A SIMULATION MODEL OF THE BUS TRANSITWAY (TRNSIM)

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Ata M. Khan

For planning and design of a bus rapid transit system and for the analysis of multimodal corridors, methodology is required for simulating bus traffic operation on a Transitway. Macroscopic models of vehicle flow are gaining popularity due to their capability to analyze complex operations and yet offer efficiency in development and applications. A macroscopic model is developed for the investigation of travel time, energy and emissions that correspond to bus volume levels on the Transitway. This paper describes the travel time part of the model. The model treats stochastic characteristics of bus traffic and passenger activities. Also, safety regimes in vehicle flow and factors affecting minimum headways in station areas are incorporated. The model is verified by comparing simulated travel time for the Ottawa-Carleton Transitway with actual data.

Introduction

Rapid public transit is receiving high priority in North American cities for alleviating traffic congestion, efficient use of energy and improving environmental quality. For medium size urban areas or corridors with moderate levels of travel demand, bus rapid transit systems can be considered as an alternative to light rail systems (Nisar and Khan, 1992). For effective planning and design of a bus rapid transit system and for the analysis of multimodal corridors, methodology is required for the simulation of the access controlled line haul facility, a Transitway -- also called a Busway. Given the complex nature of bus traffic operations on the Transitway involving passenger activity at stations as well as vehicle flow

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in the station area and between stations, detailed predictions of performance cannot be obtained without a simulation model. Such a model could be developed for micro or macro levels of analysis. Although a microsimulation model can provide details of the operation of every vehicle in the system, this level of detail is not essential neither for planning nor for concept design. Macroscopic models of vehicle operations are gaining popularity due to their capability to analyze complex operations and yet offer efficiency in development and applications.

A review of literature indicated that a limited number of Transitway model development efforts have been made. McBrayer (1992) developed a microscopic simulation model for the Karachi Mass Transit study. The details of this model have not been published. The Regional Municipality of Ottawa-Carleton developed a site-specific simulation model of the Transitway involving articulated bus operation (Regional Municipality of Ottawa-Carleton, 1988). Another simulation model was developed for Ottawa-Carleton Regional Transit Commission which was designed to replicate the movement of buses and passenger activities on a single route (OC Transpo, 1991).

A new macroscopic simulation model of the Transitway was developed for bus operation in support of research in demand management involving multimodal corridors. This new model has the capability to estimate travel time, energy consumption and emissions that correspond to bus volume levels on a Transitway. However, this paper describes only the travel time part of the model which was verified by using actual observations from the Ottawa-Carleton Transitway. The computer language of the model is Fortran 77 which is widely used for scientific computing and is highly transferable between computer facilities.

Physical Characteristics of Transitway

The Transitway is an access controlled grade separated two way rapid bus transit facility, constructed at, above or below ground level. Access is restricted to buses and emergency or maintenance vehicles at the Ottawa-Carleton Transitway. For the Transitway to be successful, it has to offer a reasonably high travel speed and reliable travel times. Design speeds of the Transitway system are shown in Table 1 (Regional Municipality of Ottawa-Carleton, 1992). For reasons of safety, passenger comfort and geometrics, the maximum speed of buses on the Ottawa-Carleton Transitway is limited to 80 km/h between stations and restricted to 50 km/h through stations. The
Table 1. The Design Speed for Various Locations on the Transitway

<table>
<thead>
<tr>
<th>Location</th>
<th>Design Speed (km/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transitway Main Busway</td>
<td>90°</td>
</tr>
<tr>
<td>Station Areas</td>
<td>60</td>
</tr>
<tr>
<td>Ramps &amp; Access Routes</td>
<td>40</td>
</tr>
</tbody>
</table>

* Max. bus speed is limited to 80 km/h for the Ottawa-Carleton Transitway.

typical right of way for Transitway is approximately 13m, including two 4m lanes and two 2.5m shoulders to accommodate disabled buses and for providing winter snow storage (if required).

Stations are an important part of the Transitway. In most cases, Transitway stations incorporate a local route interface. Between stations, only a single lane in each direction is provided. At the station area, one extra lane per direction is used for off-line operation of the station. Figure 1 shows the station area lane arrangements (Regional Municipality of Ottawa-Carleton, 1992). The design of station allows through buses to bypass loading/unloading buses. Stopping lanes are extended in both directions to provide for storage and for deceleration/acceleration functions. Entrance/exit ramps for buses at stations are provided.

Probabilistic Elements

In the concept design of the simulation model, most bus operation elements and passenger activities are probabilistic in nature. Poisson distribution is used for buses entering ramps, number of buses arriving at stations and passenger boarding and alighting activity (Banks and Carson, 1984; McClave and Benson, 1994).

In this research, the chi-square ($X^2$) test was performed for Poisson distribution for four stations of the Ottawa-Carleton Transitway. The results for four stations indicated that the calculated values for the peak hour for all stations and for the off-peak hour for two stations, were less than the critical values at a level of significance of 5 percent. Therefore, the Poisson distribution could be used to generate random numbers for bus arrival at stations.

Uniform distribution is applied for the "bus type" (i.e., articulated,
Figure 1. Station Area Lane Arrangements
standard, etc.) variable, and a negative exponential distribution is used for time interval between buses. The choice of these probability distributions is supported by literature (Guenthner and Sinha, 1983) and also by the analyses carried out as a part of this research.

In order to estimate the average number of boarding and alighting passengers at a station for use in the poisson distribution formulation, data captured by the Automatic Passenger Counting (APC) system of the OC Transpo were acquired. These data were compared with random numbers generated by using normal distribution. A comparison between the observed data and generated random numbers showed that a normal distribution is the best fit for generating average boarding and alighting passengers at Transitway stations.

Simulation Model Specifications

The model described in this paper can represent with reasonable accuracy all phases of bus operation. Figure 2 shows a macroscopic flow chart of the computer program for this model.

The model treats (a) all physical features of the transitway -- in the station areas as well as between stations, (b) the stochastic nature of bus traffic and passenger activity, (c) service characteristics, (d) safety regimes between stations, (e) minimum safe headways in the station area, and (f) queuing of buses.

The model accepts as inputs (a) simulation study time period, (b) Transitway (road) characteristics, (c) station characteristics, (d) vehicle characteristics, (e) boarding and alighting passenger information, and (f) traffic characteristics.

The outputs of this model for the analysis period include: travel time (including boarding and alighting passenger time), average speed, dwell time, total loading and unloading of passengers, vehicle-km, passengers/bus, fuel consumption, and air polluting emissions (i.e., CO, HC, NO, and CO2).

As noted earlier, the fuel consumption and emissions parts of the model are not reported in this paper. However, it is useful to note their basis. Bus fuel consumption models were adapted from an existing heavy vehicle fuel use model by taking into account bus, facility design, and operational characteristics of the Transitway. For the estimation of emissions, functions/factors based on MOBILE5c and other sources are used.

The model can also simulate bus operations in addition to the
Figure 2 continued...
A Simulation Model of the Bus Transitway (TRNSIM)

SUBROUTINE HEADWAY
Calculation of Travel Time

Is the Station Full?

NO

Calculation of Delay for Next Bus Which Arrives at the Station

Delay = 0

Add Delay to Travel Time for the Bus

Clock = Clock + Travel time of Bus

Calculation: Delay, Travel time, Avg. Speed, Vehicles/hr Vehicle-km, Boarding & Alighting Passengers, etc.

YES

SUBROUTINE REPORT
Print Outputs

END

Note: Fuel & emissions subroutines are not shown.

Figure 2. Flow Chart of the Simulation model
passengers loading and unloading activities, bus flow rate, and speed during a specified analysis period. The simulation model can estimate capacity of the Transitway based on input data.

The buses that use the Transitway are assumed to be 9m, 12m and 18m in lengths. This corresponds to small, standard and articulated buses, respectively. This capability of the model reflects the expectation that various sizes of buses would use the Transitway.

**Bus Operations Between Stations**

For vehicles travelling on the Transitway, a relationship between spacing, speed, and deceleration can be obtained as follows:

\[ S = V\delta + \frac{V^2}{2D_F} - \frac{V^2}{2D_L} + L + S_o \]  

where

- \( S \): spacing between two vehicles
- \( V \): initial speed of the two vehicles
- \( D_F \): deceleration rate of the leading vehicle
- \( D_L \): deceleration rate of the following vehicle
- \( \delta \): perception-reaction time of the following vehicle
- \( S_o \): safety margin after stop
- \( L \): length of typical bus in the stream or average of leading and following buses

There are different values of deceleration in terms of the safety level of operation, where \( D_n \) is normal or comfortable deceleration and \( D \) is emergency deceleration.

The combinations of leading and following vehicle decelerations designate various safety regimes a, b and c. For regime a, b and c, deceleration of the leading vehicle is defined as \( \infty \), \( D_n \) and \( \infty \), respectively. Deceleration of the following vehicle for regimes a, b and c are specified as \( D_n \), \( D_n \) and \( D_n \), respectively (Papacostas, 1993). Typical values for \( D_n \) and \( D_n \) are 1.72 m/sec\(^2\) and 4 m/sec\(^2\), respectively.

From Equation 1 and the fundamental relationships between volume, density, spacing and speed in a traffic stream, the equation for bus volume is obtained (Papacostas, 1993).
This relationship can be characterized for a lane of the Transitway between the two successive stations.

Here, δ is perception-reaction time. It is the total time taken for perception, identification, decision and reaction such as total time taken by a following vehicle to apply brakes in response to braking action of the leading vehicle. Actual perception-reaction times vary from individual to individual. This parameter ranges from 0.3 to 2.0 seconds, with a median value of 0.66 seconds (Vuchic, 1981). The American Association of State Highway and Transportation Officials (AASHTO) recommends a value of 2.5 seconds for stopping sight distance (McShane, 1990). Given the professional nature of transit bus drivers and on the basis of the views of public transit industry personnel, a 1 second perception reaction time was used for model development.

D; it is based on vehicle characteristics (i.e., 18 m for articulated bus, 12 m for standard bus, etc.).

D\(_F\) and D\(_\) ; deceleration rates of following and leading vehicles are important factors since these play an important role in the "vehicle following" concept. Based on acceleration test by OC Transpo and according to the Manual of Transitway Design, normal deceleration (D\(_n\)) was calculated.

Average speed is found by the following equations:

\[
V_{avg} = \frac{D}{T_{avg}}
\]  

where

\(V_{avg}\) : average speed

\(D\) : distance between two successive stations

\(T_{avg}\) : average travel time between two successive stations
The components of transit travel time include: bus-stop (idle) time, acceleration time, cruise time and deceleration time.

An acceleration test was performed by OC Transpo [for 0 to 50 ft (15.24 m), 0 to 100 ft (30.48 m), 0 to 200 ft (60.96 m) and 0 to 60 km/h] at Hurdman station (Ottawa-Carleton Transitway). Using regression analysis, a formula for $V_{avg}$ as a function of acceleration time was found. See Figure 3 for speed-time relationship.

$$V_{avg} = 9.518 \ T^{1/2} + 0.327 \ T$$

where

$$V_{avg} : \text{average speed (km/h)}$$
$$T : \text{acceleration time (sec.)}$$

Acceleration was calculated from Equation 4:

$$\frac{\partial V_{avg}}{\partial T} = a \Rightarrow a = 0.327 + \frac{9.518}{2 \ T^{1/2}}$$

where

$$a : \text{acceleration rate (km/h/sec; } 1 \ \text{km/h/sec} = 0.2778 \ \text{m/s}^2)$$

The $R^2$ value for Equation 4 was found to be 0.99. According to test results, the average acceleration was 0.96 m/s$^2$.

The deceleration lane length of 75m is based on deceleration of 0.9m/s$^2$ from 50 km/h. Taper lane was taken as 35m (Figure 1). In the absence of any deceleration rate test data available from OC Transpo and other available sources, the information contained in the Transitway Design Manual and acceleration test of the OC Transpo, were used to obtain the following relationship between acceleration and deceleration functions for buses on the Transitway:

$$D_a = \frac{1}{2a_{avg}} \ V^2$$

$$D_d = \frac{1}{2d_{avg}} \ V^2$$
A Simulation Model of the Bus Transitway (TRNSIM)

where

\( a_{\text{avg}} \): average acceleration

\( d_{\text{avg}} \): average deceleration

\( D_a \): acceleration length

\( D_d \): deceleration length

\( V \): cruise speed

By using the maximum values for acceleration and deceleration lengths and constant speed for Equations 6 and 7, deceleration is obtained in terms of acceleration.

\[
\frac{D_a}{D_d} = \frac{d_{\text{avg}}}{a_{\text{avg}}} \Rightarrow d_{\text{avg}} = \frac{150 + 50}{75 + 35} a_{\text{avg}} = 1.81 a_{\text{avg}}
\]  

(8)

\( D_a \) is composed of 150m acceleration lane and 50m taper lengths. In the case of deceleration, 35m taper plus 75m deceleration lane is used (Figure 1). Next, by substituting the average rate of acceleration in the above
formula, average deceleration was obtained as 1.72 m/s².

According to three different safety regime definitions, the values of deceleration for leading and following vehicles are found (Vuchic, 1981). In accordance with the above calculations, the normal acceleration of 1.72 m/s² is used. For emergency deceleration (D_e), 4 m/s² is suggested in the literature. Although safety regimes a, b and c are defined in Table 2, it is suggested that the regime c be used for buses (Papacostas, 1993). This regime is based on ∞ deceleration of leading vehicle and emergency deceleration of following vehicle. S_0; safety margin after stop was assumed to be 1 m (between buses); according to the experience of the OC Transpo, this value is acceptable as a safety margin.

Figures 4 and 5 show the relationship between cruise speed and flow by using values presented in Table 2.

Table 2. The speed limit based on flow of buses on Transitway for various safety regimes.

<table>
<thead>
<tr>
<th>Regime</th>
<th>Standard Bus (12 m)</th>
<th>Articulated Bus (18 m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>Q ≤ 411 km/h</td>
<td>Q ≤ 400 km/h</td>
</tr>
<tr>
<td></td>
<td>U_{cruse}=90 km/h</td>
<td>U_{cruse}=80 km/h</td>
</tr>
<tr>
<td></td>
<td>411 &lt; Q ≤ 738 km/h</td>
<td>400 &lt; Q ≤ 633 km/h</td>
</tr>
<tr>
<td></td>
<td>U_{cruse}&lt;90 km/h</td>
<td>U_{cruse}&lt;80 km/h</td>
</tr>
<tr>
<td>b</td>
<td>Q ≤ 640 km/h</td>
<td>Q ≤ 614 km/h</td>
</tr>
<tr>
<td></td>
<td>U_{cruse}=90 km/h</td>
<td>U_{cruse}=80 km/h</td>
</tr>
<tr>
<td></td>
<td>640 &lt; Q ≤ 918 km/h</td>
<td>614 &lt; Q ≤ 794 km/h</td>
</tr>
<tr>
<td></td>
<td>U_{cruse}&lt;90 km/h</td>
<td>U_{cruse}&lt;80 km/h</td>
</tr>
<tr>
<td>c</td>
<td>Q ≤ 775 km/h</td>
<td>Q ≤ 736 km/h</td>
</tr>
<tr>
<td></td>
<td>U_{cruse}=90 km/h</td>
<td>U_{cruse}=80 km/h</td>
</tr>
<tr>
<td></td>
<td>775 &lt; Q ≤ 1054 km/h</td>
<td>736 &lt; Q ≤ 881 km/h</td>
</tr>
<tr>
<td></td>
<td>U_{cruse}&lt;90 km/h</td>
<td>U_{cruse}&lt;80 km/h</td>
</tr>
</tbody>
</table>
Figure 4. Plot of Speed Flow for Standard Bus

Figure 5. Plot of Speed Flow for Articulated Bus
Effect of Grades and Geometric Design on Bus Operation

Any combination of grades and horizontal or vertical alignment can potentially reduce operating speed of buses. However, horizontal curvature can be designed for attaining a specified speed. Therefore, the effect of gradient on bus operation is of main interest.

According to the Highway Capacity Manual, the heavy vehicle adjustment factor \( f_{HV} \) is used to adjust for the effect of buses in the traffic stream. For example, the effect of grade on capacity of lanes can be calculated by using \( f_{HV} \). Any lane length of more than 1.6 km for grades of less than 3 percent, or 800 m for grades of 3 percent or more is usually considered as a separate segment (Transportation Research Board, 1994).

The vertical alignment of most lanes results in a continuous series of grades. The average grade is defined as the total rise from the beginning of the composite grade divided by the length of the grade. The horizontal alignment is designed by keeping in mind the maximum speed for the Transitway.

Bus Operation at Stations

The simulation model assigns a dwell time of random value to each bus at each stop with respect to the mean and standard deviation of boarding and alighting passengers. The basic data were obtained from the OC Transpo, and were changed for each station by using normal random generator and average time for each passenger to board and alight buses.

Based on Ottawa-Carleton public transit condition (i.e., use of bus pass), 2 and 1.5 seconds for boarding and alighting passenger times were assumed, respectively. For articulated buses, these values are decreased by 20% and 35% for boarding and alighting passenger times, respectively (Transportation Research Board, 1994).

Minimum headway based on line of sight can be specified by the user. For example, minimum headways as low as 12 seconds can be specified for Transitway capacity studies. In this research, a 15 second minimum headway is used for off-line station operation. The Canadian Urban Transit Association (1994) suggests a 15 seconds minimum headway.

Bus operation at a station is very important because in most cases, the Transitway capacity is limited by capacity of stations. If the station is full, buses which will arrive at the station must wait until an unloading/loading space becomes available. A stopping lane at the station can accommodate three or more buses (depending upon input data provided by user).
Therefore, during high volume travel condition, travel time is increased due to delays.

Station capacity is a function of minimum headway of buses in the station area. The station headway is affected by demand for service, dwell time and other factors, as described later. The dwell time depends on the passenger boarding and alighting volume and station operating activities.

Headway between successive buses at a station consists of two groups of elements. The first component is the time interval reflecting vehicle motion (i.e., acceleration and deceleration rates of buses). It depends on vehicle dynamics, operating regime and safety requirements. Dwell time is the second component which consists of door opening, passenger exchange and departure preparation (i.e., door closing). The capacity of a bus berth in station can be calculated by (Vuchic, 1981).

\[ Q_s^{(\text{max})} = \frac{3600}{H_s^{(\text{min})}} \]  

where
\[ Q_s^{(\text{max})} : \text{capacity at station (veh/h)} \]
\[ H_s^{(\text{min})} : \text{minimum headway at station between buses (sec.)} \]

The passenger service times and dwell times at bus stops are necessary for estimating bus capacity at stations. The minimum headway of buses at a stop consists of (a) dwell time, and (b) clearance times between buses.

Bus dwell time is taken to be the time for the bus to unload and load passengers and leave the bus stop. The minimum headway \( (H_{s}^{(\text{min})}) \) can be obtained as follows (Transportation Research Board, 1994). If buses have a common door for passenger boarding and alighting, dwell time can be calculated by using the following formula:

\[ H_{s}^{(\text{min})} = aN_1 + bN_2 + c \]  

where
\[ a : \text{average alighting time per passenger (sec)} \]
\[ b : \text{average boarding time per passenger (sec)} \]
\[ N_1 : \text{number of alighting passengers} \]
\[ N_2 : \text{number of boarding passengers} \]
\[ c : \text{clearance time (lost time in opening and closing doors, leaving the bus stop, or due to traffic delays when bus is ready to leave); } c \text{ is usually between 9 and 20 seconds.} \]
For separate doors (different doors for passenger boarding and alighting) the formula can be changed as follows:

\[ H_{s\text{ (min)}} = \max(aN_1, bN_2) + c \]  \hspace{1cm} (11)

Bus dwell times strongly influence bus stop performance (Gardner, Cornwell and Cracknell, 1991). According to the Manual of Transitway Design, up to three articulated buses can stop at platforms. Buses that are not required to stop at a particular station can proceed through the station area relatively unimpeded (Regional Municipality of Ottawa-Carleton, 1992).

The passenger capacity of a bus is given by (Transportation Research Board, 1994):

\[ C = C_1 + \psi C_2 \]  \hspace{1cm} (12)

where

- \( C \) : total passenger capacity per bus
- \( C_1 \) : bus sitting capacity
- \( C_2 \) : bus standing capacity
- \( \psi \) : fraction of \( C_2 \) allowed

In the simulation model \( \psi \) is assumed to be 100% and other data were assumed according to the OC Transpo information.

The boarding and alighting passenger times depend on some factors such as fare collection system, type of door control, etc. The Highway Capacity Manual suggests for typical operating conditions with single door 1.7-2.0 seconds as alighting passenger time. These values are modified to be 1.5-2.3 seconds for alighting passenger with very little hand baggage and with parcels, respectively. For typical operating conditions with single door, the boarding passenger time is suggested as between 2.6 and 3.5 seconds. For prepayment condition before entering bus (e.g., bus pass) 1.5-2.5 seconds are suggested. For single coin or token with fare box condition, 2.5-3.0 seconds are suggested by the Highway Capacity Manual. For articulated buses, a time reduction can be applied amounting to 30% (or 0.4 sec per passenger) for boarding passenger time and 27%-80% for alighting
passenger time due to the use of the bus rear and center doors (Transportation Research Board, 1994).

The bus capacity of the Transitway is constrained by the capacity of the station area. In turn, the station capacity can be found from minimum headway at the stations. Figure 6 shows bus volumes/direction and average speed that correspond to $H_{s(min)}$ of 18 seconds, 15 seconds and 12 seconds for off-line station design incorporating four passenger boarding and alighting platforms. At $H_{s(min)}$ of 12 seconds, $Q_{(max)}$ (i.e. capacity) is 300 buses/hour and average operating speed on the Transitway is 40 km/h. At $H_{s(min)}$ of 15 seconds, $Q_{(max)}$ is 240 buses/hour and average operating speed is 42 km/h. The passenger capacity that corresponds to 300 buses/h is 23,400 passengers/h and in the case of 240 buses/h, 19,200 passengers/h can be served. It should be noted that at present, the Ottawa-Carleton Transitway is operating at volume levels that are much below capacity.

The following observations on Transitway/Busway capacity drawn from literature are intended to show how results of this research compare with subjective estimates, other simulation studies and performance of actual facilities around the world. The Canadian Transit Handbook suggests a capacity of 180 buses/hour/direction with on-line station and 240 buses/hour/direction with off-line stations (Canadian Urban Transit Association, 1994).

Gardner, Cornwell and Cracknell (1991) selected eight busways out of about 40 which have been identified in the world for capacity studies. They report capacity to range from 15000 to 26000 passengers per hour per direction (p/h/d). The highest recorded passenger flow was 26000 p/h/d in Porto Alegre (Brazil). The highest recorded passenger throughput on a basic 2-lane busway (without special operational measures for serving a corridor with busy bus stations) was 19500 p/h/d in the Abidjan (Cote D’Ivore). Bus flows were recorded to be 380 per hour direction per lane. Similar two lane busways and operating conditions exist in Ankara and Istanbul (Turkey).

According to McBrayer's simulations of the Karachi Busway, passenger capacity increases as the average bus size grows. In the extreme case, a maximum capacity of some 33,000 passengers per hour in one direction is theoretically possible. However, McBrayer states that for a number of reasons this very high volume of passengers may not be attainable in actual operations. Reasons include: the use of a bus fleet consisting exclusively of
Figure 6. Transitway Speed vs. Bus Volume
very large (double deck) buses, difficulty in attaining rather-crowded average passenger loading required, and difficulty in providing the required passenger-handling capacity at the activity centres to be served (McBrayer, 1991).

Verification of the Simulation Model

A simulation model is only an approximation to the actual system. In the case of the Transitway simulation model, the general objective of validation is the determination of agreement between model output and observed data. For validation of simulation models, it is common to use the \( r^2 \), standard \( t \) and \( F \) statistical tests in order to compare the observed versus simulated information (Hsu and Hunter, 1977).

A comparison of simulation model results with OC Transpo test data and OC Transpo schedule information is presented in Figure 7. The input data were collected from the Ottawa-Carleton Transitway stations. The travel time data obtained from OC Transpo (for Route 95) were compared with simulated travel times for Blair station to Laurier station (links 1 to 8) and from Transitway station near Booth St. to Baseline station (links 9 to 14). Also shown are the scheduled travel times (for Route 95).

An examination of Figure 7 shows a reasonable agreement between data obtained from OC Transpo (actual observations) and the model output.

![Figure 7. Comparison of Simulation Model Results with Test Data and Schedule Information](image-url)
For finding the degree of correlation between the model output and observed values, a regression analysis test was performed by using the statistical package of SPSS (Norusis, 1985). An $r^2$ of 0.98 shows that the simulation result is highly correlated with observed data from OC Transpo (Table 3). Also, high t and F values show a good agreement between observed and simulated results. Figure 8 illustrates the successful comparison of the observed data vs. simulation output.

In the development of the simulation model, realistic assumptions and transit-way specific values of parameters were used. Additionally, the Ottawa-Carleton Transitway is at present operating at volume levels that are much below capacity. Under these conditions, buses are being operated almost according to free flow conditions (i.e. at maximum allowable speeds). For these reasons, a high degree of correspondence between simulated and field observations is achieved.

Conclusions

1. The conceptualization and methodology for the quantification of bus operation and passenger activity are the basis of the Transitway simulation model.

2. The simulation model's flexible structure and detailed formulations of its various components meet all requirements for macroscopic analysis of bus operation on the Transitway.

3. The Transitway simulation model was successfully verified with actual data.

4. The Transitway capacity is governed by station capacity, which in turn is largely controlled by minimum headway.

5. At 15 seconds minimum station headway, a Transitway of off-line station design incorporating four passenger boarding and alighting platforms can serve 240 buses/h/direction at average operating speed of 42 km/h. The corresponding passenger capacity is 19,200 passengers/h/direction. If 12 second headways are used, 300 buses/h/direction can be served at 40 kms/h average speed. In this case, the passenger capacity is 23,400 passengers/h/direction.

6. The simulation model offers the flexibility of application to any design of a Transitway. The user of the model can input information on physical and service aspects of a Transitway planning, design or operational problem and can obtain the effect in terms of average speed, and other important factors.
Table 3. Summary of the regression analysis of simulation output vs. actual travel time

<table>
<thead>
<tr>
<th>r</th>
<th>r²</th>
<th>t</th>
<th>F</th>
<th>t-critical*</th>
<th>F-critical**</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.99</td>
<td>0.98</td>
<td>24.3</td>
<td>590.</td>
<td>2.16</td>
<td>4.75</td>
</tr>
</tbody>
</table>

* at 5 percent level of significance and 13 degrees of freedom

** at 5 percent level of significance and (1,12) degree of freedom

Figure 8. The Observed Data vs. Simulation Output
Acknowledgements

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References

Simulation; Programmer and User Documentation. Ottawa.