Modeling Traffic Operations for Performance Measurement of the Port Mann / Highway 1 Project

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Abstract:

The Port Mann/Highway 1 (PMH1) corridor is the most congested route in the Province of British Columbia. Built in the early 1960s, when the population of Greater Vancouver was 800,000, it is one of the most important east-west corridors serving the region's 2.2 million people, and provides a critical link to the Asia Pacific Corridor through the ports of Vancouver, ergo the Gateway Program.

Most of the infrastructure along this corridor was built over 45 years ago. Moreover, many interchanges were designed using the design standards and traffic specifications of the 1960s and are not capable of carrying the current traffic demand and travel patterns. Therefore, the region is facing severe congestion, delay and mobility as well as accessibility problems. Hence, there is a crucial need for improvement to Highway 1 and construction of a new Port Mann Bridge. Furthermore, greenhouse gas emissions into the atmosphere are also severe threat to environment. Thus, the demand management strategy of expanding the HOV lane network on Highway1 for managing buses and commercial vehicles has been applied.

As part of the evaluation process for determining the successful design/build/finance/operate consortium, the Province of British Columbia (Authority) developed a series of custom tools to aid in data exchange, processing of model output, and presentation of performance measures. These tools, in combination with the core PARAMICS tool, form the traffic modeling suite. A series of six performance measures, capturing both system wide and individual network components, have been identified. This paper describes how PARAMICS software was used to confirm that the PMH1 Design Concept would maximize throughput and minimize travel time as well as approach delay while meeting all specified target values for performance indices. Implementing the Design Concept will not only increase mobility but also decrease congestion and delay on network. This will permit the Gateway Program achieve one of its goals - to reduce congestion-related idling, which contributes to reduced regional air quality.

Key Words: Gateway Program, Traffic Modeling, PARAMICS, Air Quality

1.0 INTRODUCTION

Today the Port Mann/Highway 1 (PMH1) corridor serves Greater Vancouver's 2.2 million population and is one of the most congested routes in the province of British Columbia. Consequently, the region faces severe congestion, delay, mobility and also experiences accessibility problems. In addition, the PMH1 corridor represents a critical link in the supply chain of the Asia Pacific Gateway and Corridor as it connects Metro Vancouver's ports with the rest of the Canada. Since the cost of congestion delay in this region has reached approximately 1.2 billion annually in 1999 dollars (1), there is a crucial need for improvements to Highway 1 including the construction of a new Port Mann Bridge. Congestion related idling of vehicles cause green house gas (GHG) emissions and carbon footprints in the atmosphere. Greenhouse gas emissions and carbon footprints do not dissipate quickly like other pollutants such as ozone and air pollutants; they remain in the atmosphere for many years and cause environmental problems such as rapid changes in ocean circulation and melting of polar icecaps because of higher temperatures (4).

The Gateway Program was established by the Province of British Columbia (Authority) in 2003 in response to the impact of growing regional congestion, and to improve the movement of people, goods and transit throughout Metro Vancouver with efficient transportation choices and better connections. One of the main objectives of the Gateway Program is to reduce congestion-related idling, which contributes to reduced regional air quality as well as GHG emissions. Gateway road and bridge improvements such as the PMH1 Project are part of a balanced approach to addressing the transportation needs of a growing region, and complement other regional road and transit improvements already planned or underway, including the Canada Line, the Evergreen Line, and additional transit facilities. These proposed improvements will help to create a comprehensive, effective transportation network that supports improved movement of people and goods, facilitates economic growth, increases transportation choice and provides better connections to designated population growth areas.

The PMH1 Project includes widening of Highway 1, a new 10-lane Port Mann Bridge, upgrading interchanges and improving access and safety along Highway 1 from McGill interchange in Vancouver to 216th Street in Langley, a distance of approximately 37 kilometres. The project includes congestion reduction measures such as High Occupancy Vehicles (HOV) lanes, transit and commercial vehicle priority access and a bridge toll which will pay for the project and manage traffic demand over time. With these improvements, transit service will be provided across the Port Mann Bridge for the first time in 20 years. As well, the new Port Mann Bridge will accommodate potential future light rail transit. Therefore, use of transit and ridesharing strategies such as transit signal priority and HOV lanes are expected to significantly reduce GHG emissions.

The Design Concept for the project is based on the predicted population and economic growth and associated transportation demands through to year 2031. These characteristics were modelled using PARAMICS V 5.2 for weekday morning and evening peak periods for the year 2031. The model results are used to assess network performance based on Authority-specified thresholds. Performance measurement indices include total network travel time, number of vehicles completing their journey, point to point travel time, main line performance, ramp performance as well as intersection performance. The intent of the Design Concept is to maximize throughput and minimize delay and travel time. Therefore, construction of a new Port Mann Bridge with specific HOV lanes on eastbound and westbound of Highway 1, upgrading of interchanges as well as tolling plan on bridge should reduce carbon footprint and GHG emissions because congestion is reduced along the 37km long corridor.

Figure 1 shows the project limits for the PMH1 Project and its connectivity to the Metro Vancouver region. Important interchanges include Willingdon Avenue, Kensington Avenue, Brunette Ave, Gaglardi Way, Cape Horn, 152nd Street, and 160th Street, 176th Street, 192nd Street, 200th Street and 216th Street.

The remainder of this paper addresses the following:

- Section 2 – Selected Microsimulation Software explains the features of the PARAMICS V5.2 microsimulation software used to model the proposed road network and anticipated traffic demand
- Section 3 - Model Calibration And Testing describes the procedure for calibrating the model as well as the criteria specified by the Authority to test the results
- Section 4 - Conclusions summarizes the conclusions about the microsimulation exercise of the PMH1 project

2.0 SELECTED MICROSIMULATION SOFTWARE

Simulation is the representation of all or some parts of the real world using computer models moving at equal time steps or on the next event in the whole system (5). Macrosimulation such as HCM-based models are deterministic and provide only one answer for every question and analyze intersection and particular sections of highway in isolation. On the other hand, microsimulation models incorporate randomness and provide detailed analysis. Therefore, when predicted demand exceeds capacity and the analyst wants to observe an individual vehicle's behaviour within the system then microsimulation approach is typically selected. Moreover, when queues on one section of network spills back and interferes with other sections of the network then microsimulation models are the best choice for accurate performance analysis. Nonetheless, the selection of software depends upon the user's needs (6).

The Authority developed a series of custom tools to aid in data exchange, processing of model output, and presentation of performance measures. These tools, in combination with the core PARAMICS V5.2 tool, form the traffic modeling suite. While the PMH1 model has been calibrated for the year 2031, the road network's capacity is unknown. Therefore stochastic modeling such as microsimulation has been applied to assess the model's performance because it models individual movements of vehicles on the facility network at time steps such as second by second as a function of time and space. Moreover, microsimulation depends on physical and kinematic characteristics of vehicles such as length, width, speed and maximum acceleration rate, etc. On the other hand, deterministic models capture movements of groups of vehicles on specified time intervals at given section of network and they are unable to assess performance for long durations and for complicated networks (2) (6) (7).

2.1 Features of PARAMICS used for PMH1 Project

Three of the five modules (Modeller, Processor, Analyzer, Viewer, Designer) that comprise the PARAMICS suite were used for this project and they are described below.

2.1.1 Modeller

"Modeller" is one of the modules of PARAMICS. It visualizes the network and traffic demand through graphical user interface. Basic input parameters are geographic and travel data such as road network data and origin-destination travel demand matrices. General road network data consist of geometric layouts, lane markings, turning movements, junction descriptions, etc. Network building is also performed by Modeller. Every intersection has specific node number and its details are stored in node data, while road geometry, lane specification, and distance between two nodes are found in link data. Connections between two nodes are called links. Travel demand data consists of different zones such as distinct geographical areas separated by demographic and socio-economic boundaries (canals, rivers, residential or commercial areas, etc). Zones within study areas (freeways or highways) are called internal, while those outside the study area are called external (3). In the PMH1 model, travel demand is represented by origin-destination demand matrices for both morning and afternoon peak periods. Moreover, the PMH1 model demand profile includes 15 minute time slices for fractional loading so that each 5-hour peak period demand is unaltered. Furthermore, the demand profile was not supposed to be altered for different vehicle types (i.e. high occupancy vehicles, single occupancy vehicles, light and heavy trucks). The simulation peak periods for both the AM and PM periods are 05:30 – 10:30 and 14:30 – 19:30, while the peak hours are 07:30 – 08:30 and 16:30 – 17:30, respectively. Modeller not only simulates lane changing, gap acceptance and car following behaviour for each vehicle, which are fundamental concepts of microsimulation but also provides a visual perspective of these concepts.

2.1.2 Processor

'Processor' is a very helpful tool for running simulation in batch mode because the processing and results collecting speeds have been increased tremendously without visualization of model network. Processor was used to simulate traffic in batch mode.

2.1.3 Analyzer

'Analyzer' is used to read the simulation results from Modeller and Processor for analysis and comparison purposes.

3.0 MODEL CALIBRATION AND TESTING

As indicated earlier, the model has been calibrated for the year 2031 by the Authority.

3.1 Model Input Parameters

The following are parameters specified for the project network:

- Configuration (see **Table 1**)

- Vehicle Characteristics
  - Length
  - Width
  - Height
  - Weight
  - Top Speed (km/h)
  - Acceleration (m/s^2)
  - Deceleration (m/s^2)

  Four types of vehicles (i.e. HOV, SOV, light truck, and heavy truck) are used in the PMH1 model. The physical and kinematic characteristics of each type of vehicle were provided by the Authority.

- Behaviour Characteristics
  - Default driver aggression and awareness is normal

- Link Categories
  There are 65 unique link categories
  - Type (Highway major, Urban major, and Urban minor)
  - Cost Factor (Default value for Urban major = 0.8, Highway major = 0.8, and urban minor = 1.2)
  - Headway Factor (1.0 for all links except Highway major = 0.8)

- Network Coding Conventions
  - Link Characteristics such as # of lane, posted speed limit, etc.
  - Freeway Merges
  - Lane choices
  - Freeway Diverges
  - Signposting
  - Intersections
  - Traffic Control

- Core Model Plug-Ins (PARAMICS V5.2.2)
  - Loop Aggregations
  - Decision Groups (Where vehicles have route choice governed by users)

- Other Model Plug-Ins (Azalient software)
  - Lane Choice
  - LOS
  - Trail Maker

    - Validator

- Network Demand Elements
    - OD Matrices
    - Profiles
    - Simulation Period

Figure 2 illustrates the model network between McGill interchange in Vancouver and 216th Street in Langley.

Figures 3 through **10** demonstrate the laning configuration and peak period simulated traffic at a number of locations along the network. Model network represents how traffic is anticipated to behave in 2031.

3.2 Testing Criteria

A set of performance measures, capturing both system wide and individual network components have been prescribed by the Authority. These include:

- System Metrics
    - Number of vehicles completing their journey
    - Total network travel time
    - Origin – destination or point-to-point (P2P) travel times
- Component Metrics
    - Mainline performance (speeds)
    - Ramp performance (queues)
    - Intersection performance (delay/LOS)

The calculating and reporting of the system metrics were based on multiple simulation runs of 5 hours during the AM peak period and 5 hours during the PM peak period for at least 11 different seeds. For the total network travel time and number of vehicles metrics, the “lane choice” plug-in has been invoked while for the P2P travel time metric, the “lane choice” and “Validator” plug-ins has been invoked.

Throughput and Total Travel Time Criteria

System metric for throughput was deemed to have passed if the upper bound (U_A) of 95% confidence limit of vehicles completing their journey during each peak period > number of vehicles completing their journey at AM or PM specified by the Authority.

Similarly for travel time, the design was deemed to pass if the lower bound (L_T) of 95% confidence limit of total network travel time for each peak period < travel time for AM or PM specified by the Authority. Mathematical representations are as follows.

Number of Vehicles Completing their Journey

$A_i = B_i - C_i\,; \quad \forall_i = 1, N$

$A_i =$ *number of vehicles that arrived at their destination for each simulation* $i(A_i)$

$B_i =$ *Cummulative vehicles simulated during* 5 *hours for each simulation* $i(B_i)$ *for all simulations* $i = 1, N$

$C_i =$ *Current number of vehicles simulated during* 5 *hours of each simulation*

$$Sample\ Mean = \bar{X}_A = \frac{\sum_{i=1}^{N} A_i}{N}\,;\ S_A = \sqrt{\frac{\sum_{i=1}^{N}(A_i - \bar{X}_A)^2}{N-1}}$$

$SA =$ *Standard deviation*;

Upper Bound of 95% *Confidence Limit for number of vehicles completing their journey*

$$U_A = \bar{X}_A - t_{1-\alpha/2}; N-1\ \frac{S_A}{\sqrt{N}}$$

Network Travel Time

$$Network\ Travel\ Time = i\,(T_i)\ for\ all\ simulation\ i = 1, N$$

$$Sample\ Mean = \bar{XT} = \frac{\sum_{i=1}^{N} T_i}{N}\,;\ ST = \sqrt{\frac{\sum_{i=1}^{N}(T_i - \bar{XT})^2}{N-1}}$$

$ST =$ *Standard deviation*; *Total network Travel time* (Lt)

Lower Bound of 95% *Confidence Limit for total network travel time*

$$L_T = \bar{XT} - t_{1-\alpha/2}; N-1\ \frac{S_T}{\sqrt{N}}$$

Origin-Destination (OD) Travel Time Performance Criteria

The lower bound (L_{Rj}) of 95% confidence limits of the average OD travel time for each OD pair should be < specified travel time from the Authority. Mathematical point to point travel time is demonstrated below.

Origin-Destination Travel Time

$$\bar{R}_{ij} = \sum_{k=1}^{k_{ij}} R_{ijk} \quad \forall_i = 1, N; \ \forall_j = 1, N$$

$\bar{R}_{ij}$ = *Average OD travel time for all vehicles who have traveled between OD pair J in simulation i who completed their journey during the given peak hour.*

R_{ijk} = *OD travel time for vehicle k traveling between OD pair j in simulation i during peak hour*

K_{ij} = *number of vehicles traveling between OD pair j during simulation i and during peak hour, j = number of OD pair in analysis*

$$\bar{X}_{Rj} = \text{Sample Mean} = \frac{\sum_{i=1}^{N} \bar{R}_{ij}}{N} \quad \forall_j = 1, N \qquad S_{Rj} = \text{Standard deviation}$$

$$S_{Rj} = \sqrt{\frac{\sum_{i=1}^{N} (\bar{R}_{ij} - \bar{X}_{Rj})^2}{N-1}} \quad \forall_j = 1, j$$

L_{RJ} = *Lower bound of the 95% Confidence Limit of the average travel time of vehicles for all OD pair* $j = 1, J$

$$L_{Rj} = \bar{X}_T - t_{1-\propto/2}; N-1 \frac{S_{Rj}}{\sqrt{N}} \quad \forall_j = 1, j$$

Mainline and Ramp Performance Criteria

As for component matrices, main line performance for general purpose and HOV lanes were monitored by collecting speed and volume data from loop detectors. Detectors were spaced at 100m intervals from 1 km upstream to 1 km downstream of a ramp's bull nose. Microsimulation was performed for 3 seeds, specifically the 15th, 50th and 85th percentile runs as determined during the evaluation of the total network travel time.

The main line speed is acceptable if the average speed during the peak hour (V_{avg}) > threshold speed for the percentage of time specified by the Authority and $V_{min} \leq$ threshold speed for more than specified percentage of time. Similarly for HOV lanes, V_{avg} during peak hour $\geq$ threshold speed for at least specified percentage of time. The off ramp performance is acceptable if percentage of time in the peak hour with speed < 3% of threshold speed (30km/h) (6).

The mathematical procedure for calculating performance is as follows:

Mainline Performance

$$S_{it} = \frac{\sum_{g=1}^{G} S_{itg} V_{itg}}{\sum_{g=1}^{G} V_{itg}} \qquad \forall_i = 1, I \; ; \; t = 1, T$$

$S_{it} =$ *Volume Weighted Speed at detector i during time period t for given peak period*

$S_{itg} =$ *"Measured" speed at detector i in time t on lane g for given peak period*

$V_{itg} =$ *"measured" volume at detector i in time t on lane g for given peak period*

$G =$ *number of lanes along given interchange*; $I =$ *number of detector for given interchange*; $T =$ *number of time units (for peak hour and 5 minutes analysis* $T = 12$)

Similarly for off-ramp performance during peak hour, the simulated vehicle speeds of less than target speeds should not be detected for more than the specified percentage of time by the Authority.

Intersection Performance Criteria

In order to measure intersection performance, the model was simulated for 3 hours during each of the peak periods using 15th, 50th and 85th percentile seeds while invoking “lane choice” and “level of service” plug-ins. For intersection performance, the level of service is based upon the industry standard HCM delay. Because capacity is not explicitly known for the microsimulation model, volume-to-capacity ratio was not included. For signalized intersections, the delay should be less than 55 seconds per vehicle while for unsignalized intersections, it should less than 35 seconds per vehicle for acceptable level of service A to D (6).

4.0 CONCLUSIONS

The Port Mann/Highway 1 (PMH1) corridor is the most congested route in the Province of British Columbia. Built in the early 1960s, when the population of Greater Vancouver was 800,000, it is one of the most important east-west corridors serving the region’s 2.2 million people, and provides a critical link to the Asia Pacific Corridor through the ports of Vancouver, ergo the Gateway Program.

Most of the infrastructure along this corridor was built over 45 years ago. Moreover, many interchanges were designed using the design standards and traffic specifications of the 1960s and are not capable of carrying the current traffic demand and travel patterns. Therefore, the region is facing severe congestion, delay and mobility as well as accessibility problems. Hence, there is a crucial need for improvement to Highway 1 and construction of a new Port Mann Bridge. Furthermore, greenhouse gas emissions into the atmosphere are also severe threat to environment. Thus, the demand management strategy of expanding the HOV lane network on Highway1 for managing buses and commercial vehicles has been applied.

As part of the evaluation process for determining the successful design/build/finance/operate consortium, the Province of British Columbia (Authority) developed a series of custom tools to aid in data exchange, processing of model output, and presentation of performance measures. These tools, in combination with the core PARAMICS tool, form the traffic modeling suite. A series of six performance measures, capturing both system wide and individual network components, have been identified. This paper described how PARAMICS software was used to confirm that the PMH1 Design Concept would maximize throughput and minimize travel time as well as approach delay while meeting all specified target values for performance indices. Implementing the Design Concept will not only increase mobility but also decrease congestion and delay on network. Consequently, this project will permit the Gateway Program achieve one of its goals - to reduce congestion-related idling, which contributes to reduced regional air quality.

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TABLES

Table1 - Key Configuration Parameters

Parameter	Value
Base Parameters	
Units	metric
Orientation	RHD
Time Steps (per second)	2
Inter Time Step Pause (ms)	0
Demand Factor	100%
Core	
Queue Gap Distance (m)	10.0
Queuing Speed (km/h)	7.2
Weight (tonne)	3.0
Mean Target Headway (s)	1.0
Mean Driver Reaction Time (s)	0.7
Speed Memory	3
Minimum Gap (m)	2.0
Loop Length (m)	2.0
Amber Time (s)	3.0
Default Curve Speed Factor	1.0
Speed Drift Unit	5
Wrong Lane Diversion Time (s)	300
Assignment	
Feedback Period (min)	2.00
Feedback Smoothing	0.50
Feedback Decay Factor	0.995
Feedback Envelop Decay Factor	0.000
Generalized Cost Coefficients	
Time	0.50
Distance	0.50
Toll	0.00
Perturbation	Yes
Perturbation Algorithm	Percentage
Matrix Turning Level	None
Options	
Preserve Zone Release Order	Yes

FIGURES

Source:http://www.th.gov.bc.ca/gateway/photo_pages/photos.asp?caption=Port%20Mann%20/Hwy1%20Project%20Mapimg=pmh1/large/project_extents.jpg

Figure 1 - Study Area of Project

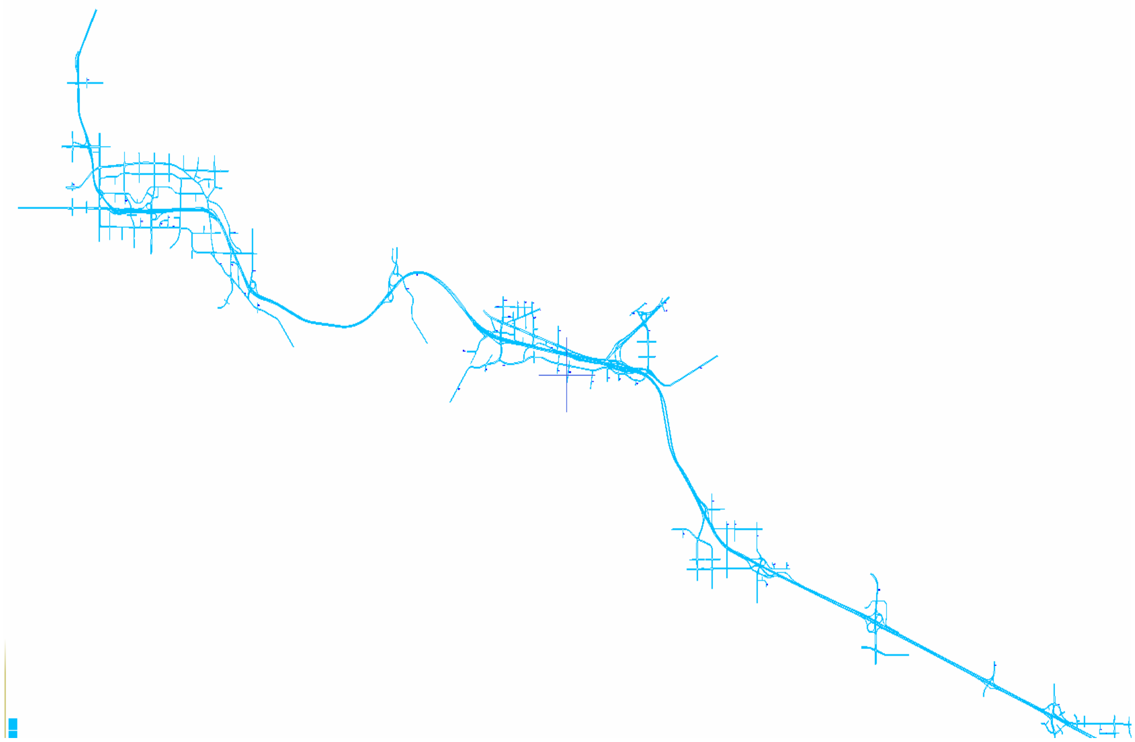

Figure 2 - PARAMICS Model Network

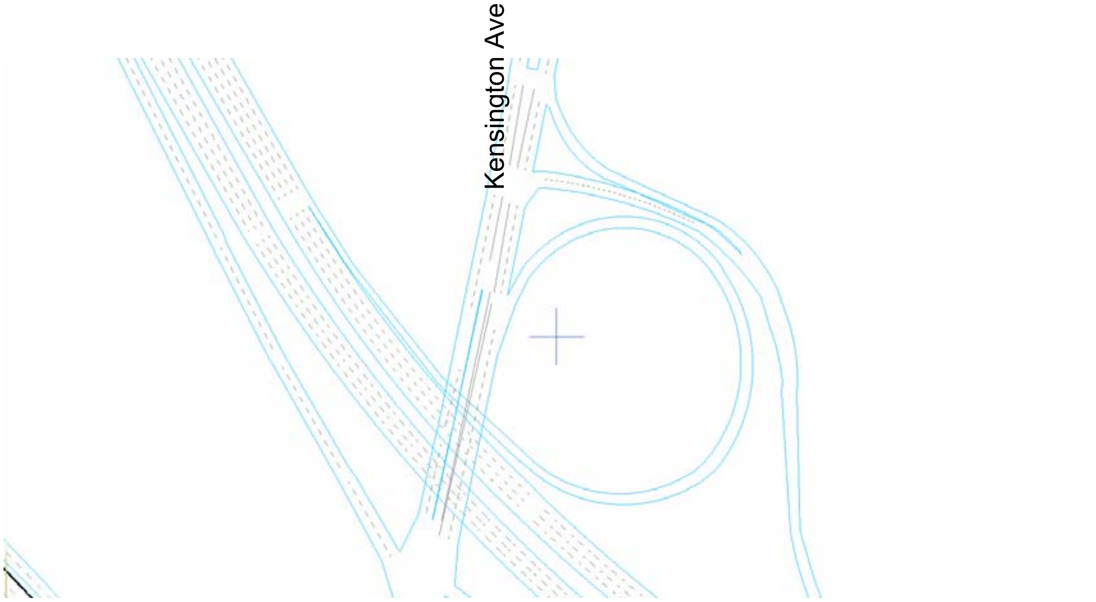

Figure 3 - Kensington Interchange Laning Configuration

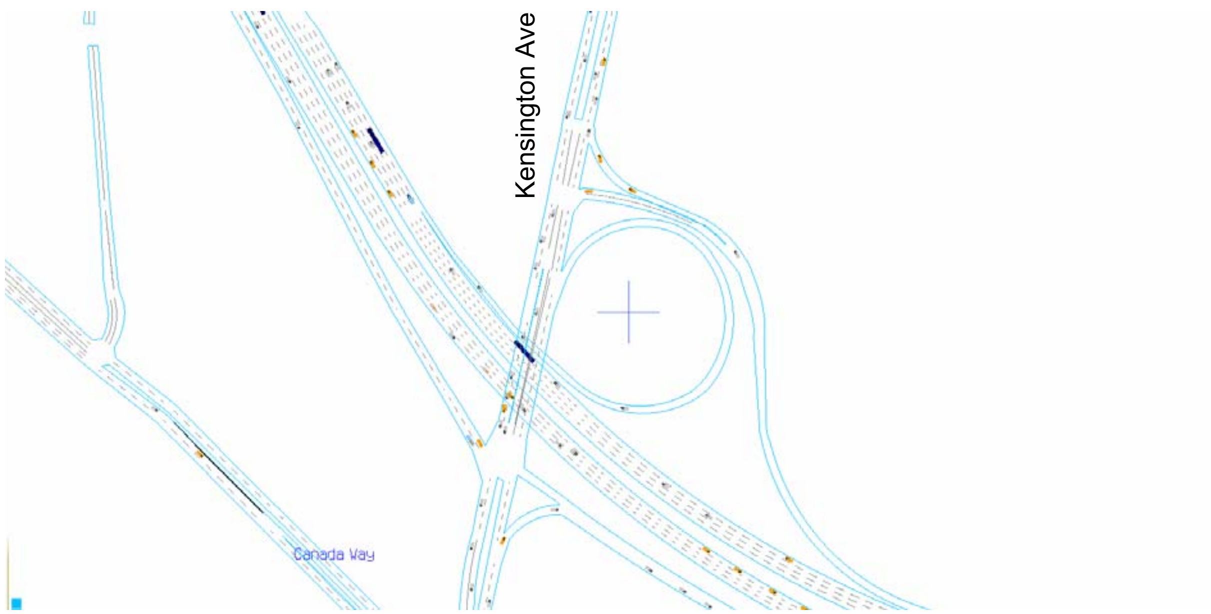

Figure 4 - Simulated Traffic at Kensington Interchange

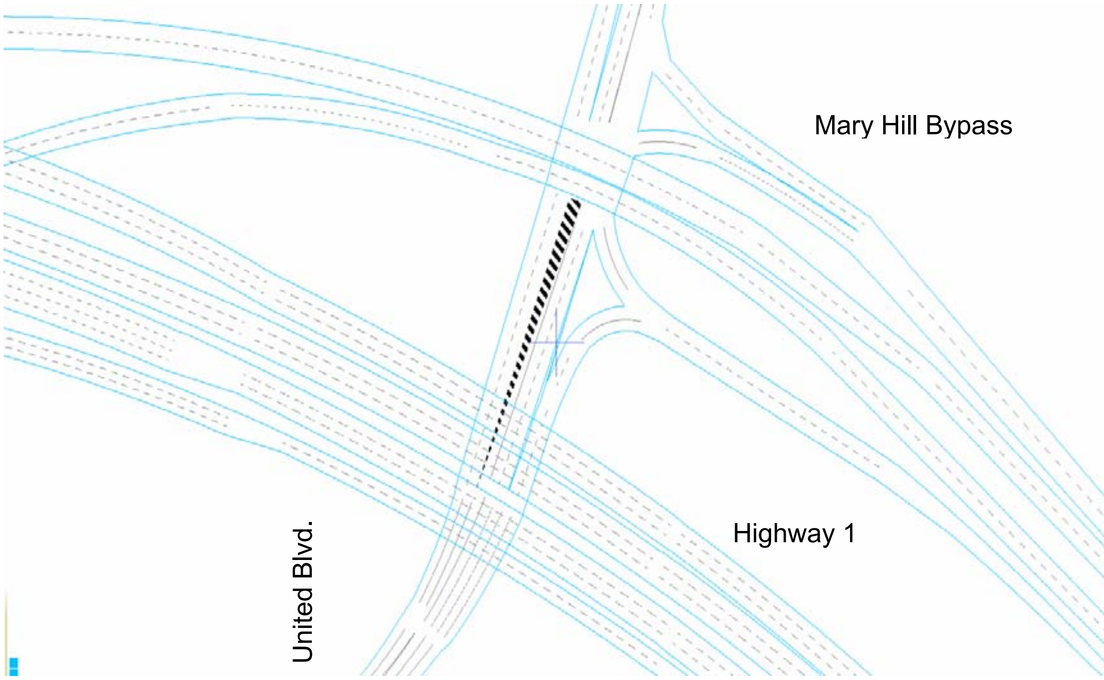

Figure 5 - Laning Configuration of United Blvd and Mary Hill Bypass

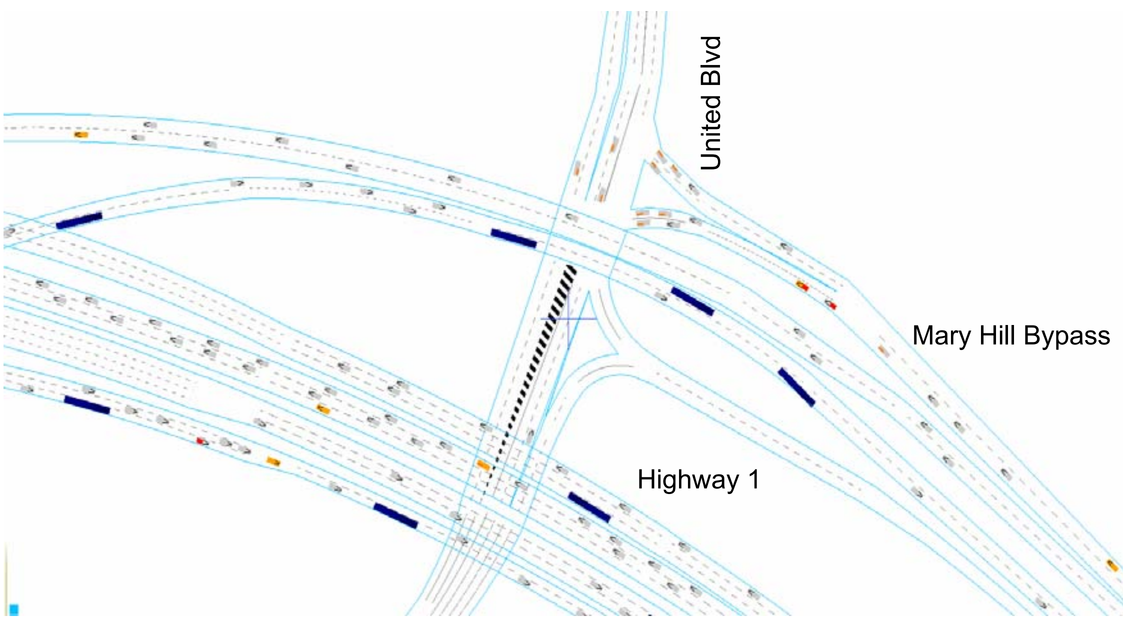

Figure 6 - Simulated Traffic on United Blvd and Mary Hill Bypass

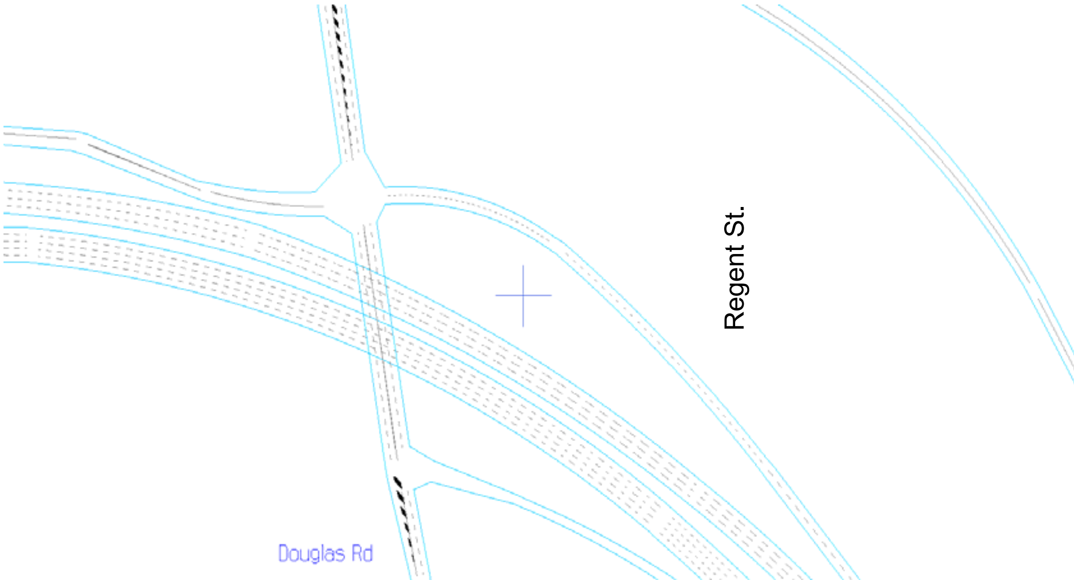

Figure 7 - Douglas Road and Regent Street Intersection North/ South

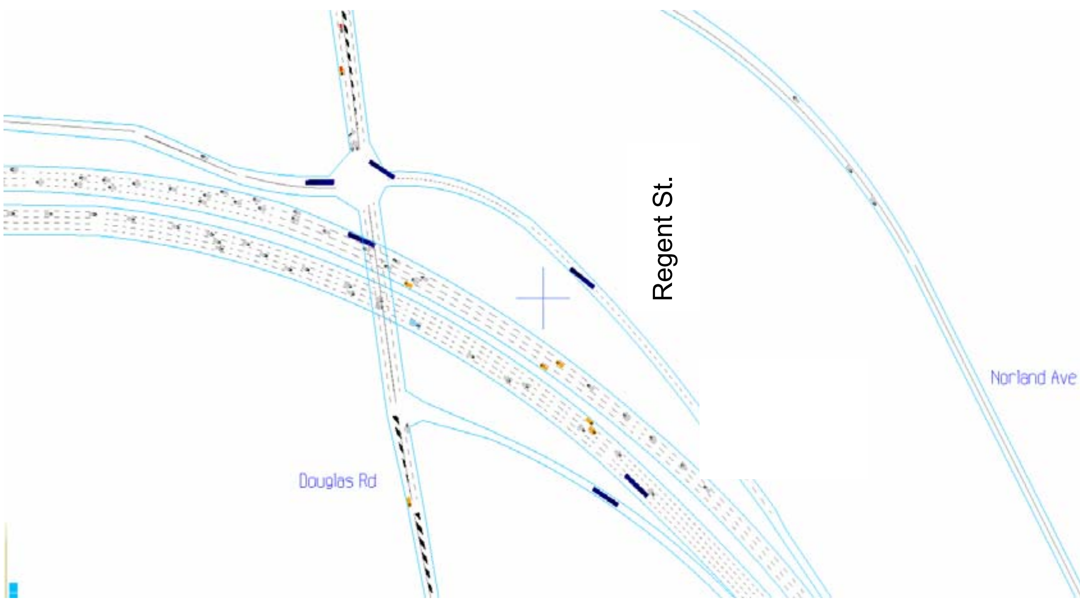

Figure 8 - Simulated Traffic on Douglas Road and Regent Street Intersection

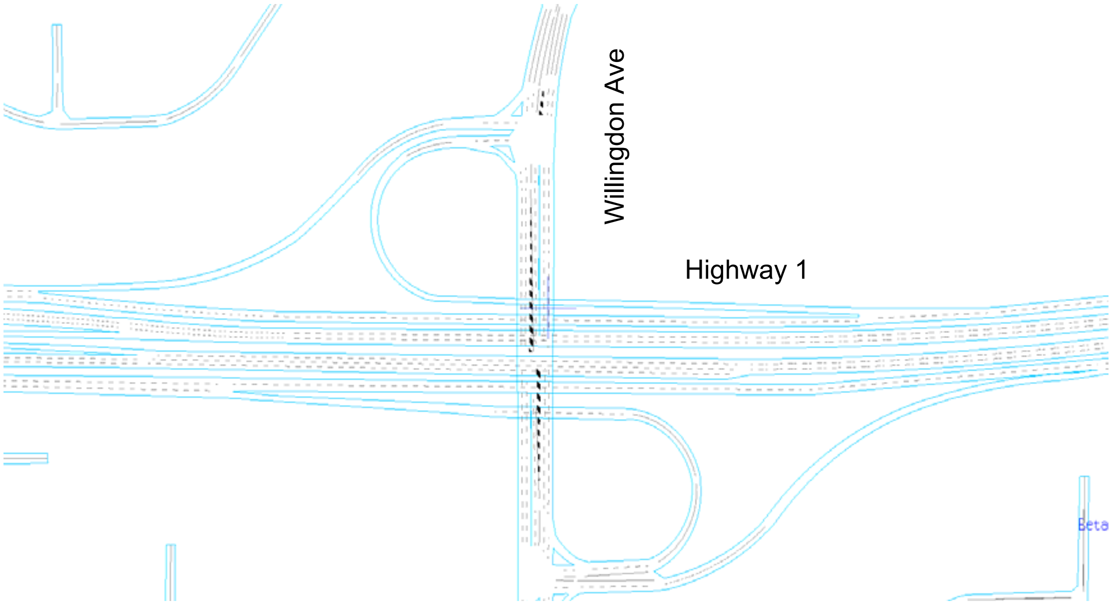

Figure 9 - Willingdon Interchange

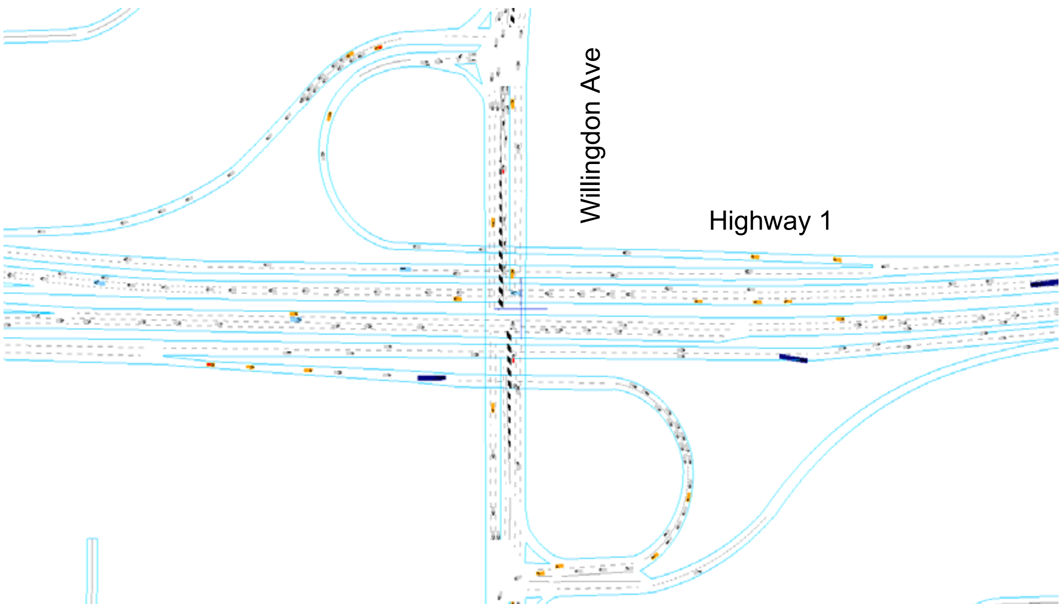

Figure 10 - Simulated Traffic at Willingdon Interchange