SIMULATION-BASED DECISION-MAKING TOOL FOR ADAPTIVE TRAFFIC SIGNAL CONTROL ON TARRYTOWN ROAD IN THE CITY OF WHITE PLAINS

Final Report

Prepared for

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ABSTRACT

Transportation corridors are vital for our region and even the nation's economy and quality of life. A corridor is usually a complicated system that may span multi-jurisdictions, contains multiple modes, include both freeways and local arterials, and be equipped with numerous traffic control and information systems. Managing such a complicated system requires care as performance improvement (such as reduced congestion) at one location of a corridor may cause performance degradation at other locations and as a whole a reduced corridor performance.

This research develops a *simulation-based* corridor decision making tool that can help evaluate alternative corridor scenarios based on corridor level mobility, fuel consumption, and emissions. Using the Tarrytown Rd in the City of White Plains, NY as a case study, this project presents (i) how a simulation-based decision-making tool can be developed; and (ii) how such a tool can be used to evaluate various corridor-wide traffic or improvement scenarios. The development of the simulation tool mainly includes the analyses of corridor data needs and collection, simulation network coding and API development, capacity calibration, origin-destination (OD) demand estimation, and simulation model calibration and validation. The scenario evaluation includes (i) the development of the scenarios which usually requires a close collaboration with the local agencies so that the evaluated scenarios are useful to their operations and management regarding the corridor; and (2) evaluations of the scenarios and results representation, which may be done based on one or multiple criteria related to corridor mobility, fuel consumption, and emissions.

The developed simulation-based tool and the scenario evaluation results revealed some important characteristics of the study corridor, based on which recommendations were provided on how the corridor might be better operated and managed under various scenarios. The results of this research further show that the proposed simulation-based decision-making tool can provide a comprehensive assessment framework for various corridor scenarios and may be used for "what-if" types of analyses for the corridor. This enables more informed decisions by the decision-makers about resource allocations and the selection of the best corridor improvement strategies.

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1. INTRODUCTION

1.1 Project Background

This project developed a micro-simulation based decision making tool for the adaptive signal control system on Tarrytown Road in the City of White Plains. The tool focused on the effectiveness and the robustness of the recently deployed adaptive signal control (SCATS) system along the Tarrytown Road (Route 119) in response to various strategy scenarios due to, e.g., recurrent congestion, holiday events, traffic incidents, among others. In addition, via micro-simulation, the project team also simulated the traffic conditions before the adaptive signal control system was implemented (referred to as “before scenario” hereafter in the report) and the condition after the system was implemented (referred to as “after scenario”). The evaluation criteria were corridor mobility, emissions, and fuel consumption. Findings and recommendations were summarized based on simulation results and data collected from the field.

Tarrytown Road in the City of White Plains is a major arterial that connects highway 287 and Route 119 to downtown White Plains. This road serves as the primary route for commute purposes from/to the downtown area and is heavily traveled, near capacity during the morning and afternoon peak hour which are identified as 8:15 am – 9:15 am for the morning peak an 5:00 pm – 6:00 pm for the afternoon peak. This corridor also experiences heavy traffic congestion (e.g., long queue length and corridor travel time) due to retail/events related trips generated or attracted by the county center and shopping malls along the corridor and in the downtown area. In this project, Paramics was used as the tool to simulate real traffic conditions on Tarrytown Road. Paramics (PARAllel MICroscopic Simulation) V6.8 is one of the microscopic traffic simulators used worldwide. It comprises a software suite of specialized tools that can model the behavior of individual vehicles in a transportation network (Quadstone Limited, 2004). The two-dimensional and three-dimensional visualization capabilities in Paramics serve as valuable features when building and evaluating simulation models. Paramics also provides a rich Application Programming Interface (API) with a large set of functions that enable the user to develop software plug-ins that can extend and/or override the default behavior built into the suite. Using microscopic traffic simulation, different traffic conditions with different control strategies can therefore be simulated, which can then provide the capacity for “what-if” types of analyses, enabling informed decisions by the decision-makers.

1.2 Project Scope

Tarrytown Road (Route 119) in the City of White Plains, NY was selected as the corridor for evaluating adaptive traffic signal control. A portion of about 1 mile that has large traffic volume, in particular during the peak hours, was selected as the simulation network for which the team developed a micro-simulation model. The network includes a portion of the corridor between the I-287 off-ramp (as the north end) and the School Street (as the south end), as shown in Figure 1.

The selected corridor connects Highway 287 and Route 119 to downtown White Plains, which carries approximately 50,000 to 60,000 vehicles daily. In the worst cases, the volume/capacity ratio is about 0.8 to 0.9 and the Level of Service (LOS) is F (the lowest) for one or multiple locations on this corridor. The City therefore considers this corridor as one of the major bottlenecks in the area.

The selected area consists of 12 intersections as listed in

Table 1, 5 of such intersections are un-signalized intersections controlled only by stop signs. The remaining seven intersections were originally operated by actuated signals but were upgraded to adaptive signals (SCATS) in November 2011.

Compared with pre-timed or actuated signal control systems, the recently deployed adaptive signal control system can collect information regarding real time traffic states (in a cycle-by cycle manner) and adjust signal parameters accordingly. As a result, adaptive control systems enable traffic to discharge faster and can lead to better traffic performance and reduced fuel consumption/emissions. In this project, the performance of SCATS is evaluated, not only for the actual real world corridor traffic conditions, but only for several “fictitious” strategy scenarios that may be resulted from corridor demand surge, lane closure, and the holiday shopping traffic.

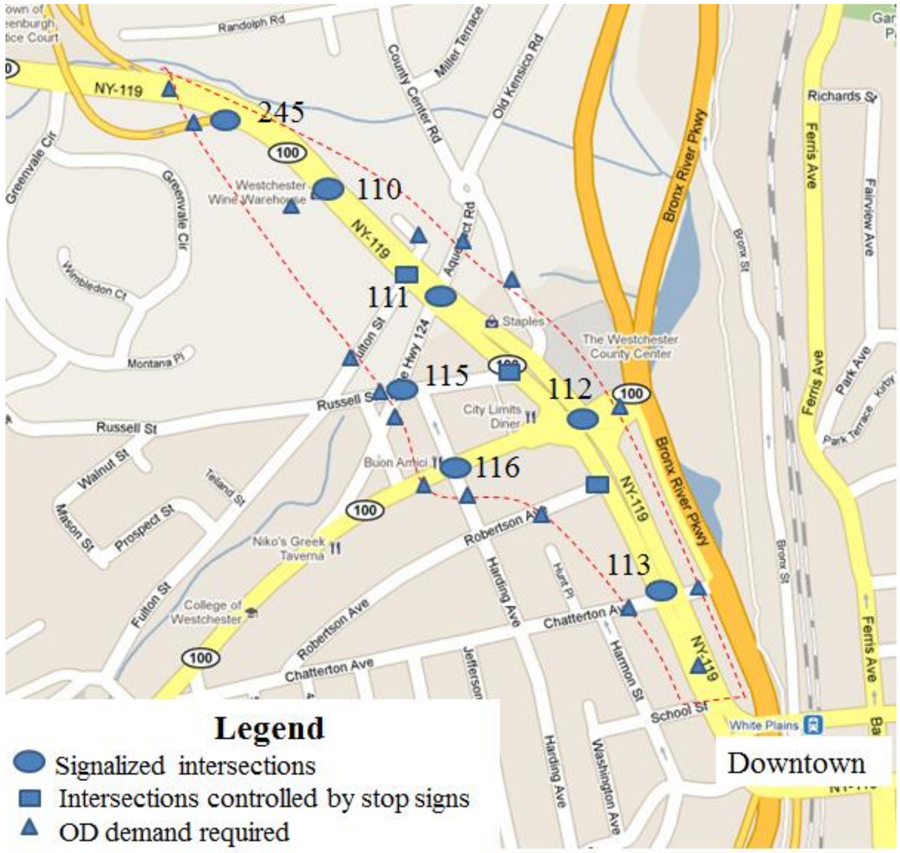


Figure 1: Scope of road network

Table 1: Overview of covered intersections

Intersection Name	Control Strategy
245: Route 119 & I-287 ramp	Traffic signal
110: Tarrytown & shopping center	Traffic signal
Tarrytown & Fulton (east)	Stop signs
Tarrytown & Fulton (west)	Stop signs
111: Tarrytown & Aqueduct	Traffic signal
115: Aqueduct & Russell	Traffic signal
Tarrytown & Russell (east)	Stop signs
Tarrytown & Russell (west)	Stop signs
116: Central & Harding	Traffic signal
112: Tarrytown & Central	Traffic signal
Tarrytown & Robertson	Stop signs
113: Tarrytown & Chatterton	Traffic signal

1.3 Organization of the Report

The rest of the report is organized as follows. Chapter 2 describes the data sources used in this project. In Chapter 3, the general procedure and further modifications in terms of network coding is summarized. In Chapter 4, the capacity calibration methods are proposed and the calibrated global parameters for before and after scenarios are presented. Chapter 5 and Chapter 6 focus on the methodology and procedure for model calibration. In Chapter 5, the methods to estimate static OD matrix and dynamic OD patterns are summarized; in Chapter 6, the procedure for model calibration/validation and the validation results of the before and after scenarios are provided. The model fine-tuning processes are largely discussed in these two chapters. In order to further validate the performance of the recently deployed adaptive signal control system, several corridor related strategy scenarios are simulated and evaluated in Chapter 7. The performance measures for the traffic system are also provided. Finally, Chapter 8 presents the recommendations of the project team based on the simulation studies and scenario evaluation results, followed by some concluding remarks in Chapter 9.

2. DATA COLLECTION AND ANALYSES

Microscopic traffic simulation requires significantly more data as compared with travel demand models. This is due to the fact that micro-simulation needs to handle the dynamics of the traffic conditions along the corridor as well as detailed modeling of vehicle driving behaviors such as car following and lane changing. A reliable and complete dataset is thus crucial for micro-simulation model development and calibration. It should not only include the demand data (traffic demand, vehicle types, etc.), but also the actual traffic performance data (volume, travel times, speeds, etc.). It is only when a complete set of traffic data is available that a model can be calibrated and validated against observed traffic conditions. This section addresses the data needs and collection issues for this project. In general, the required data can be grouped into two major categories, i.e. corridor description data and traffic description data. Each of the two categories is discussed in more details as follows.

2.1 Corridor Description Data

On the one hand, corridor description data provide a general description of the network, which includes:

- Network Geometry

Network geometric information characterizes the topology of the road network, which includes link distances, speed limits, number of lanes, lane usages, presence of turn lanes, etc.

- Traffic Control

Traffic control information describes the control strategies of the intersections, which includes signal timing plan for signalized intersection, detector information, and locations of stop signs, among others.

- Transit Information

Transit information provides a summary of complementary transportation modes (e.g., bus, express service, BRT, etc.) along the corridor. For each transportation mode, information of transit route, transit schedule, ridership, stop locations and speed should be collected. This project did not involve transit and therefore the transit related information was not collected. However, the types of transit data that would be needed and the sources of these data are still summarized in Table 2, which might be useful if future simulation studies are conducted that involve transit operations/planning.

2.2 Traffic Description Data

On the other hand, traffic description data describe the flow characteristics along the network, which provides basic parameters for describing traffic conditions and states, traffic performance measures (e.g., queue length, delay, reliability, etc.) that can be derived from these data. Traffic description data are comprised of:

- Traffic Demand

The OD trip table (the most critical input to the simulation model) represents the number of trips from a given origin to a destination. This could be static, representing the average trip pattern between the OD pair; or dynamic, capturing the detailed time-dependent (e.g., in each 15-minutes interval) demand for the given OD.

- Traffic Data

Traffic data are fundamental in terms of describing the state of traffic. It is preferable to have 15-min interval traffic volume data (e.g., link counts, turning counts, off-ramp volumes). To better assessing the mobility performance of the corridor, other data such as travel times, queue lengths, bottleneck information should also be collected.

- Traffic Mix

Traffic flow is comprised of vehicles ranging from motor cycles, passenger cars to large trucks. Traffic mix information describes the classes of vehicles and the percentage of each class traveling the corridor. It is a crucial input to the micro-simulation model.

- Traffic Incidents

The number and types of traffic incidents are important measurements to evaluate corridor safety performance. In this project, safety related performances were not evaluated. However the types of incidents related data and the data sources are summarized in Table 2 to facilitate future corridor simulation studies focusing on corridor safety considerations.

2.3 Data Needs and Collection

Based on the aforementioned data requirement, the team further categorized the data needs and the corresponding data source in Table 2. These requirements were sent to the City of White Plains (which is the major source for data collection) to verify the availability of the data, format of the data, detail of the data, coverage of the data, etc. It turned out that this was particularly important for the project because it allowed the team to validate and identify potential issues related to data and planed field data collection (in April 2012) that were critically needed for the project.

Table 2: Data needs and collection

Category	Data needs	Data Source
Network geometry	Link distance	-City of White Plains -Google Maps
	Speed limits	
	Number of lanes	
	Lane usage	
	Presence of turn lanes	
	One way (two way)	
	Length of turn pockets	
	Grade	
	Turning restrictions	
	Parking facilities (location, capacity)	
Traffic control	Signal timing plan	-City of White Plains
	Stop signs	
	Detector information	
Transit	Transit routes	-City of White Plains
	Transit schedule	
	Ridership/demand	
	Stops (location, geometry and dwell time)	
	Speeds	
BRT/Express service (if any)	Routes	-City of White Plains
	Transit schedule	
	Ridership/demand	
	Stops(location, geometry and dwell time)	
Transit signal priority system (if any)	Control logic	-City of White Plains
	Detection	
	Settings	
ITS Elements	CMS	-City of White Plains
	511	
	ATIS	
Traffic demand	OD zones/OD trip table	-Planning model (BPM or not) -City of White Plains
	OD demand (peak period) [1], [2]	
	Traffic composition (i.e., vehicle mix)	
	Planning model	
Traffic data[3]	Link counts (5-15 min time resolution)	-City of White Plains -Detectors (including newly installed ones) -Video data and manual counts
	Turning counts (5-15 min time resolution)	
	Travel times (15-30 min time resolution)	
	Bottleneck Data (locations, duration, and performance measures)	
	Queue length	
	Off ramp volumes	

	Pedestrian volumes	-Probe vehicle (GPS,
Traffic incidents	Number of traffic incidents	-City of White Plains
	Types of traffic incidents	
Others	Planned/programmed improvement strategies [4]	-City of White Plains
Notes: [1] The locations where OD demands are required are marked in Figure 1. [2] It is preferable to have demand data in a 15-minutes interval; interpolations will be made when data are provided in a longer time interval (e.g., in 30 minutes or 1 hour intervals). [3] It is preferable to have link counts and turning counts in a 5-15 minutes and travel time data in a 15-30 minutes interval; interpolations will be made when data are provided in a longer time interval. [4] The strategies provided are a list of planned and programmed improvement projects that are related to the studied corridor. This information is crucial to develop base year and future year improvement scenarios that can be evaluated via micro-simulations.		

2.4 Data Description and Analyses

Below the most critical data sources for this project are described. The original data are provided by the City of White Plains, additional data were collected to better estimate the OD matrix and the traffic conditions for the after scenarios. These datasets are later on mapped into the Paramics simulation model.

2.4.1 Before scenario datasets

The original dataset, together with a Synchro model, were given at the beginning of the project, which include the traffic mix information, pre-timed signal timing information, detector location, intersection turning counts and detector counts. One important issue of the data is that the count data were not collected on the same days, therefore the counts at upstream may not match very well with those collected at downstream intersections. In this regard, some counts were adjusted to make the observations consistent (e.g., assuming the traffic counts at the upstream intersection are realistic, the counts at the downstream intersection need to be brought down a little bit to guarantee flow conservation). The original dataset included the following data elements (for both AM and PM peak hours):

- Intersection turning counts (Synchro model, see Figure 2 as an example for the AM peak)
- Pre-timed signal timing information (Synchro model, see Figure 3 as an example for the AM peak)
- Design speed (Synchro model)
- Detector location (up-to-date before the SCATs System was deployed)
- Detector counts (September 2011, in a 15-minute interval)
- Traffic mix (empirical value, 5% of trucks)

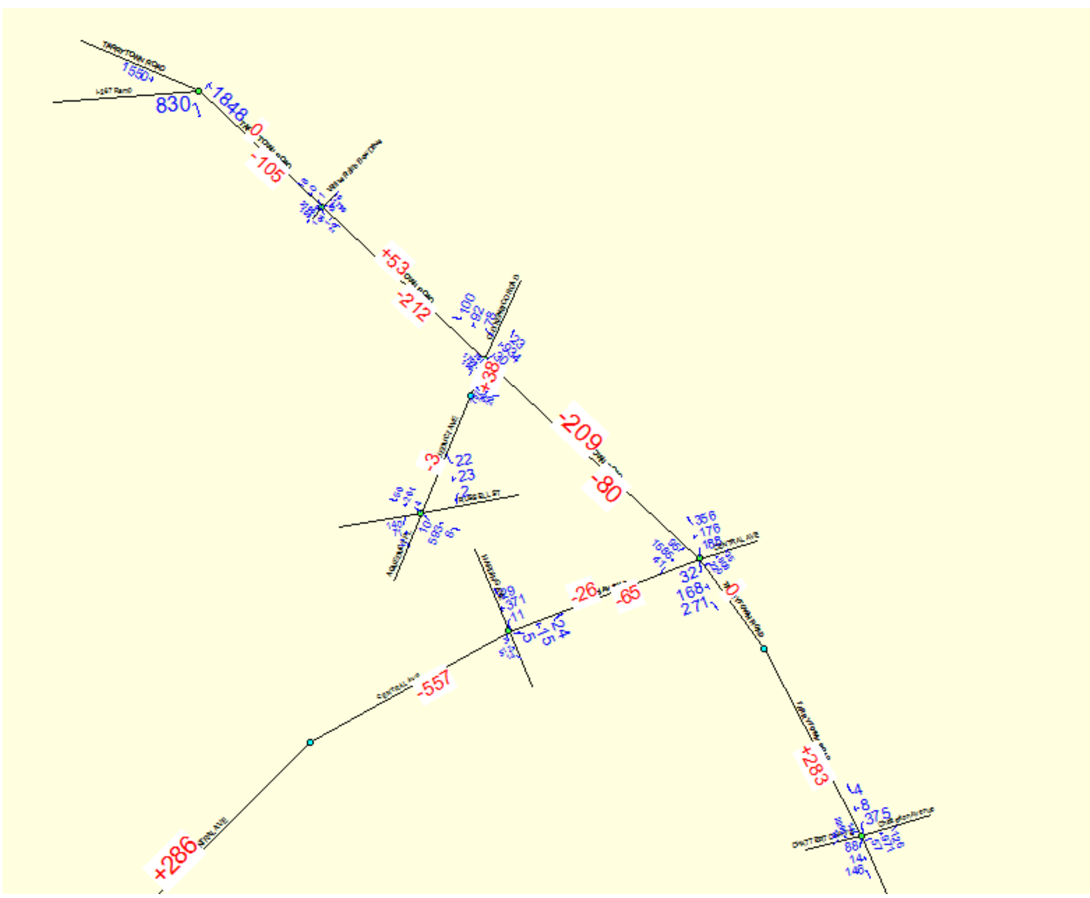
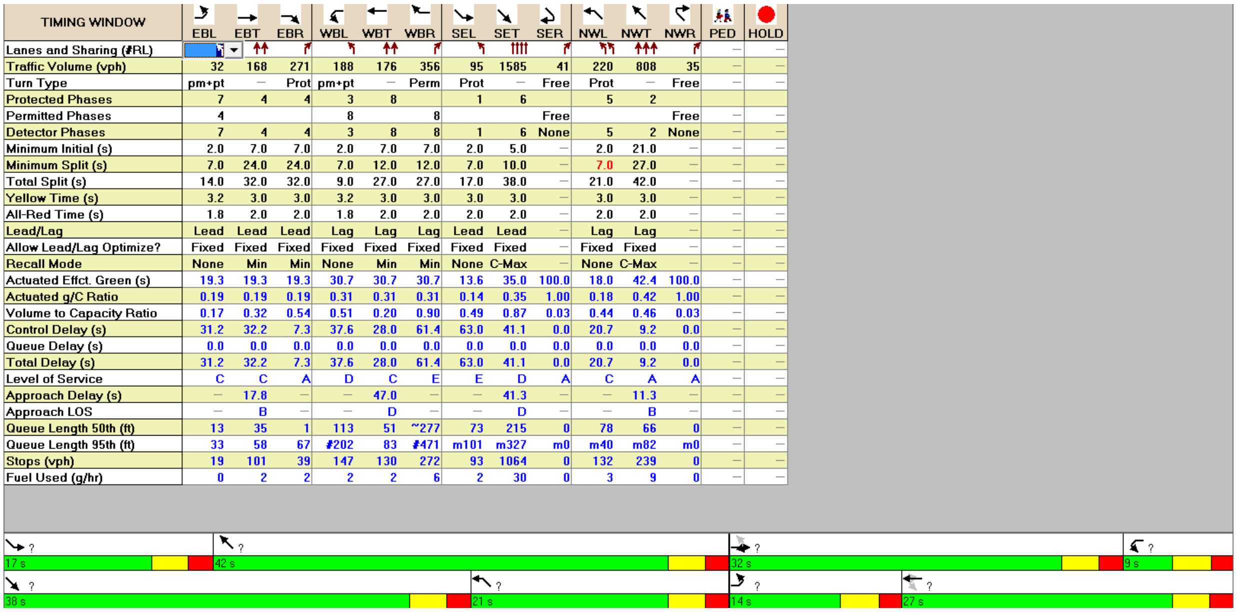


Figure 2: Intersecting turning counts (Synchro model, AM peak)



TIMING WINDOW	EBL	EBT	EBR	WBL	WBT	WBR	SEL	SET	SER	NWL	NWT	NWR	PED	HOLD
Lanes and Sharing (#RL)													—	—
Traffic Volume (vph)	32	168	271	188	176	356	95	1585	41	220	808	35	—	—
Turn Type	pm+pt	—	Prot	pm+pt	—	Perm	Prot	—	Free	Prot	—	Free	—	—
Protected Phases	7	4	4	3	8		1	6		5	2			
Permitted Phases	4			8		8			Free			Free	—	—
Detector Phases	7	4	4	3	8	8	1	6	None	5	2	None	—	—
Minimum Initial (s)	2.0	7.0	7.0	2.0	7.0	7.0	2.0	5.0	—	2.0	21.0	—	—	—
Minimum Split (s)	7.0	24.0	24.0	7.0	12.0	12.0	7.0	10.0	—	7.0	27.0	—	—	—
Total Split (s)	14.0	32.0	32.0	9.0	27.0	27.0	17.0	38.0	—	21.0	42.0	—	—	—
Yellow Time (s)	3.2	3.0	3.0	3.2	3.0	3.0	3.0	3.0	—	3.0	3.0	—	—	—
All-Red Time (s)	1.8	2.0	2.0	1.8	2.0	2.0	2.0	2.0	—	2.0	2.0	—	—	—
Lead/Lag	Lead	Lead	Lead	Lag	Lag	Lag	Lead	Lead	—	Lag	Lag	—	—	—
Allow Lead/Lag Optimize?	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed	—	Fixed	Fixed	—	—	—
Recall Mode	None	Min	Min	None	Min	Min	None	C-Max	—	None	C-Max	—	—	—
Actuated Effct. Green (s)	19.3	19.3	19.3	30.7	30.7	30.7	13.6	35.0	100.0	18.0	42.4	100.0	—	—
Actuated g/C Ratio	0.19	0.19	0.19	0.31	0.31	0.31	0.14	0.35	1.00	0.18	0.42	1.00	—	—
Volume to Capacity Ratio	0.17	0.32	0.54	0.51	0.20	0.90	0.49	0.87	0.03	0.44	0.46	0.03	—	—
Control Delay (s)	31.2	32.2	7.3	37.6	28.0	61.4	63.0	41.1	0.0	20.7	9.2	0.0	—	—
Queue Delay (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	—	—
Total Delay (s)	31.2	32.2	7.3	37.6	28.0	61.4	63.0	41.1	0.0	20.7	9.2	0.0	—	—
Level of Service	C	C	A	D	C	E	E	D	A	C	A	A	—	—
Approach Delay (s)	—	17.8	—	—	47.0	—	—	41.3	—	—	11.3	—	—	—
Approach LOS	—	B	—	—	D	—	—	D	—	—	B	—	—	—
Queue Length 50th (ft)	13	35	1	113	51	~277	73	215	0	78	66	0	—	—
Queue Length 95th (ft)	33	58	67	#202	83	#471	m101	m327	m0	m40	m82	m0	—	—
Stops (vph)	19	101	39	147	130	272	93	1064	0	132	239	0	—	—
Fuel Used (g/hr)	0	2	2	2	2	6	2	30	0	3	9	0	—	—

Figure 3: Signal timing information (Synchro model, AM peak)

2.4.2 After scenario datasets

Compared with the before scenario, the signal control strategies were changed in the after scenario. It is therefore safe to assume that data un-related to signal control (e.g., volume data, traffic mix, etc.) would remain similar as in the before scenario. Particularly for the after scenario, additional datasets were provided by the City of White Plains and also collected via field data collection in April, 2012. These datasets were used to better capture the traffic flows (especially at un-signalized intersections) and provide performance measures (e.g. queue length, travel time) for the after-scenario. The additional datasets (for both AM and PM peak hours) are summarized as below:

- Adaptive signal control strategies (as of April, 2012)
- Historical signal timing information (July, 2012)
- Turning counts at un-signalized intersections (April, 2012, see Table 3; each interval represents 15 minutes)
- Detector location (as of April, 2012)
- Detector counts (April, 2012, in a 15-minute interval)
- Travel time (April, 2012)

- Queue length (April, 2012)

Table 3: Turning counts at un-signalized intersections (April, 2012)

Location	Direction	Time	Interval 1	Interval 2	Interval 3	Interval 4
Fulton&Tarrytown W	One-way	AM 8:15~9:15	23	27	37	29
	One-way	PM 5:00~6:00	45	36	39	40
Fulton&Tarrytown E	Off Tarrytown	AM 8:15~9:15	0	0	0	0
	To Tarrytown	AM 8:15~9:15	1	2	1	0
	Off Tarrytown	PM 5:00~6:00	1	0	1	0
	To Tarrytown	PM 5:00~6:00	0	0	0	0
Russell& Tarrytown W	Off Tarrytown	AM 8:15~9:15	3	2	0	1
	To Tarrytown	AM 8:15~9:15	13	15	17	16
	Off Tarrytown	PM 5:00~6:00	5	4	5	6
	To Tarrytown	PM 5:00~6:00	14	14	13	16
Russell& Tarrytown E	Off Tarrytown	AM 8:15~9:15	0	0	0	1
	To Tarrytown	AM 8:15~9:15	11	10	15	21
	Off Tarrytown	PM 5:00~6:00	15	0	5	5
	To Tarrytown	PM 5:00~6:00	20	15	23	23
Robertson& Tarrytown	Off Tarrytown	AM 8:15~9:15	8	4	3	4
	To Tarrytown	AM 8:15~9:15	10	9	9	7
	Off Tarrytown	PM 5:00~6:00	8	13	15	10
	To Tarrytown	PM 5:00~6:00	4	11	13	7

2.4.3 Datasets for scenario evaluation

Besides the aforementioned datasets, in order to simulate some specific strategy scenarios (e.g. holiday event, traffic incidents, etc.) after the SCATs system was deployed, more data were provided by the City of White Plains. These data are summarized as follows:

- Holiday event detector counts (December 21st, 2011)
- Traffic accident detector counts (May 10th, 2012)

These datasets, together with discussions with the City of White Plains, helped develop the final scenarios that were evaluated, as summarized in detail in Chapter 7.

3. NETWORK CODING AND MODIFICATIONS

To build a micro-simulation model in Paramics, the first step is to code the network geometry with proper scale. The signal timing information and detector locations should also be appropriated mapped into the simulation network in order to correctly simulate the real world control strategies. The simulation model was then tested by loading some vehicles into the network and observing their behavior or accessing the results numerically. Some weird behaviors or unrealistic results should be observed if the network geometry was not coded correctly or the signal timing information and its related functionalities were not setup properly. In this case, proper revisions were made such as curb positions, stop-line positions and angles, link and intersection characteristics (link gradients, link headway factors, link end speeds, intersection visibility, etc.), barred turns, closures and restrictions, lane usage and behavior of traffic, signposting, and the next-lane settings in Paramics.

3.1 Network coding

In order to code the network geometry correctly, the images extracted from Google Maps were used as the background. The simulation network (in a proper scale) was overlaid on the top of that; see Figure 4. From the background images, the location of curb and stop lines, number of lanes and information regarding lane usage can be easily figured out.

Figure 4: Network coding on background images from Google Maps (Source of the image: Google)

Unless otherwise specified, all the links in the simulation model were coded as two-way links. It is also worthy to mention that in order to avoid some weird vehicle behavior (e.g., lane changing at the last minute when vehicles are approaching to the intersection), there should be at least three links from a zone (i.e. an entrance of the network) to the closest intersection.

Signal timing information and detector locations are also crucial inputs to the micro-simulation model. For the before scenario, the Actuated Signal Controller (imbedded in Paramics Modeler) was used to simulate the signal control strategy before the SCATs system was deployed. An example of the signal timing input is given in Figure 5.

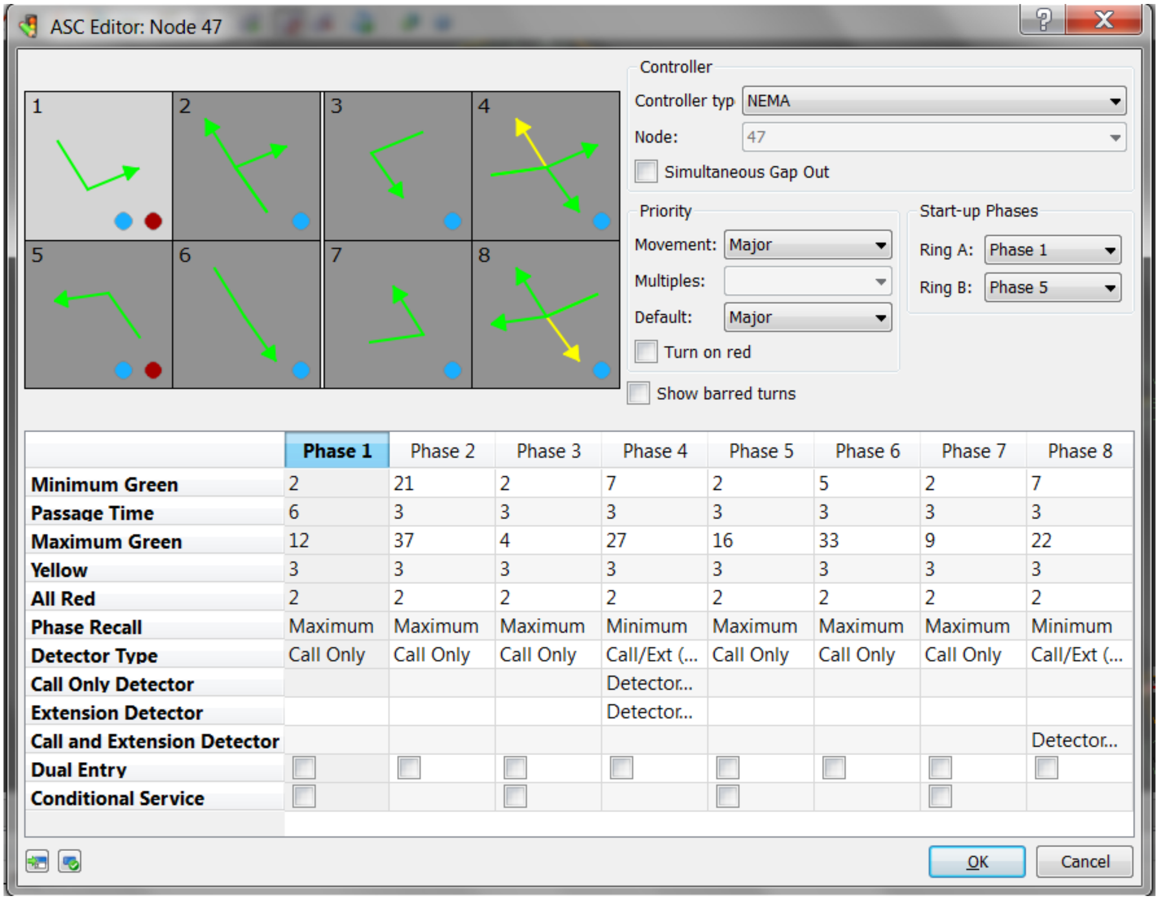


Figure 5: Signal timing input in Paramics using Actuated Signal Controller

It is shown in Figure 5 that for each signalized intersection, information regarding the movement priorities, phase order and their corresponding phase time (minimum green, maximum green, yellow and all red time, etc.) should be corrected coded. This information can be obtained from the Synchro model as introduced in the previous Chapters. The detector location should also be properly coded to make the actuated signal work. For example, in order to make the controller to give the correct green extensive time, the call-only detector should be deployed close to the stop line.

In general, the network coding for the after scenario remains similar to the before scenario, except the change of signal control strategies. To deal with this, a SCATS-based API plugin, originally developed by the National University of Singapore (Liu, 2003) and re-developed by the project team to fit the Tarrytown corridor, was used to simulate how the SCATS system works. This plugin is one of the early versions of the SCATS-based API in Paramics, which may not follow exactly the same functionality as the SCATS system deployed at Tarrytown Road.

Further modifications were made by the research team to generalize the plugin to larger networks and to deal with more phases in a cycle. The SCATS plugin requires three input information files (see Appendix 1), namely, a **Lane** input information file which characterizes different lane groups of each signalized intersection, a **Junction** input information file which defines (approximately) the phase split plans for each signalize intersection, and a **Network** input information file which contains the cycle length calibration factors, the lowest/middle/highest cycle lengths (set as 60 seconds, 100 seconds, and 125 seconds respectively for the Tarrytown Rd) for the signalized intersections throughout the network. Please refer to Liu (2003) for detailed information regarding how the SCATS plugin works in Paramics.

Besides the input files, the SCATs plugin also requires some initial signal timing inputs, including the cycle length, phase order and the length of each phase. For adaptive signals, the cycle length of an intersection is not constant. However, in the micro-simulation model, the cycle lengths were set as constant mainly for signal coordination purposes. The full cycle length for the AM peak is 120 seconds (several intersections were using half-cycle, with a 60-second cycle length) and it is 124 seconds for the PM peak (62 seconds for intersections using half-cycle). The phase order is indicated in Table 4, in which the intersection number refers to the intersection identifier and the alphabetical order refers to the phases by default in the current signal control system of the City of White Plains (see Figure 6). The initial inputs for phase split were estimated by taking the average of the historical signal timing data, see Table 5. Given some initial signal timing input, the SCATS plugin in Paramics can optimize the phase split based on the detected traffic volume for each lane group in a cycle-by-cycle manner. In other words, if the detector in one direction detects a higher traffic volume compared with the ones in other directions, the SCATS system should allocate more green time to this direction so that the signal timing system can be operated more efficiently.

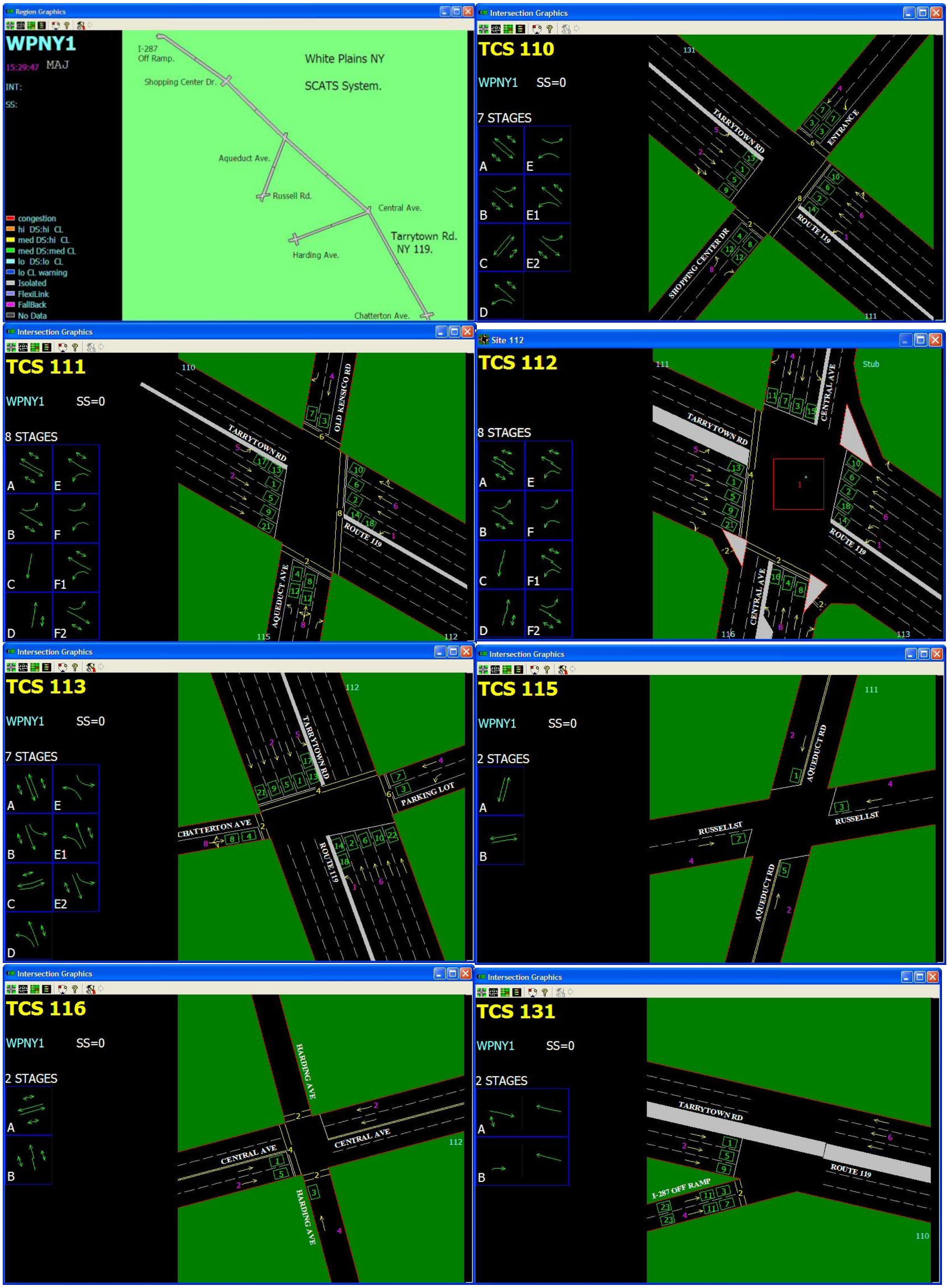


Figure 6: Graphics from the signal control system in the City of White Plains

Table 4: Phase order for after scenario

Intersection #	Phase Order (same for AM and PM)
110	C B A D
111	C D B A E
112	C D E A B
113	C D A B
115	A B
116	B A
131	A B

Table 5: Phase split for after scenario

Intersection #	Percentage of Phase Split (Green Time)
110	AM: 16/19/50/15 (15/18/56/15)
	PM: 19/19/38/24 (19/19/42/28)
111	AM: 12/26/15/34/13 (10/27/14/37/12)
	PM: 12/26/14/35/13 (11/28/13/39/13)
112	AM: 14/20/18/20/28 (13/20/17/20/30)
	PM: 13/20/28/20/19 (12/21/30/21/20)
113	AM: 26/15/44/15 (27/14/49/14)
	PM: 20/17/48/15 (21/17/55/15)
115	AM: 59/41(31/21)
	PM: 59/41 (33/21)
116	AM: 50/50 (26/26)
	PM: 50/50 (27/27)
131	AM: 42/58 (21/31)
	PM: 43/57 (23/31)

3.2 Modifications

After the traffic network was coded in Paramics, some hypothetical traffic demand can be loaded to the network. By running the simulation, the results can be assessed visually and numerically. Visual assessment is to observe the movements of vehicles on the screen to see if the traffic is moving in a realistic manner. Numerical assessment is to compare the real world statistics or inputs with the observed values to see if they match well with each other.

3.2.1 Signpost

A signpost refers to a potential hazard in Paramics (e.g., turning movements, narrowing road, etc.). The signposting distance refers to the distance from the hazard that the most aware driver could see. Therefore the signposting distance should be set large enough to make sure there is enough time for the drivers to react to the hazard. Since the network is relatively small and has some short segments, the signposting distances ere deliberately adjusted (sometimes to the upstream control points of a link, see Figure 7) to make the simulation more realistic. Moreover, the sign-range parameter was set to 3.3ft to ensure that all vehicles will see the signpost within 3.3ft distance.

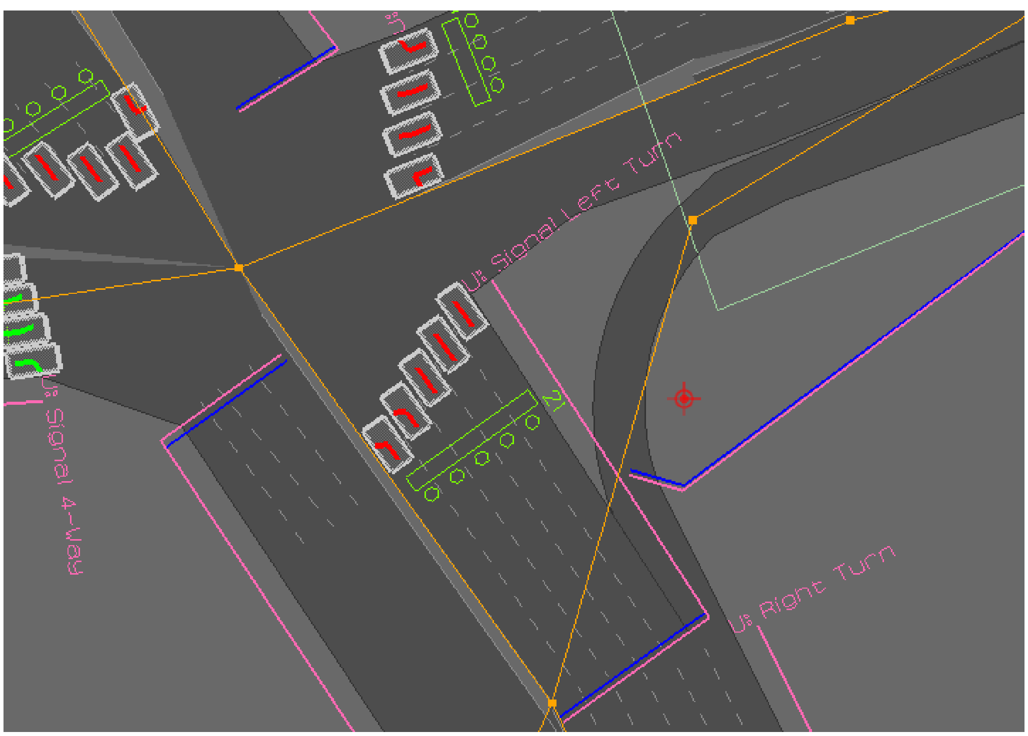


Figure 7: Signposting at the upstream control point of a link

3.2.2 Lane allocations

If the lane allocation is not properly assigned, at the junction of two links, vehicles will sometimes make unexpected and unnecessary lane-changing; see Figure 8. This could severely reduce the capacities on both lanes. To deal with this, lane allocations parameters for the downstream link need to be adjusted. For example, if one vehicle is expected to continue proceed on lane 2, a large allocation factor (e.g. 0.95) should be given to this lane and assign a small allocation factor (e.g. 0.05) to its neighboring lanes. The simulation network was carefully checked to set these parameters correctly to ensure smooth vehicle movements passing the junctions.

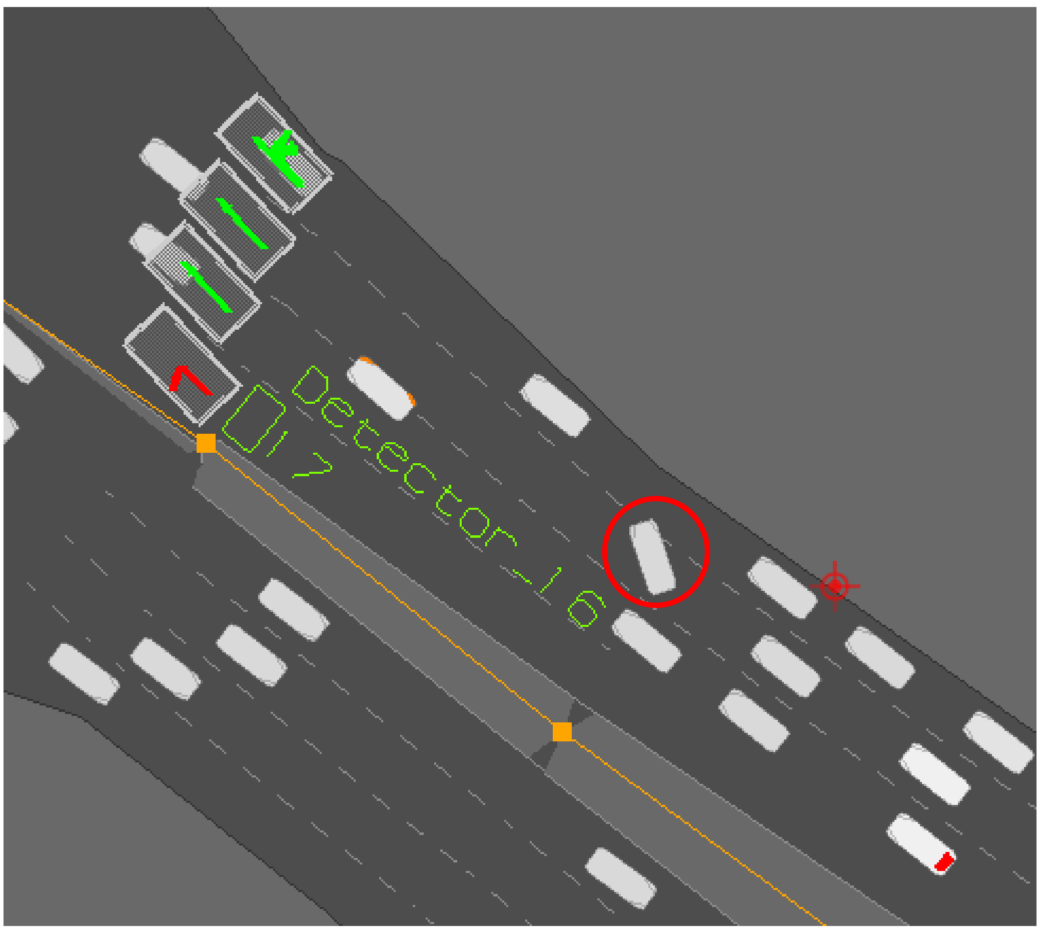


Figure 8: Signposting at the upstream control point of a link

3.2.3 Lane choices

Short links sometimes lead to short signposting distance (even though the signposting location is adjusted to the upstream point of the link). As a result, the vehicles may not have enough time to react (e.g., to change lanes) to the hazard. To solve this problem, it is better to pre-define the lane choice for a given route; see Figure 9. In the figure, for vehicles taking route A-B-C-D (left-turn movement), most of these vehicles were assigned to lane 5 and lane 6 (the two left lanes on the northbound direction of link AB) so that most of the vehicles did not have make lane-changes when they are too close to the intersection.

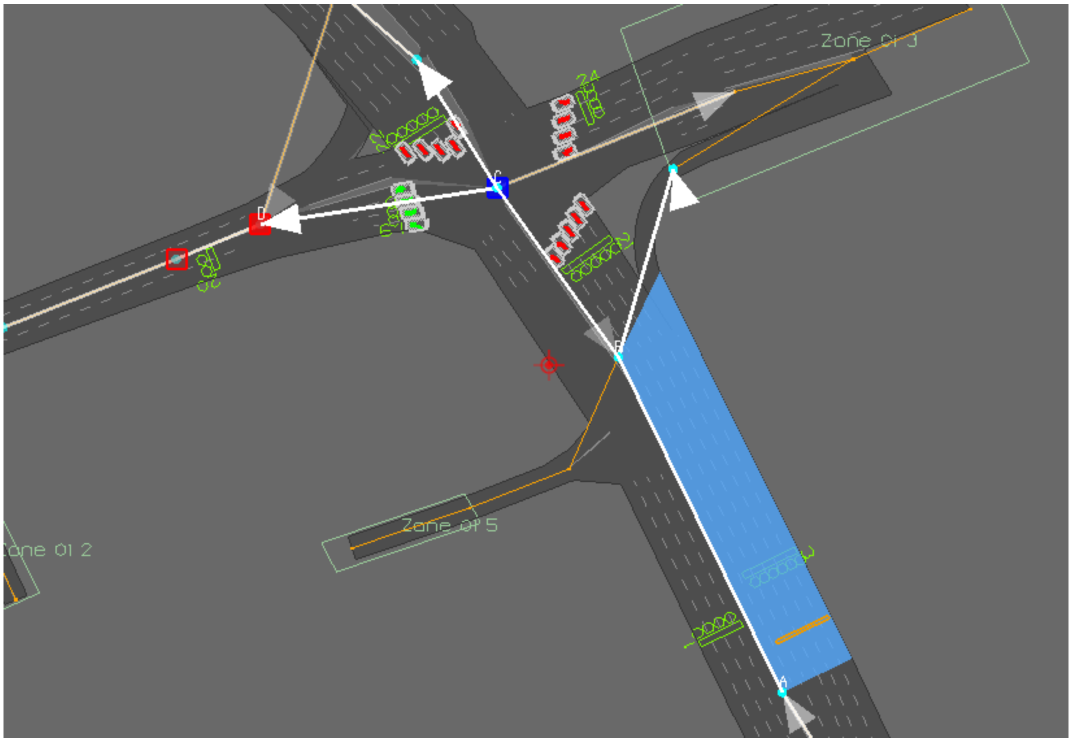


Figure 9: Signposting at the upstream control point of a link

3.2.4 Others

There were some other issues that needed to be checked and further modified, which are listed below:

- Check geometry based on the Google Maps overlays (move kerb points and stop lines as necessary)
- Check lane usage and behavior of traffic
- Check link priorities (barred/major/medium/minor) for each phase
- Check barred turns, one-way links and restrictions

- Check link and intersection characteristics (link gradients, link headway factor, link end speeds, intersection visibility)

The finalized simulation network, as shown in Figure 10, is comprised of 20 Traffic Analysis Zones (TAZs), 86 nodes and 158 links. The study area has different congestion patterns in AM and PM peak hours. For the AM peak hour (8:15-9:15AM), the congestion happened primarily in the southbound (inbound) direction; for the PM peak hour (5:00-6:00 PM), the congestion happened in the northbound (outbound). Before the SCATS system was implemented, the signalized intersections were controlled by actuated signal control strategies, which is referred to as the “Before” scenario hereafter in the report). The traffic condition after the SCATS system was implemented is referred to as the “After” scenario.

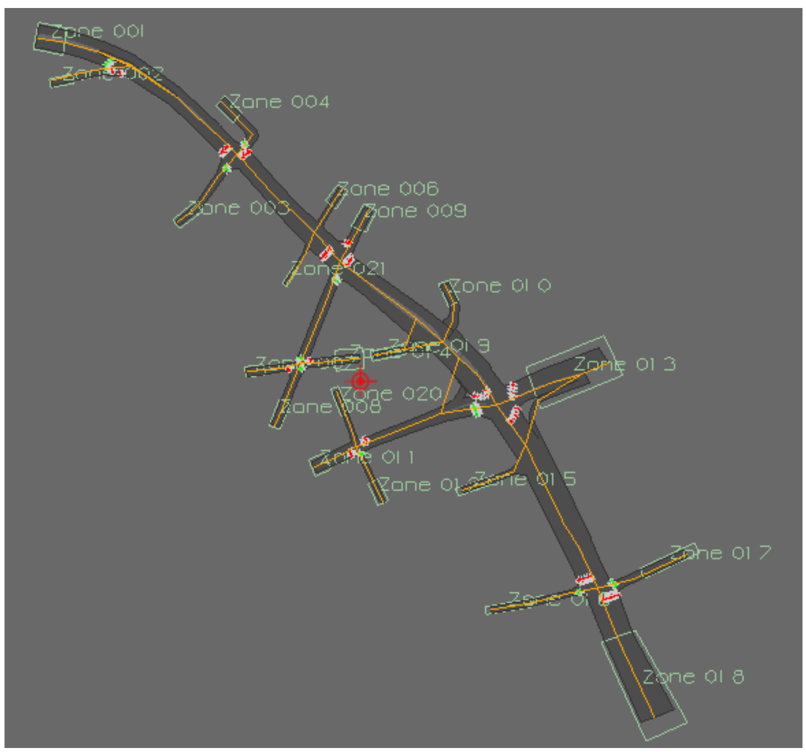


Figure 10: The Tarrytown Road corridor

4. CALIBRATION OF CAPACITY

The purpose of performing capacity calibration is to find a set of (global) model parameters so that the model can produce the simulation capacities that match the real world network capacities to the best degree. This is usually accomplished by (i) loading some arbitrary large demands so that the network is congested (but not grid locked); and (ii) matching the observed capacities in simulation with the observed capacities in real world. Particularly for signalized arterial roads, the analyst should pick important locations to collect field measurements of the capacities and compare them with the simulated values in simulation.

4.1 Field measured capacity

Since the field measured capacity values were not available, they were determined by using the following equation:

$$c_i = s_i * ({}^{g_i}/_{C})$$

Where c_i is the capacity of lane or lane group i; s_i is the saturation flow rate for lane or lane group i, which is given by the Synchro model; g_i is the effective green time for the lane or lane group i and *C* is the cycle length for the corresponding intersection.

4.2 Simulated capacity in Paramics

The next remaining question is to obtain the simulated capacity in simulation. Ideally, if the traffic keeps coming in a saturation flow rate during the effective green time of one cycle, the capacity can be approximately estimated by the number of vehicles passing the direction over the the entire cycle. However, due to the stochastic nature of traffic flow, even though the network is loaded with arbitrarily large demand, the traffic stream is not always discharging in the saturation flow rate. Therefore in this project, the largest number of vehicles within one cycle (observed during the entire period of simulation) over the cycle length was considered as an estimation of the observed capacity in micro-simulation, see equation below:

$$\hat{c}_i = \max_j\left(N_i^j\right) * (\beta)$$

Where $\hat{c}_i$ is the estimated capacity in simulation for lane or lane group i, N_i^j is the number of vehicles passing the intersection for lane or lane group i in the j-th cycle, C is the cycle length same as in the previous equation, and β is the parameter that converts the capacity in one cycle to an equivalent hourly capacity (mathematically $\beta = 3600/C$).

4.3 Global parameters

For both before and after scenario, the following global parameters were determined via capacity calibration. The value in each parenthesis is the range of the value tested for that particular parameter.

- Mean target headway (0.6s~1.0s) and drivers reaction time (0.6s~1.0s). Three basic models are used in Paramics to control the movement of individual vehicles in the network: the vehicle following, gap acceptance, and lane changing models. These models can be greatly impacted by these two parameters. The overall behavior of the models can be changed considerably by increasing or decreasing the mean headway and the mean reaction time.
- Time steps per second (2~8). The simulation time step determines when calculations are carried out during every second of simulation. The default time step is 2, which means that calculations are done every 0.5 seconds of simulation. If the time step is increased to 5, for example, the calculations will be performed every 0.2 seconds.
- Speed memory (5~8). Speed memory in Paramics simulation determines the number of time steps for which a vehicle remembers its speed. In conjunction with the time step change, speed memory can also be changed (e.g., from 3 to 8 time steps) to calibrate the capacity. Changing the size of the speed memory allows the modeling of the same reaction time with smaller time steps.

4.4 Results of capacity calibration

In this project, eight locations were selected for capacity calibration. An example of capacity calibration is given in Table 6. The table essentially indicates the capacity calibration results for a given combination of the global parameters. The difference between the field measured capacities and the simulated capacities in simulation was evaluated using the average Mean Square Error (MSE) for all the selected locations.

Table 6: Capacity calibration example

Headway	1.0		
Reactiontime	1.0		
Timestep	2		
Speed Memory	5		
Average MSE	574198		
Location No.	Description	Field Measured Capacity	Observed Capacity in Simulation
1	NY-119, through	2013.88	2420
2	Shopping center, left&through	3198.93	2540
3	Tarrytown&Aqueduct, left&through	2952.01	2000
4	Tarrytown&Chatterton, left&through	3196.7	2520
5	Tarrytown&Chatterton, left&through, south	4282.87	3420
6	Tarrytown&Central Ave, left&through	3903.54	2720
7	Tarrytown&Aqueduct, left&through, south	2406.69	2300
8	Shopping center, left&through, south	3788.13	3100

Under a given (hypothetical) demand, different combinations of parameters were tested. The one with the minimal average MSE was chosen and was used throughout the rest of the project. In practice, the time step and speed memory parameters are, in most cases, fixed; they are assumed as best values. Most calibration efforts were focused on the effects of the mean headway and reaction time. Some of the test results are shown in Table 7 (before scenario) and Table 8 (after scenario). The ones that are highlighted in the two tables were the optimal ones that were used in the simulation studies.

Table 7: Results of capacity calibration (before scenario)

Parameter combinations	Average MSE	Parameter combinations	Average MSE
Headway=1.0 Reactiontime=1.0 Timestep=2.0 Speed Memory=5.0	818374	Headway=0.7 Reactiontime=0.7 Timestep=5 Speed Memory=8	474972
Headway=0.8 Reactiontime=0.8 Timestep=5.0 Speed Memory=8.0	699769	Headway=0.7 Reactiontime=0.6 Timestep=5 Speed Memory=8	581573
Headway=0.8 Reactiontime=0.7 Timestep=2 Speed Memory=8.0	582693	Headway=0.6 Reactiontime=0.6 Timestep=5 Speed Memory=8	508621
Headway=0.75 Reactiontime=0.7 Timestep=5.0 Speed Memory=8.0	678622		

Table 8: Results of capacity calibration (after scenario)

Parameter combinations	Average MSE	Parameter combinations	Average MSE
Headway=1.0 Reactiontime=1.0 Timestep=2.0 Speed Memory=5.0	574198	Headway=0.7 Reactiontime=0.7 Timestep=5 Speed Memory=8	120436
Headway=0.8 Reactiontime=0.8 Timestep=5.0 Speed Memory=8.0	352700	Headway=0.7 Reactiontime=0.6 Timestep=5 Speed Memory=8	144221
Headway=0.8 Reactiontime=0.7 Timestep=2 Speed Memory=8.0	337535	Headway=0.6 Reactiontime=0.6 Timestep=5 Speed Memory=8	162516
Headway=0.75 Reactiontime=0.7 Timestep=5.0 Speed Memory=8.0	245769		

5. OD ESTIMATION AND FINE-TUNING

The purpose of OD estimation is to estimate the number of trips generated and attracted at each Traffic Analysis Zone (TAZ). An accurate OD matrix plays a pivotal role in micro-simulation since it is closed related to the actual traffic conditions. In general, analyst can start with an initial OD pattern matrix from urban planning models, e.g., using TRANPLAN, TP+, or TransCAD. Such models are usually developed for long-term and large-scale planning purposes, and their demand data may not reflect the pattern of the up-to-date traffic. Therefore, substantial amounts of work are usually needed for fine-tuning the initial demand data to match the field measurements. For this project, the study network is relatively small. As a result, the large scale planning-based OD data could not be directly applied because most planning models do not provide the level of detail that covers the corridor well.

Another widely used approach is to use the Paramics Estimator (integrated in the Quadstone Paramics Suite) for OD estimation. Paramics Estimator provides an open/visual framework which enables modelers to visualize/fine-tune input data as needed. It can partially solve the difficult problems of OD estimation while considering the interactions between the OD demand and other parameters such as those for behaviors and route choices. In order for Estimator to generate reasonable results, however, it still needs an initial OD demand pattern matrix as input The estimated results are highly dependent on the initial OD matrix.

To deal with this problem, the turning counts data were used to manually estimate an OD matrix, which was used as an initial input to the Paramics Estimator. However, it turned out the count data from the Synchro model were not sufficient for OD estimation; the estimation result in Paramics Estimator did not converge. The project team thus developed two specific procedures to estimate the static OD and dynamic OD profile respectively for the study corridor.

5.1 Static OD estimation

In this project, the procedure below was used to estimate the OD matrix manually; see Figure 11. Traffic counts (mainly the turning counts) were first used to infer an estimated OD matrix (may not be very accurate). Secondly this OD matrix was used as the input to the simulation model. Observed counts in simulation were then obtained after running the simulation model. The observed counts were compared with the field measurements to see if these two sets of values matched with each other. This step is similar to the calibration/validation of traffic volume which is presented later in Chapter 6. If the observed counts match well with the field measures, a reasonable OD matrix is obtained and it is OK to stop the estimation; otherwise the OD matrix is further fine-tuned and the process is repeated. The static OD estimation results for both before and after scenario can be found in the Appendix. Note that the static OD for the before scenario was fine-tuned purely based on the turning counts provided by the Synchro model, while the static OD for the after scenario was fine-tuned not only based on the turning counts from the Synchro model (since no major different was observed in terms of traffic counts between the Synchro model and the detector counts for the before scenario), but also based on the turning counts for un-signalized intersections which were collected during the field data collection in April 2012.

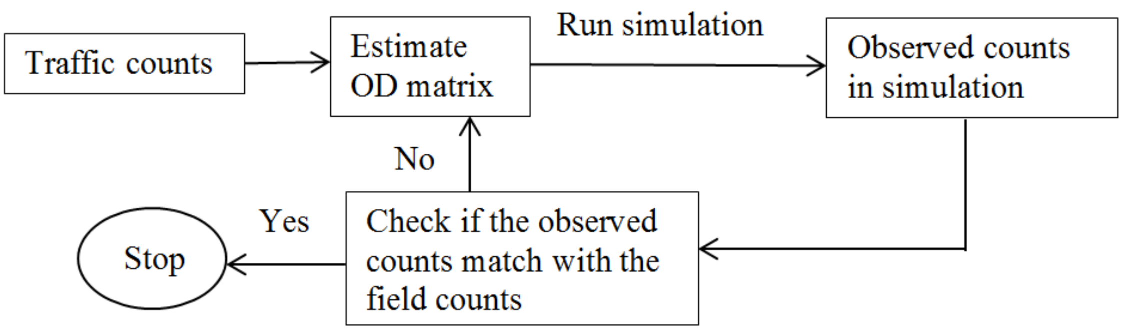


Figure 11: Procedure for static OD estimation

The proposed procedure worked reasonably well for this study network. However, this is mainly because the network is small and the values of many elements in the OD matrix are very small (not many transportation activities in minor TAZs). This procedure however is not recommended for more complex, larger networks since such manual estimation process can be resource-consuming and subject to large errors for such networks.

5.2 Dynamic OD Pattern

Static OD matrix can only provide hourly OD demand. However, such static OD matrix cannot capture the time-dependent characteristics (e.g., traffic volume in a 15-minutes interval) of real traffic stream. For the purpose of this study, dynamic OD pattern is needed to better describe how the traffic volume evolves within the peak hours.

Based upon the static OD matrix, the detector counts (in 15-minute intervals) were used to estimate the percentage of OD volume for each 15-minute interval during the peak hours. This was accomplished by using the profile of traffic counts (e.g., using the number of vehicles detected, divided by the total number of vehicles detected during the entire peak hour) to approximately represent the OD profile of the corresponding elements in the OD matrix.

To input the dynamic OD matrix in Paramics, three input files need to be prepared. Namely, an original static OD matrix which defines the hourly OD volume (see Table 9), a profile matrix which illustrates the profile number for OD pair (see Table 10), and a dynamic profile file which defines the percentage of OD flow for each time interval (see Table 11). The dynamic OD patterns for both the before and after scenarios can be found in Appendix 2.

Table 9: Static OD matrix (example)

	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	
Zone 1		8	375	0	0	……
Zone 2	14		146	5	7	
Zone 3	126	57		50	10	
Zone 4	0	1	5		0	
Zone 5	0	5	135	0		
……						

Table 10: Profile matrix (example)

	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	
Zone 1		5	5	5	5	……
Zone 2	5		5	5	5	
Zone 3	1	1		1	1	
Zone 4	1	1	1		1	
Zone 5	4	4	4	0		
……						

Table 11: Dynamic OD profile (example)

	Interval 1	Interval 2	Interval 3	Interval 4	Total
Profile 1	19.6	21.7	28.3	30.4	100
Profile 2	27.9	26.6	24.6	20.9	100
Profile 3	17.3	31.3	25.3	26.1	100
Profile 4	24.3	27.5	25.5	22.7	100
Profile 5	27.6	22.8	22.4	27.2	100

6. MODEL CALIBRATION AND VALIDATION

6.1 Calibration Procedure

Model calibration is very crucial for micro-simulation studies to ensure that the simulation model can generate results that are consistent with real world observations. Calibration of micro-simulation models is an iterative process that is in general time and resource consuming. The objective of a calibration process is to re-produce the typical real world traffic conditions in simulation by fine-tuning the model parameters (e.g., mean target headways, driver reaction times, origin-destination matrices, signal control strategies, lane-choice settings, among others). A number of the calibration steps (i.e., calibration of capacity, OD matrix estimation) have already been discussed in the previous chapters. In this chapter, a streamlined procedure is introduced for model calibration; the validation results are also presented.

The traditional process of micro-simulation model calibration relies heavily on engineering judgment, which involves adjusting model parameters (usually demand levels and network coding) until reasonable quantitative and qualitative matches between field data and simulated model results are reached (Gardes, et al., 2002 and 2003). Without a clearly defined streamlined procedure, these adjustments can be very time consuming and tedious. For large scale networks, because the number of parameters is large, this trial-and-error method sometimes cannot produce realistic results. As the number of traffic analysis zones (TAZs) in the network increases, it becomes more and more difficult to manually tweak demand matrices to reproduce observed traffic flow characteristics.

Some researchers focus on systematic approaches that involve formulating the steps of the calibration procedure as an optimization problem. Here, the calibration procedure is transformed into a search for the optimal combination of parameter values (e.g., headways and reaction times). By using certain algorithms, such as gradient search methods and genetic algorithms, the parameter combination with the best performance can be found (Xu, et al., 2004; Lee, et al., 2001; Cheu, et al., 1998). Such optimization methods have the potential to achieve a global optimum. However most of them can only handle parameters that relate to driving behavior and route choice. For large scale networks, OD demands are not well represented in the procedure. In this report, a streamlined and practical calibration procedure is presented for corridor network simulation studies. The procedure includes methods for data collection and analysis, capacity calibration, OD matrix estimation including both hourly and dynamic demands, and calibration and validation. Also, approaches for demand pattern matrix updating and dynamic OD generation are proposed along with the calibration procedure. Overall calibration/validation results show that such a procedure can provide reasonably accurate matches with the field data and is easily conducted by traffic engineers.

Key steps of the calibration process and its role in the entire simulation model development are shown in Figure 12. In particular, the calibration process is an iterative procedure and may require modifying previous steps of the simulation development such as network coding, data collection, and even project scoping. Particularly for the simulation model developed in this project, calibration did result in improved network coding but did not impact the data collection and project scoping steps.

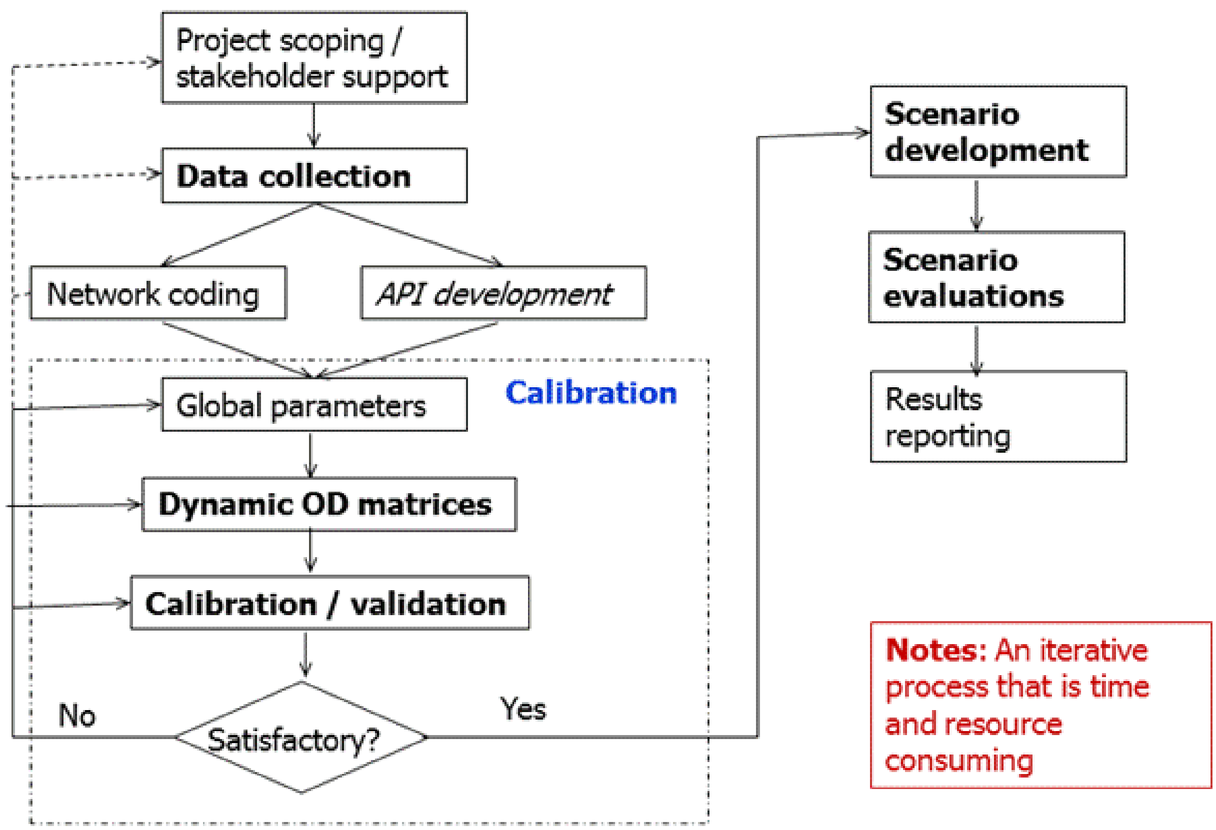


Figure 12: Micro-simulation model development and calibration procedure

The calibrated parameters and estimated dynamic OD profiles were used as input information to the fine-tuned simulation network. Output statistics gathered by the model were checked for validity, qualitatively and quantitatively. Since each run in the Paramics model is a stochastic process, each scenario was run for at least 5 times to provide more stable results. However, in this project, no large difference was observed between the runs. For validation purposes, the analysts can compare the simulated volume and other performance measures in simulation (e.g., travel times, queue lengths, etc.) with the observed field measures.

The validation results indicate how close the simulation output matches the real world observed traffic states. Table 12 shows the Federal Highway Administration (FHWA) guideline for the criteria of simulation model calibration. These criteria were adopted in this project.

Table 12: FHWA guideline for microscopic simulation model calibration

Criteria & Measures	Acceptability Targets
Hourly Flows, Model vs. Observed	
Individual Link Flows	
Within 15%, for 700 vph < Flow <2700 vph	> 85% of cases
Within 100 vph, for Flow < 700 vph	> 85% of cases
Within 400 vph, for Flow > 2700 vph	> 85% of cases
Total Link Flows	
Within 5%	All Accepting Links
GEH Statistic – Individual Link Flows	
GEH < 5	> 85% of cases
GEH Statistic – Total Link Flows	
GEH < 4	All Accepting Links
Travel Times, Model vs. Observed	
Journey Times Network	
Within 15% (or one minute, if higher)	> 85% of cases
Visual Audits	
Individual Link Speeds	
Visually acceptable Speed-Flow relationship	To analyst's satisfaction
Bottlenecks	
Visually acceptable Queuing	To analyst's satisfaction

6.2 Validation of traffic volume

According to Table 12, the key statistics to validate traffic volume is called GEH, which can be computed using the equation below:

$$GEH = \sqrt{\frac{(V - C)^2}{(V + C)/2}}$$

Where V is the simulated traffic volume in simulation, C is the field-measured traffic volume at the same location. A GEH value of less than 5 for more than 85% of the locations is considered to be acceptable.

Since the travel time and queue length data were not available for the before scenario, traffic volumes were the major consideration for calibration of the before model. Table 13 and Table 14 depicts the calibration results for the AM and PM peak hours of the before model respectively. It is worthy to mention that the traffic volumes were collected at each intersection for all major directions. It shows that the GEH for every control location of the network is less than 5, which indicates that the before model was calibrated successfully based on the guideline and criteria in Table 12.

Table 13: Volume validation results for the before scenario (AM peak)

Location	Observed	Simulation	Criteria	GEH	Criteria	Criteria Check
Route 100 off ramp	1550	1509	15%	0.74	5	Yes
I-287 off ramp	830	797	15%	0.82	5	Yes
Route 119, North	1848	1861	15%	0.21	5	Yes
Shopping center, South	2275	2273	15%	0.03	5	Yes
Shopping center, East	125	104	100	1.39	5	Yes
Shopping center, North	1824	1778	15%	0.77	5	Yes
Shopping center, West	9	6	100	0.77	5	Yes
Tarrytown&Aqueduct, South	1975	2134	15%	2.48	5	Yes
Tarrytown&Aqueduct, East	593	532	100	1.82	5	Yes
Tarrytown&Aqueduct, North	1187	1190	15%	0.06	5	Yes
Tarrytown&Aqueduct, West	270	267	100	0.13	5	Yes
Russell&Aqueduct, East	213	222	100	0.43	5	Yes
Russell&Aqueduct, West	47	36	100	1.21	5	Yes
Tarrytown&Central, South	1721	1705	15%	0.27	5	Yes
Tarrytown&Central, East	471	425	100	1.54	5	Yes
Tarrytown&Central, North	1063	1023	15%	0.88	5	Yes
Tarrytown&Central, West	720	726	100	0.16	5	Yes
Central&Harding, North	44	48	100	0.42	5	Yes
Tarrytown&Chatterton, South	2127	2038	15%	1.38	5	Yes
Tarrytown&Chatterton, East	248	276	100	1.22	5	Yes
Tarrytown&Chatterton, North	1154	1106	400	1.01	5	Yes
Tarrytown&Chatterton, West	387	377	100	0.36	5	Yes
Total	20681	20433	5%	1.22	4	Yes

Table 14: Volume validation results for the before scenario (PM peak)

Location	Observed	Simulation	Criteria	GEH	Criteria	Criteria Check
Route 100 off ramp	1262	1226	15%	0.72	5	Yes
I-287 off ramp	983	983	15%	0.00	5	Yes
Route 119, North	2793	2765	400	0.38	5	Yes
Shopping center, South	2201	2165	15%	0.54	5	Yes
Shopping center, East	275	278	100	0.13	5	Yes
Shopping center, North	2803	2741	400	0.83	5	Yes
Shopping center, West	16	14	100	0.37	5	Yes
Tarrytown&Aqueduct, South	1786	1915	15%	2.12	5	Yes
Tarrytown&Aqueduct, East	549	580	100	0.92	5	Yes
Tarrytown&Aqueduct, North	1954	1960	15%	0.10	5	Yes
Tarrytown&Aqueduct, West	268	289	100	0.89	5	Yes
Russell&Aqueduct, East	177	169	100	0.43	5	Yes
Russell&Aqueduct, West	84	96	100	0.89	5	Yes
Tarrytown&Central, South	1597	1575	15%	0.39	5	Yes
Tarrytown&Central, East	596	600	100	0.12	5	Yes
Tarrytown&Central, North	2305	2450	15%	2.10	5	Yes
Tarrytown&Central, West	537	544	100	0.21	5	Yes
Central&Harding, North	87	91	100	0.30	5	Yes
Tarrytown&Chatterton, South	1670	1603	15%	1.17	5	Yes
Tarrytown&Chatterton, East	209	199	100	0.50	5	Yes
Tarrytown&Chatterton, North	2921	2755	400	2.20	5	Yes
Tarrytown&Chatterton, West	163	168	100	0.27	5	Yes
Total	25236	25166	5%	0.31	4	Yes

Similarly for the after scenario, validation results are shown in Table 15 and Table 16 respectively for the AM and PM peak hours. Since major demand were not expected to change between the before and after scenarios, the same set of field measured counts were used for volume validation. The simulated counts in simulation were obtained using the Loop Data Aggregator, developed by California PATH; refer to Chu et al. (2005) for detailed information regarding how this plugin works in Paramics. The results in the two tables indicate that the after model was calibrated successfully in terms of traffic counts based on the guideline and criteria in Table 12.

Table 15: Volume validation results for the after scenario (AM peak)

Location	Observed	Simulation	Criteria	GEH	Criteria	Criteria Check
Route 100 off ramp	1550	1500	15%	0.91	5	Yes
I-287 off ramp	830	832	15%	0.05	5	Yes
Route 119, North	1848	1925	15%	1.25	5	Yes
Shopping center, South	2275	2345	15%	1.03	5	Yes
Shopping center, East	125	125	100	0.00	5	Yes
Shopping center, North	1824	1914	15%	1.47	5	Yes
Shopping center, West	9	6	100	0.77	5	Yes
Tarrytown&Aqueduct, South	1975	2111	15%	2.13	5	Yes
Tarrytown&Aqueduct, East	593	506	100	2.62	5	Yes
Tarrytown&Aqueduct, North	1187	1154	15%	0.68	5	Yes
Tarrytown&Aqueduct, West	270	249	100	0.92	5	Yes
Russell&Aqueduct, East	213	219	100	0.29	5	Yes
Russell&Aqueduct, West	47	45	100	0.21	5	Yes
Tarrytown&Central, South	1721	1854	15%	2.22	5	Yes
Tarrytown&Central, East	471	550	100	2.47	5	Yes
Tarrytown&Central, North	1063	1062	15%	0.02	5	Yes
Tarrytown&Central, West	720	677	100	1.15	5	Yes
Central&Harding, North	44	33	100	1.25	5	Yes
Tarrytown&Chatterton, South	2127	2306	15%	2.69	5	Yes
Tarrytown&Chatterton, East	248	222	100	1.20	5	Yes
Tarrytown&Chatterton, North	1154	1131	400	0.48	5	Yes
Tarrytown&Chatterton, West	387	373	100	0.51	5	Yes
Total	20681	21139	5%	2.24	4	Yes

Table 16: Volume validation results for the after scenario (PM peak)

Location	Observed	Simulation	Criteria	GEH	Criteria	Criteria Check
Route 100 off ramp	1262	1244	15%	1.39	5	Yes
I-287 off ramp	983	996	15%	0.51	5	Yes
Route 119, North	2793	2772	400	0.53	5	Yes
Shopping center, South	2201	2265	15%	0.77	5	Yes
Shopping center, East	275	293	100	0.18	5	Yes
Shopping center, North	2803	2748	400	1.18	5	Yes
Shopping center, West	16	15	100	0.52	5	Yes
Tarrytown&Aqueduct, South	1786	1760	15%	2.31	5	Yes
Tarrytown&Aqueduct, East	549	568	100	1.83	5	Yes
Tarrytown&Aqueduct, North	1954	1986	15%	0.14	5	Yes
Tarrytown&Aqueduct, West	268	273	100	1.26	5	Yes
Russell&Aqueduct, East	177	183	100	0.61	5	Yes
Russell&Aqueduct, West	84	94	100	1.26	5	Yes
Tarrytown&Central, South	1597	1509	15%	0.55	5	Yes
Tarrytown&Central, East	596	667	100	0.16	5	Yes
Tarrytown&Central, North	2305	2453	15%	2.97	5	Yes
Tarrytown&Central, West	537	465	100	0.30	5	Yes
Central&Harding, North	87	85	100	0.42	5	Yes
Tarrytown&Chatterton, South	1670	1633	15%	1.66	5	Yes
Tarrytown&Chatterton, East	209	216	100	0.70	5	Yes
Tarrytown&Chatterton, North	2921	2795	400	1.45	5	Yes
Tarrytown&Chatterton, West	163	189	100	0.39	5	Yes
Total	25236	25209	5%	0.13	4	Yes

6.3 Validation of travel time and queue length

In order to provide more rigorous validation of the after scenario, field experiments were conducted in April, 2012 to collect travel time and queue length information.

Corridor travel times were collected via probe vehicle runs. The route for the probe vehicle run is about 1 mile one way. The north end of the route is at 290 Tarrytown Road; the south end of the route is at the intersection of Main St and Bank St. Table 17 and Table 18 list the measured corridor travel times for both directions. The validation results of corridor travel time are indicated in Table 19. The difference between the field measured travel time and the corridor travel time observed in simulation is less than 5% for both direction, which indicates that the after model was calibrated successfully in terms of capturing corridor travel times.

Table 17: Corridor travel times (AM peak)

AM Peak	Travel Time Samples (Seconds)	
	Northbound	Southbound
8:15:00-8:20:00	160	104
8:20:00-8:25:00	76	147
8:25:00-8:30:00	95	79
8:30:00-8:35:00	116	141
8:35:00-8:40:00	118	107
8:40:00-8:45:00	141	169
8:45:00-8:50:00	75	136
8:50:00-8:55:00	109	87
8:55:00-9:00:00	132	125
9:00:00-9:05:00	81	126
9:05:00-9:10:00	91	175
9:10:00-9:15:00	145	183

Table 18: Corridor travel times (PM peak)

PM Peak	Travel Time Samples (Seconds)	
	Northbound	Southbound
17:00:00-17:05:00	82	115
17:05:00-17:10:00	137	145
17:10:00-17:15:00	106	139
17:15:00-17:20:00	172	NA
17:20:00-17:25:00	138	143
17:25:00-17:30:00	103	NA
17:30:00-17:35:00	57	72
17:35:00-17:40:00	114	125
17:40:00-17:45:00	68	NA
17:45:00-17:50:00	NA	134
17:50:00-17:55:00	158	151
17:55:00-18:00:00	110	125

Table 19: Travel time validation results for after scenario

Scenario		Observed Average Travel Time	Average Travel Time in simulation	Difference
AM	Northbound	111.6s (standard deviation 28.7s)	111.4s (standard deviation 28.1s)	0.2%
	Southbound	131.6s (standard deviation 33.7s)	134.6s (standard deviation 29.5s)	2.3%
PM	Northbound	112.5s (standard deviation 35.2s)	114.0s (standard deviation 28.0s)	1.3%
	Southbound	125.4s (standard deviation 25.2s)	127.9s (standard deviation 29.5s)	2.0%

According to Table 12, the micro-simulation model should also be validated by analyzing the queuing processes at key locations of the corridor. During the field experiment, cycle-by-cycle queue length information was collected at two intersections of the corridor (for both the AM peak and PM peak). The locations are indicated in Figure 13(a), (b) for the AM peak and Figure 14(a), (b) for the PM peak.

Figure 13(a): Queue length data collection (Route 100 off-ramp, AM peak)

Figure 13(b): Queue length data collection (northbound Tarrytown & Aqueduct, AM peak)

Figure 14(a): Queue length data collection (westbound Tarrytown & Aqueduct, PM peak)

Figure 14(b). Queue length data collection (northbound Tarrytown & Central Ave, PM peak)

The queue length validation results are shown in Table 20(a), (b) for the AM peak and in Table 21(a), (b) for the PM peak. Due to the stochastic nature of micro-simulation, the cycle-by-cycle queue length did not exactly follow the field measures. However, in terms of the average queue length of the lane group, the values observed in simulation general match well with the field measured values. This indicates that the after model was successfully calibrated in terms of capturing queue lengths at these two locations. Furthermore, based on the results of traffic volumes, corridor travel times, and queue lengths, it can be claimed that the after model was calibrated successfully.

Table 20(a): Queue length validation results (Route 100 off-ramp, AM peak)

Time	Observed			Simulation		
	Lane2	Lane3	Lane4	Lane2	Lane3	Lane4
8:15:40-8:16:07	4	6	5	4	4	5
8:17:36-8:18:14	6	5	8	4	5	6
8:19:35-8:20:03	5	8	6	4	6	7
8:21:31-8:22:00	8	8	8	4	5	7
8:23:30-8:24:00	6	8	9	6	8	8
8:25:49-8:26:01	3	1	2	5	9	8
8:27:37-8:28:04	3	5	5	3	4	6
8:29:39-8:30:10	3	5	9	4	4	7
8:31:28-8:32:00	5	5	9	3	8	10
8:33:22-8:33:51	5	7	11	4	6	9
8:35:16-8:35:47	1	7	7	5	6	9
8:36:49-8:37:16	6	6	8	5	8	8
8:38:47-8:39:19	5	9	11	4	6	8
8:40:52-8:41:21	7	8	8	5	7	8
8:42:54-8:43:25	3	6	9	5	8	7
8:44:54-8:45:23	6	8	9	6	8	9
8:46:55-8:47:25	6	7	8	6	7	7
8:48:58-8:49:27	6	7	8	5	7	8
8:51:04-8:51:34	8	8	9	6	8	8
8:53:09-8:53:49	5	6	12	5	7	9
8:55:24-8:55:51	3	8	10	4	8	7
8:57:28-8:57:59	7	11	9	5	7	11
8:59:33-9:00:07	9	11	12	8	9	10
9:01:34-9:02:11	8	12	12	4	6	9
9:03:34-9:04:16	6	8	12	6	8	11
9:05:31-9:06:11	6	11	10	5	8	10
9:07:36-9:08:18	7	8	10	5	5	8
9:11:38-9:12:20	5	6	10	4	5	7
9:13:43-9:14:25	8	12	12	6	10	10
Average	5.5	7.5	8.9	4.8	6.8	8.2

Table 20(b): Queue length validation results (northbound Tarrytown & Aqueduct, AM peak)

Time	Observed		Simulation	
	Lane1	Lane2	Lane1	Lane2
8:14:03-8:15:36	7	8	4	5
8:15:53-8:17:22	5	8	4	6
8:17:53-8:19:12	4	6	6	6
8:19:39-8:21:07	7	10	6	6
8:21:36-8:23:02	10	9	7	9
8:23:33-8:24:41	10	10	7	9
8:25:12-8:26:44	7	6	8	8
8:27:14-8:28:45	8	10	2	7
8:29:14-8:31:37	6	9	7	8
8:31:20-8:32:30	8	5	8	10
8:32:59-8:34:24	7	10	6	8
8:34:56-8:36:21	10	8	10	11
8:36:50-8:38:18	12	12	9	9
8:38:48-8:40:19	13	13	9	11
8:40:49-8:42:34	12	13	9	11
8:43:04-8:44:32	10	11	6	7
8:45:14-8:46:35	12	11	12	13
8:47:31-8:48:48	4	5	10	9
8:49:30-8:50:58	9	12	9	12
8:51:37-8:53:10	12	10	8	11
8:53:40-8:55:13	10	10	12	14
8:55:44-8:57:16	7	5	10	12
8:57:50-8:59:39	6	4	6	6
8:59:58-9:01:30	8	7	8	9
9:03:36-9:04:39	6	7	7	8
9:04:39-9:05:41	5	6	7	9
9:06:12-9:07:48	9	9	9	11
9:08:18-9:09:52	6	7	10	11
9:10:23-9:11:53	6	7	10	7
9:12:29-9:14:02	6	7	9	5
Average	8.1	8.5	7.8	8.9

Table 21(a): Queue length validation results (westbound Tarrytown & Aqueduct, PM peak)

Time	Observed			Simulation		
	Lane2	Lane3	Lane4	Lane2	Lane3	Lane4
5:00:20-5:01:22	3	5	8	4	5	6
5:02:21-5:03:23	5	5	9	6	6	7
5:04:22-5:05:28	1	4	5	5	5	4
5:06:28-5:07:33	4	6	5	6	4	5
5:08:29-5:09:30	2	5	11	6	8	10
5:10:26-5:11:30	1	11	12	6	6	7
5:12:28-5:13:20	6	6	10	4	6	7
5:14:20-5:15:25	7	12	15	6	9	10
5:16:23-5:17:26	6	12	14	6	8	9
5:18:27-5:19:25	8	10	12	6	8	8
5:20:27-5:21:30	8	9	13	8	8	7
5:22:32-5:23:27	4	8	9	5	5	8
5:24:27-5:25:28	5	8	8	4	4	5
5:26:29-5:27:31	2	8	14	4	4	6
5:28:34-5:29:37	6	10	10	5	7	9
5:30:43-5:31:49	3	3	2	3	3	4
5:32:52-5:34:07	6	7	7	5	6	7
5:35:08-5:36:10	4	7	8	8	8	9
5:37:07-5:38:14	3	8	10	7	5	7
5:39:15-5:40:19	4	6	5	4	7	6
5:41:16-5:42:17	4	2	2	4	6	8
5:43:21-5:44:37	1	2	5	5	9	9
5:45:44-5:46:50	5	8	6	1	3	3
5:47:49-5:48:49	2	6	9	5	5	3
5:49:57-5:50:57	2	4	9	4	6	4
5:52:08-5:53:12	3	2	4	6	6	7
5:54:11-5:55:14	3	3	4	3	5	4
5:56:11-5:57:06	3	4	3	3	5	7
5:57:50-5:58:56	4	3	5	2	6	8
Average	4.0	6.3	8.1	4.9	6.0	6.7

Table 21(b): Queue length validation results (northbound Tarrytown & Central Ave, PM peak)

Time	Observed					Simulation				
	Lane1	Lane2	Lane3	Lane4	Lane5	Lane1	Lane2	Lane3	Lane4	Lane5
5:00:09-5:01:20	3	5	7	7	7	4	2	2	3	5
5:02:15-5:03:10	3	3	2	3	1	6	6	6	6	9
5:04:17-5:05:19	4	6	5	5	5	5	5	6	6	7
5:06:17-5:07:24	2	3	5	7	8	3	6	8	6	7
5:08:03-5:09:11	3	7	9	8	15	5	4	3	6	6
5:10:02-5:11:06	3	2	4	7	7	4	5	5	8	11
5:12:00-5:13:06	6	6	4	8	7	4	7	4	4	6
5:14:08-5:15:18	6	3	12	10	12	3	4	9	8	7
5:16:06-5:17:07	3	4	6	9	15	8	8	3	5	6
5:18:08-5:19:20	5	6	10	14	12	6	8	7	8	6
5:20:22-5:21:15	3	3	6	7	8	5	8	3	7	8
5:22:18-5:23:20	4	5	3	6	3	5	4	7	4	5
5:24:28-5:25:25	3	6	2	4	4	2	3	5	5	6
5:26:33-5:27:31	3	6	2	3	2	5	6	8	11	10
5:28:38-5:29:38	3	3	5	6	5	5	5	4	5	6
5:30:41-5:31:43	3	1	5	5	4	4	7	5	7	8
5:32:48-5:33:50	6	8	2	4	6	5	5	5	3	4
5:34:52-5:35:56	2	5	5	6	7	5	3	11	11	14
5:37:06-5:38:01	1	1	1	4	3	7	6	10	10	9
5:39:17-5:40:18	3	5	5	6	3	3	5	5	5	5
5:41:36-5:42:25	6	7	1	2	6	3	4	3	4	4
5:43:28-5:44:36	1	2	2	4	4	2	6	6	5	7
5:45:38-5:46:44	4	4	1	1	4	4	5	4	5	6
5:47:43-5:48:45	2	2	1	1	2	4	6	1	2	5
5:49:45-5:50:48	2	6	2	3	3	2	3	1	2	5
5:51:46-5:52:47	6	9	7	6	6	1	3	3	3	1
5:53:46-5:54:54	3	3	3	3	3	4	4	5	6	6
5:55:49-5:56:51	1	2	3	5	4	5	3	4	4	4
5:57:44-5:58:39	4	7	5	9	10	3	3	4	6	6
Average	3.4	4.5	4.3	5.6	6.1	4.2	5.0	5.1	5.7	6.5

7. SCENARIO EVALUATIONS

The developed simulation models, especially the after models, can serve as a decision making tool to help assess the performance of the transportation system during peak hours, under specific scenarios. Furthermore, the effectiveness and robustness of the recently deployed adaptive signal control system can also be tested under other traffic conditions using the after model. This can enable more informed decisions under these specific traffic scenarios.

7.1 Development of Evaluation Scenarios

The team discussed extensively with engineers and managers at the City of White Plains to figure out what scenarios the city is most interested to evaluate in simulation. These scenarios include corridor demand surge due to nearby freeway accidents or closure, corridor lane closure due to accidents or construction, demand variation due to holiday shopping, among others. It is important to develop these scenarios since one needs to understand how the current traffic system would react to such special traffic situations. By doing so, recommendations can be provided to operate the system in a more efficient manner when these scenarios happen. For example, in response to nearby accidents, vehicles may have to be directed to the Tarrytown Rd. As a result, this may lead to demand surge of the corridor. One thus needs to study if such demand surge can be properly handled using the current adaptive signal control strategies, or if certain improvements need to be implemented.

The team also considered the capability of the simulation model (as aforementioned, due to resource limitations, an early version of SCATS was implemented in simulation which cannot simulate some of the recent advanced features of SCATS, such as BRT, signal priority or preemption) and data availability when deciding which exact scenarios to evaluate.

Table 22 is a finalized list of scenarios which was tested using micro-simulation models.

Table 22: List of Evaluation Scenarios

List of the scenarios	Description	Notes
Scenario #1		
a. Baseline	Same as the after scenarios	For both AM and PM peak hours
b. Demand increase	Demand increase for trips from mainline at the off-ramp to downtown	50% increase for the AM peak
c. Demand increase +	Study the effectiveness of	Test the half-cycle and full-cycle strategies at

Signal cycle lengths	different signal cycle lengths	the off-ramp signal. If none of them works well, try other (longer) cycle lengths
Scenario #2		
a. Holiday Event	demand increases 30% at the off-ramp (mainline) and increases 10% at the Central Ave going to the downtown	The PM peak
Scenario #3		
a. Traffic incidents	Variable lane closure	Lane closure before the PM peak (the simulated demand is 90% of the peak PM demand) between the intersections of the Shopping center and Aqueduct St, for traffic going northbound (outbound). The lane closure starts at 10 minutes and lasts for 30 minutes and is cleared during the next 20 minutes in simulation
* All the simulation runs have 15 minutes warm-up time; the demand during the warm-up time is 75% of the peak demand		

7.2 Baseline scenario and demand increase

The after model calibrated and validated in the previous chapters was used as the baseline scenario. The calibration/validation results (e.g., model parameters, OD matrix, traffic volume and performance measures) of the baseline scenario can be found in the previous chapters.

On top of the baseline scenario, modifications were made to the baseline so that other traffic conditions can be implemented and tested. The first scenario simulated here was for demand increase, in which the OD demand from the Route 100 off-ramp (mainline) increased 50% due to, e.g., a traffic accident happened close to Exit-7 of the eastbound I-287 during the morning peak.

Due to the large demand increase from the off-ramp, the northbound of the study corridor became very congested and longer corridor travel time and larger queue length were observed. Although multi-cycle grid blockage was not observed at the shopping center intersection and the Aqueduct intersection, long queues (which spills back to the upstream intersections/off-ramps) were occasionally observed at these two intersections.

In this context, the feasibility of using different cycle lengths (to help such large traffic volume discharge faster) was further tested at the intersection of the Tarrytown Rd and the shopping center. For these scenarios, the results of travel time are shown in Table 23 and the results of queue lengths are shown in Table 24 and Table 25.

Table 23: Corridor travel time of demand increase scenarios

Scenario	Baseline	Demand Increase (Half-cycle)	Demand Increase (Full-cycle)
Northbound	111.4s (std 28.1s)	110.0s (std 27.8s)	108.4s (std 26.9s)
Southbound	134.6s (std29.5s)	150.9s (std 33.7s)	172.5s (std 42.7s)

Table 24: Queue length of demand increase scenarios (Tarrytown Rd. & shopping center)

Time	Baseline			Demand Increase + Half Cycle			Demand Increase+Full Cycle		
	Lane2	Lane3	Lane4	Lane2	Lane3	Lane4	Lane2	Lane3	Lane4
8:15:40-8:16:07	4	4	5	7	10	13	1	4	6
8:17:36-8:18:14	4	5	6	5	8	11	4	6	8
8:19:35-8:20:03	4	6	7	6	10	10	2	4	8
8:21:31-8:22:00	4	5	7	5	8	11	3	6	9
8:23:30-8:24:00	6	8	8	7	11	11	4	7	9
8:25:49-8:26:01	5	9	8	5	7	8	2	7	7
8:27:37-8:28:04	3	4	6	9	12	15	5	9	10
8:29:39-8:30:10	4	4	7	5	11	11	4	10	11
8:31:28-8:32:00	3	8	10	5	12	11	5	9	11
8:33:22-8:33:51	4	6	9	5	7	9	6	11	12
8:35:16-8:35:47	5	6	9	5	8	11	4	7	8
8:36:49-8:37:16	5	8	8	7	8	8	7	10	11
8:38:47-8:39:19	4	6	8	5	10	12	5	10	10
8:40:52-8:41:21	5	7	8	7	10	11	5	11	12
8:42:54-8:43:25	5	8	7	6	12	16	6	9	10
8:44:54-8:45:23	6	8	9	5	11	13	6	12	13
8:46:55-8:47:25	6	7	7	5	7	11	11	16	20
8:48:58-8:49:27	5	7	8	7	11	12	7	11	11
8:51:04-8:51:34	6	8	8	8	10	10	9	11	13
8:53:09-8:53:49	5	7	9	6	13	16	7	11	13
8:55:24-8:55:51	4	8	7	7	13	14	11	15	21
8:57:28-8:57:59	5	7	11	8	16	17	7	10	14
8:59:33-9:00:07	8	9	10	10	20	23	8	11	12
9:01:34-9:02:11	4	6	9	11	16	18	7	12	15
9:03:34-9:04:16	6	8	11	9	12	13	3	8	6
9:05:31-9:06:11	5	8	10	7	8	10	4	9	11
9:07:36-9:08:18	5	5	8	3	7	8	5	6	8
9:11:38-9:12:20	4	5	7	3	6	8	4	8	8
9:13:43-9:14:25	6	10	10	4	6	7	5	6	7
Average	4.8	6.8	8.2	6.3	10.3	12.0	5.4	9.2	10.8

Table 25: Queue length of demand increase scenarios (Tarrytown Rd. & Aqueduct Rd.)

Time	Baseline		Demand Increase + Half Cycle		Demand Increase+Full Cycle	
	Lane1	Lane2	Lane1	Lane2	Lane1	Lane2
8:14:03-8:15:36	4	5	7	5	7	6
8:15:53-8:17:22	4	6	9	10	10	11
8:17:53-8:19:12	6	6	6	7	6	7
8:19:39-8:21:07	6	6	6	6	6	7
8:21:36-8:23:02	7	9	8	9	7	9
8:23:33-8:24:41	7	9	6	7	7	7
8:25:12-8:26:44	8	8	2	7	2	6
8:27:14-8:28:45	2	7	7	8	7	6
8:29:14-8:31:37	7	8	10	12	10	9
8:31:20-8:32:30	8	10	9	9	8	10
8:32:59-8:34:24	6	8	12	13	9	10
8:34:56-8:36:21	10	11	7	7	8	9
8:36:50-8:38:18	9	9	9	11	9	9
8:38:48-8:40:19	9	11	10	12	10	10
8:40:49-8:42:34	9	11	7	8	5	5
8:43:04-8:44:32	6	7	12	10	9	10
8:45:14-8:46:35	12	13	5	8	6	7
8:47:31-8:48:48	10	9	8	8	8	8
8:49:30-8:50:58	9	12	9	12	7	8
8:51:37-8:53:10	8	11	12	13	12	13
8:53:40-8:55:13	12	14	11	11	8	9
8:55:44-8:57:16	10	12	9	9	11	10
8:57:50-8:59:39	6	6	11	12	12	12
8:59:58-9:01:30	8	9	11	14	7	7
9:03:36-9:04:39	7	8	8	9	5	6
9:04:39-9:05:41	7	9	8	10	10	10
9:06:12-9:07:48	9	11	11	13	5	9
9:08:18-9:09:52	10	11	7	9	9	12
9:10:23-9:11:53	10	7	13	12	7	8
9:12:29-9:14:02	9	5	9	11	8	11
Average	7.8	8.9	8.6	9.7	7.8	8.7

Compared with the half-cycle scenario, running full-cycle at the off-ramp did shorten the queue lengths at the shopping center intersection (see Table 24 and Table 25). However, running full-cycle at the off-ramp also increased the queue lengths at the upstream segments (i.e. off-ramp and mainline) and increased the total travel time. As illustrated in Table 23, the travel time for the southbound (inbound) traffic increased more than 20 seconds. This means the half-cycle strategy is more suitable for this demand increase scenario.

It is also noteworthy that compared with the baseline case, the travel time for the northbound (outbound) traffic decreased a little bit. This is because the southbound flow dropped during the congestion period. This implies that fewer vehicles were detected by the southbound detectors, therefore the SCATs system tended to give more time for the northbound phases.

7.3 Holiday event

The second scenario was to model the traffic condition for the PM peak during holidays. According to the detector data collected on the PM peak, December 21st, 2012, the traffic demand at the off-ramp (mainline) and the demand from Central Ave. to the downtown area (inbound direction) increased 30% and 10%, respectively. This is particularly because more shopping related trips were generated during the holidays.

For this scenario, the results of corridor travel times and queue lengths can be found in Table 26, Table 27 and Table 28. Compared with the demand increase scenario during the AM peak (in Table 19), the traffic demand on the southbound mainline of Tarrytown Rd. of the holiday event scenario was much lower. Therefore the adaptive signal control system handled this scenario reasonably well. As a result, the corridor travel time for the southbound (inbound) direction increased about 4.5 seconds during the holiday event compared with the baseline scenario. Even though the traffic demand of the northbound (outbound) direction did not change, the corridor travel time of this direction increased slightly. This is because the adaptive signal control system detected larger traffic volumes in the southbound direction and therefore allocated more time to the southbound phases. As a result, the splits of the northbound phases were shortened.

Table 26: Corridor travel time of holiday event scenario

Scenario	Baseline	Holiday Event
Northbound	114.0s (std 28.0s)	116.6s (std 26.8s)
Southbound	127.9s (std 29.5s)	132.4s (std 30.0s)

Table 27: Queue length of holiday event scenario (Tarrytown Rd. & Central Ave.)

Time	Baseline					Holiday Event				
	Lane1	Lane2	Lane3	Lane4	Lane5	Lane1	Lane2	Lane3	Lane4	Lane5
5:00:09-5:01:20	4	2	2	3	5	4	3	4	3	6
5:02:15-5:03:10	6	6	6	6	9	5	8	4	8	9
5:04:17-5:05:19	5	5	6	6	7	5	6	5	7	6
5:06:17-5:07:24	3	6	8	6	7	4	6	10	9	12
5:08:03-5:09:11	5	4	3	6	6	4	6	6	7	6
5:10:02-5:11:06	4	5	5	8	11	4	7	5	4	6
5:12:00-5:13:06	4	7	4	4	6	4	3	4	4	5
5:14:08-5:15:18	3	4	9	8	7	1	3	6	8	10
5:16:06-5:17:07	8	8	3	5	6	7	6	4	6	9
5:18:08-5:19:20	6	8	7	8	6	6	6	6	7	5
5:20:22-5:21:15	5	8	3	7	8	8	14	9	9	9
5:22:18-5:23:20	5	4	7	4	5	4	6	4	4	6
5:24:28-5:25:25	2	3	5	5	6	3	6	7	7	6
5:26:33-5:27:31	5	6	8	11	10	4	2	5	6	7
5:28:38-5:29:38	5	5	4	5	6	7	6	7	7	7
5:30:41-5:31:43	4	7	5	7	8	5	3	5	7	9
5:32:48-5:33:50	5	5	5	3	4	5	5	7	5	7
5:34:52-5:35:56	5	3	11	11	14	3	7	10	7	6
5:37:06-5:38:01	7	6	10	10	9	1	5	9	8	11
5:39:17-5:40:18	3	5	5	5	5	3	9	11	9	8
5:41:36-5:42:25	3	4	3	4	4	5	11	13	5	5
5:43:28-5:44:36	2	6	6	5	7	9	8	7	8	6
5:45:38-5:46:44	4	5	4	5	6	7	2	8	5	7
5:47:43-5:48:45	4	6	1	2	5	5	5	3	5	4
5:49:45-5:50:48	2	3	1	2	5	4	3	3	4	4
5:51:46-5:52:47	1	3	3	3	1	3	4	2	3	2
5:53:46-5:54:54	4	4	5	6	6	4	4	4	3	4
5:55:49-5:56:51	5	3	4	4	4	7	3	4	6	5
5:57:44-5:58:39	3	3	4	6	6	3	3	8	4	5
Average	4.2	5.0	5.1	5.7	6.5	4.6	5.5	6.2	6.0	6.6

Table 28: Queue length of holiday event scenario (Tarrytown Rd. & Aqueduct Rd.)

Time	Baseline			Holiday Event		
	Lane2	Lane3	Lane4	Lane2	Lane3	Lane4
5:00:20-5:01:22	4	5	6	6	4	6
5:02:21-5:03:23	6	6	7	6	6	6
5:04:22-5:05:28	5	5	4	6	6	5
5:06:28-5:07:33	6	4	5	5	6	6
5:08:29-5:09:30	6	8	10	11	13	11
5:10:26-5:11:30	6	6	7	7	6	5
5:12:28-5:13:20	4	6	7	5	4	6
5:14:20-5:15:25	6	9	10	6	7	7
5:16:23-5:17:26	6	8	9	8	7	7
5:18:27-5:19:25	6	8	8	7	7	6
5:20:27-5:21:30	8	8	7	7	8	7
5:22:32-5:23:27	5	5	8	9	8	7
5:24:27-5:25:28	4	4	5	4	5	5
5:26:29-5:27:31	4	4	6	4	4	4
5:28:34-5:29:37	5	7	9	7	5	5
5:30:43-5:31:49	3	3	4	5	4	5
5:32:52-5:34:07	5	6	7	6	4	7
5:35:08-5:36:10	8	8	9	8	8	9
5:37:07-5:38:14	7	5	7	7	5	5
5:39:15-5:40:19	4	7	6	6	5	8
5:41:16-5:42:17	4	6	8	8	9	7
5:43:21-5:44:37	5	9	9	10	9	7
5:45:44-5:46:50	1	3	3	4	5	5
5:47:49-5:48:49	5	5	3	5	6	6
5:49:57-5:50:57	4	6	4	4	5	4
5:52:08-5:53:12	6	6	7	5	4	5
5:54:11-5:55:14	3	5	4	5	4	4
5:56:11-5:57:06	3	5	7	8	7	8
5:57:50-5:58:56	2	6	8	4	2	4
Average	4.9	6.0	6.7	6.3	6.0	6.1

7.4 Traffic incidents

The third scenario is to model the traffic conditions when traffic incidents (e.g. lane closure caused by traffic accident) happen. Particularly in this case, the right lane between Shopping center and Aqueduct St for traffic going northbound (outbound) was closed before the PM peak (simulated by reducing peak PM demand by 10%). Within the study period of an hour, the lane closure started at 10 minutes and lasted for 30 minutes; the jammed traffic was then cleared during the next 20 minutes in simulation.

For this scenario, the results of corridor travel time can be found in Table 29. Same results (in a 5-minute resolution) are also illustrated in Figure 15,

Figure 16 and Figure 17. The results indicate that the travel time for southbound (the direction without lane closure) remained stable during the period of study. For the northbound direction, during the period of time of lane closure, the corridor travel time increased moderately. However, after 20 minutes of lane-closure, the corridor travel times began to increase dramatically. And after the lane opened again, it took about 10 minutes to recover to the normal traffic condition. This is because the queues (i.e., excess demand) need to be fully cleared after the lane was re-opened. It is also noteworthy that the deviation of travel time during lane closure was much larger than the travel time for normal traffic conditions. Similar conclusions can also be reached by analyzing the queue length results as shown in Table 30 and Table 31.

Table 29: Corridor travel time of traffic incidents scenario

Scenario	Baseline (90%)	Traffic Incident (Start-up and normal)	Traffic Incident (Lane Close)	Traffic Incident (Recovery)
Northbound	112.1s (std 31.6s)	101.7s (std 25.4s)	161.6s (std 54.9s)	157.7s (std 68.1s)
Southbound	127.1s (std 31.8s)	123.2s (std 30.9s)	125.3s (std 30.0s)	132.6s (std 27.9s)
Scenario	Baseline (90%)	Traffic Incident (Overall)		
Northbound	112.1s (std 31.6s)	143.2s (std 59.7s)		
Southbound	127.1s (std 31.8s)	126.8s (std 29.8s)		

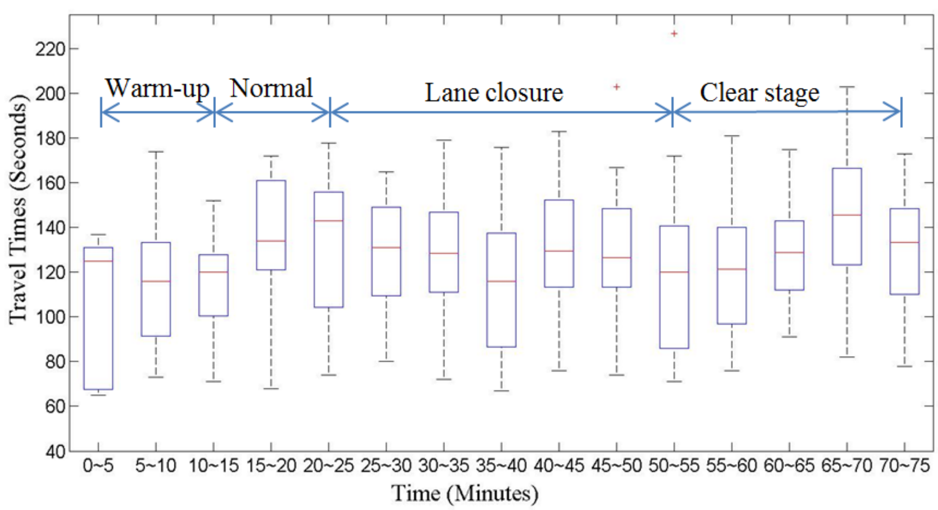


Figure 15: Dynamic travel time for traffic incident scenario (southbound)

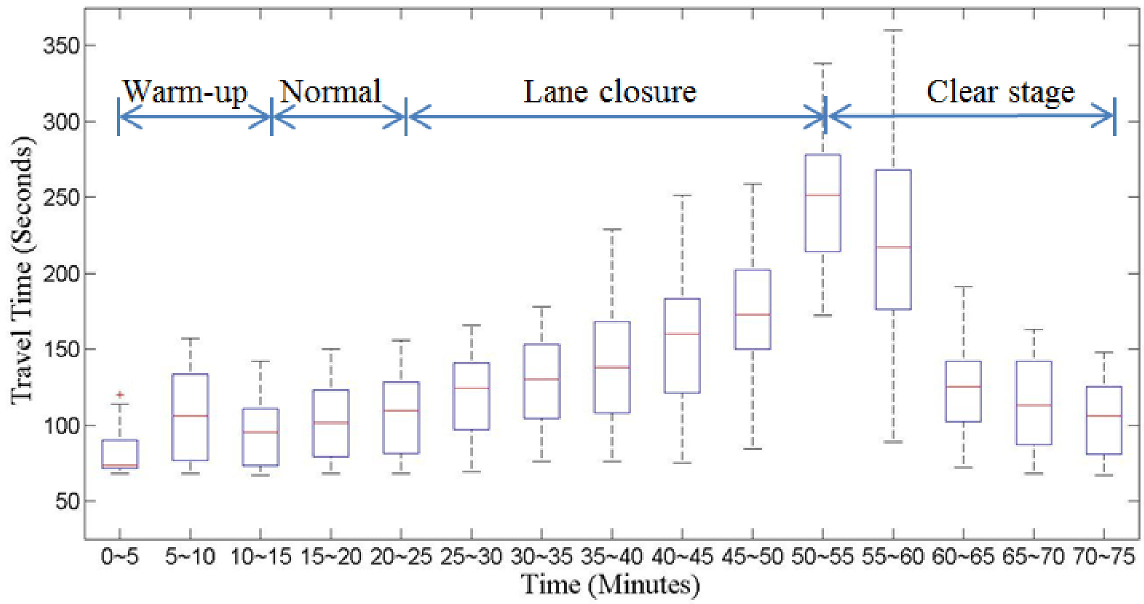


Figure 16: Dynamic travel time for traffic incident scenario (northbound)

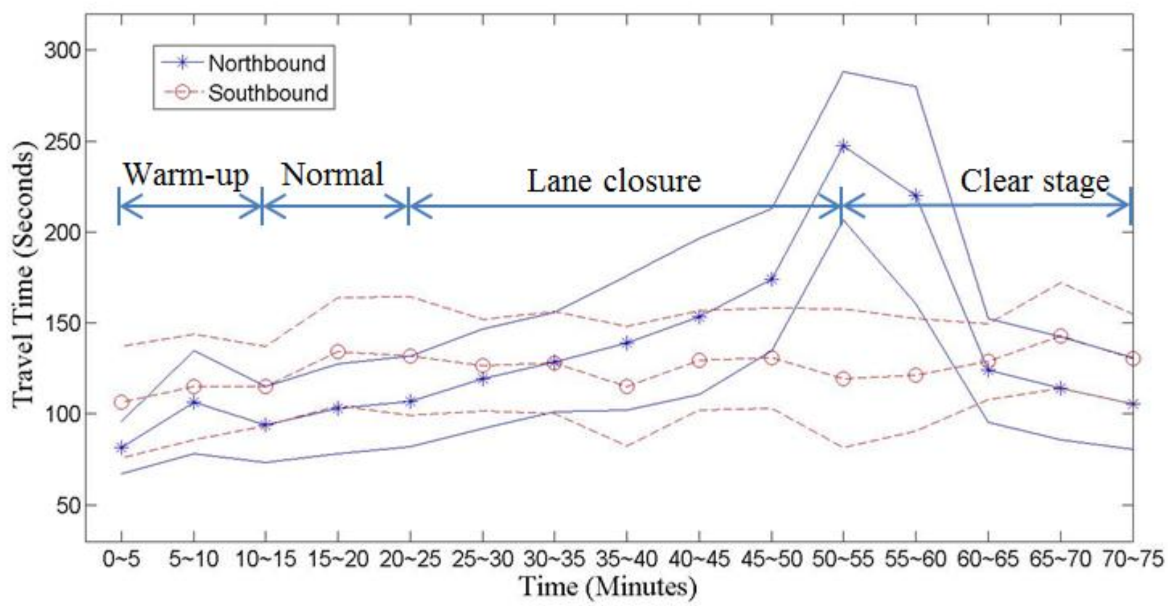


Figure 17: Dynamic travel time for traffic incident scenario (both directions)

Table 30: Queue length results of traffic incidents scenario (Tarrytown Rd. & Central Ave.)

Time	Baseline (90%)					Traffic Incident				
	Lane1	Lane2	Lane3	Lane4	Lane5	Lane1	Lane2	Lane3	Lane4	Lane5
5:00:09-5:01:20	3	5	2	3	5	3	5	2	3	5
5:02:15-5:03:10	5	5	2	5	5	5	5	2	6	5
5:04:17-5:05:19	6	2	6	6	5	6	2	7	4	5
5:06:17-5:07:24	6	6	9	9	6	7	6	7	7	8
5:08:03-5:09:11	2	4	2	3	5	2	4	2	3	5
5:10:02-5:11:06	3	6	4	3	3	3	4	4	5	4
5:12:00-5:13:06	5	4	5	7	7	6	4	3	3	3
5:14:08-5:15:18	5	5	6	5	8	2	3	8	5	6
5:16:06-5:17:07	6	4	5	6	6	5	7	5	6	6
5:18:08-5:19:20	5	4	4	5	7	5	4	3	3	6
5:20:22-5:21:15	5	7	6	5	6	1	1	7	5	6
5:22:18-5:23:20	7	6	4	4	5	8	8	9	7	6
5:24:28-5:25:25	3	4	5	7	7	3	2	5	5	7
5:26:33-5:27:31	4	3	5	7	8	4	5	3	3	4
5:28:38-5:29:38	4	4	7	8	6	5	5	9	9	9
5:30:41-5:31:43	5	6	4	5	6	5	8	6	6	7
5:32:48-5:33:50	9	6	5	7	8	5	4	4	5	7
5:34:52-5:35:56	9	6	6	6	5	4	6	9	7	7
5:37:06-5:38:01	9	6	9	6	8	5	6	4	6	7
5:39:17-5:40:18	5	6	7	6	6	4	7	9	12	13
5:41:36-5:42:25	3	3	6	7	5	7	9	4	6	5
5:43:28-5:44:36	3	4	5	4	6	8	6	6	7	7
5:45:38-5:46:44	3	3	5	4	5	4	6	5	3	6
5:47:43-5:48:45	2	3	4	6	6	6	4	6	2	5
5:49:45-5:50:48	3	2	6	4	6	2	3	3	3	5
5:51:46-5:52:47	2	2	5	5	5	3	3	4	5	7
5:53:46-5:54:54	5	5	3	4	7	2	3	2	5	6
5:55:49-5:56:51	4	3	4	4	5	4	2	5	4	4
5:57:44-5:58:39	3	4	6	5	6	4	5	4	5	4
Average	4.6	4.4	5.1	5.4	6.0	4.4	4.7	5.1	5.2	6.0

Table 31: Queue length results of traffic incidents scenario (Tarrytown Rd. & Aqueduct Rd.)

Time	Baseline (90%)			Traffic Incident		
	Lane2	Lane3	Lane4	Lane2	Lane3	Lane4
5:00:20-5:01:22	8	5	7	8	5	7
5:02:21-5:03:23	8	5	7	8	3	7
5:04:22-5:05:28	6	6	5	6	7	5
5:06:28-5:07:33	8	5	6	8	5	5
5:08:29-5:09:30	6	5	4	6	5	5
5:10:26-5:11:30	4	4	4	5	4	3
5:12:28-5:13:20	5	4	5	4	3	3
5:14:20-5:15:25	7	5	6	2	4	5
5:16:23-5:17:26	6	7	6	10	3	5
5:18:27-5:19:25	5	4	5	7	5	5
5:20:27-5:21:30	6	5	4	9	8	9
5:22:32-5:23:27	8	8	10	8	9	8
5:24:27-5:25:28	9	10	11	8	9	5
5:26:29-5:27:31	7	8	10	6	7	8
5:28:34-5:29:37	3	3	3	2	5	9
5:30:43-5:31:49	5	2	2	22	15	18
5:32:52-5:34:07	8	7	8	26	28	27
5:35:08-5:36:10	6	6	6	29	28	25
5:37:07-5:38:14	7	5	6	25	31	32
5:39:15-5:40:19	7	5	7	26	26	30
5:41:16-5:42:17	5	6	6	5	5	7
5:43:21-5:44:37	5	5	4	11	12	8
5:45:44-5:46:50	5	4	5	10	7	10
5:47:49-5:48:49	6	5	5	9	9	5
5:49:57-5:50:57	5	4	6	3	3	3
5:52:08-5:53:12	2	2	3	7	6	4
5:54:11-5:55:14	5	5	8	8	6	4
5:56:11-5:57:06	5	4	6	5	6	5
5:57:50-5:58:56	3	5	6	6	4	4
Average	5.9	5.1	5.9	10.0	9.2	9.3

7.5 Fuel consumption/emission results

Fuel consumption and emissions are also important consideration when evaluating and selecting corridor-wide traffic control and management strategy scenarios. Paramics Monitor (provided in the Paramics Suite) was used to estimate the emissions and fuel consumption for different scenarios analyzed in this project. Paramics Monitor is an easy-to-use plug-in which covers the emission/fuel consumption models from multiple sources (e.g., the CMEM model, UK highway agency model, VERSIT+, etc.). Based on the input information regarding vehicle emission classes and vehicle dynamics (e.g., speed and acceleration) for each vehicle in the network, the plug-in can provide aggregated emission/fuel consumption statistics for each link as well as the entire corridor. Three input files need to be provided in order to make the plug-in work properly. Namely, a **pollution** file which characterizes the fuel consumption/emission level for each vehicle emission class (and for different vehicle dynamics); a pollution vehicle type (**pv_type**) file which defines the vehicle emission class for each vehicle type in the simulation; and a **pollution-control** file which configures the plug-in. Examples of the input files are included in Appendix 3.

The emission/fuel consumption results can be aggregated for a pre-defined time interval (e.g. every 5 minutes or for the entire simulation period). Table 32 provides the system-wide emission/fuel consumption results for different scenarios for the entire simulation period. The results indicate that the demand increase scenario leads to a large increase in fuel consumption/emissions. Compared with running full cycle for the off-ramp intersection, running half cycle can help reduce both fuel consumption and emissions. Similar results were obtained for other scenarios, for example, lane closure due to traffic incident can result in a dramatic increase in fuel consumption and emissions.

Particularly for the traffic incident scenario, the dynamic (aggregated for every 5 minutes) fuel fuel consumption/emissions results are presented in Table 33. It shows in the table that the fuel consumption/emission values began to increase dramatically after the lane was closed for 20 minutes; minutes; and after the lane was re-opened, it took about 10-15 minutes for the traffic to recover to to the normal stage. The results are consistent with the dynamic travel times presented in

Figure 16.

Table 32: System wide emission/fuel consumption results

Emission	Carbon Monoxide (kg)	Carbon Dioxide (kg)	Total Hydrocarbons (kg)	Oxides of Nitrogen (kg)	Fuel Consumption (L)	Particulate Matter (g)
Baseline AM	81.9	1051.5	17.4	8.9	517.2	19.1
Demand Increase (half cycle)	94.1	1200.7	20.1	10.0	591.2	21.0
Demand Increase (full cycle)	98.5	1249.2	21.0	10.1	615.7	21.7
Baseline PM	92.9	1226.8	20.4	10.5	603.6	22.4
Holiday Event	99.3	1268.8	21.2	10.7	624.6	22.5
Baseline PM (90%)	84.1	1081.9	17.9	9.4	532.0	19.5
Traffic Incident	107.4	1330.9	22.8	10.4	658.4	22.3

Table 33: System wide emission/fuel consumption results for traffic incident scenario

Emission	Carbon Monoxide (kg)	Carbon Dioxide (kg)	Total Hydrocarbons (kg)	Oxides of Nitrogen (kg)	Fuel Consumption (L)	Particulate Matter (g)
0~5min	3.2	40.3	0.7	0.4	19.9	0.7
5~10min	4.7	58.7	1.0	0.5	29.0	0.9
10~15min	4.1	55.2	0.9	0.5	27.0	1.2
15~20min	5.7	71.4	1.2	0.7	35.2	1.6
20~25min	6.2	81.8	1.3	0.7	40.1	1.6
25~30min	6.3	78.9	1.3	0.7	38.9	1.1
30~35min	6.9	88.5	1.5	0.7	43.5	1.7
35~40min	7.0	88.0	1.5	0.7	43.4	1.9
40~45min	8.1	99.4	1.7	0.7	49.2	1.5
45~50min	10.3	119.1	2.2	0.8	59.9	1.4
50~55min	11.5	130.5	2.4	0.8	65.5	1.4
55~60min	10.9	130.8	2.3	0.9	65.0	1.6
60~65min	9.8	126.0	2.1	0.9	62.0	2.3
65~70min	7.1	90.9	1.5	0.8	44.6	2.4
70~75min	5.6	71.4	1.2	0.6	35.2	1.0

8. FINDINGS AND RECOMMENDATIONS

As illustrated in Table 34, the Tarrytown Rd corridor in the City of White Plains is currently heavily traveled and has very heavy peak hour traffic (near the capacity). Compared with the actuated signal timing plans previously used in the corridor, the recently deployed adaptive signal control system SCATS can adjust the signal timing parameters according to the traffic states in a cycle-by-cycle manner, which helps to mitigate traffic congestions and fuel consumption/emission of the corridor.

Table 34: Real world peak hour counts vs. capacity

Time of Day	Location	Capacity	Real Counts	Excessive Capacity
AM Peak	NY-119, through, northbound	1602	1098	31%
	Shopping center, through, northbound	3026	2340	23%
	Tarrytown&Aqueduct, through, northbound	2414	1798	26%
	Tarrytown&Central Ave, through, northbound	2422	2091	14%
	Tarrytown&Chatterton, through, northbound	3025	2459	19%
PM Peak	Tarrytown&Chatterton, through, southbound	3351	2492	26%
	Tarrytown&Central Ave, left, southbound	748	384	49%
	Tarrytown&Central Ave, through, southbound	1881	1554	17%
	Tarrytown&Aqueduct, through, southbound	2095	1916	9%
	Shopping center, through, southbound	2932	2674	9%

The scenario evaluation results show that the corridor has slight excessive capacity that may be able to handle 10% - 30% demand surge at one or a few locations. This is consistent with the results in Table 34. However, large demand increase (>=50%) even at one single location may lead to breakdowns at the corridor which could result in heavy congestion.

SCATS can properly handle small to medium demand increases along the corridor, especially if half-cycle or reasonable signal coordination strategies are applied. Nevertheless, for very large demand increases, corridor throughput will decrease which will lead to capacity drop in the heavily-congested direction. In this regard, some demand management strategies would be helpful. For example, real time information via variable message signs can be provided to the travelers so that some travelers can take alternative routes. Note here that this observation, i.e., SCATS may not handle well very large demand surge, is probably a bit conservative. This is because the simulation models implemented an early version of SCATS as aforementioned. The version of SCATS currently deployed along the corridor is more advanced and therefore is expected to behave much better with respect to those demand surge scenarios. This however needs to be verified in real world traffic in future studies.

When the mainline demand surges at the off-ramp location, the evaluation results show that, compared with the full-cycle strategy, using half-cycle is slightly more beneficial to the corridor in terms of travel times (improved by about 10%) and corridor fuel consumption and emissions. However, the queue lengths at some of the cross streets may get worse, e.g., at the intersection of the shopping center. Therefore, one needs to be careful when using the half-cycle strategy especially when combined with different mainline coordination strategies. Further investigations of the trade-offs between the full-cycle and half-cycle strategies are thus recommended in future studies.

Lane closure due to road maintenance or traffic incidents *at or near the peak hours* may lead to heavy congestion across the corridor; in the worst case, long queues at the intersections may spill back and block the upstream intersections as well. Fuel consumption and emission levels of the corridor also increase dramatically for the lane closure scenarios. This is because at or near the peak hours, the corridor demand is already high. Lane closure can cause dramatic capacity reduction at some specific corridor locations, resulting in heavier congestion. Although not done in the current project, it is expected that when the lane closure happens during the off-peak periods, the impact of the lane closure may be much less significant. This is because during the off-peak periods, corridor demand is much smaller compared with its capacity, making it possible to accommodate capacity reductions due to lane closure at specific locations. It is recommended that further investigation of lane closure during the off-peak periods be conducted to validate this conjecture. In any case, system operators need to re-open the closed lane(s) as soon as possible (especially if lane closure happens at or near the peak hours). Otherwise, certain demand management strategies may need to be applied to divert corridor traffic to alternative routes.

The evaluation results of the holiday scenarios show that SCATS can handle reasonably well the small to medium demand increases at one or several locations of the corridor due to increased holiday shopping traffic going to the downtown of White Plains. One should notice here that only one demand scenario is evaluated in this project based on real traffic data collected during one holiday. In reality, the corridor traffic may vary significantly during different holiday seasons (e.g., Christmas vs. Independence Day). This may lead to possibly different evaluation results. Therefore, more extensive evaluations of the holiday scenarios are recommended in future studies. It is expected however that SCATS can handle reasonably well holiday scenarios as long as the demand increases along the corridor is not too large.

It should also be pointed out that the simulation network developed in this project is fairly small, containing mainly the main road (Tarrytown Rd) and the seven intersections where SCATS are deployed and a few stop-sign-controlled intersections. Due to the limited scope of the simulation network, certain strategies, such as providing traveler information to divert traffic to alternative routes, cannot be evaluated using the current simulation model. Also, the true effects of some of the scenarios studied in this project may not be completely revealed in this small-size network. Therefore, it is recommended that future studies can focus on building a larger-size simulation network, ideally to include the nearly freeways and more arterial streets, and evaluating different scenarios and more corridor strategies using this large-size simulation network.

In summary, the developed simulation-based decision making tool provides a useful platform to evaluate various traffic scenarios that do not need to be implemented in real world. Based on the capabilities of existing simulation packages, such evaluations can be done via multiple criteria including congestion (travel times, delays, queue lengths), fuel consumption, and emissions. The decision-making tool thus provides a comprehensive assessment framework for the strategy scenarios and may be used for "what-if" types of analyses for the corridor. Such analyses can help identify the most promising corridor strategy scenarios (at the same time remove the least promising strategy scenarios) that can then be tested/evaluated in real world. This enables more informed decisions by the decision-makers about resource allocations and the selection of the best corridor improvement strategies.

9. CONCLUSIONS

A micro-simulation based decision making tool was developed in this project on the effectiveness and resilience of the recently deployed adaptive signal control system at the Tarrytown Road. This project can be generally divided into two phases: model development/calibration and scenario evaluation.

In the first phase, a micro-simulation model was built in Paramics which can reflect the traffic conditions at the selected corridor. This project presented the process of data collection and analyses, calibration of capacity, OD estimation and fine-tuning, and model calibration/validation. The model was calibrated in a streamlined procedure which tuned the model parameters in an iterative process so that the observations in simulation can match with the field measurements. Efforts regarding field data collection and performance measures were also summarized, which played an important role in terms of OD estimation and model validation. Reasonably accurate calibration results were obtained for the developed models.

In the second phase, some specific traffic scenarios (including corridor demand surge due to nearby freeway accidents or closure, corridor lane closure due to accidents or construction, demand variation due to holiday shopping, etc.) were developed via close collaboration with the City of White Plains. These scenarios were simulated to assess the resilience of the current traffic adaptive control system. It is important to develop these scenarios since one needs to understand how the current traffic system would react to such special traffic conditions, in terms of congestion, fuel consumption, and emissions. By doing this, recommendations were provided to help operate the system in a more efficient manner.

It was found via the study that the recently deployed adaptive signal control system along the corridor (i.e., SCATS) is capable of adjusting the signal parameters based on the real traffic states, which provides more efficiency to the traffic system. However, since the study corridor is currently heavily traveled and has large peak hour traffic (near capacity), a dramatic demand increase (e.g., 50% demand increase on the mainline) or traffic incidents (e.g., lane closure) may result in heavy congestion and dramatic increases of fuel consumption and emissions. To deal with this, reasonable signal control (e.g., running the half-cycle strategy) and coordination strategies should be applied. Appropriate demand management strategies, such as providing traveler information and guidance so that travelers can be directed to alternative routes, is also recommended for the corridor when corridor demand increases very significantly.

The procedures presented for developing the simulation-based decision-making tool should be generally applied to other corridor-related studies, although proper modifications should be expected when dealing with specific features of a corridor (e.g., if transit operations is important for a corridor, transit related simulation components should be integrated into the tool). Also the actual corridor scenarios that need to be evaluated may vary from corridor to corridor. However, the development of the scenarios usually requires a close collaboration with the local agencies (who manages the corridor) so that the to-be-evaluated scenarios are useful to their operations and management regarding the corridor.

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APPENDIX 1: SCATS INPUT FILES

Lane information input file:

#LaneInformation

#ID	NODEname		DECname		LANE	SA	PHASE	SPACETIME	OFFSETPLAN
1	8	29	1	1	1	5	1		
2	8	29	2	1	1	5	1		
3	8	29	3	1	1	5	1		
4	8	25	1	1	2	5	1		
5	8	25	2	1	2	5	1		
6	33	9	1	1	1	5	1		
7	33	9	2	1	1	5	1		
8	33	7	1	1	2	5	1		
9	39	10	1	1	1	5	1		
10	59	4	1	1	1	5	1		
11	59	4	2	1	1	5	1		
12	59	5	1	1	1	5	1		
13	59	6	1	1	2	5	1		
14	59	6	2	1	2	5	1		
15	59	6	3	1	2	5	1		
16	59	6	4	1	2	5	1		
17	59	6	5	1	2	5	1		
18	59	6	6	2	2	5	1		
19	59	2	1	1	3	5	1		
20	59	2	2	1	3	5	1		
21	59	2	3	1	3	5	1		
22	59	2	4	1	3	5	1		
23	59	6	1	1	3	5	1		
24	59	6	2	1	3	5	1		
25	59	6	3	1	3	5	1		
26	59	6	4	1	3	5	1		
27	59	6	5	1	3	5	1		
28	59	2	1	1	4	5	1		
29	59	2	2	1	4	5	1		
30	59	2	3	1	4	5	1		
31	59	2	4	1	4	5	1		
32	59	2	5	2	4	5	1		
33	9	11	1	1	2	5	1		
34	9	11	2	1	2	5	1		
35	9	11	3	1	2	5	1		
36	9	11	4	2	2	5	1		
37	9	11	1	1	3	5	1		
38	9	11	2	1	3	5	1		
39	9	11	3	1	3	5	1		
40	9	12	1	1	3	5	1		
41	9	12	2	1	3	5	1		
42	9	12	3	1	3	5	1		

……

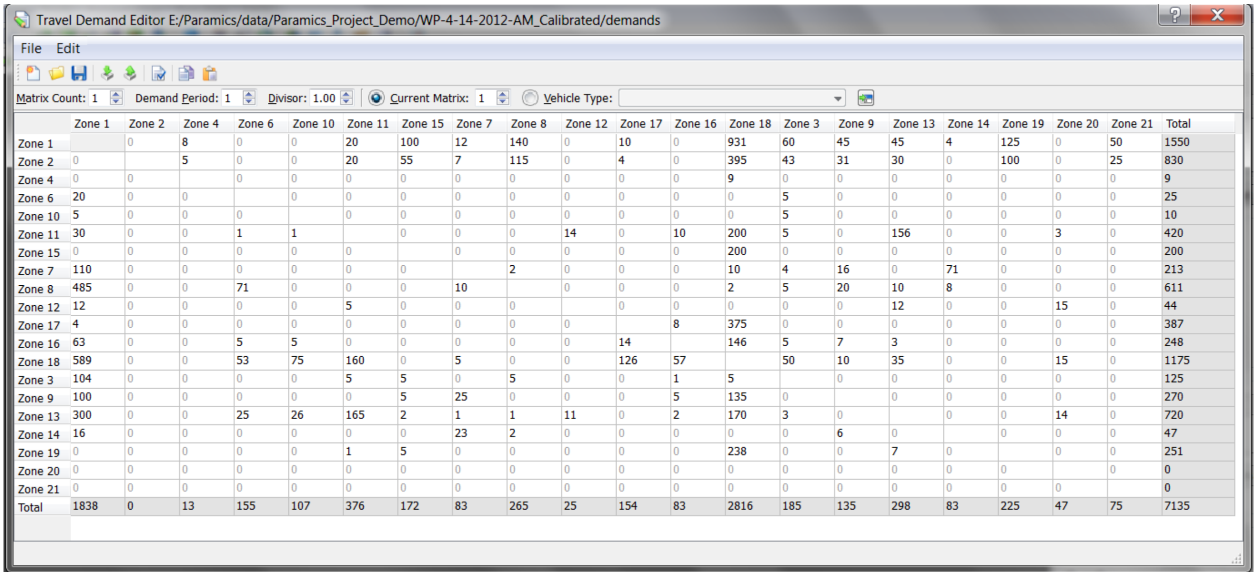
Junction information input file:

```
#Junction Name.        SplitPlanNo.   PhaseNo.
#SplitPlanID   Phase1 Phase2 Phase3 Phase4.....
^
8       1       2
1       42      58
^
9       1       4
1       16      19      50      15
^
33      1       2
1       59      41
^
39      1       2
1       50      50
^
59      1       4
1       26      15      44      15
^
24      1       5
1       12      26      15      34      13
^
47      1       5
1       14      20      18      20      28
```

Network information input file:

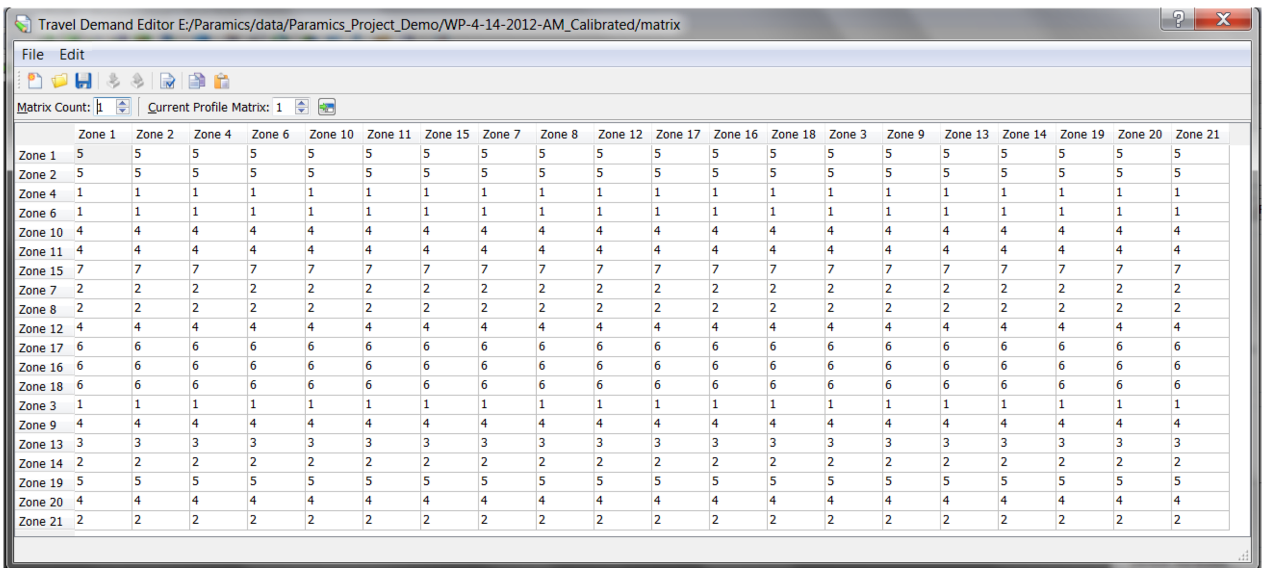
```
#DS_SZ1%    DS_SZ2%    Lowest_Cycletime    Middle_Cycletime    Highest_Cycletime
90    110    60    100    125
```

APPENDIX 2: OD ESTIMATION RESULTS



	Zone 1	Zone 2	Zone 4	Zone 6	Zone 10	Zone 11	Zone 15	Zone 7	Zone 8	Zone 12	Zone 17	Zone 16	Zone 18	Zone 3	Zone 9	Zone 13	Zone 14	Zone 19	Zone 20	Zone 21	Total
Zone 1		0	8	0	0	20	100	12	140	0	10	0	931	60	45	45	4	125	0	50	1550
Zone 2	0		5	0	0	20	55	7	115	0	4	0	395	43	31	30	0	100	0	25	830
Zone 4	0	0		0	0	0	0	0	0	0	0	0	9	0	0	0	0	0	0	0	9
Zone 6	20	0	0		0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	25
Zone 10	5	0	0	0		0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	10
Zone 11	30	0	0	1	1		0	0	0	14	0	10	200	5	0	156	0	0	3	0	420
Zone 15	0	0	0	0	0	0		0	0	0	0	0	200	0	0	0	0	0	0	0	200
Zone 7	110	0	0	0	0	0	0		2	0	0	0	10	4	16	0	71	0	0	0	213
Zone 8	485	0	0	71	0	0	0	10		0	0	0	2	5	20	10	8	0	0	0	611
Zone 12	12	0	0	0	0	5	0	0	0		0	0	0	0	0	12	0	0	15	0	44
Zone 17	4	0	0	0	0	0	0	0	0	0		8	375	0	0	0	0	0	0	0	387
Zone 16	63	0	0	5	5	0	0	0	0	0	14		146	5	7	3	0	0	0	0	248
Zone 18	589	0	0	53	75	160	0	5	0	0	126	57		50	10	35	0	0	15	0	1175
Zone 3	104	0	0	0	0	5	5	0	5	0	0	1	5		0	0	0	0	0	0	125
Zone 9	100	0	0	0	0	0	5	25	0	0	0	5	135	0		0	0	0	0	0	270
Zone 13	300	0	0	25	26	165	2	1	1	11	0	2	170	3	0		0	0	14	0	720
Zone 14	16	0	0	0	0	0	0	23	2	0	0	0	0	0	6	0		0	0	0	47
Zone 19	0	0	0	0	0	1	5	0	0	0	0	0	238	0	0	7	0		0	0	251
Zone 20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0
Zone 21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0
Total	1838	0	13	155	107	376	172	83	265	25	154	83	2816	185	135	298	83	225	47	75	7135

Figure 18: Static OD matrix of before scenario (AM peak)

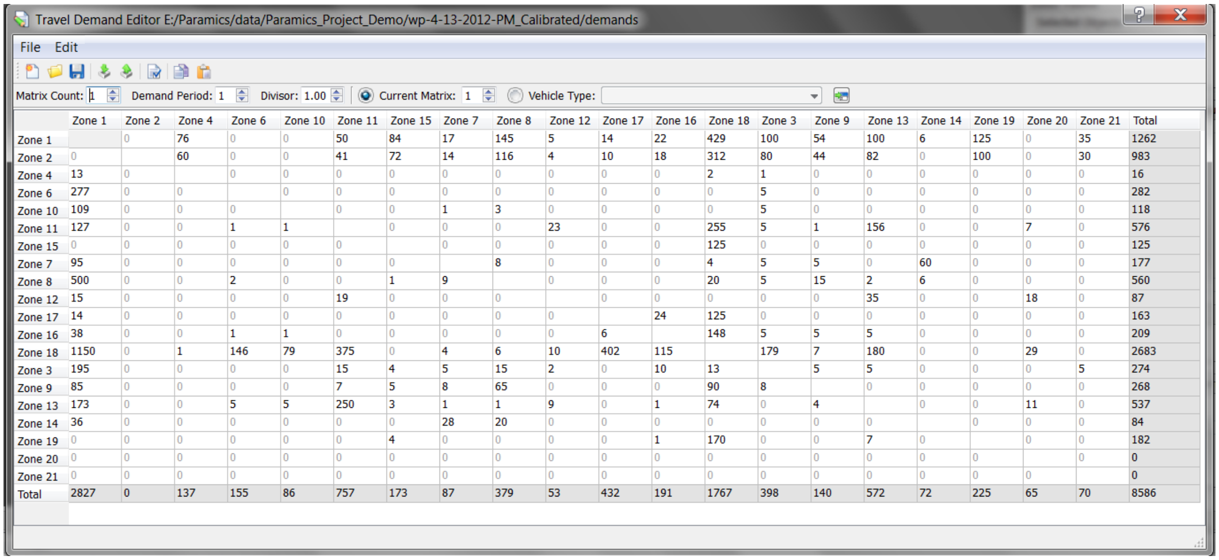


	Zone 1	Zone 2	Zone 4	Zone 6	Zone 10	Zone 11	Zone 15	Zone 7	Zone 8	Zone 12	Zone 17	Zone 16	Zone 18	Zone 3	Zone 9	Zone 13	Zone 14	Zone 19	Zone 20	Zone 21
Zone 1	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Zone 2	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Zone 4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Zone 6	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Zone 10	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Zone 11	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Zone 15	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
Zone 7	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Zone 8	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Zone 12	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Zone 17	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
Zone 16	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
Zone 18	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
Zone 3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Zone 9	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Zone 13	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Zone 14	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Zone 19	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Zone 20	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Zone 21	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2

Figure 19: Profile matrix of before scenario (AM peak)

Table 35: Dynamic OD profile of before scenario (AM peak)

	Interval 1	Interval 2	Interval 3	Interval 4	Total
Profile 1	19.6	21.7	28.3	30.4	100
Profile 2	27.9	26.6	24.6	20.9	100
Profile 3	17.3	31.3	25.3	26.1	100
Profile 4	24.3	27.5	25.5	22.7	100
Profile 5	27.6	22.8	22.4	27.2	100
Profile 6	23.8	25.6	28.9	21.7	100
Profile 7	25.1	26.8	24.9	23.2	100



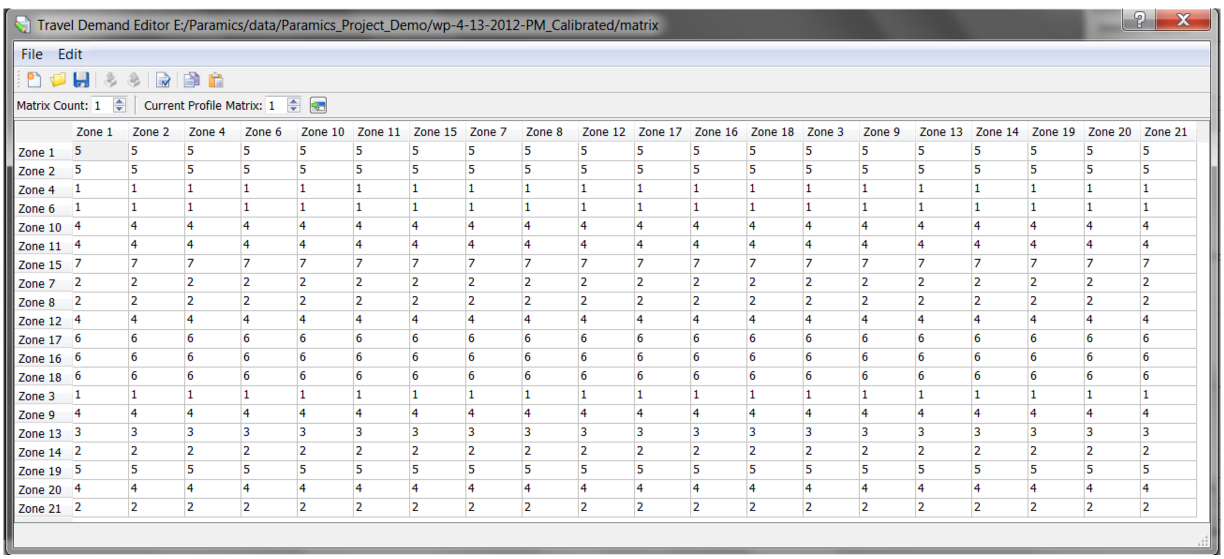
Travel Demand Editor E:/Paramics/data/Paramics_Project_Demo/wp-4-13-2012-PM_Calibrated/demands

File Edit

Matrix Count: 1 Demand Period: 1 Divisor: 1.00 Current Matrix: 1 Vehicle Type:

	Zone 1	Zone 2	Zone 4	Zone 6	Zone 10	Zone 11	Zone 15	Zone 7	Zone 8	Zone 12	Zone 17	Zone 16	Zone 18	Zone 3	Zone 9	Zone 13	Zone 14	Zone 19	Zone 20	Zone 21	Total
Zone 1		0	76	0	0	50	84	17	145	5	14	22	429	100	54	100	6	125	0	35	1262
Zone 2	0		60	0	0	41	72	14	116	4	10	18	312	80	44	82	0	100	0	30	983
Zone 4	13	0		0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	16
Zone 6	277	0	0		0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	282
Zone 10	109	0	0	0		0	0	1	3	0	0	0	0	5	0	0	0	0	0	0	118
Zone 11	127	0	0	1	1		0	0	0	23	0	0	255	5	1	156	0	0	7	0	576
Zone 15	0	0	0	0	0	0		0	0	0	0	0	125	0	0	0	0	0	0	0	125
Zone 7	95	0	0	0	0	0	0		8	0	0	0	4	5	5	0	60	0	0	0	177
Zone 8	500	0	0	2	0	0	1	9		0	0	0	20	5	15	2	6	0	0	0	560
Zone 12	15	0	0	0	0	19	0	0	0		0	0	0	0	0	35	0	0	18	0	87
Zone 17	14	0	0	0	0	0	0	0	0	0		24	125	0	0	0	0	0	0	0	163
Zone 16	38	0	0	1	1	0	0	0	0	0	6		148	5	5	5	0	0	0	0	209
Zone 18	1150	0	1	146	79	375	0	4	6	10	402	115		179	7	180	0	0	29	0	2683
Zone 3	195	0	0	0	0	15	4	5	15	2	0	10	13		5	5	0	0	0	5	274
Zone 9	85	0	0	0	0	7	5	8	65	0	0	0	90	8		0	0	0	0	0	268
Zone 13	173	0	0	5	5	250	3	1	1	9	0	1	74	0	4		0	0	11	0	537
Zone 14	36	0	0	0	0	0	0	28	20	0	0	0	0	0	0	0		0	0	0	84
Zone 19	0	0	0	0	0	0	4	0	0	0	0	1	170	0	0	7	0		0	0	182
Zone 20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0
Zone 21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0
Total	2827	0	137	155	86	757	173	87	379	53	432	191	1767	398	140	572	72	225	65	70	8586

Figure 20: Static OD matrix of before scenario (PM peak)



Travel Demand Editor E:/Paramics/data/Paramics_Project_Demo/wp-4-13-2012-PM_Calibrated/matrix

File Edit

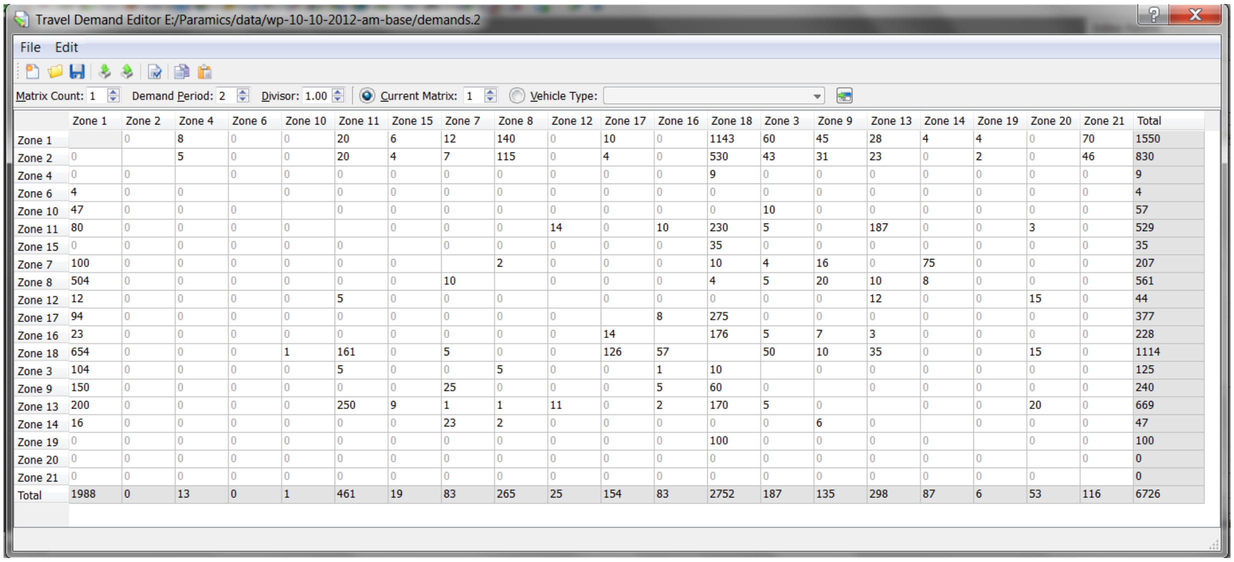
Matrix Count: 1 Current Profile Matrix: 1

	Zone 1	Zone 2	Zone 4	Zone 6	Zone 10	Zone 11	Zone 15	Zone 7	Zone 8	Zone 12	Zone 17	Zone 16	Zone 18	Zone 3	Zone 9	Zone 13	Zone 14	Zone 19	Zone 20	Zone 21
Zone 1	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Zone 2	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Zone 4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Zone 6	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Zone 10	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Zone 11	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Zone 15	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
Zone 7	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Zone 8	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Zone 12	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Zone 17	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
Zone 16	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
Zone 18	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
Zone 3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Zone 9	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Zone 13	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Zone 14	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Zone 19	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Zone 20	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Zone 21	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2

Figure 21: Profile matrix of before scenario (PM peak)

Table 36: Dynamic OD profile of before scenario (PM peak)

	Interval 1	Interval 2	Interval 3	Interval 4	Total
Profile 1	25.7	22.9	29.7	21.7	100
Profile 2	25.5	27.4	24.5	22.6	100
Profile 3	28.8	21.2	27.5	22.5	100
Profile 4	26.3	25.0	25.3	23.4	100
Profile 5	23.9	25.8	25.2	25.1	100
Profile 6	26.8	26.8	24.4	22.0	100
Profile 7	26.8	24.3	25.1	23.8	100



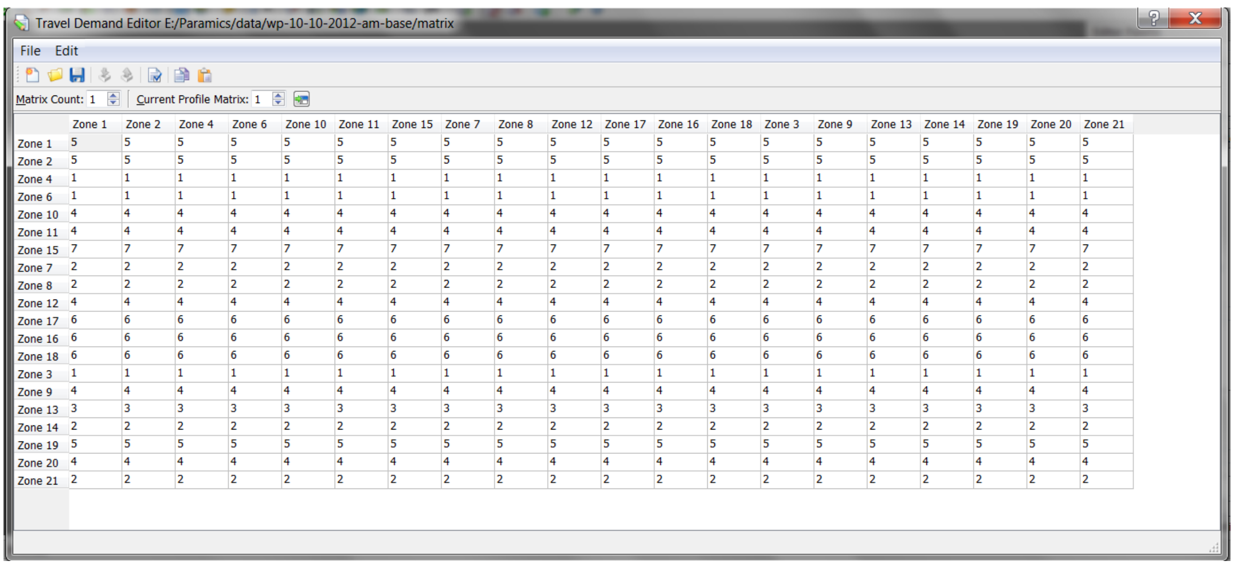
Travel Demand Editor E:/Paramics/data/wp-10-10-2012-am-base/demands.2

File Edit

Matrix Count: 1 Demand Period: 2 Divisor: 1.00 Current Matrix: 1 Vehicle Type:

	Zone 1	Zone 2	Zone 4	Zone 6	Zone 10	Zone 11	Zone 15	Zone 7	Zone 8	Zone 12	Zone 17	Zone 16	Zone 18	Zone 3	Zone 9	Zone 13	Zone 14	Zone 19	Zone 20	Zone 21	Total
Zone 1		0	8	0	0	20	6	12	140	0	10	0	1143	60	45	28	4	4	0	70	1550
Zone 2	0		5	0	0	20	4	7	115	0	4	0	530	43	31	23	0	2	0	46	830
Zone 4	0	0		0	0	0	0	0	0	0	0	0	9	0	0	0	0	0	0	0	9
Zone 6	4	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
Zone 10	47	0	0	0		0	0	0	0	0	0	0	0	10	0	0	0	0	0	0	57
Zone 11	80	0	0	0	0		0	0	0	14	0	10	230	5	0	187	0	0	3	0	529
Zone 15	0	0	0	0	0	0		0	0	0	0	0	35	0	0	0	0	0	0	0	35
Zone 7	100	0	0	0	0	0	0		2	0	0	0	10	4	16	0	75	0	0	0	207
Zone 8	504	0	0	0	0	0	0	10		0	0	0	4	5	20	10	8	0	0	0	561
Zone 12	12	0	0	0	0	5	0	0	0		0	0	0	0	0	12	0	0	15	0	44
Zone 17	94	0	0	0	0	0	0	0	0	0		8	275	0	0	0	0	0	0	0	377
Zone 16	23	0	0	0	0	0	0	0	0	0	14		176	5	7	3	0	0	0	0	228
Zone 18	654	0	0	0	1	161	0	5	0	0	126	57		50	10	35	0	0	15	0	1114
Zone 3	104	0	0	0	0	5	0	0	5	0	0	1	10		0	0	0	0	0	0	125
Zone 9	150	0	0	0	0	0	0	25	0	0	0	5	60	0		0	0	0	0	0	240
Zone 13	200	0	0	0	0	250	9	1	1	11	0	2	170	5	0		0	0	20	0	669
Zone 14	16	0	0	0	0	0	0	23	2	0	0	0	0	0	6	0		0	0	0	47
Zone 19	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0		0	0	100
Zone 20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0
Zone 21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0
Total	1988	0	13	0	1	461	19	83	265	25	154	83	2752	187	135	298	87	6	53	116	6726

Figure 22: Static OD matrix of after scenario (AM peak)



Travel Demand Editor E:/Paramics/data/wp-10-10-2012-am-base/matrix

File Edit

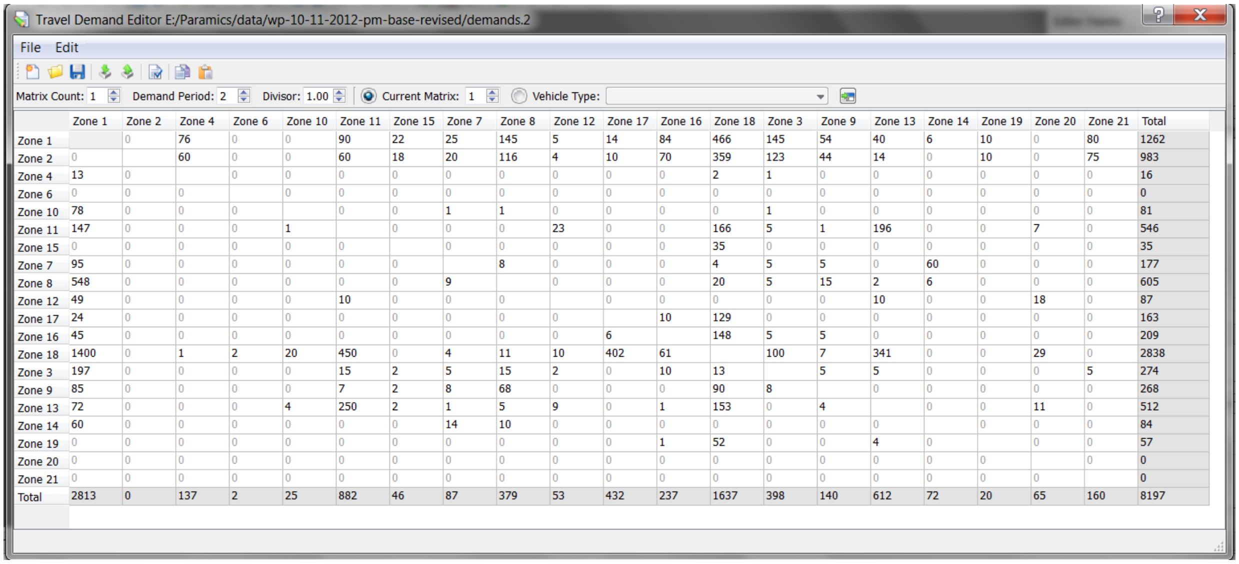
Matrix Count: 1 Current Profile Matrix: 1

	Zone 1	Zone 2	Zone 4	Zone 6	Zone 10	Zone 11	Zone 15	Zone 7	Zone 8	Zone 12	Zone 17	Zone 16	Zone 18	Zone 3	Zone 9	Zone 13	Zone 14	Zone 19	Zone 20	Zone 21
Zone 1	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Zone 2	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Zone 4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Zone 6	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Zone 10	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Zone 11	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Zone 15	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
Zone 7	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Zone 8	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Zone 12	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Zone 17	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
Zone 16	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
Zone 18	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
Zone 3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Zone 9	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Zone 13	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Zone 14	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Zone 19	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Zone 20	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Zone 21	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2

Figure 23: Profile matrix of after scenario (AM peak)

Table 37: Dynamic OD profile of after scenario (AM peak)

	Interval 1	Interval 2	Interval 3	Interval 4	Total
Profile 1	21.5	27.3	23.4	27.8	100
Profile 2	24.5	28.1	25.3	22.1	100
Profile 3	20.8	29.6	30.1	19.5	100
Profile 4	22.8	30.7	26.3	20.2	100
Profile 5	26.6	24.3	27.2	21.9	100
Profile 6	27.3	14.7	28.9	29.1	100
Profile 7	23.4	23.0	28.3	25.3	100

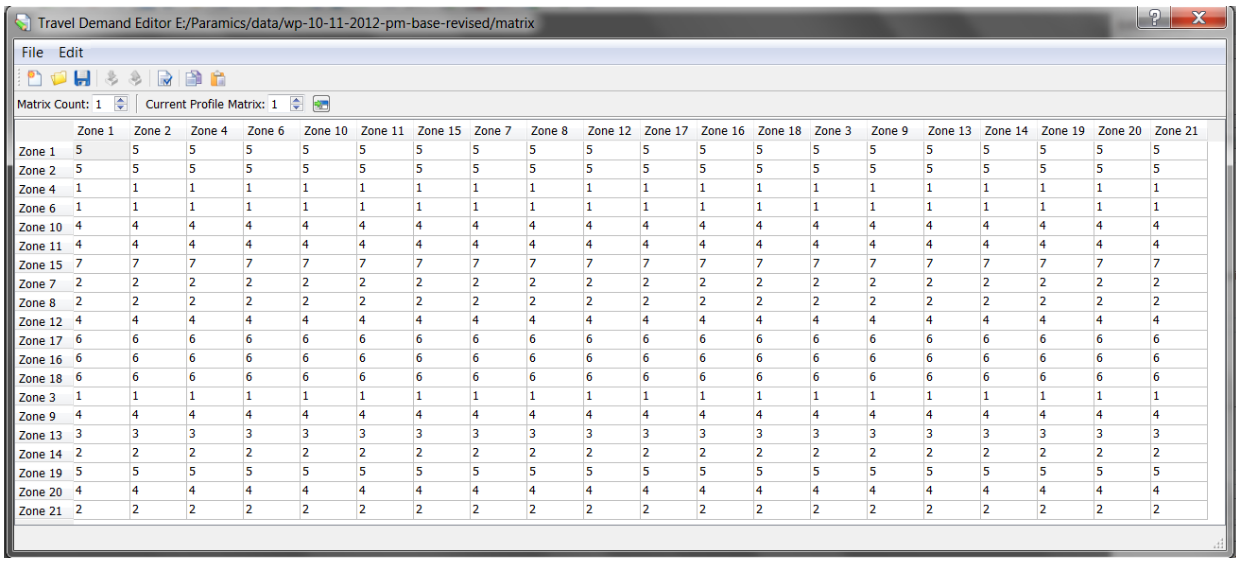

Travel Demand Editor E:/Paramics/data/wp-10-11-2012-pm-base-revised/demands.2

File Edit

Matrix Count: 1 Demand Period: 2 Divisor: 1.00 Current Matrix: 1 Vehicle Type:

	Zone 1	Zone 2	Zone 4	Zone 6	Zone 10	Zone 11	Zone 15	Zone 7	Zone 8	Zone 12	Zone 17	Zone 16	Zone 18	Zone 3	Zone 9	Zone 13	Zone 14	Zone 19	Zone 20	Zone 21	Total
Zone 1		0	76	0	0	90	22	25	145	5	14	84	466	145	54	40	6	10	0	80	1262
Zone 2	0		60	0	0	60	18	20	116	4	10	70	359	123	44	14	0	10	0	75	983
Zone 4	13	0		0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	16
Zone 6	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Zone 10	78	0	0	0		0	0	1	1	0	0	0	0	1	0	0	0	0	0	0	81
Zone 11	147	0	0	0	1		0	0	0	23	0	0	166	5	1	196	0	0	7	0	546
Zone 15	0	0	0	0	0	0		0	0	0	0	0	35	0	0	0	0	0	0	0	35
Zone 7	95	0	0	0	0	0	0		8	0	0	0	4	5	5	0	60	0	0	0	177
Zone 8	548	0	0	0	0	0	0	9		0	0	0	20	5	15	2	6	0	0	0	605
Zone 12	49	0	0	0	0	10	0	0	0		0	0	0	0	0	10	0	0	18	0	87
Zone 17	24	0	0	0	0	0	0	0	0	0		10	129	0	0	0	0	0	0	0	163
Zone 16	45	0	0	0	0	0	0	0	0	0	6		148	5	5	0	0	0	0	0	209
Zone 18	1400	0	1	2	20	450	0	4	11	10	402	61		100	7	341	0	0	29	0	2838
Zone 3	197	0	0	0	0	15	2	5	15	2	0	10	13		5	5	0	0	0	5	274
Zone 9	85	0	0	0	0	7	2	8	68	0	0	0	90	8		0	0	0	0	0	268
Zone 13	72	0	0	0	4	250	2	1	5	9	0	1	153	0	4		0	0	11	0	512
Zone 14	60	0	0	0	0	0	0	14	10	0	0	0	0	0	0	0		0	0	0	84
Zone 19	0	0	0	0	0	0	0	0	0	0	0	1	52	0	0	4	0		0	0	57
Zone 20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0
Zone 21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0
Total	2813	0	137	2	25	882	46	87	379	53	432	237	1637	398	140	612	72	20	65	160	8197

Figure 24: Static OD matrix of after scenario (PM peak)


Travel Demand Editor E:/Paramics/data/wp-10-11-2012-pm-base-revised/matrix

File Edit

Matrix Count: 1 Current Profile Matrix: 1

	Zone 1	Zone 2	Zone 4	Zone 6	Zone 10	Zone 11	Zone 15	Zone 7	Zone 8	Zone 12	Zone 17	Zone 16	Zone 18	Zone 3	Zone 9	Zone 13	Zone 14	Zone 19	Zone 20	Zone 21
Zone 1	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Zone 2	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Zone 4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Zone 6	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Zone 10	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Zone 11	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Zone 15	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
Zone 7	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Zone 8	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Zone 12	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Zone 17	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
Zone 16	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
Zone 18	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
Zone 3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Zone 9	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Zone 13	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Zone 14	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Zone 19	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Zone 20	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Zone 21	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2

Figure 25: Profile matrix of after scenario (PM peak)

Table 38: Dynamic OD profile of after scenario (PM peak)

	Interval 1	Interval 2	Interval 3	Interval 4	Total
Profile 1	19.6	21.7	28.3	30.4	100
Profile 2	27.9	26.6	24.6	20.9	100
Profile 3	17.3	31.3	25.3	26.1	100
Profile 4	24.3	27.5	25.5	22.7	100
Profile 5	27.6	22.8	22.4	27.2	100
Profile 6	23.8	25.6	28.9	21.7	100
Profile 7	25.1	26.8	24.9	23.2	100

APPENDIX 3: PARAMICS MONITOR INPUT FILES

Pollution file:

```
Define Pollutants
1 "Carbon Monoxide"
2 "Carbon Dioxide"
3 "Total Hydrocarbons"
4 "Oxides of Nitrogen"
5 "Fuel Consumption"
6 "Particulate Matter"

##############################################################################
##   Non Catalyst Petrol --- Small                              ##
##############################################################################
Pollution Vehicle Type 1

## Carbon Monoxide
Pollutant Type 1
Axis Count 2
Axis 1 Type speed_accln Unit mmpsss Size 36
values
-40 -38 -36 -34 -32 -30 -28 -26 -24 -22 -20 -18 -16 -14 -12 -10 -8 -6 -4 -2 0
  2   4   6   8  10  12  14  16  18  20  22  24  26  28  30

Axis 2 Type speed Unit kph Size 27
values
  0   3   9  15  21  27  33  39  45  51  57  63  69  75  81  87  93  99  105
111 117 123 129 135 141 147 153

data
101.2793	101.1054	100.8731	100.4078	99.76514	98.94076
	97.92672	96.71034	95.27413	93.59824	91.67142	89.53223
	87.27701	85.05211	83.08788	81.6797	80.25901	79.15412
	78.83874	86.2444	98.64617	114.1327	132.0215	150.8874
	163.1709	171.9371	179.9602	187.5635	195.5029	204.0655
	212.4275	219.9922	226.3793	231.2925	233.8201	235.7932

101.4533	101.2796	101.0481	100.5847	99.94619	99.12945
	98.12781	96.92916	95.5137	93.8535	91.91074	89.65209
	87.24463	84.84891	82.5484	80.97079	80.35681	79.23988
	79.27528	87.3524	96.64453	111.8957	132.2777	150.3714
	161.622	173.4283	180.977	186.2942	194.9333	204.378
	213.2622	221.1685	227.8628	233.0289	235.6917	237.7727
……
```

Pollution vehicle type (pv_type) file:

vehicle type 1 pollution vehicle type 1
vehicle type 2 pollution vehicle type 2
vehicle type 3 pollution vehicle type 3
vehicle type 4 pollution vehicle type 4
vehicle type 5 pollution vehicle type 5
vehicle type 6 pollution vehicle type 6
vehicle type 7 pollution vehicle type 7
vehicle type 8 pollution vehicle type 8
vehicle type 11 pollution vehicle type 7

Pollution-control file:

tool "Monitor Pollution Interface"
api coefficients 9
300 "Pollution Save Period"
1.0 "Pollution Scale (PS)"
0.0 " PS = 10^x " range -2 to 5 precision 2
true "Carbon Monoxide ug/m/s"
true "Carbon Dioxide"
true "Total Hydrocarbons"
true "Oxides of Nitrogen"
true "Fuel Consumption"
true "Particulate Matter"