Calibrating a Simulation-Based Dynamic Traffic Assignment: A Case Study of Downtown Calgary

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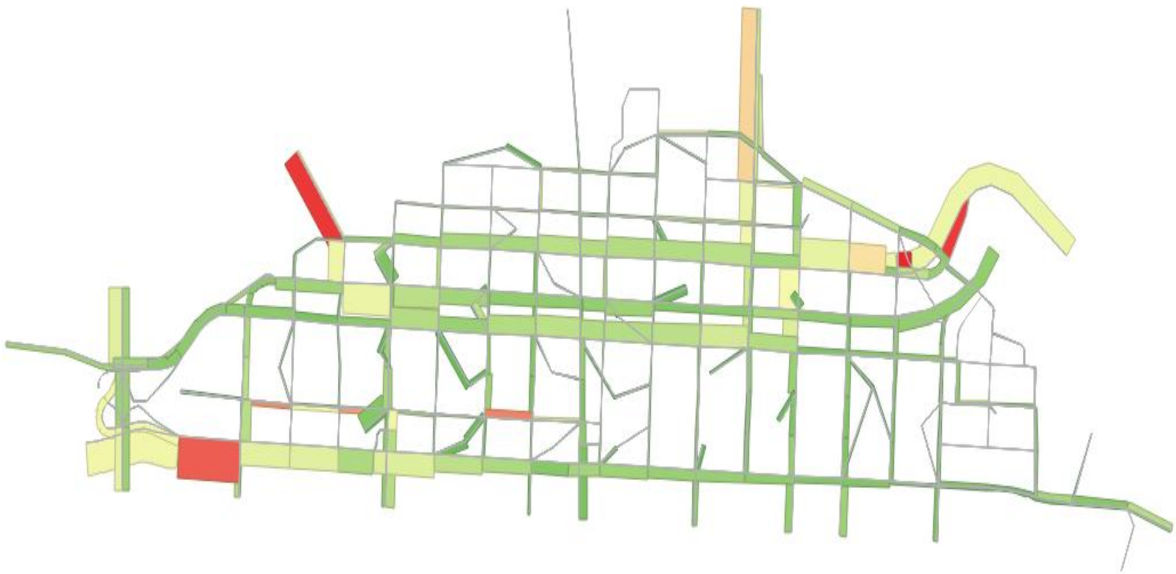

ABSTRACT

This paper presents the development and calibration of a Dynamic Traffic Assignment (DTA) model for Calgary's Downtown subnetwork, using the Alberta Spatial, Economic, and Transportation Model (ASET) as its foundation. The study aims to simulate traffic flows accurately through a Simulation-Based DTA (SB-DTA) approach using DYNAMEQ, incorporating temporal variations and real-time dynamics to capture traffic conditions more realistically. The introduction discusses urban congestion and the four-step traffic forecasting model, emphasizing DTA's advantages over Static Traffic Assignment (STA) by integrating time-dependent factors and real-time simulations. The methodology details the construction of a subarea network from ASET, its transformation into DYNAMEQ's format, and calibration with historical data by modifying demand matrices for AM and PM peak traffic. The results reveal significant discrepancies between simulated and historical traffic metrics, suggesting the need for refined calibration strategies and highlighting issues such as unsignalized intersections, junction capacities, and free flow speeds. This leads to unrealistic outcomes, indicating that intersection controls, accurate signal timing plans, and historical traffic count data are crucial to enhancing the model's accuracy. In conclusion, the study emphasizes incorporating these elements in future work to align simulated metrics with real-world patterns, support effective traffic management, and refine DTA models for more accurate traffic simulations in urban areas.

1.0. INTRODUCTION

Traffic congestion is a phenomenon in urban transport networks in which vehicles on the roads build up either during peak travel periods or when there are road accidents. For any cars on the road, this would mean slower speeds, increased travel times, and increased queuing. Under extreme cases, this could also lead to congestion spillback, forcing network gridlocks. As the urban population grows, activities and vehicular volumes exacerbate congestion, prompting transport planners and traffic engineers to develop models to capture traffic dynamics that reflect timely and strategic road capacity optimization to accommodate growth. The four-step model (trip generation, trip distribution, modal split, traffic/transit assignment) is a forecast model (first three steps) used in determining future vehicular demand and traffic/transit assignment to distribute forecasted demand to minimize travel times for individual vehicles. Traffic assignment has two (2) types, namely static and dynamic. Static traffic assignment (STA) utilizes volume delay functions (VDF), which means that travel time on a link depends only on the flow *of* that link and does not depend on the flows on other links; STA is also time-invariant and assumes the equilibrium time is long enough to achieve *steady state* conditions for analysis. STA is useful for long-term transport planning; however, it does not utilize temporal variations of traffic and traffic flow dynamics to accurately simulate traffic flow conditions during peak travel hours and road disruption scenarios such as lane closures, road accidents, and highway ramps. Dynamic Traffic Assignment (DTA) is the extension of STA that incorporates temporal features to estimate flow paths during different times of the day. DTA is an iterative process that shows the shortest route based on the departure time of *each* road user.

This term paper aims to perform a Simulation-Based DTA (SB-DTA) using DYNAMEQ and calibrate the model by manipulating demand inputs to accurately mimic AM Peak traffic conditions. The network model used for this study was the Alberta Spatial, Economic, and Transportation Model (ASET), and the City of Calgary transport network was subsetted from this model, which is the focus of this study. Some arterials were selected to conduct link analysis and compare traffic behavior between experienced and simulated traffic conditions. This study is structured as follows: **Section 2** involves a literature review of DTA, how the algorithm works mathematically and in simulation, and how other jurisdictions use DYNAMEQ in day-to-day traffic operations. **Section 3** provides the steps taken in building the SB-DTA model and the calibration and validation of the model. **Section 4** discusses the results of multiple DTA runs, and finally, **Section 5** concludes the study with summarized results, limitations, and future works.

2.0. LITERATURE REVIEW

2.1. Dynamic Traffic Assignment (DTA)

Dynamic Traffic Assignment, most commonly called DTA, is a modeling approach that is an extension of Static Traffic Assignment (STA); however, it captures the relationship between dynamic route choice behaviors (time-dependent shortest path and departure time) and traffic flow theory (i.e., congestion spillback, queueing) (Sloboden et al., 2012). DTA seeks to provide an improved, more concise means of coherently representing the dynamic interaction between travel choices, traffic flows, and spatiotemporal time and cost measures. Critical differences between STA and DTA are summarized in **Table 1** below (Chiu et al., 2011).

Table 1. Key Differences between STA and DTA (Chiu et al., 2011)

STA	DTA
The analysis period is long enough to achieve steady-state conditions. Hence, link outflow is equal to link inflow.	The analysis incorporates traffic flow theory, which captures real-time traffic evolution during peak and non-peak travel periods. DTA captures the travel time increase due to less link inflow.

Demand and capacities are constant over time; variables used in modeling are time invariants.	Demand changes over time, and so does the shortest path at different departure times.
Flow does not ever drop (lack of transient state analysis), and demand can exceed unrealistic capacity. $\left(\frac{v}{c} > 1\right)$	Captures transient traffic states through advanced traffic flow theorems, representing link level performance (increase in travel time and density, decrease in speed) when congestion occurs (i.e., increased queue lengths leading to congestion spillback).
First-in-first-out (FIFO) rules where vehicular travel times through a link are the same, which is unrealistic since most roads have more than one lane, allowing for lane changing and faster travel times for other road users.	Lane-changing and other driving behaviors are captured; nth-order models and fundamental traffic equations are incorporated to accurately capture driving behavior and traffic dynamics.

2.2. Historical Development of DTA Models

Merchant and Nemhauser's critical works (1978) laid the foundation for the field of DTA, marking a momentous shift from STA models that were extensively used in traffic engineering at the time. Their core contributions were two (2) critical papers: (1) introducing the concept of dynamic user equilibrium (DUE) and (2) optimizing traffic flows or, as described in the paper, dynamic system optimum (DSO). The focus of this subsection will be on the contributions of the first paper and how it evolved. The model developed was a discrete-time model and a nonlinear, nonconvex mathematical programming problem where traffic congestion was explicitly included in the flow equations. This initial formulation is limited to multiple origins and one destination, ideal for modeling peak morning commutes. The model is a minimization problem given by:

$$minimize \sum_{i=1}^{I} \sum_{j=1}^{a} h_{ij}(x_{ij})$$

Subject to

$$x_{i+1} = x_{ij} - g_j(x_{ij}) + d_{ij}, \qquad i = 0, \dots, I-1, \forall\, j \in \mathcal{A}$$

$$\sum_{j \in A(q)} d_{ij} = F_i(q) + \sum_{j \in B(q)} g_j(x_{ij}), \qquad i = 0, \dots, I-1, \forall\, j \in \mathcal{A}$$

$$x_{0j} = R_j \geq 0, \qquad \forall\, j \in \mathcal{A}$$

$$d_{ij} \geq 0, \qquad i = 0, \dots, I-1, \forall\, j \in \mathcal{A}$$

$$x_{ij} \geq 0, \qquad i = 1, \dots, I, \forall\, j \in \mathcal{A}$$

The first constraint is the *fundamental transformation equations* (state or coupling equations), where x_{ij} is the number of vehicles on the arc *j* at the beginning of the *ith* period, and d_{ij} the decision variable represents the number of vehicles admitted to the arc *j* during the ith period. The function g_j represents *congestion* (i.e., nondecreasing, continuous, concave functions) and is time-independent. This function will depend on two (2) parameters: the length and physical characteristics of the arc. The first constraint equation assumes that the number of vehicles that leave an arc in a given period will depend only on the number on the arc at the beginning of the analysis period (i.e., none of the d_{ij} vehicles that enter during a period will leave during this period.). This assumption is unrealistic; however, it was found valid for analysis with shorter periods or a problem with large arc lengths. The second constraint is the *flow conservation* equation, where $F_i(q)$ *external* input to node q, $A(q)$ represents the number of arcs *leaving* node q, and $B(q)$ represents the arcs *entering* node q. The last three constraints represent non-negativity constraints where the number of vehicles at the origin ($x_{0j} = R_j$), at arc *j* during the *ith* period (d_{ij}), and at the beginning of the *ith* period (x_{ij}) must be greater than zero. Given all these constraints, the cost function $h_{ij}(x_{ij})$ is minimized for all time steps in the planning horizon (I) and arcs

(a). This mathematical formulation has established new frontiers for the subsequent model development in DTA. **Table 2** below summarizes what each researcher has contributed to improving the model presented. The information presented in this table was taken from Peeta and Ziliaskopolus (2001).

Table 2. Timeline of DTA Model Algorithm Development (Peeta & Ziliaskopolus, 2001)

Study	Type of DTA Model	Study and Model Description
Smith and Ghali (1990)	Analytical	They explored integrating traffic control mechanisms within dynamic traffic assignments to manage urban congestion. They introduced a responsive traffic control policy, P0, examining its effects under steady demand and its theoretical integration into traffic assignment models. The study also highlights stability results for systems with constant demand, responsive control, and varying demand with fixed signal settings. Key variables include traffic flow (x_i), saturation flow (s_i), and signal timing (h and p), with a focus on minimizing total travel costs $(\sum c_i x_i w(x,h)+r)$ under equilibrium conditions. The work in this study demonstrates the natural fit of P_0 static assignments, extending to dynamic scenarios with explicit queueing, but acknowledges challenges in combining dynamic demand with responsive control.
Mahmassani and Peeta (1990)	Simulation-Based	This paper delved into urban traffic dynamics, comparing SO and UE assignments under dynamic conditions. It utilizes a simulation-based algorithm and focuses on the Advanced Traveller Information System's (ATIS) potential to mitigate congestion through strategic route guidance. The analysis encapsulates variables such as r_{ij}^t for vehicle trips and employing equations to model traffic flow and assignment, such as Merchant and Nemhausser's, indicates that ATIS aligned with SO can substantially improve traffic management in high congestion by guiding drivers towards routes that optimize network performance.
Ben-Akiva et al. (1996)	Simulation-Based	This study detailed the creation of **DynaMIT**, a DTA system for real-time traffic management and predictive route guidance. **DynaMIT** integrates traffic volume and control system data to estimate and predict time-dependent O-D flows and network conditions, generating SO route guidance that aligns with anticipated traffic states. The system comprises a *mesoscopic*-level traffic simulator and a disaggregate-level demand simulator and employs *Kalman Filter* methods for dynamic O-D matrix estimation. The guidance generation component of **DynaMIT** is developed to provide consistent and unbiased guidance, ensuring that users cannot find a path that is preferable to the one recommended by the system, thereby achieving SO. This involves solving a fixed-point problem $x=f(x)$, where x represents variables used for guidance generation and $f(x)$ denotes the predicted outcomes based on the traveler's reaction to the provided guidance. The iterative process, adjusted by a time-smoothing algorithm, aims to minimize guidance inconsistency by refining forecasts of travel times (nT_t) and

		utilizing inputs like estimated O-D trips ($X_{o,d}^{k,u}$) across vehicle guidance classes.
Boyce et al. (1995)	Analytical	This study developed an algorithm for dynamic user optimal (DUO) route choice modeling, which is crucial for ITS and real-time traveler information systems. It describes the driver's route choices based on current network conditions through an *optimal control theory* formulation, with the time-dependent O-D matrix known. The study transforms the continuous-time DUO problem into a discrete-time nonlinear programming (NLP) formulation using a sequence of NLPs solved by the Frank-Wolfe method. Fundamental equations include the transformation of state variables over time, $\frac{dx_{rs}}{dt} = u_{rs}(t) - v_{rs}(t)$ representing the difference between inflow and outflow on a route segment for an O-D pair, and flow conservation constraints ensuring total inflow equals total outflow at nodes.
Florian et al. (2001)	Simulation-based	The DTA model introduced in this paper was for ITS applications, leveraging a mesoscopic approach for enhanced computational efficiency. The model, applied to a segment of the Stockholm road network, utilizes a mesoscopic space-time queue network loading method, facilitating faster than real-time traffic simulation. It operates by dynamically estimating origin-destination (O-D) flows and adjusting traffic signal settings to optimize network performance, characterized by minimizing total travel times and improving traffic flow distribution. The formulation includes attributes such as lane-specific vehicle counts (x_{lane}), maximum flow (Q), and jam density (K) per lane, alongside a route choice mechanism that aims for user-optimal conditions by solving a series of linear search problems, $h^* \in R$ which h^* minimizes $S(h')$ actual path travel times.

2.3. Simulation-Based DTA

Equilibrium in DTA models is typically based on the concept of experienced travel time (instead of instantaneous travel time) for all the routes in a network. Using instantaneous travel time, the shortest path is calculated using the minimum travel time based on the snapshot of the link travel times at the time of trip departure. This methodology works, but link travel times change dynamically (traffic evolution), and this assumes complete driver information pre-departure, which does not represent reality. On the other hand, the shortest path calculated using experienced travel time will result in a time-dependent shortest path with minimal experienced travel time (Chiu et al., 2011). Figure 1 below illustrates travel time calculations for different departure times for a simple link in a series network. This means that experienced travel time can only be realized after going through a trip. In reality, this means driving through multiple times, which is costly; therefore, the other way to determine this is through traffic simulation.

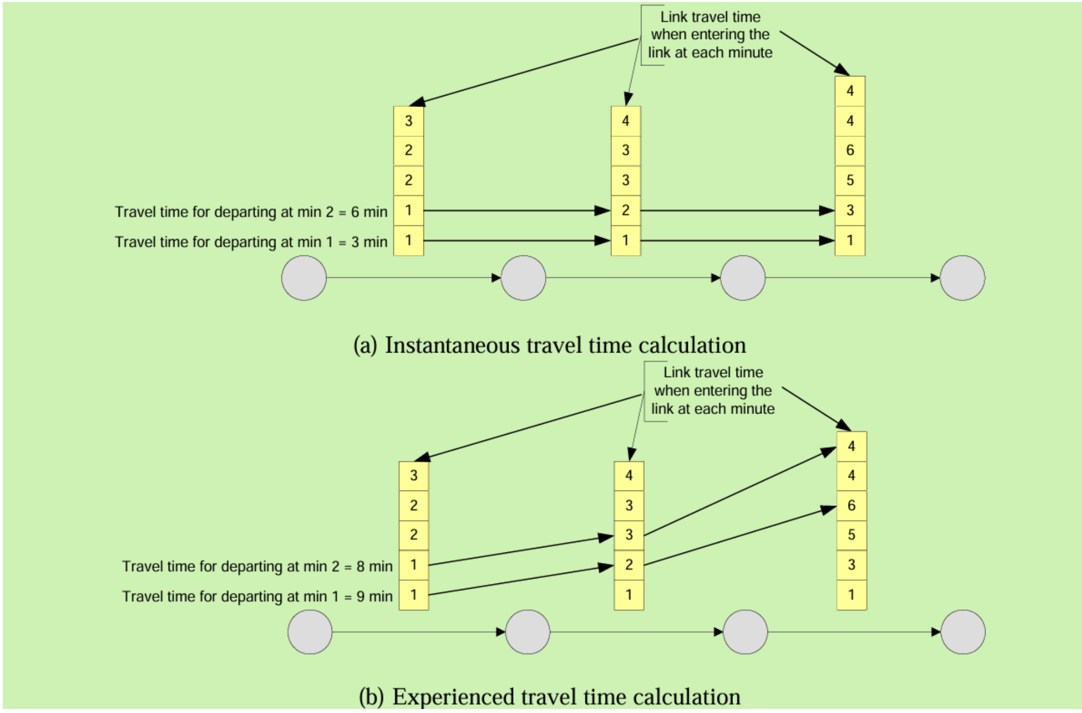

Figure 1 Determining Experienced vs. Instantaneous Travel Time (Chiu et al., 2011)

2.3.1. Algorithm

Before understanding the simulation-based DTA algorithm, it is crucial to know how this compares with STA. In STA, Wardrop's UE principle (Wardrop, 1952) is utilized to define equilibrium conditions that satisfy the following criteria:

> *In a model network with many possible routes for **each O-D pair**, all used routes have equal and lowest **travel time (generalized cost)**. No user may lower their travel time (**generalized cost**) by unilaterally changing to a different route.*

Now, with sim-based DTA, it utilizes the early works such as Merchant and Nemhauser (1978) to establish a dynamic user equilibrium (DUE) that is identical to the STA UE criteria:

> *In a network with many O-D zones and in a specific time period, for each **O-D pair and departure time increment**, all used routes have equal and **lowest experienced travel time (generalized cost)**, and no user may lower their experienced travel time (generalized cost) through unilateral action.*

The STA and sim-based DTA processes are similar, as shown in **Figures 2** and **3**. The initial shortest path is calculated for STA, which is then used for an all-or-nothing assignment. Travel times are then calculated using volume delay functions. If travel times are not converged (i.e., not equal), the newly calculated shortest path is used, and the assignment is repeated until equilibrium is reached. On the other hand, sim-based DTA is also an iterative process where the *time-dependent* shortest path is calculated, and then traffic assignment is performed. Once all vehicles are assigned, a traffic simulation is conducted to determine *experienced travel time*. If the travel times are not converged (i.e., not equal), the newly calculated *time-dependent* shortest path and the assignment are repeated until *dynamic* user equilibrium is achieved (Chiu et al., 2011).

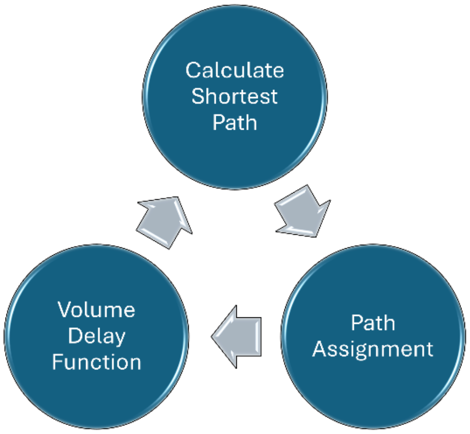

Figure 2 STA Algorithmic Structure (Chiu et al., 2011)

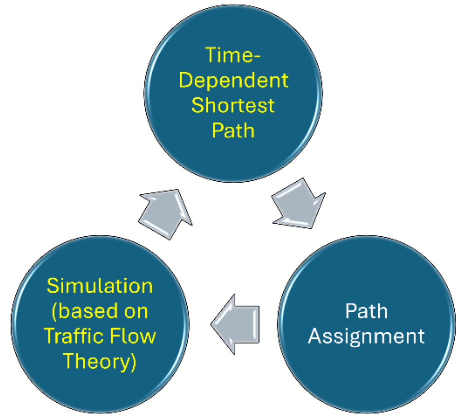

Figure 3 DTA Solution Algorithm Framework (Chiu et al., 2011)

The most common method of achieving DUE in sim-based DTA is to apply three algorithmic components in a sequence and solve them through iteration until the *stopping criterion* is achieved. The first element is **network loading**, which seeks to answer the following question: *Given a set of route choices (i.e., routes and route flows), what are the resulting route travel times?* The second element is **path set update**, which seeks to answer the question: *Given the current route travel times, what are the new shortest routes (per O-D par and departure time interval)?* The last element is **path assignment adjustment**, which seeks to answer the question: *Given the updated route sets, how should vehicles (or flows) be assigned to routes to better approximate DUE* (Chiu et al., 2011)? This process is illustrated in **Figure 3** above; however, in a more generalized sense, **Figure 4** describes the general DTA algorithmic procedure. The generalized procedure would require the elements mentioned earlier, where the network loading model includes the analysis period composed of simulation and assignment intervals. DUE is achieved when time-varying components such as travel time and intersection delay have minimal variations, in which case the sim-based DTA model has been considered to converge. The convergence criterion for the sim-based DTA is determining the total relative gap (rel_{gap}) given by **Equation 2** below:

$$rel_{gap} = \frac{\sum_t \sum_{i \in I} \left(\sum_{k \in K_i} f_k^t \tau_k^t \right) - \sum_t \sum_{i \in I} d_i^t u_i^t}{\sum_t \sum_{i \in II} d_i^t u_i^t}$$

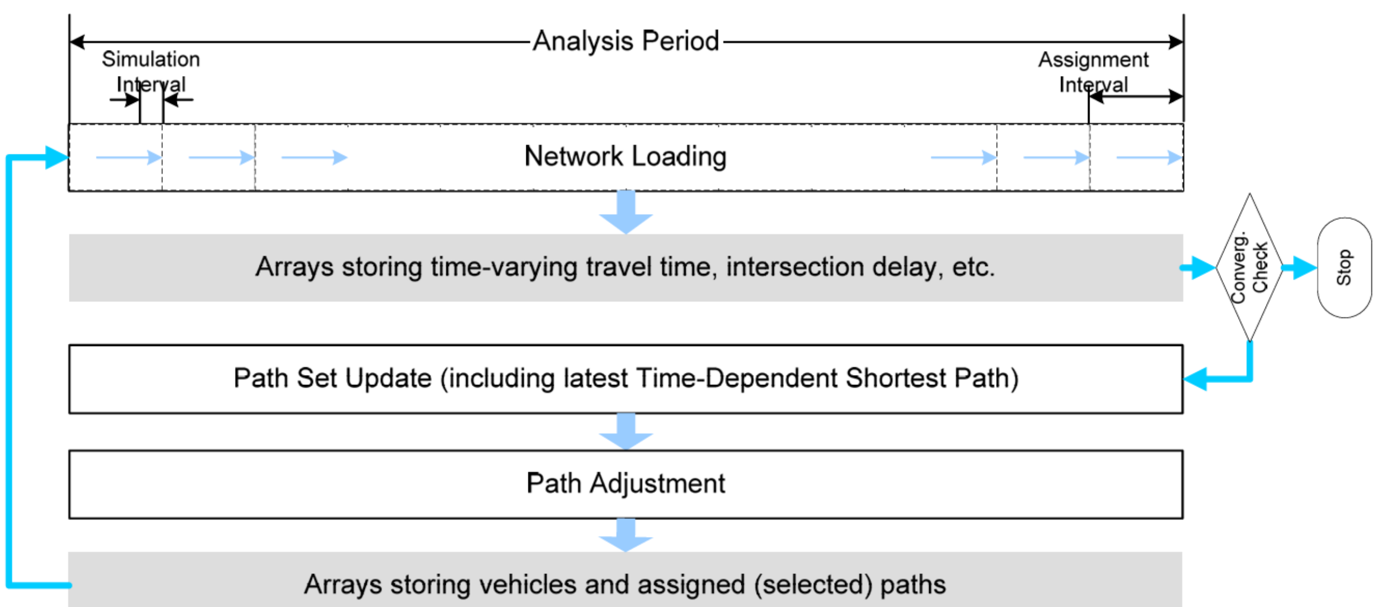

Figure 4 General Sim Based DTA Algorithmic Procedure (Chiu et al., 2011)

Where T is the set of all departure time intervals, t is the departure time interval, $t \in T$, I is the set of all origin-destination trip pairs, i is the origin-destination trip pair, $i \in I$, K_i is the set of all used routes for origin-destination pair i, k is the used route for origin-destination pair i, $k \in K_i$, f_k^t is the flow from used route k at departure time interval t, τ_k^t is the experienced travel time on used route k at departure time interval t, d_i^t is the total flow from origin-destination pair i at departure time interval t, and u_i^t is the shortest route travel time from origin-destination pair i at departure time interval t. In this equation, the collection of terms in the numerator describes the total gap, which calculates how far the current assignment solution is to the ideal shortest path time. The intuition of this stopping criterion is that if all routes have travel time very close to the shortest route travel time (i.e., the terms $f_k^t \tau_k^t$ and $d_i^t u_i^t$ are both equal, or both term values are close to each other), the total relative gap will be very close to zero, suggesting DTA convergence.

2.4. DYNAMEQ

DYNAMEQ, which stands for *DYNAMic EQuilibrium*, is a simulation-based DTA model consisting of two main components: a traffic flow simulation model and a routing model. The routing model emulates how drivers choose their route through a given network and their desired destination. The traffic simulation model describes the other aspects of the driving process. These are deceleration/acceleration due to traffic lights, traffic controls, and lane-changing behaviors (Mahut & Florian, 2010). The traffic flow in a DYNAMEQ model is based on a car-following theory and the concepts of gap acceptance and lane-changing behaviors, which means inputs such as vehicle lengths, lane dimensions, and connectivity are crucial to building an effective model (Gliebe & Bergman, 2011). DYNAMEQ's general structure of the solution algorithm is shown in Figure 5 below, similar to **Figure 4** mentioned earlier in this section. Experienced travel times result from vehicle interactions as they flow through the network from their O-D and cannot be known in advance. Hence, the cyclical problem is solved using an iterative approach, as shown in **Figure 5** (Mahut & Florian, 2010). DYNAMEQ is widely used to study the impact of signals, ramp metering, transit priority, and intersection layout. This software is also used to understand traffic dynamics under scenarios such as lane blockage, work zones, bridge closures, and detours (Bentley Systems).

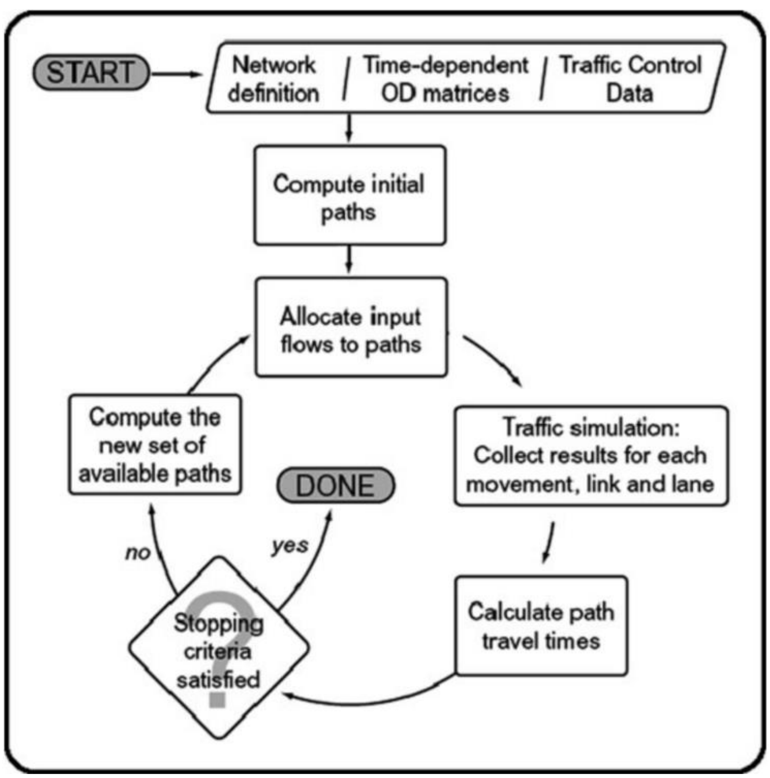

Figure 5 DYNAMEQ General Solution Algorithm Framework

2.4.1. DYNAMEQ Examples

Numerous municipalities have used sim-based DTA, such as DYNAMEQ, which has been found effective for the specific purpose of the DTA model. In this section, four (4) examples will be presented where DYNAMEQ was used to improve transport planning and traffic operations: Macleod Trail/Shawnessy Boulevard Interchange Scenario (City of Calgary), the City of Edmonton Citywide DTA Model, the City of Edmonton Subarea Bridge Closure Scenario, the City of Montreal CBD DTA Model, and the City of San Francisco Citywide DTA Model.

City of Calgary – Macleod Trail / Shawnessy Boulevard Interchange Scenario

Mahut et al. (2004) created a DTA model using the City's subnetwork to simulate the effect of retrofitting a signalized intersection into a partial cloverleaf interchange in the SW area of the City. The O-D matrix was refined using extensive database inputs and matrix adjustment algorithm, and network topology was updated to include an interchange and more detailed arterial intersections with traffic signal control plans. Calibration was achieved by adjusting parameters such as gap-acceptance values and average vehicle length against a set of turning movement counts, resulting in high confidence in the model results.

City of Edmonton

The City adopted DYNAMEQ for citywide traffic simulation and DTA modeling to make informed operation decisions for various infrastructure projects. This DTA model complemented the City's travel demand model (EMME) and offered detailed operational insights for various citywide scenarios, such as traffic diversion, queueing, and delay impacts. The DTA model initially focused on evaluating the implications of infrastructure alternatives but later focused on the effects of road and transit improvement projects. A recent example of the DTA model used in infrastructure delivery was planning for the Valley Line LRT project, where the model is used for traffic impact analysis to assess the traffic level of service at every stage of the project until opening day. This citywide model is now trusted for operational traffic planning and longer-term studies, seamlessly integrating with regional travel models (ASET) and enabling the City to make efficient, smart infrastructure investment decisions to maximize public resources (Bentley Systems).

Another example of the City using the DTA model was to validate traffic conditions during a bridge closure within a subarea. In the Summer of 2013, the Stony Plain Road bridge over Groat Road was closed for four (4) months, which allowed the City to apply the DTA model to evaluate traffic diversion and network impacts. The DTA model was calibrated with traffic data collected when the bridge was open and validated using data from the closure period, providing a credible assessment of the model's forecasting capability under unchanged demand conditions. This exercise highlights the benefits of a DTA model in capturing time-dependent congestion and accurately estimating traffic diversion due to network changes. This example demonstrated the importance of data collection, demand adjustment, and careful consideration of network boundary and capacity parameters in DTA model development and validation (Xin et al., 2014).

City of Montreal

The City of Montreal used DYNAMEQ to implement a DTA model covering its Central Business District (CBD), including the 9-km Notre Dame Street corridor, spanning a total area of 100 km^2. This DTA model served as a bridge between travel demand models for long-range planning of metropolitan regions and microsimulation software for traffic operations, effectively addressing the gap between these two methodologies. It was utilized to analyze three scenarios: the transformation of an urban expressway into a signal-free access-controlled facility, a downtown exit ramp serving the regional transit hub, and an urban arterial with various redesign alternatives to evaluate their impacts on traffic in the adjoining neighborhood (Volet et al., 2007).

City of San Francisco, California, USA

The City of San Francisco developed a Citywide DTA model to analyze various policy scenarios and its integration with the existing activity-based travel model. The City's approach combined a mesoscopic DTA model with explicit representations of the City's complex traffic controls and transit routes. The model evaluated strategies for demand reduction and transit efficiency improvements, such as cordon-based congestion pricing and bus rapid transit (BRT) systems. Much of the project involved developing an open-source toolkit to automate converting critical data into DTA model inputs, addressing challenges in calibrating a model in a congested urban environment. The model's validation showed reasonable alignment with observed data, and scenario testing highlighted differences in results between the DTA and STA models, particularly in scenarios introducing significant changes to traffic flow (Erhardt et al., 2013).

2.5. Off-Line Calibration of Sim-Based DTA Models

Off-line calibration in dynamic traffic assignment (DTA) models involves systematically adjusting model parameters using historical data to ensure the accuracy of the mode's predictions across various traffic conditions observed over time. This method is distinct from on-line calibration, which dynamically updates the model parameters based on real-time data to respond to current traffic conditions, aiming to provide immediate and accurate traffic forecasts. Off-line calibration necessitates a comprehensive set of resources, including extensive historical traffic data and sophisticated software tools capable of handling complex computations and simulations. These resources are crucial for developing a reliable model that accurately reflects typical traffic patterns over different days, weather conditions, and traffic incidents (Balakrishna, 2007). In the context of DYNAMEQ, off-line calibration plays a critical role. It provides the foundation of well-calibrated parameters that DYNAMEQ uses to simulate realistic traffic scenarios. These simulations are essential for effective traffic management, optimizing traffic flows, and enhancing overall traffic planning. The calibrated DYNAMEQ model can accurately predict traffic behaviors and responses to various management strategies, thus supporting more informed decision-making and planning processes in urban traffic systems.

3.0. METHODOLOGY

This study will create a DTA model for Downtown Calgary based on the regional travel demand and economic model. The regional model utilizes static traffic assignment to distribute flow throughout the province. The DTA model will then be calibrated and validated to replicate traffic conditions accurately during each scenario.

3.1. Network Data

Network elements (e.g., nodes, links, centroids, zones), turning movements, modal split, travel demand, and traffic counts are crucial for creating a sim-based DTA model. For this study, a sim-based DTA model will be constructed from the ASET model provided by *Alberta Transportation and Economic Corridors*. ASET, which stands for Alberta Spatial, Economic, and Transport (ASET), is a simulation system designed for **demand forecasting** and **policy analysis**. The model comprises 524 land use zones (LUZ) and about 5000 traffic analysis zones (TAZ). Also contained in this model are pertinent data such as socioeconomic (household income, tax assessments), demographic (existing and forecasted population, number of dwellings), infrastructure (highways, bridges, legal boundaries, utilities), and transportation (O-D demand, mode split) (citation here). The ASET model runs in EMME, a software counterpart of DYNAMEQ, which utilizes static traffic assignment to run the model, which is helpful for long-term planning and strategic infrastructure implementation. The ASET model assumes fall traffic condition throughout its analysis period which means that traffic conditions that are captured during the traffic assignment process are from the months of August, September, and October (Alberta Transportation, & HBA Specto Incorporated, 2019).

3.2. Static to Dynamic Model

The ASET model was subsetted precisely to capture network elements and demand matrices for Downtown Calgary, as shown in **Figure 6**. This was achieved by defining an EXTRA attribute in EMME called @subarea. If the attribute value on the node equals 1, it belongs to the subarea; otherwise, it is not (0). This subarea analysis was performed using SOLA (second-order linear approximation) traffic assignment. Once the subarea traffic assignment was complete, the subnetwork with demand was extracted and transformed into a DYNAMEQ network and demand format. The transformed network in DYNAMEQ will result in a more detailed representation of the network, showing the physical number of lanes, turning movement, and extent of intersections (nodes). However, it is essential to note that this transfer will yield some intersection geometry errors that need correcting before running a DTA specification. It is also worth noting that the ASET model (EMME) used virtual volume delay functions at the intersection level to represent traffic controls instead of using signal timing plans, which affects the newly formed subnetwork in DYNAMEQ. Realistically, it is customary that each intersection in the DYNAMEQ model be assigned a signal timing plan (traffic control plan), as shown in **Figure 5** above, to achieve a realistic representation of traffic conditions. However, for time's sake, it was agreed to conduct the analysis assuming all intersections are unsignalized (no control). Lastly, the demand and time interval are another crucial aspect of the DTA model. The demand is divided according to Mahut et al.'s time interval (2004).

Figure 6 Downtown Calgary Traffic Network

3.3. Model Calibration

For this study, the DTA model will be primarily calibrated using the concept of off-line calibration, which means it will be calibrated according to historical traffic information. The most typical approach in calibrating a DTA model in DYNAMEQ, as proposed by Mahut et al. (2004), is the use of empirical data such as movement counts. In the case of the Downtown Calgary subnetwork, field count data is not available, which means calibration using such data is not feasible. This study will focus on calibrating the DTA model by altering the demand matrix obtained from the STA subarea analysis. This study's calibration process would involve multiplying numerical factors for the entire matrix or each time interval. The operation is performed until the closest link travel time is almost identical to the historical traffic information from INRIX.

4.0. RESULTS AND DISCUSSIONS

4.1. OD Matrix Calculations and DTA Scenario Definition

The demand matrix from the EMME provincial model was discretized using a 15-minute time interval from 7 AM to 8 AM for the AM Peak network and 4 PM to 5 PM for the PM Peak network. Using the methodology of Mahut et al. (2004), we modified the demand matrix further by combining the demand from 7:15 to 7:45, which made this interval equal to 30 minutes. Also, cars are the only travel modes considered in the matrix for simplicity's sake. The modified base demand matrix is given in **Figures 7** and **8**, where these base matrices are used to create new matrices by applying certain numerical factors at each interval until such condition replicates historical traffic conditions. **Tables 3** and **4** describe the transformation for each newly created matrix for AM and PM conditions, illustrating the operations conducted at specific intervals.

Each calculated demand matrix corresponds to a DTA scenario. Again, DTA specification was followed using the specifications from Mahut et al. (2004). Each DTA is composed of the following: The car is considered the only mode of travel, the maximum number of iterations is equal to 50, no control plans (assumed unsignalized for all intersections), and simulation and lane detection results will run from 7 AM to 9 AM for the AM Peak and 4 PM to 6 PM for the PM Peak. The result intervals will be presented in 5-minute intervals. Once all of the DTA scenarios are defined, all of the DTA scenarios are run all at once to save time. Once all DTA scenarios are run, it is also optional to visualize the result using an animation; therefore, if desired, we run a command to calculate the vehicle trajectories for each DTA scenario.

Interval	Duration	End	Min	Max	Negative	Sparsity	Volume
1	00:15	07:15	0.0003...	927.851	0	77.7 %	5240
2	00:30	07:45	0.0007...	294.861	0	75.1 %	3439
3	00:15	08:00	0.0007...	93.7598	0	88.1 %	899

Figure 7 Base AM Travel Demand from EMME

Interval	Duration	End	Min	Max	Negative	Sparsity	Volume
1	00:15	16:15	0.0079...	1564.95	0	75.7 %	5425
2	00:30	16:45	0.0085...	548.56	0	71.8 %	5016
3	00:15	17:00	0.0176...	122.452	0	88.6 %	758

Figure 8 Base PM Travel Demand from EMME

Table 3 – AM Calculated Demand Matrices through Matrix Calculator

Matrix Name	DTA Scenario	Operation(s)
am1	D1	base$2*(**2.5**) to Interval 2
		base$3*(6) to Interval 3
am2	D2	base$2*(**2.5**) to Interval 2
		base$2*(6.5) to Interval 3
am3	D3	base$2*(**3**) to Interval 2
		base$3*(6) to Interval 3
am4	D4	base$2*(**3**) to Interval 2
		base$3*(6.5) to Interval 3
am5	D5	base$2*(**3.5**) to Interval 2
		base$3*(6) to Interval 3
am6	D6	base$2*(**3.5**) to Interval 2
		base$3*(6.5) to Interval 3

am7	D7	base$2*(**4**) to Interval 2
		base$3*(6) to Interval 3
am8	D8	base$2*(**4**) to Interval 2
		base$3*(6.5) to Interval 3
am9	D9	base$2*(**4.5**) to Interval 2
		base$3*(6) to Interval 3
am10	D10	base$2*(**4.5**) to Interval 2
		base$3*(6.5) to Interval 3

Table 4 - PM Calculated Demand Matrices through Matrix Calculator

Matrix Name	DTA Scenario	Operation(s)
pm1	D1	base$2*(**2.5**) to Interval 2
		base$3*(7) to Interval 3
pm2	D2	base$2*(**2.5**) to Interval 2
		base$3*(7.5) to Interval 3
pm3	D3	base$2*(**3**) to Interval 2
		base$3*(7 to Interval 3
pm4	D4	base$2*(**3**) to Interval 2
		base$3*(7.5) to Interval 3
pm5	D5	base$2*(**3.5**) to Interval 2
		base$3*(7) to Interval 3
pm6	D6	base$2*(**3.5**) to Interval 2
		base$3*(7.5) to Interval 3
pm7	D7	base$2*(**4**) to Interval 2
		base$3*(7) to Interval 3
pm8	D8	base$2*(**4**) to Interval 2
		base$3*(7.5) to Interval 3
pm9	D9	base$2*(**4.5**) to Interval 2
		base$3*(7) to Interval 3
pm10	D10	base$2*(**4.5**) to Interval 2
		base$3*(7) to Interval 3

4.2. Ground Truth / Historical Traffic Data

It is crucial to compare the results of DTA runs to ground truth data for validation and calibration purposes. This study utilized historical traffic data from INRIX's Roadway Analytics platform to compare link travel time and speed at various intervals. This study's historical information gathered from INRIX was from August 1, 2020, to October 31, 2020, and August 1, 2023, to October 31, 2023, to account for the analysis period specified in the provincial model as the Fall season and analysis periods are from 7 to 8 AM (AM Peak) and 4 to 5 PM (PM Peak) in 15-minute intervals, similar to the DTA model. Before comparing, critical links were also identified through a scan of Google Maps's typical traffic fabric, which is the portion of the roadway where congestion typically happens during morning or afternoon commutes. As shown in **Figure 9**, the links in red and blue colors are the links that are typically congested during AM and PM peak travel, respectively. For the AM scenario, according to Google Maps, the most commonly congested roads near and within Downtown Calgary are Bow Trail / 9 Avenue SW EB, 10 Street NW (Louise Bridge) SB, 4th Avenue Flyover, and Centre Street SB (entering Downtown). Lastly, for the PM scenario, the most commonly congested roads are 4th Avenue SW WB, 10 Street NW (Louise Bridge) NB, 1 Street SE SB (between 9 Avenue and 6 Avenue), and Macleod Trail SE NB (between 9 Avenue and 6 Avenue). These selected links are the main calibration area where we aim to achieve as close as possible to link travel times and speeds from historical data. **Table 5** below summarizes the road class according to the City of Calgary's classification standards.

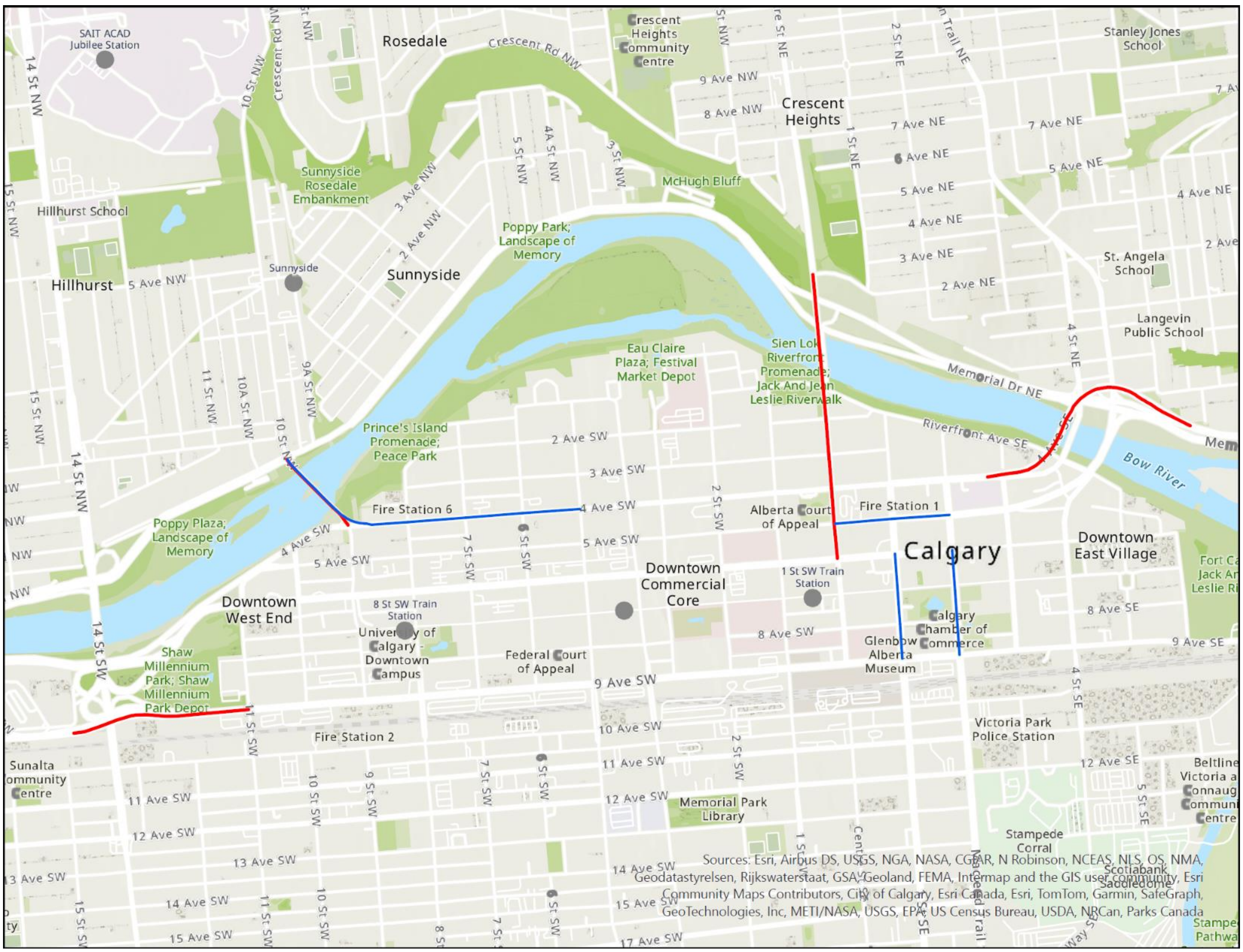

Figure 9 Critical / Most Congested Links during AM/PM Peak Travel

Table 5 – Select Links Road Classification

Link Name	Scenario	Road Classification
Bow Trail	AM	Arterial Steet
9 Avenue SW	AM	Arterial Steet
10 Street NW SB	AM	Neighborhood Boulevard
Centre Street SB	AM	Urban Boulevard, Arterial Street
4 Avenue Flyover	AM	Skeletal Road
Macleod Trail NB (9 Avenue SE to 6 Avenue SE)	PM	Arterial Steet
1 Street SE (9 Avenue SE to 6 Avenue SE)	PM	Arterial Steet
5 Avenue SW (Centre Street to Macleod Trail	PM	Arterial Steet
10 Street NW NB	PM	Neighborhood Boulevard
4 Avenue SW WB (9 Street SW to 5 Street SW)	PM	Arterial Steet

Average speed and travel time for AM and PM Peak scenarios are also compared for validation. Given that in 2020, we were in a pandemic setting (COVID-19) that limited the amount of unnecessary travel, the speeds should at least be higher than usual (lower travel times) during peak travel periods. **Tables 6** and **7** summarize the speed and travel time comparisons between scenarios, showcasing the differences between the speed and travel time of both periods. Generally, when comparing speeds, speeds during peak travel should be higher in 2020 than in 2023; hence, the table should yield a negative difference, while travel time will be the opposite, resulting in a decrease (positive difference) from 2023 to 2020. It should be noted that there were some instances where either speed increased (i.e., 2023 peak travel speeds are higher than 2020) from 2020 to 2023, which can be anomalous since there will be more demand in 2023 than in 2020. The same goes for travel time; some links have increased travel time (i.e., 2020 peak travel times are higher than 2023) during 2020 rather than 2023.

Table 6 – AM and PM Scenario Historical Speeds (2020 and 2023)

Link Name: Bow Trail				**Link Name:** 10 Street NW NB (Louise Bridge)			
Road Class: Arterial Street				**Road Class:** Neighborhood Boulevard			
Time Interval	**Speed (2023)**	**Speed (2020)**	**Difference**	**Time Interval**	**Speed (2023)**	**Speed (2020)**	**Difference**
7:00 - 7:15	52.955	54.600	-1.65	4:00 - 4:15	30.652	28.467	2.19
7:15 - 7:30	50.333	56.231	-5.90	4:15 - 4:30	30.788	28.477	2.31
7:30 - 7:45	48.742	56.662	-7.92	4:30 - 4:45	30.705	27.392	3.31
7:45 - 8:00	48.621	56.077	-7.46	4:45 - 5:00	29.887	26.5	3.39
Link Name: 9 Avenue SW near 11 Street SW				**Link Name:** 4 Ave SW (between 8 St SW and Exit turn)			
Road Class: Arterial Street				**Road Class:** Arterial Street			
Time Interval	**Speed (2023)**	**Speed (2020)**	**Difference**	**Time Interval**	**Speed (2023)**	**Speed (2020)**	**Difference**
7:00 - 7:15	43.190	43.892	-0.70	4:00 - 4:15	30.576	33.523	-2.95
7:15 - 7:30	40.735	44.885	-4.15	4:15 - 4:30	30.864	34.092	-3.23
7:30 - 7:45	39.857	45.200	-5.34	4:30 - 4:45	30.667	34.4	-3.73
7:45 - 8:00	39.318	44.639	-5.32	4:45 - 5:00	29.47	34.354	-4.88
Link Name: 10 Street NW				**Link Name:** 4 Ave SW (between 8 St SW and 7 St SW)			
Road Class: Neighborhood Boulevard				**Road Class:** Arterial Street			

Time Interval	Speed (2023)	Speed (2020)	Difference	Time Interval	Speed (2023)	Speed (2020)	Difference
7:00 - 7:15	24.379	26.738	-2.36	4:00 - 4:15	35.394	34.754	0.64
7:15 - 7:30	23.061	26.615	-3.55	4:15 - 4:30	35.409	35.031	0.38
7:30 - 7:45	21.47	26.415	-4.95	4:30 - 4:45	35.364	35.6	-0.24
7:45 - 8:00	21.197	26.446	-5.25	4:45 - 5:00	34.318	36.215	-1.90
Link Name: Centre Street SB (Samis Road to 2 Avenue SW)				**Link Name:** 4 Ave SW (between 7 St SW and 6 St SW)			
Road Class: Urban Boulevard				**Road Class:** Arterial Street			
Time Interval	**Speed (2023)**	**Speed (2020)**	**Difference**	**Time Interval**	**Speed (2023)**	**Speed (2020)**	**Difference**
7:00 - 7:15	36.470	23.031	13.44	4:00 - 4:15	39.515	35.646	3.87
7:15 - 7:30	37.515	22.631	14.88	4:15 - 4:30	39.879	35.523	4.36
7:30 - 7:45	38.212	22.000	16.21	4:30 - 4:45	39.803	36.123	3.68
7:45 - 8:00	38.561	22.169	16.39	4:45 - 5:00	38.833	37.092	1.74
Link Name: Centre Street SB (2 Avenue to 3 Avenue)				**Link Name:** 4 Ave SW (between 6 St SW and 5 St SW)			
Road Class: Arterial Street				**Road Class:** Arterial Street			
Time Interval	**Speed (2023)**	**Speed (2020)**	**Difference**	**Time Interval**	**Speed (2023)**	**Speed (2020)**	**Difference**
7:00 - 7:15	15.076	18.231	-3.16	7:00 - 7:15	38.818	35.615	3.20
7:15 - 7:30	15.955	18.231	-2.28	7:15 - 7:30	38.682	35.477	3.21
7:30 - 7:45	15.939	17.446	-1.51	7:30 - 7:45	38.485	36.338	2.15
7:45 - 8:00	16.227	17.415	-1.19	7:45 - 8:00	37.364	37.2	0.16
Link Name: Centre Street SB (3rd Avenue to 4th Avenue)				**Link Name:** 5 Ave SW (between Centre St S and 1 St SE)			
Road Class: Arterial Street				**Road Class:** Arterial Street			
Time Interval	**Speed (2023)**	**Speed (2020)**	**Difference**	**Time Interval**	**Speed (2023)**	**Speed (2020)**	**Difference**
7:00 - 7:15	14.955	18.354	-3.40	4:00 - 4:15	31.439	34.738	-3.30
7:15 - 7:30	15.682	18.246	-2.56	4:15 - 4:30	30.864	34.323	-3.46
7:30 - 7:45	15.712	17.446	-1.73	4:30 - 4:45	30.742	33.338	-2.60
7:45 - 8:00	15.818	17.400	-1.58	4:45 - 5:00	29.545	32.862	-3.32
Link Name: Centre Street SB (4th Avenue to 5th Avenue)				**Link Name:** 5 Ave SW (between 1 St SE and Macleod Trail SE)			
Road Class: Arterial Street				**Road Class:** Arterial Street			
Time Interval	**Speed (2023)**	**Speed (2020)**	**Difference**	**Time Interval**	**Speed (2023)**	**Speed (2020)**	**Difference**
7:00 - 7:15	14.242	18.277	-4.04	4:00 - 4:15	31.939	34.431	-2.49
7:15 - 7:30	14.939	18.246	-3.31	4:15 - 4:30	31.318	34.785	-3.47
7:30 - 7:45	15.288	17.446	-2.16	4:30 - 4:45	31.545	33.554	-2.01
7:45 - 8:00	15.545	17.246	-1.70	4:45 - 5:00	30.212	32.462	-2.25
Link Name: Centre Street SB (5th Avenue to 6th Avenue)				**Link Name:** 1 St SE (between 9 Ave SE and 8 Ave SE)			
Road Class: Arterial Street				**Road Class:** Arterial Street			
Time Interval	**Speed (2023)**	**Speed (2020)**	**Difference**	**Time Interval**	**Speed (2023)**	**Speed (2020)**	**Difference**
7:00 - 7:15	14.197	18.262	-4.07	4:00 - 4:15	30.955	33.692	-2.74
7:15 - 7:30	14.864	18.246	-3.38	4:15 - 4:30	31.561	33.446	-1.89
7:30 - 7:45	15.424	17.446	-2.02	4:30 - 4:45	32.576	33.631	-1.06
7:45 - 8:00	15.652	17.185	-1.53	4:45 - 5:00	30.985	33.246	-2.26
Link Name: 4th Avenue Flyover				**Link Name:** 1 St SE (between 8 Ave SE and 6 Ave SE)			
Road Class: Arterial Street				**Road Class:** Arterial Street			

Time Interval	Speed (2023)	Speed (2020)	Difference
7:00 - 7:15	54.167	55.254	-1.09
7:15 - 7:30	52.977	54.977	-2.00
7:30 - 7:45	53.197	55.454	-2.26
7:45 - 8:00	53.742	55.7	-1.96

Time Interval	Speed (2023)	Speed (2020)	Difference
4:00 - 4:15	26.530	31.338	-4.81
4:15 - 4:30	27.030	30.477	-3.45
4:30 - 4:45	27.500	30.831	-3.33
4:45 - 5:00	26.258	31.062	-4.80
Link Name: Macleod Trail NB (between 9 Ave and 8 Ave SE)			
Road Class: Arterial Street			
Time Interval	**Speed (2023)**	**Speed (2020)**	**Difference**
4:00 - 4:15	29.030	23.200	5.83
4:15 - 4:30	29.015	22.908	6.11
4:30 - 4:45	28.212	22.785	5.43
4:45 - 5:00	27.136	22.000	5.14
Link Name: Macleod Trail NB (between 8 Ave and 6 Ave SE)			
Road Class: Arterial Street			
Time Interval	**Speed (2023)**	**Speed (2020)**	**Difference**
4:00 - 4:15	27.848	23.354	4.49
4:15 - 4:30	27.576	23.031	4.55
4:30 - 4:45	27.136	23.569	3.57
4:45 - 5:00	26.136	22.785	3.35

Table 7 – AM and PM Historical Travel Times (2020 and 2023)

Link Name: Bow Trail			
Road Class: Arterial Street			
Time Interval	**Travel Time (2023)**	**Travel Time (2020)**	**Difference**
7:00 - 7:15	19.92	19.44	0.48
7:15 - 7:30	21.18	18.96	2.22
7:30 - 7:45	22.02	18.78	3.24
7:45 - 8:00	22.50	18.90	3.60
Link Name: 9 Avenue SW near 11 Street SW			
Road Class: Arterial Street			
Time Interval	**Travel Time (2023)**	**Travel Time (2020)**	**Difference**
7:00 - 7:15	24.78	25.98	-1.20
7:15 - 7:30	26.28	25.44	0.84
7:30 - 7:45	27.06	25.14	1.92
7:45 - 8:00	27.42	25.26	2.16
Link Name: 10 Street NW			
Road Class: Neighborhood Boulevard			
Time Interval	**Travel Time (2023)**	**Travel Time (2020)**	**Difference**
7:00 - 7:15	46.02	39.66	6.36

Link Name: 10 Street NW NB (Louise Bridge)			
Road Class: Neighborhood Boulevard			
Time Interval	**Travel Time (2023)**	**Travel Time (2020)**	**Difference**
4:00 - 4:15	41.52	44.04	-2.52
4:15 - 4:30	41.52	44.28	-2.76
4:30 - 4:45	42.12	45.84	-3.72
4:45 - 5:00	43.74	47.04	-3.30
Link Name: 4 Ave SW (between 8 St SW and Exit turn)			
Road Class: Arterial Street			
Time Interval	**Travel Time (2023)**	**Travel Time (2020)**	**Difference**
4:00 - 4:15	14.34	13.32	1.02
4:15 - 4:30	14.28	12.90	1.38
4:30 - 4:45	14.46	12.84	1.62
4:45 - 5:00	15.00	12.78	2.22
Link Name: 4 Ave SW (between 8 St SW and 7 St SW)			
Road Class: Arterial Street			
Time Interval	**Travel Time (2023)**	**Travel Time (2020)**	**Difference**
4:00 - 4:15	17.52	17.76	-0.24

7:15 - 7:30	47.52	39.72	7.80	4:15 - 4:30	17.52	17.58	-0.06
7:30 - 7:45	50.82	39.78	11.04	4:30 - 4:45	17.70	17.40	0.30
7:45 - 8:00	51.9	39.78	12.12	4:45 - 5:00	18.06	17.04	1.02
Link Name: Centre Street SB (Samis Road to 2 Avenue SW)				**Link Name:** 4 Ave SW (between 7 St SW and 6 St SW)			
Road Class: Urban Boulevard				**Road Class:** Arterial Street			
Time Interval	**Travel Time (2023)**	**Travel Time (2020)**	**Difference**	**Time Interval**	**Travel Time (2023)**	**Travel Time (2020)**	**Difference**
7:00 - 7:15	43.56	69.12	-25.56	4:00 - 4:15	16.32	18.18	-1.86
7:15 - 7:30	42.36	69.60	-27.24	4:15 - 4:30	16.20	18.12	-1.92
7:30 - 7:45	41.34	72.12	-30.78	4:30 - 4:45	16.20	17.82	-1.62
7:45 - 8:00	41.16	72.36	-31.20	4:45 - 5:00	16.68	17.46	-0.78
Link Name: Centre Street SB (2 Avenue to 3 Avenue)				**Link Name:** 4 Ave SW (between 6 St SW and 5 St SW)			
Road Class: Arterial Street				**Road Class:** Arterial Street			
Time Interval	**Travel Time (2023)**	**Travel Time (2020)**	**Difference**	**Time Interval**	**Travel Time (2023)**	**Travel Time (2020)**	**Difference**
7:00 - 7:15	26.34	21.72	4.62	7:00 - 7:15	15.72	17.22	-1.50
7:15 - 7:30	25.08	21.66	3.42	7:15 - 7:30	15.72	17.16	-1.44
7:30 - 7:45	24.90	22.44	2.46	7:30 - 7:45	15.78	16.86	-1.08
7:45 - 8:00	24.78	22.74	2.04	7:45 - 8:00	16.38	16.50	-0.12
Link Name: Centre Street SB (3rd Avenue to 4th Avenue)				**Link Name:** 5 Ave SW (between Centre St S and 1 St SE)			
Road Class: Arterial Street				**Road Class:** Arterial Street			
Time Interval	**Travel Time (2023)**	**Travel Time (2020)**	**Difference**	**Time Interval**	**Travel Time (2023)**	**Travel Time (2020)**	**Difference**
7:00 - 7:15	24.54	19.38	5.16	4:00 - 4:15	20.40	18.54	1.86
7:15 - 7:30	23.58	19.44	4.14	4:15 - 4:30	20.82	18.66	2.16
7:30 - 7:45	23.28	20.40	2.88	4:30 - 4:45	20.64	19.50	1.14
7:45 - 8:00	23.28	20.70	2.58	4:45 - 5:00	21.60	19.56	2.04
Link Name: Centre Street SB (4th Avenue to 5th Avenue)				**Link Name:** 5 Ave SW (between 1 St SE and Macleod Trail SE)			
Road Class: Arterial Street				**Road Class:** Arterial Street			
Time Interval	**Travel Time (2023)**	**Travel Time (2020)**	**Difference**	**Time Interval**	**Travel Time (2023)**	**Travel Time (2020)**	**Difference**
7:00 - 7:15	28.38	22.44	5.94	4:00 - 4:15	19.50	18.36	1.14
7:15 - 7:30	27.30	22.38	4.92	4:15 - 4:30	19.86	18.06	1.80
7:30 - 7:45	26.82	23.40	3.42	4:30 - 4:45	19.68	18.78	0.90
7:45 - 8:00	26.64	23.82	2.82	4:45 - 5:00	20.34	19.86	0.48
Link Name: Centre Street SB (5th Avenue to 6th Avenue)				**Link Name:** 1 St SE (between 9 Ave SE and 8 Ave SE)			
Road Class: Arterial Street				**Road Class:** Arterial Street			
Time Interval	**Travel Time (2023)**	**Travel Time (2020)**	**Difference**	**Time Interval**	**Travel Time (2023)**	**Travel Time (2020)**	**Difference**
7:00 - 7:15	25.86	20.64	5.22	4:00 - 4:15	12.18	11.16	1.02
7:15 - 7:30	24.54	20.58	3.96	4:15 - 4:30	11.88	11.22	0.66
7:30 - 7:45	24.00	21.36	2.64	4:30 - 4:45	11.58	11.10	0.48
7:45 - 8:00	24.00	21.84	2.16	4:45 - 5:00	12.12	11.16	0.96
Link Name: 4th Avenue Flyover				**Link Name:** 1 St SE (between 8 Ave SE and 6 Ave SE)			
Road Class: Arterial Street				**Road Class:** Arterial Street			
Time Interval	**Travel Time (2023)**	**Travel Time (2020)**	**Difference**	**Time Interval**	**Travel Time (2023)**	**Travel Time (2020)**	**Difference**
7:00 - 7:15	49.08	24.21	24.87	4:00 - 4:15	29.34	24.84	4.50
7:15 - 7:30	50.58	24.36	26.22	4:15 - 4:30	28.68	26.76	1.92

7:30 - 7:45	50.46	24.24	26.22	4:30 - 4:45	28.02	25.92	2.10
7:45 - 8:00	49.86	24.56	25.30	4:45 - 5:00	29.46	25.26	4.20

Link Name: Macleod Trail NB (between 9 Ave and 8 Ave SE)			
Road Class: Arterial Street			
Time Interval	**Travel Time (2023)**	**Travel Time (2020)**	**Difference**
4:00 - 4:15	12.96	16.50	-3.54
4:15 - 4:30	13.02	16.68	-3.66
4:30 - 4:45	13.56	16.80	-3.24
4:45 - 5:00	14.22	17.70	-3.48

Link Name: Macleod Trail NB (between 8 Ave and 6 Ave SE)			
Road Class: Arterial Street			
Time Interval	**Travel Time (2023)**	**Travel Time (2020)**	**Difference**
4:00 - 4:15	28.14	34.44	-6.30
4:15 - 4:30	28.62	35.04	-6.42
4:30 - 4:45	29.40	33.90	-4.50
4:45 - 5:00	30.36	35.34	-4.98

4.3. Modeling Results

The DTA scenarios derived from the new matrices formed from the Matrix Calculator command in DYNAMEQ (as shown in **Tables 3** and **4**) were run to determine and analyze link-specific attributes, which for this study are speed and travel time. For each DTA scenario, link speed and travel time for the select links specified in **Figure 9** above were extracted from the DTA run results and recorded per time interval. The AM and PM link results are summarized in tabular form and included in the **Appendix**. A couple of tables are included in this subsection to discuss the results of the DTA modeling conducted in this study. The modeling results for this study suggested a notable discrepancy between observed and simulated traffic parameters (link speed and link travel time). Our model's computed link speed and travel time through various DTA scenarios showed huge discrepancies from the INRIX traffic dataset for each link from either the AM or PM scenario. As an example, **Tables 8** and **9** below illustrate the modeling results of the Bow Trail SW link, as also indicated in **Figure 10**. **Table 8** summarizes the calculated speed (in km/h) at each DTA scenario and time interval, while **Table 9** summarizes the calculated link travel time (in seconds). In both tables, it can be observed that regardless of the matrix transformation (as it corresponds to the DTA scenario), it rarely changed the speed and travel time values, which can be read as an unrealistic outcome. A few errors in the model network and specific network attributes were either wrongly defined or assumed, which will be discussed in the following subsection.

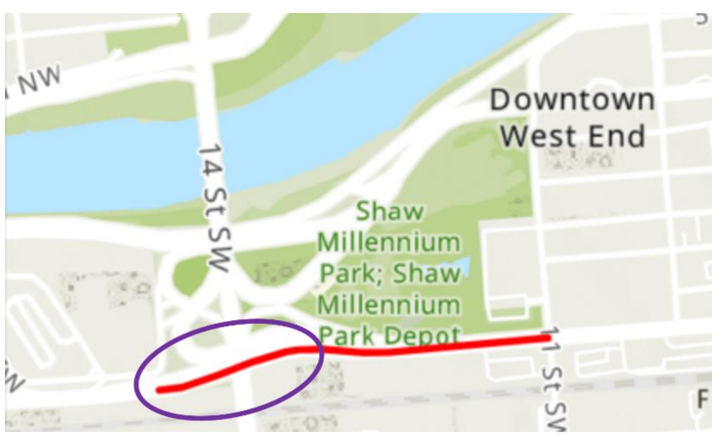

Figure 10 Bow Trail SW Link

Table 8 – Bow Trail SW DTA Results, Speed (AM Peak)

Link: Bow Trail SW													
Time Interval	**Historical (2023)**	**Historical (2020)**	**B0**	**D1**	**D2**	**D3**	**D4**	**D5**	**D6**	**D7**	**D8**	**D9**	**D10**
7:00 - 7:15	52.955	54.600	60	60	60	60	60	60	60	60	60	59	59
7:15 - 7:30	50.333	56.231	60	60	60	60	60	60	60	60	60	60	58
7:30 - 7:45	48.742	56.662	60	60	60	60	60	60	60	60	60	60	60
7:45 - 8:00	48.621	56.077	60	60	60	60	60	60	60	60	60	60	60

Table 9 – Bow Trail SW DTA Results, Travel Time (AM Peak)

Link: Bow Trail SW													
Time Interval	**Historical (2023)**	**Historical (2020)**	**B0**	**D1**	**D2**	**D3**	**D4**	**D5**	**D6**	**D7**	**D8**	**D9**	**D10**
7:00 - 7:15	19.92	19.44	27	27	27	27	27	27	27	27	27	27	27
7:15 - 7:30	21.18	18.96	27	27	27	27	27	27	27	27	27	27	27
7:30 - 7:45	22.02	18.78	27	27	27	27	27	27	27	27	27	27	27
7:45 - 8:00	22.50	18.90	27	27	27	27	27	27	27	27	27	27	27

4.4. Modeling Errors

As observed from the previous subsection, it was evident that our model did not reasonably produce the result we had hoped for, which is adjusting the demand such that it mimics the same traffic characteristics as the historical traffic data extracted from INRIX's Roadway Analytics. Some known errors and assumptions may have affected the result of our model runs, which are summarized below:

- **Unsignalized Intersection Assumptions.** Due to the steep learning curve of the application and limited time to perform the analysis, it was agreed to perform the analysis using the assumption that intersections are *unsignalized* (no control) for all the intersections in the subnetwork. Recall that **Figure 5** illustrates the DTA algorithmic procedure in DYNAMEQ, where a **traffic control plan** is essential to building this dynamic model to accurately capture spatiotemporal pattern shifts in traffic. Assuming *all* of the junctions are *unsignalized* affected the way traffic was characterized. For example, in a fully signalized intersection, vehicle movement depends on the signal cycle and protected turns, while in *unsignalized* intersections, generally in this study's context, meant no control and, as such, allowed for a vehicle to traverse the intersection where the first vehicle approaching the intersection will be the first to exit. This assumption left out the crucial aspect of traffic dynamics, which is queueing (waiting vehicles), where this is the norm for *controlled* intersections and was inaccurately represented in our modeling efforts.
- **Junction Capacity.** This issue was related to the first point described, assuming all of the junctions in the subnetwork are *unsignalized* (uncontrolled). One solution discussed was assigning junction capacity (also a function) from EMME and then importing it back to DYNAMEQ. **Figure 11** shows the interface where the capacities would be imported and kept on the *Capacities/Alignment*s tab. While this would fix the capacity at the intersection level, this would also mean resetting the cleaned network without the junction capacity analysis, which would take longer to rebuild the network. Therefore, the results presented in this study were from the network without the junction capacity analysis from EMME.
- **Link Free Flow Speed.** When importing the EMME network to DYNAMEQ, one crucial link attribute (optional in the EMME tool) was assigned the attribute with free flow speed value. There was no proper documentation in the node attribute description that definitively describes the free flow speed in the link; therefore, for this study, the free flow speed used was from DYNAMEQ's default value of 60 km/h, which as seen in the summary tables, calculated speeds were almost in this value and unrealistic. The same issue with the junction capacity is that the network would have to be rebuilt, which takes some time, given our limited time for this study.

- **Demand Matrix Transformation.** This study aimed to calibrate the DTA model for the Downtown Calgary subnetwork by transforming the base demand from EMME. The proposed matrix transformations presented in Tables 3 and 4 attempt to replicate Mahut et al. (2004) matching the demand patterns from 7 AM to 8 AM, where the demand increases after the first interval and decreases after the second interval. No matter how much we increase the factors on each interval, the results will likely be the same as what we currently have if the preceding bullet points of issues and errors still need to be addressed.

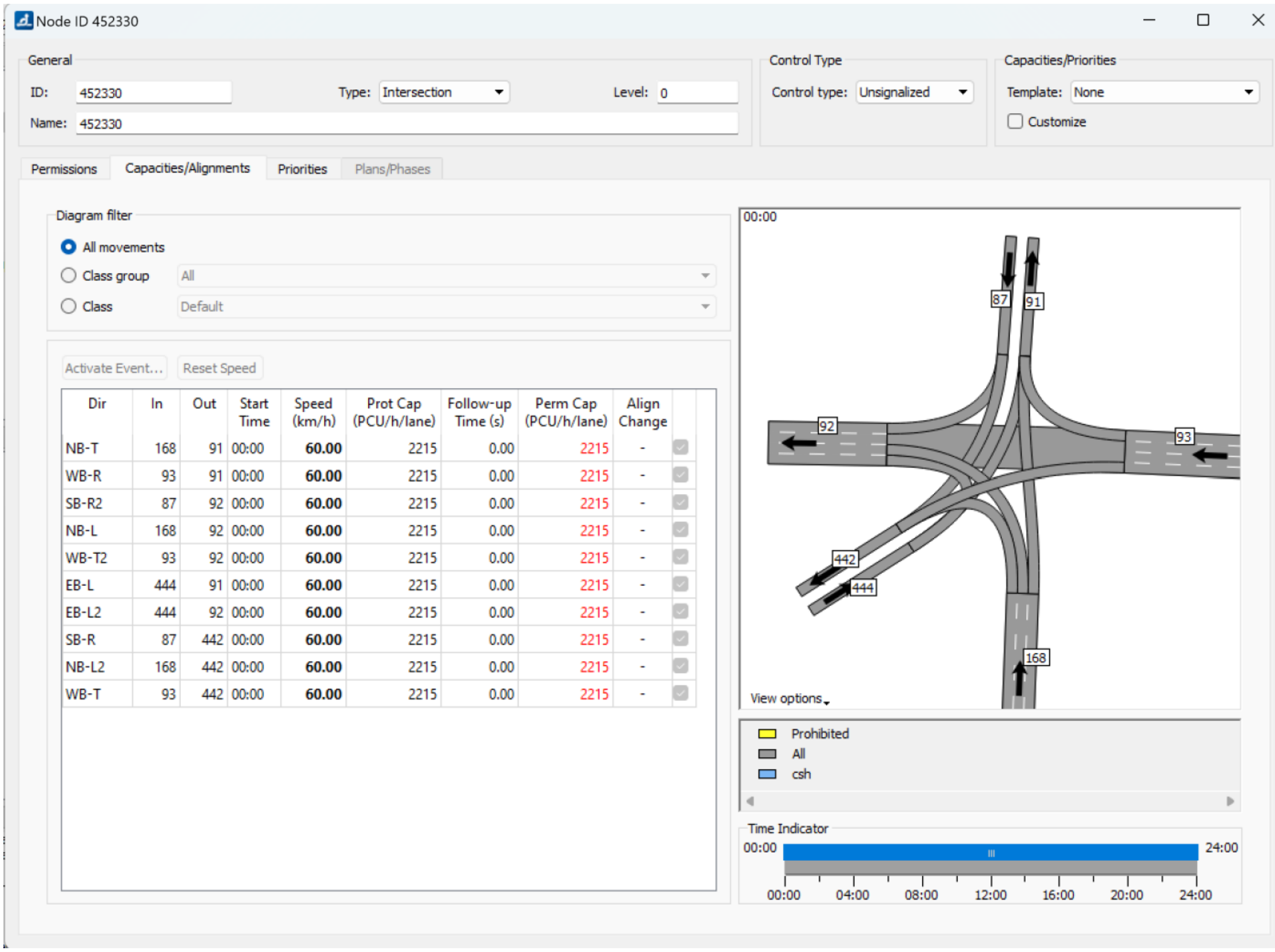

Figure 11 Junction Capacity Inputs in DYNAMEQ

5.0. CONCLUSIONS

This study explored dynamic traffic assignment (DTA) modeling for Calgary's downtown area, utilizing the Alberta Spatial, Economic, and Transportation Model (ASET) as its foundation. The simulation-based DTA (SB-DTA) model aims to capture traffic dynamics accurately and reflect real-time congestion patterns during peak hours. The results, however, highlighted notable disparities between simulated traffic metrics and historical data. Despite the iterative model construction approach, discrepancies were observed in link speeds and travel times across critical routes. For instance, simulated speeds on major links, such as Bow Trail and 10th Street NW, remained constant and inconsistent with real-world traffic flows, failing to reflect Calgary's current traffic conditions accurately. The discrepancies revealed a need for more comprehensive calibration strategies. The demand matrix transformation from the ASET model into specific time intervals and applying various numerical factors provided limited improvement. This indicated that more refined approaches might be needed to bridge the gap between simulated and real-world traffic metrics. Thus, The study laid the groundwork for further research, underscoring the need for enhanced calibration and more accurate modeling techniques. Future iterations should refine these methods to align simulated and actual traffic patterns better, supporting effective traffic management and informed decision-making. Additionally, incorporating intersection controls, accurate signal timing plans, and junction capacities would enhance the model's accuracy, providing a more realistic representation of Calgary's traffic conditions.

5.1. Study Limitations

Given the time constraints of this study, it is crucial to acknowledge the following limitations, which will serve as a guide for future studies about the subject matter:

- Future studies should pay meticulous attention to correcting turning movements for all junctions. This crucial aspect significantly influences the simulation's behavior, mirroring real-life scenarios where cars make turning and movement decisions based on various intersection layouts and treatments.
- The availability of crucial data from the EMME to DYNAMEQ migration, mainly historical traffic count data for the subnetwork, is paramount. Its absence in this study made it difficult to determine how sparse the base and DTA run counts would be. Historical traffic counts, a vital calibration parameter, must be available for future studies to use as ground truth data and guide the calibration process alongside other traffic parameters such as speed and travel time (Mahut et al., 2004).
- A traffic control plan (signal timing plan) plays a pivotal role in running a DTA model, as shown in **Figure 5** above. When migrating from EMME to DYNAMEQ, it was acceptable to use the static traffic assignment on EMME to use volume delay functions as pseudo-control for intersections; however, DYNAMEQ specifically utilizes a signal timing plan for individual intersections to capture dynamic traffic conditions at junctions and decision points effectively. The migration to DYNAMEQ induces defaults such as the type of intersection for each node, and it is by default as *unsignalized*, which was used in this study. Implementing a signal timing plan for each intersection is time-consuming, and this study assumed unsignalized intersections for *all* intersection nodes, which can affect how traffic is presented on DYNAMEQ. Future studies must meticulously implement a signal timing scheme for each intersection node to adequately capture vehicular delay and other traffic parameters during DTA runs.
- During model runs, it was observed that the free flow speed on links rarely fluctuates (only changing from 50 to 60 kph) in response to changing traffic conditions. This suggests that the free flow speed for each link needs to be adequately defined. Future work must account for the overall time spent in network validation.
- This study ignored the effects of transit assignment, where the effect of buses and light rail trains on traffic dynamics was shelved. For a more realistic model result, transit assignment must be included. Considering our study area, Downtown Calgary, multiple bus routes and light rail right-of-way can affect private vehicle driving patterns.
- Finally, it is suggested that future studies use the city's EMME model rather than the provincial version since it is likely maintained in the city's interest compared to subsetting from the entire province's road network, which may have many bypasses and shortcuts (virtual VDF for intersections) in performing traffic assignment.

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APPENDIX

AM Scenario – Speed Results

Link: Bow Trail SW

Time Interval	Historical (2023)	Historical (2020)	B0	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
7:00 - 7:15	52.955	54.600	60	60	60	60	60	60	60	60	60	59	59
7:15 - 7:30	50.333	56.231	60	60	60	60	60	60	60	60	60	60	58
7:30 - 7:45	48.742	56.662	60	60	60	60	60	60	60	60	60	60	60
7:45 - 8:00	48.621	56.077	60	60	60	60	60	60	60	60	60	60	60

Link: 9 Avenue SW

Time Interval	Historical (2023)	Historical (2020)	B0	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
7:00 - 7:15	43.190	43.892	56	55	55	55	55	55	55	55	55	54	54
7:15 - 7:30	40.735	44.885	59	58	57	55	55	55	56	54	54	53	52
7:30 - 7:45	39.857	45.200	60	57	58	57	57	56	56	56	55	54	54
7:45 - 8:00	39.318	44.639	60	59	59	59	59	58	59	58	59	58	58

Link: 10 Street NW SB (Louise Bridge)

Time Interval	Historical (2023)	Historical (2020)	B0	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
7:00 - 7:15	24.379	26.738	59	59	59	59	59	59	59	59	59	58	58
7:15 - 7:30	23.061	26.615	59	59	59	59	59	59	59	58	58	57	57
7:30 - 7:45	21.470	26.415	60	58	58	58	58	58	58	58	58	57	57
7:45 - 8:00	21.197	26.446	60	58	57	57	58	58	57	58	56	57	57

Link: Centre Street SB - Samis Road to 2 Avenue SW

Time Interval	Historical (2023)	Historical (2020)	B0	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
7:00 - 7:15	36.470	23.031	60	60	60	60	60	60	60	60	60	60	60
7:15 - 7:30	37.515	22.631	60	60	60	59	59	59	59	58	58	59	59
7:30 - 7:45	38.212	22.000	60	59	59	60	60	59	60	59	59	58	58
7:45 - 8:00	38.561	22.169	60	59	59	59	59	59	60	60	60	59	59

Link: Centre Street SB - 2 Avenue to 3 Avenue

Time Interval	Historical (2023)	Historical (2020)	B0	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
7:00 - 7:15	15.076	18.231	59	59	59	59	59	58	58	59	59	59	59
7:15 - 7:30	15.955	18.231	60	59	59	58	58	59	59	58	58	57	58
7:30 - 7:45	15.939	17.446	60	60	59	58	58	58	58	56	57	58	57
7:45 - 8:00	16.227	17.415	60	60	58	58	58	59	59	59	58	59	58

Link: Centre Street SB - 3 Avenue to 4 Avenue

Time Interval	Historical (2023)	Historical (2020)	B0	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
7:00 - 7:15	14.955	18.354	57	55	57	57	57	56	56	57	57	57	57
7:15 - 7:30	15.682	18.246	59	58	58	58	58	57	57	57	56	55	54
7:30 - 7:45	15.712	17.446	59	58	57	58	57	57	56	55	55	55	55
7:45 - 8:00	15.818	17.4	60	57	56	56	56	57	56	56	55	56	56

Link: Centre Street SB - 4 Avenue to 5 Avenue

Time Interval	Historical (2023)	Historical (2020)	B0	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
7:00 - 7:15	14.242	18.277	58	58	58	58	58	58	58	58	58	58	58
7:15 - 7:30	14.939	18.246	58	58	58	56	56	56	55	55	55	55	55
7:30 - 7:45	15.288	17.446	58	55	57	56	56	55	55	53	54	52	54
7:45 - 8:00	15.545	17.246	58	49	47	46	48	49	49	49	47	47	49
Link: Centre Street SB - 5 Avenue to 6 Avenue													
Time Interval	**Historical (2023)**	**Historical (2020)**	**B0**	**D1**	**D2**	**D3**	**D4**	**D5**	**D6**	**D7**	**D8**	**D9**	**D10**
7:00 - 7:15	14.197	18.262	55	54	54	55	55	55	55	56	56	56	56
7:15 - 7:30	14.864	18.246	57	56	56	56	56	55	56	55	54	53	54
7:30 - 7:45	15.424	17.446	58	56	57	57	54	55	53	56	53	54	54
7:45 - 8:00	15.652	17.185	59	56	56	57	55	56	56	55	57	55	57
Link: 4th Avenue Flyover													
Time Interval	**Historical (2023)**	**Historical (2020)**	**B0**	**D1**	**D2**	**D3**	**D4**	**D5**	**D6**	**D7**	**D8**	**D9**	**D10**
7:00 - 7:15	54.167	55.254	60	60	60	60	60	60	60	60	60	60	60
7:15 - 7:30	52.977	54.977	60	60	60	60	60	60	60	60	60	60	60
7:30 - 7:45	53.197	55.454	60	60	60	60	60	60	60	60	60	60	60
7:45 - 8:00	53.742	55.700	60	60	60	60	60	60	60	60	60	60	60

AM Scenario – Travel Time Results

Link: Bow Trail SW													
Time Interval	**Historical (2023)**	**Historical (2020)**	**B0**	**D1**	**D2**	**D3**	**D4**	**D5**	**D6**	**D7**	**D8**	**D9**	**D10**
7:00 - 7:15	19.92	19.44	27	27	27	27	27	27	27	27	27	27	27
7:15 - 7:30	21.18	18.96	27	27	27	27	27	27	27	27	27	27	27
7:30 - 7:45	22.02	18.78	27	27	27	27	27	27	27	27	27	27	27
7:45 - 8:00	22.50	18.90	27	27	27	27	27	27	27	27	27	27	27
Link: 9 Avenue SW													
Time Interval	**Historical (2023)**	**Historical (2020)**	**B0**	**D1**	**D2**	**D3**	**D4**	**D5**	**D6**	**D7**	**D8**	**D9**	**D10**
7:00 - 7:15	24.78	25.98	15	15	15	15	15	14	14	14	14	15	15
7:15 - 7:30	26.28	25.44	14	14	14	14	14	14	14	14	15	15	16
7:30 - 7:45	27.06	25.14	13	14	14	14	14	14	14	14	14	15	14
7:45 - 8:00	27.42	25.26	13	13	14	14	14	13	14	13	14	14	14
Link: 10 Street NW (Louise Bridge)													
Time Interval	**Historical (2023)**	**Historical (2020)**	**B0**	**D1**	**D2**	**D3**	**D4**	**D5**	**D6**	**D7**	**D8**	**D9**	**D10**
7:00 - 7:15	46.02	39.66	9	9	9	9	9	9	9	9	9	9	9
7:15 - 7:30	47.52	39.72	9	9	9	9	9	9	9	9	9	9	9
7:30 - 7:45	50.82	39.78	9	9	9	9	9	9	9	9	9	9	9
7:45 - 8:00	51.90	39.78	9	9	9	9	9	9	9	9	9	9	9
Link: Centre Street SB - Samis Road to 2 Avenue SW													
Time Interval	**Historical (2023)**	**Historical (2020)**	**B0**	**D1**	**D2**	**D3**	**D4**	**D5**	**D6**	**D7**	**D8**	**D9**	**D10**
7:00 - 7:15	43.56	69.12	13	13	13	13	13	13	13	13	13	13	13

7:15 - 7:30	42.36	69.60	13	13	13	13	13	13	13	13	13	13	13
7:30 - 7:45	41.34	72.12	13	13	13	13	13	13	13	13	13	14	13
7:45 - 8:00	41.16	72.36	13	13	13	13	13	13	13	13	13	13	13

Link: Centre Street SB - 2 Avenue to 3 Avenue													
Time Interval	**Historical (2023)**	**Historical (2020)**	**B0**	**D1**	**D2**	**D3**	**D4**	**D5**	**D6**	**D7**	**D8**	**D9**	**D10**
7:00 - 7:15	26.34	21.72	7	7	7	7	7	7	7	7	7	7	7
7:15 - 7:30	25.08	21.66	7	7	7	7	7	7	7	7	7	7	7
7:30 - 7:45	24.90	22.44	7	7	7	7	7	7	7	7	7	7	7
7:45 - 8:00	24.78	22.74	7	7	7	7	7	7	7	7	7	7	7

Link: Centre Street SB - 3 Avenue to 4 Avenue													
Time Interval	**Historical (2023)**	**Historical (2020)**	**B0**	**D1**	**D2**	**D3**	**D4**	**D5**	**D6**	**D7**	**D8**	**D9**	**D10**
7:00 - 7:15	24.54	19.38	6	7	7	7	7	7	7	7	7	7	7
7:15 - 7:30	23.58	19.44	6	6	6	6	6	7	7	7	7	7	7
7:30 - 7:45	23.28	20.40	6	6	7	6	6	7	7	7	7	7	7
7:45 - 8:00	23.28	20.70	6	6	7	7	7	7	7	7	7	7	7

Link: Centre Street SB - 4 Avenue to 5 Avenue													
Time Interval	**Historical (2023)**	**Historical (2020)**	**B0**	**D1**	**D2**	**D3**	**D4**	**D5**	**D6**	**D7**	**D8**	**D9**	**D10**
7:00 - 7:15	28.38	22.44	6	6	6	6	6	6	6	6	6	6	6
7:15 - 7:30	27.30	22.38	6	6	6	7	7	7	7	7	7	7	7
7:30 - 7:45	26.82	23.40	6	7	7	7	7	7	7	7	7	7	7
7:45 - 8:00	26.64	23.82	6	8	8	8	8	8	8	8	8	8	8

Link: Centre Street SB - 5 Avenue to 6 Avenue													
Time Interval	**Historical (2023)**	**Historical (2020)**	**B0**	**D1**	**D2**	**D3**	**D4**	**D5**	**D6**	**D7**	**D8**	**D9**	**D10**
7:00 - 7:15	25.86	20.64	7	7	7	7	7	7	7	7	7	7	7
7:15 - 7:30	24.54	20.58	6	7	7	7	7	7	7	7	7	7	7
7:30 - 7:45	24	21.36	6	7	7	6	7	7	7	7	7	7	7
7:45 - 8:00	24	21.84	6	7	7	7	7	7	7	7	7	7	7

Link: 4th Avenue Flyover													
Time Interval	**Historical (2023)**	**Historical (2020)**	**B0**	**D1**	**D2**	**D3**	**D4**	**D5**	**D6**	**D7**	**D8**	**D9**	**D10**
7:00 - 7:15	49.08	24.21	53	53	53	53	53	54	54	53	53	53	53
7:15 - 7:30	50.58	24.36	53	53	53	54	54	53	53	54	54	54	54
7:30 - 7:45	50.46	24.24	53	53	53	53	53	54	54	53	53	53	53
7:45 - 8:00	49.86	24.56	53	53	53	53	53	53	54	53	53	53	54

PM Scenario – Speed Results

Link: 10 Street NW NB (Louise Bridge)													
Time Interval	**Historical (2023)**	**Historical (2020)**	**B0**	**D1**	**D2**	**D3**	**D4**	**D5**	**D6**	**D7**	**D8**	**D9**	**D10**
4:00 - 4:15	30.652	28.467	60	60	60	60	60	60	60	60	60	60	60
4:15 - 4:30	30.788	28.477	60	60	60	60	60	60	60	60	60	60	60
4:30 - 4:45	30.705	27.392	60	60	60	60	60	60	60	60	60	60	60

4:45 - 5:00	29.887	26.500	60	60	60	60	60	60	60	60	60	60	60
Link: 4 Avenue SW - 9 Street to 8 Street SW													
Time Interval	**Historical (2023)**	**Historical (2020)**	**B0**	**D1**	**D2**	**D3**	**D4**	**D5**	**D6**	**D7**	**D8**	**D9**	**D10**
4:00 - 4:15	30.576	33.523	54	54	53	53	52	53	53	52	51	52	52
4:15 - 4:30	30.864	34.092	58	54	52	52	52	48	49	47	46	42	42
4:30 - 4:45	30.667	34.400	59	55	54	52	51	48	48	47	47	39	39
4:45 - 5:00	29.470	34.354	58	55	54	55	53	55	54	53	52	53	53
Link: 4 Avenue SW - 8 Street to 7 Street SW													
Time Interval	**Historical (2023)**	**Historical (2020)**	**B0**	**D1**	**D2**	**D3**	**D4**	**D5**	**D6**	**D7**	**D8**	**D9**	**D10**
4:00 - 4:15	35.394	34.754	59	58	58	58	58	58	58	58	58	57	57
4:15 - 4:30	35.409	35.031	58	57	56	56	56	55	54	52	52	50	50
4:30 - 4:45	35.364	35.600	59	56	56	56	55	52	54	53	53	48	48
4:45 - 5:00	34.318	36.215	60	57	56	57	57	56	56	56	55	56	56
Link: 4 Avenue SW - 7 Street to 6 Street SW													
Time Interval	**Historical (2023)**	**Historical (2020)**	**B0**	**D1**	**D2**	**D3**	**D4**	**D5**	**D6**	**D7**	**D8**	**D9**	**D10**
4:00 - 4:15	39.515	35.646	60	59	59	60	60	59	59	60	60	58	58
4:15 - 4:30	39.879	35.523	60	58	59	58	59	58	58	57	57	57	57
4:30 - 4:45	39.803	36.123	60	57	58	58	58	57	58	57	57	57	57
4:45 - 5:00	38.833	37.092	60	57	58	58	58	57	56	57	57	58	58
Link: 4 Avenue SW - 6 Street to 5 Street SW													
Time Interval	**Historical (2023)**	**Historical (2020)**	**B0**	**D1**	**D2**	**D3**	**D4**	**D5**	**D6**	**D7**	**D8**	**D9**	**D10**
4:00 - 4:15	38.818	35.615	60	59	59	60	60	59	59	60	60	59	58
4:15 - 4:30	38.682	35.477	60	58	59	58	59	58	58	57	57	57	57
4:30 - 4:45	38.485	36.338	60	57	58	58	58	58	58	57	57	57	57
4:45 - 5:00	37.364	37.200	60	57	58	58	58	57	57	57	57	58	58
Link: 5 Avenue SW - Centre Street to 1 Street SE													
Time Interval	**Historical (2023)**	**Historical (2020)**	**B0**	**D1**	**D2**	**D3**	**D4**	**D5**	**D6**	**D7**	**D8**	**D9**	**D10**
4:00 - 4:15	31.439	34.738	55	54	55	54	54	53	53	53	53	54	54
4:15 - 4:30	30.864	34.323	58	57	55	53	54	53	53	49	48	47	47
4:30 - 4:45	30.742	33.338	58	57	55	53	53	51	48	48	48	45	45
4:45 - 5:00	29.545	32.862	59	57	57	57	57	56	57	55	55	55	55
Link: 5 Avenue SW - 1 Street SE to Macleod Trail SE													
Time Interval	**Historical (2023)**	**Historical (2020)**	**B0**	**D1**	**D2**	**D3**	**D4**	**D5**	**D6**	**D7**	**D8**	**D9**	**D10**
4:00 - 4:15	31.939	34.431	59	59	59	58	58	58	58	58	58	58	58
4:15 - 4:30	31.318	34.785	59	58	58	58	58	58	58	57	57	57	57
4:30 - 4:45	31.545	33.554	60	59	58	58	58	58	58	58	58	57	57
4:45 - 5:00	30.212	32.462	60	59	59	59	58	59	59	59	58	59	59
Link: 1 Street SE - 9 Avenue to 8 Avenue SE													
Time Interval	**Historical (2023)**	**Historical (2020)**	**B0**	**D1**	**D2**	**D3**	**D4**	**D5**	**D6**	**D7**	**D8**	**D9**	**D10**
4:00 - 4:15	30.955	33.692	57	57	56	57	57	56	55	56	56	56	56
4:15 - 4:30	31.561	33.446	58	55	56	53	53	55	55	54	53	52	52

Time Interval	Historical (2023)	Historical (2020)	B0	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
4:30 - 4:45	32.576	33.631	59	56	56	56	56	55	55	52	53	52	52
4:45 - 5:00	30.985	33.246	60	57	56	56	56	57	56	55	55	56	56

Link: 1 Street SE - 8 Avenue to 6 Avenue SE													
Time Interval	**Historical (2023)**	**Historical (2020)**	**B0**	**D1**	**D2**	**D3**	**D4**	**D5**	**D6**	**D7**	**D8**	**D9**	**D10**
4:00 - 4:15	26.530	31.338	60	60	60	60	60	60	60	60	60	60	60
4:15 - 4:30	27.030	30.477	60	60	60	60	59	59	60	60	59	59	59
4:30 - 4:45	27.500	30.831	60	60	60	60	59	59	60	59	60	59	59
4:45 - 5:00	26.258	31.062	60	60	60	60	60	60	60	60	60	60	60

Link: Macleod Trail SE NB - 9 Avenue to 8 Avenue SE													
Time Interval	**Historical (2023)**	**Historical (2020)**	**B0**	**D1**	**D2**	**D3**	**D4**	**D5**	**D6**	**D7**	**D8**	**D9**	**D10**
4:00 - 4:15	29.030	23.200	60	60	60	60	60	60	60	60	60	60	60
4:15 - 4:30	29.015	22.908	60	60	60	59	59	60	60	59	59	59	59
4:30 - 4:45	28.212	22.785	60	60	60	60	60	59	60	59	60	59	59
4:45 - 5:00	27.136	22.000	60	60	60	60	60	60	60	60	59	60	60

Link: Macleod Trail SE NB - 8 Avenue to 6 Avenue SE													
Time Interval	**Historical (2023)**	**Historical (2020)**	**B0**	**D1**	**D2**	**D3**	**D4**	**D5**	**D6**	**D7**	**D8**	**D9**	**D10**
4:00 - 4:15	27.848	23.354	59	58	58	58	58	58	57	57	58	57	57
4:15 - 4:30	27.576	23.031	59	59	57	57	57	56	55	55	55	55	55
4:30 - 4:45	27.136	23.569	59	59	58	57	56	56	56	55	54	52	52
4:45 - 5:00	26.136	22.785	60	59	57	57	57	58	58	59	57	57	57

PM Scenario – Travel Time Results

Link: 10 Street NW NB (Louise Bridge)													
Time Interval	**Historical (2023)**	**Historical (2020)**	**B0**	**D1**	**D2**	**D3**	**D4**	**D5**	**D6**	**D7**	**D8**	**D9**	**D10**
4:00 - 4:15	41.52	44.04	9	9	9	9	9	9	9	9	9	9	9
4:15 - 4:30	41.52	44.28	9	9	9	9	9	9	9	9	9	9	9
4:30 - 4:45	42.12	45.84	9	9	9	9	9	9	9	9	9	9	9
4:45 - 5:00	43.74	47.04	9	9	9	9	9	9	9	9	9	9	9

Link: 4 Avenue SW - 9 Street to 8 Street SW													
Time Interval	**Historical (2023)**	**Historical (2020)**	**B0**	**D1**	**D2**	**D3**	**D4**	**D5**	**D6**	**D7**	**D8**	**D9**	**D10**
4:00 - 4:15	14.34	13.32	11	11	12	12	12	11	12	12	12	12	12
4:15 - 4:30	14.28	12.90	11	11	12	12	12	13	13	13	13	15	15
4:30 - 4:45	14.46	12.84	10	11	11	12	12	13	13	13	13	16	16
4:45 - 5:00	15.00	12.78	10	11	11	11	11	11	11	12	12	12	12

Link: 4 Avenue SW - 8 Street to 7 Street SW													
Time Interval	**Historical (2023)**	**Historical (2020)**	**B0**	**D1**	**D2**	**D3**	**D4**	**D5**	**D6**	**D7**	**D8**	**D9**	**D10**
4:00 - 4:15	17.52	17.76	11	11	11	11	11	11	11	11	11	11	11
4:15 - 4:30	17.52	17.58	11	11	11	11	11	11	12	12	12	12	12
4:30 - 4:45	17.70	17.40	10	11	11	11	11	12	12	12	12	13	13
4:45 - 5:00	18.06	17.04	10	11	11	11	11	11	11	11	11	11	11

Link: 4 Avenue SW - 7 Street to 6 Street SW

Time Interval	Historical (2023)	Historical (2020)	B0	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
4:00 - 4:15	16.32	18.18	11	11	11	11	11	11	11	11	11	11	11
4:15 - 4:30	16.20	18.12	11	11	11	11	11	11	11	11	11	11	11
4:30 - 4:45	16.20	17.82	11	11	11	11	11	11	11	11	11	11	11
4:45 - 5:00	16.68	17.46	10	11	11	11	11	11	11	11	11	11	11

Link: 4 Avenue SW - 6 Street to 5 Street SW

Time Interval	Historical (2023)	Historical (2020)	B0	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
4:00 - 4:15	15.72	17.22	10	10	10	10	10	10	10	10	10	11	10
4:15 - 4:30	15.72	17.16	10	11	10	10	10	10	10	11	11	11	11
4:30 - 4:45	15.78	16.86	10	11	10	11	11	11	11	11	11	11	11
4:45 - 5:00	16.38	16.50	10	10	11	11	11	11	11	11	11	11	11

Link: 5 Avenue SW - Centre Street to 1 Street SE

Time Interval	Historical (2023)	Historical (2020)	B0	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
4:00 - 4:15	20.40	18.54	12	12	12	12	12	12	12	12	12	12	12
4:15 - 4:30	20.82	18.66	11	11	12	12	12	12	12	13	13	13	13
4:30 - 4:45	20.64	19.50	11	11	11	12	12	13	13	13	13	14	14
4:45 - 5:00	21.60	19.56	11	11	11	11	11	11	11	11	12	12	12

Link: 5 Avenue SW - 1 Street SE to Macleod Trail SE

Time Interval	Historical (2023)	Historical (2020)	B0	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
4:00 - 4:15	19.50	18.36	11	11	11	11	11	11	11	11	11	11	11
4:15 - 4:30	19.86	18.06	11	11	11	11	11	11	11	11	11	11	11
4:30 - 4:45	19.68	18.78	11	11	11	11	11	11	11	11	11	11	11
4:45 - 5:00	20.34	19.86	11	11	11	11	11	11	11	11	11	11	11

Link: 1 Street SE - 9 Avenue to 8 Avenue SE

Time Interval	Historical (2023)	Historical (2020)	B0	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
4:00 - 4:15	12.18	11.16	6	6	7	7	7	6	6	6	4	7	7
4:15 - 4:30	11.88	11.22	6	7	7	7	7	7	7	7	5	7	7
4:30 - 4:45	11.58	11.10	6	7	7	7	7	7	7	7	6	7	7
4:45 - 5:00	12.12	11.16	6	6	7	7	7	6	7	7	3	7	7

Link: 1 Street SE - 8 Avenue to 6 Avenue SE

Time Interval	Historical (2023)	Historical (2020)	B0	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
4:00 - 4:15	29.34	24.84	13	13	13	13	13	12	12	13	13	13	13
4:15 - 4:30	28.68	26.76	12	12	13	13	13	13	13	13	13	13	13
4:30 - 4:45	28.02	25.92	12	12	13	13	13	13	13	13	13	14	14
4:45 - 5:00	29.46	25.26	12	12	12	12	12	12	12	13	13	13	13

Link: Macleod Trail SE NB - 9 Avenue to 8 Avenue SE

Time Interval	Historical (2023)	Historical (2020)	B0	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
4:00 - 4:15	12.96	16.50	6	6	6	6	6	6	6	6	6	6	6
4:15 - 4:30	13.02	16.68	6	6	6	6	6	6	6	6	6	6	6
4:30 - 4:45	13.56	16.80	6	6	6	6	6	6	6	6	6	6	6

4:45 - 5:00	14.22	17.70	6	6	6	6	6	6	6	6	6	6	6
Link: Macleod Trail SE NB - 8 Avenue to 6 Avenue SE													
Time Interval	**Historical (2023)**	**Historical (2020)**	**B0**	**D1**	**D2**	**D3**	**D4**	**D5**	**D6**	**D7**	**D8**	**D9**	**D10**
4:00 - 4:15	28.14	34.44	12	12	13	13	13	13	13	13	13	13	13
4:15 - 4:30	28.62	35.04	12	12	13	13	13	13	13	13	14	13	13
4:30 - 4:45	29.40	33.90	12	12	13	13	13	13	13	13	13	13	13
4:45 - 5:00	30.36	35.34	12	12	12	13	12	13	12	12	13	13	13