Analyzing Transit Travel Time Performance

HERBERT S. LEVINSON

A detailed analysis of transit speeds, delays, and dwell times based on surveys conducted in a cross section of U.S. cities is summarized. The relationships and parameters provide inputs for planning service changes and assessing their impacts. The surveys and analyses find that car speeds are consistently 1.4 to 1.6 times as fast as bus speeds; time the typical bus speeds about 48 to 75 percent of its moving, 9 to 26 percent at passenger stops, and 12 to 26 percent in traffic delays; and peak-hour bus travel times approximate 4.2 min/mile in suburbs, 6.0 in the city, and 11.50 in the central business district. Bus dwell times (including door opening and closing) approximate 5 sec plus 2.75 times the number of passengers; during peak hours local buses stop at 68 to 78 percent of the designated stops. Bus travel times and speeds were derived as a function of stop frequency, stop duration, and bus acceleration and deceleration times observed in the field. Reducing bus stops from eight to six per mile and dwell times from 20 to 15 sec would reduce travel times from 6 to 4.3 min/mile, a time saving greater than that which could be achieved by eliminating traffic congestion. Transit performance should be improved by keeping the number of stopping places to a minimum. Fare-collection policies and door configurations and widths are important in reducing dwell time, especially along high-density routes. Such time savings will likely exceed those achieved from providing bus priority measures or improving traffic flow.

Transit travel times and operating speeds influence service attractiveness, costs, and efficiency. They also provide important descriptions of system performance for use in the transportation planning process. Yet, despite their importance, relatively few studies have been made to quantify these factors as they relate to ridership density, traffic conditions, and land use.

A detailed analysis of transit speeds, delays, and dwell times based on surveys conducted in a cross section of U.S. cities in 1980 (1) is summarized. The study was initially designed to verify and update INET reports on transit speed and roadway type (2). In a broader sense, however, it provides parameters for use in planning service changes and estimating their impacts.

The study included the following steps:

1. Available literature on transit-delay characteristics over the last several decades was assembled and analyzed;
2. Field studies were conducted of bus (and rail) performance in Boston, Chicago, New Haven, and San Francisco in 1979 and 1980;
3. Transit acceleration and deceleration characteristics were simulated and compared with actual times observed in the field; and
4. Results were integrated to produce a consistent and realistic picture of transit performance in U.S. cities.

Research findings address the following areas:

1. A comparison of line-haul bus and car travel times,
2. Bus speeds and delay,
3. Passenger service times at bus stops,
4. Bus (and train) dwell times (per stop) and stop frequencies (stops per mile),
5. Bus acceleration and deceleration, and
6. Transit speeds as a function of stop frequencies and dwell times.

The components of transit travel time that have been quantified are shown in Figure 1.

BUS AND CAR SPEEDS

Ratios of car to bus speed in Chicago's Loop, midtown Manhattan, Dallas, New Haven, and San Jose are shown in Table 1 (3-6). Car speeds are consistently 1.4 to 1.6 times faster than bus speeds. These ratios appear independent of year of study or type of city.

TRANSIT SPEED AND DELAY

Peak-hour transit speed and delay data for eight cities are summarized in Tables 2 and 3 (7-10). Minutes per mile (delay rate) has been used as the basic parameter, since it enables times to be added as needed. Means, standard deviations, and percentage distributions are given for time spent moving, at passenger stops, and in traffic delays. (The

Figure 1. Transit time components.

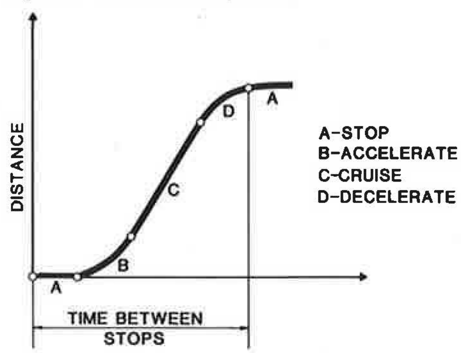


Table 1. Comparative bus and car speeds for selected urban areas.

City and Year	No. of Routes	Relation of Car to Bus Speed (min/mile): Morning Peak Ratio	Morning Peak SD	Midday Ratio	Midday SD	Evening Peak Ratio	Evening Peak SD
Chicago (Loop), 1950	NA	–	–	1.39[a]	–	1.38	–
Dallas, 1972	14	1.61	0.28	–	–	1.65	0.16
New Haven, 1975	15	–	–	1.54	0.22	–	–
Midtown Manhattan, 1968	16	1.59	0.35	1.63	0.43	1.48	0.30
San Jose, 1968	NA	1.42	–	1.48	–	1.37	–

Notes: NA = not available.
Some data are from the Bureau of Traffic Operations, New York City Department of Transportation.

[a]8:00 a.m. to 6:00 p.m.

Table 2. Travel time and delay for typical transit routes.

Mode	City and Year	No. of Routes or Streets	Avg. Travel Time (min/mile)	Proportion of Journey Time (%) Spent for Traffic Delays	Passenger Stops	Moving	Remarks
Bus	Oakland, Alameda-Contra	4	4.95	19.4	26.7	53.9	Suburban
	Costa County, CA; 1979	1	3.18	18.6	23.6	57.9	Intercity
	Minneapolis, MN; 1977	3[a]	11.34	25.8	24.0	50.2	CBD
	Philadelphia, PA; 1977	2[a]	11.41	26.5	25.8	47.7	CBD
	Santa Clara, CA; 1969	3	4.38	16.2	9.1	74.7	Suburban
	St. Louis, MO; 1957-1958	20	5.47	12.1	17.9	70.0	City lines
	New Haven, CT; 1979-1980	2	6.14	19.0	18.4	62.6	Urban-suburban
Streetcar	Beacon St., Boston, MA; 1968	1	6.06	14.8	22.9	62.3	In center reservation
	St. Louis, MO; 1957-1958	4	6.60	12.7	17.7	69.6	City lines

Note: Some data are from field surveys in conjunction with the Regional Planning Agency of South Central Connecticut.
[a]Streets.

Table 3. Transit travel times for typical routes.

Mode	City and Year	No. of Routes or Streets	Travel Time (min/mile) Avg or Total Mean	SD	Traffic Delays Mean	SD	Passenger Stops Mean	SD	Moving Mean	SD	Remarks
Bus	Oakland, Alameda-Contra	4	4.95	0.37	0.96	0.19	1.32	0.26	2.67	0.16	Suburban
	Costa County, CA; 1979	1	3.18	0.25	0.59	0.11	0.75	0.07	1.84	0.26	Intercity
	Minneapolis, MN; 1977	3	11.34	1.96	2.93	1.46	2.72	1.23	5.69	1.19	CBD
	New Haven, CT; 1979-1980	1	5.88	0.51	0.99	0.14	1.15	0.22	3.74	0.31	Urban
		1	6.40	0.86	1.35	0.38	1.10	0.37	3.95	0.73	Urban
	Philadelphia, PA; 1977	2	11.41	0.88	3.03	0.50	2.94	0.64	5.44	0.36	CBD
	Santa Clara, CA; 1969	3	4.38	0.20	0.71	0.08	0.40	0.06	3.27	0.10	Suburban (low density)
	St. Louis, MO; 1957-1958	20	5.47	0.48	0.66	0.29	0.98	0.21	3.83	0.37	City lines
Streetcar	Beacon St., Boston, MA; 1968	1	6.07	0.83	0.90	0.24	1.39	0.46	3.78	0.22	In center reservation
	St. Louis, MO; 1957-1958	4	6.60	1.09	0.84	0.46	1.17	0.24	4.59	0.38	City lines

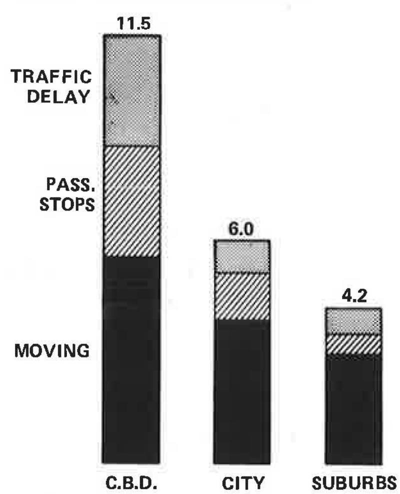
Note: Some data are from field surveys in conjunction with the Regional Planning Agency of South Central Connecticut.

Table 4. Estimated peak-hour transit travel times by component.

Component	Travel Time (min/mile)[a] CBD	City	Suburbs
Traffic delay	3.00 ± 1.00	0.90 ± 0.30	0.70 ± 0.10
Passenger stops	3.00 ± 1.00	1.20 ± 0.30	0.50 ± 0.10
Moving	5.50 ± 1.00	3.90 ± 0.30	3.00 ± 0.12
Total	11.50 ± 3.00	6.00 ± 0.90	4.20 ± 0.30

Note: Data are from Tables 2 and 3.
[a]Plus-or-minus values represent one standard deviation.

Figure 2. Peak-hour bus travel times.



standard deviations reflect the variations among average times reported for various bus or streetcar routes in each community.)

Reported ranges for U.S. cities in the time spent enroute are moving, 48 to 75 percent; at passenger stops, 9 to 26 percent; and in traffic delays, 12 to 26 percent.

Transit travel times vary by type and location of route. Generalized peak-hour travel times for the central business district (CBD), central city, and suburban bus lines by time component are shown in Table 4 and Figure 2 in minutes per mile. The following characteristics may be noted:

1. Peak-hour bus travel times approximate 4.20 min/mile in suburban areas, 6.00 min/mile in the central city, and 11.50 min/mile in the CBD.
2. The time in motion approximates 3.00 min/mile in the suburbs, 3.90 min/mile in the central city, and 5.50 min/mile in the CBD. It appears to vary inversely with the frequency of stops.
3. Passenger stops account for 0.50 min/mile in the suburbs, 1.20 min/mile in the city, and 3.00 min/mile in the CBD.
4. Traffic delay amounts to 0.70 min/mile in the suburbs, 0.90 min/mile in the city, and 3.00 min/mile in the CBD.

In the central city, passenger stop delay exceeds traffic delays, whereas they are about equal in the CBD. Therefore, ways to reduce passenger delays on a citywide basis may prove more beneficial than efforts focused only on alleviating traffic congestion at key locations.

BUS-STOP FREQUENCIES AND PASSENGER SERVICE TIMES

Information on passenger stops and dwell times was obtained from specially conducted field surveys in Boston, Chicago, New Haven, and San Francisco. The results of these studies are summarized in Table 5 in which the following information is given on a route-by-route basis:

1. Route location and distance;
2. Range and mean of actual stops made per mile;
3. Range and mean for maximum dwell times reported;
4. Range and mean for the average dwell times reported; and
5. Representative formulas for estimating passenger dwell times, including time spent opening and closing doors.

The formulas take the following form:

$$T = an + b$$

where n is the number of interchanging passengers per bus and T is the total stopped time per bus in seconds. Representative values of the coefficients a and b are as follows:

Location	Activity	a	b
Boston	Mainly discharging	1.2-1.7	4.0
Boston	Paying when outbound	2.0	4.3
New Haven	Boarding and alighting	2.6-3.0	3.9-5.6

The formula $T = 2.75n + 5$ sec provides a reasonable estimate of the dwell times in any community.

The variations in dwell time along specific routes reflect the location of stop, surrounding land uses, and the number of interchanging bus lines. Although stops generally average less than 20 sec, buses spent 30 to 60 sec at major transfer points, terminals, or rail-bus interchange locations. Examples of dwell times at major bus stops are shown in Table 6.

In estimating bus performance, it is necessary to

Table 5. Summary of observed bus-stop frequencies and passenger dwell times.

City	Bus Route	Distance (miles)	Time of Day	Direction	Stops per Mile: Range^a	Stops per Mile: Mean^b	Dwell Time per Stop (sec): Maximum: Range^a	Maximum: Mean	Average: Range^a	Average: Mean	Representative Formula	Remarks
Boston	1	4.0	p.m.	Both	5.0-5.5	5	29-35	32	10.4-13.2	11.8	1.7n + 4.0	Urban route, mainly discharging passengers
	1	4.0	Midday	Both	3.3-3.5	3	37-61	49	14.4-17.3	15.7	2.5n + 5.0	Urban route, high density
	71	3.3	a.m.	SB	6.7	7	37	37	11.6^c	11.6^c	2.6n + 2.1	White-collar passengers Urban-suburban route
	71	3.3	Midday	Both	2.7-4.5	3	12-29	20	8.6-13.0	10.9	3.1n + 5.1	Suburban-urban route
	77	5.3	p.m.	NB	4.7	5	38	38	13.1	13.1	2.0n + 4.3	Pay when entering inbound, when leaving outbound; suburban limited stops
	77	5.3	Midday	Both	1.3-1.5	1	21-28	25	$7.0\text{-}8.5^c$	7.8^c	1.2n + 4.0	Mainly alighting passengers; suburban limited stops
	240A	8.8	Midday	Both	1.1-1.5	1	34-54	41	$9.8\text{-}18.2^c$	13.6^c	$3.7n + 5.7^c$	Suburban line
Chicago	11	6.2	a.m.	SB	5.2	5	40	40	13.2	13.2	NA	Urban line
	11	1.2	a.m.	SB	6.7	7	40	40	17.7	17.7		Urban line, heavy section
	22	1.7	Midday	SB	6.5	6	27	27	14.1	14.1	NA	Central section, high-density line
New Haven				SB			$21\text{-}40^d$	28^d	$8.5\text{-}14.3^d$	10.5^d		
	B-1	4.1	p.m.	Southern leg	3.2-4.7	4	40-51	39			3.2n + 3.9	Urban route
	B-1	8.2	p.m.	SB through center	5.1-7.2	6	$35\text{-}53^d$	44^d	$11.0\text{-}15.7^d$	14.5^d	2.7n + 5.6	Urban route
	D1-2	6.6	p.m.	NB (northern leg)	4.1-5.6	5	$26\text{-}39^d$	30^d	$10.1\text{-}13.5^d$	11.6^d	2.5n + 5.1	Urban-suburban route
	D1-2	10.4	p.m.	SB through center	3.7-5.0	4	$25\text{-}53^d$	34^d	$11.3\text{-}13.1^d$	11.9^d	3.0n + 5.1	Urban-suburban route
	J1,2,3	4.8	p.m.	SB (southern leg)	5.2-6.3	6	$30\text{-}45^d$	38^d	$9.5\text{-}11.5^d$	10.8^d	2.8n + 4.4	Urban-suburban route
	J1,2,3	8.5	p.m.	NB through center	2.9-5.5	4	$22\text{-}32^d$	30^d	$8.7\text{-}11.9^d$	10.7^d	2.6n + 4.6	Urban-suburban route
	Q	3.0	a.m.	EB	5.3-6.0	6	$9\text{-}20^d$	16^d	$4.5\text{-}8.2^d$	6.5^d	NA	Urban route
San Francisco	Stockton	NA	a.m.	To center		6	30	30	21	21.0	NA	Urban route
Boston	Green Line	2.3	a.m.	Inbound	6.2	6	NA	33	NA	18.0	NA	Light-rail line, urban route
	Green Line	2.3	p.m.	Outbound	6.6	7	NA	37	NA	17.5	NA	Light-rail line, urban route

[a] Ranges are for averages for runs along each route. [b] Mean stops per mile rounded to nearest integer. [c] Excludes terminal stops. [d] Excludes main CBD stops.

Table 6. Typical dwell times at major bus stops, 1979-1980.

Type of Stop	City	Route	Location	Time of Day	Observed Dwell Time (sec)	
					Mean	SD
End of bus line at rail transit station	Boston	1, Massachusetts Avenue	Harvard Square, Red Line	p.m., midday	33	18
			Dudley Square, Orange Line	p.m., midday	38	13
		71, Watertown	Brattle Station, Red Line	a.m.	37	NA
		240, Randolph	Ashmont, Red Line	a.m.	55	NA
Transfer point at rail transit station	Boston	1, Massachusetts Avenue	Auditorium, Green Line	p.m.	36	8
		1, Massachusetts Avenue	Central Square, Red Line	p.m.	24	6
		77, Arlington Ltd.	Harvard Square, Red Line	a.m., midday	25	NA
	Chicago	11, Lincoln	Western, Ravenswood	a.m.	23	NA
		11, Lincoln	Fullerton, North, South	a.m.	23	NA
Major transfer point to another bus line	Chicago	11, Lincoln	Foster	a.m.	40	NA
	New Haven	Congress, Savin Rock	West Haven Center	p.m.	29	9
Major non-CBD stop, movie, town hall, hospital, school, etc.	Boston	71, Watertown	Watertown Square	a.m., midday	26	4
	Boston	77, Arlington Ltd.	Three major stops	p.m.	34	6
	New Haven	Congress	Yale, New Haven Hospital	p.m.	40	18

Notes: NA = not available.
Data are from field studies.

Table 7. Designated versus actual bus stops, 1979-1980.

City	Route	Time of Day	No. of Runs	Direction	Stops per Mile		
					Scheduled	Actual	Actual to Scheduled (%)
Boston	1, Massachusetts Avenue	p.m.	2	NB	6.5	5.2	80.0
	71, Watertown-Brattle	a.m.	2	EB	7.6	6.7	88.0
	240, Randolph-Ashmont	a.m.	2	NB	1.7	1.5	83.3
	1, Massachusetts Avenue	Midday	4	NB, SB	6.5	3.4	52.3
	71, Watertown-Brattle	Midday	4	EB, WB	7.6	3.1	40.8
	77, Arlington Heights Ltd.	Midday	4	NB, SB	4.7	1.4	29.8
	240, Randolph-Ashmont	Midday	2	NB, SB	1.7	1.3	76.7
Chicago	11, Lincoln	a.m.	1	SB	7.7	5.2	67.5
	11, Lincoln, heavy 1.2 miles	a.m.	1	SB	8.3	6.7	80.7
	22, Clark	Midday	1	SB	11.2	6.5	58.0
New Haven	Q, Edgewood	a.m.	3	EB	6.6	5.7	85.8

Note: Data are from field studies.

know how often a bus stops as well as how long. Table 7 compares the number of scheduled stopping places with the bus stops actually made during peak and off-peak conditions. During peak hours local buses stopped at 68 to 78 percent of the designated stopping places. During off-peak periods, the ratio of actual to scheduled stops was as low as 30 percent. These figures suggest that transit systems could reduce the number of designated stops without adversely affecting ridership.

ACCELERATION AND DECELERATION TIME

Bus acceleration and deceleration time was computed by two separate methods, and the results were then compared. Actual times observed in field studies were summarized. Times were computed based on assumed cruise speeds and rates of acceleration and deceleration set forth in the first edition of the Transportation and Traffic Engineering Handbook (11). In effect, speed profiles were developed for various stop spacings.

Table 8 (7,12) gives detailed data on bus acceleration and deceleration based on various field studies. Total acceleration and deceleration time per stop ranged from 11 to 23 sec, depending on stop frequencies. Analysis of these data showed that the total acceleration plus deceleration time per stop followed this formula:

$$T = 23.4 - 1.53X \qquad R = -0.78$$

where X is the number of stops made per mile and T is the total acceleration and deceleration time per stop.

Acceleration and deceleration time based on this formula is compared below with that obtained based on theoretical calculations: The theoretical calculations assumed that a bus accelerates at its normal or maximum rate to reach the maximum possible cruise speed and subsequently decelerates at the maximum comfortable rate to a full stop (1):

No. of Stops per Mile	Acceleration and Deceleration Time (sec)	
	Field Survey	Theoretical Calculation
1	21.9	44-62
2	20.3	44
3	18.8	37
4	17.3	30
5	15.8	24
6	14.2	24
7	12.7	18
8	11.2	13-18

The acceleration and deceleration time observed in the field was consistently less than that derived from the vehicle performance calculations, especially as the spacing between stops increases. For example, at six stops per mile, the field surveys found a 14-sec acceleration and deceleration time, whereas a bus

Table 8. Observed bus acceleration and deceleration times per stop.

City	Route	Avg Stops per Mile (X)	Acceleration and Deceleration Time per Stop (T) (sec) Mean	SD	Remarks
Boston	1	3	14.8	3.8	Urban, high-density line
	71	3	20.2	4.3	Suburban line
	77	1	22.3	5.7	Suburban, limited stops
	240A	1	22.5	5.0	Suburban
Oakland	51	NA	17.3	3.0	Suburban
New Haven	Q	6	10.8	1.8	Urban
Chicago	11	5	18.0	2.7	Urban
	22	6	16.8	5.9	Urban, high density
Hong Kong	Small single-deck bus	-	14.5	4.4	
	Large single-deck bus	-	16.7	4.4	

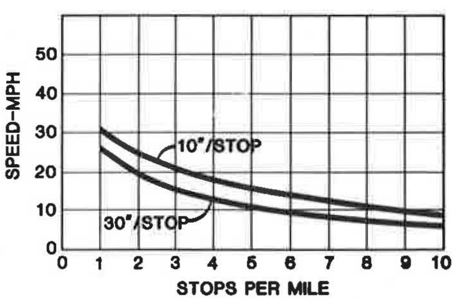
Note: Data are from field studies.

Table 9. Bus travel times and speeds as function of stop spacing.

	Dwell Time per Stop							
	10 sec		15 sec		20 sec		30 sec	
Stops per Mile	Minutes per Mile	Miles per Hour	Minutes per Mile	Miles per Hour	Minutes per Mile	Miles per Hour	Minutes per Mile	Miles per Hour
1	1.97	30.5	2.05	29.3	2.13	28.2	2.30	26.1
2	2.40	25.0	2.56	23.4	2.73	22.0	3.07	19.5
3	2.85	21.0	3.10	19.4	3.35	17.9	3.85	15.6
4	3.27	18.3	3.60	16.6	3.93	15.3	4.60	13.0
5	3.75	16.0	4.17	14.4	4.58	13.1	5.42	11.1
6	4.30	14.0	4.80	12.5	5.30	11.3	6.30	9.5
7	4.67	12.8	5.25	11.4	5.83	10.3	7.00	8.6
8	5.33	11.3	6.00	10.0	6.67	9.0	8.00	7.5
9	6.00	10.0	6.75	8.9	7.50	8.0	9.00	6.7
10	7.00	8.6	7.83	7.7	8.67	6.9	10.33	5.8
12	8.17	7.3	9.23	6.5	9.33	6.4	11.33	5.3

Note: Based on an acceleration and decleration rate of 3 mph/sec and acceleration-deceleration times observed in field.

Figure 3. Bus speed versus stops.



reaching its maximum possible cruise speed would spend 24 sec accelerating and decelerating.

Several factors underlie these differences:

1. Buses usually do not reach their maximum attainable cruise speeds between stops when operating on city streets because of posted speed limits, intersection interference, traffic signal controls, or street congestion. A bus making one stop per mile on a suburban street may never exceed 30 to 35 mph even though theoretically it would reach 50 to 60 mph.
2. Acceleration sometimes takes place through a series of steps in which the bus operates at several cruise speeds. Only the first step was considered as acceleration in the field.

Bus travel times and speeds as a function of stop spacing, dwell times, and observed acceleration and deceleration patterns are shown in Figure 3 and Table 9. Bus speeds as a function of stop spacing are similar to those reported in previous studies (13). These exhibits provide a practical guide for estimating bus travel times for various operating conditions and for assessing the changes in travel times resulting from reducing the frequency and duration of stops.

For example, at eight stops per mile and 20 sec/stop, bus travel time is 6 min. If the stops are reduced to six per mile and the dwell time to 10 sec/stop, bus travel time would be 4.30 min. This time saving exceeds the minute per mile buses normally lose due to traffic delay.

APPLICATIONS

General guidelines for peak-hour bus dwell times and stop frequencies as a function of location and route type are summarized below. These data provided inputs for Table 9 in estimating overall bus performance.

Passenger stops made per mile, passenger dwell time per stop, and acceleration and deceleration time per stop are given as a function of general location:

1. The number of passenger stops per mile actually made decreases with decreasing population density; suggested values are 8, CBD; 6, city; 4, inner suburbs; and 2, outer rural areas.
2. Passenger dwell times (seconds per stop) range from 30 (average) to 60 (major) sec in the CBD; they

average 15 sec in the city and 10 sec/stop in suburban areas.

3. Acceleration and deceleration time loss per stop average 11-13 sec in the CBD, 14-15 sec in the city, and 17-25 sec in suburban areas.

The type of route and type of stop vary among urban areas; they reflect ridership densities (reported by the transit agency), route configuration, and land use patterns.

Type of Route

Suggested guidelines for bus dwell times by type of route are given next (these exclude the CBD). A heavy urban route, for example, would have stops averaging 20 sec as compared with 16 sec for a medium route and 12 sec for a light route. For suburban and rural areas, heavy routes would have stops averaging 16 sec; medium routes, 12 sec; and light routes, 8 sec.

CBD Stops

Guidelines for peak-hour dwell times at CBD bus stops are shown below (based on 1979 New Haven data):

	Peak-Hour Dwell Time (sec)		
Type of Stop	Maximum	Avg. Mean	SD
Business	120	50	35
Other	60	20	15
Outlying	20	10	7

Bus dwell times will average 50-60 sec at the busiest stops, 20-30 sec at most stops, and 10 sec at lightly used stops on the CBD fringe. The maximum dwell times will be twice these values.

Major Bus Stops

Suggested guidelines for dwell times at major bus stops during evening peak hours include 40 sec for the end of the bus line at rail transit, 30-35 sec at the transfer point to rail transit or at a major bus stop, and 30-35 sec at other major stops.

Stops per Mile

Guidelines for the number of bus stops per mile actually made by type of route and area are given below:

Type of	Bus Stops per Mile		
Route	Urban	Suburban	Rural
Heavy	7	5	3
Medium	6	4	2
Light	5	3	2

Buses operating on a heavy urban route would make seven stops per mile as compared with six for a medium urban route and five for a light one.

IMPLICATIONS

The preceding parameters and relationships can be used directly in developing and assessing operating and service changes. They also provide inputs to long-range planning procedures. Field studies should be conducted to obtain city-specific parameters if greater precision is needed.

Several service planning and policy implications are apparent. Transit performance should be improved by keeping the number of stopping places to a minimum. Fare-collection policies and door configurations and widths are especially important in reducing dwell times along high-density routes. Many European transit systems have adopted such actions, but implementation in the United States generally has been limited even though the U.S. transit industry has recognized the need for fewer stopping places for 75 years.

It is desirable to eliminate traffic-induced congestion by improving general traffic flow or by providing bus priority lanes or streets or, in selected situations, bus signal preemption. These actions will improve bus performance in congested areas. Nevertheless, these gains often may be less than those resulting from reducing passenger service delays over the entire system. Herein lies an important challenge to transit operators.

ACKNOWLEDGMENT

The research summarized here was conducted for UMTA in 1980. The help of Thomas Hillegass and Larry Quillian of UMTA and Herbert Burstein of the Regional Planning Agency of South Central Connecticut is especially appreciated.

REFERENCES

1. H.S. Levinson. INET Transit Travel Time Analysis. UMTA, Final Rept., April 1982.
2. R.B. Dial, G.S. Rutherford, and L. Quillian. Transit Network Analysis: INET. UMTA, July 1979.
3. Study and Recommendations for Improving Traffic Movement in the Central Business District. City of Chicago, 1950.
4. Dallas Bus Operational Study, Volume 2. Wilbur Smith and Associates, New Haven, CT, 1972.
5. Transit Development Program, New Haven, Connecticut. Wilbur Smith and Associates, New Haven, CT, 1975.
6. San Jose--Santa Clara County Bus Study. Wilbur Smith and Associates, New Haven, CT, 1968.
7. Alameda--Contra Costa Transit District Bus Priority Techniques Study. California Department of Transportation, Sacramento, draft final rept., June 29, 1979.
8. R. Edminster and D. Koffman. Streets for Pedestrians and Transit: An Evaluation of Three Transit Malls in the United States. UMTA, Rept. UMTA-MA-06-0049-79-1, Feb. 1979.
9. St. Louis Metropolitan Area Transportation Study. W.C. Gilman and Co., St. Louis, MO, 1959.
10. Surface Car Line Operations Study: Beacon Street, Green Line, Brookline, and Boston. Bruce Campbell and Associates, Boston, MA, May 1969.
11. Transportation and Traffic Engineering Handbook, 1st ed. (J. Baerwald, ed.). Prentice-Hall, Englewood Cliffs, NJ, 1976.
12. H.S.W. Leong. Warrant for Provisions of a Bus Bay. Proc., Australian Road Research Board, Vol. 4, No. 1, 1968.
13. Bus Route and Schedule Guidelines. NCHRP, Synthesis 69, 1980.

Publication of this paper sponsored by Committee on Bus Transit Systems.