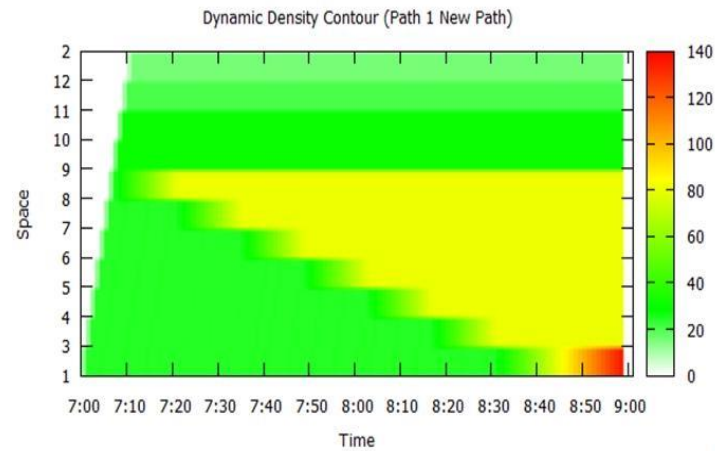


## Lesson 2

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



Please share your comments online for improving this document. If you have any questions or encounter any problems, please feel free to contact us ([jiangtao.liu@asu.edu](mailto:jiangtao.liu@asu.edu); [xzhou74@asu.edu](mailto:xzhou74@asu.edu)). Your any feedback is greatly appreciated!

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

#### 2.2 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.

### 2.3 Contents:

Introduction to Dynamic Network Loading: Input and Output

Overview of 3-corridor network and experiments

#### (1) Network

- 1) Check the property of the network
- 2) Calculate travel time of three paths and find links with minimum capacity

#### (2) OD demand matrix

#### (3) Traffic states as a result of demand-supply interactions

- (I) Network Level Text Display
- (II) Path Level Dynamic Contour Plot
- (III) Link Level MOE Display
- (IV) Time-dependent Link MOE Visualization
- (V) Introduction to two methods for traffic state estimation

#### (4) One-iteration Simulation setup

Case1: demand = supply (multiplier = 1.0)

- (1) DTALite (KW Simulation Model)
- (2) Graphical Method

Case2: demand > supply (multiplier = 1.2)

- (1) DTALite (KW Simulation Model)
- (2) Graphical Method

Case3: demand > supply (multiplier = 1.3)

- (1) DTALite (KW Simulation Model)
- (2) Graphical Method

#### (5) Multi-iteration evaluation of road pricing scenarios

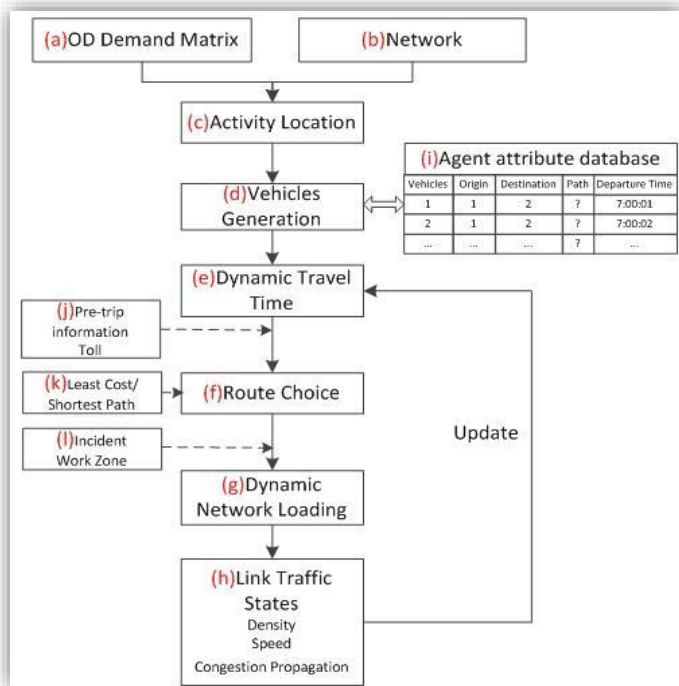


Fig.1. The process of dynamic network loading

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).

	<p>5. At the following step within an <b>iterative assignment process</b>, the route choice module (f) will again recompute the route selection for each agent using updated travel times (e), for another iteration of dynamic network loading (g), until the model is converged or reaches the maximum number of iterations.</p> <p>6. The <b>pre-trip information and road toll charges</b> (j) can also affect travelers' route choice behavior by changing generalized link travel times . <b>Traffic incidents and work zones</b> (l) are considered as capacity reduction events which are fed into the traffic network loading program (g).</p>
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## 2.4 Introduction to Dynamic Network Loading: Input and Output

A dynamic traffic assignment program includes two major components: dynamic network loading and traveler route assignment. In this learning document, we focus on the first dynamic network-loading module using single assignment iteration. Its general process is shown below:

### Methods:

This document utilizes two methods to compute traffic states under different levels of traffic demand and the same bottleneck capacity.

- Analytical model and graphical solution method
- Newell's simplified Kinematic Wave Model (Newell, 1993), which is implemented in the DTALite simulation engine.

By systematically comparing results from those two methods, students are expected to verify and understand the demand-supply interaction mechanism of a dynamic network loading program. Doing this set of exercises could help students tackle more complicated topics, such as dynamic route choice and traffic management scenario evaluation.

### Overview of 3-corridor network and experiments:

The demand time period in this experiment covers from 7:00 am to 9:00 am, and the hypothetical traffic network is shown in Fig. 2. To understand a dynamic network loading data set, we will go over the following data elements first:

#### (1) Network

This network includes 40 nodes, 55 links, 6 zones and 6 activity locations. There are two major zones: origin zone 1 and destination zone 2, which are associated with three major paths (path 1, path 2, and path 3) as shown in Fig. 2.

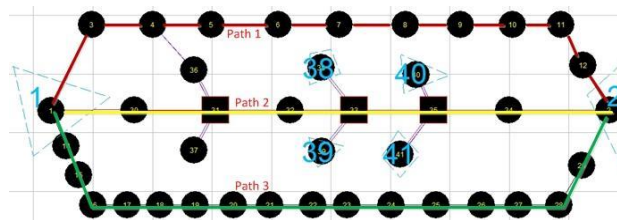


Fig. 2. Layout of 3-corridor Traffic Network

#### 1) Check the property of the network

Please first use NeXTA to find the number of nodes, links, zones, and activity locations. The properties of the network are shown in Table

1.

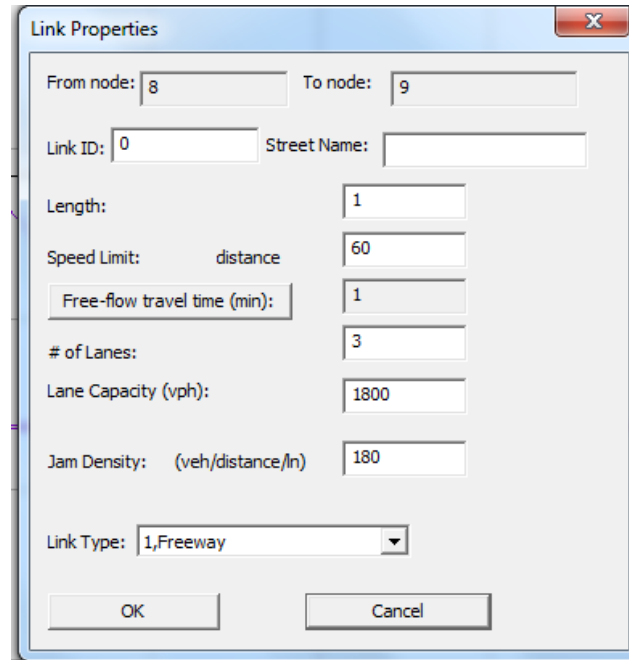
Table 1. Properties of traffic network

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

**Link properties:**

To check the link properties in NeXTA, please follow the steps below for link 8->9 as an example, shown in Fig. 3.

Select the “Link” in the GIS layers panel, then right click to choose “View Link Properties for Selected Link”.



The screenshot shows a 'Link Properties' dialog box with the following fields and values:

Field	Value
From node:	8
To node:	9
Link ID:	0
Street Name:	
Length:	1
Speed Limit:	60
Free-flow travel time (min):	1
# of Lanes:	3
Lane Capacity (vph):	1800
Jam Density: (veh/distance/ln)	180
Link Type:	1, Freeway

At the bottom are 'OK' and 'Cancel' buttons.

Fig. 3. Properties of link 8->9

#### Node and link tables:

To check node and link tables, please follow the steps in Fig. 4.

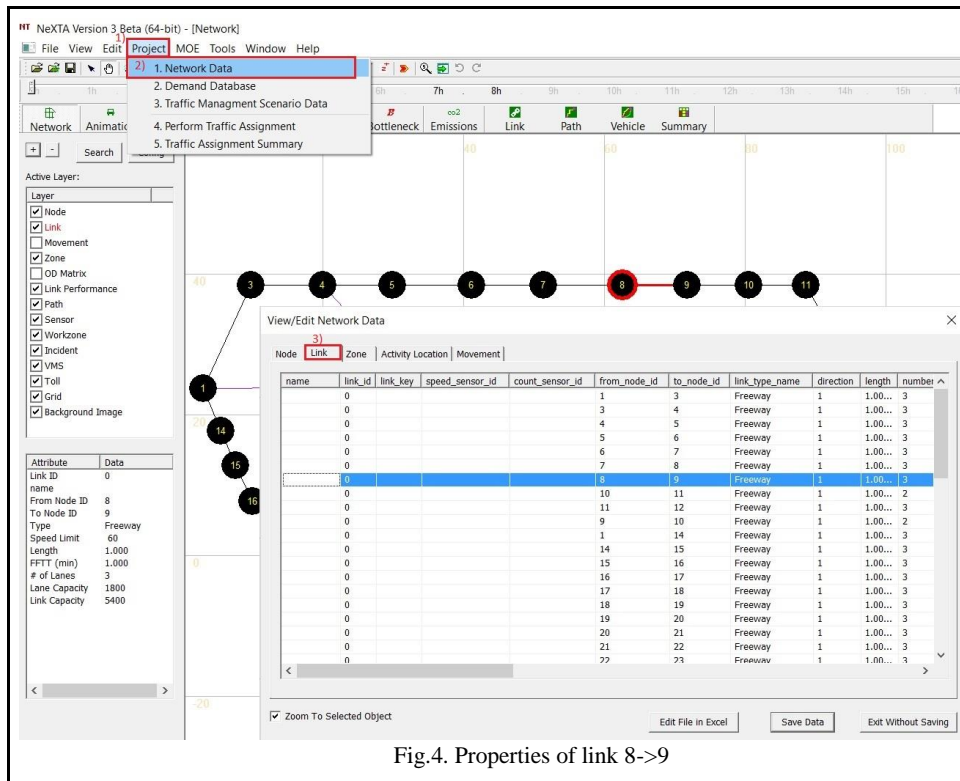


Fig.4. Properties of link 8->9

## STEPS

- Step 1:** click the “Project” in menu bar.  
**Step 2:** click “1.Network Data”.  
**Step 3:** click “node”, “link”, “zone”, etc. in the tab page.

## Problem 1 (for students):

- a. Which node is defined as the origin node of zone 1? (check input\_activity\_location file)



- b. Which node is defined as the destination node of zone 2? (check input\_activity\_location file)
- c. How many trips are loaded from 7AM to 8AM? (Check input\_demand\_file\_list file and associated demand file.)

## 2) Calculate travel time of three paths and find links with minimum capacity

In this experiment, we will examine major features of the dynamic network-loading module in DTALite by using a single assignment iteration. In DTALite's first iteration, all drivers use the first path (which is the minimum travel time path), calculated based on a free-flow condition. We first go over two approaches for calculating the travel time of a path.

### (i) Manual calculation by using data from input\_link.csv

The data from input\_link.csv for calculation of path 1 is shown in table 2. Students can also calculate path travel times on paths 2 and 3

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

7	8->9	1	1	5400
8	9->10	1	1	3600
9	10->11	1	1	3600
10	11->12	1	1	5400
11	12->2	1	1	7200
Subtotal	---	11	11	---

In Table 2, based on the capacity of links, the bottleneck is link 9->10 and link 10->11. It should be remarked here, DTALite assumes homogeneous link capacity (which means that the capacity of any sections of the link is equal), so the capacity value puts a constraint on both incoming flow and outgoing flow of a link, such as, the link shown in Fig. 5.

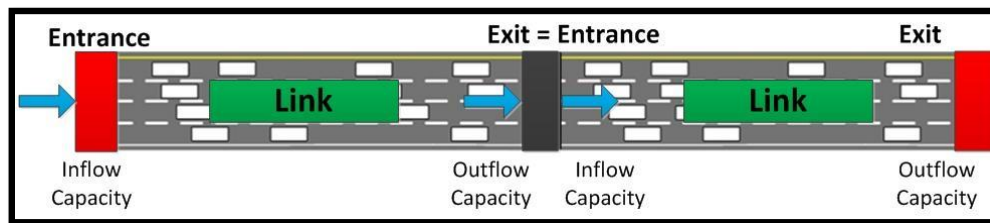


Fig. 5. Capacity analysis of one link

For link 8->9, although its (outgoing flow) capacity is 5400 vehicles per hour per link, its actual number of output flow volume being discharged also depends on the inflow capacity of its next link, link 9->10, with a capacity of 3600 vehicles per hour per link. Thus, when the demand of link

8->9 is greater than 3600 per hour, at its exit point (i.e. the downstream node 9), a queue will be formed as a result of traffic congestion, and will be propagated to other upstream links. Table 3 summarizes the travel times on three paths.

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	

The free-flow travel times of path 1, path 2, and path 3 are 11 min, 12 min, and 17 min, respectively. Since path 1 has the least travel time, it will be first chosen when the OD demand is sufficiently small. In the following session, we will focus on path 1.

## Problem 2 (for students)

- Which path will be selected at the first iteration?
- Find links with minimum capacity along three paths. Show the upstream node and downstream node numbers of those links and the hourly capacity values. Please use an image to highlight these links in the traffic network.
- What is the expected speed on link 8->9, if the demand is 5400 vehicles per hour, and all vehicles use the first path?

## (ii) Obtain travel time of paths through NeXTA

The method of selecting a path is shown in Fig. 6. The travel time of path 2 and path 3 can be obtained, similarly.

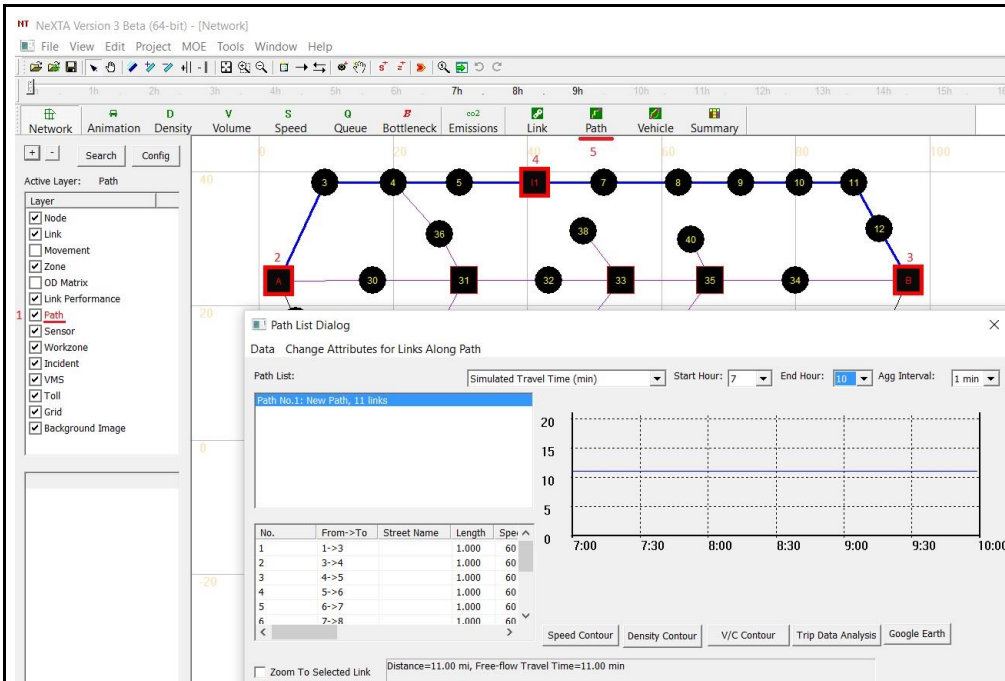


Fig.6. Path list dialog

### 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

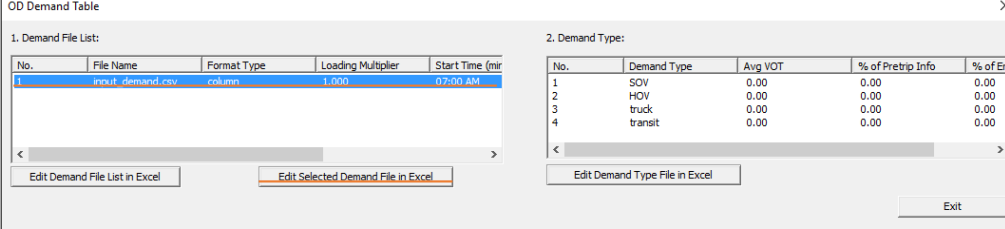
Intermediate Destination here”.

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

## (2) OD demand matrix

For checking the OD demand, there are two methods:

- Method 1: check the input\_demand\_file\_list.csv and input\_demand.csv in table 1;
- Method 2: through the NeXTA's interface the result is shown in Fig.7.



The screenshot shows the 'OD Demand Table' window. It contains two tables. The first table, '1. Demand File List', has columns: No., File Name, Format Type, Loading Multiplier, and Start Time (mir). The second table, '2. Demand Type', has columns: No., Demand Type, Avg VOT, % of Pretrip Info, and % of En. Below the first table is a button 'Edit Demand File List in Excel'. Below the second table is a button 'Edit Demand Type File in Excel'. An 'Exit' button is at the bottom right.

No.	File Name	Format Type	Loading Multiplier	Start Time (mir)
1	input_demand.csv	column	1.000	07:00 AM

No.	Demand Type	Avg VOT	% of Pretrip Info	% of En
1	SOV	0.00	0.00	0.00
2	HOV	0.00	0.00	0.00
3	truck	0.00	0.00	0.00
4	transit	0.00	0.00	0.00

**STEPS**

**Step 1:** Click on “Project” in the menu bar

**Step 2:** “2. Demand Database”

**Step 3:** Click on the row of “1. Demand File List”.

**Step 4:** Click on the “Edit Selected Demand File in Excel”.

The corresponding OD demand file (“input\_demand.csv”) will be open in Excel.

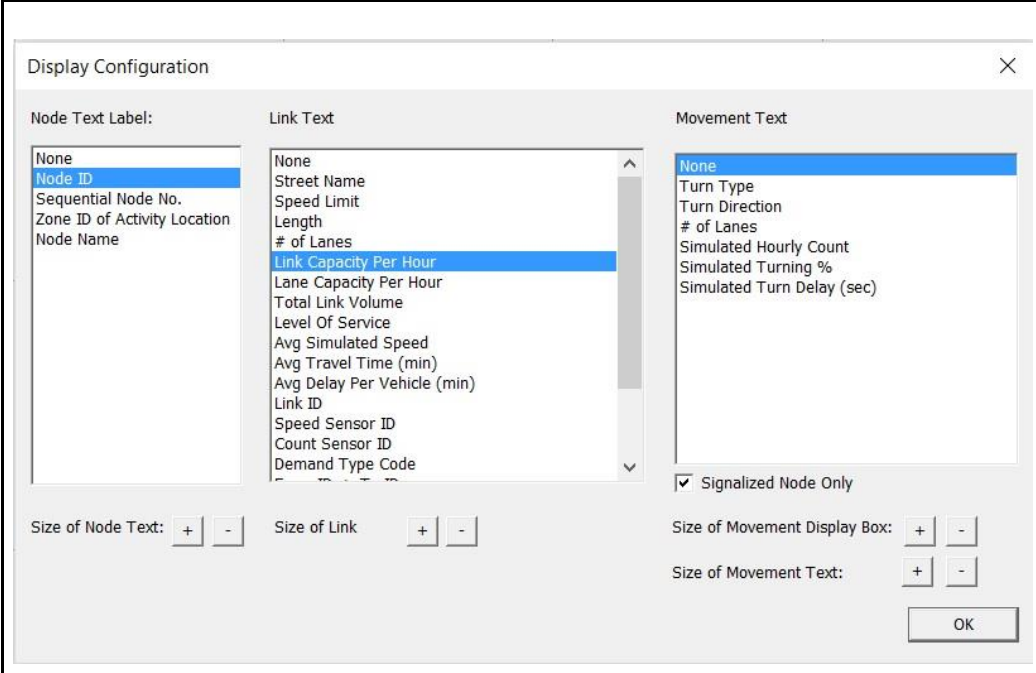
Fig.7.OD demand

## (3) Traffic States as a result of demand-supply interactions

NeXTA provides a number of visualization interfaces for checking the traffic states such as density and volume.

### (I) Network Level Text Display

Please follow the steps in Fig. 8 to view traffic states for all links in the network. For example, check the “Link Capacity Per Hour”.



**Display Configuration**

Node Text Label: None, Node ID, Sequential Node No., Zone ID of Activity Location, Node Name

Link Text: None, Street Name, Speed Limit, Length, # of Lanes, **Link Capacity Per Hour**, Lane Capacity Per Hour, Total Link Volume, Level Of Service, Avg Simulated Speed, Avg Travel Time (min), Avg Delay Per Vehicle (min), Link ID, Speed Sensor ID, Count Sensor ID, Demand Type Code

Movement Text: None, Turn Type, Turn Direction, # of Lanes, Simulated Hourly Count, Simulated Turning %, Simulated Turn Delay (sec)

☒ Signalized Node Only

Size of Node Text: + -    Size of Link: + -    Size of Movement Display Box: + -    Size of Movement Text: + -    OK

**STEPS**

**Step 1:** Click on the “Config” button at the top of the GIS layers panel

**Step 2:** “Link Capacity Per Hour” in “link text”

**Step 3:** Slide the “time bar” to the simulation time at 7am to 9am

**Step 4:** View the link capacity of any links in the network.

Fig.8. Procedure of analyzing the bottleneck

## (II) Path Level Dynamic Contour Plot

Please follow the steps in Fig. 6 to define a path using NeXTA, and then plot “Density Contour”, “Speed Contour”, “V/C Contour”, shown in Fig.9.

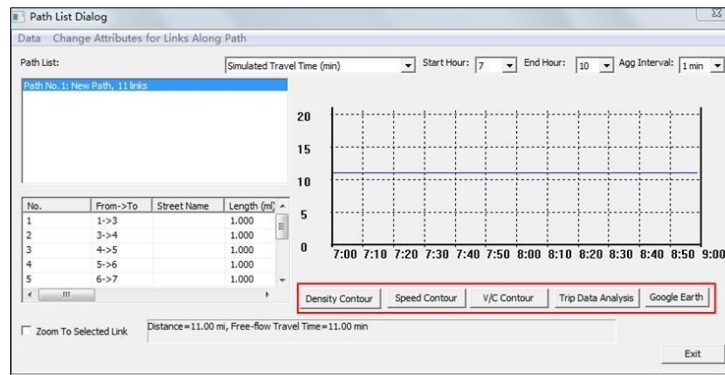


Fig.9. Path list dialog

## (III) Link Level MOE Display

After simulation, select the “Link performance” layer of the GIS layer panel and then click one link to see the link MOE dialog shown in Fig.10.

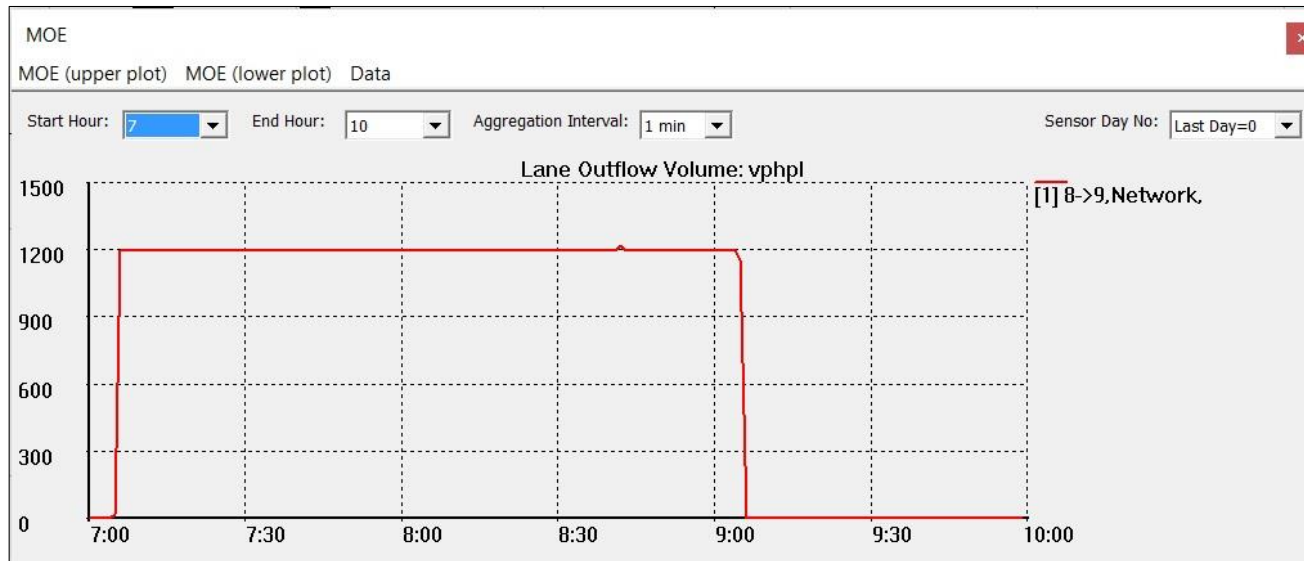


Fig.10. Interface of the MOE of link 8->9

Please click the “MOE (upper plot)” in the menu bar, and examine different traffic state variables shown in Fig.11. One can use the key combination “control +click” to select multiple links into the link MOE display.



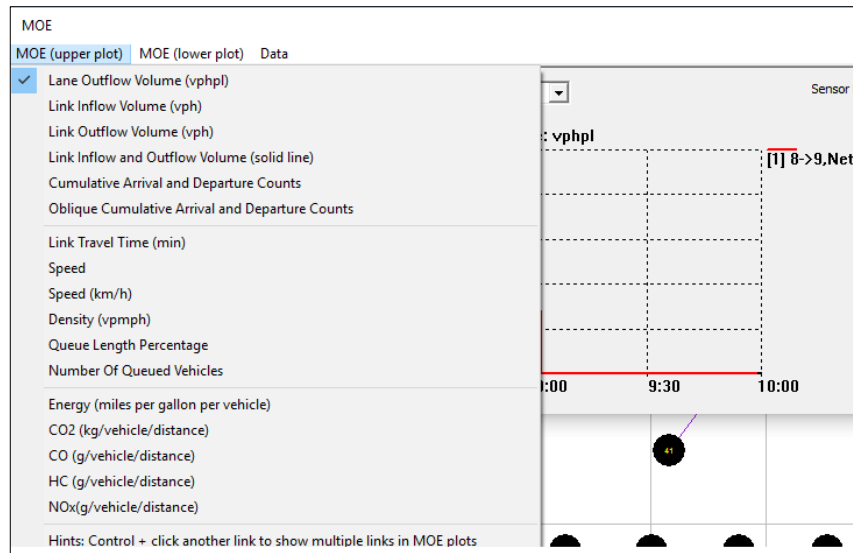


Fig.11. Detailed content of Link MOE

#### (IV) Time-dependent Link MOE Visualization

Following the steps introduced in Lesson 1.1, one can also visualize traffic states using the tool bars shown in Fig.12.

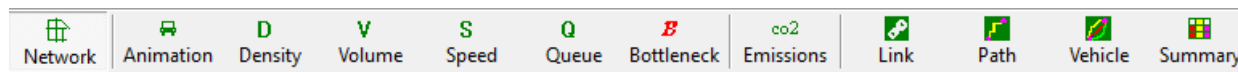


Fig.12. Shortcut icons for traffic simulation and analysis

## (V) Introduction to two methods for traffic state estimation

Now we introduce two calculation methods for estimating traffic states in this document.

### (i) Graphical method

Take the freeway on path 1 as an example. Its property is shown in the Fig.13, and the flow-density relationship for different lanes of links can be plotted in Fig. 14.

Link Properties

From node: 8To node: 9

Link ID: 0Street Name:

Length: 1

Speed Limit: distance 60

Free-flow travel time (min): 1

# of Lanes: 3

Lane Capacity (vph): 1800

Jam Density: (veh/distance/ln) 180

Link Type: 1, Freeway

OKCancel

Fig.13. Properties of link

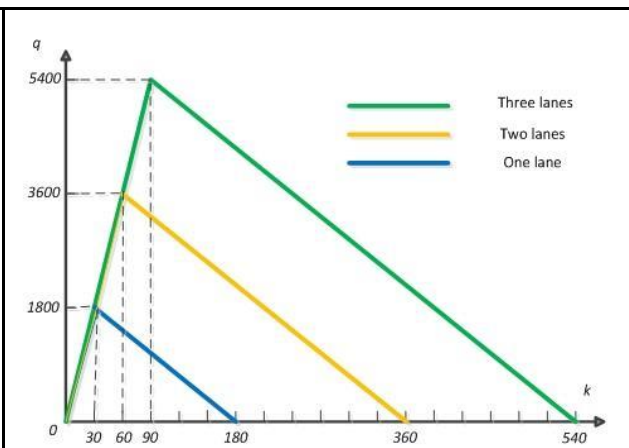


Fig.14. The flow-density relationship for different lanes of links

## (ii) KW simulation model in DTALite

Dr. Newell's papers on kinematic wave modeling are

*A Simplified Theory of Kinematic Waves in Highway Traffic*, part 1, 2, 3, ( G.F.Newell, 1993 )

DTALite has implemented the simulation steps, and interested readers can find the source code at <https://code.google.com/p/nexta/source/list>.

The high-level overview of the three test cases in our experiment is shown in Fig.15.

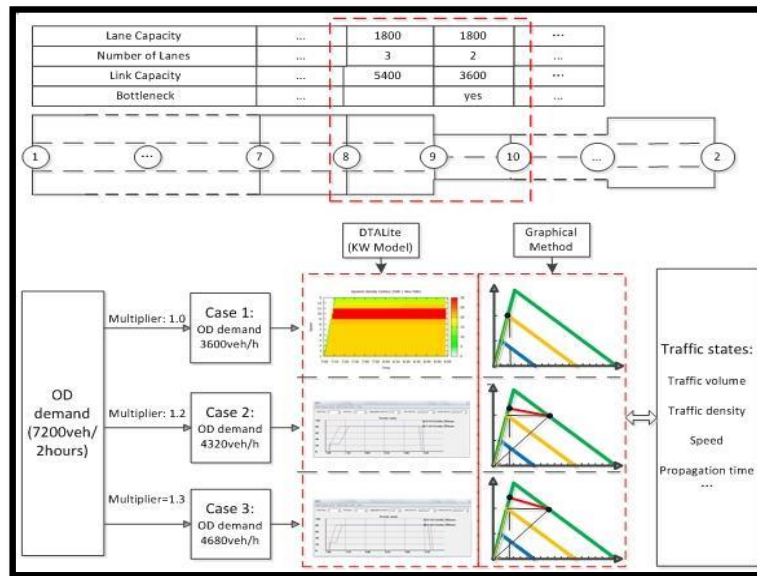


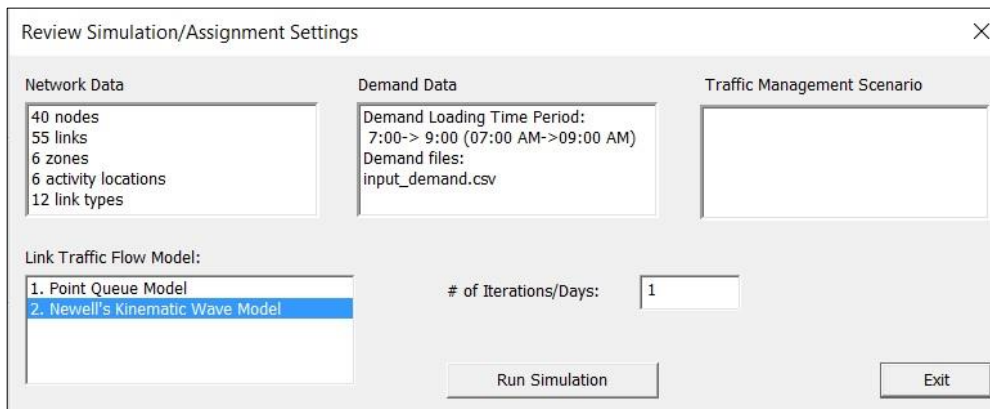
Fig.15. High-level overview of three testing cases

#### (4) Simulation setup

Review “network data”, “demand data” and “traffic management scenarios”.

- : Clicking the button  in the tool bar

The interface is shown in Fig.16.



Review Simulation/Assignment Settings

Network Data

40 nodes  
55 links  
6 zones  
6 activity locations  
12 link types

Demand Data

Demand Loading Time Period:  
7:00-> 9:00 (07:00 AM->09:00 AM)  
Demand files:  
input\_demand.csv

Traffic Management Scenario

Link Traffic Flow Model:

1. Point Queue Model  
2. Newell's Kinematic Wave Model

# of Iterations/Days: 1

Run Simulation

Exit

Fig.16. the interface of simulation settings

**Case 1: demand = supply (multiplier = 1.0)**

**(1) DTALite (KW Simulation Model)**

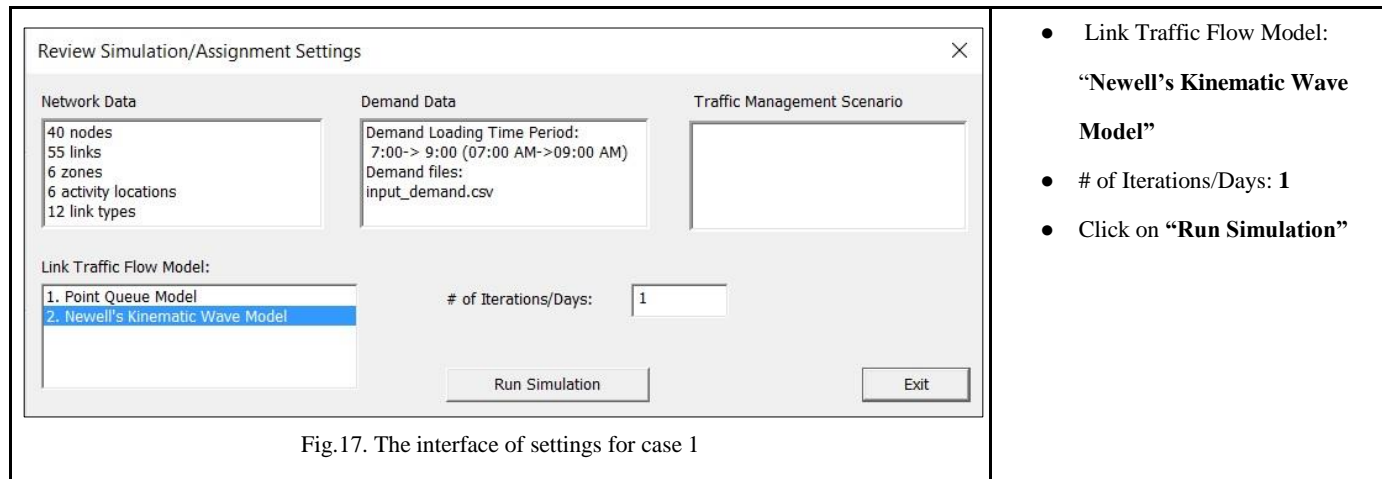
When the demand multiplier is 1.0, the hourly OD demand is  $0.5 * 7200 * 1 = 3600$  vehicles. The limit capacity of the path 1 is 3600, so now the demand is equal to the path capacity.

**1) Check the value of traffic demand**

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.

**2) Setup simulation settings**

Please use the following simulation settings shown in Fig.17.



- Link Traffic Flow Model:  
 “Newell’s Kinematic Wave Model”
- # of Iterations/Days: 1
- Click on “Run Simulation”

3) View the result of simulation and analyze traffic states

3.1) Traffic variable: “Total Volume over Capacity Ratio”

(i) View the simulation result: “Total Volume over Capacity Ratio” in the file “output\_summary” as highlighted in the table 4. One can observe this file in the project folder.

Table 4. Simulation Data of Path 1 in the file output\_summary.

from_node_id	to_node_id	type_code	link_type	link_length	start_time_min	end_time_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

(ii) Analyze the simulation result: “Total Volume over Capacity Ratio”

Question: Why Link 9->10 and link 10->11 are easy to be bottleneck? It is due to its capacity and traffic demand. In this case, the path 1 is only chosen. The capacity of the link is 3600 per hour, the OD demand is 3600 vehicles per hour, so its volume/capacity is 1.

3.2) View the traffic states of one path

(i) View the simulation result

Through the operation mentioned above, the traffic states of path 1 can be viewed in Fig.18.

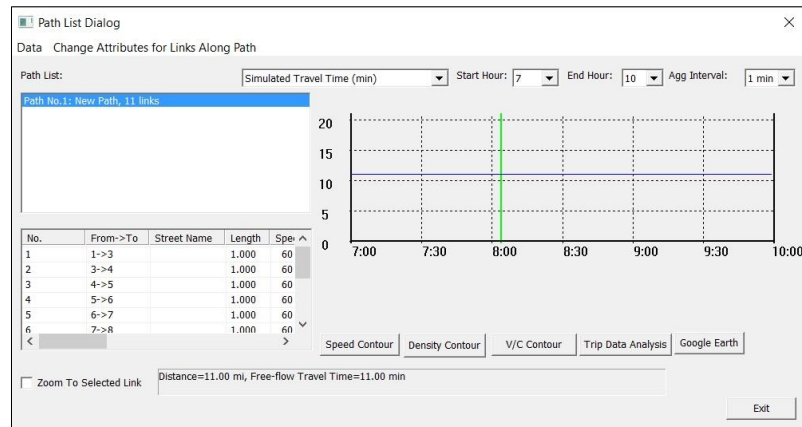


Fig. 18. Path List Dialog for Path 1.

Then, click on the “Density Contour”, “Speed Contour”, and “V/C Contour” to analyze the details of this traffic assignment. The assumption is that you have installed the *gnuplot* software at <http://sourceforge.net/projects/gnuplot/files/>.

(ii) Analyze the simulation result:

In this case, the density contour is shown in Fig. 19. Similarly, other analyses can also be displayed easily.



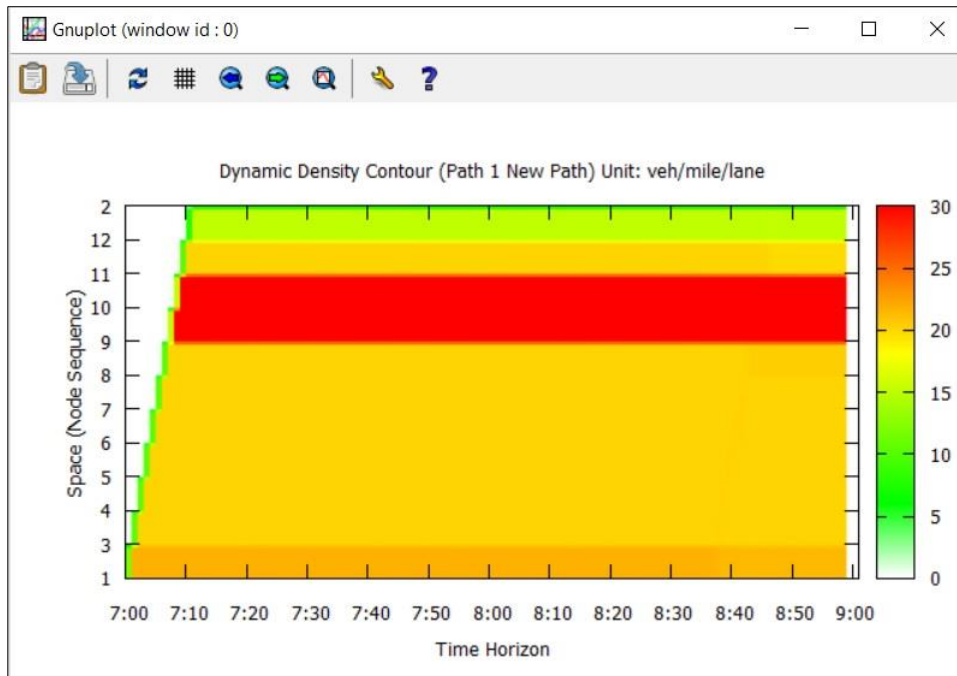


Fig. 19. The plot of dynamic density of path 1

From this figure, link 9->10 and link 10->11 has a high density, which is consistent with the above "Total Volume over Capacity Ratio".

### 3.3) View link MOE of bottleneck links

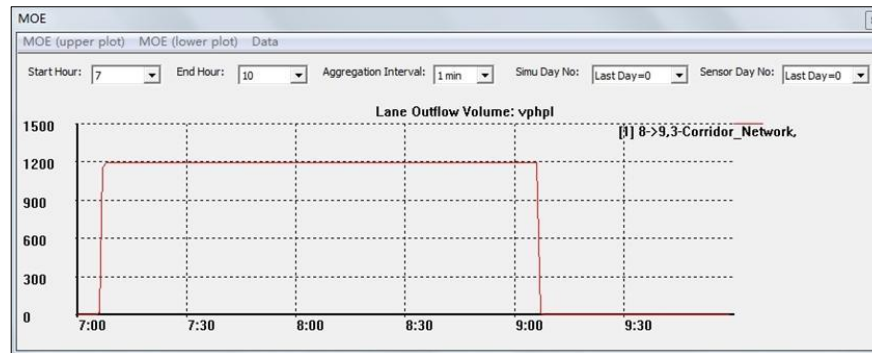


Fig.20. Simulated lane volume of link 8->9

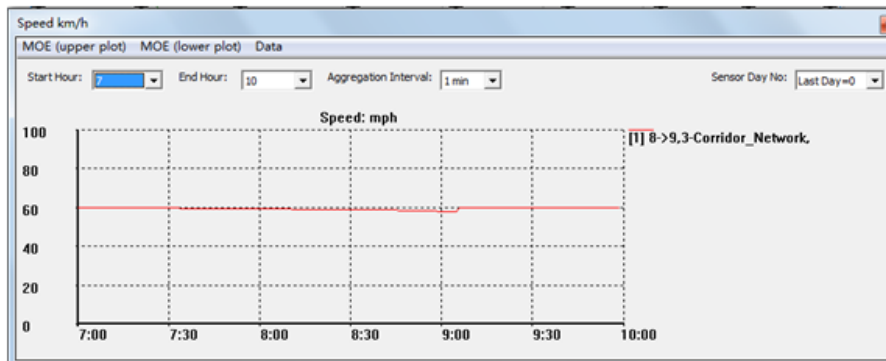


Fig.21. Simulated speed of link 8->9

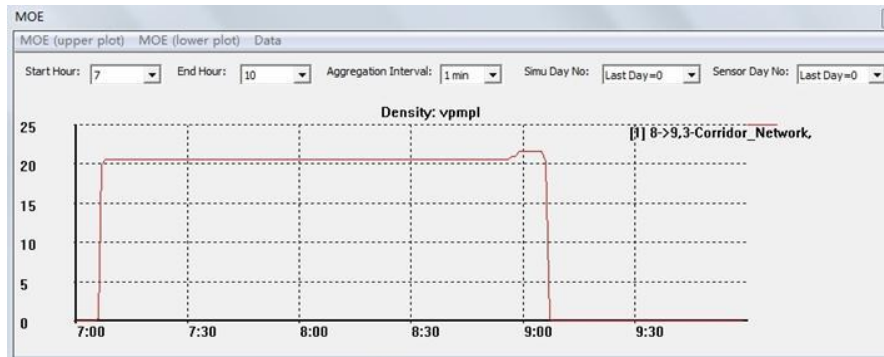


Fig.22. Simulated density of link 8->9

### Problem 3 (for students)

Please show the traffic density, speed and link and lane-based volume time series plots for links 8->9 and link 9->10. Explain why the density on link 8->9 is 20 vehicles per mile per lane, shown in Fig. 22.

### Problem 4 (for students)

In order to have detailed data extracted from the simulation results, please click on Menu->Data ->Export Link MOE to CSV File.

Please plot the flow-density points in the Q-K relationship figure for links 8->9 and 9->10.

## (2) Graphical Method

In order to ensure DTALite provides results from the analytical method, we now examine link 8->9 and link 9->10. Recall that, link 8->9 has three lanes and link 9->10 has two lanes. One can derive their traffic states using the graphical method shown in Fig.23. and Fig.24.

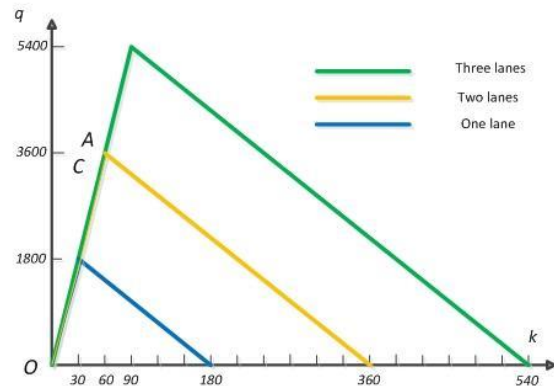
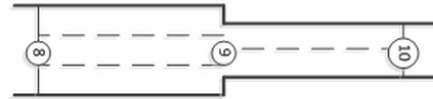


Fig.23. The flow-density relationship for different states of links



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

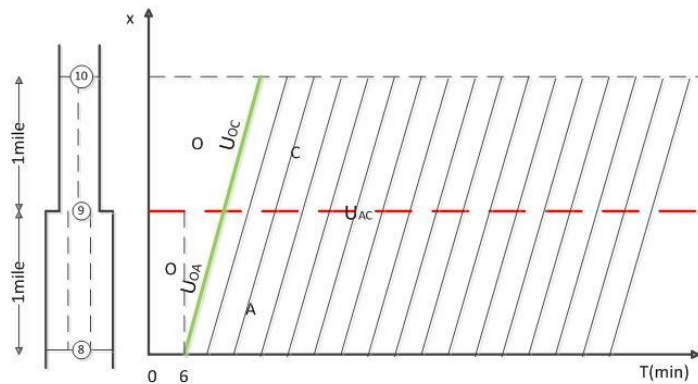


Fig.24. Vehicles' trajectory in space-time diagram

**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.

**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

	<p>is 30 vpmpl(lane).</p> <p><b>Propagation time duration:</b> N/A</p>
--	--

### **Case2: demand > supply (multiplier=1.2)**

#### **(1) DTALite (KW Simulation Model)**

When the demand multiplier is 1.2, the hourly OD demand is  $0.5 \times 7200 \times 1.2$  (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. The procedures are

- 1) Go to input\_demad\_file\_list
- 2) Change the loading multiplier to 1.2 in the excel sheet
- 3) Run the simulation for 1 iteration.
- 4) View its density contour shown in Fig.25.

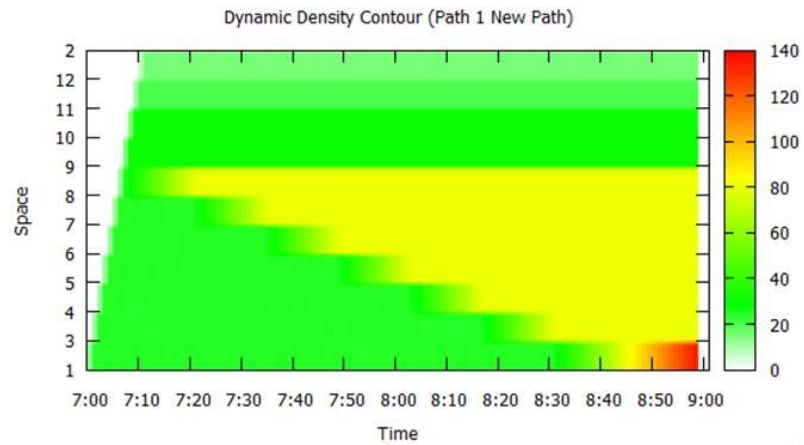


Fig.25. Density contour of path 1 in case 2

Indicated by the above figure, 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.

3) Check the speed, density, and propagation time of link 8->9 from the "Link MOE" dialog, shown in Fig.26. and Fig.27, respectively.

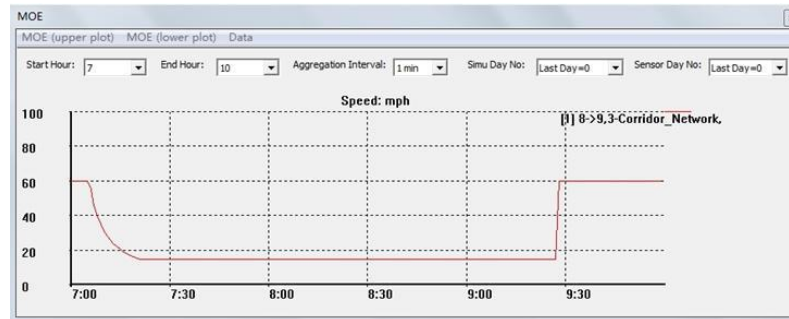


Fig.26. Simulated speed of link 8->9

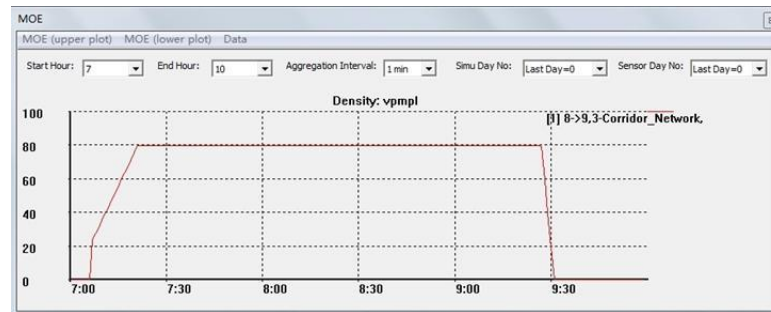


Fig.27. Simulated density of link 8->9

### Problem 5

Describe traffic speed and density evolutions on links 7->8 and 8->9. Calculate the traffic congestion speed.

**Hints:** 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). First, we need to select two links simultaneously, link 8->9 and link 7->8. Using key combination “ctrl +mouse click”, we can obtain the link MOE plot shown in Fig.28 and then measure the queue propagation time.

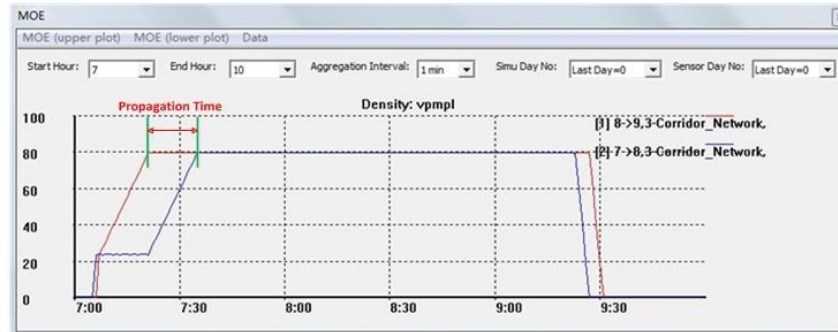


Fig.28. the simulation density of two links, 8->9 and 7->8

One can also precisely measure the exact propagation time duration using exported link MOE csv file. The method for exporting the Link MOE csv is: click the “Export Link MOE to CSV File” of “Data” in the menu bar of MOE dialog.

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

Thus, the propagation time duration is 14 min.

## (2) Graphical Method

Given an increased demand, the flow-density plot is updated in Fig.29.and the graphical illustration is shown in Fig.30.



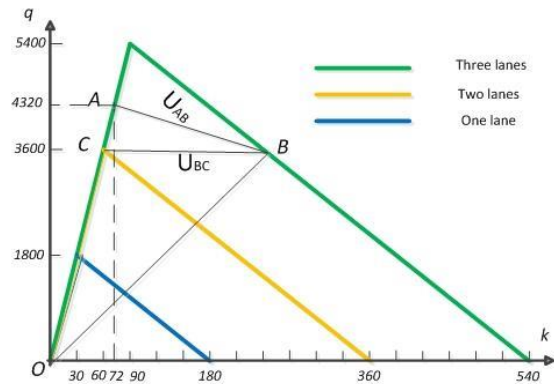
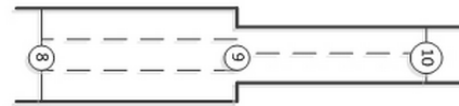


Fig.29. The flow-density relationship for different states of links



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

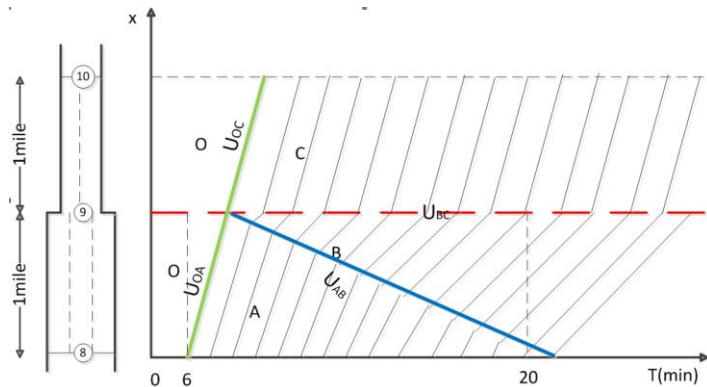


Fig.30. Vehicles' trajectory in time-space diagram

**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.

## Problem 6

Please compare the results between the simulation method and the graphical method. What is the expected start time for vehicles on link 7->8 seeing traffic congestion?

### Case 3: demand > supply (multiplier = 1.3)

#### (1) DTALite (KW Simulation Model)

In this case, the demand OD is still 7200 from 7am to 9am, and the multiplier is 1.3. The analysis process is the same as case 2 ( $0.5 \times 7200 \times 1.3 = 4680$  vehicles).

Select the “Link MOE” of the GIS layer panel -> click the link 8->9. Then show the “speed” and “density” of MOE to analyze the traffic state. For example, when clicking the “speed (mph)”, it is shown in Fig.31; when clicking the “density (vpmpl)”, it is shown in Fig.32.

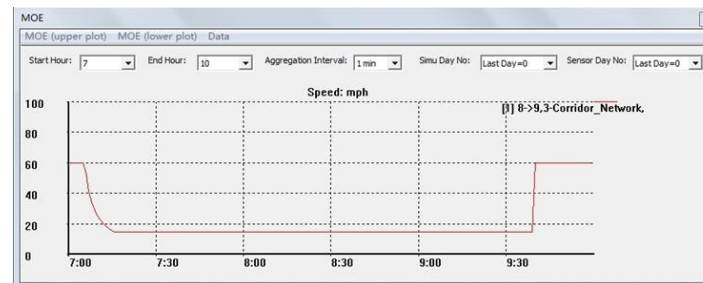


Fig.31. Simulated density of link 8->9

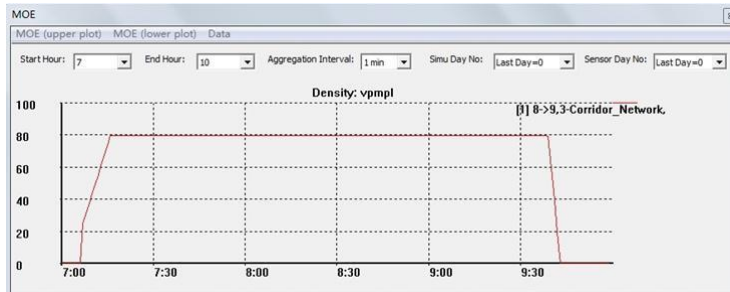


Fig.32 Simulated speed of link 8->9

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 Fig.33.

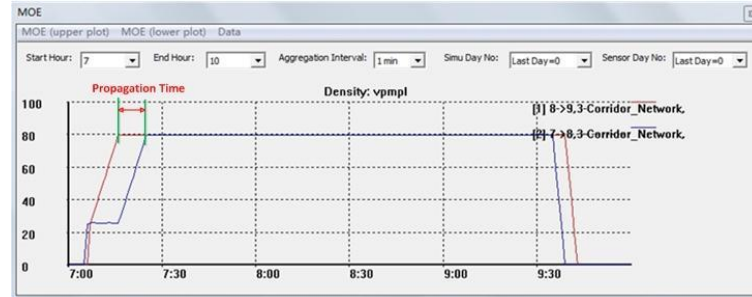
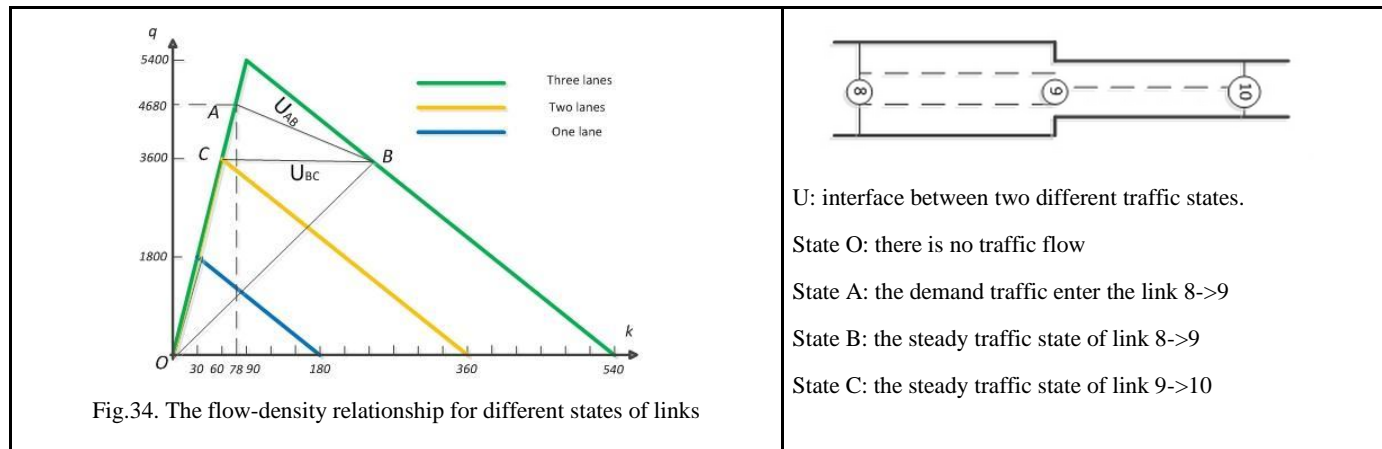
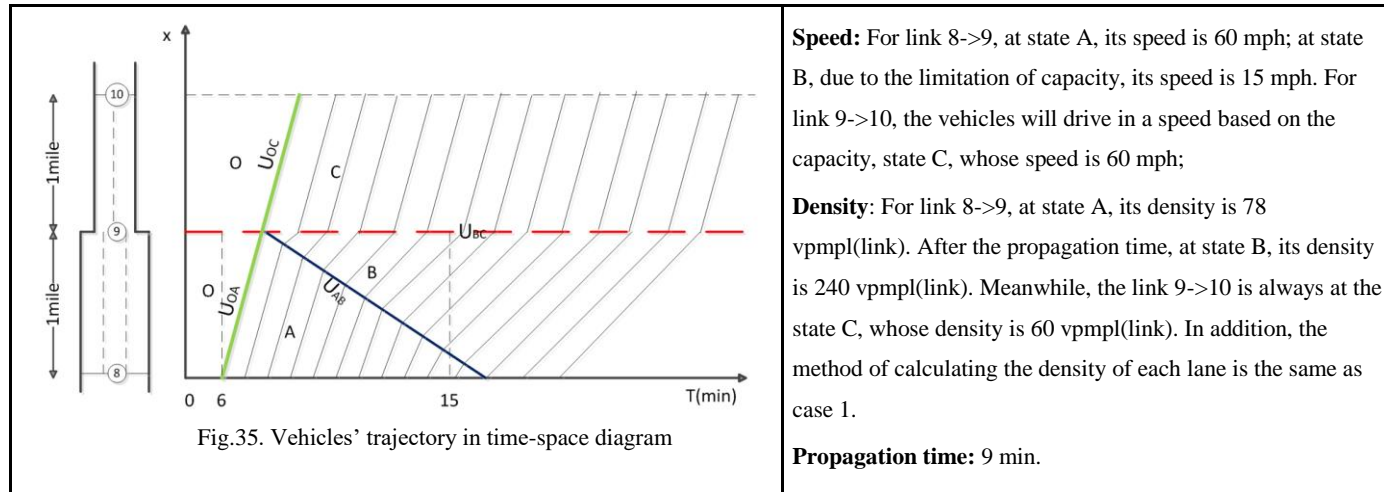


Fig.33. Simulated density of two links, 8->9 and 7->8

## (2) Graphical Method

Given an increased demand, the corresponding flow-density relationship is illustrated in Fig.34 and the graphical illustration is shown in Fig.35.





### Problem 7

Please compare the results of cases 1, 2 and 3, and plot path 1 travel time in time horizon under three OD demand levels.

#### Remark:

You can access to "export\_path\_MOE.csv" from menu bar of path dialog "Data"-> "Export Path Statistics To External CSV File" as shown in fig. 36. to analyze travel time of path 1 for different cases.

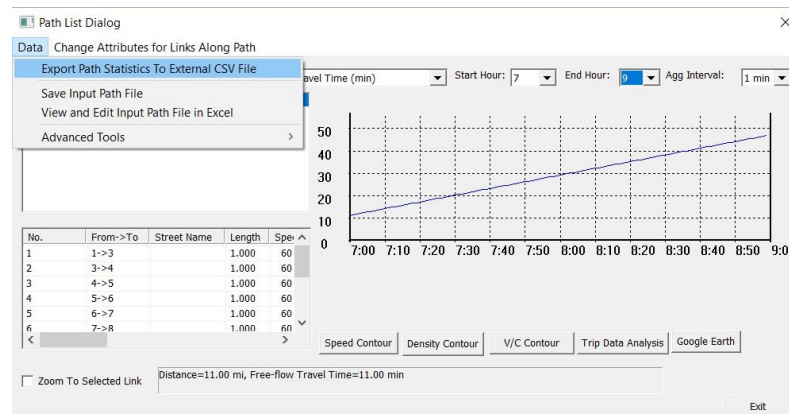


Fig. 36. Process of Exporting export\_path\_MOE File from NeXTA after Simulation for Case 3.

### Problem 8

In case 3, how much time does it take from traffic congestion propagating from the bottleneck to the origin node? Please calculate the congestion propagation time analytically, and then check your estimated value based on the “density contour” or “speed contour” in NeXTA.

## 5. Traffic States as a result of demand-supply interactions

### 1. Base case without toll settings

The 3-corridor traffic network is chosen as our test case.

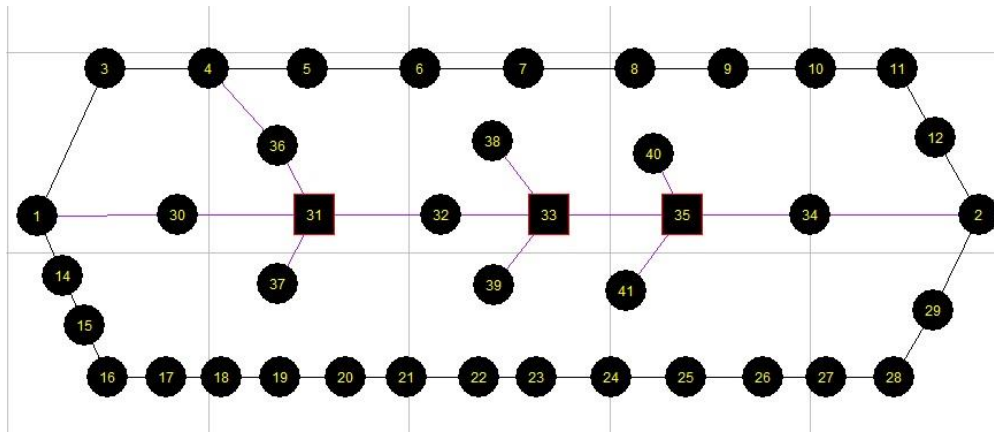


Fig. 37. Layout of 3-corridor Traffic Network

#### Network Input Data:

40 nodes are loaded from file C:\Users\jliu215\E\Test\2016\_Summer\1\_base\_case\input\_node.csv.  
48 links are loaded from file C:\Users\jliu215\E\Test\2016\_Summer\1\_base\_case\input\_link.csv.  
2 zone info records are loaded from file C:\Users\jliu215\E\Test\2016\_Summer\1\_base\_case\input\_zone.csv.  
2 activity location entries are loaded from file C:\Users\jliu215\E\Test\2016\_Summer\1\_base\_case\input\_activity\_location.csv.

Fig. 38. Data Loading Status

**Commented [XZ1]:** Please add figure numbers for the text below.

There are three main paths from zone 1 (node 1) to zone 2 (node 2), which are listed as follows:

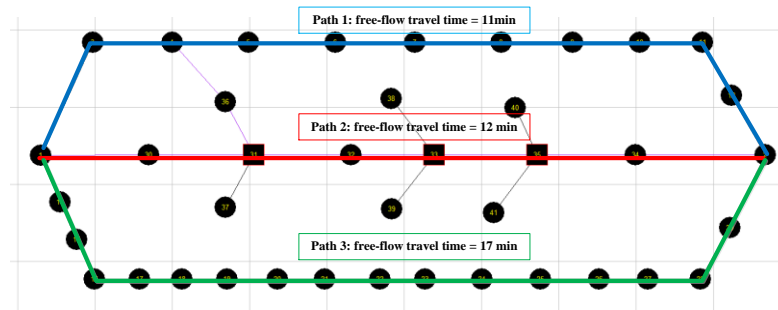


Fig. 39. Direction of Paths with Associated Travel Times

Now we just run one iteration as our base case, and the specific settings and data set can be downloaded at “[https://github.com/xzhou99/learning-transportation/blob/master/Lessons/Lesson%202/Data%20Set/Lesson2\\_Toll\\_Scenario/1\\_base\\_case.zip](https://github.com/xzhou99/learning-transportation/blob/master/Lessons/Lesson%202/Data%20Set/Lesson2_Toll_Scenario/1_base_case.zip)”. Since the shortest path is path 1, all vehicles choose path 1 at 1<sup>st</sup> iteration. The result can be checked in NeXTA as follows:



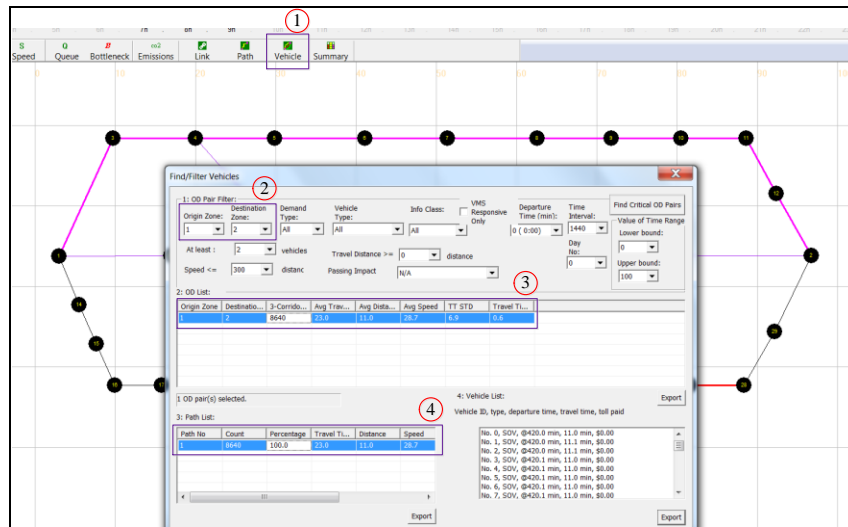


Fig. 40. Vehicle Dialog Box of Base Condition.

Step 1: Click “Vehicle” to call the dialogue of “Find/Filter Vehicle”.

Step 2: Choose the target OD pair and corresponding conditions. In this case, we choose OD pair 1→2.

Step 3: Click the OD list to check the general summary of OD pair 1→2.

Step 4: Choose one used path in Path List, which is visualized in traffic network as shown in the fig. 40. Meanwhile, the general information of each vehicle that choose that path is listed in Vehicle List. It is obvious that all vehicles choose path 1 after 1 iteration.

## 2. Scenario with link-based toll for low-income travelers

This section will examine the link-based toll function implemented in DTALite when all travelers belong to a low-income group, which indicates that travelers will have a low value of travel time (VOT). The specific settings and data set can be downloaded at

“[https://github.com/xzhou99/learning-transportation/blob/master/Lessons/Lesson%202/Data%20Set/Lesson2\\_Toll\\_Scenario/2\\_scenario\\_toll\\_low\\_income.zip](https://github.com/xzhou99/learning-transportation/blob/master/Lessons/Lesson%202/Data%20Set/Lesson2_Toll_Scenario/2_scenario_toll_low_income.zip)”.

In this data set, there is only one kind of demand type, namely, SOV, which can be checked in input\_demand\_file\_list.csv. The average VOT is assumed as \$10/hour and is set in input\_demand\_type.csv as highlighted in table. 5.

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. The free-flow travel time of path 1 is 11 min, so the generalized travel time of path 1 will be 12.2 min and is more than the free-flow path travel time of path 2, which is 12 min. As a result, all travelers should choose path 2 after the 1<sup>st</sup> iteration. The method of checking the result is same as that introduced in Section 1.

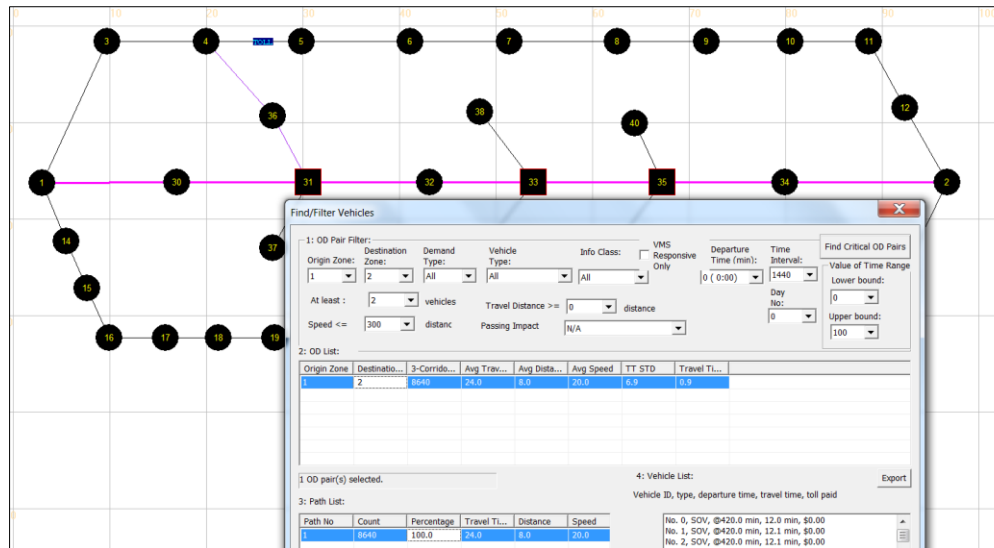


Fig. 41. Visualizing Vehicle Path for Low-income Travelers.

### 3. Scenario with link-based toll for high-income travelers

This section will examine the result of same tolling scenario for high-income travelers. The link-based toll settings keep unchanged in Scenario\_Link\_Based\_Toll.csv. The average of VOT for SOV will be \$20/hour in input\_demand\_type.csv.

Table. 6. Average VOT of SOV in the file input\_demand\_type.csv

demand_type	demand_type_name	avg_VOT
1	SOV	20

The specific data set is at “[https://github.com/xzhou99/learning-transportation/blob/master/Lessons/Lesson%20Data%20Set/Lesson2\\_Toll\\_Scenario/3\\_scenario\\_toll\\_high\\_income.zip](https://github.com/xzhou99/learning-transportation/blob/master/Lessons/Lesson%20Data%20Set/Lesson2_Toll_Scenario/3_scenario_toll_high_income.zip)”. As calculated in Section

2, the generalized path travel time of path 1 will be  $11 + \frac{0.2}{20/60} = 11.6$  min, which is less than 12 min of path 2's free-flow travel time. It indicates that all traveler will choose path 1 after the 1<sup>st</sup> iteration. The same steps in Section 1 is used to check the result. Meanwhile, we can observe that all travelers need to pay \$0.2 by using path 1 in the Vehicle List.

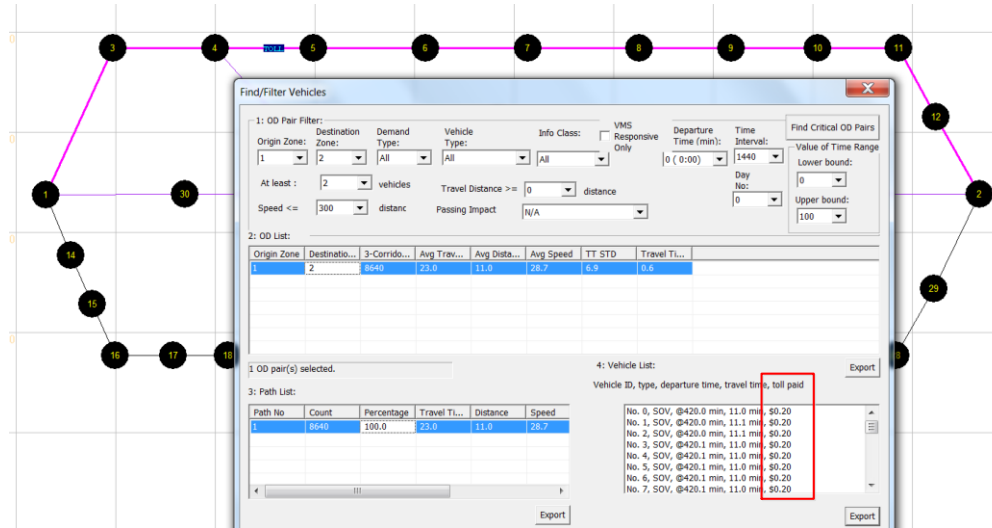


Fig. 42. Visualizing Vehicle Path for High-income Travelers.

#### 4. Scenario with link-based toll for low-income and high-income travelers

This section will examine the route choice result when same link-based toll scenario is used for both low-income and high-income travelers. We assume that there are 8000 SOV travelers and 640 HOV travelers in input\_demand\_1.csv and input\_demand\_2.csv, respectively. In this case, SOV and HOV correspond the low-income group and high-income group, so their average VOT will be \$10/hour and \$20/hour in input\_demand\_type.csv. The data set can be downloaded at [https://github.com/xzhou99/learning-transportation/blob/master/Lessons/Lesson%202/Data%20Set/Lesson2\\_Toll\\_Scenario/4-scenario\\_toll\\_1\\_iteration.zip](https://github.com/xzhou99/learning-transportation/blob/master/Lessons/Lesson%202/Data%20Set/Lesson2_Toll_Scenario/4-scenario_toll_1_iteration.zip). As analyzed in Section 3, under the same toll scenario in Scenario\_Link\_Based\_Toll.csv, low-income travelers and high-income travelers will choose path 2 and path 1, respectively, after the 1<sup>st</sup> iteration.

**Remark:** Path number in the Path list is not consistent with the path number defined in Section 1. We use the path number defined in Section 1 for illustration in this document.

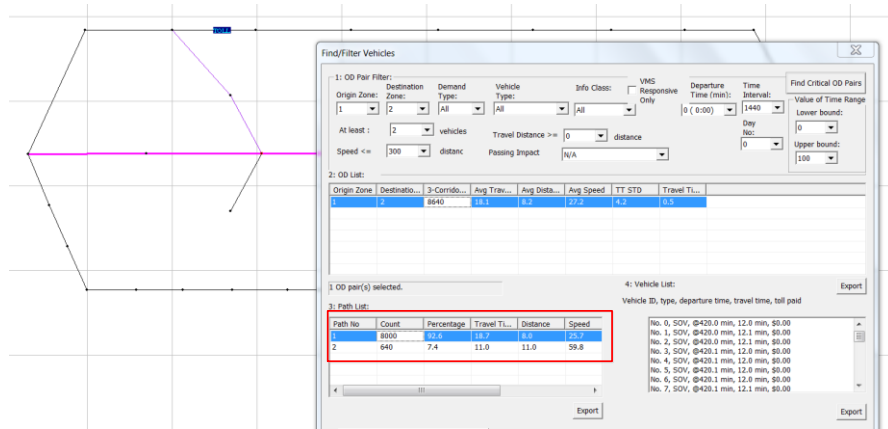



Fig. 43. Visualizing Vehicle Path for Low-income Travelers.

In this Path List, we can observe that there are two used paths. When the first path is clicked, path 2 is visualized in the traffic network and 8000 SOV travelers select path 2 as their route choice. Meanwhile, it is also shown in the Path List that the average travel time of path 2 is 18.7 min, but path 1 only has 11 min that is the free-flow travel time. It means that some travelers on path 2 will switch to path 1 if more iterations are performed. The following is the result of running 20 iterations for user equilibrium state. Click on the simulation button  of NeXTA and run it for 20 iterations.

Review Simulation/Assignment Settings

Network Data Summary:

40 nodes  
48 links  
2 zones  
2 activity locations  
12 link types

Demand Data Summary:

Demand Loading Time Period:  
7:00-> 9:00 (07:00 AM->09:00 AM)  
Demand files:  
input\_demand\_1.csv  
input\_demand\_2.csv

Traffic Management Scenario Summary:

1 links with road toll.

Link Traffic Flow Model:

1. Point Queue Model  
2. Newell's Knematic Wave Model

# of Iterations/Days: 20

Run Simulation

Exit

Fig. 44. Simulation Setting

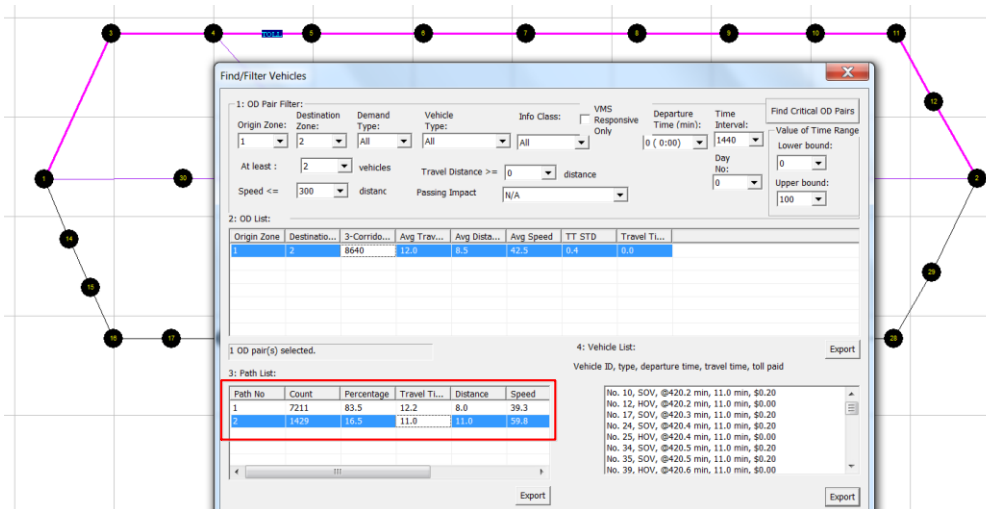


Fig. 45. Visualizing Vehicle Path for HOV Travelers.

The Path List shows that some travelers on path 2 switch to path 1, and the average travel time of path 2 becomes 12.2 min and path 1 still has the free-flow travel time, 11 min. For SOV travelers, the generalized path travel time of path 1 is  $11 + \frac{0.2}{10/60} = 12.2$  min, which is equal to the path travel time of path 2, so the user equilibrium is reached for them. All HOV travelers still choose path 1, whose generalized travel time is  $11 + \frac{0.2}{20/60} = 11.6$  min, so it can also conclude that the user equilibrium is found for HOV users. In addition, we can observe that the generalized travel time of SOV and HOV users is different under the user equilibrium condition. Therefore, the traffic state we obtained is a multi-class user equilibrium.

### 5. agent-based travel demand test

DTALite can also read agent-based file as input demand. This section will use the output\_agent.csv file in Section 2 as the input agent file to test the function in DTALite. We change output-agent.csv as input\_agent.csv and modify the settings in input\_demand\_file\_list.csv. As a result, values of fields “file name, and “format\_type” change to “input\_agent.csv” and “agent\_csv”, respectively. Changes are shown in figure 47.

scenario	file_sequence	file_name	format_type	number	loading_multiplier	subtotal	start_time	end_time	apply_adc	number_c	demand_type_1
0	1	input_agent.csv	agent_csv	1	1	0	420	540	0	1	1

Fig. 46. Applying changes in input\_demand\_file\_list

Please note that the prepared data set with the above mentioned changes can be readily downloaded at “[https://github.com/xzhou99/learning-transportation/blob/master/Lessons/Lesson%202/Data%20Set/Lesson2\\_Toll\\_Scenario/5\\_agent\\_test.zip](https://github.com/xzhou99/learning-transportation/blob/master/Lessons/Lesson%202/Data%20Set/Lesson2_Toll_Scenario/5_agent_test.zip)”. In theory, the result should be same as that of Section 2, because we read the same input demand just with different format. The result is shown as follows.

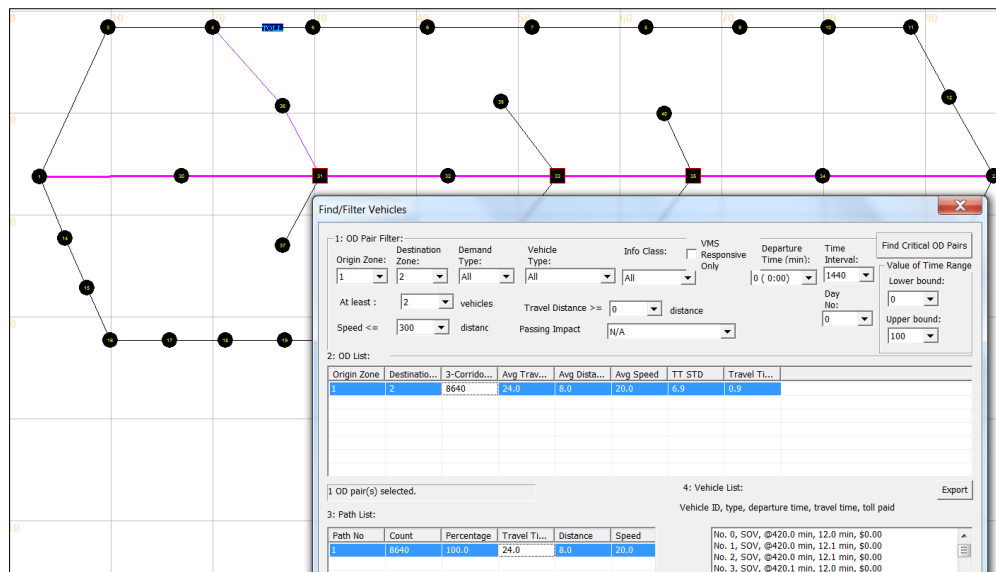


Fig. 47. Visualizing Vehicle Path for SOV Travelers.



### Solution Problems in Learning Document 3.2

Prepared by Tony Liu ([jiangtao.liu@asu.edu](mailto:jiangtao.liu@asu.edu)) and Xuesong Zhou ([xzhou74@asu.edu](mailto:xzhou74@asu.edu))

#### Problem 1:

(1) Which node is defined as the origin node of zone 1? (check input\_activity\_location file)

An origin node is a node where traffic demand (activity) is loaded from the origin zone, so the node is the activity location (i.e. centroid) of the origin zone. The node 1 is the origin node of zone 1. You can also check from NeXTA menu bar “Project”->“Network Data”->“Zone” tab.

View/Edit Network Data		
Node	Link	Zone
Activity Location	Move	
zone_id	node_id	external_OD_flag
1	1	0
2	2	0
38	38	0
39	39	0
40	40	0
41	41	0

(2) Which node is defined as the destination node of zone 2? (check input\_activity\_location file)

Node 2 is the destination node.

View/Edit Network Data		
Node	Link	Zone
Activity Location	Move	
zone_id	node_id	external_OD_flag
1	1	0
2	2	0
38	38	0
39	39	0
40	40	0
41	41	0

**(3) How many trips are loaded from 7AM to 8AM. (check input\_demand\_file\_list file and associated demand file.)**

From input\_demand\_file\_list.csv, we can find the demand file as input\_demand.csv and a demand duration covering from 420 min to 540 min, and the input\_demand.csv file further shows demand from zone 1 to zone 2 as 7200, leading to a total demand of  $7200 * 1$  (loading multiplier) = 7200 during 7am to 9am. Therefore, the trips loaded from 7am to 8am are 3600.

**Problem 2:**

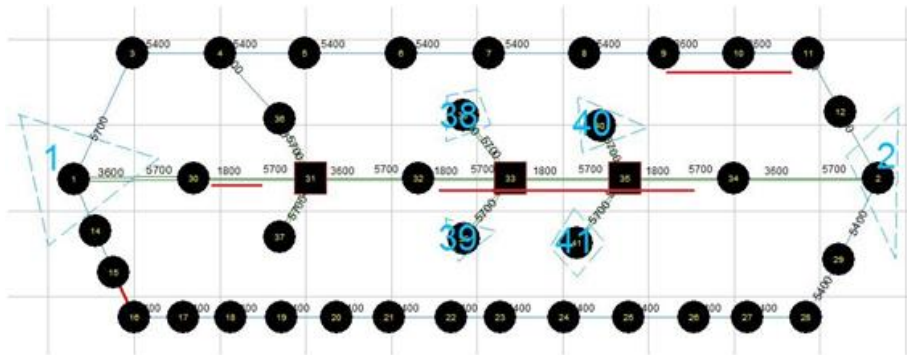
**(1) Which path will be selected at the first iteration?**

Since the free-flow travel times of path 1, path 2, and path 3 are 11 min, 12 min, and 17 min, respectively, path 1 has the least travel time and will be selected at the first iteration.

**(2) Find links with minimum capacity along three paths. Show the upstream node and downstream node numbers of those links and the hourly capacity values. Please use an image to highlight these links in the traffic network.**

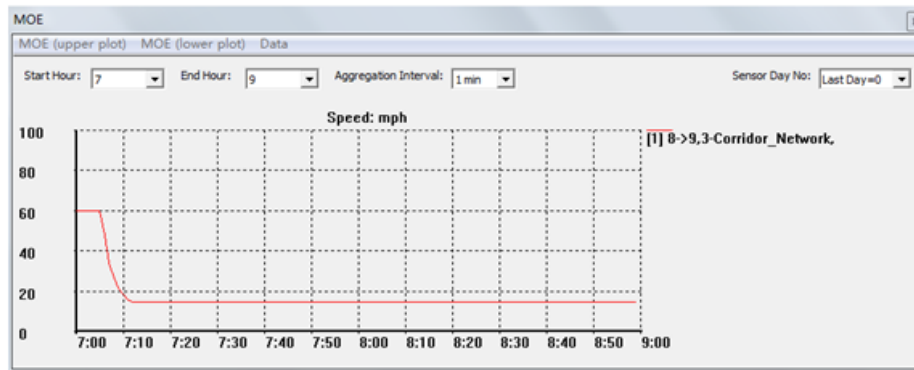
On path 1, the links with the minimum capacity are 9->10 and 10->11 with capacity of 3600vph; On path 2, the links with the minimum capacity are 30->31, 32->33, 33->35 and 35->34 with capacity 1800vph; On path 3, all links have capacity 5400vph. Those links in the traffic network can be visualized in the following Figure. (please click “Config” at top of GIS panel ->”Link Capacity Per Hour” in “Link Text”-> “OK” to show the text labels in the network)

Remark: if you download the dataset linked in the learning document, please check the capacity and number of lanes for link9->10. Its lane capacity should be 1800vph, and the number of lanes are 2.



**(3) What is the expected speed on link 8->9, if the demand is 5400 vehicles per hour, and all vehicles use the first path?**

When the demand is 5400vph: since the path 1 will be first selected and the capacity of link 8->9 and link 9->10 is 5400vph and 3600vph, respectively, node 9 will form a bottleneck. At the beginning of traffic simulation, the expected speed of link 8->9 is the free-flow speed of 60 mph, and then the speed will decrease as the congestion propagates. You can also set the demand multiplier as 1.5 (5400/3600) in input\_demand\_file\_list to check your analysis. The speed plot is shown as below:



Remark:

When you set the simulation settings, please choose “Newell’s Kinematic Wave Model” as follows:

Review Simulation/Assignment Settings

×

Network Data

40 nodes  
55 links  
6 zones  
6 activity locations  
12 link types

Demand Data

Demand Loading Time Period:  
7:00-> 9:00 (07:00 AM->09:00 AM)  
Demand files:  
input\_demand.csv

Traffic Management Scenario

Link Traffic Flow Model:

1. Point Queue Model

2. Newell's Kinematic Wave Model

# of Iterations/Days:

1

Run Simulation

Exit

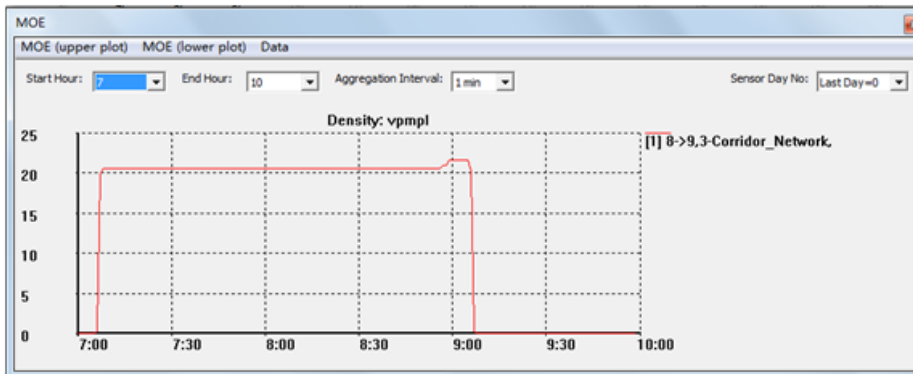
### Problem 3:

Please show the traffic density, speed and link and lane-based volume time series plots for links 8->9 and link 9->10. Explain why the density on link 8->9 is 20 vehicles per mile per lane, shown in Fig. 22.

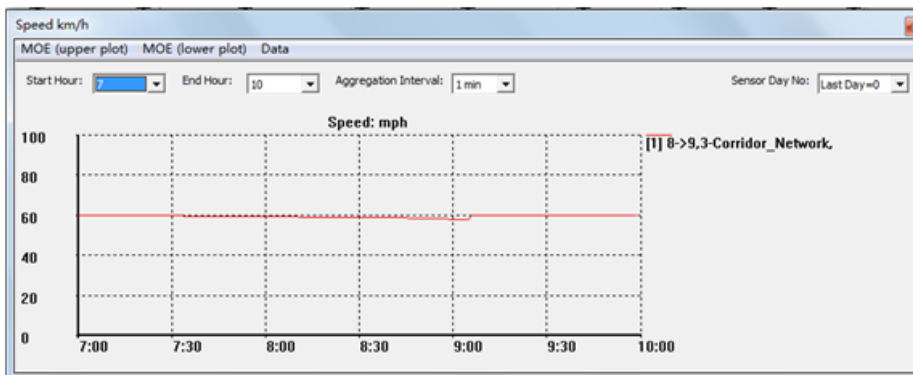
### Remark:

There would be an approximation error in NeXTA simulation.

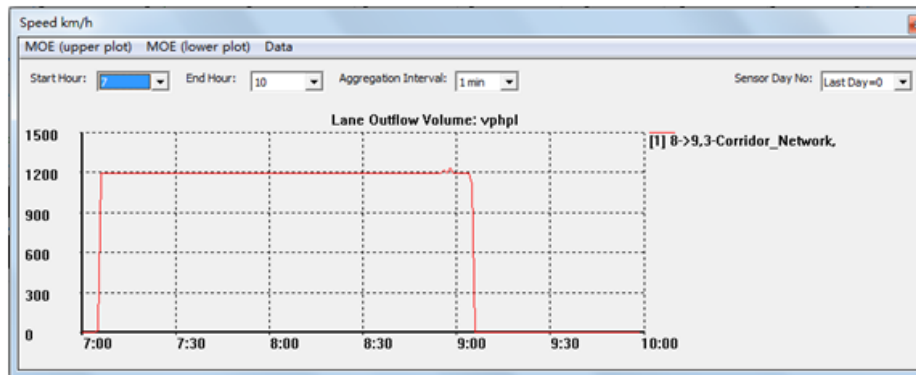
Traffic density for link 8->9:



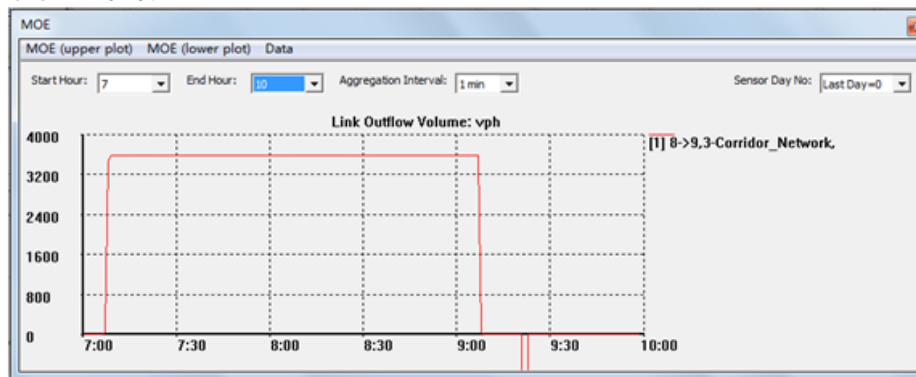
Traffic speed for link 8->9:



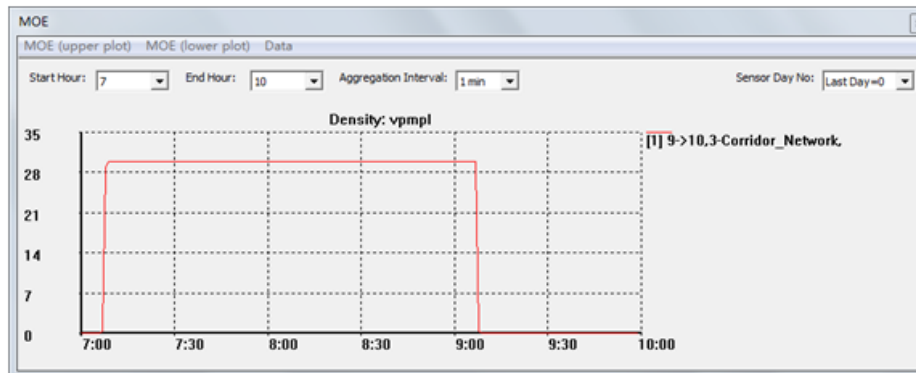
Traffic lane-based volume for link 8->9:



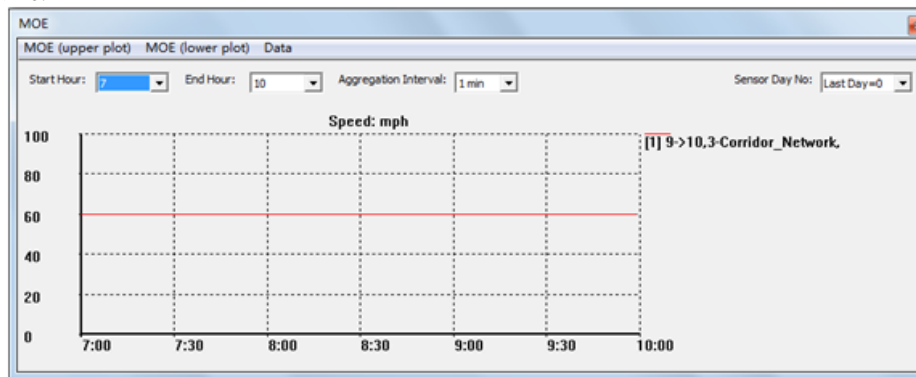
Traffic link-based volume for link 8->9:



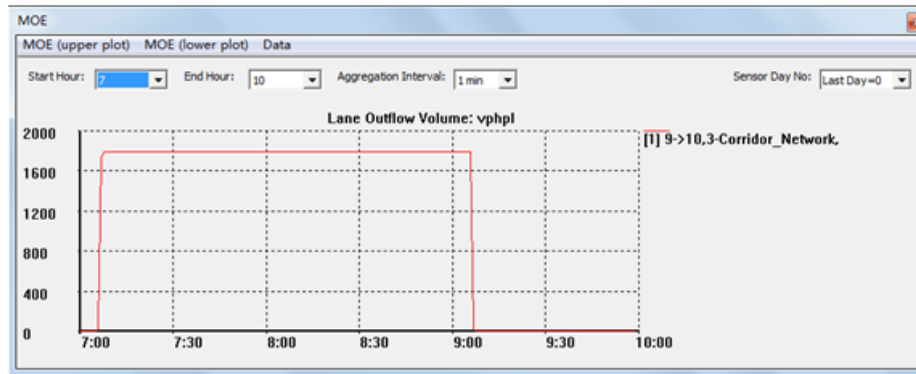
Traffic density for link 9->10:



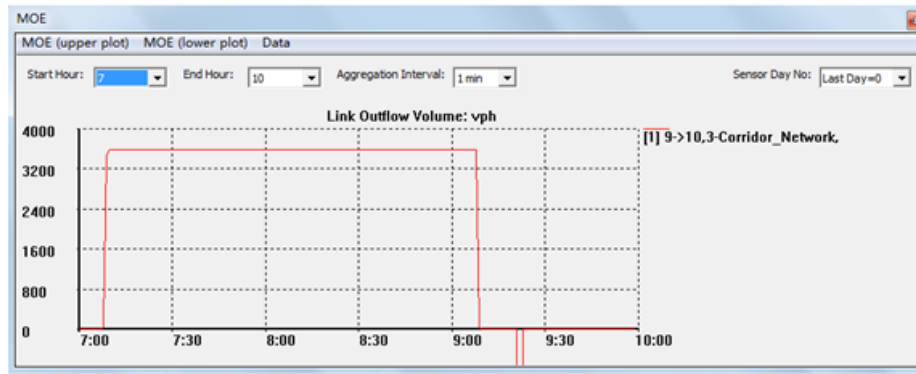
Traffic speed for link 9->10:



Traffic lane-based volume for link 9->10:

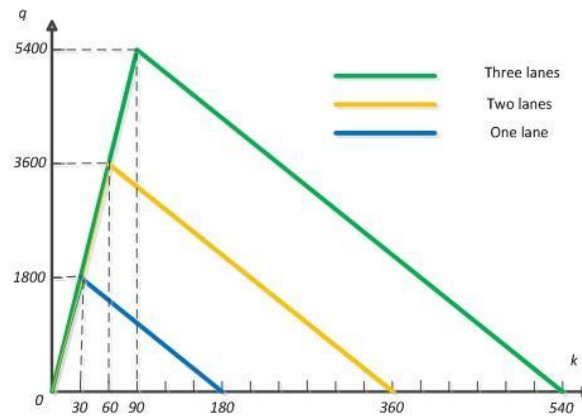


Traffic link-based volume for link 9->10:



Based on the Q-K relationship, when link outflow is 3600 vehicles/per hour, the corresponding density is 60vpmpl. Since the lane number is 3 for link 8->9, the final lane density is  $(60/3)20$  vpmp. This is also right about link 9->10, the corresponding density is 60 vpmp. As a result, the density for each lane is  $(60/2)30$  vpmp.





**Problem 4:**

In order to have detailed data extracted from the simulation results, please click on Menu bar of MOE dialog->Data ->Export Link MOE to CSV File.

Please plot the flow-density points in the Q-K relationship figure for links 8->9 and 9->10.

Based on the exported csv file, the lane outflow volume and density are listed in the following table for the link 8->9:

Lane outflow volume	density
0	0
1200	20

As observed from this table, there are generally two traffic states (lane outflow volume, density), state 1(0, 0) and state 2 (1200, 20).

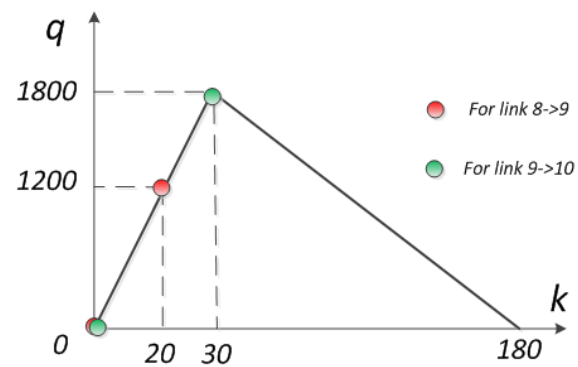
The length of link 8->9 is 1 mile, and the speed is free-flow speed, 60mph, so the travel time from node 8 to node 9 at the beginning when traffic flow comes in just needs 1/60 h (1 min). It means that for link 8->9, the process from traffic state 1(0, 0) to traffic state 2 (1200, 20) just needs 1

min. In the exported statistics csv file, the statistic time interval is 1min, so you can just see two traffic states. For link 9->10, the same analysis method can be applied.

The below table is for link 9->10, lane outflow volume and density.

Lane outflow volume	density
0	0
1800	30

Q-K curve is shown in the below figure for both link 8->9 and 9->10.

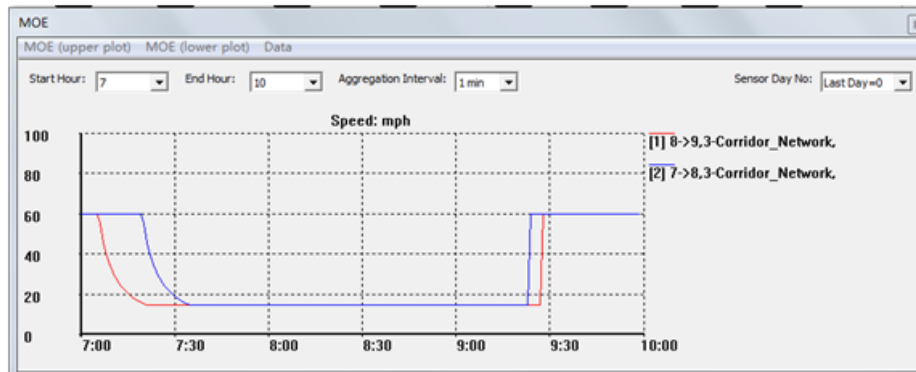


#### Problem 5:

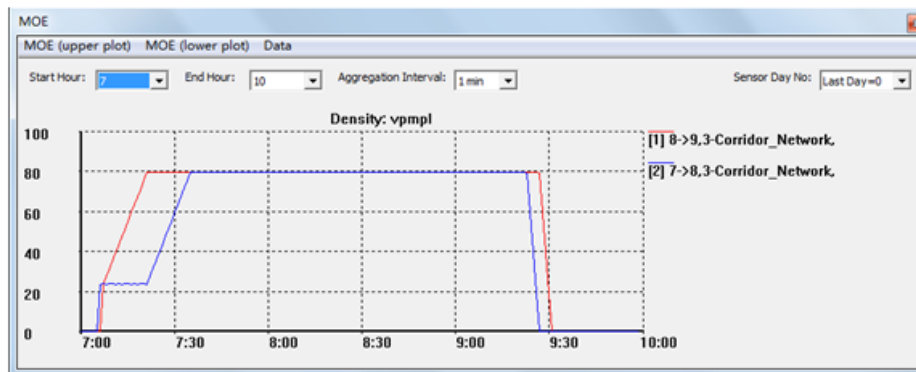
**Describe traffic speed and density evolution on links 7->8 and 8->9. Calculate the traffic congestion speed.**

In order to describe traffic speed and density evolution on link 7->8 and 8->9, we can use its speed and density plot in NeXTA:

(1) Speed:



(2) Density:

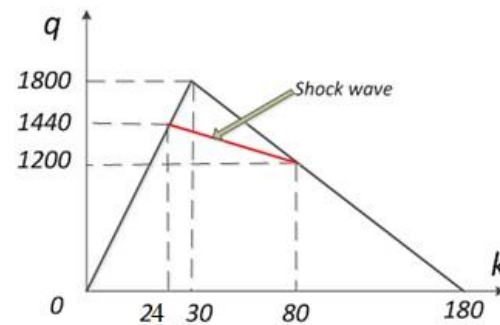
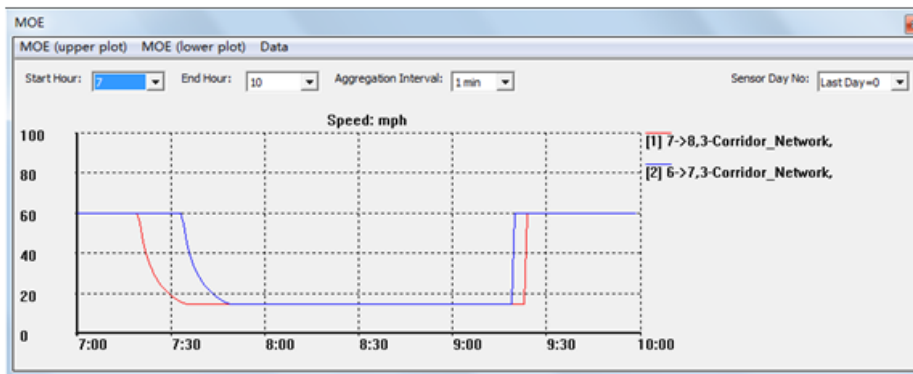


So we can observe that at the beginning, traffic is in free-flow state, and then due to the bottleneck impact, the congestion begins to propagate. After 14 min, it reaches at point 8, and at this time, the link 7->8 begins to form queues. As the length of link 8->9 is 1 mile, the congestion speed is  $(1\text{mile}/14\text{min}) = 60/14$  mph.

**Problem 6:**

Please compare the results between the simulation method and the graphical method. What is the expected start time for vehicles on link 7->8 seeing traffic congestion?

For 7->8, the same simulation method and graphical method are used:



Since the properties of link 7->8 is the same as that of link 8->9, so the propagation time is still 14min. The expected start time for vehicles on link 7->8 seeing traffic congestion is 455 min.

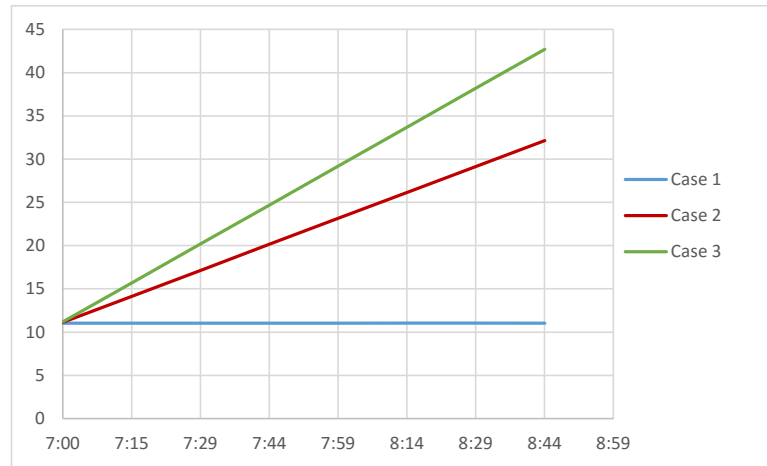
**Problem 7:**

**Please compare the results of cases 1, 2 and 3, and plot path 1 travel time in time horizon under three OD demand levels.**

After running simulation, the travel time in the time horizon can be obtained in the export\_path\_MOE.csv file. So the final results under three OD demand levels are listed in the following table:

		case 1	case 2	case 3
path_no	departure time	travel_time_in_m in	travel_time_in_m in	travel_time_in_m in
1	7:00	11.03	11.13	11.18
1	7:15	11.03	14.14	15.68
1	7:30	11.03	17.14	20.19
1	7:45	11.03	20.14	24.68
1	8:00	11.03	23.14	29.19
1	8:15	11.04	26.14	33.68
1	8:30	11.03	29.14	38.19
1	8:45	11.04	32.14	42.69

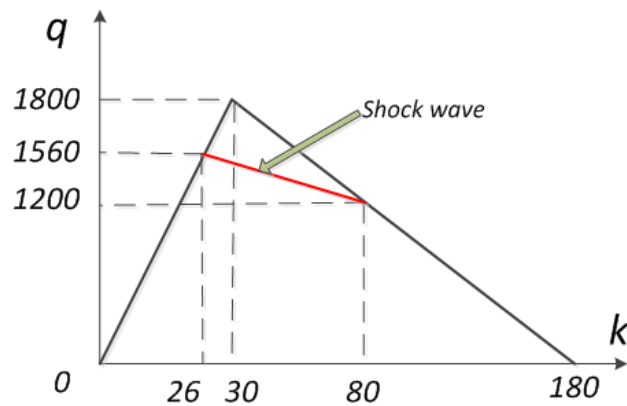
The figure is plotted as follows:



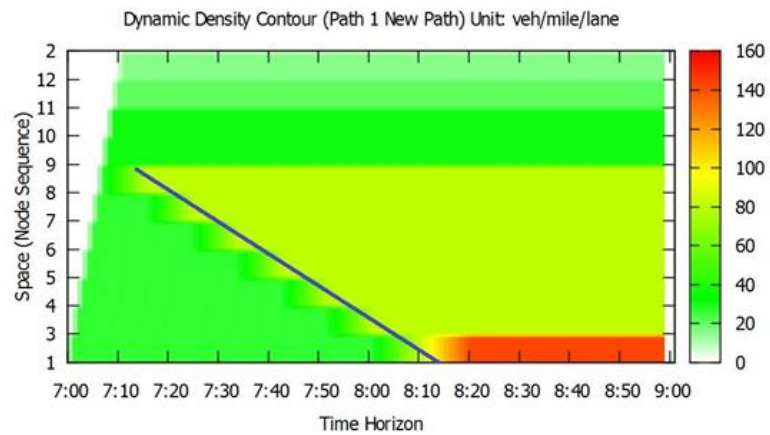
**Problem 8:**

**In case 3, how much time does it take from traffic congestion propagating from the bottleneck to the origin node? Please calculate the congestion propagation time analytically, and then check your estimated value based on the “density contour” or “speed contour” in NeXTA.**

Based on the Q-K relationship, the propagation speed is  $(1560-1200)/(80-26)=20/3$  mph:



The length from node 1 to node 9 is 7 mile, so the propagation time is  $7 \cdot (3/20) \cdot 60\text{min} = 63\text{ min}$ ;  
Based on the density contour in NeXTA:



The observed propagation time from the plot is about 63 min, which is consistent with the analytical calculation result.