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INTRODUCTION

The Richmond Street North section of the City of London’s proposed Bus Rapid Transit (BRT) network represents some significant modification to the roadway network design and will also result in significant changes to traffic operations.

Implementation of the BRT, in parallel with the University Drive bridge closure to general traffic along with roadway improvements on Adelaide Street North (grade separation at the railroad crossing) and Western Road / Wharncliffe Road (widening down to Oxford Street) will result in significant changes to traffic patterns in the Richmond Street North neighbourhood.

As a result, a focused and detailed traffic analysis was undertaken for this area to supplement the system wide traffic analysis presented in Appendix E1: Traffic Analysis. This focused traffic modelling analysis has three main objectives:

1- Evaluate the impacts of the proposed University Drive bridge closure to general traffic and the roadway improvements on Adelaide Street North (grade separation at the railroad crossing) and Western Road / Wharncliffe Road (widening down to Oxford Street), without the BRT, on traffic flows in the Richmond Street North area;

2- Evaluate the impact of the BRT project on the road network. The project has potential for impacts on Richmond Street’s capacity that could affect route choice and the itineraries chosen by drivers that currently use the Richmond Street North corridor. The analysis aims to assess the amount of traffic diverted from Richmond Street North to parallel corridors and if there is significant diversion to adjacent local streets;

3- Evaluate the impact of the BRT project on the Richmond Street North corridor traffic operations using a micro-simulation model for evaluating delay and travel times for the range of different design scenarios;

4- Produce micro-simulation videos to present the different scenarios and their impacts on traffic conditions at public presentations (PIC5) to help visualize the results.

This technical memorandum presents the methodology of the model calibration process, the future scenario development and the modelling assumptions that were considered in this assessment. The principle results from the modelling are presented and analyzed to compare the different scenarios impacts and make a determination on which scenario to carry forward.
2 METHODOLOGY

This section presents the methodology used to develop the focused area model to achieve the objectives set out in Section 1. Two types of models are used to evaluate the impact of the different scenarios: a macroscopic model (static) and a microscopic model (dynamic). Together, those two models can assign trips on the road network in order to analyze the impact of the different BRT alternatives on the traffic conditions.

In the macroscopic model, traffic is considered as a flow. The assigned flow on a given roadway link is influenced by variables that influence the traffic flow. The variables that affect flow in the model are the capacity of the link and the mathematical relationship between the flow and the mean speed on the link. In such models, the delays are considered as a “user cost” and each traveller’s route choice is assigned to minimize their own travel time cost. This model type is useful to analyze the impacts of the different analyzed scenarios on the route choice and the traffic flow at a city scale.

In a microscopic model, vehicles are modeled as individual objects. Microscopic models need to consider many more variables, such as vehicles properties (size, acceleration, deceleration), car following behaviour (distance between cars, spacing at stops, etc.), lane-changing behaviour (visibility distance, gap between vehicles, etc.), etc. The model coding is more detailed because it is necessary to specify traffic control plans (traffic signal programs), signage, lane assignments, auxiliary turning lanes, etc. The calibration step is also longer because there are many variables that have impacts on the analysis results.

The Aimsun software was chosen to build the Richmond North model, based on several advantages of the software, notably the ability to do static and dynamic model in the same software.

2.1 CURRENT SCENARIO CALIBRATION

The calibration process is critical to ensure that the model reflects existing conditions as closely as possible, recognizing there are always variations in traffic on a daily basis. The following section describes the calibration process, the variables calibrated and the data used to validate the model. Key model assumptions area also presented.

2.1.1 ANALYSIS PERIOD AND DATA INPUT

The macroscopic static traffic assignment model considers the traffic demand in the afternoon peak period, between 3 pm – 6 pm. This analysis period was chosen as it generally represents the worst case scenario based on the traffic data analyzed for this project. It should be noted that the overall traffic analysis for the project (presented in Appendix E1: Traffic Analysis) considered both the AM and PM peak conditions.

2.1.2 STUDY AREA

The study areas for the Richmond North corridor analysis is defined by two zones reflecting the purpose of the two levels on modelling. Figure 1 presents the study areas.

ZONE OF ANALYSIS

This zone corresponds to the micro-simulation study area. It includes all of the Richmond Street North corridor between University Drive and Oxford Street, their parallel streets (St. George Street and Wellington Street) and a zone located to the south of Oxford Street to Central Avenue. The network and intersection coding of this zone required a detail level sufficient to support the microsimulation analysis.

INFLUENCE AREA

The influence area corresponds to the analysis zone applied in the macroscopic analysis. This zone included all of the major north-south corridors with potential to be affected by a variation of capacity in the microscopic analysis zone.
The zone of influence includes the road network between Fanshawe Park Road in the north, the Thames River to the south, Adelaide Street in the east, and Western Road in the west.

**Figure 1: Study Areas**
2.1.3 CALIBRATION PROCESS

The calibration process of the static and the dynamic models can be presented in 6 main steps.

Figure 2 : Calibration process

VDF = Volume Delay Function
V/C = Volume-to-Capacity
2.1.4 DATA USED

To develop and calibrate the static and dynamic Aimsun models in the study area, a large amount of data is required. This included traffic counts conducted specifically for this modelling exercise, other traffic counts, intersection plans and signal timing.

The following is a summary of the data used to build and calibrate the model:

- A subnetwork of the City-wide traffic model corresponding to the zone of influence. This subnetwork included the different links, nodes, centroids, and their characteristics (capacity, speed, etc.).
- A vehicular demand matrix corresponding to the subnetwork zone for the PM peak period.
- Synchro files that contain all the current traffic signal programming for the microscopic analysis zone.
- All the traffic counts for intersections by turning movement available within the influence zone (macroscopic zone), in 15 min intervals, by vehicles class. The traffic counts are provided by Spectrum Traffic who uses the Miovision technology to generate traffic counts from automated computer-based video analytic solution. The counts used at intersections inside the microscopic analysis zone are from September 2017, and those have been completed by other counts coming from an older counts campaign (March 2015) elsewhere in the macroscopic analysis zone.
- The geometric design plans of the different future scenarios analyzed for BRT along Richmond Street.
- The 2016 “Rapid Transit Integration Framework” report from Dillon, which contains all the local service transit modifications proposed with the arrival of BRT.
- The General Transit Feed Specifications (GTFS) (September 2017) from the London Transit Commission that contains all the data relative to the current public transit service routes, frequencies and stops.
- All the Open Street Maps data in the influence area. That data is used to make a first draft of the existing road network geometry.
- Site information from site visits supplement with Google Street-View, Google Maps and Google Earth, which was used to validate roadway geometry and intersection operations data.

2.1.5 CALIBRATION CRITERIA

Before starting the calibration process, it is essential to use a standardize set of criteria to ensure that the model is sufficiently-calibrated to achieve the objective of the study. In lieu of any specific local guidelines, the calibration criteria applied are the Transportation Model Development Guidelines,¹ for the model category “Small area/corridor”.

STATIC MODEL

The static assignment (macroscopic) model is used to assign the path of vehicle trips. The objective of this model is to establish realistic trip route assignments for the modeled vehicles, as close as possible to observed data. In order to recreate current conditions observed in London within the analysis area.

The static assignment model was based on the city-wide travel demand model² previously prepared by the City of London. This model has already been calibrated at a regional scale, and travel demand is adjusted at screen lines (predetermined boundaries). The objective of the calibration process was therefore not to duplicate the regional calibration on a screen-line basis, but rather to refine the static trip assignments for the microsimulation zone to ensure that the level of detail required for this analysis could be achieved. For this reason, only the traffic counts contained in the microsimulation zone were used to calibrate the model.


² VISUM Travel Demand Model
To measure the calibration of the model, 11 criteria were established. The following table presents the criteria and the level of accuracy used to determine if the model was properly calibrated.

### Table 1: Static calibration criteria

<table>
<thead>
<tr>
<th>NO.</th>
<th>CRITERIA</th>
<th>TARGET OF ACCEPTABILITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>GEH &lt; 10 on turning movements</td>
<td>&gt; 90% of traffic counts in the micro simulation area</td>
</tr>
<tr>
<td>2</td>
<td>GEH &lt; 7.5 on turning movements</td>
<td>&gt; 80% of traffic counts in the micro simulation area</td>
</tr>
<tr>
<td>3</td>
<td>GEH &lt; 5 on turning movements</td>
<td>&gt; 60% of traffic counts in the micro simulation area</td>
</tr>
<tr>
<td>4</td>
<td>Turning counts &gt; 400 vph within 20%</td>
<td>&gt; 90% of turn traffic counts &gt; 400 vph of the micro simulation area</td>
</tr>
<tr>
<td>5</td>
<td>Turning counts &gt; 400 vph within 10%</td>
<td>&gt; 75% of turn traffic counts &gt; 400 vph of the micro simulation area</td>
</tr>
<tr>
<td>6</td>
<td>Turning counts &lt; 400 vph within 100 vph</td>
<td>&gt; 90% of turn traffic counts &lt; 400 vph of the micro simulation area</td>
</tr>
<tr>
<td>7</td>
<td>Turning counts &lt; 400 vph within 50 vph</td>
<td>&gt; 75% of turn traffic counts &lt; 400 vph of the micro simulation area</td>
</tr>
<tr>
<td>8</td>
<td>R² value</td>
<td>&gt; 0.95</td>
</tr>
<tr>
<td>9</td>
<td>Line of best fit (y=ax+b)</td>
<td>0.95 &lt; a &lt; 1.05</td>
</tr>
<tr>
<td>10</td>
<td>Route choice logical</td>
<td>&gt; 95% of the path of the 100 biggest OD pairs are coherent.</td>
</tr>
</tbody>
</table>

GEH = a statistic that provides an empiric difference measure (details below)

VPH = vehicles per hour

The first three criteria are GEH statistic, which is an empiric difference measure generally used as a calibration criterion. GEH combines the absolute difference (in vehicles per hour) and the relative difference (in percentage) between observed and simulated traffic flow values. This measure is useful because it can weigh the importance of a high absolute difference in function of the size order of the traffic count.

The GEH formula is defined as:

$$GEH = \sqrt{\frac{2(M - O)^2}{M + O}}$$

Where:

- M is the modelled flow (vehicles per hour);
- O is the observed flow (vehicles per hour).

A GEH measurement of less than 5 is generally considered a good calibration on the observed data. GEH measurements greater than 5 and less than 10 are acceptable if they are limited in number, well-distributed spatially, have no significant impact on traffic conditions, and the vehicle routings remain consistent. GEHs greater than 10 require investigation to understand whether it is a model error or erroneous or aberrant data.
The calibration effort was focused on the highest observed values (generally representative of through movements on the arterial road network as Richmond Street and Oxford Street) and on the general fit of the model ($R^2$ and the “line of best fit” equation for graphed results). This limitation on the calibration had an impact on the results, and it is important to know that the calibration on each turning movement was not necessarily correct, but all critical movements, and the model in general was representative of observed traffic counts and traffic flows.

Criteria 4 and 5 contribute to validating the relative fit on the highest value of observed values. Criteria 6 and 7, conversely, ensure to limit the absolute difference on smallest observed values. Criteria 8 and 9 ensure a good general fit between observed and modelled flow. These criteria ensure that the modelled demand is within an acceptable range of the observed demand. Finally, Criteria 10 is a manual check of the principal Origin-Destination (OD) route choice assignments to ensure that the modeled path chosen is reasonable (e.g. no counter-intuitive paths, U-turns, etc.).

**DYNAMIC MODEL**

The microscopic model was used to simulate traffic flow, travel speeds and travel times. The objective of the calibration of the dynamic model was therefore to calibrate driver behaviour to reproduce, as closely as possible, the observed traffic flow rates, travel speeds, travel time, observed queue lengths, etc. Recognizing that the refinement of the travel demand and the adding of dynamic traffic assignment (DTA), affects the modeled traffic flow, and therefore those criteria were again validated in the dynamic model.

The scope of the dynamic modeling analysis was to compare traffic operations in the Richmond Street North corridor under each of the four BRT design concept scenarios. The overall London BRT study is currently in the feasibility/conceptual design phase, and the dynamic traffic model is intended to allow a comparison of the four BRT design concept scenarios in order to understand the differences between the, in terms of traffic operations, provide a comparative assessment of the design alternatives.

To measure the calibration of the dynamic model, several calibration criteria were established. Table 2 presents the calibration criteria used to validate the dynamic model.

**Table 2: Dynamic Calibration Criteria**

<table>
<thead>
<tr>
<th>NO.</th>
<th>CRITERIA</th>
<th>TARGET OF ACCEPTABILITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>GEH &lt; 10 on turning movements</td>
<td>&gt; 90% of traffic counts in the micro simulation area</td>
</tr>
<tr>
<td>2</td>
<td>GEH &lt; 7.5 on turning movements</td>
<td>&gt; 80% of traffic counts in the micro simulation area</td>
</tr>
<tr>
<td>3</td>
<td>GEH &lt; 5 on turning movements</td>
<td>&gt; 60% of traffic counts in the micro simulation area</td>
</tr>
<tr>
<td>4</td>
<td>Turning counts &gt; 400 vph within 20%</td>
<td>&gt; 90% of turn traffic counts &gt; 400 vph of the micro simulation area</td>
</tr>
<tr>
<td>5</td>
<td>Turning counts &gt; 400 vph within 10%</td>
<td>&gt; 75% of turn traffic counts &gt; 400 vph of the micro simulation area</td>
</tr>
<tr>
<td>6</td>
<td>Turning counts &lt; 400 vph within 100 vph</td>
<td>&gt; 90% of turn traffic counts &lt; 400 vph of the micro simulation area</td>
</tr>
<tr>
<td>7</td>
<td>Turning counts &lt; 400 vph within 50 vph</td>
<td>&gt; 75% of turn traffic counts &lt; 400 vph of the micro simulation area</td>
</tr>
<tr>
<td>8</td>
<td>$R^2$ value</td>
<td>&gt; 0.95</td>
</tr>
<tr>
<td>9</td>
<td>Line of best fit ($y=ax+b$)</td>
<td>0.95 &lt; a &lt; 1.05</td>
</tr>
</tbody>
</table>
Route choice logical

> 95% of the path of the 100 biggest OD pairs are coherent.

Travel time of the origins-destination included in the gap
usually observed at the same time according to Google Maps
Both directions on Richmond St. Between Oxford St. and University St.

Virtual queues of more than 10 vehicles at the end of the simulation period
None

Lost vehicles
< 1% of the vehicles

Realistic queues
All network

Realistic bottleneck
All network

GEH = a statistic that provides an empiric difference measure (details above)

VPH = vehicles per hour

Several of these criteria that are used are similar to those used in the static (macroscopic) model, and a more detailed description is provided previously. In addition, criterion 11 is useful to ensure that the observed and simulated travel times are within an acceptable range. The objective is to keep the mean modelled travel time value between the min and max observed travel time values. Criteria 12 to 15 were used to validate that the modelled trips on the road network are realistic and representative of the observed behaviour of road users.

2.1.6 MODEL NETWORK AND INTERSECTION CODING

Before starting the calibration process, model verification is required to correct any network and intersection coding errors. The base coding of the model came from available Open Street Maps and the city-wide transportation model data provided by the City. The data was subsequently refined to ensure correct coding. The following key aspects of the model were verified:

For the influence area:
— Topology of the road network
— Route types
— Lane types
— Posted speeds
— Number of lanes
For the analysis zone :
— Lane markings
— Intersection controls (Stop, yield, red turn on red)
— Timing plan for traffic signals
— Auxiliary turn lanes
— Bus routings, frequencies and schedule

2.1.7 STATIC ASSIGNMENTCALIBRATION

For this study, the static (macroscopic) model was first calibrated, and this model was used to generate the route choice assignment for vehicles. This model must be calibrated in order to ensure accurate representation of current traffic flows and route choices.
The static assignment was done only once for the entire peak period, from 3pm to 6pm. In the static model, the assigned volumes were equally distributed and the routes remained the same for the entire three-hour analysis period. An adjustment was made after to account for temporal variation (distribution of traffic throughout the three-hour peak) in demand in the dynamic (microscopic) model.

The basic assumption used in the model is that the relative traffic distribution and assignment remains the same for the three-hour analysis period. The assignment itself follows the principle of the equilibrium of travel times of users, where each user will seek to minimize their own travel time by choosing a route that minimizes the cost to the user, and recognizing the increase to the cost of other users by its presence. This cost was determined by using Volume-Delay Function (VDF) curves, which graph the relationship between the number of vehicles passing through a section, and the speed that can be reached by these vehicles. The process is iterative and searches, from one iteration to the next, to reassign the vehicles in the model on alternative routes until the minimum times in the network are achieved.

For the static traffic assignment, a base theoretical road network capacity of 800 passenger car units (PCU)/ln/h was used for arterial roads, and 700 PCU/ln/h for collector and local streets. Capacities were adjusted as necessary in the calibration process to reproduce observed flow rates. Two VDF (Volume delay functions) were applied, one for local streets and one for arterial roads.

Once the verification of model inputs was completed, the calibration phase of the static model can begin. The objective of the static model calibration is to ensure that the actual data (counts) at the various points of the network, and the routes applied to road users in the model between the different points of origin and destination are correctly reflected. At this stage of the process, the base matrix was not adjusted for counts, so it is normal to obtain significant differences between observed and simulated flow rates. Thus, for this first stage of calibration, the focus was more on the assignment of routes and the flow proportion between parallel corridors than on the flows values. The objective was to ensure that the modeled routes were consistent with reality and that the V/C (volume-to-capacity) analysis accurately reflected observed constraints in the traffic network.

To reproduce the constraints on routes, the two key variables were adjusted:

— Capacity: Link capacity was first set by default, depending on the route type. For all the links where the assigned flow was largely below the capacity of the link, the impact of the accuracy of the link capacity was limited when calculating delays using the VDFs. However, when the modeled flow was very close to the theoretical capacity of the link, the link capacity was adjusted more precisely to better represent the actual capacity based on traffic counts.

— Addition of user-defined costs: Additional costs have been defined for turning movements as a TPF (turn penalty function). Constant costs were defined to penalize all the left turns equally and all the right turns equally to improve the general fit on turning movement (lower cost on modeled turning movements would result in an increase in the turn volumes, and conversely, higher costs applied to turns decrease the turn volume).

Figure 3 shows the affected traffic flow rates as a function of the flow rates observed following the preliminary calibration of the static assignment, before adjustment of the original Origin-Destination matrix coming from the VISUM model. The R² (coefficient of determination) of the relationship is 0.93, which is a more than acceptable result.
2.1.8 MATRIX DEMAND ADJUSTMENT

The basic matrix used the hourly PM peak hour matrix from the City-wide model.

The first step of the matrix adjustment was to adjust the hourly matrix during the peak period duration (three-hour). The matrix was multiplied by a factor given until that the rate of regression between observed values over the 3-hour analysis period and assigned volume was close to one. In the present case, the 3-hour period’s matrix was calculated to be to 2.5x the peak hour volume.

The matrix was adjusted based on the traffic flow observed (traffic counts). The demand was then adjusted over the entire analysis period because the adjustment algorithm used considers the counts to be representative of the demand.

The adjustment algorithm then balanced the vehicles on the network to attempt to achieve equilibrium using the matrix from the previous step. The R² test was then used to calculate the difference between the assigned and observed flow rates to confirm if the new trip assignment reflects the observed counts. A new correction of the matrix, as described above, is then undertaken, followed by a new static assignment. This process is repeated until the specified maximum number of iterations is reached. In this case, 20 iterations were sufficient to reasonably reflect the actual observed traffic counts.

Figure 4 shows the flow rates affected as a function of the flows observed following the adjustment of the original matrix. The adjustment of the matrix resulted in an increased R² of the regression from 0.93 to 0.97, and the differences between observed and affected values decreased. However, there remained some turn movements with discrepancies between the modeled results and those observed. Those turn volumes were checked manually, and it was concluded that the discrepancies were caused by geometric configuration limitations. Those turn volumes cannot be explained by the actual centroid configuration in the model, and refinement of the model would be necessary to ensure the alignment of the modeled and observed traffic counts. However, the turning movements in question do not affect traffic capacity on the Richmond Street North corridor, and were therefore not considered to have a significant impact on the result of the comparative analysis of BRT design concepts.
2.1.9 STATIC ASSIGNMENT VALIDATION

The validation of the static assignment makes it possible to verify that the model respects the established calibration criteria.

Table 3 below presents the results of the calibration exercise and verification of compliance with the acceptance criteria.

Table 3: Static Calibration Criteria – Validation

<table>
<thead>
<tr>
<th>NO.</th>
<th>CRITERIA</th>
<th>TARGET OF ACCEPTABILITY</th>
<th>CALIBRATION RESULT</th>
<th>ACCEPTABILITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>GEH &lt; 10 on turning movements</td>
<td>&gt; 90% of traffic counts in the micro simulation area</td>
<td>91.7% of traffic counts in the micro simulation area (561/612)</td>
<td>Yes</td>
</tr>
<tr>
<td>2</td>
<td>GEH &lt; 7.5 on turning movements</td>
<td>&gt; 80% of traffic counts in the micro simulation area</td>
<td>81.9 % of traffic counts in the micro simulation area (501/612)</td>
<td>Yes</td>
</tr>
<tr>
<td>3</td>
<td>GEH &lt; 5 on turning movements</td>
<td>&gt; 60% of traffic counts in the micro simulation area</td>
<td>60.1 % of traffic counts in the micro simulation area (368/612)</td>
<td>Yes</td>
</tr>
<tr>
<td>4</td>
<td>Turning counts &gt; 400 vph within 20%</td>
<td>&gt; 90% of turn traffic counts &gt; 400 vph of the micro simulation area</td>
<td>95.3% of turn traffic counts &gt; 400 vph of the micro simulation area (61/64)</td>
<td>Yes</td>
</tr>
<tr>
<td>5</td>
<td>Turning counts &gt; 400 vph within 10%</td>
<td>&gt; 75% of turn traffic counts &gt; 400 vph of the micro simulation area</td>
<td>82.8% of turn traffic counts &gt; 400 vph of the micro simulation area (53/64)</td>
<td>Yes</td>
</tr>
</tbody>
</table>
2.1.10 DYNAMIC MODEL CALIBRATION

The dynamic (microscopic) model calibration aims to reproduce the behaviour of drivers in order to be able to reproduce the observed speeds, travel times, traffic flows, and queue lengths observed on the road network. For the dynamic model, a portion of the demand is assigned using Dynamic Traffic Assignment (DTA) to add route choice randomly. After, to calibrate the dynamic model, two types of adjustments are made the adjustment of the demand and the adjustment of the local parameters.

DYNAMIC TRAFFIC ASSIGNMENT (DTA):

Microscopic model trip assignments are based on the macroscopic static traffic assignment (VISUM demand adjusted locally on traffic counts) at 90% and 10% of DTA, and is added randomly in the route choice process.

DEMAND ADJUSTMENT

The first step of the dynamic calibration process is to split the three-hour demand matrix into smaller 15-minute period matrices. The microsimulation is a dynamic process, and the demand changes during the simulation period. An Origin-Destination departure adjustment algorithm was used to split the three-hour adjusted matrix into 12 15-minute matrices based on traffic volume counts. The algorithm generates a “warm-up” matrix, to ensure that the model is populated with vehicles before the start of the simulation period. Figure 5 shows the distribution of the demand over the three-hour analysis period.
ADJUSTMENT OF LOCAL PARAMETERS

Some local adjustment parameters have been modified to improve the calibration. The calibration focused on overall travel time on the Richmond Street North corridor and the general driver behaviour that could affect the simulation.

The following parameters have been adjusted:

— Lane assignments
— Driver behaviour (cooperation and aggressiveness)
— Decisions distances

The following table compares the observed travel times from Google datasets, and modelled travel times from the Aimsun model, on Richmond Street north between Oxford Street and University Drive.

<table>
<thead>
<tr>
<th>DIRECTION</th>
<th>OBSERVED MIN</th>
<th>OBSERVED MAX</th>
<th>MEAN MODELLED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northbound</td>
<td>2 min</td>
<td>7 min</td>
<td>2:24 min</td>
</tr>
<tr>
<td>Southbound</td>
<td>2 min</td>
<td>8 min</td>
<td>3:16 min</td>
</tr>
</tbody>
</table>

The mean modelled values of travel time were determined to be in the range of the observed minimum and maximum value of travel time. The standard deviations of the travel times were less than 20 seconds for both directions at all time periods, so the variability of the model was less than the variability of the observed value. Furthermore, the mean travel time modelled was closer to the minimum observed value than the maximum. This is normal, because the high travel time values are generally due to incidents or rare events, so the mean observed values are generally closer than minimum observed value than maximum observed value. For the purpose of this analysis, therefore, the travel time is considered calibrated.

2.1.11 DYNAMIC MODEL VALIDATION

The validation of the dynamic (microscopic) model confirms that the model respects the established calibration criteria.

Table 5 lists the acceptance criteria and targets presented earlier, and the calibration results. The results are compiled using the average of 10 iterations of the microscopic simulation for the three hours of the study period.
<table>
<thead>
<tr>
<th>NO.</th>
<th>CRITERIA</th>
<th>TARGET OF ACCEPTABILITY</th>
<th>CALIBRATION RESULT</th>
<th>ACCEPTABILITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>GEH &lt; 10 on turning movements</td>
<td>&gt; 90% of traffic counts in the micro simulation area</td>
<td>93.3% of traffic counts in the micro simulation area (571/612)</td>
<td>Yes</td>
</tr>
<tr>
<td>2</td>
<td>GEH &lt; 7.5 on turning movements</td>
<td>&gt; 80% of traffic counts in the micro simulation area</td>
<td>86.3% of traffic counts in the micro simulation area (528/612)</td>
<td>Yes</td>
</tr>
<tr>
<td>3</td>
<td>GEH &lt; 5 on turning movements</td>
<td>&gt; 60% of traffic counts in the micro simulation area</td>
<td>69.9% of traffic counts in the micro simulation area (368/612)</td>
<td>Yes</td>
</tr>
<tr>
<td>4</td>
<td>Turning counts &gt; 400 vph within 20%</td>
<td>&gt; 90% of turn traffic counts &gt; 400 vph of the micro simulation area</td>
<td>96.9% of turn traffic counts &gt; 400 vph of the micro simulation area (62/64)</td>
<td>Yes</td>
</tr>
<tr>
<td>5</td>
<td>Turning counts &gt; 400 vph within 10%</td>
<td>&gt; 75% of turn traffic counts &gt; 400 vph of the micro simulation area</td>
<td>76.6% of turn traffic counts &gt; 400 vph of the micro simulation area (49/64)</td>
<td>Yes</td>
</tr>
<tr>
<td>6</td>
<td>Turning counts &lt; 400 vph within 100 vph</td>
<td>&gt; 90% of turn traffic counts &lt; 400 vph of the micro simulation area</td>
<td>94.2% of turn traffic counts &lt; 400 vph of the micro simulation area (516/548)</td>
<td>Yes</td>
</tr>
<tr>
<td>7</td>
<td>Turning counts &lt; 400 vph within 50 vph</td>
<td>&gt; 75% of turn traffic counts &lt; 400 vph of the micro simulation area</td>
<td>76.6% of turn traffic counts &lt; 400 vph of the micro simulation area (454/548)</td>
<td>Yes</td>
</tr>
<tr>
<td>8</td>
<td>R² value</td>
<td>&gt; 0.95</td>
<td>0.968</td>
<td>Yes</td>
</tr>
<tr>
<td>9</td>
<td>Line of best fit ((y=ax+b))</td>
<td>0.95 &lt; a &lt; 1.05</td>
<td>a = 0.963</td>
<td>Yes</td>
</tr>
<tr>
<td>10</td>
<td>Route choice logical</td>
<td>&gt; 95% of the path of the 100 biggest OD pairs are coherent</td>
<td>100% of the path of the 100 biggest OD pairs are coherent</td>
<td>Yes</td>
</tr>
<tr>
<td>11</td>
<td>Travel time of the origins-destination included in the gap usually observed at the same time according to Google Maps</td>
<td>Both directions on Richmond St. Between Oxford St. and University St.</td>
<td>100% (2/2)</td>
<td>Yes</td>
</tr>
<tr>
<td>12</td>
<td>Virtual queues of more than 10 vehicles at the end of the simulation period</td>
<td>None</td>
<td>None</td>
<td>Yes</td>
</tr>
<tr>
<td>13</td>
<td>Lost vehicles</td>
<td>&lt; 1% of the vehicles</td>
<td>&lt;1% (53/28341)</td>
<td>Yes</td>
</tr>
<tr>
<td>14</td>
<td>Realistic queues</td>
<td>All the network</td>
<td>Validated manually for all the network</td>
<td>Yes</td>
</tr>
<tr>
<td>15</td>
<td>Realistic bottleneck</td>
<td>All the network</td>
<td>Validated manually for all the network</td>
<td>Yes</td>
</tr>
</tbody>
</table>

The results show that the model was considered calibrated and that the profile adjustment of the demand, the adding of dynamic traffic assignment (DTA) have improved the calibration on traffic counts compared to the static assignment model.
2.2 SCENARIO DESCRIPTION

This section presents the analysis of the future scenarios. To be able to analyze the impact of the BRT project in the City of London, two scenarios have been analyzed; one with, and one without the BRT project. Furthermore, the analysis compared the traffic impacts under the four alternative BRT design concepts on Richmond Street North.

2.2.1 FUTURE TRAFFIC FLOWS AND CONDITIONS WITHOUT THE BRT

As stated previously, the future traffic flows and conditions in Richmond Street North corridor will not only be impacted by the implementation of the BRT, but also by the closure of the University Drive Bridge to general traffic, and the proposed road improvements on Adelaide Street (grade separation at the railroad crossing) and in the Western Road – Wharncliffe Road corridor (widening to Oxford Street). While the model does reflect an unconstrained crossing of the rail corridor on Adelaide Street North, the relative impact of the proposed Adelaide Street North grade separation at the CP railroad crossing is not quantified in the model (due to the limitations in modeling train operations).

In order to properly assess the impacts associated with the specific projects, the following scenarios were modeled:

1. Existing conditions (based on the calibration presented above);
2. Road improvements on the Western Road – Wharncliffe Road corridor;
3. Road improvements on Western Road – Wharncliffe Road corridor, University Bridge closure to public traffic, and Blackfriars Bridge reopening (one lane in the eastbound direction only).

Scenario 3, above, was considered as the Base Case scenario, which will be considered, along with the Existing Conditions scenario, as reference scenarios when analyzing the impact of the four alternative BRT design concepts.

2.2.2 FUTURE TRAFFIC FLOWS AND CONDITIONS WITH BRT SCENARIOS

All the BRT scenarios included changes to Richmond Street’s configuration between Oxford Street and University Drive.

Four alternative BRT design concepts were considered in the present analysis:

1. 2 lanes of general traffic, with curb-side running BRT;
2. 2 lanes of general traffic with centre running BRT;
3. 4 lanes of general traffic, with curb-side running BRT;
4. 4 lanes of general traffic, with centre running BRT.

The conceptual plans of those four alternative BRT design concepts are presented in Appendix A. The modelled geometry of Richmond Street that has been coded in the Aimsun model corresponds to those plans.

All the future scenarios take into account the Base Case scenario, including the following proposed improvements to the broader road network:

- Widening of Western Road/Wharncliffe Road from Platt’s Lane to Oxford Street
- Closure of University Drive Bridge to general traffic
- Opening of one lane on Blackfriars Bridge in the eastbound direction only

2.3 ASSUMPTIONS

This section presents the main assumptions used in the modelling process for the static assignment (microscopic) model and the dynamic (microscopic) model of the Richmond Street.
2.3.1 STATIC TRAFFIC ASSIGNMENT ASSUMPTIONS

The following are the principal assumptions made in the modelling process to develop the four alternative BRT design concepts analyzed for the static traffic assignment.

- All the future scenarios used the current vehicular demand from the city-wide model, adjusted using available traffic counts in each micro-zone as discussed earlier. The same base demand was used to evaluate all the scenarios and no changes were made with respect to the traffic zone configuration from the city-wide model.
- The static traffic assignment model considers the traffic demand between 3 pm—6 pm.
- The model doesn’t consider any modal shift due to a change of travel time between the scenarios, and therefore the modeled automobile demand is constant. The vehicular demand remains the same as currently observed and no increase of transit ridership that would result in a mode shift is considered. This can be considered a conservative approach since the goal of BRT is to encourage more use of transit.

2.3.2 MICROSCOPIC MODELLING ASSUMPTION

The following assumptions were made in the modelling process to develop the four alternative BRT design concepts analyzed in the microscopic modelling process.

- The proposed BRT stop locations and the Richmond Street corridor geometry were coded according to the design concepts available (November 27, 2017) for each scenario.
- No changes were made to roadway geometries and signal timing plans and cycle lengths outside of the Richmond Street corridor between Oxford Street and University Drive.
- A BRT frequency of 5 minutes, and average bus stop time of 30 seconds/stop, was considered for all scenarios.
- The local bus schedule was adjusted for all scenarios to correspond with the proposed 2027 transit service as proposed by Dillon in their recent Transit Master Plan exercise.
- An actuated-coordinated signal timing plan for the Richmond Street corridor was applied, with a 100 second cycle length for each scenario, sufficient to accommodate minimum pedestrian crossing requirements.
- The traffic signal at the intersection of University Drive/Richmond Street was programmed to offer a high level of service for the BRT with two on-demand signal phases per cycle to maximize operating speeds.
- No Transit Signal Priority (TSP) was considered in the model to improve the public transit efficiency on the Richmond Street corridor. Traffic signal progression, however, was included in the model for the Richmond Street corridor.
- All secondary traffic signal phases were considered to be on minimum recall, with a minimum generic green time and pedestrian clearance times.
- Exclusively protected left-turn (and u-turn) signal phases were applied for all left-turns from Richmond Street to cross streets, for all scenarios.
- The micro-simulation model did not consider any pedestrian, bike, street parking and short-stopping vehicle interactions.
3 RESULTS AND ANALYSIS

This section presents the key microsimulation analysis results for the four alternative BRT design concepts. The results presented address the main objectives of the traffic model presented in Section 1.

3.1 STATIC ASSIGNMENT

The static assignment (macroscopic) model is intended to analyze the impact of traffic reassignment on the road network under the different scenarios. The future scenarios were all analyzed with the three other road network modifications previously presented (widening of Western Road/Wharncliffe Road from Platt’s Lane to Oxford Street, closure of University Drive Bridge to general traffic and opening of one lane on Blackfriars Bridge in the eastbound direction only). The future assignment scenario without BRT has been evaluated in order to be able to assess the impact of these other projects separately, to allow for a clear assessment of the incremental impact of the BRT scenarios.

3.1.1 IMPACTS OF ROAD IMPROVEMENTS ON WESTERN RD AND WHARNCLIFFE RD AND UNIVERSITY BRIDGE CLOSURE

For this analysis, 3 separate road network scenarios were considered. As previously discussed, all scenarios consider the existing traffic demand. The scenarios analyzed were:

- Current scenario without any road improvements or modifications;
- Western Road and Wharncliffe Road widening without any change on Richmond Street; and
- Western Road and Wharncliffe Road widening, University Drive Bridge closure and Blackfriars Bridge eastbound opening without any change on Richmond Street.

Appendix B presents the following traffic flow maps:

- Current traffic flow;
- Traffic flow on the road network including the proposed Western Road and Wharncliffe Road widening;
- Traffic flow on the road network including the proposed Western Road and Wharncliffe Road widening variation (compared to the current scenario);
- Traffic flow on the road network including all proposed base network changes (Western Road and Wharncliffe Road widening, University Drive Bridge closure and Blackfriars Bridge eastbound opening);
- Traffic flow on the road network including all proposed base network changes (Western Road and Wharncliffe Road widening, University Drive Bridge closure and Blackfriars Bridge eastbound opening) variation (compared to the current scenario);

All of the maps present mean flow (or mean flow variation) in vehicles per hour (vph) during the PM peak period (3pm-6pm).

The key findings of the analysis of those scenarios are:

- The proposed Western Road widening will result in an increase in the traffic volume on Western Road in both directions (around 200 vph in both directions on north of Oxford Street) and a decrease in the traffic volume on Richmond Street (around 90 vph, southbound and 30 vph northbound)
- Closing University Drive Bridge will result in an increase in the traffic volume of approximately 50 vph on Western Road (and an associated reduction of approximately 50 vph on Richmond Street) when compared to the scenario with only the widening of Western Road.
- The majority of the users of the University Drive Bridge will use Windermere Road to reach Richmond Street.
3.1.2 IMPACTS OF THE BRT

For the static assignment model, only two alternatives with BRT on Richmond Street were analyzed (2 general purpose traffic lanes vs 4 general purpose traffic lanes, each with two dedicated BRT lanes) due to limitations of this level of model. The preliminary analysis has concluded that the location of the BRT lanes (i.e. curb-side or centre running) does not appear to have a significant impact on the capacity of the corridor. The alternative analyzed were, therefore:

- Western Road widening, University Drive Bridge closure and Blackfriars Bridge eastbound with two general traffic lanes and two BRT lanes on Richmond Street (either centre or side running);
- Western Road widening, University Drive Bridge closure and Blackfriars Bridge eastbound with four general traffic lanes and two BRT lanes on Richmond Street (either centre or side running).

The Current scenario and the Base Case scenario were used as reference scenarios to calculate the reassignment for all scenarios.

Appendix C presents the following traffic flow maps for the Richmond Street north corridor:

- 2 lanes of general traffic, with BRT traffic flow;
- 2 lanes of general traffic, with BRT traffic flow variation compared to the Current scenario;
- 2 lanes of general traffic, with BRT traffic flow variation compared to Base Case scenario;
- 4 lanes of general traffic, with BRT traffic flow;
- 4 lanes of general traffic, with BRT traffic flow variation compared to the Current scenario;
- 4 lanes of general traffic, with BRT traffic flow variation compared to Base Case scenario;

All of the maps present mean flow (or mean flow variation) in vph during the PM peak period (3pm-6pm).

The key findings of the analysis are:

- The alternative with two lanes of general traffic (with BRT) results in a reduction in capacity of the Richmond Street corridor. This corridor will be less attractive to through traffic, and the traffic flow is anticipated to decrease by around 200 vph per directions. In general, longer trips are expected to remain on Richmond Street, but some (fewer than 20 vph) will be reassigned to Western Road. The local trips would be more susceptible to be reassigned to other parallel routes (mainly St-Georges Street, Wellington Street, Waterloo Street and Colborne Street). A total of around 200 vph in local trips will be reassigned to those routes (and in a lesser volume, to others) but no street in the network is anticipated to experience a significant increase of traffic volume; the maximum increase is anticipated to be in the order of only 50 vph).

- The scenario with four lanes of general traffic (with BRT) doesn’t appear to have a significant impacts on the road network capacity. The major traffic reassignments shown on the maps are the result of the proposed widening of Western Road and the closure of University Drive Bridge to general traffic and not the presence of BRT.

3.2 MICROSIMULATION

As discussed previously, the microsimulation scenarios have two major objectives:

1- Evaluate the impact of the proposed BRT project on the traffic condition on the Richmond Street corridor using microsimulation model for evaluating delay and travel time on the different for different scenarios.

2- Prepare microsimulation videos to present the different BRT design concept scenarios and their impacts on traffic conditions at a public presentations.

Microsimulation scenarios also provide more temporal distributed information about traffic flow variations.

3.2.1 TRAFFIC FLOW

Appendix D presents the traffic flow simulated and the theoretical V/C ratio for each interval of 15 min of the PM peak period for the different scenarios analyzed. Traffic flow maps are presented in vehicles per hour.

Traffic flow volumes are consistent with the static assignment results and the demand profiled.
3.2.2 TRAVEL TIME

The forecast travel times under each scenario have been analyzed using the microsimulation model to evaluate the impact of the different scenarios on the travel time on Richmond Street. The travel time was calculated in both directions (northbound and southbound) for cars and the buses. The following figures present the results of the analysis:

General traffic travel time on Richmond St. between Oxford St. and University Dr.
The results indicate that:

— The northbound travel time is anticipated to be around 30 to 90 seconds higher than the existing condition. This is largely due to the phase(s) added at University Drive/Richmond Street intersection. The anticipated impact is less with the 4-lane alternatives.

— No significant impact on travel time in the southbound direction is anticipated. A small increase is, however, expected under the centre-running BRT scenarios due to the addition of an exclusive signal phase at University/Richmond intersection.

— For the bus travel time, no significant variation was observed between the scenarios. While not explicitly modeled, the proposed addition of TSP will likely help to reduce those travel times and optimize bus operations. Travel times were calculated assuming three stops on the BRT with a mean boarding time of 30 seconds at each stop.

The results show that the Richmond Street is expected to operate under the proposed BRT alternatives with a level of service similar to existing, due to the natural reassignment of automobile traffic with the widening of Western Road, and potential loss of general traffic capacity on Richmond Street in the scenarios with two-lanes of general traffic.

### 3.2.3 Delay

Appendix E presents the delay by approach for each 15-minute interval of the PM peak period for the different scenarios analyzed.

The following key observations apply to all of the scenarios modeled:

— The highest delays were observed on secondary approaches of the signalized intersections along Richmond Street. Traffic signal optimization would limit the delay on the Richmond Street North corridor traffic movements.

— Delays are significant for all approaches of the Oxford Street/Richmond Street intersection. This intersection is operating at capacity in the PM peak period for all alternatives. This intersection has the same capacity in all the alternatives due to the restriction of lanes south of Oxford Street.

— Scenarios with two-lanes of general traffic have lower levels of service on cross streets due to the reduction of green time necessary to preserve enough through capacity on Richmond Street.
4 SUMMARY

The traffic modelling analysis had three main objectives:

**EVALUATE THE IMPACT OF THE PROPOSED ROAD IMPROVEMENTS AND UNIVERSITY BRIDGE CLOSURE ON TRAFFIC FLOWS, WITHOUT THE PROPOSED BRT (BASE CASE SCENARIO)**

- The University Drive bridge closure will likely result in an increase of traffic on Windermere Road (+160 vph on westbound) and the northern portion of Richmond Street (+200 to +300 vph northbound) between University Drive and Windermere Road;
- The proposed road improvement projects are expected to result in a reduction in traffic flow on Richmond Street between Oxford Street and University Drive (approximately -100 vph northbound and -200 vph southbound) and, in a smaller amounts on most of the local streets near this part of Richmond Street;
- The proposed improvements on Western Road are expected to attract some traffic away from Richmond Street and Talbot Street (-200 to -250 vph, in both directions);
- With the proposed Adelaide Street rail grade-separation in place, Adelaide Street is expected to attract around 100 additional vph that would otherwise be on Richmond Street.

**EVALUATE THE IMPACT OF THE TWO GENERAL TRAFFIC LANES BRT ALTERNATIVE ON THE ROAD NETWORK.**

- The alternative with two-lanes (one per direction) of general traffic has less capacity than the existing condition. Some trip reassignments are caused by this capacity reduction are observed. Some through trips will be reassigned to the Western Road. The addition of capacity due to the proposed widening of Western Road and the University Drive bridge closure will, combine to result in reduced demand on Richmond Street and increases the attractiveness of the Western Road corridor.
- On Richmond Street, it is expected that the two general purpose lane BRT alternatives will result in a reduction of demand by approximately 200 vph in both directions on Richmond Street between Oxford Street and University Drive as a result of the lane reductions. This reduction would be combined with the effect of the University Drive bridge closure;
- The streets running parallel to Richmond Street (St. George Street, Wellington Street and Waterloo Street) are expected to experience an increase in peak periods traffic flow of less than 75 vph, compared to current volumes, due to the capacity reduction on Richmond Street.
- Local streets are not expected to experience significant increases in “non-neighbourhood” traffic;
- Traffic operations under both the curb-running and centre-running BRT scenarios are considered equal at a macro level of analysis. The placement of the BRT (curbside vs centre) does not appear to have a significant impact on general capacity of the corridor.

**EVALUATE THE IMPACT OF THE FOUR GENERAL TRAFFIC LANES BRT ALTERNATIVE ON THE ROAD NETWORK.**

- When compared to the Base Case scenario, the options with four general traffic lanes (two per direction) are not expected to result in any significant impacts on traffic diversion, as these options maintain or improve traffic capacity compared to the existing condition;
- The most notable impact of the proposed changes on traffic flow is expected to result from the capacity reduction at the Oxford Street / Richmond Street intersection. Additional traffic diversions (in the order of 20 vph or less) are anticipated on adjacent Streets (Talbot Street, St. George Street, St. James Street, etc.) to bypass the Oxford Street / Richmond Street intersection which will be at capacity.
- Both the curb-running and centre-running BRT scenarios are considered equal at a macro level of analysis. The placement of the BRT (curb-side vs centre) does not appear to have a significant impact on general capacity of the corridor.
EVALUATE THE IMPACT OF THE BRT PROJECT USING A MICROSIMULATION MODEL FOR THE FOUR BRT ALTERNATIVES.

— The anticipated northbound travel time will be approximately 30 to 90 seconds (depending on the BRT scenario) more than the existing condition. The overall impact on travel time is less with the four lanes scenarios.
— No impact on travel time in the southbound direction is expected in the PM peak period under the curb-running BRT scenario. A minor increase in travel time is anticipated under the centre-running BRT scenarios due to the addition of an exclusive BRT signal phase at the University/Richmond intersection.
— For BRT travel time, a significant variation is not anticipated between any of the scenarios.
— All approaches of the Oxford/Richmond intersection are at capacity during the PM peak period due to the reduction in capacity south of Oxford Street due to right-of-way issues. This intersection has the same capacity constraints in all the scenarios and will be a major control on traffic flows of the Richmond Street North corridor.
— The scenarios with two general traffic lanes have less capacity than the existing condition. Some diversion of traffic will be caused by this capacity reduction. Some through trips will divert to the Western Road. The addition of capacity on the Western/Wharncliffe corridor and the closure of the University Drive bridge to general traffic combine to also divert traffic demand from Richmond Street.
APPENDIX

A GEOMETRIC PLANS