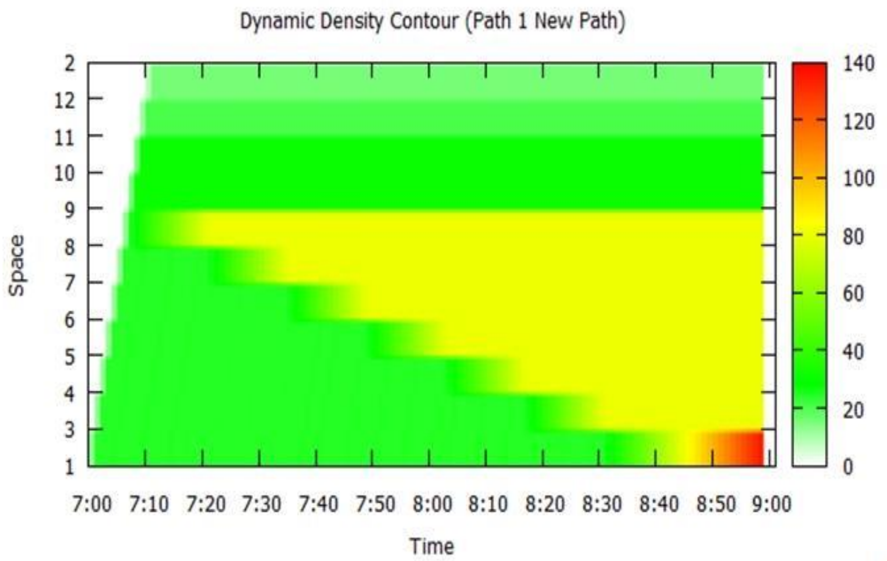
Lesson 2

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



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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:

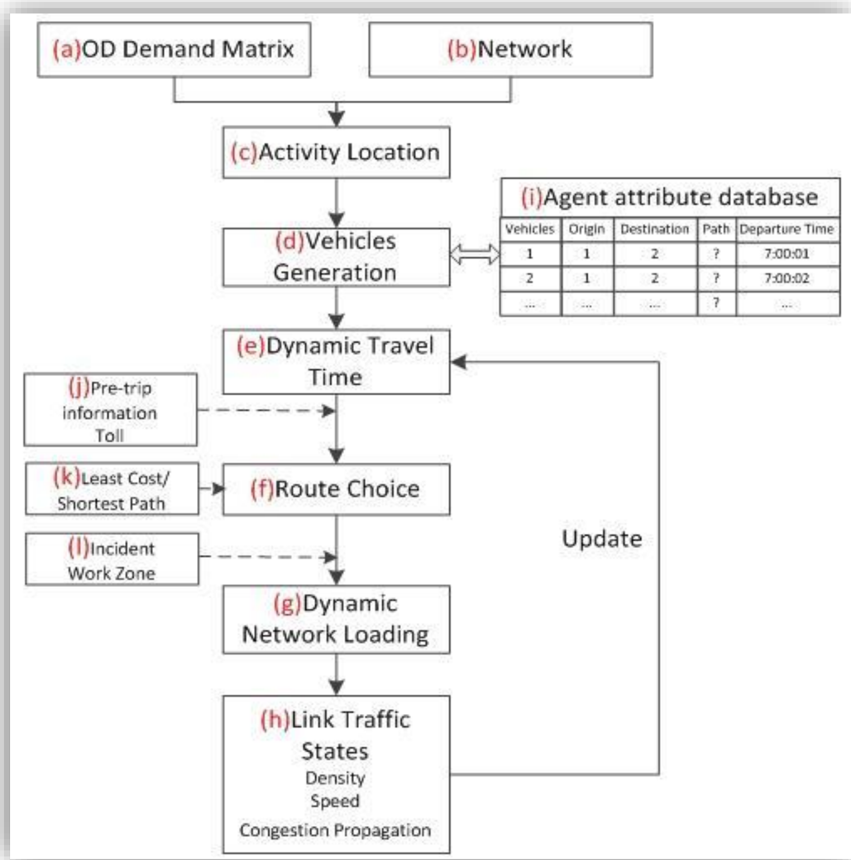


Fig.1. The process of dynamic network loading

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).

	5. At the following step within an **iterative assignment process**, the route choice module (f) will again recomputed 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. 6. The **pre-trip information and road toll charges** (j) can also affect travelers' route choice behavior by changing generalized link travel times . **Traffic incidents and work zones** (l) are considered as capacity reduction events which are fed into the traffic network loading program (g).

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 hypothetic 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.

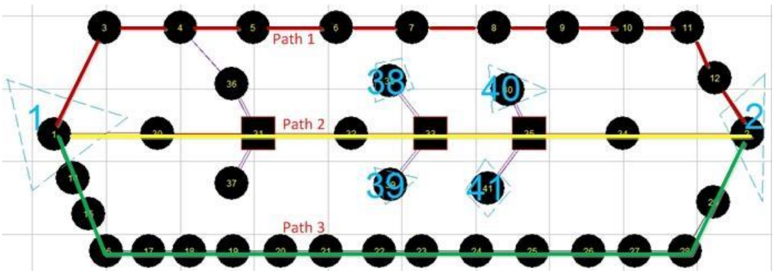


Fig. 2. Layout of 3-corridor Traffic Network

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	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…

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”.

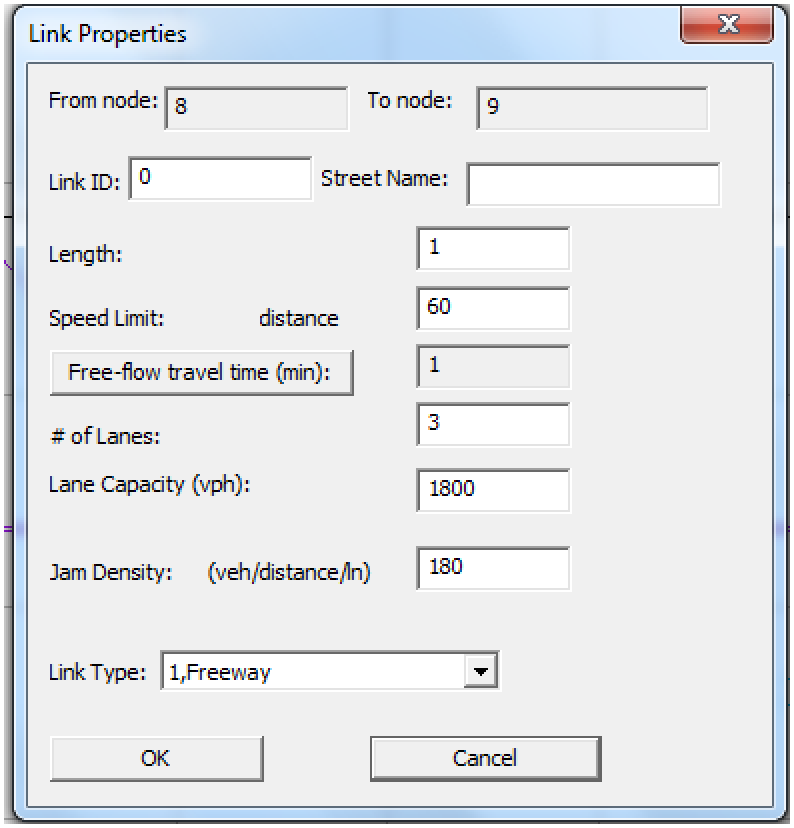


Fig. 3. Properties of link 8->9

Node and link tables:

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

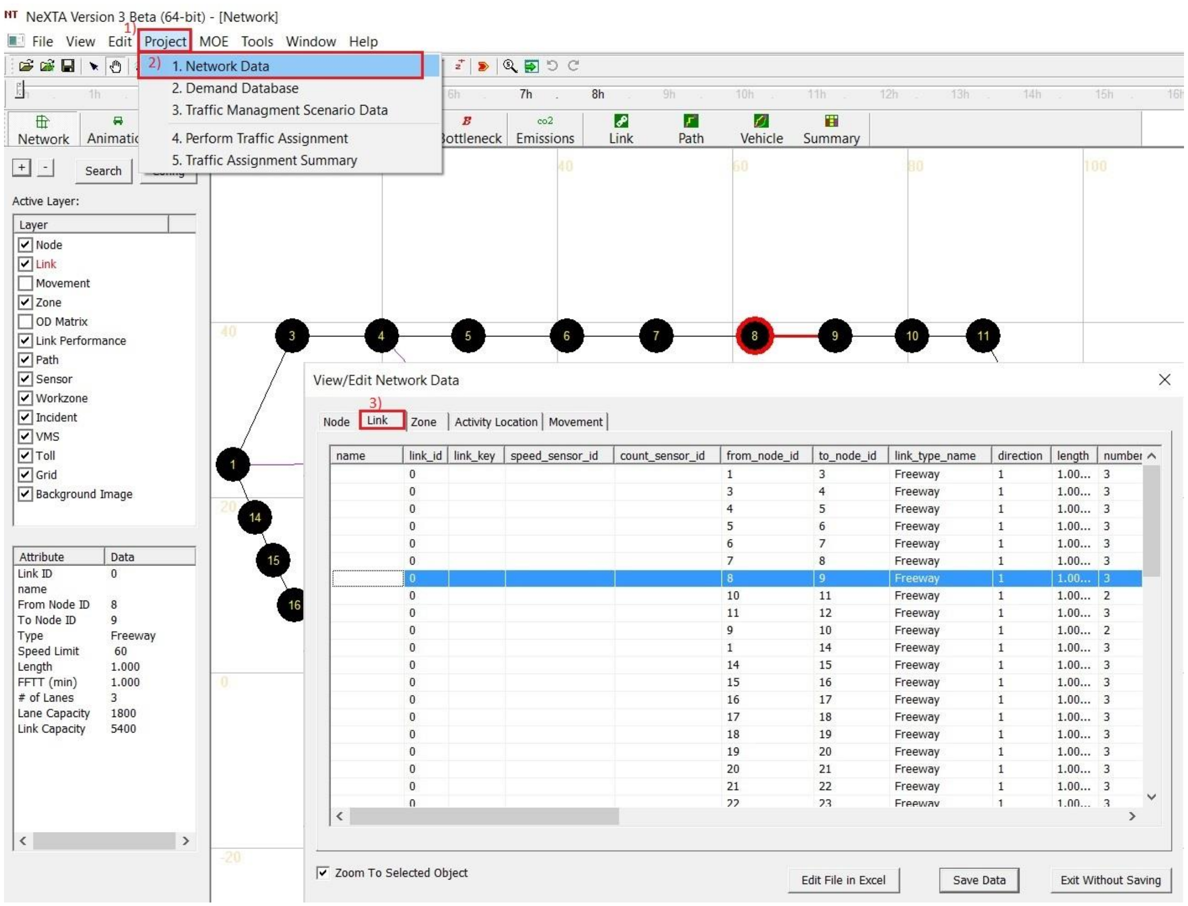


Fig.4. Properties of link 8->9

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.

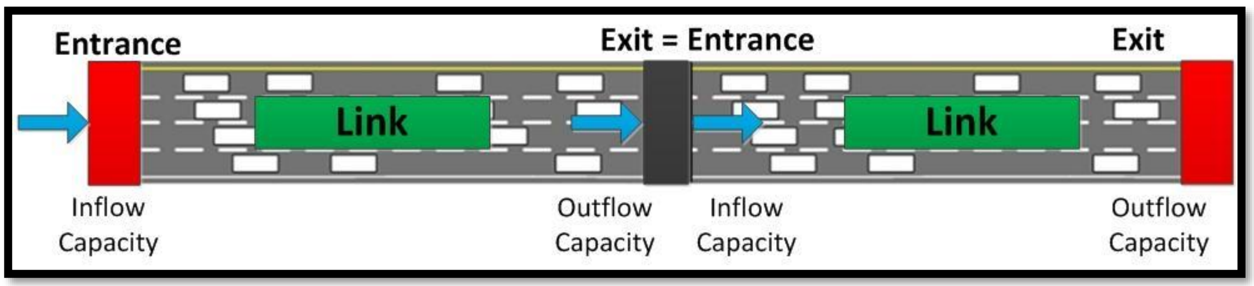


Fig. 5. Capacity analysis of one link

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) 

a) Which path will be selected at the first iteration?

b) 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.

c) 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.

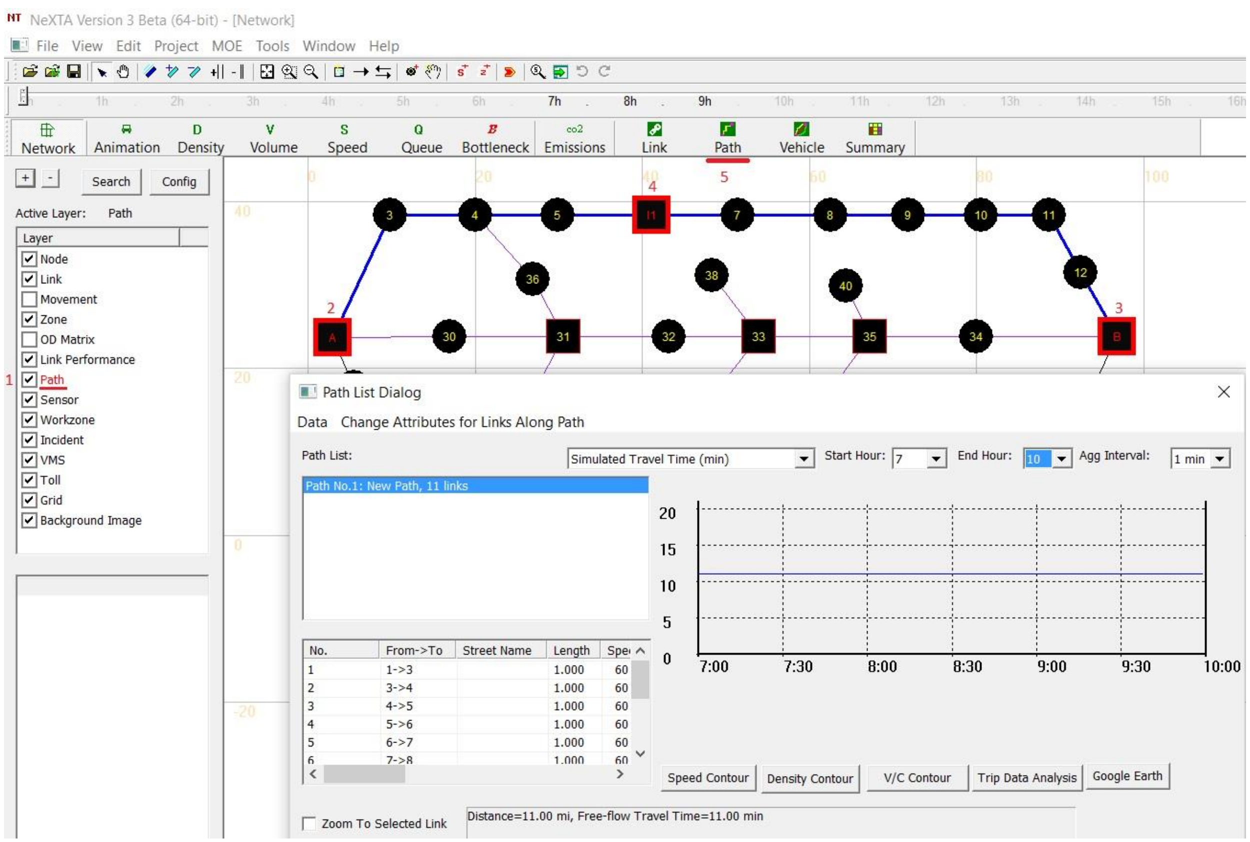


Fig.6. Path list dialog

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"

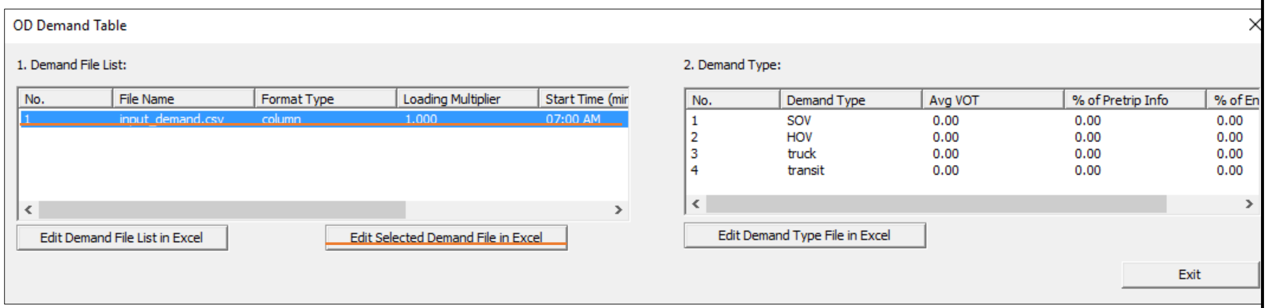
Step 4: Select any node (e.g. node 6) of the path 1-> right click to choose "Add Intermediate Destination here".

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.



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.

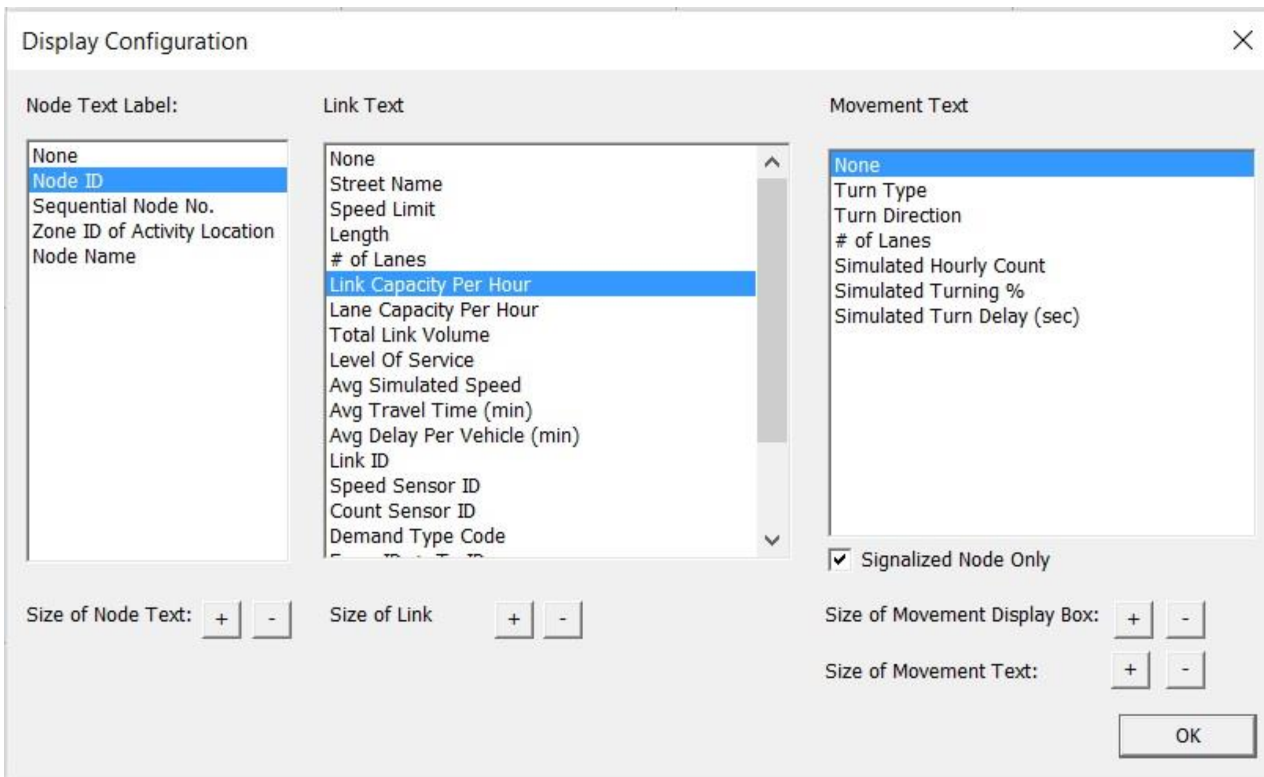
Fig.7.OD demand

(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”.



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.

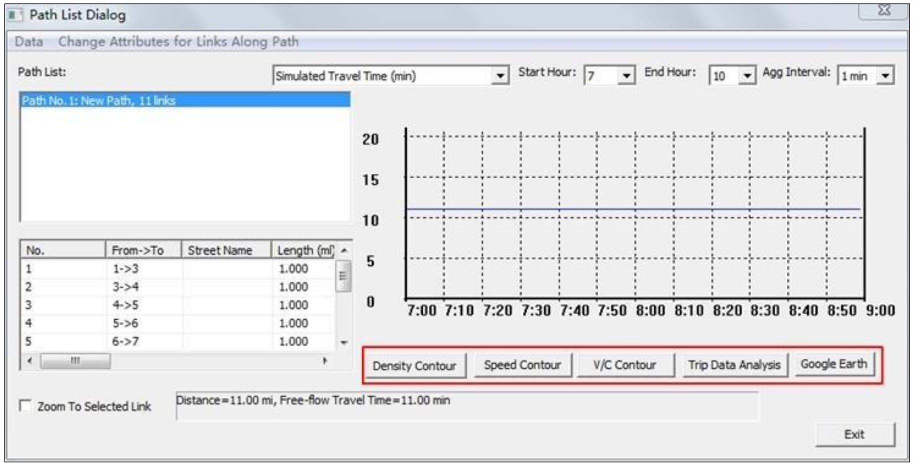


Fig.9. Path list dialog

(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.

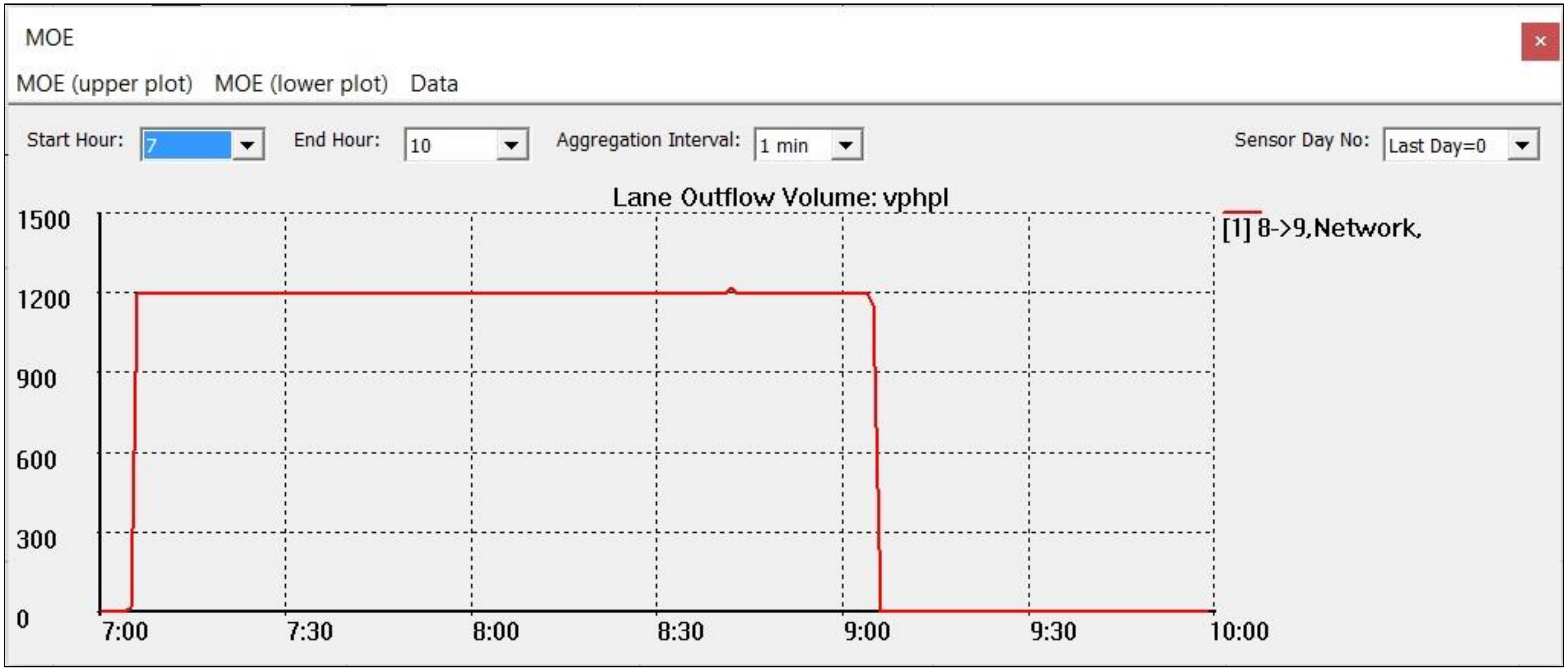


Fig.10. Interface of the MOE of link 8->9

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.

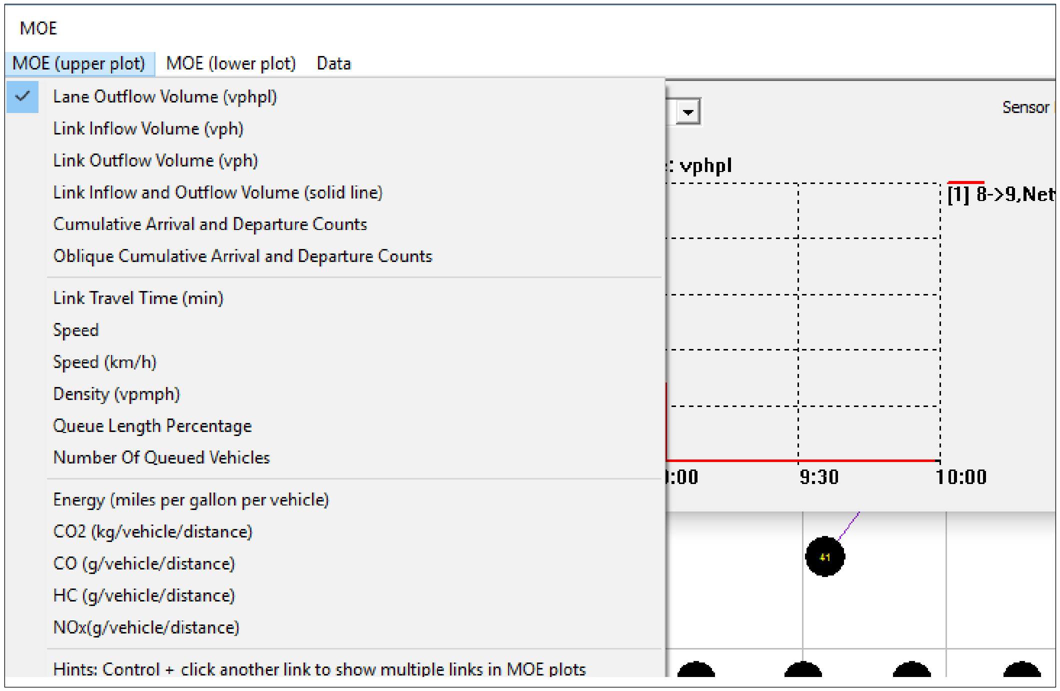


Fig.11. Detailed content of Link MOE

(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.

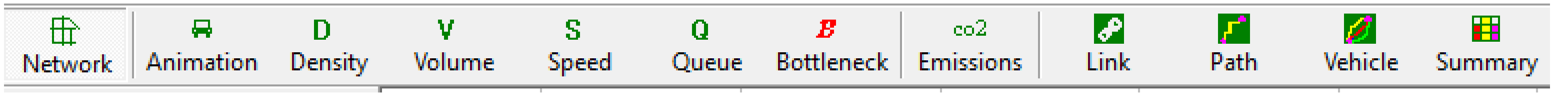


Fig.12. Shortcut icons for traffic simulation and analysis

(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.

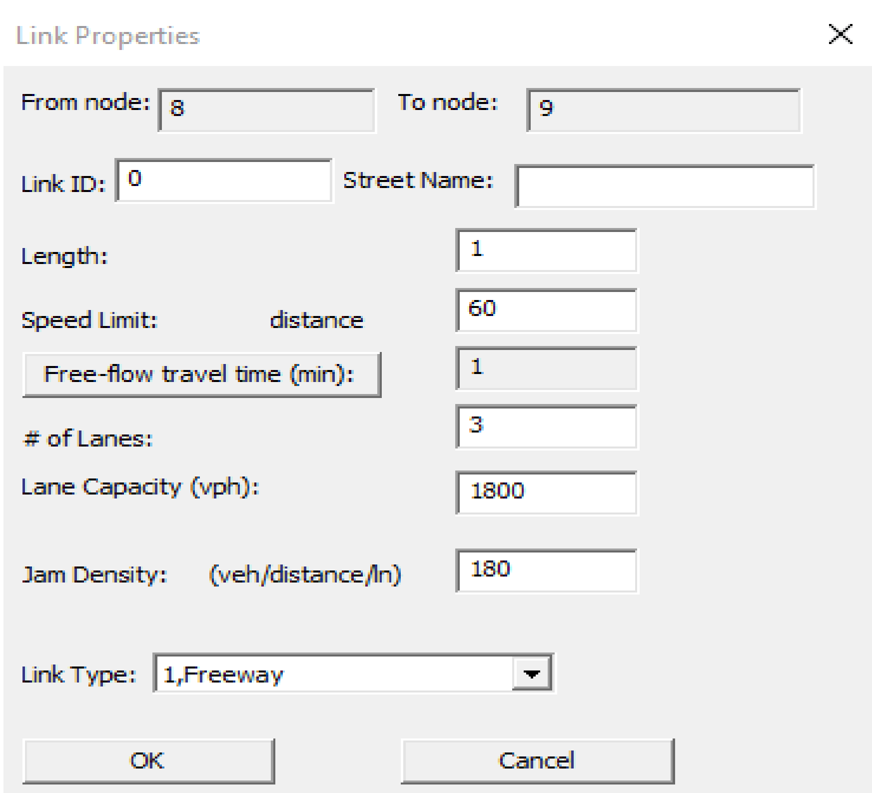


Fig.13. Properties of link

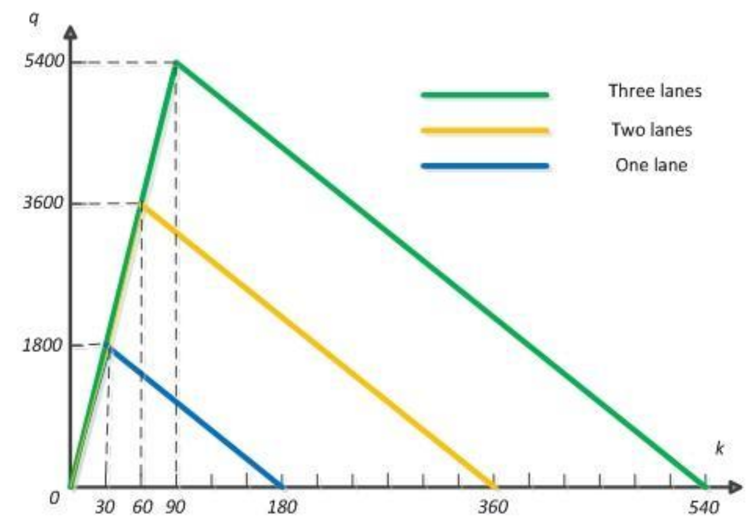


Fig.14. The flow-density relationship for different lanes of links

(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.

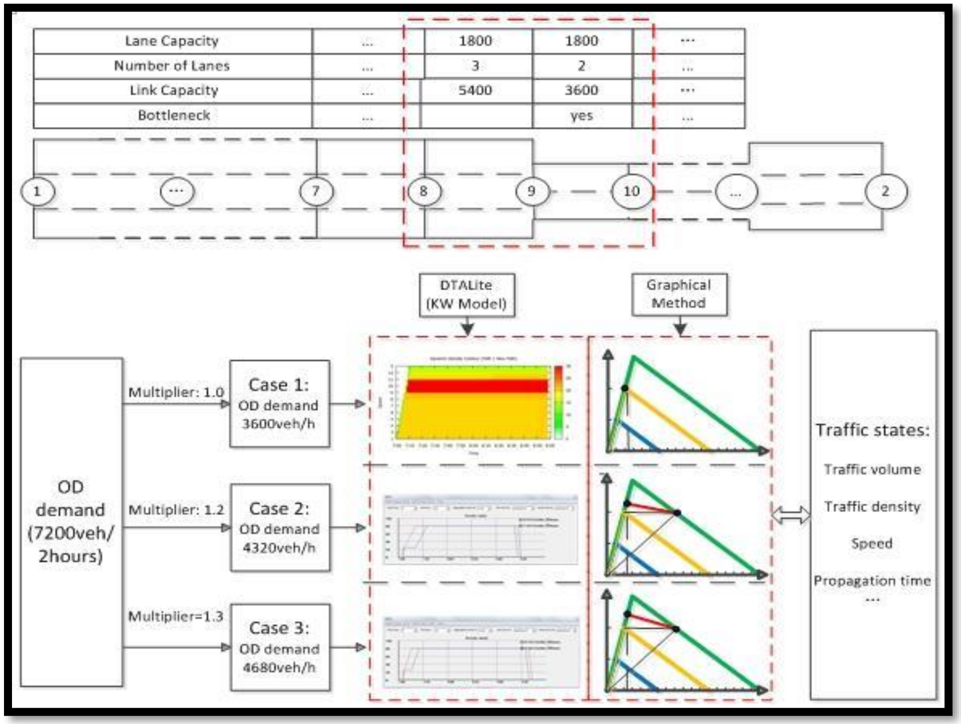


Fig.15. High-level overview of three testing cases

(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.

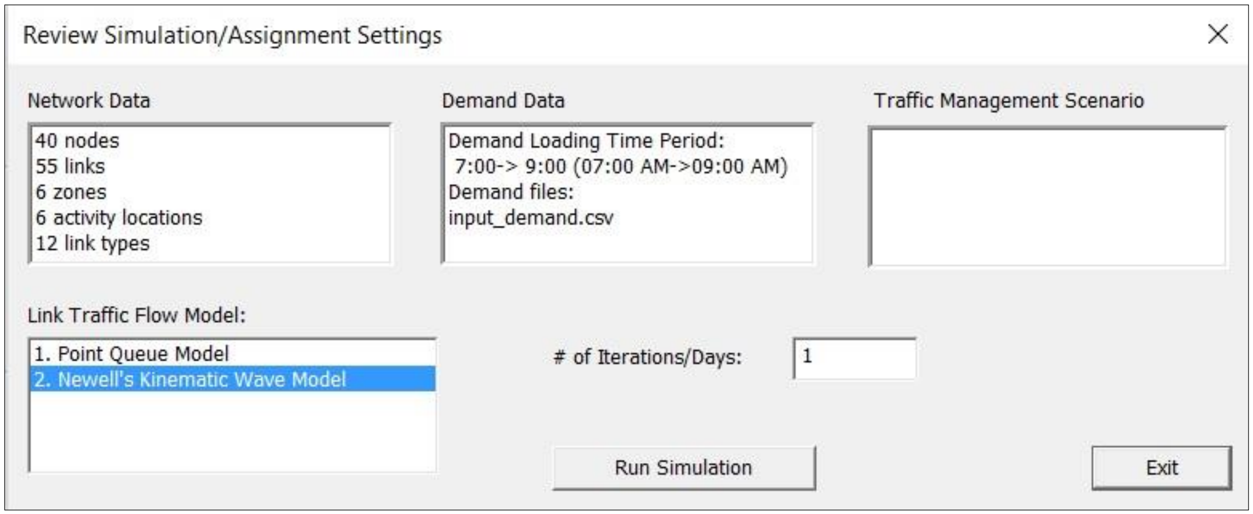


Fig.16. the interface of simulation settings

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.

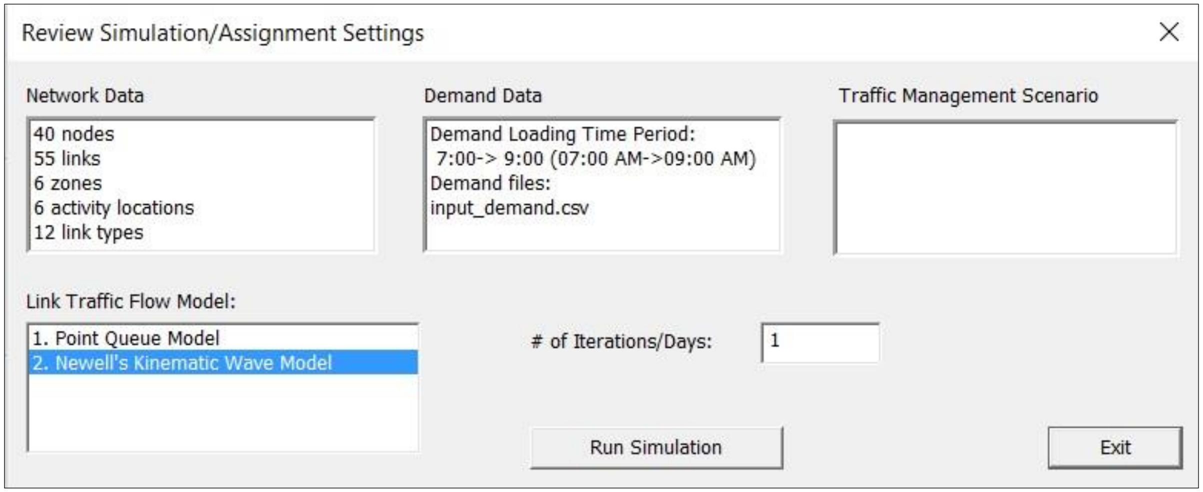


Fig.17. The interface of settings for case 1

- 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_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**

(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.

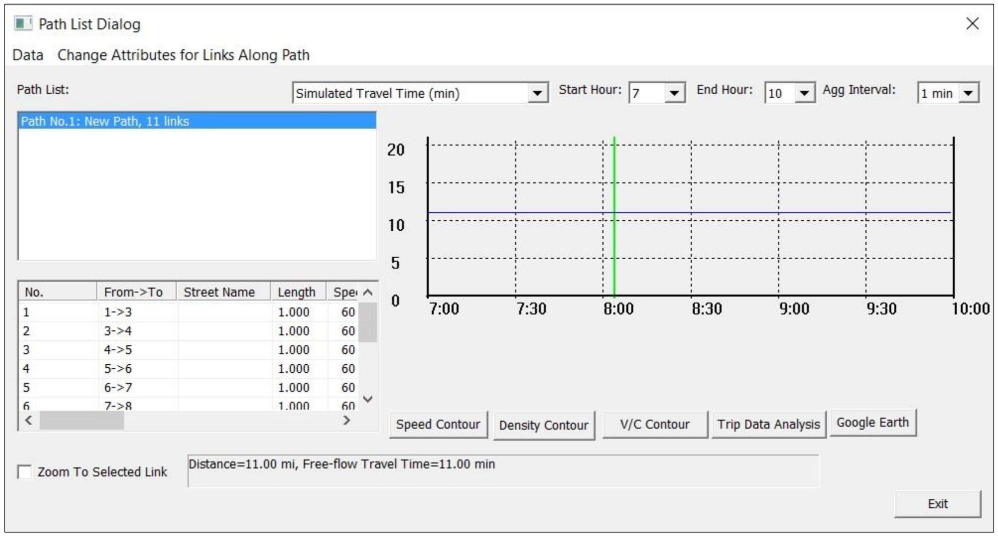


Fig. 18. Path List Dialog for Path 1.

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.

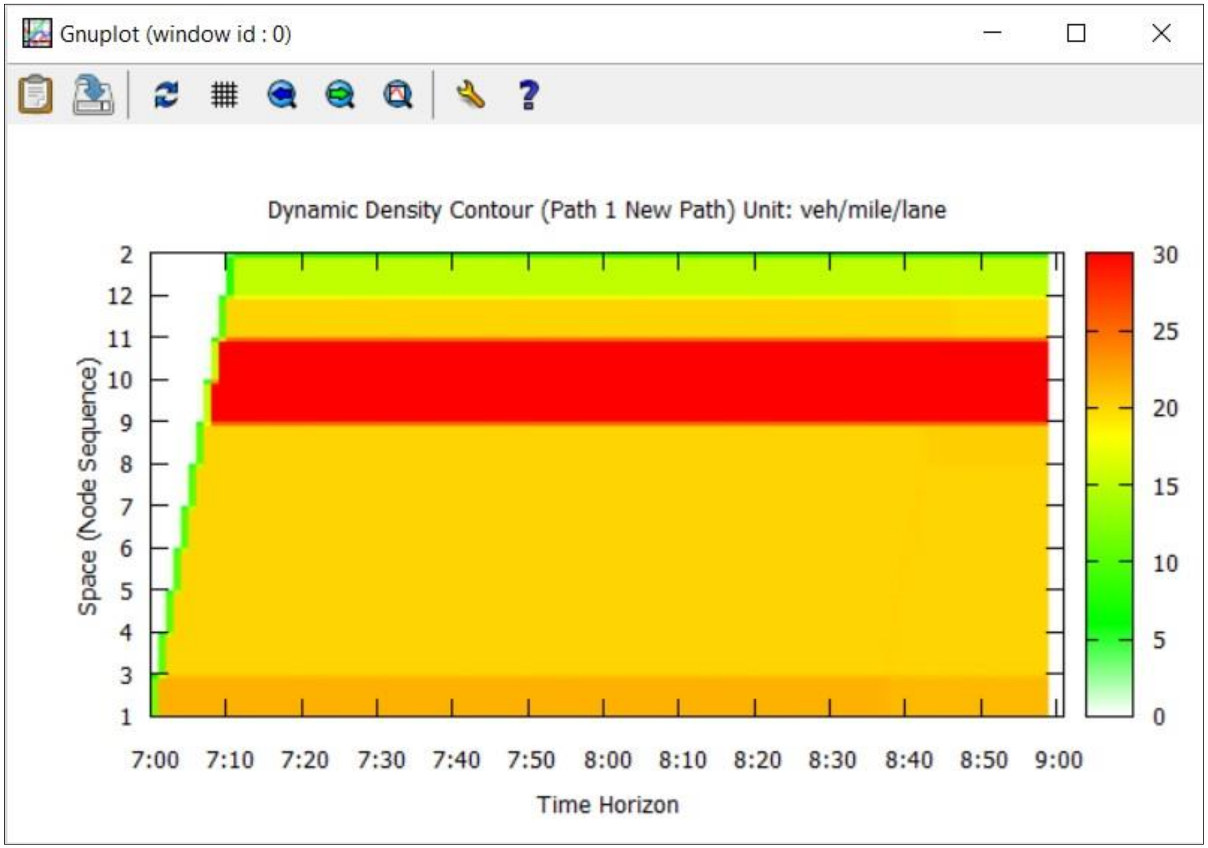


Fig. 19. The plot of dynamic density of path 1

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

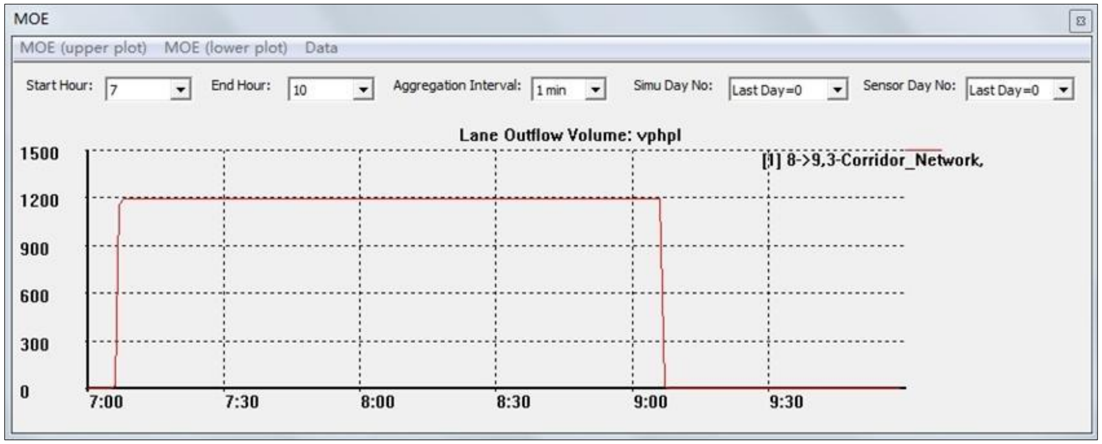


Fig.20. Simulated lane volume of link 8->9

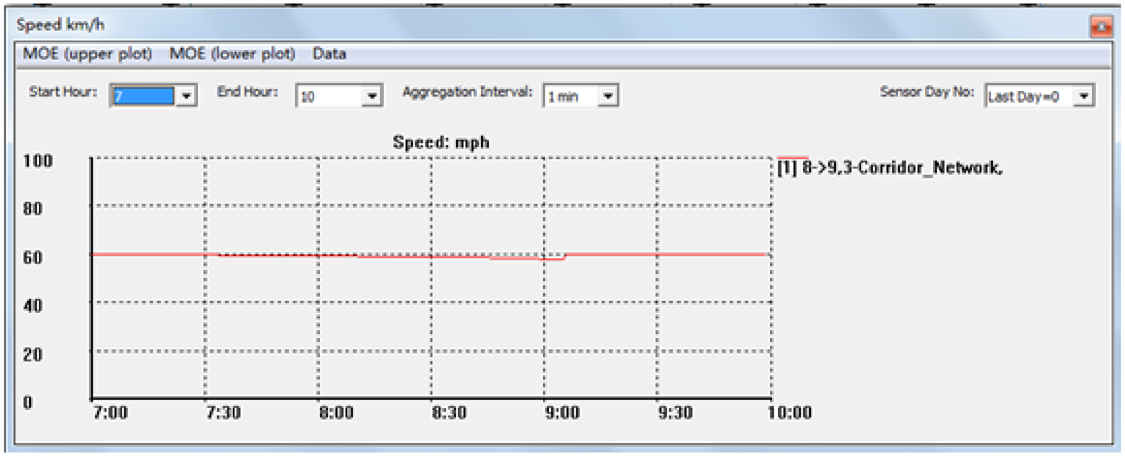


Fig.21. Simulated speed of link 8->9

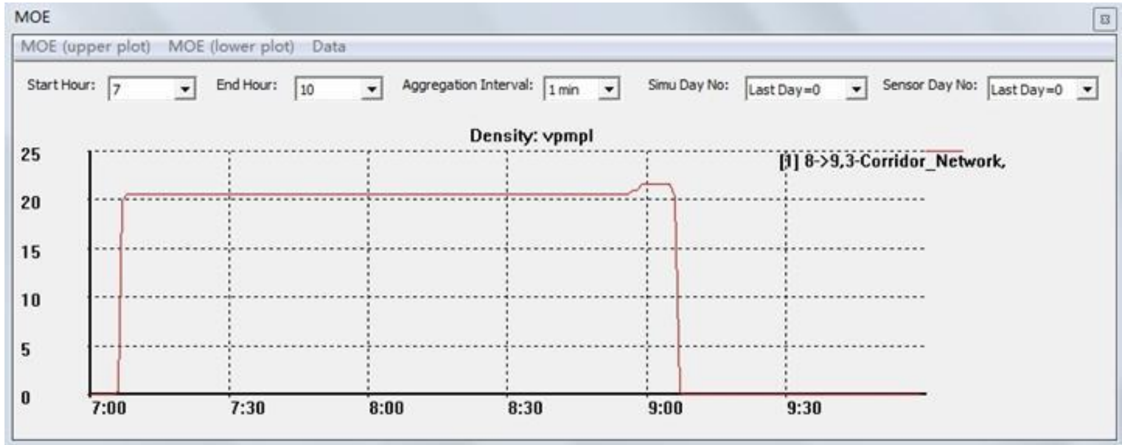


Fig.22. Simulated density of link 8->9

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.

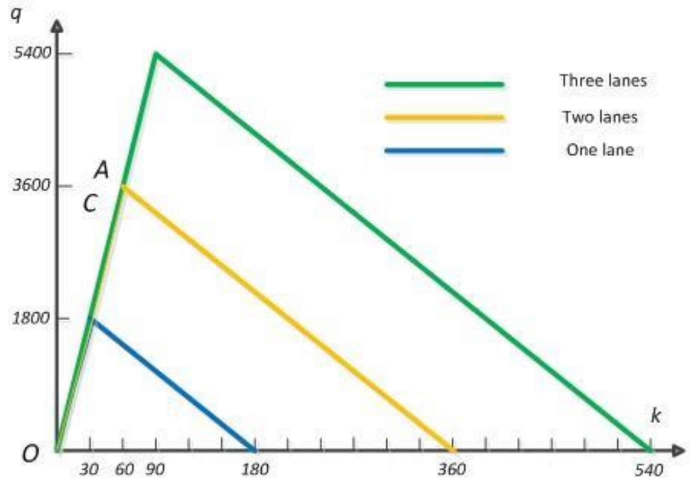
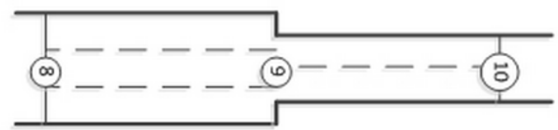


Fig.23. The flow-density relationship for different states of links



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

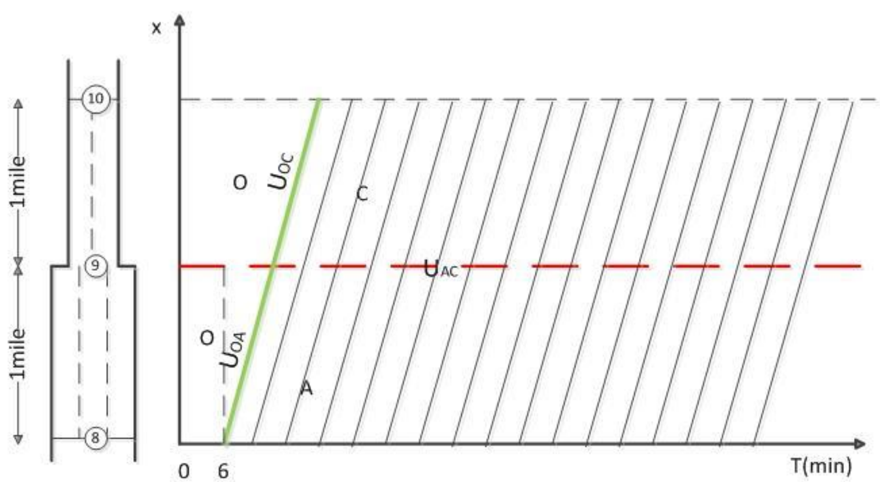


Fig.24. Vehicles' trajectory in space-time diagram

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

	is 30 vpmpl(lane). **Propagation time duration**: N/A

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*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. 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.

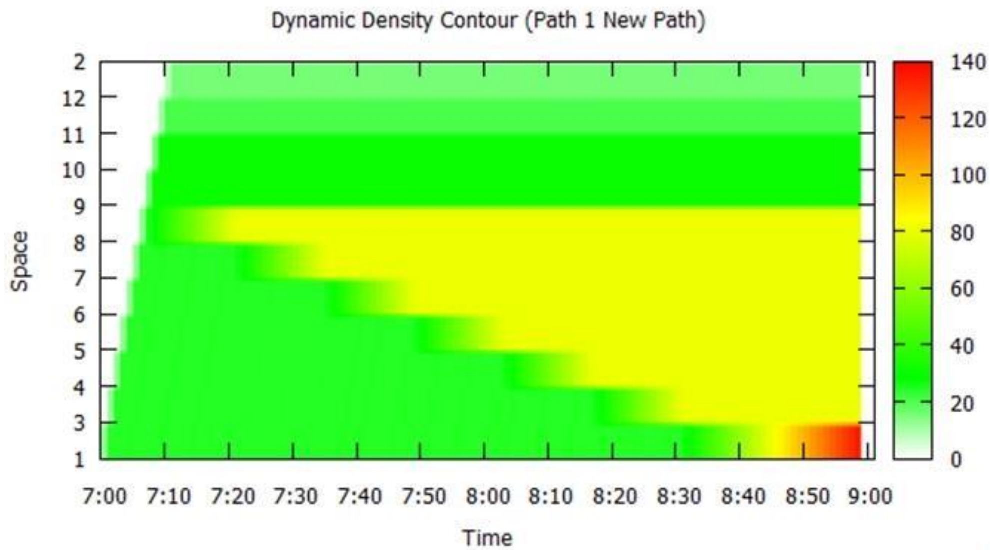


Fig.25. Density contour of path 1 in case 2

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.

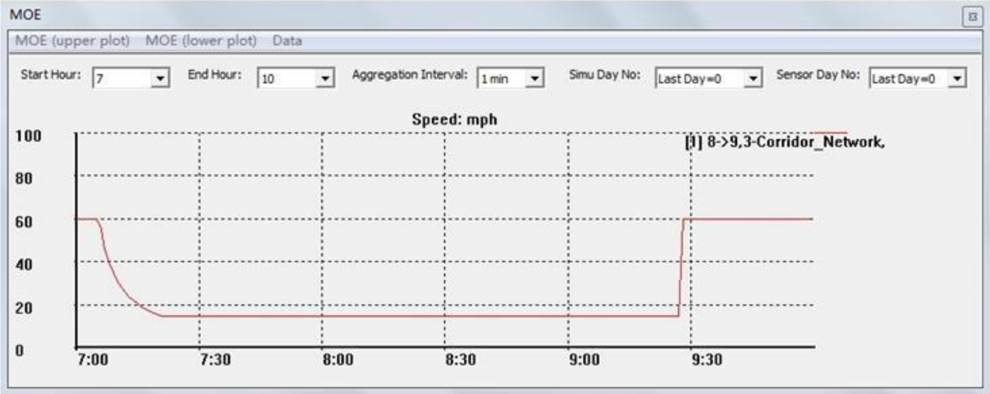


Fig.26. Simulated speed of link 8->9

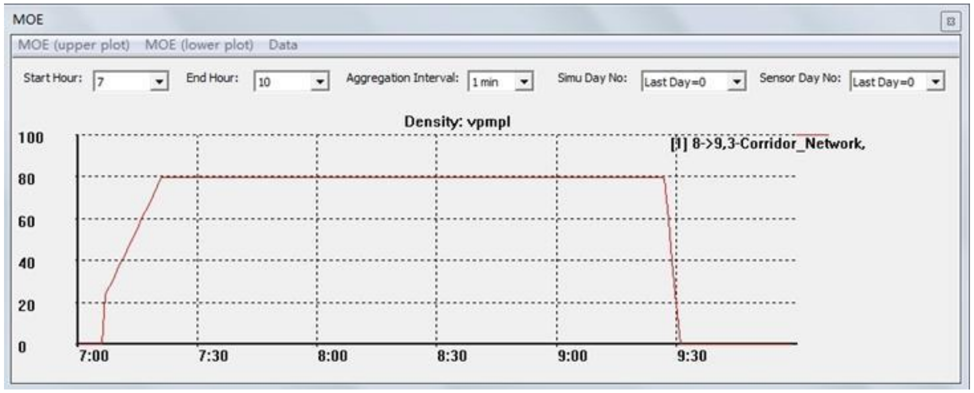


Fig.27. Simulated density of link 8->9

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.

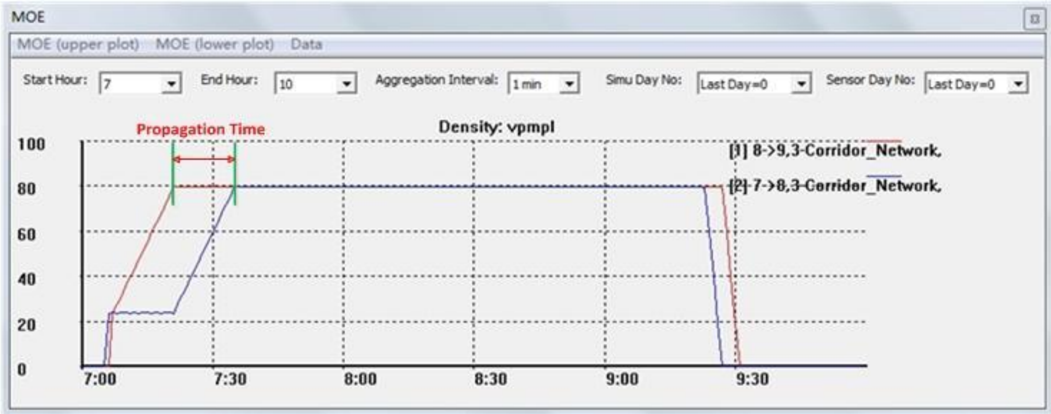


Fig.28. the simulation density of two links, 8->9 and 7->8

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.

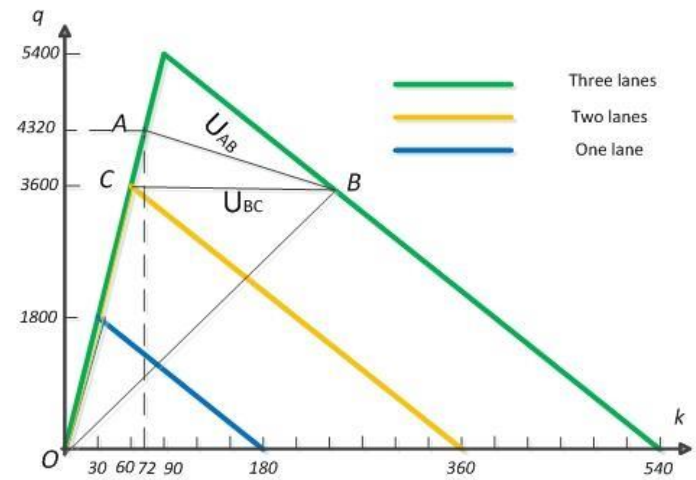
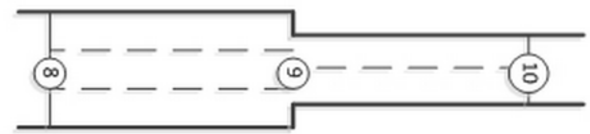


Fig.29. The flow-density relationship for different states of links



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

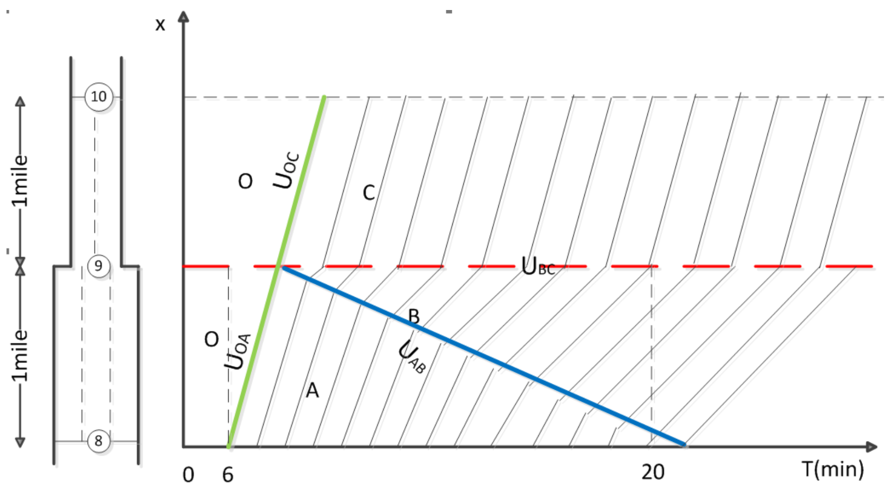


Fig.30. Vehicles' trajectory in time-space diagram

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*7200*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.

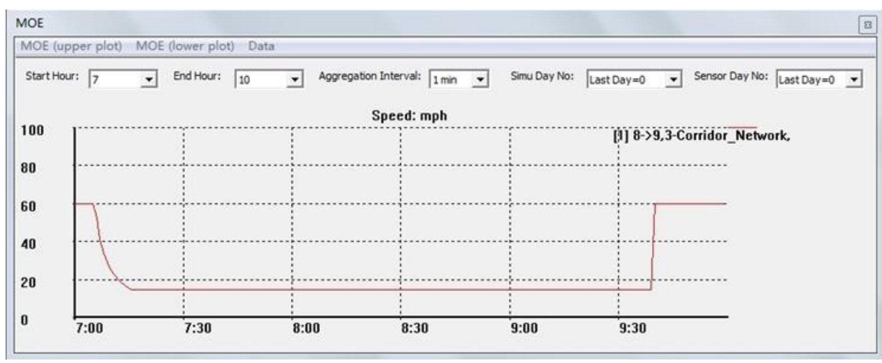


Fig.31. Simulated density of link 8->9

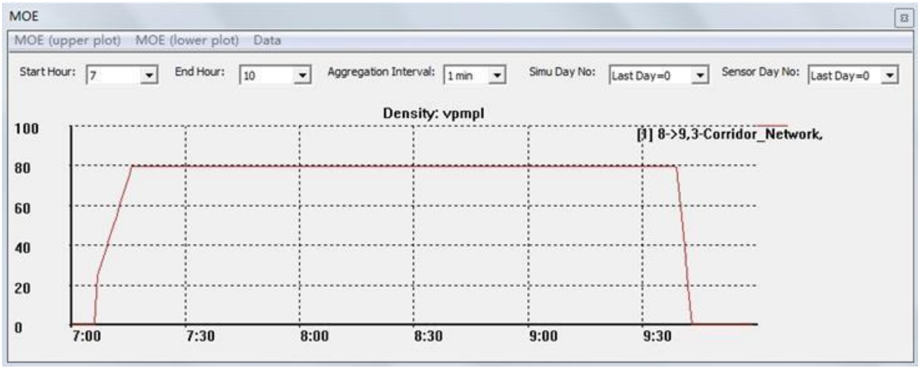


Fig.32 Simulated speed of link 8->9

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.

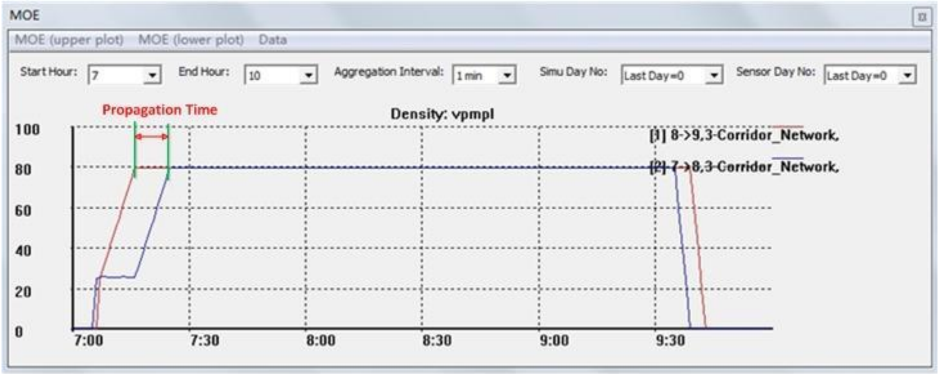


Fig.33. Simulated density of two links, 8->9 and 7->8

(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.

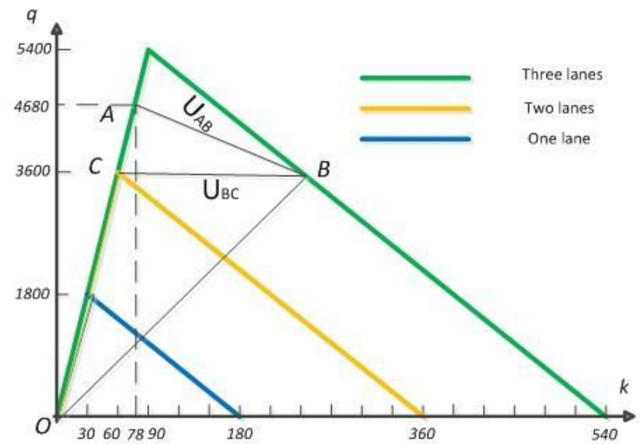
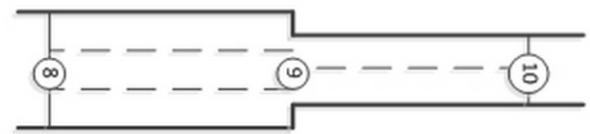


Fig.34. The flow-density relationship for different states of links



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

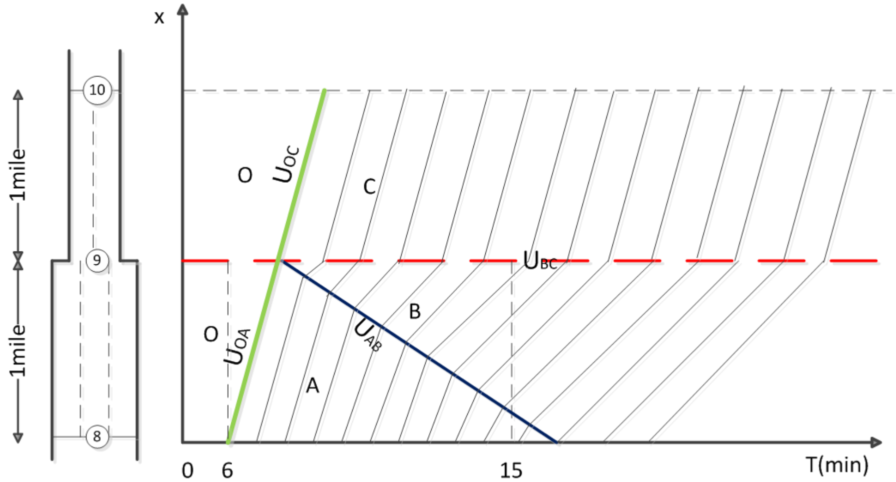


Fig.35. Vehicles’ trajectory in time-space diagram

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;

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(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: 9 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.

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.

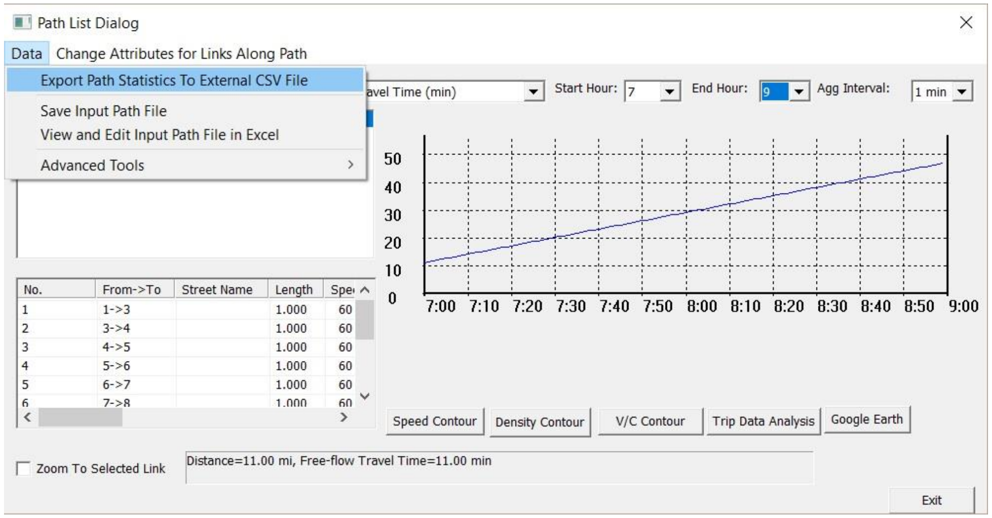


Fig. 36. Process of Exporting export_path_MOE File from NeXTA after Simulation for Case 3.

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.

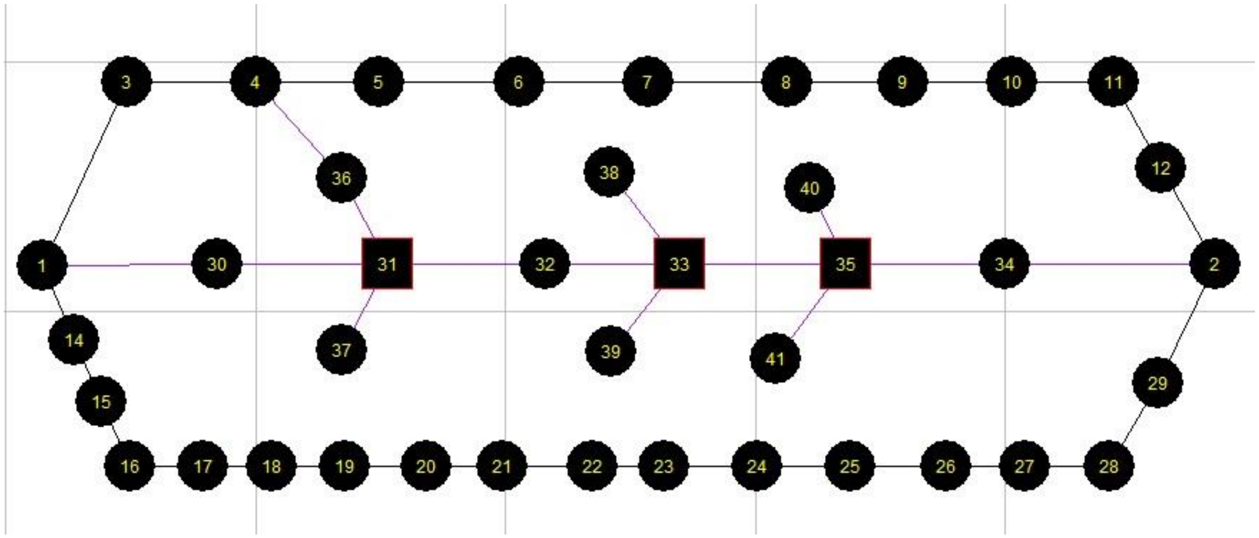


Fig. 37. Layout of 3-corridor Traffic Network

```
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

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

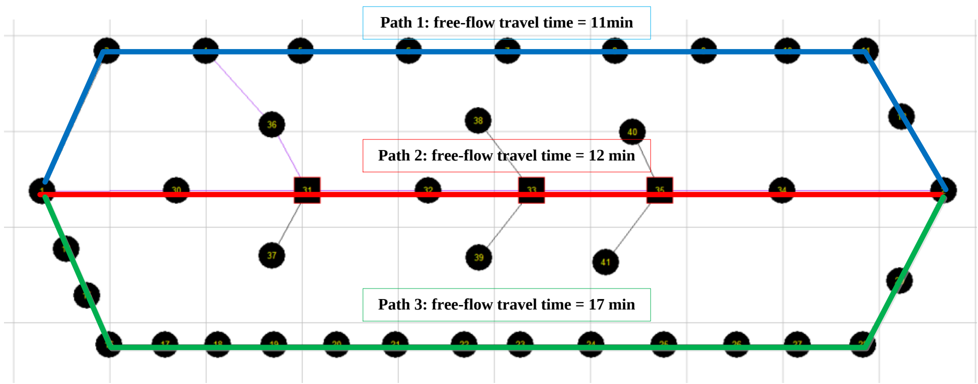


Fig. 39. Direction of Paths with Associated Travel Times

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". Since the shortest path is path 1, all vehicles choose path 1 at 1st iteration. The result can be checked in NeXTA as follows:

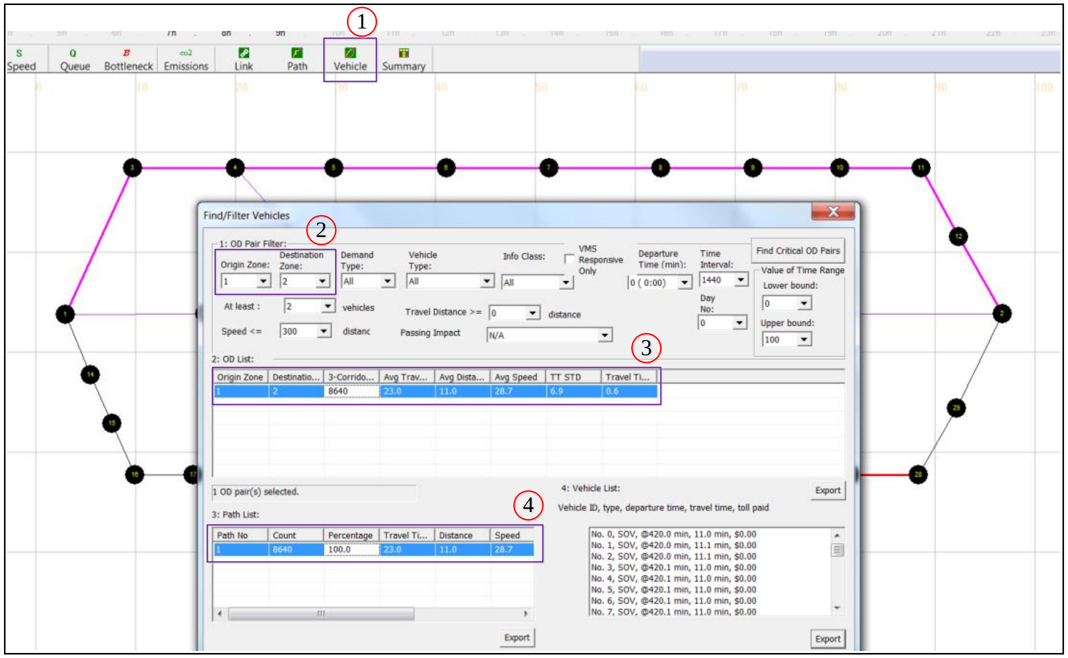


Fig. 40. Vehicle Dialog Box of Base Condition.

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”.

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 that the free-flow path travel time of path 2, which is 12 min. As a result, all travelers should choose path 2 after the 1st iteration. The method of checking the result is same as that introduced in Section 1.

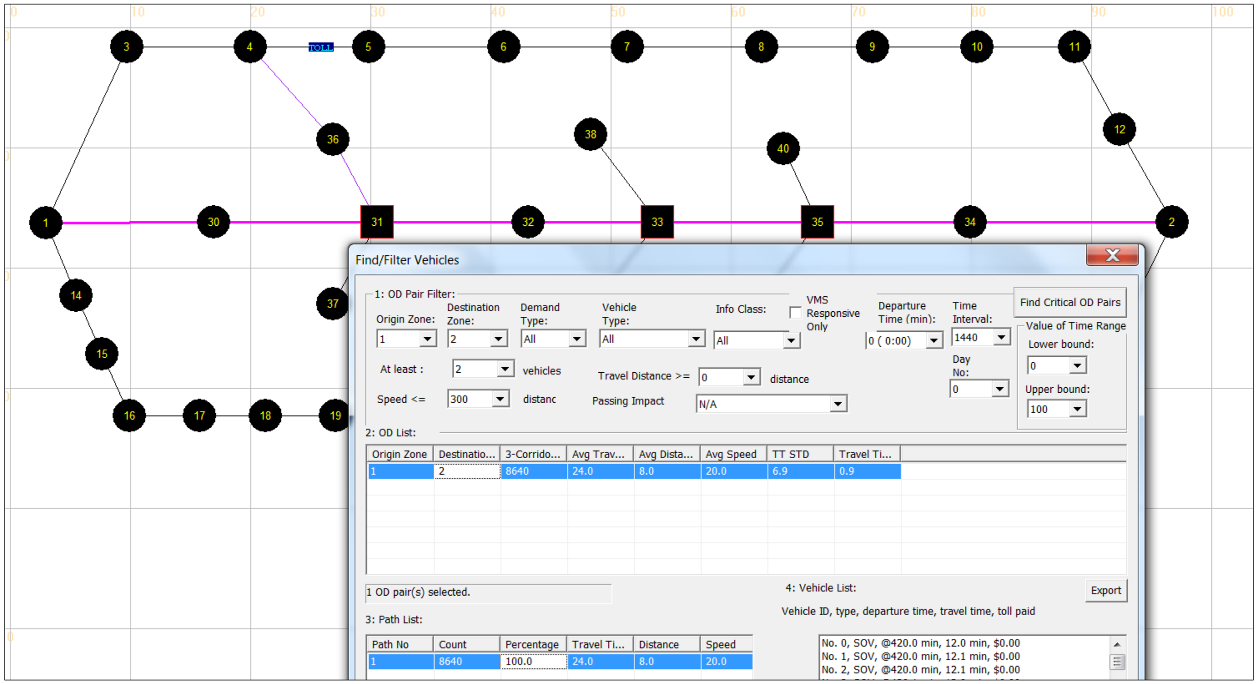


Fig. 41. Visualizing Vehicle Path for Low-income Travelers.

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%202/Data%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 1st 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.

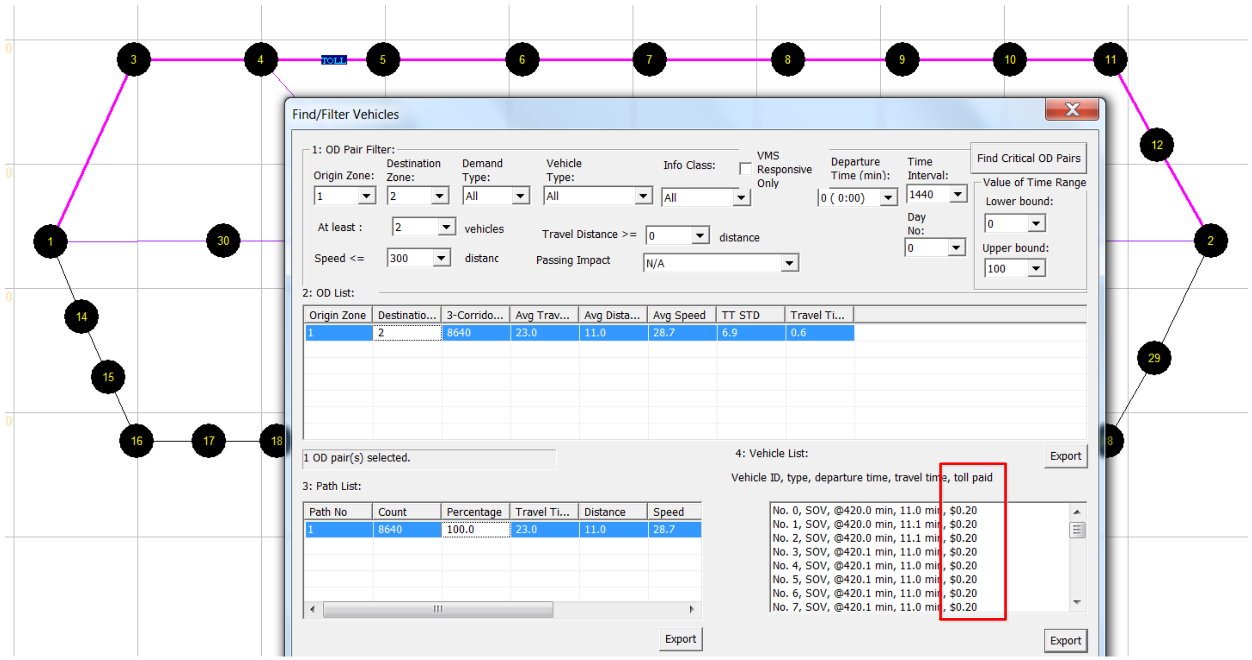


Fig. 42. Visualizing Vehicle Path for High-income Travelers.

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-come 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". 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 1st 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.

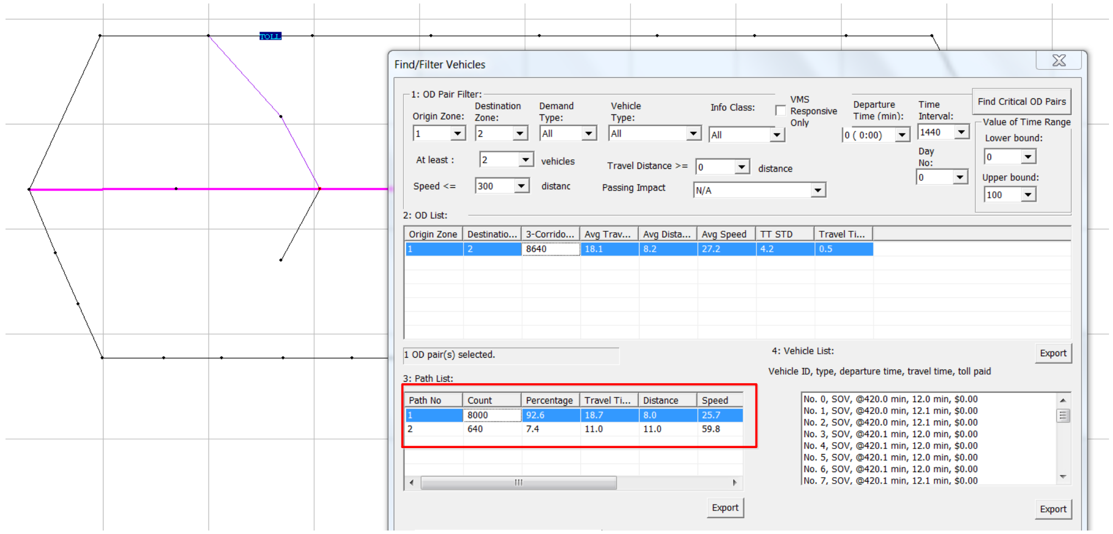


Fig. 43. Visualizing Vehicle Path for Low-income Travelers.

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.

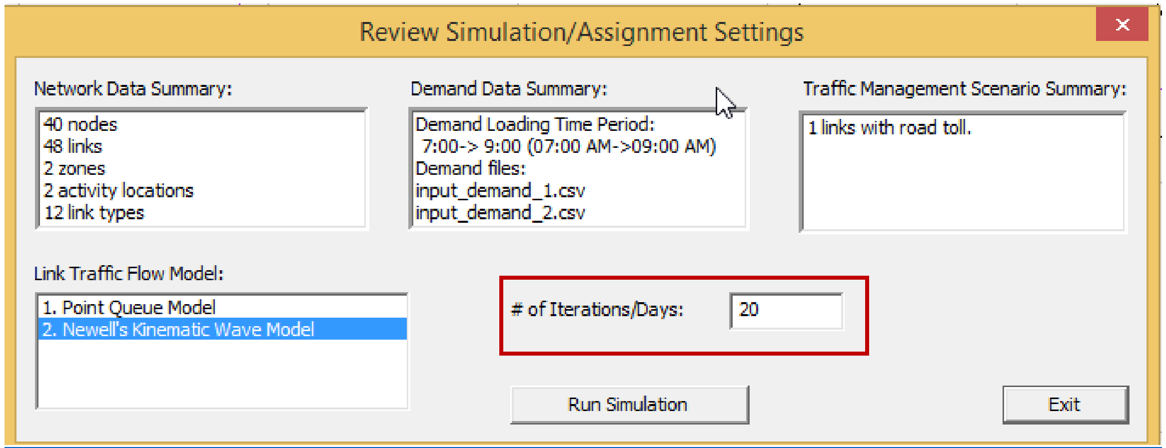


Fig. 44. Simulation Setting

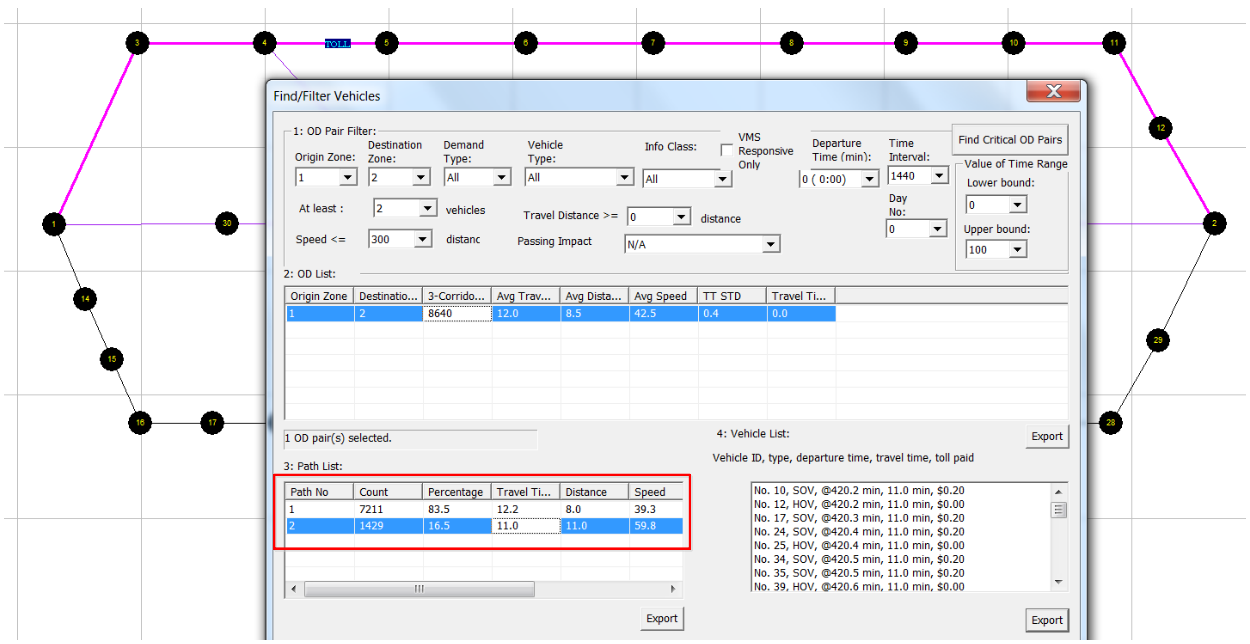


Fig. 45. Visualizing Vehicle Path for HOV Travelers.

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 observed 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_i	file_seque	file_name	format_type	number_	loading_multiplier	subtotal_i	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”. 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.

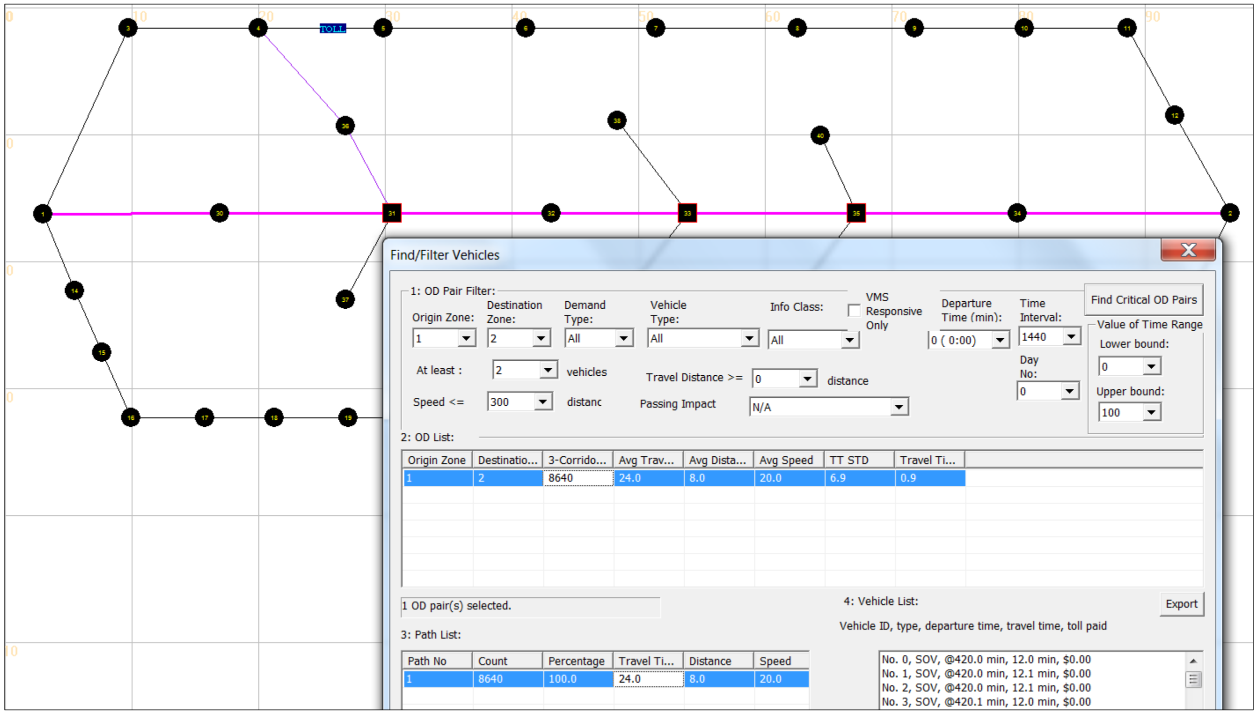
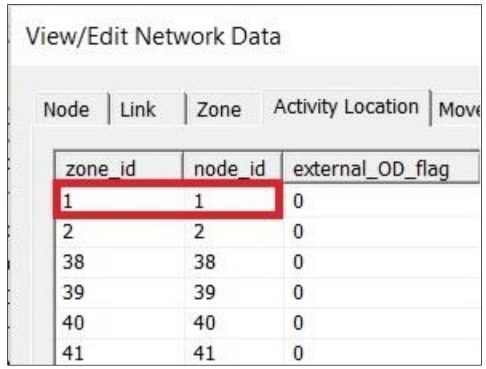


Fig. 47. Visualizing Vehicle Path for SOV Travelers.

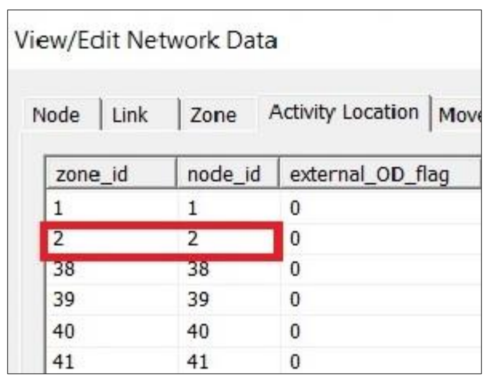
Solution Problems in Learning Document 3.2
Prepared by Tony Liu (jiangtao.liu@asu.edu) and Xuesong Zhou (xzhou74@asu.edu)

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.



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.

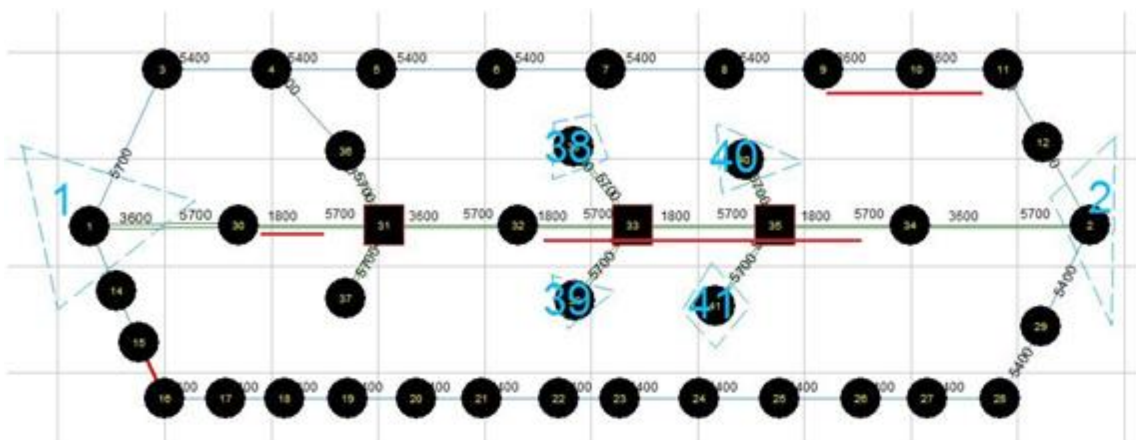


zone_id	node_id	external_OD_flag
1	1	0
2	2	0
38	38	0
39	39	0
40	40	0
41	41	0

(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.

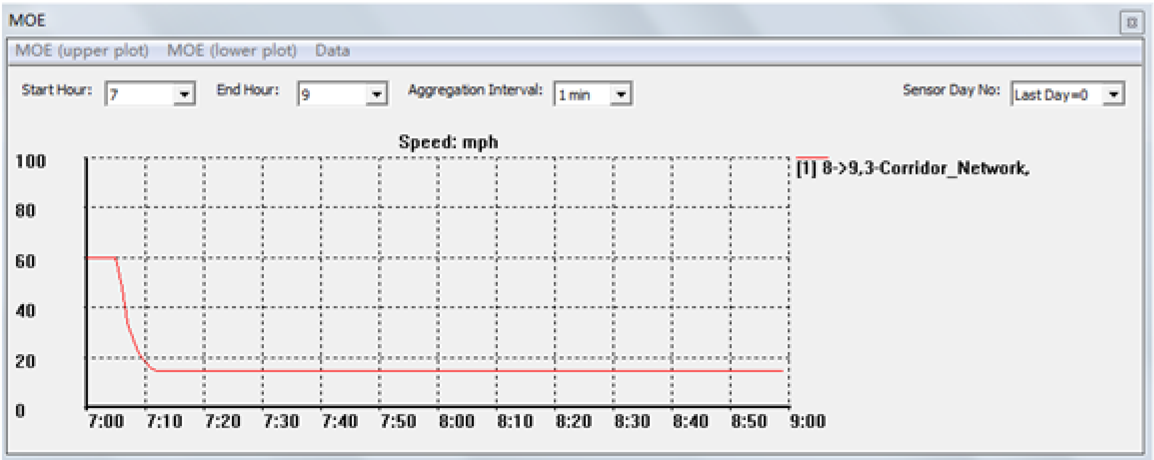
Problem 2:
(1) Which path will be selected at the first iteration?
Since the free-flow travel times of path 1, path 2, and path 3 are 11 min, 12 min, and 17 min, respectively, path 1 has the least travel time and will be selected at the first iteration.

(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.



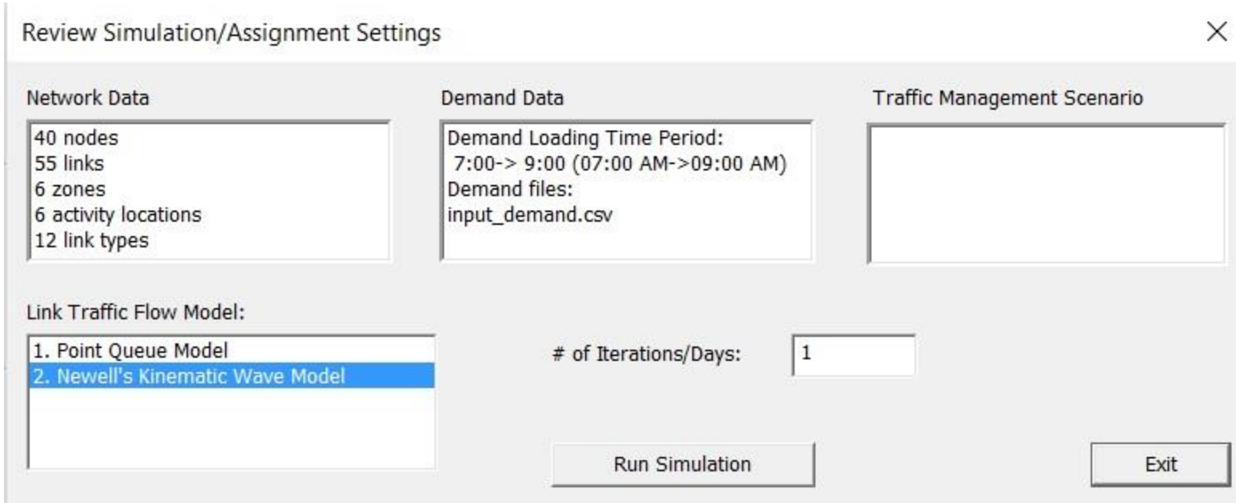
(3) What is the expected speed on link 8->9, if the demand is 5400 vehicles per hour, and all vehicles use the first path?

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:

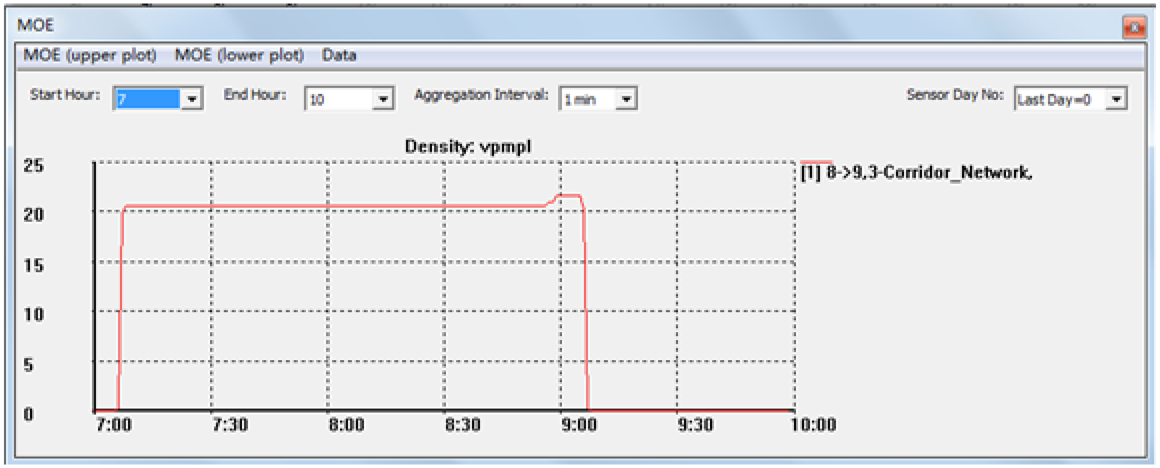
When you set the simulation settings, please choose "Newell's Kinematic Wave Model" as follows:



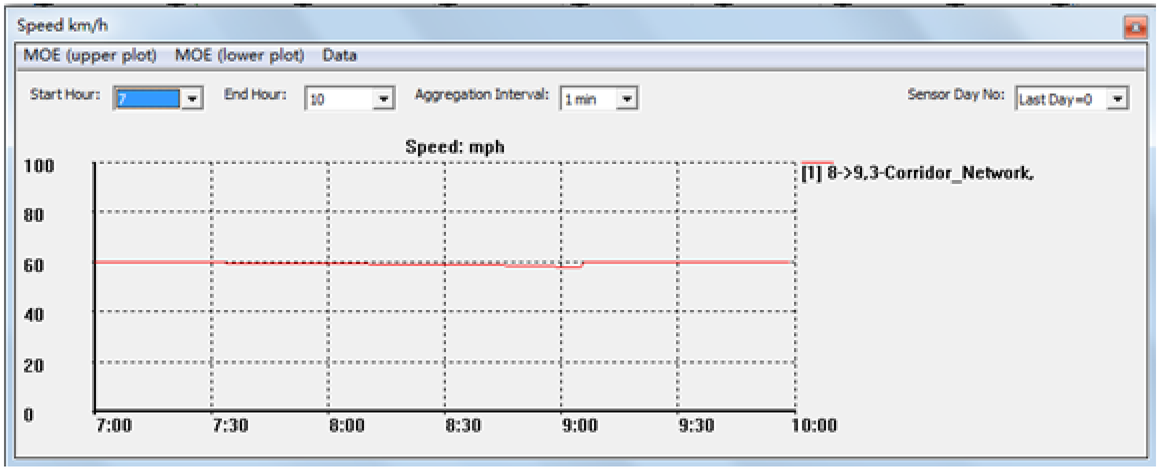
Problem 3:
Please show the traffic density, speed and link and lane-based volume time series plots for links 8->9 and link 9->10. Explain why the density on link 8->9 is 20 vehicles per mile per lane, shown in Fig. 22.

Remark:
There would be an approximation error in NeXTA simulation.

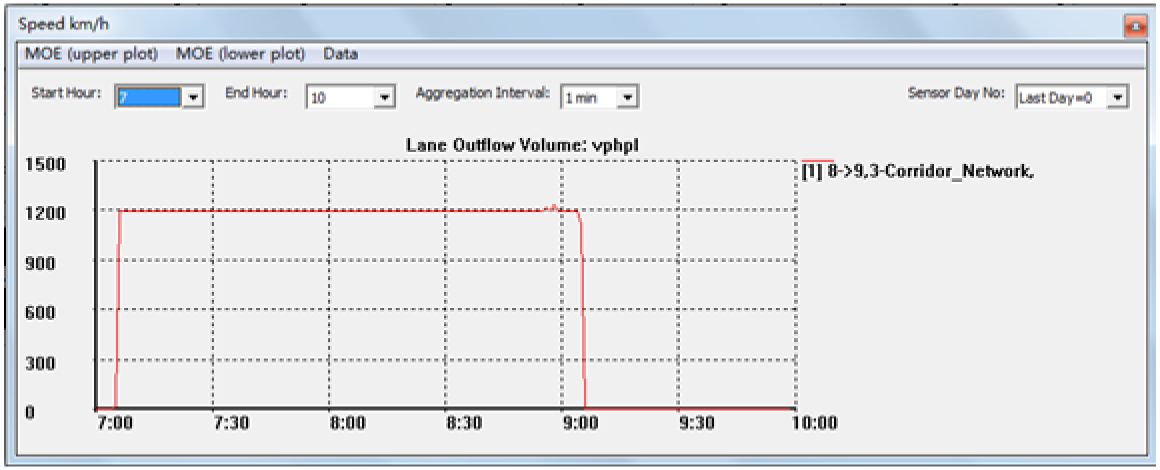
Traffic density for link 8->9:



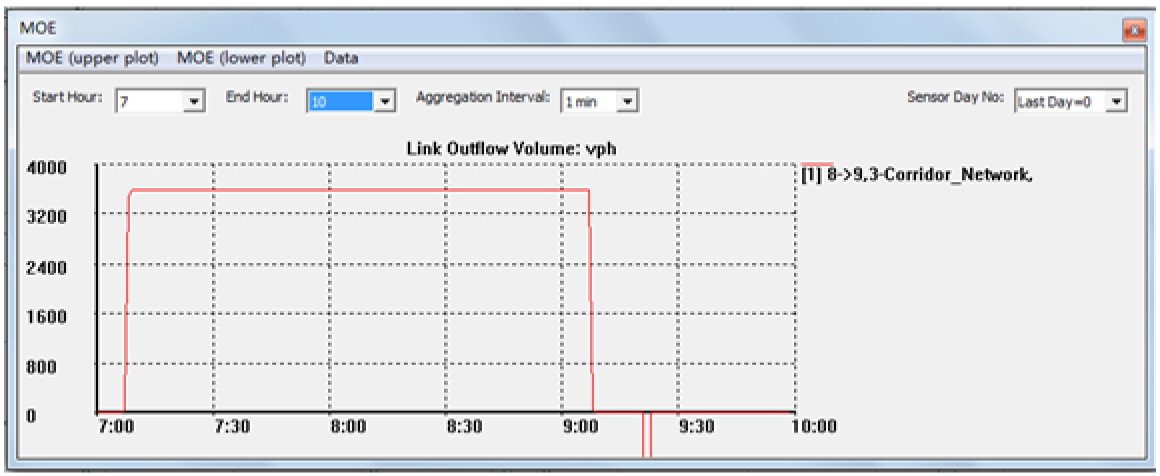
Traffic speed for link 8->9:



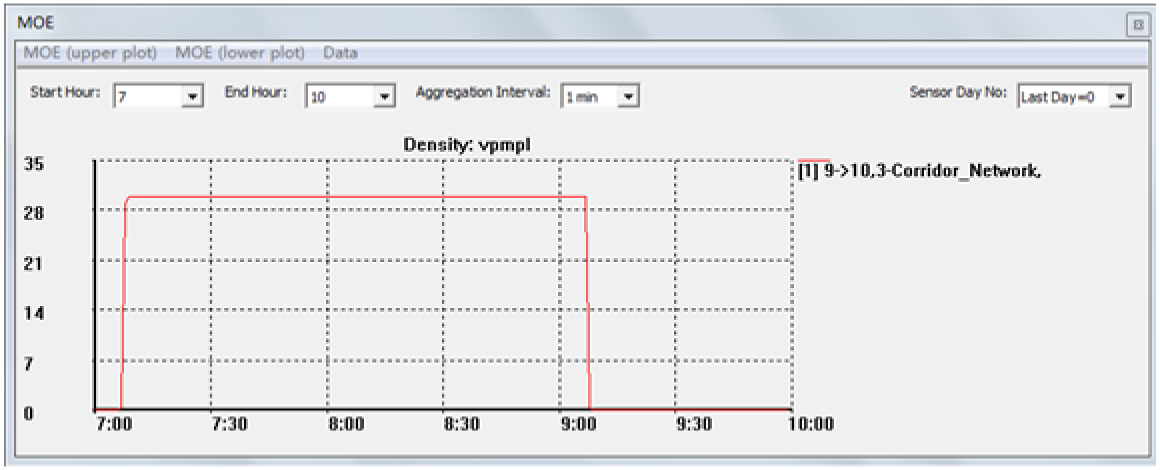
Traffic lane-based volume for link 8->9:



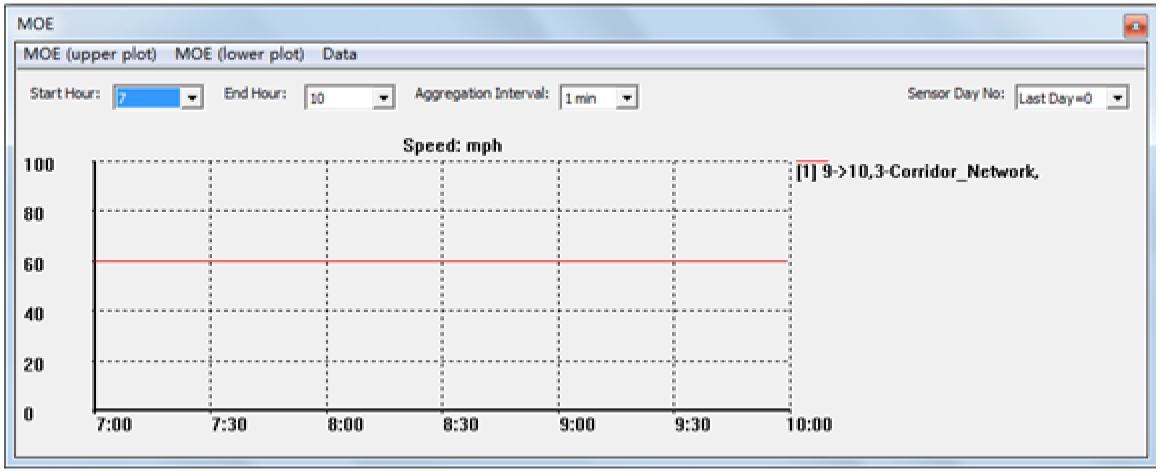
Traffic link-based volume for link 8->9:



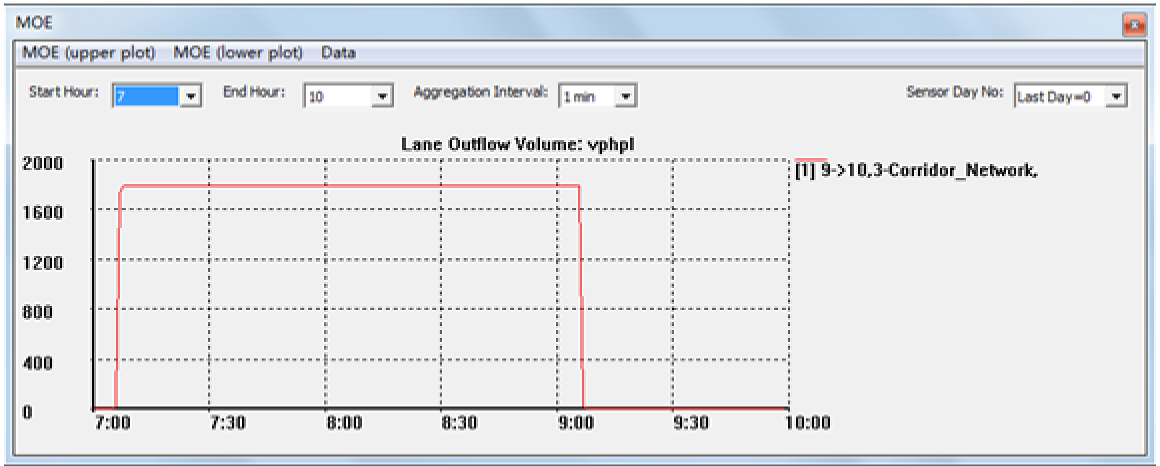
Traffic density for link 9->10:



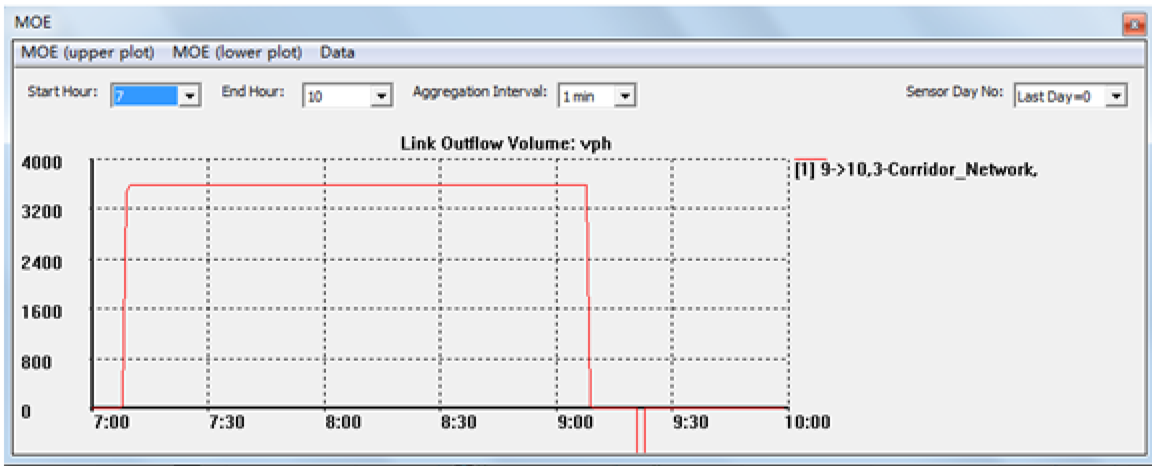
Traffic speed for link 9->10:



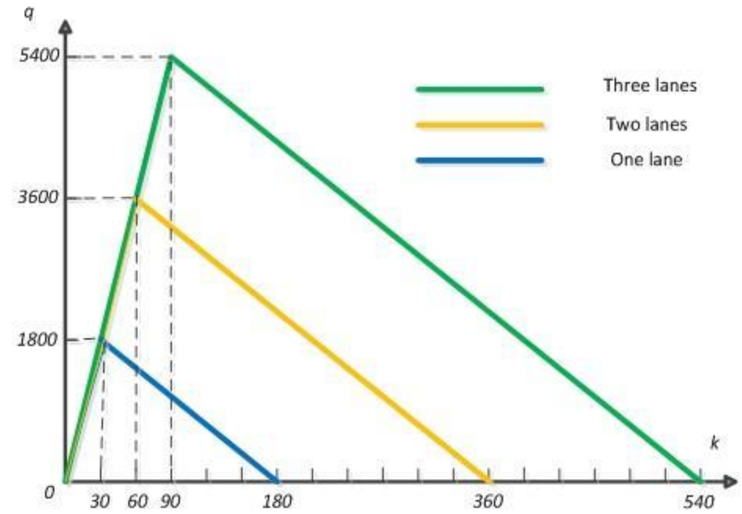
Traffic lane-based volume for link 9->10:



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 vpmpl. This is also right about link 9->10, the corresponding density is 60 vpmpl. As a result, the density for each lane is (60/2)30 vpmpl.



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

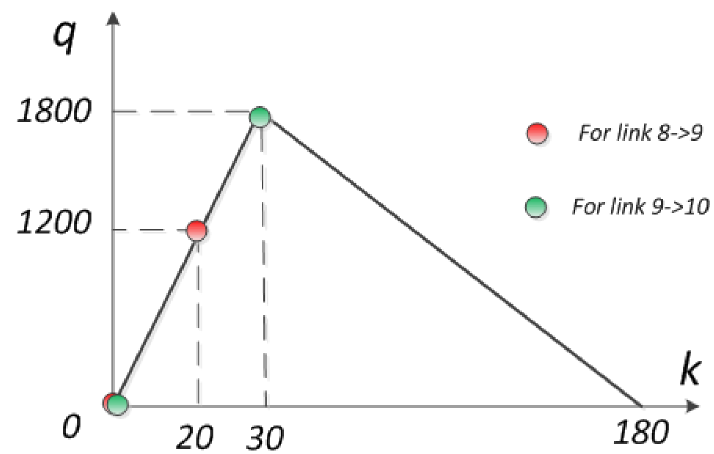
As observed from this table, there are generally two traffic states (lane outflow volume, density), state 1(0, 0) and state 2 (1200, 20).
The length of link 8->9 is 1 mile, and the speed is free-flow speed, 60mph, so the travel time from node 8 to node 9 at the beginning when traffic flow comes in just 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

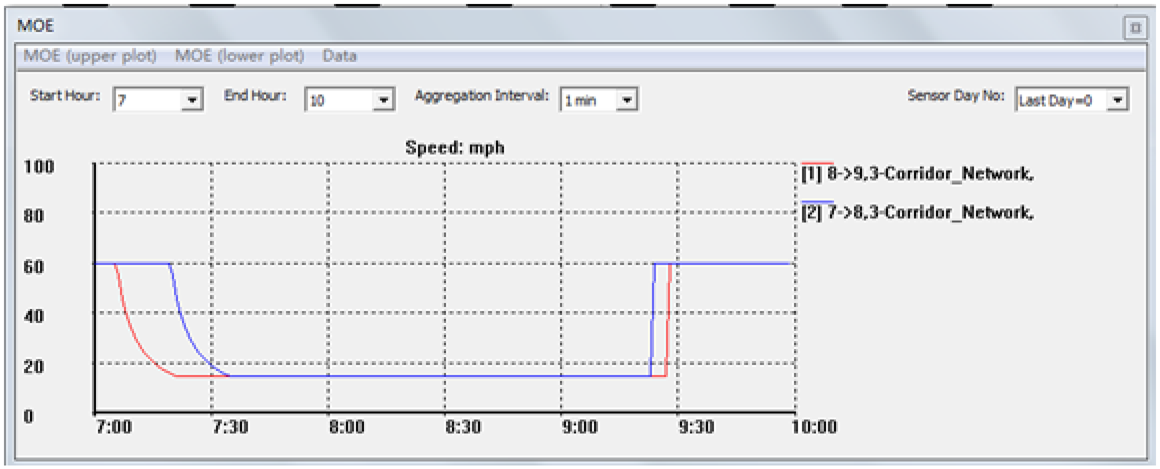
Q-K curve is shown in the below figure for both link 8->9 and 9->10.



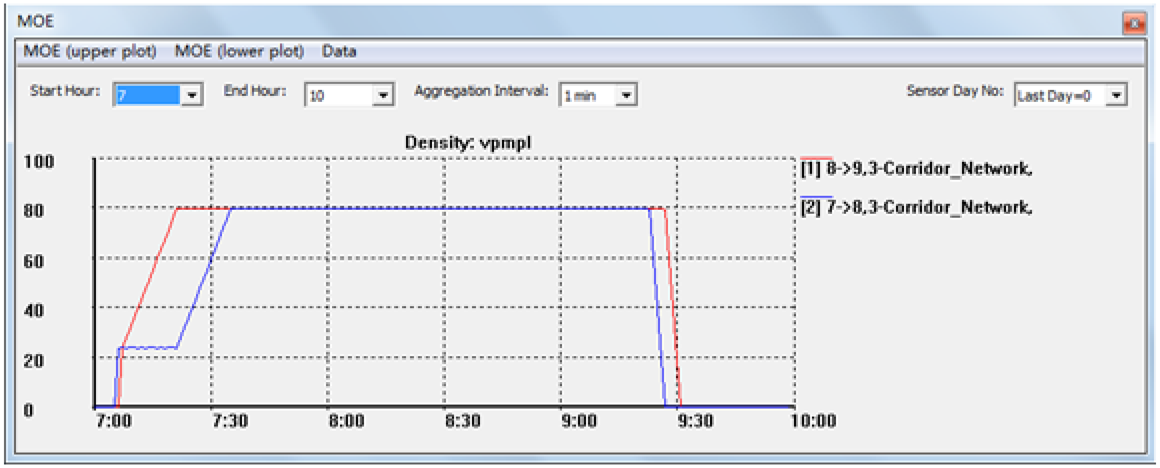
Problem 5:
Describe traffic speed and density evolution on links 7->8 and 8->9. Calculate the traffic congestion speed.

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:

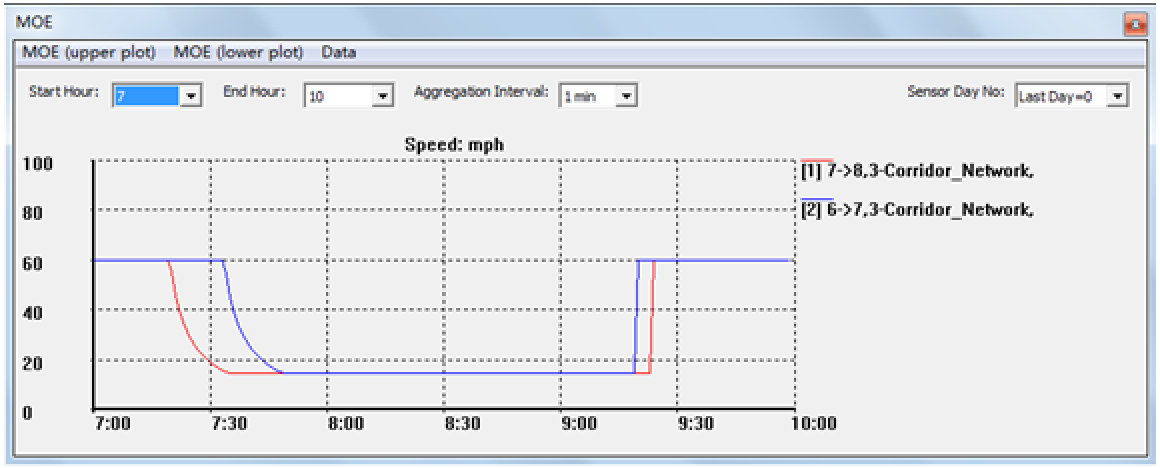


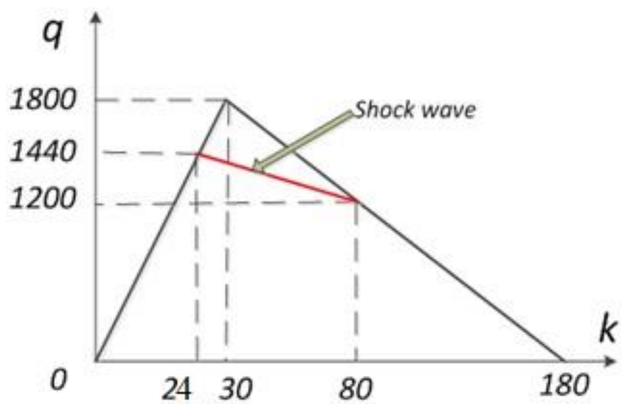
So we can observe that at the beginning, traffic is in free-flow state, and then due to the bottleneck impact, the congestion begins to propagate. After 14 min, it reaches at point 8, and at this time, the link 7->8 begins to form queues. As the length of link 8->9 is 1 mile, the congestion speed is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

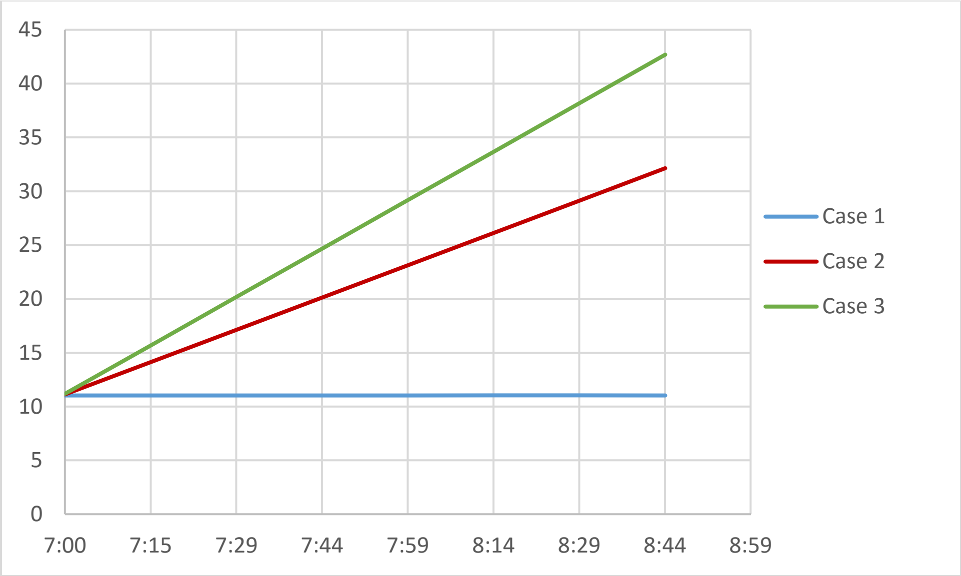
Problem 7:

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:

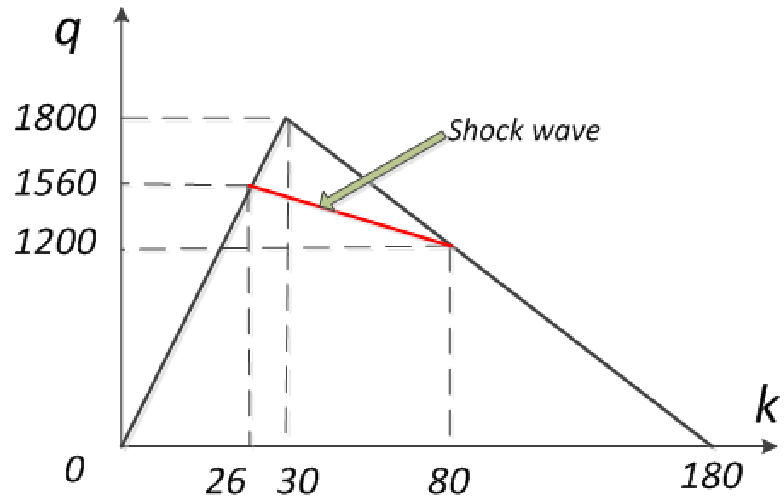
		case 1	case 2	case 3
path_no	departure time	travel_time_in_min	travel_time_in_min	travel_time_in_min
1	7:00	11.03	11.13	11.18
1	7:15	11.03	14.14	15.68
1	7:30	11.03	17.14	20.19
1	7:45	11.03	20.14	24.68
1	8:00	11.03	23.14	29.19
1	8:15	11.04	26.14	33.68
1	8:30	11.03	29.14	38.19
1	8:45	11.04	32.14	42.69

The figure is plotted as follows:

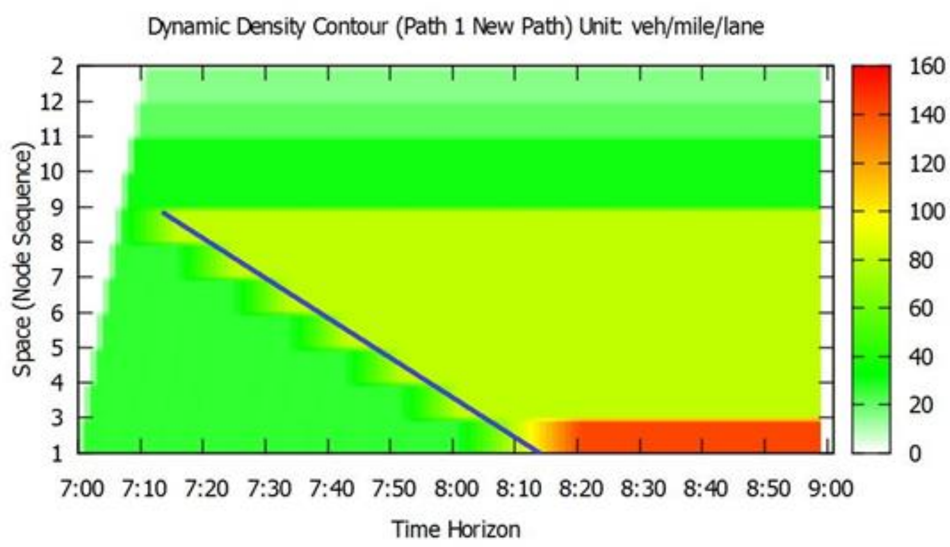


Problem 8:
In case 3, how much time does it take from traffic congestion propagating from the bottleneck to the origin node? Please calculate the congestion propagation time analytically, and then check your estimated value based on the "density contour" or "speed contour" in NeXTA.

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*(3/20)*60min = 63 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.