REGIONAL APPLICATION OF 24-HOUR DYNAMIC TRANSIT ASSIGNMENT

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1 Introduction

Dynamic Assignment (DA) explains how network volumes build up over time and helps to understand congestion. Dynamic Transit Assignment predicts how passengers move through the network while taking into account how travel conditions change over time. An important output is passenger volumes that vary over time on stops, links and routes.

In the South Coast region of British Columbia, Canada (Metro Vancouver), congestion occurs in the rapid transit network, when passenger demand meets or exceeds capacity. These capacity issues were a major motivation for TransLink as the transit agency to put the Regional Transit Model (RTM) in place. The RTM is a decision support model that is used for transit operations planning and service planning. The model covers 24 hours of the operating day with a detailed supply and demand model. The demand model includes dynamic transit assignment. The initial version of the RTM which was calibrated in 2006, covered only the rail network and was presented at the 2007 TRB Planning Application Conference [2]. Since then, the RTM has been expanded to cover all transit services in the region and has been successfully applied in several service planning and operations planning studies [3].

This paper summarizes the experience with the calibration and application of the dynamic transit assignment model, which is part of the RTM. Section 2 of the paper gives an overview of Metro Vancouver's transit network, major transit planning projects, and current capacity issues. Section 3 presents the time-dynamic, schedule-based assignment method that is used. In section 4, we report our experience in model development on the supply side and the demand side. Section 5 presents some successful applications of the model. Section 6 draws conclusions and shows perspectives for future improvements and applications of the model.

2 Transit in the Metro Vancouver Area and Current Capacity Issues

The Metro Vancouver Area in British Columbia is a growing metropolitan area with a population of 2.2 million residents that is projected to grow to 3 million by 2031. Urban growth boundaries and increased transit supply have contributed to densification and to a rise in transit ridership from 63 annual linked trips per resident in 1999 up to 78 in 2007. TransLink's plans and the Provincial Transit Plan outline significant improvements and expansions of the regional transit system.

The South Coast British Columbia Transportation Authority, known as TransLink, is the regional transportation planning and funding agency. The regional transit system integrates several modes: the **bus system** with local routes and limited-stop routes ("B-Lines"); a **commuter rail** line ("West Coast Express"); a **passenger ferry** ("SeaBus") links downtown Vancouver with North Vancouver. The backbone of the transit system is **SkyTrain** [10], an automated, driverless train system which carries over 210,000 passengers per day. A second automated train system is nearing completion and will open in August 2009 as the "**Canada Line**". There are also plans to add **BRT** and **LRT** lines to the network.

The two SkyTrain lines ("Expo" and "Millennium") total 50 km (31 miles) and serve 33 stations. The combined peak headway is 108 seconds on the common segment between the Waterfront and Columbia stations. Currently, SkyTrain operates at and over capacity during the peak hours, mainly during the morning peak. At Broadway station, which is a major transfer hub, passengers traveling inbound during the morning peak sometimes have to wait for up to three trains to be able to board (see figure 1). Since 2007, there have been efforts to mitigate this bottleneck through operational means. The SkyTrain capacity issues have been a major motivation to develop the new Regional Transit Model (RTM) and the 24-hour dynamic transit assignment. The model has contributed to better understand the dynamics of transit demand and to test operational alternatives.

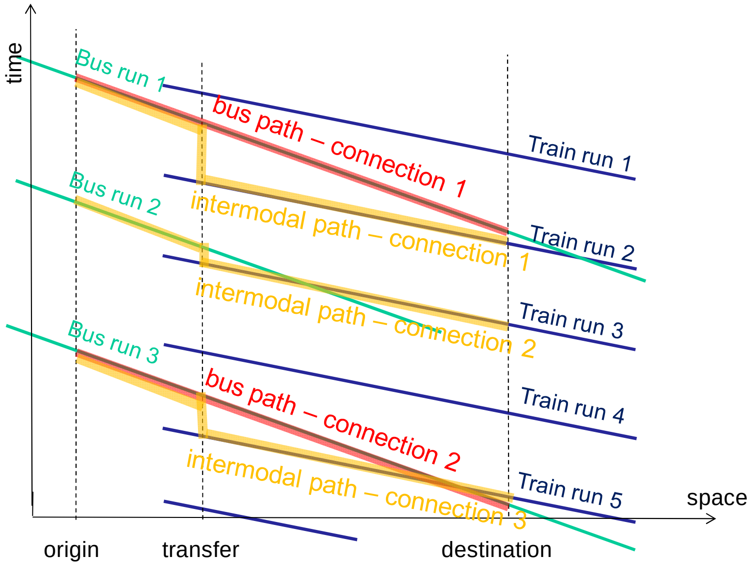
Figure 1: Crowded platform at the most serious network bottleneck: Broadway station, inbound platform

3 The Dynamic Transit Assignment Algorithm

Transit passenger assignment methods can be grouped in “headway-based” or “schedule-based” categories. While the academic literature is rich in work based on either method [6, 8], most planning software packages offer only headway-based assignments, either shortest-path based or multi-path based [7]. The VISUM software provides a schedule based method, called the “timetable-based assignment” which is applied in this model [4, 9]. It assumes that the operations schedule is sufficiently reliable, and as a result vehicle and train runs are considered deterministic. The schedule is a detailed data set of the departure and arrival times for each vehicle run in the network. The path builder uses the schedule to build a search graph and finds connections with a branch-and-bound approach. This schedule-based assignment method is naturally a time-dynamic method, as the time-component is explicitly incorporated in path-building and in path choice. In fact, the schedule data are stored down to the second, and passenger paths are built with a one-second precision over the entire assignment period. As a result, transport supply and conditions of travel vary during the day and the assignment is time-dynamic [4, 6]. The choice between alternative paths and connections is based on a stochastic model. In the Vancouver RTM we used a Box-Cox transformed LOGIT. The impedance or utility includes in-vehicle time, several out-of-vehicle components, a penalty for the difference between desired and effective departure time, and a correction term for similarity of paths.

Figure 2 shows a schematic example in a time-space diagram: bus and train runs are the basic schedule. The path builder develops paths from o to do, either direct by bus or alternatively using bus and then transferring to a train. For both paths, there are multiple connections (red and yellow) at different times of day with varying arrival times.

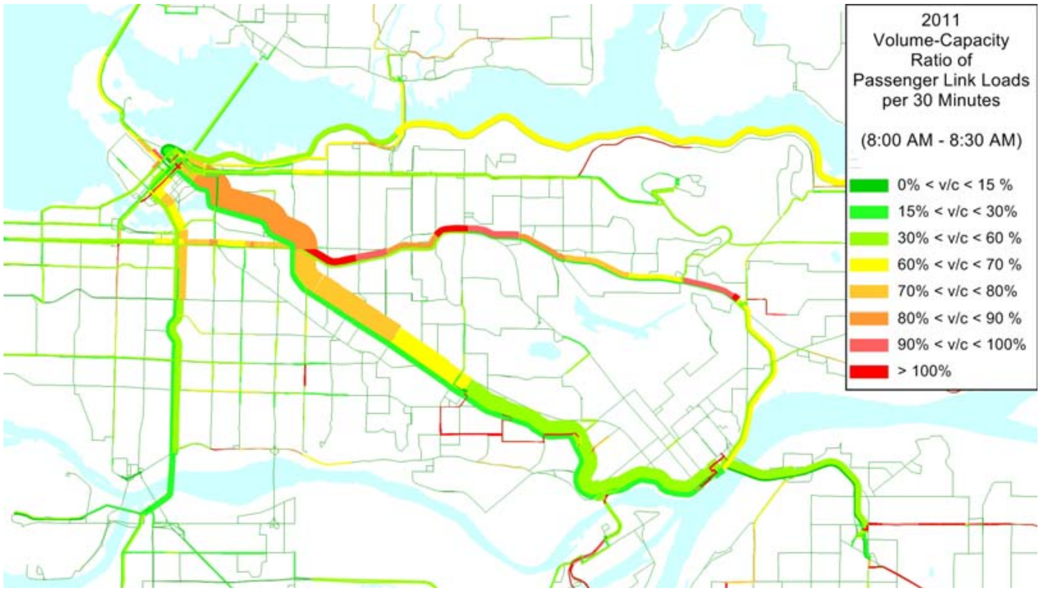
Figure 2: Schematic time-space chart of schedule based path building



While VISUM allows computation of passenger volumes or loads for individual bus or train runs, this level of detail is typically not analyzed. In this model we have aggregated passenger volumes to 15-minute or 30-minute intervals. As a result of the assignment, 15-minute or 30-minute volumes are computed for each network element such as line routes, links and stops.

It is possible to extend VISUM's schedule based assignment with an iterative routine which then incorporates capacity constraints in path choice. This model, the RTM does not apply capacity-constraint passenger assignment at this time, although the supply model determines the capacity for each vehicle run.

Figure 3: Map of Regional DA Results (30-Minute Internal 8:00-8:30)



4 Model Development: Time-Dependent Demand and Supply

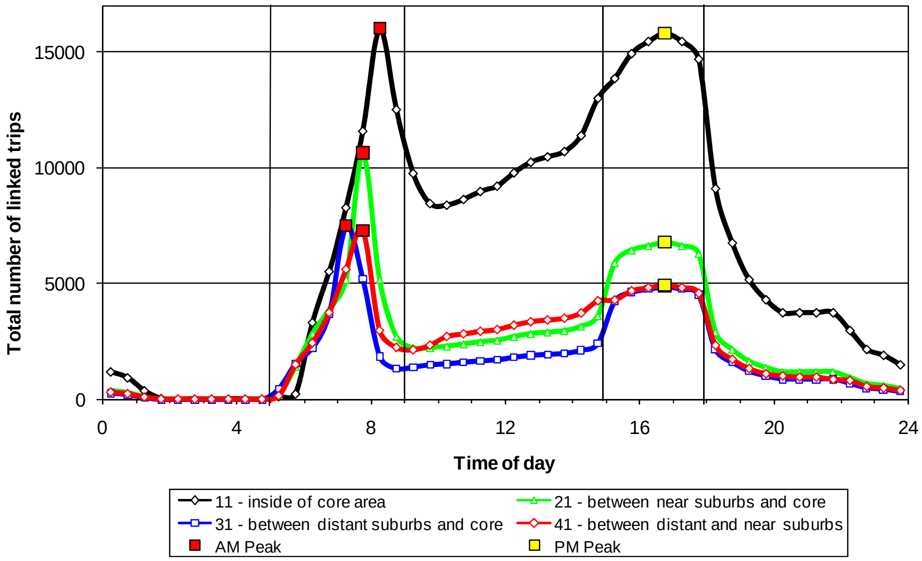
The time-dynamic assignment model requires user input on the supply and demand sides. In this section of the paper we describe how these inputs were prepared and calibrated.
The **transit supply** is based on three inputs: the network topology, the operations schedule for 24 hours and the fleet model. The network topology consists of links and stops. The stops in the RTM represent the geo-coded locations used in the automated vehicle-location system (AVL) and the automated passenger-count system (APC). The operations schedule is imported for the existing case from the same source that feeds TransLink's online passenger information system, which allows the user to search for transit itineraries at any time of the day. This schedule data base includes all routes and route patterns with their run and dwell times plus the actual timetable, which is the enumeration of all vehicle runs for each route pattern. The third input is the fleet model which includes all available vehicles and train-units with their capacities. The fleet is assigned to the schedule to determine time-dynamic capacities all over the network. In addition the RTM includes a line-blocking algorithm which has been applied in multiple studies to estimate fleet requirements for operations scenarios [2, 3].

There are basically two ways to provide **demand input** for a DA model, either a set of consecutive OD matrices, where each matrix covers one time slice; or a constant OD matrix associated with time-of-day distribution of desired departure time or desired arrival time. We use a hybrid approach: four OD matrices with specific distributions of desired departure time. The departure time distributions vary for different market segments. The demand for the RTM was calibrated based on counts. The coverage of the network with recent counts was very good. All rail services have 24-hour station boarding counts, most of them for the 2007 base year. Some rail counts were between 2 and 5 years old and were updated with growth factors. In addition, the new Automated Passenger Count (APC) system was able to provide 24-hour route boarding statistics for all bus services, except the local Community Shuttles. For selected routes, the APC would also provide 24-hour on/off statistics.

The model includes four **OD matrices** representing the demand in different times of day: AM, midday, PM, evening. The OD matrices for the base year 2007 have been derived from outdated matrices from a four-stage model in combination with counts, using an automated matrix calibration method [5]. The counts used for automated calibration were mainly link loads on major rail and ferry links. All other counts have been used as calibration targets but not as direct input of the automated calibration.

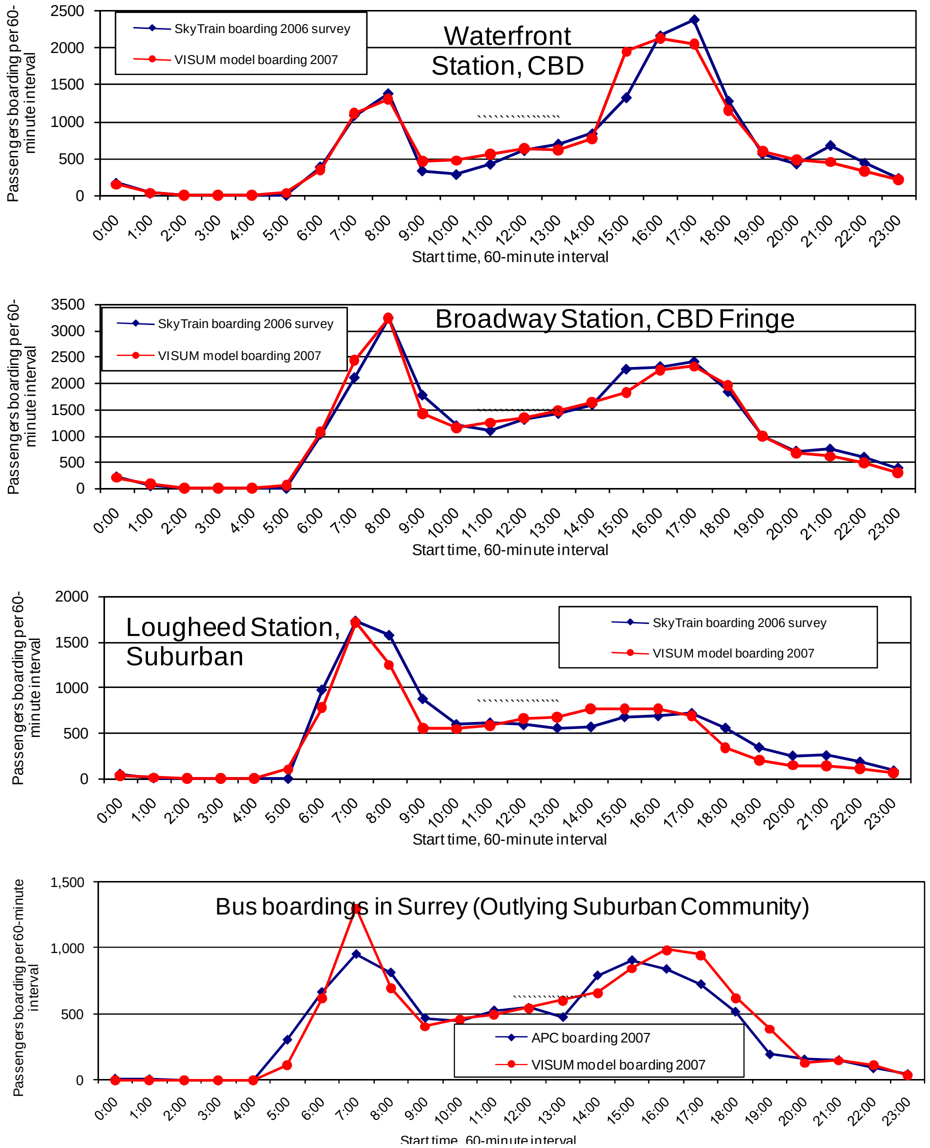
The second input for the DA model on the demand side is **distributions of desired departure times**. The available household survey did not have an adequate sample size and time-detail to allow the determination of departure time curves. As a result, the departure time distribution was determined from boarding counts. As the model calibration progressed, we found that one uniform distribution of desired departure times does not reflect behaviour adequately for the entire region. Instead, four different departure time distributions are used as shown in figure 4. The black curve with an AM peak at 8:00 was determined from SkyTrain boarding counts and is now used for the markets with origin and destination in the centre. The green curve has its AM peak 30 minutes earlier and is applied to OD pairs with the origin in “near” suburbs and up to 45 minutes of ride time away from the center. The blue curve represents travelers from “outer” suburbs with an AM peak another 30 minutes earlier at 7:00. In other words, the distance to the centre determines the desired departure time in the morning. It is remarkable that for the PM, no modification for different markets was found necessary. It seems that the morning peak travel is dominated by desired arrival times (from work or school schedules), while the PM peak is determined by desired departure times.

Figure 4:
Time distribution of desired departure for different market segments



The model **validation** was first conducted on aggregated levels, like total unlinked boardings for one time period, per mode, per line, per station. Once the aggregated levels had been approved, validation was conducted for time-dynamic passenger volumes. Overall, there were several important network objects with recent boarding or loading counts: 10 SkyTrain stations, in central and suburban locations, one SkyTrain link load survey, bi-directional link counts for the “SeaBus” ferry and the West-Coast-Express commuter rail. All of these time-dynamic volumes have been validated and examples are shown in figure 5. In addition, the **Automated Passenger Count system (APC)** provided recent route-boardings in one-hour intervals for individual bus lines or groups of bus lines, which have been used to understand the differences in demand distribution for the urban, suburban and rural areas. The APC system in the Vancouver region can be considered cutting edge because of the data processing and evaluation tool which allows querying various aggregated and disaggregated statistics [1]. The system was relatively new and still being calibrated itself; as a result we had to review and adjust some APC based calibration targets in the midst of our own calibration. Still, APC has contributed significantly to this model and is expected to play en even more prominent role in providing time-dynamic ridership data for future model calibrations.

Figure 5: Validation of time-dynamic passenger demand for selected network locations



It can be seen in figure 5 that the peak of departure in suburban areas takes place approximately one hour before the peak in the centre and that the model replicated the observed behaviour. To understand these charts, it should be noted that the volumes are aggregates of time-dynamic trips; some of the intercepted trips might have started 5 minutes ago, some others might already be 90 minutes on the ride; they are recorded at a particular stop at the time when they board; in the case of link volumes they are recorded when they pass through. The good fit of the model and count time lines was achieved by calibrating OD matrices and departure time distributions as explained earlier.

The **future year demand** blends the existing count-based matrices with forecasts from the regional long-range planning model. Based on the assumption that a large part of the future demand is identical to the existing demand, we use the "delta method" as follows:

Future Year OD demand = existing year calibrated OD demand + Δ

Where:

Δ : growth in the long-range planning model's OD matrices

Within the TransLink organization, the two models have complementary roles: the RTM supports transit operations and service planning, while the long-range planning model (on the emme/2 platform) predicts the impacts of urban development and shifts in modal split.

5 Application in Service and Operations Planning

The first series of applications of the RTM focused on SkyTrain and its capacity problems with the following studies and analyses:

- Based on an extensive analysis of alternatives, the RTM helped to conclude that the present operating plan is optimal with regard to capacity, as there is no better way to operate with the existing fleet on the existing network.
- The future capacity of the critical segment Waterfront-Broadway can be expanded to 220% of today's capacity; assuming that the headway will be reduced from 108s to 90s, the fleet will be expanded and will allow trains of higher capacity (5-car consists rather than the currently maximum of 4-car consists for the second generation SkyTrain design, also know as Mark-II).
- The fleet strategy was reviewed. RTM simulations of future scenarios contributed to the conclusion that it is desirable to add 3-car train units to the fleet (in addition to the current 2-car units) to allow 5-car consists in the future. The time-line for future fleet orders was reviewed and adjusted.

For two future extensions of the rapid transit network, namely the Evergreen Line and the UBC Line, the RTM has been used to analyze alternative concepts for the SkyTrain and LRT options and to develop operating concepts and to determine fleet requirements.

Another application of the RTM has been the analysis of the bus network adjustment in the context of the opening of Canada Line, a new automated light metro line which will open in August 2009. Several bus routes will be discontinued. Others will be realigned to feed directly into the new rail stations, and service frequencies will be adjusted. The RTM estimated the ridership for each bus line and the number of buses needed for the adjusted operations.

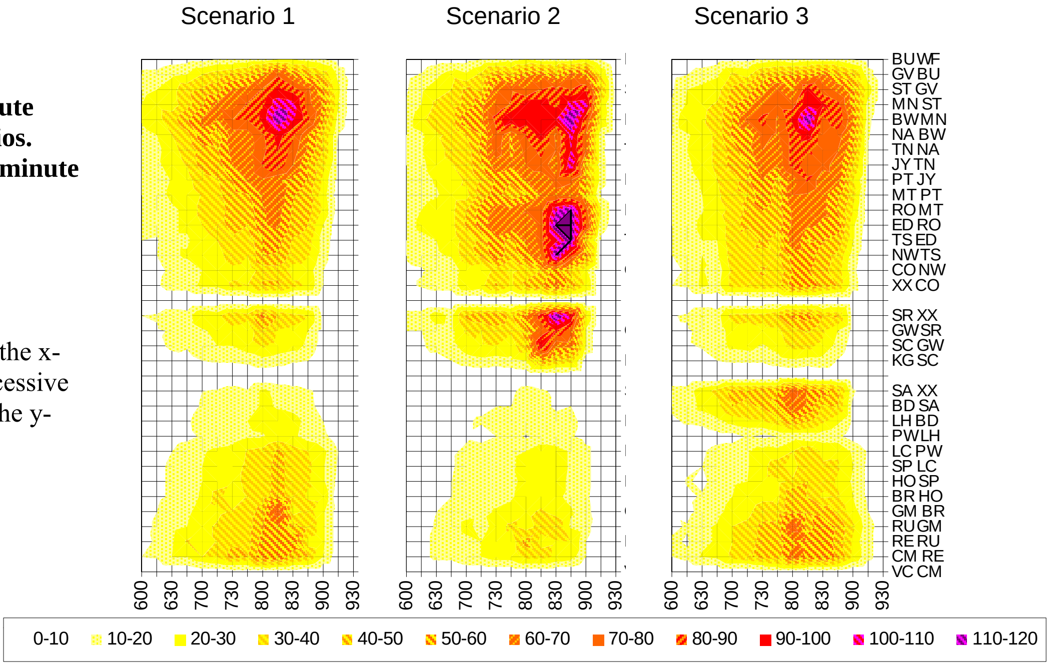


Figure 6: Time-dynamic comparison of route operating scenarios. V/C ratio per 15-minute time interval.

Time of day is on the x-axis; space as successive network links on the y-axis.

6 Conclusions and Future Perspectives

Since 2007, 24-hour dynamic transit assignment is a new tool in TransLink's planning and modelling practice. A time-dynamic 24-hour approach requires more time and labor in data preparation, calibration and model application than an aggregated model. One lesson we learned is that it has several advantages to start with calibrating a sub-network, as we did with the initial rail-only model: It allowed us to get familiar with the tools, the data and the key challenges of model application without dealing with the full complexity of regional application. Also, the initial smaller model helped the stakeholders to better understand the methodology and allowed them to actively define and shape the final product.

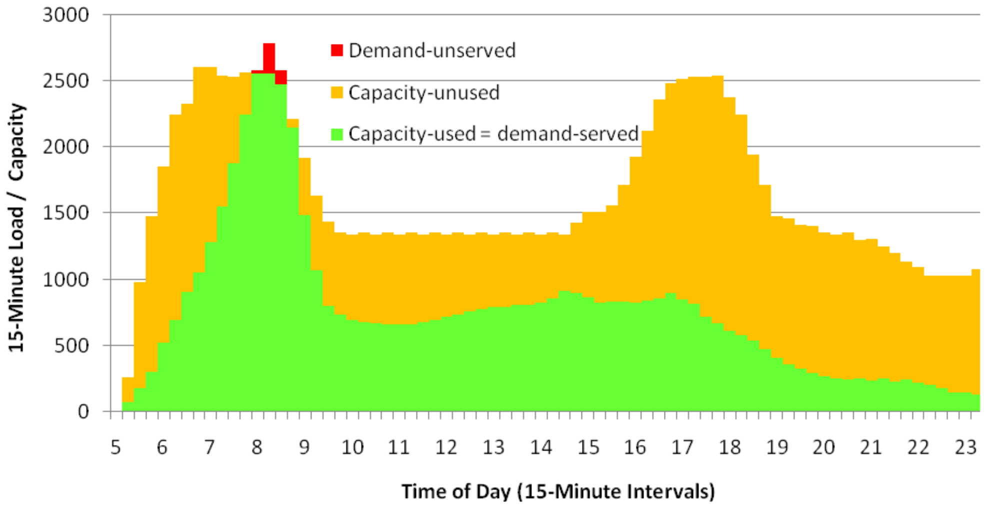
Overall, the new model and its applications were very well received and the RTM has become a key resource in TransLink's transit planning projects. According to the feedback from the model stakeholders, the major benefits of the 24-hour time-dynamic approach are:

- Time-dynamic analysis is important in transit planning because both demand and capacity are varying over time. Dynamic models help to match capacity and demand. In contrast, capacity is more or less constant on highways where dynamic models have become more common these days.
- The 24-hour perspective and the ability to analyze not only the peak but also off-peak periods; while long-range planning typically focuses on the peak-hour, off-peak analysis is important for short-term and mid-term operations planning, allowing to test variations in train compositions or reduced service headways.

- An important benefit comes from visualizations that contribute to the discussion of congestion problems. Figure 7 shows a visualization of capacity versus demand on the most critical bottleneck of the SkyTrain network from Broadway station, inbound (Figure 1). The chart provides the following insights:
  - The temporary character of congestion: It is only for a very short time that demand really exceeds capacity, while 95% of the day capacity is sufficient and 90% of the day capacity is very comfortable.
  - The challenge to provide capacity that would exactly match demand: capacity needs to be provided almost symmetrically for in and outbound to cover the demand peak which is strongly directional (here: inbound in the morning).
  - Putting the cost of congestion mitigation into perspective and motivating the discussion of peak-spreading policies in addition to investments in new capacity.
  - The phenomenon that today's peak demand has shifted to later in the morning, and that the operations peak period has come out of sync with demand.

We experimented with different **time-steps**, 15 and 30 minutes. Internally the VISUM software uses one second as the time-step or time unit, in which passenger movement and vehicle rotations are computed. What we really chose for our application as "time step", is really the "analysis interval", for which demand and supply outputs are aggregated on all links, stops and transit route segments. For passenger demand analysis, 15 minutes seem very reasonable. Most transit planners are trained to look at 60-minute loads and capacities, and as a result, we sometimes ended up aggregating our results to avoid confusion. Currently, the regional model runs on a 30-minute time step mainly to fit the available computer hardware at TransLink. Soon, with off-the shelf 64-Bit PCs we will switch back to 15-minute intervals.

Figure 7: Time-dynamic passenger loads and capacities of one network link (Broadway inbound, 2006)



In our experience, the time-interval for supply statistics must be significantly larger than the average headway. Figure 7 shows results from the 15-minute aggregation, where train capacity and demand have been smoothed with floating averages. Smoothing is needed because of the fact that transit capacity is "lumpy" and can be very volatile between adjacent 15-minute intervals even with service headways of under 2 minutes, as in our case. This issue was even more acute in our Vancouver application given the range of train lengths in use, with the lowest capacity train having half the passenger capacity of the largest.

Looking forward, the model will continue to contribute the operations analysis to strategic transit studies, as well as to transit area plans. Several future model cases are planned to be built, for example 2025, as soon as the next 10-year regional transit plan has been shaped.

The following model improvements have been discussed and tested and will be implemented when time and resources permit:

- A re-calibration of transfer volumes within stations using recently conducted surveys.
- Adding capacity-constraints to the passenger assignment model, so that passengers are either held at the station where the departing train has run out of capacity, or diverted to less congested paths, or even diverted to a different departure time.
- Improve interface with the long-range planning model application.
- Adding a departure time choice model.

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