A Multiclass Dynamic Traffic Assignment Model for Special Events Management

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Abstract

The City of Vancouver is committed to improve public transit and reduce congestion to accommodate people traveling to, from, and within the city in various transportation modes. The Stadium District of the city also hosts a vast amount of special events, including the National Hockey League, the Canadian Football League, and the oncoming 2010 Winter Olympic and Paralympics Games. Special events present unique challenges to downtown transportation management. During special events, the transportation management has to address a surge in vehicle and pedestrian demand and account for potential evacuation.

To aid decision making in planning for these events, the City of Vancouver looks for new tools. For special events analysis, it is important account for: 1) the dynamic nature of the travel demand flow; 2) and the capacity changes at the supply side due to the interaction between pedestrians and vehicles; and 3) and the impacts of short term route closures. To meet these requirements, the Downtown Vancouver Emergency and Transportation Management System (DVTEMS) was developed by the City of Vancouver. DVTEMS is a multi-modal dynamic traffic assignment model with a specific focus on pedestrian behavior and route choice. DVTEMS explicitly models changing demand and network conditions and can represent traffic flow in a far more accurate manner compared to the conventional regional planning model using static traffic assignment.

DVTEMS was built on the commercially available VISUM platform, and involves custom development of specialized modules to model the two-way capacity of sidewalks, the inundation of pedestrians onto vehicle space, and the impact of pedestrians on vehicle turning capacities. Taking a heuristic approach, the model runs iteratively to assign the pedestrian and private vehicle demand to an integrated network towards a multiclass equilibrium solution. The model has been calibrated and extended to address a variety of planning events and evaluate key strategies for traffic management during special events. This paper summarizes the model development and applications of DVTEMS. It is also intended to share the authors' experience in advanced topics such as dynamic traffic assignment, pedestrian modeling and model integration through this customized model application.

Introduction

The City of Vancouver is consistently ranked as one of the best places to live in the world. Much of this success is due to the commitment of the City to pedestrians, transit, and bicycles and the quality of life provided this commitment. In addition to its role as the central business district for the Greater Vancouver Region, the City also hosts a magnitude of special events, including the Annual Celebration of Lights, Vancouver Sun Run, the Alcan Dragon Boat Festival, the National Hockey League, the Canadian Football League, and the upcoming 2010 Winter Olympic and Paralympic Games. In preparation for these events, the City continuously looks to optimize the planning and security for its patrons and seeks to plan ahead for potential emergency situations.

Special events, especially large-scale global events or concurrence of multiple events, and potential evacuation activities, present great challenges to transportation planning and management. In most cases, the existing transportation system is insufficient in capacity to handle the unusual surge in resultant demand from these scenarios (Yuan and Han, 2005). Also, the capacity may be reduced further with a mix of vehicle and pedestrian in the event traffic and different human behaviors in presence of evacuation scenarios. Therefore, it is critical to through active transportation modeling to quantitatively assess pedestrian and vehicle operations under a variety of scenarios, identify bottlenecks, and make decisions about potential event planning, in order to maximize the utility of the existing transportation system and resource.

For special-event transportation planning, it is important to account for the dynamic nature of the travel demand during special events, the capacity change at the supply side due to the interaction between pedestrians and vehicles, and the impact of short term route closures. From the modeling perspective, either macroscopic regional travel demand model or microscopic traffic simulation model is typical choice. However, existing regional travel demand model, using static traffic assignment, is insufficient for special events or evacuation traffic analysis, because traffic modeling based on the static user-equilibrium theory cannot reproduce the temporal phenomena in presence of special events. Moreover, the regional travel demand model is often designed with limited consideration of pedestrian activities. On the other hand, microsimulation model, by explicitly modeling pedestrian behaviors at the operational level, may be more realistic in presenting congestion than static models (Bastian and Rouphai, 2007). However, conventional microsimulation model is limited in producing consistent route choices on a congested network, as it removes the well-constructed mathematical properties of equilibrium assignment in the static models (Ziliaskopoulos and Peeta, 2002). Simulation model is also more demanding in terms of data inputs, calibration efforts and computational cost.

To this end, a customized multiclass dynamic traffic assignment model was developed for the City of Vancouver to support the decision making by the City and other stakeholders for special-event transportation planning and management. The new model was built on the commercially available VISUM platform. It involves custom scripting to model pedestrian and vehicle-pedestrian interactions, including the uneven directional pedestrian flow on sidewalks, the inundation of pedestrians onto vehicle space, and the impact of pedestrians on vehicle turning capacities. This paper summarizes the development and applications of the Downtown Vancouver Emergency and Transportation Management System (DVTEMS).

Model Development

<u>Base Network</u>

Figure 1 below shows the DVTEMS base network. The DVTEMS model includes the entire Vancouver downtown peninsula with special focus on the area surrounding GM Place and BC Place Stadium (the red shadowed area). The DVTEMS was constructed on the basis of the City of Vancouver GIS street centerline data and NAVTEQ data. Additional data from the sidewalk inventory were incorporated into the model to represent the full pedestrian and vehicle network for the study area, including specific pedestrian elements such as the Seawall and pedestrian paths around BC Place Stadium and GM Place.

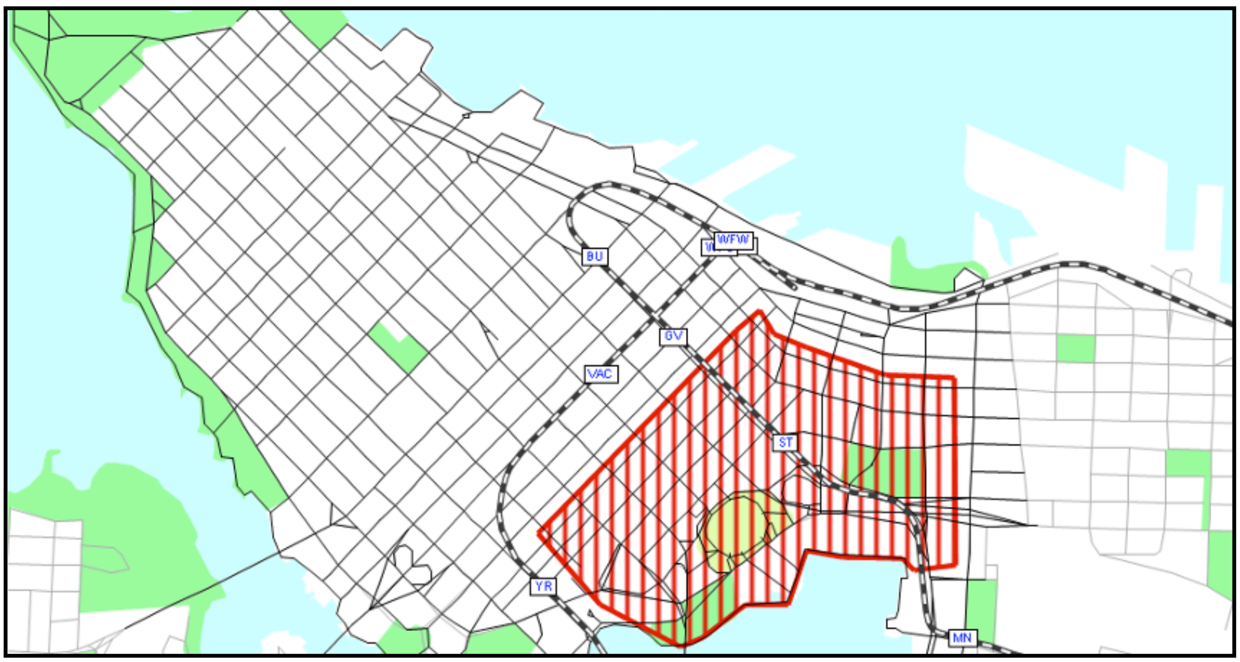

Figure 1. DVTEMS Base Network

The same DVTEMS base network was used for both vehicles and pedestrians traffic assignment, with different capacity specifications. For the vehicle network, in addition to pre-defined link and turn capacities, the true network capacity is subject to change with the impact of pedestrians at both link and turn levels. For the pedestrian network, it is important to distinct if and how the total available capacity of a sidewalk is distributed among pedestrians walking in the two opposite directions. These concerns were addressed through the custom scripts and models as explained in the late section of the paper.

<u>Dynamic Assignment Module</u>

The DVTEMS model uses dynamic assignment rather than more traditional static assignment methods to assign the pedestrian and private vehicle demand simultaneously to the integrated network. Pedestrians are assigned to the pedestrian network between specific points such as:

- From/to the point of transfer to another transportation mode such as SkyTrain stops;
- From/to land use elements such as buildings within zones; and
- From/to special generators such as BC Place Stadium and GM Place.

The use of dynamic assignment for this model is a critical feature behind the model's ability to answer the questions posed by the City related to vehicles, pedestrians, and transit as well as their impacts on and interaction with each other. Static assignments are the more conventional approach in regional travel demand modeling. While being a viable option for a low resolution analysis, static assignments do not satisfactorily capture the temporal effects of congestions and impacts of time-varying demands and supplies. Dynamic assignment, by contrast, has been used more recently in advanced applications and convinced to be more appropriate for high-resolution analysis of special events, temporary road closures, and evacuation procedures, as the concerns of DVTEMS. In these cases, the strengths of dynamic assignment provide the detail required to analyze a network on a more in-depth level.

The DVTESM was built on the VISUM platform, and uses the Dynamic User Equilibrium (DUE) model embedded within VISUM. The DUE model in VISUM was based on the formulation and solution method developed by Gentile and Meschini (2005). Compared to static assignment, the DUE can accept time-varying input attributes at both demand and supply sides (e.g. demand time series and capacity), and instead of using volume-delay functions, the DUE adopts fundamental flow diagrams and kinematic waves theory to model link travel times. In the DUE, the dynamic equilibrium is expressed as a fixed point problem in terms of arc flow temporal profiles. Figure 2 shows the trapezoidal fundamental diagram for vehicle dynamic assignment.

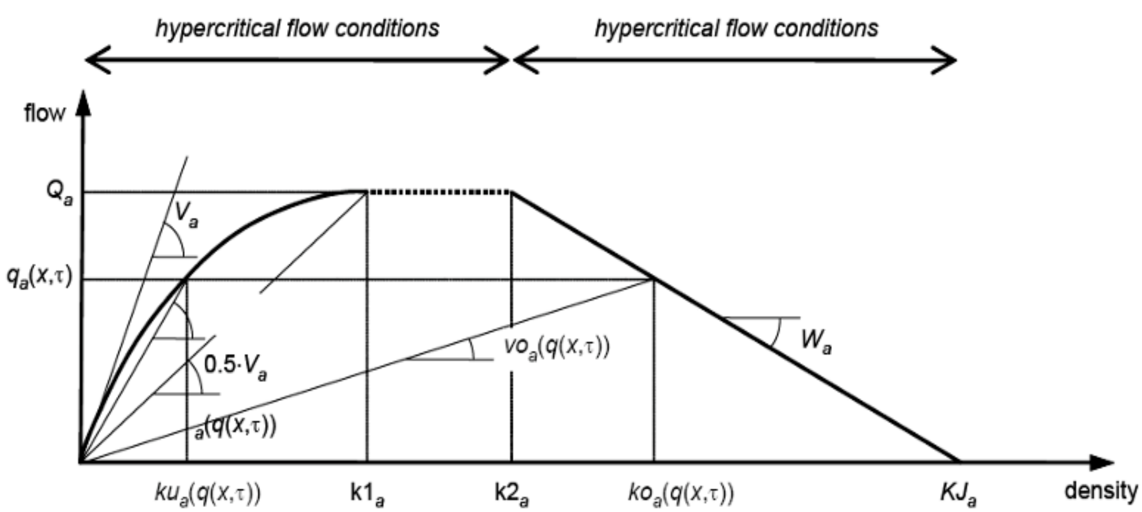

Figure 2: Fundamental Diagram for Vehicle Dynamic Assignment (from VISUM manual)

To apply the DUE for pedestrian assignment, we adjust the fundamental diagram parameters (e.g. weave speeds and jam density) according to the experimental studies of the relation between longitudinal space used by pedestrians and their speed (Daamen and Hoogendorrn, 2003). Figure 3 shows the fundamental diagram derived for pedestrian dynamic assignment.

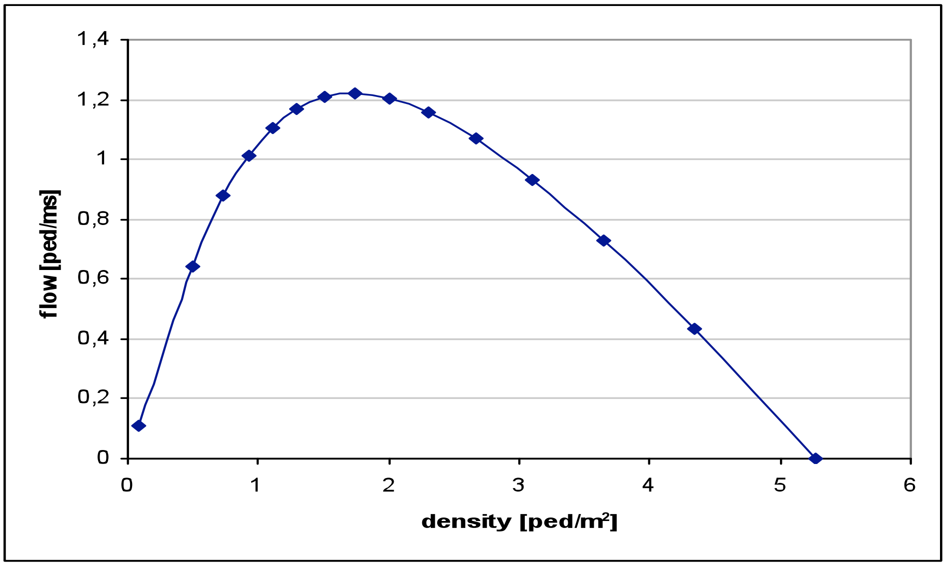

Figure 3: Fundamental Diagram for Pedestrian Dynamic Assignment (from Daamen and Hoogendorrn, 2003)

Modelling Vehicle-Pedestrian Interactions

To identify the appropriate approach for modeling vehicle-pedestrian interactions for DVTEMS, three theoretical types of possible vehicle-pedestrian interactions are reviewed and discussed in this section. Each type of interaction, from normal to chaotic, is somehow worse than the previous one. The modelling approach for each type of interaction is also discussed.

Normal interaction
This is the base scenario and simplest case, where pedestrians use only sidewalks and cross roads at signals or at crossing points. In this scenario, no longitudinal interaction occurs, while transversal interaction can be neglected or taken into account through a priori turn delays for vehicles. Therefore, in this case it is possible to perform two separate assignments (pedestrian and vehicles) in no particular order.

Controlled interaction
The second case is the typical case for special events, where it is planned to assign some roads (or road lanes) to pedestrians, however pedestrians can't spread on lanes reserved to vehicles. In this way, again, no longitudinal interaction occurs, and we can simply assume:

pedestrian capacity = sidewalk capacity + road capacity assigned to pedestrians
vehicle capacity = road capacity – road capacity assigned to pedestrians

By contrast to the first case (normal interactions), transversal interaction may not be negligible in this case, due to the large number of pedestrians involved. However, it would be plausible in this case pedestrians would have priority over vehicles when crossing roads (except in a controlled way, such as with adjusted signal control or with the presence of police control). In this case, the turn delay and turn capacities for vehicles depend on pedestrian flows at intersections (turn capacity for car is typically reduced by pedestrians at interactions). This case may be modelled by the following procedure:

1) Set pedestrian capacities and lanes, and vehicle capacities and lanes respectively;
2) Perform pedestrian assignment with pedestrian capacities and lanes defined above;
3) Update vehicle turn delays and turn capacities accordingly with pedestrian flows at intersection and/or crossing points, through appropriate delay and capacity reduction functions;
4) Perform vehicle assignment with link capacities and turn delays and capacities defined as above.

It is to note that in this case vehicles have reduced capacities for two reasons: less number of lanes on each road (or no lanes), and less turn capacities due to transversal interaction with pedestrians. The reduction of vehicle lanes will reduce both link capacities and link storage capacities (i.e. maximum number of vehicles on the link).

Random interaction
The last case applies to special event and/or evacuation scenario, in which, although pedestrians should stay on sidewalks (or assigned lanes), they may randomly and discontinuously occupy a part of the vehicle lane near to the sidewalk, resulting a sort of "longitudinal friction" with car flows. Here we refer to the situation with very crowded sidewalks, where faster pedestrians "hop-off" and "hop-on" the sidewalk in order to pass slower people. This is also the case to be modeled by the DVTEMS, whereas capacity loss due to a partially chaotic pedestrian behaviour. Within this interaction context, both road capacity and vehicle free-flow speed may be adjusted, as in this situation drivers have to reduce their speed for safety reasons, because pedestrians may randomly interact with their trajectory. Moreover, same as for the previous case, the longitudinal friction may cause a partial lane reduction, resulting in a storage capacity reduction. Therefore, this type of interaction may be modeled as follows:

1) Perform pedestrian assignment with pedestrian capacities;
2) Update vehicle link free flow speeds, capacities and n. of lanes accordingly with pedestrian flows on the same link, through suitable reduction functions;
3) Perform vehicle assignment with link capacities just defined.

In case that random interaction and controlled interaction may occur jointly, they may be modelled together as follows:

1) Set predefined pedestrian capacities and lanes, and predefined vehicle capacities and lanes;
2) Perform pedestrian assignment with pedestrian capacities and lanes just defined;
3) Update vehicle turn delays and turn capacities accordingly with pedestrian flows at intersection and/or crossing points, through appropriate delay and capacity reduction functions;
4) Reduce further vehicle link free flow speeds, capacities and n. of lanes accordingly with pedestrian flows on the same link, through suitable reduction functions;
5) Perform vehicle assignment with link capacities and turn delays and capacities just defined.

In addition to the vehicle-pedestrian interactions, it is also important to understand and take into account the pedestrians interaction in assignment – if and how the total capacity of a sidewalk is distributed among pedestrians walking in the two opposite directions. A further question is if and how the presence of pedestrians walking in the opposite direction may cause a loss of sidewalk capacity. For the applications of DVTEMS, the first case is prevailing, and it may be addressed through an iterative and heuristic assignment procedure, as discussed in the following section.

Customized Interactions

Following the discussion in the previous section, we identify the need of customized module development for modeling pedestrian and pedestrian-vehicle interactions. In the end, three types of interactions have been developed, researched, and included in the DVTEMS model:

- Two-way Sidewalk Capacity;
- Inundation of Pedestrians on Vehicle Space; and
- Pedestrian Impact on Vehicle Turn Capacities.

These interactions are highly complex and are not internal to VISUM. Rather, they have been incorporated into VISUM using Python scripting, which is an open source language simpler to use than a macro language. There is a direct Python interface with VISUM, which allows additional calculations not internal to VISUM to be incorporated with the VISUM data elements with no user modification of the scripts after original development. Each of the interactions listed above has been described in the following sub-sections.

Two-way Sidewalk Capacity (Pedestrians)
Pedestrian networks are different than vehicle networks in that the full capacity of a facility can be utilized by one direction or another or a combination of both. In other words, the full width of the sidewalk may be used by pedestrians in either direction rather than assigned to one direction, as lanes on a street are assigned for vehicles.

During times when pedestrian flows are generally balanced by direction, it can be assumed that the full capacity of the pedestrian facility is generally balanced as well. When there is uneven flow, however, it is important that the assignment process allow for the heavier flow direction to take up more of the pedestrian space, i.e., if pedestrian flow is heavy in one direction, the capacity for that direction should not be limited to 50% of the sidewalk since, in reality, this heavy direction will take up more than 50% of that width.

To account for this directional interaction, a special iterative loop calculation for each link was developed for the DVTEMS model, which can be described in seven basic steps:

1) Capacity for each direction of flow is equal to 100% of the total link capacity
2) An initial pedestrian assignment is run, assuming that both directions can utilize the full capacity of the facility
3) If the initial assignment results in the one-way pedestrian volume being greater than 50% of the total link capacity, then go to Step 4, otherwise, go to Step 5.
4) Proportion the total sidewalk capacity based on the proportion of pedestrian flow in each direction from the initial assignment. Go to Step 6.

5) Assign one-way pedestrian capacity equal to 50% of total pedestrian capacity
6) Re-assign pedestrians to the network using this adjusted or proportioned pedestrian capacity.
7) Check for convergence. If not converged, go to Step 1 and repeat.

Inundation of Pedestrians on Vehicle Space

Inundation is the encroachment of pedestrians on vehicle space. This was identified as a key element to capture the additional capacity available or taken by pedestrians during times when the true pedestrian facility becomes so congested that people begin to walk out onto the street. This inundation can only be calculated after the two-way pedestrian interaction assignment has been completed as described in the previous subsection.

In addition, certain parameters need to be defined by the user to set the stage for inundation occurrence. These parameters have been defined and incorporated into the DVTEMS VISUM model and are:

- *Inundation allowed (yes/no)* – Global parameter allows for testing of scenario with or without inundation allowed anywhere;
- *On-street parking allowed (yes/no)* – Link setting that is one factor in determining whether inundation can occur as on-street parking takes up the curbside lane of capacity that pedestrians would desire during inundation;
- *Pedestrian allowed on road (yes/no)* – Link setting that will also allow inundation to occur on a specific link that may be used to represent physical barricades that keep pedestrians from utilizing vehicle space; and
- *Pedestrian Link volume-to-capacity threshold for inundation (0 to 1.0)* – Global parameter used to calibrate when inundation occurs during specific events.

With these parameters defined, the process for calculating inundation is completed in six steps:

1) Vehicle capacity is set to 0 (vehicle assignment has not been run at this point).
2) Pedestrian link capacity is set to the pedestrian capacity from the two-way interaction calculations + the pedestrian capacity available in the vehicle space.
3) Pedestrians are assigned to the network.
4) Pedestrian link capacity is set to the capacity actually used by pedestrians in the initial assignment.
5) Vehicle link capacity is re-assigned based on the remaining capacity not used by pedestrians.
6) Vehicles are assigned to the network based on the capacities resulting from the inundation assignment of pedestrians.

Pedestrian Impact on Vehicle Turn Capacities

As stated previously, once the pedestrian assignment is complete, the number of pedestrians using each intersection in the downtown peninsula is known and can therefore be used in the calculation of impacts on vehicle capacity prior to vehicle assignment occurring. The actual impedances due to pedestrians were calculated using standard methodologies for signalized intersection capacity (Highway Capacity Manual 2000). Based on the signalized intersection characteristics described above, the impacts on vehicles due to pedestrians (f_p) was calculated using the reduced formulas shown in Table1.

Table 1. Pedestrian Adjustments on Vehicle Capacity (from HCM 2000)

Turn Type	Movement	
	Left-Turn	Right-Turn
Protected	n/a	n/a
Permitted	1-0.13*(v_{pedg}/2000)	1-0.5*(v_{pedg}/2000)
Protected + Permitted	1-0.03*(v_{pedg}/2000)	1-0.385*(v_{pedg}/2000)
Single-Lane	(1-0.13*(vpedg/2000)) X (1-0.5*(vpedg/2000)	

These factors are calculated at each signalized intersection in the DVTEMS model, based on the number of pedestrians entering the intersection during the assignment period. The factors are then multiplied by the initial vehicle turn capacity to obtain a new turn capacity accounting for pedestrians for each movement at each intersection in the DVTEMS model, The car assignment is then completed using this newly calculated capacity.

Model Calibration

The base model was calibrated utilizing the pedestrian and vehicle counts provided by the City. In North America, there are no specific standards for calibration of dynamic assignment models; therefore, for the DVTEMS model, static assignment calibration standards were used as a guideline. Generally, due to the dynamic component, dynamic assignment models are much more difficult to calibrate, resulting in lower calibration results than static models. In this case, the DVTEMS dynamic assignment exceeded even static assignment standards, in terms of relative means square errors between volumes and counts.

Model Applications

The DVTEMS is designed for three use cases, as identified by the City of Vancouver:

- Special event traffic management;
- Emergency evacuation pre-planning;
- Public space re-allocation.

Each of these Use Cases had many possible Scenarios, and four specific Scenarios were defined and tested for this project:

- Simultaneous events BC Place and GM Place Dual Events;
- Olympic events during a typical 2010 Winter Olympic day;
- Granville SkyTrain Station Shutdown;
- Northeast False Creek (NEFC) Buildout.

For each modeling scenario, the DVTEMS provides four types of outputs:

- Travel time to/from stadium by transit system
- Volume by time interval by transport system (15-minut interval for 24 hour period)
- Pedestrian level of service (LOS) and density
- Visual outputs in VISUM

Conclusions

In this paper, a multiclass dynamic assignment was developed for the City of Vancouver with a specific focus on pedestrian behavior and route choice. The DVTEMS model explicitly models changing demand and network conditions and can represent traffic flow in a far more accurate manner compared to the conventional regional planning model using static traffic assignment. The model serves to support the decision making by the City and other stakeholders for special-event transportation planning and management.

The DVTEMS Model can now be applied by the City of Vancouver to test their own set of sub-scenario parameters. The City also looks to continue working with the stakeholder group to address specific concerns through the DVTEMS Model and relay the evaluation and critical information to those stakeholders through the export of the DVTEMS results to the City web-mapping service. In addition to the web-mapping service, the City of Vancouver will also continue to have the ability to communicate evaluation results through the graphical and detailed quantitative output from the DVTEMS Model.

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