Bus Service Times and Capacities in Manhattan

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Bus dwell times, passenger service times, and bus capacities are analyzed for the Midtown Manhattan Central Business District. Surveys were conducted in 1988 at seven sites on Madison, Fifth, and Sixth Avenues. Service times per passenger averaged approximately 8 sec as a result of complex fare structures. Dwell times were best predicted by an exponential model that explained more than two-thirds of the variance. Application of the *Highway Capacity Manual* formula for the capacity of a bus stop produced acceptable results in cases for which the lane was used exclusively by buses. More significantly, the reductive factor of 0.83, as given in the *Highway Capacity Manual*, was found to closely approximate the reductive effects of buses on the capacity of Midtown Manhattan streets.

The New York City Department of City Planning (DCP) has been updating its methodology for evaluating the capacity impacts of express buses in Midtown Manhattan. Accordingly, in 1988, DCP commenced a study to verify and update the passenger car equivalent (PCE) values used in its analysis. As the study progressed, it became apparent that new approaches were necessary, and that answers were needed to questions such as the following:

- How do fare collection policies affect passenger service times?
- How do the values of the reductive factor R compare with those given in the 1985 *Highway Capacity Manual (HCM)* (*1*)?
- How well do *HCM* (*1*) methodologies estimate the capacities of bus stops?

To address these questions, the available literature on dwell times and bus capacities was reviewed. Special field studies were made of bus performance on Midtown Manhattan avenues, and suggested capacity guidelines were developed. This paper presents the results of these surveys and analyses.

BACKGROUND

The HCM (*1*) presents methodologies for use in the analysis of the capacity and level of service of various types of roadways. Each specific analysis begins with the assumption of certain ideal conditions and then utilizes adjustment factors to reflect actual conditions. The ideal of primary importance here is that all vehicles operating in a traffic stream are passenger cars. This assumption is, of course, routinely violated in large urban areas such as New York City.

To allow for this, the *HCM* (*1*) uses the concept of passenger car equivalent (PCE), defined as "the number of passenger cars that are displaced by a single heavy vehicle of a particular type under prevailing traffic, roadway, and control conditions." It is assumed that any heavy vehicle will have the same impact on the capacity and level of service of a segment as the equivalent number of passenger cars. The PCE of any heavy vehicle is not a fixed number but rather a function of prevailing conditions.

The *HCM* (*1*) gives the value of 1.5 as the PCE of a through bus (i.e., a bus operating, usually on an urban arterial, without stopping to receive or discharge passengers); in other words, such a bus is assumed to be equivalent in traffic impact to approximately 1.5 cars. Techniques are presented for estimating the PCE of a bus whose passenger service activity impedes the flow of other traffic, on the basis of signal phasing, stop duration, and average vehicle headway. This methodology, which incorporates nationwide averages, is summarized in the *HCM*'s Table 12–8 and the equation accompanying it (*1*).

LITERATURE SEARCH

Prior research into bus operations and their effects on traffic has focused not on bus PCEs but on the dwell times of buses operating on both local and suburban routes. Factors contributing to dwell time include the configuration and occupancy of the bus, the number of boarding and alighting passengers, the frequency of stops, and the method of fare collection (*1*).

Hoey and Levinson (*2*) reported boarding times ranging from 2 to 8 sec per passenger according to the fare collection mechanism used. Specific boarding times per passenger were observed to be approximately 2.0 sec when the fare was either prepaid (in the form of a pass), postpaid (i.e., paid on leaving the bus), or nonexistent; 2.6 to 3.0 sec when fares were paid with a single coin; 3.0 to 4.0 sec for multicoin fares; and 6.0 to 8.0 sec when paper currency was involved. The large disparity associated with paper currency stems in part from the use of bill-taking fareboxes, which tend to jam (*3*), and in part from the practice of having drivers handle cash fares, make change, and give refunds.

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To highlight factors other than fare collection, Zografos and Levinson (*4*) examined dwell times for a no-fare transit system. The most important of these other factors were the number of boarding passengers and the number of passengers already aboard. Indeed, the average time of 2.0 sec per passenger was found to apply primarily when relatively few persons boarded a relatively uncrowded bus.

The number of boarding passengers is also addressed by Guenthner and Sinha (*5*), who developed a marginally acceptable (R^2 = 0.36) logarithmic model (presented here with notation changed):

$$P = 5.0 - 1.2(\ln N) \qquad (1)$$

where

P = dwell time per passenger, and
N = total number of boarding and alighting passengers.

Other factors cited as possibly relevant include the existence of structured or multicoin fares, the use of single-door buses, the presence of passengers with special needs, and the distribution of stops.

Levinson (*6*) presents a thorough analysis of travel times as they relate to bus speeds, dwell times, stop frequency, and bus acceleration. He finds average dwell times of approximately 16 sec for heavily patronized suburban routes (similar to the type considered by DCP) and 50 to 60 sec at very busy central business district (CBD) boarding points.

The *HCM* (*1*) reviews all of the foregoing and suggests boarding times of 2.6 sec per passenger for single-coin fares, 3.0 sec for exact multicoin fares, and 3.5 sec for exact fares when standees are present.

DATA COLLECTION

Field reconnaissance investigations were conducted to observe express bus operations and bus priority treatments on Madison, Fifth, and Sixth avenues. Three priority treatments are in effect: a double-width exclusive bus lane (XBL) for buses only on Madison Avenue (with right turns prohibited); a two-lane red zone on Fifth Avenue for buses and right turns; and a single-lane red zone on Sixth Avenue for buses and right turns. Of these treatments, the two-lane red zone was found to be the most effective.

Seven midtown express bus stops were studied. Each stop is a major boarding point for the operator(s) serving it or is an area susceptible to traffic problems:

1. Madison Avenue from 44th to 45th Street,
2. Madison Avenue from 46th to 47th Street,
3. Fifth Avenue at 48th Street,
4. Fifth Avenue from 43rd to 42nd Street,
5. Fifth Avenue from 41st to 40th Street,
6. Sixth Avenue from 43rd to 44th Street, and
7. Sixth Avenue from 44th to 45th Street.

Each site was surveyed over three consecutive days (a Tuesday, a Wednesday, and a Thursday) between 4:30 and 5:30 p.m. Altogether, 449 buses were counted, representing 68 routes operated by 14 carriers. The following factors were included in the survey:

- Dwell times included the passenger service time plus the time needed to open and close the doors.
- Passengers were counted as they boarded each bus. Because these were peak-hour express routes, there were no alightings. Any passenger who disembarked after learning that he had boarded the wrong bus was considered to have been served, and was therefore counted. On the other hand, straggling passengers, for whom the doors were reopened after the bus had begun to leave the stop, were not counted.
- Three methods of fare collection were observed: (a) coin-only fareboxes, which require the exact fare in any combination of subway tokens or coins; (b) coin-and-bill fareboxes, which accept subway tokens, coins, and dollar bills; and (c) payment of the fare directly to the driver, who will change any bill up to \$20. The coin-and-bill fareboxes, as well as the New York City Transit Authority's coin-only fareboxes, are electronic. For the purposes of this analysis, these fare collection procedures were combined into a single indicator variable, BILLS, which took values of 1 if bills were accepted and 0 otherwise.
- Three causes of bus operation-related delays were noted: (a) bus held for schedule adjustment; (b) queue of buses serving the same or adjacent stop; and (c) straggling passengers being served. An indicator variable B in the dwell time analysis accounted for the presence of such delays.
- Three cases of delay attributable to general traffic conditions were noted: (a) red lights; (b) right turns into a side street; and (c) overall congestion. The first two tended to occur at near-side bus stops. An indicator variable T in the dwell time analysis accounted for the presence of these delays.

In addition, traffic counts were conducted at all bus stops in question and at the intersections immediately beyond them. These counts provided a basis for comparisons of bus and car volumes at each site. For each vehicle using the curb lane, information was collected pertaining to type (e.g., automobile), function (e.g., taxi), and actual activity (e.g., stopping to discharge a rider). Also noted was activity belonging at the curb (such as passengers boarding a bus) but occurring in the moving lanes. Intersection counts were more traditional in scope: vehicles entering the intersection in each lane were classified by type. Tables 1 and 2 present the peak-hour bus and passenger car flows observed in the curb and second lanes.

DWELL TIME ANALYSIS

Bus dwell times and passenger service times obtained from the various surveys are presented in Tables 3 and 4. These tables show the means, standard deviations, and coefficients of variation by survey site and method of fare collection, respectively.

In apparent violation of prior research findings, average dwell time per passenger ranged from a low of 5.52 sec at Site 6, where only coins were taken, to a high of 9.22 at Site 7, where bills were accepted. Also, the service times averaged 6.13 sec per passenger on coin-only buses and 8.55 sec on coin-and-bill buses. The *HCM* (*1*), Table 12–9, gives a range of 6 to 9 sec for complex cash fares.

It should be noted that the standard deviations presented in Table 2 are very close to one another, indicating that a change in fare collection policy would simply shift the

TABLE 1 PEAK-HOUR CURB LANE FLOW RATES BY CORRIDOR AND VEHICLE CLASSIFICATION

SITE*		BUSES per hour	CARS per hour	TRUCKS per hour	TOTAL per hour
#1	Madison Av/44-45 St	34	6	1	41
#2	Madison Av/46-47 St	45	1	0	46
#3	Fifth Av/48 St	36	24	0	60
#4	Fifth Av/43-42 St	48	10	4	62
#6	Sixth Av/43-44 St	18	98	10	126
#7	Sixth Av/44-45 St	14	19	3	36

* Volumes recorded at site #5 are unreliable due to construction at 41st Street.

TABLE 2 PEAK-HOUR SECOND-LANE FLOW RATES BY CORRIDOR AND VEHICLE CLASSIFICATION

SITE*		BUSES per hour	CARS per hour	TRUCKS per hour	TOTAL per hour
#1	Madison Av/44-45 St	112	152	28	292
#2	Madison Av/46-47 St	128	44	8	180
#3	Fifth Av/48 St	160	180	40	380
#4	Fifth Av/43-42 St	128	244	20	392
#6	Sixth Av/43-44 St	84	320	56	460
#7	Sixth Av/44-45 St	84	340	52	476

* Volumes recorded at site #5 are unreliable due to construction at 41st Street.

TABLE 3 SUMMARY OF EXPRESS BUS DWELL TIME DATA BY SITE FOR THREE TYPICAL FALL BUSINESS DAYS, 4:30 TO 5:30 p.m.

SITE NUMBER AND LOCATION [number of buses surveyed]			DWELL TIME (seconds)	NUMBER of PASSENGERS	DWELL TIME per PASSENGER (seconds)
1.	MADISON AVENUE	mean	123.58	13.85	9.08
	44TH-45TH STREETS	std dev	109.41	7.47	5.59
	[94 buses]	c.v.	0.89	0.54	0.62
2.	MADISON AVENUE	mean	52.39	8.36	6.60
	46TH-47TH STREETS	std dev	33.59	4.31	3.61
	[58 buses]	c.v.	0.64	0.52	0.55
3.	FIFTH AVENUE	mean	84.08	9.43	9.15
	48TH STREET	std dev	50.09	4.72	2.84
	[37 buses]	c.v.	0.60	0.50	0.31
4.	FIFTH AVENUE	mean	44.04	7.65	7.15
	43RD-42ND STREETS	std dev	36.24	5.88	5.01
	[83 buses]	c.v.	0.82	0.77	0.70
5.	FIFTH AVENUE	mean	25.56	5.28	6.08
	41ST-40TH STREETS	std dev	15.75	3.73	5.05
	[80 buses]	c.v.	0.62	0.71	0.83
6.	SIXTH AVENUE	mean	32.94	6.31	5.52
	43RD-44TH STREETS	std dev	14.63	3.01	4.28
	[35 buses]	c.v.	0.44	0.48	0.78
7.	SIXTH AVENUE	mean	50.81	5.77	9.22
	44TH-45TH STREETS	std dev	36.54	3.61	5.35
	[62 buses]	c.v.	0.72	0.63	0.58
	ALL SITES	mean	61.85	8.40	7.67
	[449 buses]	std dev	67.62	6.06	5.05
		c.v.	1.09	0.72	0.66

TABLE 4 SUMMARY OF EXPRESS BUS DWELL TIME DATA BY METHOD OF FARE COLLECTION FOR THREE TYPICAL FALL BUSINESS DAYS, 4:30 TO 5:30 p.m.

SITE NUMBER AND LOCATION [number of buses surveyed]		DWELL TIME (seconds)	NUMBER of PASSENGERS	DWELL TIME per PASSENGER (seconds)
FAREBOX - COINS ONLY	mean	27.81	5.59	6.13
[115 buses]	std dev	15.79	3.56	4.95
	c.v.	0.57	0.64	0.81
NO FAREBOX	mean	44.04	7.65	7.15
[83 buses]	std dev	36.24	5.88	5.01
	c.v.	0.82	0.77	0.70
FAREBOX - COINS, BILLS	mean	83.33	9.94	8.55
[251 buses]	std dev	80.83	6.50	4.91
	c.v.	0.97	0.65	0.57
COMBINED BILL ACCEPTANCE	mean	73.57	9.37	8.21
[334 buses]	std dev	74.32	6.43	4.97
	c.v.	1.01	0.69	0.61
ALL METHODS	mean	61.85	8.40	7.67
[449 buses]	std dev	67.62	6.06	5.05
	c.v.	1.09	0.72	0.66

distribution of service time per passenger, P. Also, the difference between the mean P for coins only and the mean P for combined bill acceptance is statistically significant at the 95 percent confidence level, confirming earlier findings regarding boarding times when bills are used. Further, the difference between the mean P for coin-and-bill fareboxes and the mean P for payment to the driver is also statistically significant at 95 percent confidence, implying that humans process bills less slowly than do machines.

In light of the recommended boarding times specified in the *HCM* (*1*), even the lowest average value of 5.52 sec per passenger warrants an explanation. The fare for each of the outer-borough express services was \$3.50 at the time of the survey. The three coin-only carriers (New York City Transit Authority, Triboro Coach, and Green Bus Lines) accept silver currency and subway tokens; NYCTA also accepted at the time of the survey a special express token that has since been phased out. The typical patron of these operators' services, then, used at least 5 coins (three subway tokens and two quarters) and often as many as 14 coins (if payment was entirely in quarters). This number of coins is far greater than what would be required for typical multicoin fares, and therefore should lead to longer than average boarding times.

The next step was to regress the dwell time D against the number of passengers N and then introduce BILLS, bus-induced delay B, and traffic delay T into the model. The resulting equations, all of whose coefficients are significant at 95 percent confidence level, are as follows:

$$D = -6.33 + 8.12N \qquad R^2 = 0.53 \tag{2}$$

$$D = -15.78 + 7.80N + 16.32\,\text{BILLS} \qquad R^2 = 0.54 \tag{3}$$

$$D = -15.96 + 7.62N + 14.51\,\text{BILLS} + 26.64B \qquad R^2 = 0.56 \tag{4}$$

$$D = 8.07N^{0.89} \qquad R^2 = 0.67 \tag{5}$$

$$D = 6.63N^{0.84}\exp(0.40\,\text{BILLS}) \qquad R^2 = 0.70 \tag{6}$$

$$D = 6.65N^{0.83}\exp(0.39\,\text{BILLS} + 0.20B) \qquad R^2 = 0.71 \tag{7}$$

The exponential models produced a higher correlation, and did not produce negative dwell times for zero boarding passengers. Note that the inclusion of B in Equation 7 contributed less than 0.01 to the value of R^2. However, the coefficient's t-statistic was 2.59, indicating statistical significance at 95 percent confidence; B was therefore retained.

ANALYSIS OF VOLUMES AND THEORETICAL CAPACITIES

A further analysis of bus volumes and capacities was made for bus stops along each avenue. Such an approach produces a more meaningful way of examining the effects of additional

buses at existing stops. The analysis builds on the methods set forth in Chapter 12 of the *HCM* (*1*).

The capacity of a bus stop on an arterial street is given in Equation 12–10(b) of the *HCM* (*1*):

$$c = \frac{3{,}600\ (g/C)R}{t + (g/C)D} \tag{8}$$

where

c = the capacity of the stop (buses per hour);
g = green plus amber time per cycle (sec);
C = cycle length (sec);
R = reductive factor to compensate for dwell time and arrival fluctuations;
t = clearance time between buses (about 15 sec); and
D = average bus dwell time (from Table 1).

Of the variables appearing in Equation 8, both c (the one of interest) and R (an input) are unknown at the outset; c must therefore be computed in a roundabout fashion. Because R, the reductive factor, accounts for variations in arrivals and dwell times, it serves much the same role as the standard deviation s of dwell time. It follows, then, that R can be replaced in the equation by some function of s, as in Equation 9.

$$c = \frac{3{,}600\ (g/C)}{t + (g/C)\ (D + zs)} \tag{9}$$

where z is the value of the standard normal random variable corresponding to the expected or assumed probability that the bus stop will operate efficiently.

Of prime importance here is the concept of efficiency. Under ideal conditions, a bus should be able to enter a stop, perform its service, and leave the stop without waiting for the preceding bus to do the same. When this ideal is violated, failure occurs: queues form and spill over into mixed traffic lanes. If this process tends to happen 30 percent of the time, then the stop is said to operate at 30 percent failure, or 70 percent efficiency. In general, for any efficiency rate E, the unknown is z such that $P(Z < z) = E$. The *HCM* (*1*) suggests 70 percent, giving $z = 0.524$, as a conservative rate of efficiency.

Values of c for each site were computed from Equation 9 and then backsubstituted into Equation 8 to obtain values of R. Table 5 presents these values for 30 and 15 percent failure. (The latter is used for comparison.) The average R value for 30 percent failure is 0.814, which compares well with the value of 0.833 suggested in the *HCM* (*1*).

In Tables 6 and 7 (for 30 and 15 percent failure, respectively), these theoretically derived capacities are adjusted for deviations in the distribution of peak-hour traffic through multiplication by a peak-hour factor of 0.91 (generally accepted for the analysis of New York City traffic).

The number of boarding positions, or berths, at each site was determined from field observation. These were converted into effective berths on the basis of the physical characteristics of each site and the berth efficiency factors given in *HCM* Table 12–19. For example, the four physical berths at each of Sites 1 and 2 became 2.45 effective berths. However, the two berths at each of Sites 4, 6, and 7 are far enough apart to qualify as two effective berths.

The observed flow rates from Table 3 were divided by the adjusted capacities to obtain ratios of bus volume to bus capacity. The disparity between values for sites on the same corridor is explained by the similar disparity in the dwell times for the same sites (see Table 3). For example, the dwell time and bus v/c ratio are much higher for Sites 1 and 3, respectively, than for Sites 2 and 4, respectively.

As can be seen, the locations on Madison and Fifth Avenues operate close to or at capacity. In this respect, the capacity computations verify visual observations of bus operations. Sixth Avenue appears to provide a substantial capacity reserve. However, these capacities may be overstated, because they are not adjusted for blockages on ineffective green time. Thus,

TABLE 5 VALUES OF c AND R ASSUMING FAILURE RATES OF 30 AND 15 PERCENT

SITE	30% FAILURE		15% FAILURE	
	c	R	c	R
#1 Madison Av/44-45 St	17.20	0.73	13.57	0.57
#2 Madison Av/46-47 St	36.62	0.82	31.17	0.70
#3 Fifth Av/48 St	25.96	0.81	21.91	0.68
#4 Fifth Av/43-42 St	39.41	0.79	32.76	0.66
#5 Fifth Av/41-40 St	57.95	0.87	51.29	0.77
#6 Sixth Av/43-44 St	54.15	0.88	48.67	0.79
#7 Sixth Av/44-45 St	37.56	0.80	31.43	0.67

TABLE 6 THEORETICAL CURB LANE CAPACITIES AND *v/c* RATIOS AT 30 PERCENT FAILURE BETWEEN 4:30 AND 5:30 p.m.

SITE*	R	THEORETICAL CAPACITY (buses/hr)	NUMBER of ACTUAL BERTHS	NUMBER of EFFECTIVE BERTHS	PEAK HOUR FACTOR	ADJUSTED THEORETICAL CAPACITY per BERTH (buses/hr)	ADJUSTED THEORETICAL CAPACITY BLOCKFACE (buses/hr)	OBSERVED FLOW RATE along BLOCKFACE	VOLUME/ CAPACITY RATIO
#1 Madison Av/44-45 St	0.73	17.20	4	2.45	0.91	15.65	38.35	34	0.89
#2 Madison Av/46-47 St	0.82	36.62	4	2.45	0.91	33.32	81.64	45	0.55
#3 Fifth Av/48 St	0.81	25.96	2	1.75	0.91	23.63	41.35	36	0.87
#4 Fifth Av/43-42 St	0.79	39.41	2	2.00	0.91	35.86	71.73	48	0.67
#6 Sixth Av/43-44 St	0.88	54.15	2	2.00	0.91	49.28	98.56	18	0.18
#7 Sixth Av/44-45 St	0.80	37.56	2	2.00	0.91	33.66	67.32	14	0.21

* Volumes recorded at site #5 are unreliable due to construction at 41st Street.

TABLE 7 THEORETICAL CURB LANE CAPACITIES AND *v/c* RATIOS AT 15 PERCENT FAILURE BETWEEN 4:30 AND 5:30 p.m.

SITE*	R	THEORETICAL CAPACITY (buses/hr)	NUMBER of ACTUAL BERTHS	NUMBER of EFFECTIVE BERTHS	PEAK HOUR FACTOR	ADJUSTED THEORETICAL CAPACITY per BERTH (buses/hr)	ADJUSTED THEORETICAL CAPACITY BLOCKFACE (buses/hr)	OBSERVED FLOW RATE along BLOCKFACE	VOLUME/ CAPACITY RATIO
#1 Madison/44-45	0.57	13.57	4	2.45	0.91	12.35	30.25	34	1.12
#2 Madison/46-47	0.70	31.17	4	2.45	0.91	28.36	69.48	45	0.65
#3 Fifth/48	0.68	21.91	2	1.75	0.91	19.94	34.89	36	1.03
#4 Fifth/43-42	0.66	32.76	2	2.00	0.91	29.81	59.62	48	0.81
#6 Sixth/43-44	0.79	48.67	2	2.00	0.91	44.29	88.57	18	0.20
#7 Sixth/44-45	0.67	31.43	2	2.00	0.91	28.60	57.20	14	0.24

* Volumes recorded at site #5 are unreliable due to construction at 41st Street.

the actual road space available for new buses is less than that presented in the tables.

IMPLICATIONS

The following implications are apparent from the preceding analyses:

1. The overly long passenger service times (up to 9.22 sec per passenger) reflect the use of dollar bills and large numbers of coins. These service times could be reduced if passengers were permitted and encouraged to use a single token, a pass, or any other time-saving mechanism.
2. The reductive factor value of 0.833 set forth in the *HCM* (*1*) for 30 percent failure appears reasonable. The study yielded values between 0.73 and 0.87, with an average of 0.814.

3. The *HCM* (*1*) methodology for estimating the capacity of a bus stop provides reasonable results—but only when buses have full use of the curb lane. When the lane is shared with other traffic, appropriate deductions must be made.

On streets such as Fifth and Madison Avenues, buses have use of designated berths and dedicated lanes. This policy gives much higher capacities than those obtained from the *HCM* (*1*) equation for a single bus stop. More research should be undertaken into both the interactions of buses with mixed traffic in such lanes and the efficiency of multiberth bus stops. These are promising areas for further investigation.

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