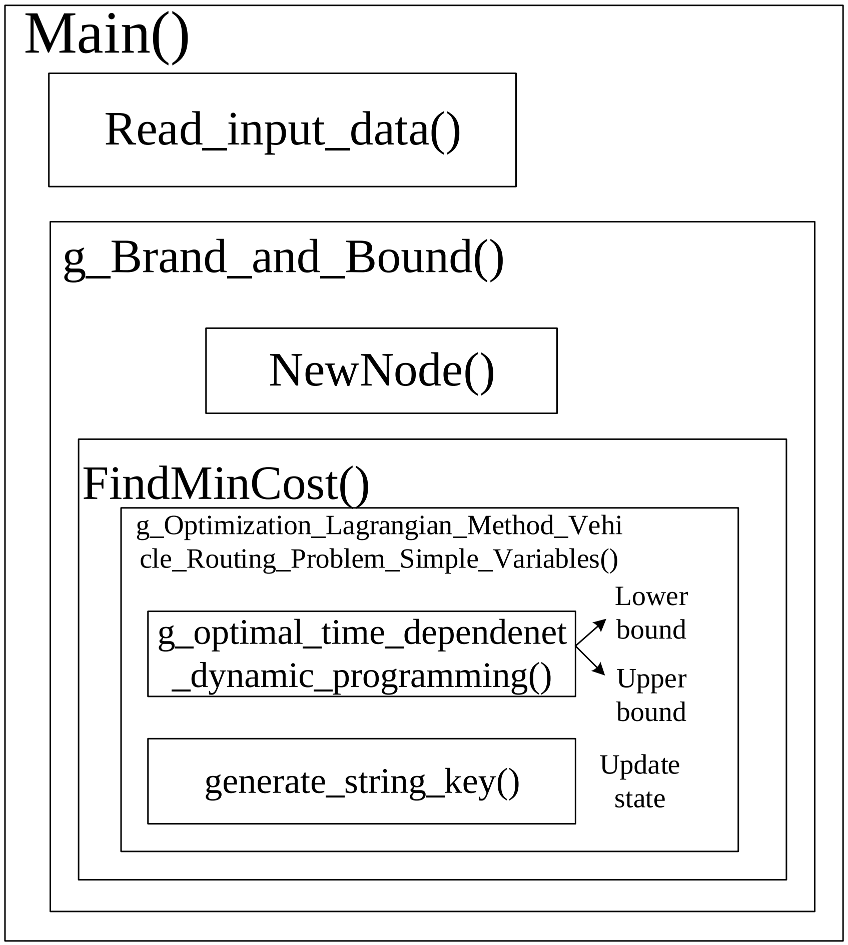
from_node_id	to_node_id	link_type_name	travel_t	distance
1001	2002		5	1.340584
1001	2003		5	1.340584
1001	5		3	0.669487
2002	1001		5	1.340584
2002	1004		5	1.340584

Input_agent

agent_id	agent_type	from_node_id	to_node_id	departure_time	arrival_time	capacity
1	1	501	600	0	130	3
2	1	502	600	0	130	3
3	1	503	600	0	130	3
4	1	504	600	0	130	3
5	1	505	600	0	130	3
6	1	506	600	0	130	3

1. Lagrangian lower bound and primal upper bound
2. Passenger and vehicles' assignments and time-space routes

Main functions



Generate_string_key():

```
::string generate_string_key()

 //std::string string_key;
 stringstream s;

 s << "n";
 s << current_node_id;  // space key
 for (std::map<int, int>::iterator it = passenger_service_state.begin();
 {
     s << "_";

     s << it->first << "["<< it->second << "]";

 }
```

Such as: n4_1[1]_3[2]_4[2], means node 4 with pickup of p1, delivery of p3 and delivery of p4

Including nodeID, passenger ID, and pickup or delivery state

Convenient for visiting in dynamic programming

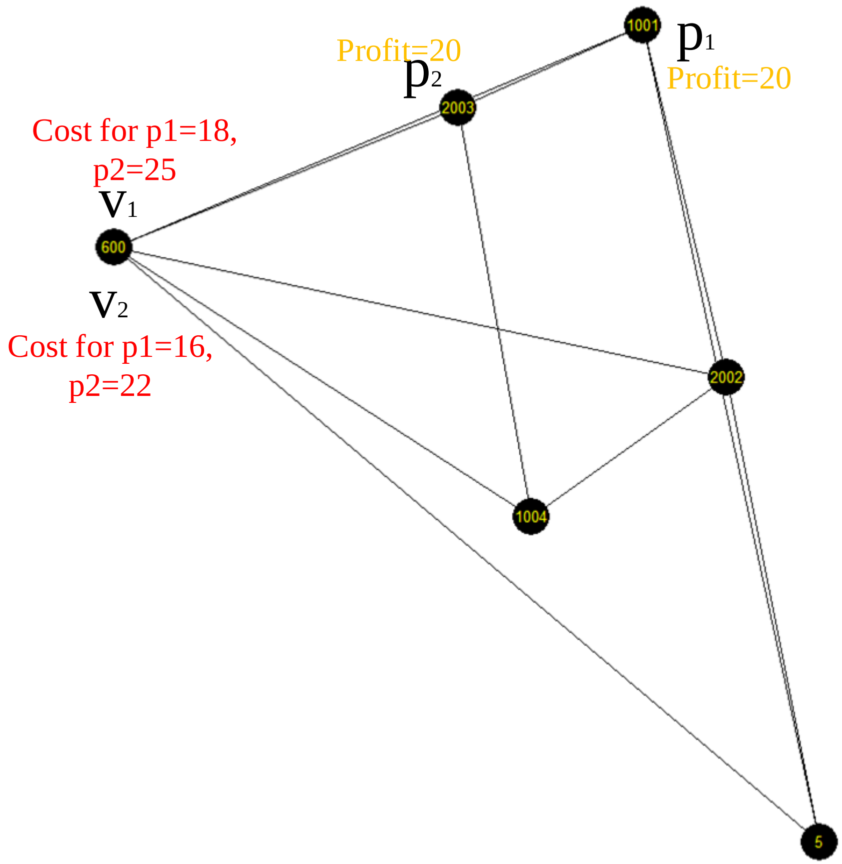
Main Class

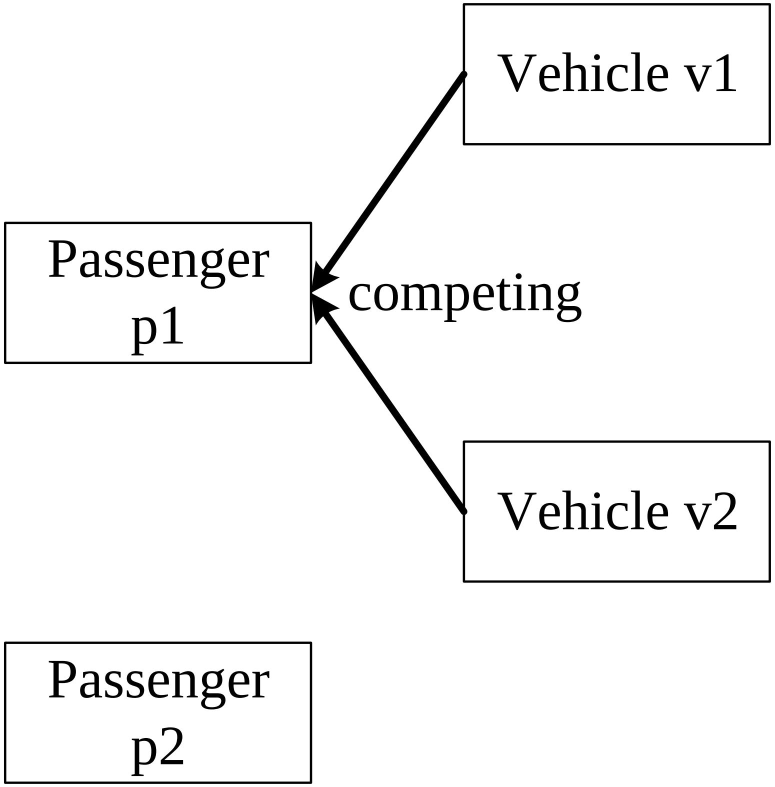
Class Name	Major functions	Major variables	Used modules
Node	CalculateCost()	PassengerID, VehicleID, LowerBound, UpperBound	Basic data
VRP_exchange_data //in one node	AddP2VAssignment (int p, int v)	LowerBound, UpperBound, V2PAssignmentVector	Branch & Bound
V2PAssignment //vehicles assigned for each p	AddCompettingVehID (int vehicle_id)	input_prohibited_vehicle_id_vector: not allowable vehicles output_competting_vehicle_id_vector: competing vehicles	Branch & Bound
CVSState //for vehicle scheduling states		LabelCost, PrimalLabelCost passenger_service_state	C_time_indexed_state_vector &DP
C_time_indexed_state_vector	update_state (CVSState new_element)	m_VSStateVector //vector of CVSState	DP

Main variables

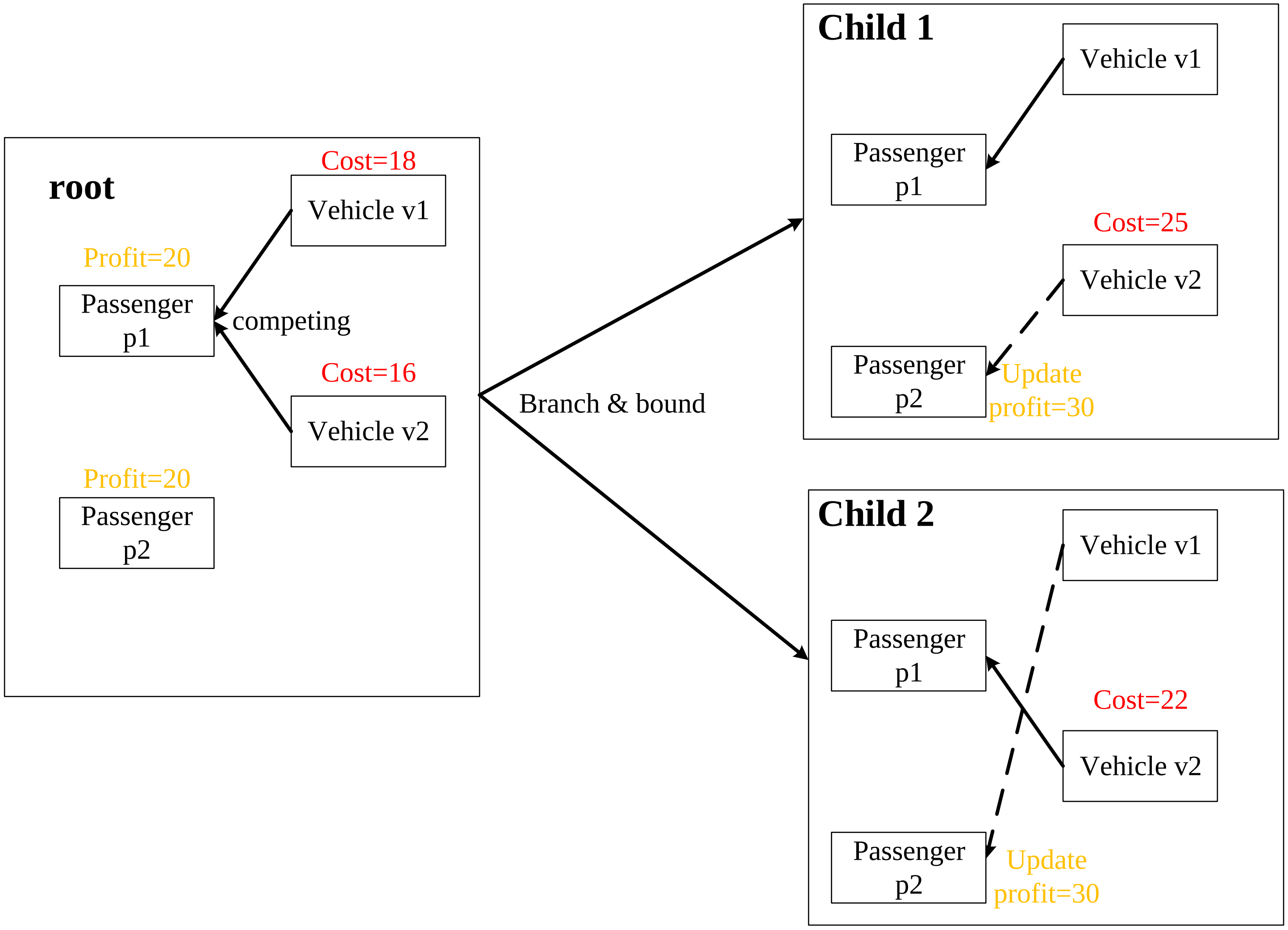
For passengers	For vehicles
g_passenger_base_profit[passenger_id] →profit of passengers (LR multipliers)	g_time_dependent_state_vector[vehicle_id][t]. m_VSStateVector →state vector of a vehicle
competing_vehicle_size →competing vehicels	g_ending_state_vector[vehicle_id] →final state of a vehicle
input_prohibited_vehicle_id_vector →in Branch and Bound, vehicles which cannot serve passenger p	

Branch & Bound





Branch & Bound



Branch & Bound

```
for (int p = 1; p < min_Node->l_vrp_data.V2PAssignmentVector.size(); p++) // for each p
{
    int competing_vehicle_size = min_Node->l_vrp_data.V2PAssignmentVector[p].output_competting_vehicle_id_vector.size();
    if (competing_vehicle_size >= 2) // if there are more than 2 competing vehicles
    {
        // first vi inclusive braches
        for (int vi = 0; vi < competing_vehicle_size; vi++)
        {
            BBDebugfile << "   Branch: pax " << p << " with competing v[ " << vi << "]=" << min_Node->l_vrp_data.V2PAssig

            // create a new tree node
            Node* child = newNode(min_Node->l_vrp_data, min_Node);
            int veh_id = min_Node->l_vrp_data.V2PAssignmentVector[p].output_competting_vehicle_id_vector[vi];
            child->VehicleID = veh_id;
            child->PassengerID = p;

            BBDebugfile << "   New Node " << child->node_id << " with vehicle " << child->VehicleID << " to Pax " << chil

            child->l_vrp_data.AddP2VAssignment(p, veh_id);  // designate p to veh_id
```

Assignment Problem Using Branch-And-Bound Method link:
https://math.stackexchange.com/questions/1466459/assignment-problem-using-branch-and-bound-method

Dynamic Programming

For vehicle v
  For time t
    for state w
      for outbound of current w's node i
      calculate labelCost of (i,t,w):
      if(the state does not exist)
        create it
      else if(the label cost of the temp state <
              label cost of the existing state)
        update the cost of the state

Loop

```
for (int t = departure_time; t <= arrival_time; t++)  //first loop: time
{
    // step 1: sort m_VSStateVector by labelCost for scan best k elements in step2 @CR
    g_time_dependent_state_vector[vehicle_id][t].Sort();

    // step 2: scan the best k elements
    for (int w_index = 0; w_index < min(BestKSize, g_time_dependent_state_vector[vehicle_id][t].m_VSStateVector.size()
    {
        CVSState* pElement = &(g_time_dependent_state_vector[vehicle_id][t].m_VSStateVector[w_index]);

        int from_node = pElement->current_node_id;
        // step 2.1 link from node to toNode
        for (int i = 0; i < g_outbound_node_size[from_node]; i++)
        {
            int to_node = g_outbound_node_id[from_node][i];
            int to_node_passenger_id = g_node_passenger_id[to_node];
            int to_node_type = g_node_type[to_node];
            int link_no = g_outbound_link_no[from_node][i];

            int next_time = max(g_node_timestamp[to_node], t + g_link_free_flow_travel_time[link_no]);
```

Calculate the cost of the node

```
LabelCost -= g_passenger_base_profit[passenger_id];//LB

//LabelCost -= local_vehicle_passenger_additional_profit[vehicle_id][passenger_id];
LabelCost += max(0, passenger_service_time[passenger_id] - g_passenger_order_time[passenger_id]);
//UB-------------delay
PrimalLabelCost += max(0, passenger_service_time[passenger_id] - g_passenger_order_time[passenger_id]);
```

Update the cost of the node

```
if (new_element.LabelCost < m_VSStateVector[state_index].LabelCost)
{
    m_VSStateVector[state_index].Copy(&new_element);
}
```

Lagrangian Relaxation for Lower Bound

// step 1.2. update LB^*

– update LB^k by substituting solution vector Y_{LB}^k in the objective function of the dual problem (E

– update LB^* by $max(LB^k, current\ LB^*)$ and Y^* by its corresponding solution;

// step 1.3. sub-gradient calculation

– calculate the total number of visits of passenger p's origin by expression (14);

$$\sum_{v\in(V\cup V^*)}\ \sum_{(i,j,t,s,w,w')\in\Psi_{p,v}} y(v,i,j,t,s,w,w') \quad (14)$$

– compute sub-gradients by Eq. (15);

$$\nabla L_{\lambda^k(p)} = \sum_{v\in(V\cup V^*)}\ \sum_{(v,i,j,t,s,w,w')\in\Psi_{p,v}} y(v,i,j,t,s,w,w') - 1 \ \text{for} \quad \forall p \quad (15)$$

– update arc multipliers by Eq. (16);

$$\lambda^{k+1}(p) = \lambda^k(p) + \theta^k(p)\nabla L_{\lambda^k(p)} \ \text{for} \quad \forall p \quad (16)$$

– update arc cost $\xi(v,i,j,t,s,w,w')$ for each arc $(v,i,j,t,s,w,w') \in \Psi_{p,v}$ by Eq. (17);

$$\xi(v,i,j,t,s,w,w') = \boxed{c(v,i,j,t,s,w,w')} + \boxed{\lambda^{k+1}(p)} \quad (17)$$

– update step size by Eq. (18);

$$\theta^{k+1}(p) = \frac{\theta^0(p)}{k+1} \quad (18)$$

```
LabelCost -= g_passenger_base_profit[passenger_id];//LB

LabelCost += max(0, passenger_service_time[passenger_id] - g_passenger_order_time[passenger_id]);

        LR_global_lower_bound += path_cost_by_vehicle_v;

        fprintf(g_pFileDebugLog, "LR_global_lower_bound += pat

    }  //for each v
       //min CX + lamda(1 - # of visits)
    for (int p = 1; p <= g_number_of_passengers; p++)
    {
        LR_global_lower_bound += g_passenger_base_profit[p]
    }
```

Sub-gradient algorithm

```
nt p = 1; p <= g_number_of_passengers; p++)

oat StepSize = 1 / (LR_iteration + 1.0f);
 (StepSize < g_minimum_subgradient_step_size)  //1.3.1 keep the minimum step size

  StepSize = g_minimum_subgradient_step_size;
}

int constant = 5;
g_passenger_base_profit[p] += constant*StepSize * (g_passenger_number_of_visits[p] - 1);
```

Lagrangian Relaxation for Lower Bound

```
PrimalLabelCost += max(0, passenger_service_time[passenger_id] - g_passenger_order_time[passenger_id]);
```

```
LR_global_upper_bound += path_cost_by_vehicle_v;
```

Upper bound generates the solution without the profit of passengers.

Example

Node	Lower Bound	Upper Bound
0	2	21
1 (v1-p1)	10020 (cut)	
2 (v2-p1)	10020 (cut)	
3 (p1 exclusive)	10020 (cut)	

```
number of nodes = 9
number of links = 19
read 9 nodes, 19 links, 2 passengers, 2vehicles

Computational time:,0
End of Lagrangian Iteration Process

Computational time:,0
End of Lagrangian Iteration Process

Computational time:,0
End of Lagrangian Iteration Process

Computational time:,0
End of Lagrangian Iteration Process
CPU Running Time = 27 milliseconds
End of Optimization
free memory..
```

Thank You!

Questions, Comments, and Suggestions are Welcome.

Please Contact:

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