Simulation of Bus Lane Operations in Downtown Areas

R. W. Bowes and J. van der Mark, De Leuw Cather, Canada, Ltd.

An investigation of potential operational capacities of downtown bus lanes was carried out in Ottawa, Canada. The results could improve coordination between bus priority treatments within downtown areas and those on the major transit corridors feeding the downtown areas. This paper describes the simulation model that was developed during the course of the study to simulate bus behavior in a downtown bus lane. Several operating strategies were tested and evaluated. Depending on the strategy selected, a bus flow rate of 150 to 170 buses/h can be achieved. This flow rate can accommodate 8000 to 8000 passengers/h with acceptable loading standards, operating speeds, and existing standard equipment. Further tests and research are suggested.

Bus priority systems, introduced in many cities, may utilize different measures from the groups listed below:

1. Freeway related measures: reserved lanes, separate roadways, exclusive ramps, queue jumping, metered collection, and bypass of toll barriers;
2. Arterial related measures: reserved lanes with flow or contra-flow, separate roadways (bus-only streets), special signalization, special turn permission, and pulling away priority at bus stops;
3. Busway measure: exclusive bus-only roadway either grade separated or with at-grade intersections; and
4. Terminal measure: off-street loading, unloading, and short-term storage of buses, usually connected to freeways or arterials with bus priority measures.

Coordination of the operational capabilities of these various measures could lead to an improved level of service and more efficient use of buses during peak periods. For example, if downtown bus lanes can accommodate the large number of buses arriving from reserved freeway lanes from suburban areas, overall travel times can be reduced. Generally accepted minimum installation criteria for bus lanes are 30 to 90 buses/h (4); maximum operating capacities of downtown bus lanes are currently 90 to 120 buses/h. These are sometimes exceeded, as in Ottawa, where flows in excess of 140 buses/h occur in some bus lanes.

The success of bus transit in this context relies on how well the system in the future a municipality’s improved bus-based system can meet peak-hour transit needs in major demand areas. The capacity limits of a bus-based system will probably be experienced in the downtown collection and distribution system rather than on reserved freeway lanes and busways between downtown and suburban areas. Because bus lane volumes in Ottawa are already as high as any that have ever occurred in the transit industry’s experience, a study was commissioned to investigate the operating capacities of bus lanes in a downtown environment.

After briefly reviewing the literature and summarizing field experiments, this paper will describe the simulation model we developed during the course of the project. A number of bus operating strategies were tested and...

References:

33. S. Yagar. CORQ: A Model for Predicting Flows and Queues in a Road Corridor. TRB, Transportation Research Record 533, 1975, pp. 77-87.

Publication of this paper sponsored by Committee on Traffic Flow Theory and Characteristics.
evaluated, and the results are reported and suggestions for further tests and research made.

LITERATURE REVIEW

An extensive literature review revealed the following findings with regard to bus lanes in downtown areas.

1. Operational capacities are currently in the range of 90 to 120 buses/h, although this maximum has been exceeded.
2. Extensive bus operation research has been carried out, but the potential capacity of downtown bus lanes has not been fully investigated.
3. Preemption of downtown traffic signals is not very beneficial, but fixed-time signal plans have offered buses some measure of priority over other traffic.
4. The maximum number of passengers at the most heavily patronized stop is a major capacity restriction.
5. The interaction between buses and right-turning vehicles in the section of the bus lane immediately before the traffic signal (hereafter called the common section) has been the subject of a number of investigations.
6. Bus lane simulation models are applicable to specific situations only. Most models do not allow for either overtaking by buses or interference by pedestrians, contrary to actual practice in Canadian cities.

FIELD EXPERIMENTS

The purpose of the field experiments was to find values for the different parameters to be used in the simulation model. These values were then compared and supplemented with those cited in the literature (2, 3, 4, 5) and those of the operational experience of Ottawa transit operators. The experiments were conducted on test sections of two downtown Ottawa streets during the afternoon peak period in July and August of 1975. These streets, Albert Street and Slater Street, are both one-way and have with-flow bus lanes and three other traffic lanes. Most observations were carried out with the aid of closed-circuit television. Experiments were conducted to determine the following:

1. Minimum distance between individual berths at a bus stop;
2. Total bus stop delay time, defined as the interval between the moment the bus stops and the moment it sets in motion again;
3. Total bus stop delay time in operating strategies, such as bus platooning, in which an advance passenger information system will be used (such a system would inform waiting passengers of which bus was coming next so that they could form a queue before it arrived);
4. Existing operational conditions on the test sections in downtown Ottawa (this included bus load checks, running times, number of right-turning vehicles, and lane distribution of traffic); and
5. Additional bus-flow data, such as acceleration rates, deceleration rates, cruising speeds, and headways when buses are operating as single units or in platoons.

SIMULATION MODEL

An analysis of the great number of factors influencing bus operations and the continuous nature of some factors required a simulation model. The bus lane operating strategy simulation model (BLOSSIM), developed during this project, simulates bus movements only; the effects of other traffic components are introduced by means of coefficients.

Model Description

The key ingredient of the model is a constraint representing the minimum distance \( D_{min} \) in meters between two buses. This parameter is expressed as a function of the speeds of the two buses only and varies for the different sections and lanes and is \( 13 + D \) for a bus lane outside the common section (that portion of the bus lane in advance of the intersection where automobiles may enter to turn right, Figure 1), \( 13 + D, _+D \) for a bus lane within the common section, and \( 19 + D, \) for lane 2.

\[
D = (12 V_l) - (7 V_2)/30
\]  

\( D, \) is based on a maximum cruising speed of \( 11 \text{ m/s} (35 \text{ ft/s}) \) and bus headways of \( 3 \text{ s} \) derived from observations. \( V_1 \) is the speed of the lead bus and \( V_2 \) is the speed of the following bus. The filtering distance \( D, \) equals \( R \times C, \) where \( R \) is a random number between 0 and 6 and \( C \) represents headways between two vehicles; \( C = 6 \text{ m} \) was adopted.

The equation shows that the absolute minimum separation \( D_{min} \) (measured from bus front to bus front) is \( 13 \text{ and } 19 \text{ m} (42 \text{ and } 62 \text{ ft}) \) for buses in the bus lane and in lane 2 respectively. The other two coefficients are delay caused by right-turning vehicles \( (C_r) \) and additional delay caused by pedestrians crossing the side street and so interfering with right-turning traffic \( (C_m) \).

At each time interval \( (1 \text{ s}) \) model buses must either accelerate, if traveling at a speed less than the maximum cruising speed, or decelerate, depending on the bus in front, the state of the traffic lights, and the need to pick up passengers. A bus will stop for a red traffic signal, to load passengers, and for the bus in front.

The same separation criteria are applied to buses in front of and behind the bus that makes a lane change. A bus driver will try to change lanes if he or she experiences a delay. These delays may be caused by a bus ahead boarding passengers or by right-turning vehicles affected by pedestrian interference.

The model is programmed in FORTRAN IV so that the simulation can be implemented on a large IBM S/360/370 installation under operating System. An important feature of the implementation is the separation of the simulation functions from the reporting function. Special care was taken to represent a typical downtown area, although most of the parameter values are related to conditions in downtown Ottawa.

Input Data

The road system simulated consists of six blocks, each 180 m (600 ft) long. A block is measured as shown in Figure 1.

There are three stops per block and these can be located in the middle of the block, in the center, or far side. We prepared a table by route that gives the measurement from the zero point at block 1 along the total system to the point at which each stop is located. We can vary not only the location of the bus stops but also the allocation of buses per stop.

Spacing between bus stops is fixed at 26 m (86 ft) so one bus can pull in between two buses or the second bus can pull out, plus some extra space for model flexibility. Also, the far side location is set into the block at a sufficient distance to allow a bus to cross the stop line but not to enter the bus stop. The location of a bus stop from the zero point \( (1 \text{ m} = 3.28 \text{ ft}) \) is
The delay time at a bus stop equals $2B - 7$ s, where $B$ is the number of passengers boarding. The delay time is reduced to $2B + 5$ s when a passenger information system is used. All buses on each route must stop at all designated stops and incur a minimum penalty of 7 or 5 s, even if no one boards.

The model has 18 bus routes divided equally into three groups, A, B, and C. The A routes stop at all A bus stops, and so on. The frequency of the routes varies.

Passengers are generated for each route at each stop as a function of route frequency, which in actual practice is determined by demand. A random number (seed number) is selected to start up the generation of buses and passengers. The generation rate can vary for each route and bus stop and thus reflects a uniform or non-uniform profile along the test section. In the test program the generation rate is higher in blocks 1 and 6 than in blocks 2 and 5, and higher in 2 and 5 than in 3 and 4.

Average bus occupancy is also variable, but 50 to 55 is our system aim. Bus capacity varies but is set in the model at 80 passengers, which is reached by some buses in most runs. Even when full, buses stop at all stops and incur a minimum penalty of 2 s.

Each intersection is signal controlled, and each cycle length is 80 s with 40 s green and 4 s amber in the direction of travel. Variable offsets are set at 15, 25, 40, and 65 s in the model. Automobiles may enter and turn right in a common section of the bus lane for 45 m (150 ft) back from the stop line in blocks 2, 4, and 6.

The top speed and acceleration or deceleration rates are variable. In the model, a top speed of 11 m/s (35 ft/s) has been used. Acceleration and deceleration rates have been set at 1.2 and 1.5 m/s (4 and 5 ft/s) respectively.

Table 1 summarizes input characteristics and values used in the model runs.

**Output Data**

Each model run can produce the following three types of output data:

1. Terminal data including particulars for each bus, such as the time it enters and leaves each block, the number of passengers, mean speed, and so on, and the number of buses and the number of passengers per hour;
2. Photographs of events and status of queues during the run at selected time points; and
3. Comprehensive traces of individuals or groups of buses during a time period.

---

### Table 1. Model input characteristics.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Fixed or Variable</th>
<th>Values Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of blocks</td>
<td>F</td>
<td>6</td>
</tr>
<tr>
<td>Length of block excluding intersection, m</td>
<td>F</td>
<td>100</td>
</tr>
<tr>
<td>Location of common section, block no.</td>
<td>V</td>
<td>2, 4, 6</td>
</tr>
<tr>
<td>Number of bus stops per block</td>
<td>F</td>
<td>3</td>
</tr>
<tr>
<td>Number of bus routes per stop</td>
<td>F</td>
<td>6</td>
</tr>
<tr>
<td>Location of each stop</td>
<td>V</td>
<td>Varies</td>
</tr>
<tr>
<td>Spacing between stops, m</td>
<td>V</td>
<td>14 or 26</td>
</tr>
<tr>
<td>Minimum delay per stop, s</td>
<td>V</td>
<td>5 or 7</td>
</tr>
<tr>
<td>Delay per passenger per stop, s</td>
<td>V</td>
<td>5 or 7</td>
</tr>
<tr>
<td>Cycle length for traffic signals, s</td>
<td>V</td>
<td>80</td>
</tr>
<tr>
<td>Time of amber time, s</td>
<td>V</td>
<td>4</td>
</tr>
<tr>
<td>Time offset between adjacent signals, s</td>
<td>V</td>
<td>15, 25, 40, 65</td>
</tr>
<tr>
<td>Bus capacity, seats and standees, m</td>
<td>V</td>
<td>80</td>
</tr>
<tr>
<td>Bus acceleration rate, m/s</td>
<td>V</td>
<td>1.2</td>
</tr>
<tr>
<td>Bus deceleration rate, m/s</td>
<td>V</td>
<td>1.5</td>
</tr>
<tr>
<td>Maximum speed, m/s</td>
<td>V</td>
<td>11</td>
</tr>
<tr>
<td>Bus flow generated, buses/h</td>
<td>V</td>
<td>150 to 185</td>
</tr>
<tr>
<td>Bus passenger flow generated, passengers/h</td>
<td>V</td>
<td>7500 to 9300</td>
</tr>
</tbody>
</table>

Note: 1 m = 3.28 ft.

---

### Table 2. Summary of simulation results.

<table>
<thead>
<tr>
<th>Operating Conditions</th>
<th>Model Results</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Buses Allowed to Overtake Buses</td>
</tr>
<tr>
<td>Strategy</td>
<td>Yes</td>
</tr>
<tr>
<td>Alternating bus stop spacing</td>
<td></td>
</tr>
<tr>
<td>Buses operating in platoons of three</td>
<td></td>
</tr>
<tr>
<td>Bus overtaking allowed, no right turns by other vehicles</td>
<td></td>
</tr>
<tr>
<td>Variations in traffic signal offset</td>
<td></td>
</tr>
<tr>
<td>No bus overtaking allowed</td>
<td></td>
</tr>
</tbody>
</table>

Note: 1 m = 3.28 ft.
Model Testing

Before examining different bus operating strategies, a detailed analysis for model realism was made of bus running times, interference coefficients, and bus operations in the second lane. Further, we needed to know how to measure the bus flow rate, which seed number (to start up the generation process) to use, and how long to extend each computer run. Testing with different seed numbers and run lengths indicated variations in flow rates comparable to those for vehicle counts. We decided to investigate a number of bus operating strategies using the same seed number and run length of approximately 60 min.

STRATEGY EVALUATION

The results of the computer runs indicate that with the described set of test conditions some strategies are more effective than others. Table 2 briefly summarizes the results of the simulation runs.

The most effective strategy we tested is one in which alternating bus stops are employed to increase the average bus stop spacing from 180 to 360 m (600 to 1200 ft). The buses on half of the routes stop in blocks 1, 3, and 5; those on the other routes stop in blocks 2, 4, and 6. This strategy yields a flow rate of approximately 160 bus/h and a good quality of service as measured by average bus occupancy and average operating speed through the six-block test section. This strategy was felt to be the most effective, because it achieved the best compromise among bus volume, speed, and occupancy. Other strategies did achieve higher bus volumes but only at a cost of lower average speeds. Even higher volumes are probably also possible with this strategy if right turns by automobiles are restricted.

If overtaking is not possible, platooning could be applied. This is a strategy whereby buses in a group of three or more are introduced into the bus lane and then proceed through the system as a group. Their order of arrival at a bus stop is automatically given in advance to waiting passengers by means of a scanning system, which allows passengers to form into lines and board more efficiently. In addition, platooning allows signal offsets to be adjusted to accommodate bus movements. This strategy yielded a high flow rate that was sensitive to variations in traffic signal offsets. The speed, however, was relatively low. The necessary advance bus arrival sign system may be expensive unless buses are already equipped with detecting devices, although the driver could operate the sign system by radio.

The third strategy, wherein buses are allowed to overtake but other vehicles are not allowed to make right turns from the common section, produces high throughput with acceptable bus occupancy but low speed. This point to banning right turns by automobiles from the common section. However, some right turns in the downtown area would be required, and the location of the common sections is thus important.

The influence of variations in traffic signal offset is inconclusive for existing operations with bus overtaking and right turns by automobiles because of the multiplicity of stops and bus routes in the system and the interaction among throughput, bus occupancy, and speed. Although overtaking by buses is permitted in all major Canadian cities, it is not always possible because of traffic in adjacent lanes. This would influence bus operation considerably. Allowing no overtaking would reduce bus throughput and quality of service. The provision of bus bays would remedy this.

CONCLUSIONS AND RECOMMENDATIONS

BLOSSIM is a valuable tool in the analysis of bus operating strategies. Using the same seed number and run lengths of approximately 60 min, we were able to evaluate several strategies.

Bus flow rates of between 150 and 170 vehicles/lane-h can be achieved without having to resort to extraordinary and unconventional operating strategies. This flow rate can accommodate 8000 to 9000 passengers/h with acceptable loading standards, operating speeds, and existing standard equipment.

To refine the model and to extend the knowledge of operating strategies we recommend the following subjects for further research:

1. Model validation through additional runs to establish sensitivity to seed number and run length,
2. Model modification to incorporate variations in block length,
3. Investigation of additional strategies,
4. Additional field validation tests, and
5. Refinement of the algorithm that defines the distances between buses, particularly for bus movements in the second lane.

ACKNOWLEDGMENTS

The research described in this paper was part of a study carried out by De Leuw Cather, Canada, Ltd., under the direction of a working committee representing the Canada Transportation Development Agency of Transport, the Ontario Ministry of Transportation and Communications, the Ottawa-Carleton Regional Transit Commission and Transportation Department, and the National Capital Commission. The assistance of the committee members during the study is appreciated. Neil V. McEachern and Tony Zimmer of Group Five Consulting, Ltd., contributed greatly to the development of the model. The original study was carried out in imperial units.

REFERENCES


Publication of this paper sponsored by Committee on Highway Capacity and Quality of Service.