Impact of Traffic Congestion on Bus Travel Time in Northern New Jersey

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Traffic congestion in Northern New Jersey imposes a substantial time operational penalty on bus service. The purpose of a project was to quantify the additional travel time that buses need because of traffic congestion. A regression model was developed to estimate the travel time rate (in minutes per mile) of a bus as a function of car traffic time rate, number of passengers hoarding per mile, and the number of bus stops per mile. The model was used to estimate the bus travel time rate if cars were traveling under free-flow conditions, and the results were compared with the observed bus travel times.

Traffic congestion imposes a substantial operational and monetary penalty on bus transportation by increasing the time required to provide service, Congestion in New Jersey is high and is forecast to be greater; traffic volumes are predicted to increase by 7% by 2005 over the levels in 1998 and 18% by 2015 (I). The roadway network in New Jersey currently operates at or above its desired capacity at many locations during peak periods. Consequently, even small increases in traffic volume will result in significant increases in traffic delay and cost. Transit buses operate almost exclusively in mixed traffic and share New Jersey roadways with automobiles and trucks. Therefore, congestion will have an impact not only on automobile drivers and passengers and truck operators but also on bus riders.

The purpose of this study was to quantify the impact of congestion on bus travel time in Northern New Jersey. The basic approach involved developing a model that estimated bus travel time as a function of overall car travel time. The model was then used to estimate the proportion of bus travel time due to the increase in traffic time over free-flow conditions.

The paper starts with a brief overview of previous studies of bus travel time. The second section covers collection and initial analysis of the data. The third section describes the development of the model of bus travel time. This is followed by a discussion of the implications of the model. The final section presents the conclusions of the study.

OVERVIEW OF TRAVEL TIME STUDIES

Studies of bus stop spacing and bus speeds have been performed since the early 1900s. In the years following World War II, transit speed and delay studies were conducted in many cities as part of traffic engineering programs. Since the early 1970s, an increasing number of studies have analyzed the relation of bus speeds to stop spacing, dwell times at stops, and traffic congestion.

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Previous Travel Time Studies

A 1974 study by Wilbur Smith and Associates *(2)* showed the general relationship between bus stop spacing and traffic congestion, but it did not quantify the latter.

In 1980, Levinson (3) conducted an analysis of bus travel times and speeds collected in a cross section of U.S. cities to provide inputs for the transportation system modeling process. Three basic analyses were conducted:

1. Bus and car speeds were compared.
2. Bus travel times and delays were estimated from various field studies.
3. Bus travel times were derived based on dwell times, traffic congestion, actual acceleration and deceleration rates, and distance between stops.

Car speeds were generally 1.4 to 1.6 times as fast as bus speeds. The peak-hour bus travel times approximate 14 mph in suburbs, 10 mph in the city, and 5 mph in the central business district (CBD). The time in motion approximates 3.00 mi/mi in the suburbs, 3.90 mi/mi in the central city, and 5.50 min/mi in the CBD. The passenger stops accounted for 0.50 min/mi in the suburbs, 1.20 min/mi in the city, and 3.00 mi/mi in the CBD. The passenger dwell times ranged from 30 to 60 s per stop in the CBD, and the acceleration and deceleration time loss per stop averaged 11.13 s in the CBD.

For *TCRP Research Results Digest No. 38,* St. Jacques and Levinson *(4)* summarized the impact of bus stop density, dwell time, and operating environment on bus travel time rates. (See Table 1.) These studies estimated the impact of automobile traffic on bus speeds based on empirical evidence.

Manhattan CBD Study

Another approach is to use car travel times as a basic input in estimating bus travel times. A 1997 study of the congestion impact on bus service travel times in Manhattan by McKnight and Paaswell (5) found that congestion affected bus speeds in several ways. The most obvious way was that the maximum speed at which the buses could operate between bus stops was limited by the flow of general traffic. Besides limiting the maximum speed of vehicles, heavy traffic causes additional delays because of a variety of situations, such as

TABLE 1 Recommended Bus Travel Times for Various Stop Spacing, Dwell Times, and Operating Environments (4)

Base Travel Time Rates (min/mi)									
Average dwell time per stop (s)	Stops per mile								
	2	4	5	6	7	8	9	10	12
10	2.40	3.27	3.77	4.30	4.88	5.53	6.23	7.00	8.75
20	2.73	3.93	4.60	5.30	6.04	6.87	7.73	8.67	10.75
30	3.07	4.60	5.43	6.30	7.20	8.20	9.21	10.33	12.75
40	3.40	5.27	6.26	7.30	8.35	9.53	10.71	12.00	14.75
50	3.74	5.92	7.08	8.30	9.52	10.88	12.21	13.67	16.75
60	4.07	6.58	7.90	9.30	10.67	12.21	13.70	15.33	18.75

Additional Travel Time Losses (min/mi)				
Central Business District				
	Bus Lane No Right Turns	Bus Lane with Right Turn Delay	Bus Lanes Blocked by Traffic	Mixed Traffic Flow
Typical	1.2	2.0	2.5 - 3.0	3
Signal set for buses	0.6	1.4	N/A	N/A
Signals more frequent than bus stops	1.7 - 2.2	2.5 - 3.0	3.0 - 4.0	3.5 - 4.0
Arterial Roads Outside of CBD				
	Bus Lane		Mixed Traffic	
Typical	0.7		1.2	
Range	0.5 - 1.0		0.8 - 1.6	

double- and triple-parked cars and delivery vans, vehicle queues waiting to make right or left turns, and taxis making sudden stops or turns to pick up passengers. The impact of these situations was often exacerbbated for buses because of the need for buses to have frequent access to the curb lane at bus stops.

That study had also found that the difference between bus and automobile speeds was greater when the streets were more congested. (*See* Table 2.) At the maximum speeds recorded in the study, cars were moving 1.69 times as fast as buses, close to the range reported in Levinson (3). However, at the lowest speed, car speeds were 2.36 times as fast as bus speeds. This finding is consistent with the observation that under very congested conditions, buses are doubly affected: first by the low speed of the stream of traffic and, second by interference from other vehicles when moving in and out of the stream of traffic at bus stops.

McKnight and Paaswell (*5*) also developed regression model for New York City Transit (NYCT) that showed the relationship between bus travel times and general traffic travel times:

$$BT = 2.6 + 0.57\,AT + 0.0079\,P + 0.39\,BS + 0.54\,NS \qquad (1)$$

where

BT = bus travel time (*mi/mi*),
AT = automobile travel time (mi/mi),
P = passengers boarding all buses per hour in route segment per mile,
BS = bus stops per mile, and
NS = 1 for mutes operating primarily north–south, 0 otherwise.

DATA COLLECTION AND INITIAL ANALYSIS

The main task of the project was to model bus travel time rates in terms of car travel time rates (minutes per mile). The dependent variable was the travel time rate (minutes per mile) of one bus trip on a given segment of route. The primary explanatory variable was a measure of traffic level, expressed in the same form as for the bus

TABLE 2 Midtown Manhattan Bus and Automobile Travel Times and Speeds (5)

	Times (min/mi)		Speeds (mph)		Time Difference	Speed Ratio
	Bus	Auto	Bus	Auto	Auto/Bus	Auto/Bus
Average	11.0	6.1	5.5	9.8	4.3	1.78
At lowest speeds	27.0	11.5	2.2	5.2	8.7	2.36
At highest speeds	4.7	2.8	12.7	21.4	3.0	1.69

travel time rate for the same route segment. In addition, variables that represented other causes forbus delays, such as passengerboardings and alightings, number of bus stops, number of traffic signals, and geometry of the roadways and route, were collected.

The basic unit of analysis was one bus traveling on one route segment. A route segment was defined as a section of the route between two adjacent time points, with a time point (TP) being the location at which the schedule had a recorded time. The analysis used data from two mutes (59 and 62) in northern New Jersey. (See Figure 1.) Both routes were local routes, traveling from downtown Newark through several suburbs. The roads that the buses traveled varied from arterials to collectors and from two to four lanes, with and without street parking. They traveled through commercial, industrial, residential, and quasi-open land.

Three types of data were needed for the analysis: (1) bus operational characteristics for each run on each segment (e.g., travel time, passenger boardings), (2) characteristics of the route and street layout (which would be constant for a specific segment), and (3) data on traffic. Bus operational data were obtained from two sources. For the largest proportion of data, study team members rode the buses and recorded time between TPs, frequency of bus stopping for passenger activity, and numbers of passengers hoarding and alighting at each stop. This information was supplemented by data from automatic passenger counting (APC) equipment, which included Global Positioning System locating capability. Eight buses had APC equipment that recorded the foregoing information by precise location and time.

The data on route and street layout included segment length, number of traffic signals, and number of left tums in the route. Data were collected and checked by team members on the buses and by team members following the route in cars.

Travel times by car between TPs were recorded during several car mps. For Route 59, 10 outbound car trips and 8 inbound car trips were made; for Route *62*, there were *8* outbound and 9 inbound trips. The car trips were classified by time of day: a.m. peak (7 a.m. to 10 a.m.), midday (10 a.m. to 4 p.m.), p.m. peak (4 p.m. to 7 p.m.), and post-p.m. *peak* (after 7 p.m.). The times for each period were averaged and then converted to car travel time rates by dividing by the distance between TPs.

The final data set included *690* records, with each record representing one bus trip on one route segment. To control for the differing lengths of the route segments, the variables were standardized by dividing by the segment length. Table 3 presents the basic descriptive statistics for the standardized variables. Bus speeds varied from approximately 4 to almost 33 mph, while car speeds varied from about *7* to 34 mph. While the minimum, maximum, and mean values for bus speeds were all lower than the respective statistics for cars, the ratio of bus travel time to car travel time was less than one for a few records. This result may have been in part because the observations for cars were not collected at the same time as those for buses. The range of operating conditions in the data set for the buses probably varied more than those for cars. The preliminary analysis **was** done with Excel and **SPSS,** and modeling was done with **SPSS.**

RELATIONSHIPS AMONG VARIABLES

Bus travel time is plotted against potential explanatory variables in Figure 2. Figure *2a* shows bus travel time plotted versus **car** travel time. While there is considerable "scatter," a distinct positive relationship can be seen. The majority of the observations are above the

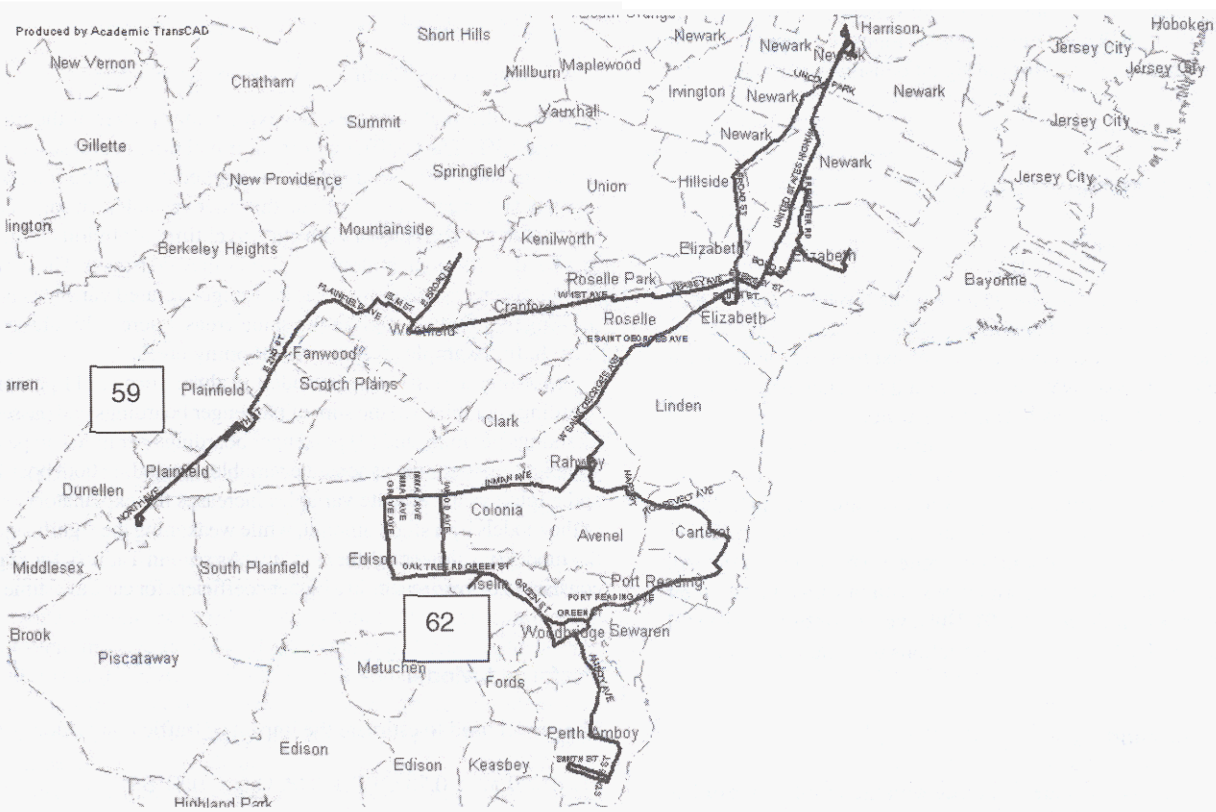

FIGURE 1 Map of Routes 59 and 62.

TABLE 3 Descriptive Statistics of Standardized Variables

Variable	N	Minimum	Maximum	Mean	Standard Deviation	Coefficient of Variation
Bus travel time rate (min/mi)	690	1.82	14.82	4.76	2.01	0.42
Car travel time rate (min/mi)	690	1.76	8.24	3.50	1.42	0.41
Bus stops per mile	690	0.49	10.00	4.38	1.57	0.36
Actual stops per mile	690	0	7.46	1.74	1.31	0.75
Ons per mile	690	0	78.79	5.14	9.08	1.77
Offs per mile	690	0	27.62	3.41	4.21	1.23
Ons and offs per mile	690	0	86.57	8.55	9.96	1.16
Signals per mile	565	0.64	18.75	4.94	4.14	0.84
Left turns per mile	660	0	6.67	0.86	1.28	1.49
Bus speed (mph)	690	4.05	32.88	14.48	5.10	0.35
Car speed (mph)	690	7.28	34.03	19.28	5.75	0.30
Bus to car travel time ratio	690	0.59	5.11	1.41	0.47	0.33

1 = 1 diagonal line; that indicates most buses were moving more slowly than the average car times recorded for the time period and route segment.

Bus travel time versus passenger boardings per mile (Figure *2b)* also shows a positive slope, although the most noticeable feature is the massive clustering at zero through about 10 boardings per mile. Passenger alightings per mile (Figure *2c)* are more spread out, but any slope is much more difficult to detect.

The relationship of bus travel times to bus stops per mile (Figure 2d) is harder to interpret. There is more variation in bus times as the number of bus stops per mile increases; a line through the midpoints of the variation would slope up but also would be curved. The scatter plot of bus travel times versus the number of times the bus actually stopped in the segment (Figure 2e) is more uniform hut shows a weak relationship. The graph of bus travel time versus left turns per mile (Figure *2f)* shows a distinct upward slope. Figure *2g* shows how bus travel times tend to increase as the signal density (signals per mile) increases.

MODEL OF BUS TRAVEL TIME

Modeling Process

Multiple regression analysis was used to relate bus travel time to traffic level. The dependent variable was travel time rate for one bus run on one mute segment measured in minutes per mile. The average car travel time rate on the mute segment during the same period of day was the measure of traffic level. Other independent variables included passengers boarding, passengers alighting, number of bus stops, number of traffic signals, turns, and so forth.

The names and descriptions of the variables are listed in Table 4.

The correlations between these input variables and the dependent variable, bus travel time in minutes per mile, is shown in Table *5*. All of the variables show **strong** correlations with bus travel time (their correlations are significant at 0.99). However, most of the potential input variables also have strong correlations with car travel time.

Summary of Models

Many linear regression models, starting with the simplest one of bus travel time as a function of car travel time, were tried. A few models with the constant forced through zero were also tried. A few nonlinear forms were tried, but they were inferior to the linear models; further, the graphs of bus travel times versus the other variables did not suggest nonlinear relations.

Table 6 summarizes the main models that were tested. Each row represents a model of bus travel time, from the simplest at the top to the most complex at the bottom. Basic statistical measures of the model are shown at the tight. Note that the number of records for the models varies because some records were missing data for left turns or traffic signals, or both. All of the coefficients in the table were significant at the 95% or higher level, and most were significant at the 99% level.

The simplest model explains 46% of the variation in bus travel time per mile.

$$BTT = \underset{(9.3)}{1.38} + \underset{(24.4)}{0.96}\ CTT \qquad (2)$$

() is t-value of coefficient $= 0.46$ $F = 597$

With additional variables, the explanatory power of the models reached 63%. The coefficient for car travel time decreases as additional independent variables are added because of the intercorrelation between car travel time and the other variables. In some cases, the reason for correlation with car travel time is obvious (e.g., left turns and traffic signals slow cars just as they do buses). The correlation between car travel time and passenger-related variables is that passenger activity is high in the same areas where vehicular traffic is high, for example, downtown shopping areas.

Passenger activity was included in three forms: (1) passenger boardings per mile, (2) the sum of passenger boardings and passenger alightings per mile, and (3) passenger boardings per mile and passenger alightings per mile as separate variables. Including both boardings and alightings as separate variables increases the explanatory power of the models by a slight amount, while weakening the significance of the model (i.e., lowering the F-value). As seen in Table 6, forcing the constant to be zero results in a higher coefficient for car travel time rate.

Preferred Model

The model used to estimate the impact of traffic congestion is this:

$$BTT = \underset{(2.8)}{0.52} + \underset{(19.5)}{0.73}\ CTT + \underset{(10.1)}{0.06}\ Ons + \underset{(9.8)}{0.31}\ BS \qquad (3)$$

() is t-value of coefficient $R^2 = 0.62$ $F = 365$

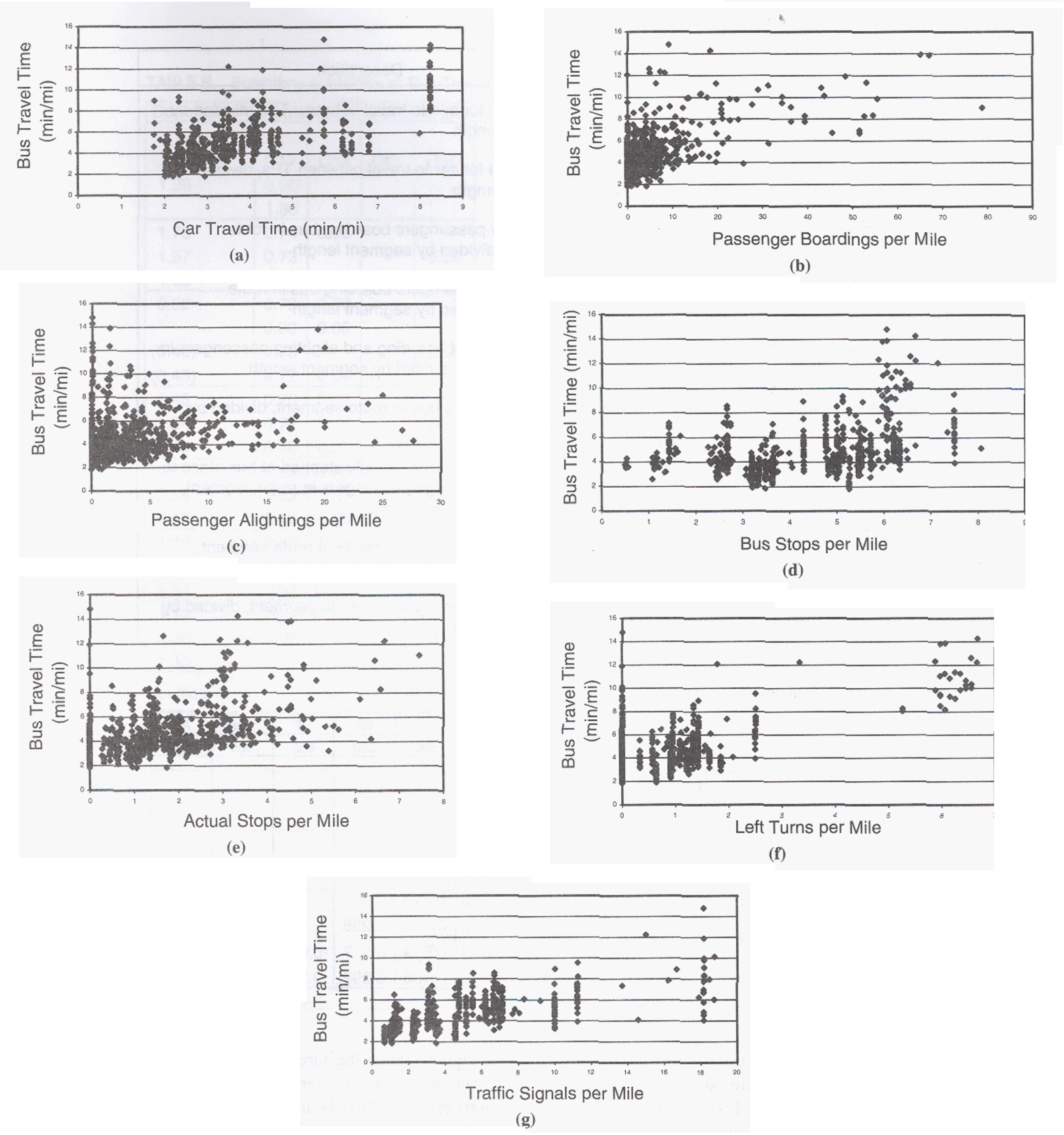

FIGURE 2 Relationship of bus travel time to other variables.

This relatively simple model includes the two primary ways in which buses differ from other traffic: they stop at bus stops and they wait while passengers hoard. Using ons and offs instead of just ons might seem more logical and does produce a slightly better model (F-value is higher). But it would require additional work to gather or estimate variables to use the model in a predictive procedure. Further, the most important coefficient for current purposes, that of car travel time, is the same in both models.

The use of actual stops instead of total bus stops also appears more logical, but the models with actual stops are poorer (lower and F). Also, actual stops have to be estimated, whereas the total of bus stops is within the control of the agency and known.

However, there may he a logical appeal to a model without a constant term. The model of bus travel time rate without the constant that is most similar to the preferred model is as follows:

$$BTT = 0.80\,CTT + 0.06\,\text{Ons} + 0.37\,BS \quad (4)$$

The coefficient of general traffic travel time rate is about 10% higher, and the coefficient for the number of bus stops per mile also increases, but the model is similar to the model shown in Equation 2. Reasons for keeping the constant term in the model are that then may be a nonproportional reason for buses to be slower than traffic, for instance, less maneuverability of the larger vehicle, which is reflected

TABLE 4 Variables Used in Bus Travel Time Analysis

Variable	Abbreviation	Description
Bus travel time rate	BTT	Time (min) for bus to travel between TPs, divided by segment length
Car travel time rate	CTT	Time (min) for car to travel between TPs, divided by segment length
Boardings/bus/mile	Ons	Number of passengers boarding bus in route segment, divided by segment length
Alightings/bus/mile	Offs	Number of passengers boarding bus in route segment, divided by segment length
Ons & offs/bus/mile	O&O	Total number of boarding and alighting passengers in route segment, divided by segment length
Bus stops/mile	BS	Number of bus stops in route segment, divided by segment length
Actual stops/bus/mile	AS	Number of times bus actually stopped at bus stops to pick up or discharge passengers in route segment, divided by segment length
Left turns/mile	LT	Number of left-turns bus made in route segment, divided by segment length
Signals/mile	Sig	Number of traffic signals in route segment, divided by segment length

TABLE 5 Correlations of Travel Time Variables

	BTT	CTT	Ons	Offs	O&O	BS	LT	Sig	AS
N	690	690	690	690	690	690	660	565	690
BTT: Bus travel time (min/mi)	1								
CTT: Car travel time (min/mi)	0.682	1							
Ons: Boardings per mile	0.588	0.456	1						
Offs: Alightings per mile	0.160	0.078	-0.012	1					
O&O: Ons and offs per mile	0.604	0.448	0.906	0.411	1				
BS: Bus stops per mile	0.401	0.146	0.299	0.096	0.313	1			
LT: Left turns per mile	0.536	0.637	0.339	-0.007	0.306	0.238	1		
Sig: Signals per mile	0.666	0.552	0.590	0.046	0.539	0.327	-0.022	1	
AS: Actual stops per mile	0.441	0.277	0.385	0.343	0.496	0.398	0.233	0.169	1

by the constant term, and the inability to use the R^2 for evaluating models. Additionally, when bus speeds were estimated as a function of car speeds by using the foregoing model and the model with the same explanatory variables with the constant suppressed, the results varied by less than 1/2 mph over the range of variables in the data set.

IMPLICATIONS OF MODEL

The model has a straightforward logic. Bus travel time rates are roughly equivalent w traffic travel time rates plus the number of stops multiplied by the time lost in decelerating and accelerating and the number of boarding passengers times the service time per passenger. The coefficient of bus stops (0.31 min per bus stop) represents 18 s lost during deceleration and acceleration. The coefficient for passenger boardings (0.06 min per boarding) represents 3.6-s service time per passenger and is within the range reported in the Transit Capacity and Quality of Service Manual (6).

Figure 3 shows the impact of car speeds on bus speed assuming that the number of bus stops and boarding passengers is constant (four bus stops per mi and five boarding passengers per mi, close to the means in the database were used). The model implies that as car speeds increase from 8 to 30 mph, bus speed increases from 8 to 17 mph.

The regression coefficients of the New Jersey model (Equation 3) are similar to those found in the Manhattan study (Equation 1) (5). The difference in the coefficient of average travel time rate of traffic implies that there is a stronger relation between general traffic and bus speeds in New Jersey. This situation might be due lo the more complex operating environment in Manhattan, with double-parked cars, many pedestrians who often spill over into the streets, narrower streets, and other factors.

	Manhattan Study (Avenues)	*New Jersey Study*
Average travel time rate (min/mi)	0.57	0.73
Passengers boarding per mile	0.079	0.06
Bus stops per mile	**0.39**	0.31

TABLE 6 Summary of Models of Bus Travel Time

Dependent Variable: Bus travel time (min/mi)												
Constant	CTT	Ons	Offs	O&O	BS	AS	LT	Sig	R^2	F	N	No. of Var's
1.38	0.96								0.46	597	690	1
	1.30								a	6872	690	1
1.78	0.74	0.08							0.56	441	690	2
1.57	0.73			0.08					0.58	466	690	2
1.63	0.72	0.08	0.06						0.58	312	690	3
0.52	0.73	0.06			0.31				0.62	365	690	3
	0.80	0.06			0.37				a	3663	690	3
(0.40)	0.73			0.06	0.30				0.62	380	690	3
(0.45)	0.72	0.06	0.05		0.30				0.62	286	690	4
1.46	0.70	0.06				0.30			0.59	332	690	3
1.34	0.71			0.06		0.23			0.59	333	690	3
1.42	0.70	0.07	0.03			0.25			0.60	253	690	4
0.57	0.65	0.06			0.33		0.15		0.62	268	660	4
0.56	0.63			0.06	0.30		0.17		0.63	280	660	4
0.59	0.63	0.06		0.05	0.30		0.17		0.63	224	660	5
1.16	0.40	0.04			0.26			0.14	0.52	151	565	4
1.28	0.36			0.04	0.22			0.14	0.54	163	565	4
1.34	0.34	0.04	0.06		0.21			0.16	0.54	132	565	5
1.12	0.38	0.04			0.25		0.19	0.14	0.53	124	565	5
1.25	0.33			0.05	0.22		0.18	0.15	0.54	134	565	5
1.30	0.31	0.04	0.06		0.21		(0.17)	0.16	0.55	112	564	6

Coefficients in ( ) are not significant at the 99% level.
NOTE a: The line was forced through the origin. R^2 is not comparable.

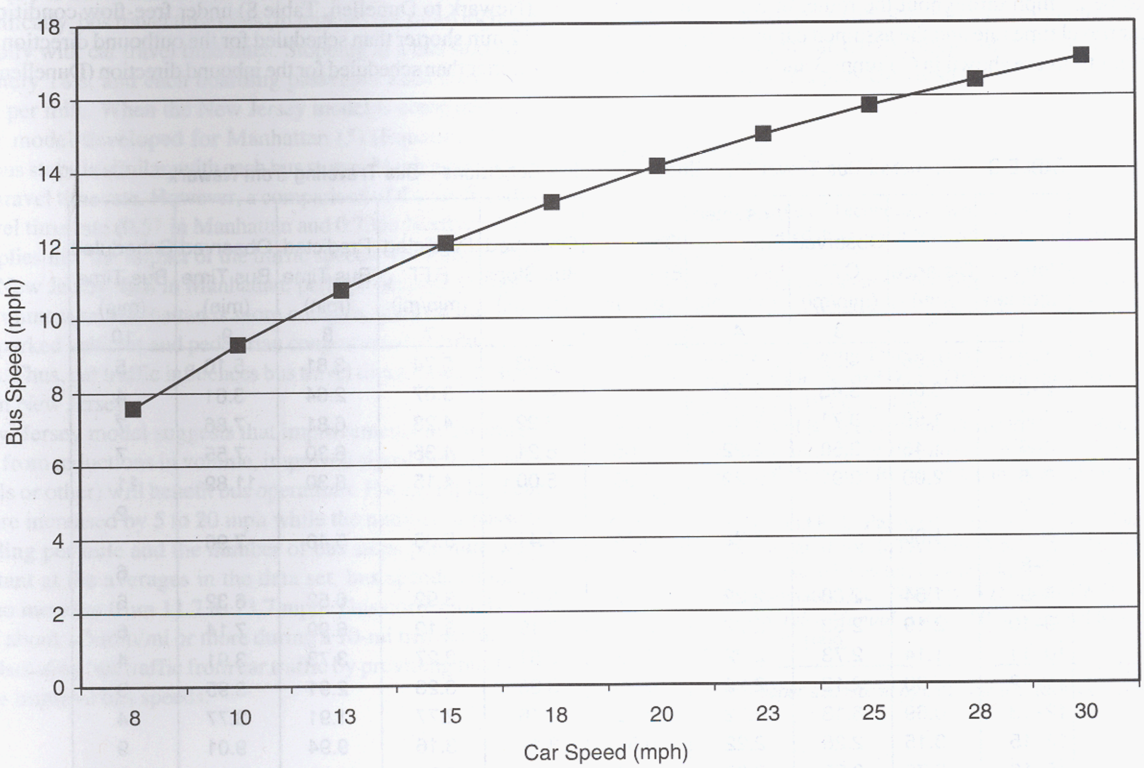

FIGURE 3 Impact of decreasing traffic speed on bus speed and travel time rate.

TABLE 7 Relative Impact of Explanatory Variables on Bus Travel Time

	Car Travel Time (min/mi)	Passenger Boardings per Mile	Bus Stops per Mile
5th percentile	2.1	0	1.4
95th percentile	6.8	20.4	6.4
90% range	4.7	20.4	4.9
Coefficient	0.73	0.06	0.31
Impact on bus time	3.43	1.22	1.53

The impact of a specific variable on the bus travel time rate depends on both the coefficient and the magnitude of the variation of the variable. Table 7 shows how the explanatory variables affect bus travel time rate, with the 90% range (i.e., from the 5th to 95th percentiles) of the independent variables in the database. (The top and bottom 5% were removed to reduce the influence of extremes; standard deviations were not used because the passenger boardings are skewed toward zero.) The table indicates that a variation in car travel time rates of 4.7 min/mi results in a 3.43-min increment in bus travel time rate. A 90% range increment of passenger boardings per mile (20.4) results in a 1.22-min/mi increment in bus travel time, and a 90% range increment of bus stops per mile (4.9) results in an increase of 1.53 min/mi for travel time rate buses. Thus, the impact of observed variation in traffic time is more than twice as large as the impact of either passenger boardings or bus stops, at least for conditions encountered in Northern New Jersey.

Tables 8 and 9 show the application of the model to estimate bus travel times on Route 59 if there were no traffic congestion. Free-flow traffic speeds for Route 59, which operates on arterials, were estimated to be 27 mph throughout the route, or 2.22 min/mi. The observed car travel time rate and the assumed car travel time rate for free-flow conditions are shown in Columns 3 and 4. Column 5 is the average observed boardings per mile and Column 6 is the number of bus stops per mile for each route segment. Column 7 is the bus travel time rate predicted by the model using the values in Columns 4,5, and 6 for the three input variables. This represents the estimated bus travel time rate under free-flow conditions. In Column 8 the predicted travel time rate (Column 7) is converted to time (in minutes) by multiplying it by the route length (Column 2). Columns 9 and 10 show the average observed times and the scheduled times for each route segment. Segments 6 to 7 and 7 to 8 (from Broad and Grand to Jersey and Elmora, in Elizabeth) were combined because of difficulties in collecting data; Segment 6 to 7 was exceedingly short (less than 1/10 mi), and the bus made a left turn that was prohibited for cars in Segment 7 to 8.

The difference between the predicted and observed bus times represents the degradation of bus times due to traffic congestion. There are a few segments where the predicted time is longer than the observed, most notably Segment 15 to 13 in the inbound direction, but generally the predicted times are close to or less than the observed times. The total predicted bus time for the complete trip (Newark to Dunellen, Table 8) under free-flow conditions is about 12 min shorter than scheduled for the outbound direction and 10 min shorter than scheduled for the inbound direction (Dunellen to Newark,

TABLE 8 Estimated Bus Travel Time Under Free-Flow Conditions—Bus Traveling from Newark

Route Segment	Distance (mi)	Observed CTT (min/mi)	Assumed Free Flow CTT (min/mi)	Observed Boardings (per mi)	Observed Bus Stops (per mi)	Predicted BTT (min/mi)	Predicted Bus Time (min)	Observed Bus Time (min)	Scheduled Bus Time (min)
1	2	3	4	5	6	7	8	9	10
1–2	0.66	4.52	2.22	28.82	6.03	5.74	3.81	5.10	5
2–3	0.68	3.45	2.22	5.92	4.43	3.87	2.64	3.61	4
3–4	1.59	3.71	2.22	3.15	6.29	4.28	6.81	7.86	7
4–5	1.45	3.50	2.22	4.65	6.21	4.35	6.30	7.55	7
5–6	2.00	3.91	2.22	7.60	5.00	4.15	8.30	11.89	11
6–7									2
6–8	1.08		2.22	10.34	7.41	5.06	5.46	7.96	
7–8									6
8–9	1.64	2.68	2.22	2.25	5.51	3.99	6.52	6.32	6
9–10	2.19	2.83	2.22	0.94	3.19	3.19	6.99	7.14	6
10–11	1.14	2.73	2.22	0.72	3.51	3.27	3.73	3.91	4
11–12	0.90	2.12	2.22	0.98	3.33	3.23	2.91	3.95	3
12–13	0.69	6.13	2.22	3.02	1.46	2.77	1.91	3.77	4
13–15	3.15	2.26	2.22	0.50	3.17	3.16	9.94	9.01	9
15–16	2.70	2.95	2.22	1.20	4.82	3.71	10.00	9.96	10
16–17	2.98	3.49	2.22	1.20	5.03	3.77	11.25	11.75	15
Totals	22.9						86.6	99.8	99

TABLE 9 Estimated Bus Travel Time Under Free-Flow Conditions—Bus Traveling Toward Newark

Route Segment	Distance (mi)	Observed CTT (min/mi)	Assumed Free Flow CTT (min/mi)	Observed Boardings per Mile	Observed Bus Stops per Mile	Predicted BTT (min/mi)	Predicted Bus Time (min)	Observed Bus Time (min)	Scheduled Bus Time (min)
17–16	3.05	3.93	2.22	4.37	4.92	3.93	11.98	12.28	15
16–15	2.75	3.06	2.22	4.39	5.45	4.10	11.27	13.01	10
15–13	3.12	2.24	2.22	1.48	3.21	3.22	10.06	7.96	9
13–12	0.75	5.14	2.22	3.81	2.67	3.20	2.40	4.40	4
12–11	0.93	2.21	2.22	2.61	5.41	3.98	3.70	2.53	3
11–10	1.10	2.77	2.22	2.60	3.63	3.42	3.77	3.95	4
10–9	2.17	2.59	2.22	4.45	3.69	3.55	7.71	7.50	6
9–8	1.58	2.34	2.22	6.53	5.08	4.11	6.48	6.23	6
8–7	1.05	4.17	2.22	7.14	4.76	4.05	4.25	6.35	6
7–6	0.09		2.22	155.11	11.11	14.89	1.34	1.19	1
6–5	1.93	2.26	2.22	3.81	5.19	3.98	7.67	11.54	12
5–4	1.43	4.67	2.22	6.95	5.59	4.29	6.15	7.25	8
4–3	1.71	2.69	2.22	1.51	5.87	4.05	6.93	7.70	7
3–2	0.65	7.99	2.22	0.00	6.15	4.05	2.63	3.85	4
2–1	0.79	4.02	2.22	0.79	7.63	4.56	3.60	5.39	5
Total	23.1						89.9	101.1	100

Table 9). Thus, congestion has increased running time on this route by 12% to 15%.

CONCLUSIONS

The model of bus travel time rate reflects the dynamics of bus movement. Specifically, bus travel time rates (in minutes per mile) increase proportionally with car travel time rates. Stopping at a bus stop adds approximately 18 s, and each boarding passenger adds 3 to 4 s to travel time per mile. When the New Jersey model is compared with the similar model developed for Manhattan (5) (Equation 1), the impact of bus stops is similar, with each bus stop in Manhattan adding 23 s to the travel time rate. However, a comparison of the coefficients for car travel time rate (0.57 in Manhattan and 0.73 in Northern New Jersey) implies that the impact of the traffic speeds was significantly greater in New Jersey than in Manhattan, perhaps because the operating environment in Manhattan is more complex, with factors such as double-parked vehicles and pedestrian congestion also influencing bus speeds. Thus, car traffic influences bus travel times more strongly in Northern New Jersey.

The New Jersey model suggests that improvements in car traffic flow (e.g., from reductions in volume, improved signal timing, parking controls or other) will benefit bus operations. For example, if car speeds were increased by 5 to 20 mph while the number of passengers boarding per mile and the number of bus stops per mile were held constant at the averages in the data set, bus speeds could be expected to increase from 1 1.7 to 13.7 mph, This corresponds to a savings of about 1.5 min/mi or more during a IO-mi trip, about one-quarter h. Isolating bus traffic from car traffic by providing bus lanes would also improve bus speeds.

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