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Impact of Congestion on Bus Operations and Costs

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16. Abstract

Traffic congestion in Northern New Jersey imposes substantial operational and monetary penalty on bus service. The purpose of this project was to quantify the additional time and costs due to traffic congestion. A regression model was developed that estimates the travel time rate (in minutes per mile) of a bus as a function of car traffic time rate, number of passengers boarding per mile, and the number of bus tops per mile. The model was used to estimate the bus travel time rate if cars were traveling under free flow conditions, and the results compared to the observed bus travel times. A second model was developed that estimated operating costs as a function of vehicle hours and peak vehicles. This model was used to estimate the cost of the additional time represented by the difference in current time minus travel time estimated under free flow conditions.

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SUMMARY

The purpose of this study is to quantify the impact of traffic congestion on bus operations and costs to New Jersey Transit, and to forecast the future impacts of congestion on operations and costs.

As traffic volumes or congestion increase, traffic speeds decrease, as established in traffic engineering formulas and curves that show speed as a function of the traffic volume to capacity ratio. This results in additional time being required to travel a fixed distance. The hypothesis of this study is that congestion also decreases bus speeds and increases the travel time for buses. The basic approach of this study involved developing a regression model that estimates bus travel time rate (in minutes per mile) as a function of the travel time rate for traffic.

The data for calibrating the model were from two local bus routes operating in Northern New Jersey, Routes 59 and 62. The data were collected by study team members riding the buses and following the routes in cars as well as from automatic passenger counter (APC) equipment on eight buses. The APC equipment records exact time and location using the global positioning system as well as passenger activity. The best model of bus travel time rate was:

$$BTT = 0.52 + 0.73\ CTT + 0.06\ Ons + 0.31\ BS \qquad R^2 = 0.62$$

Where
- BTT = Bus travel time rate (min/mile)
- CTT = Car travel time rate (min/mile)
- Ons = Passenger boardings per bus per mile
- BS = Bus stops per mile (note that this is not the number of times that a bus stops during a specific trip, but the number of bus stop locations in the route segment)

The travel time model was used to estimate the increment in bus vehicle hours due to the increase in traffic travel time over free flow time. This was done by estimating the bus travel time rate using the following values for the explanatory variables: car travel time rate under free flow conditions (2.22 min/mile), the average number of passenger boardings per bus per mile for each route segment, and the average number of bus stops per mile for each segment. The resulting bus travel time rate was compared to the bus travel time rate implied by the route schedule. The results for Route 59 indicated that 12 minutes of the one-way outbound scheduled time of 99 minutes is due to traffic congestion and 10 minutes of the one-way inbound scheduled time of 100 minutes is due to traffic congestion. This analysis was extended to all bus trips on Route 59 in the 6 AM to 6 PM period indicating a total increment of time per weekday due to congestion of 12 hours 53 minutes. When further extended to all non-holiday weekdays for one year, the congestion impact was 3156 vehicle hours for Route 59.

NJ Transit has determined that the total cost of adding a vehicle hour of service is \$56.80. However, the cost of operating an existing bus for an additional hour is less than adding a new bus in order to operate the additional hour. In order to separate the monetary cost of operating for one more hour from the cost of adding a bus, a second model of cost as a function of vehicle hours and peak vehicles was developed, using New Jersey Transit FY2002 data on variable operating cost, vehicle hours, miles and peak vehicles for 92 individual routes. The best cost model was:

$$VC = + 43.18\ VH + 125.46\ PVD$$

Where

- VC = Operational variable cost per route for FY2002
- VH = vehicle hours per route in FY2002
- PVD = Peak vehicle days in FY2002. Peak vehicle days is the peak vehicle requirement per day summed for all days per year.

The cost model indicates that if an existing bus has to operate for a slightly longer time, the cost is \$43.18 per vehicle hour. However, if additional buses are needed to maintain the schedule, the cost would be \$56.80 per vehicle hour. Looking at Route 59 again, the 3156 vehicle hours per year due to congestion costs New Jersey Transit about \$179,000 per year, which represents 4.5 percent of the total cost attributed to Route 59 in FY2002.

The essence of this process is that the additional bus travel time per mile due to congestion is equal to 0.73 times the increment of general traffic time rate due to congestion. To determine the increment of general traffic time due to congestion on a broader basis, travel rate indices (TRIs) for the individual counties in New Jersey were used. TRIs are the ratio of actual travel time per mile to free flow travel time per mile. A New Jersey Institute of Technology study estimated TRIs for all New Jersey counties. The increases in bus travel time rate (in minutes per mile) and bus travel time (in hours) due to congestion were calculated from the indices for a sample of 39 bus routes in Northern New Jersey. The results for the 39 routes suggest that 93,600 vehicle hours of the total 1.2 million vehicle hours are due to congestion and the cost for the increase \$5.3 million. When this is further extrapolated to all New Jersey Transit bus routes in Northern New Jersey, the total increment in time due to congestion is 349,000 vehicle hours and the monetary cost of congestion would be \$20.3 million.

Traffic levels were forecasted to increase by about five percent in the next five years. To calculate the impact on vehicle hours and costs, new TRIs were calculated for a five percent increase in volume to capacity ratios for the New Jersey counties. Using the new TRIs, the increment in vehicle hours and costs were calculated using the same 39 routes as above and extrapolated to the Northern New Jersey bus system. The results indicate that the time increment due to congestion would be 423,000 vehicle hours and the monetary cost of the time would be \$27.0 million.

The current and future impacts are summarized in the following table.

Summary of Current and Future Impact of Congestion on Vehicle Hours and Costs

	Current			Future	
	Current (FY2002)	Part due to congestion	Current w/o congestion	Congestion increment	Total
Vehicle hours	4,419,836	349,000	4,070,836	423,367	4,494,203
Operational variable expense ($)	241,304,918	20,343,642	220,961,276	26,975,592	247,936,867
Total expense ($)	361,758,967	20,343,642	341,415,325	26,975,592	368,390,916

INTRODUCTION

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 forecasted to be greater in the future; traffic volumes are predicted to increase by seven percent by 2005 over the levels in 1998, and 18 percent by 2015.[(1)] The roadway network in New Jersey currently operates at or above its defined capacity at many locations during the 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 sharing New Jersey roadways with autos and trucks. Therefore, measured congestion will not only impact auto drivers and passengers and truck operators but also bus riders.

The purpose of this study is to quantify the impact of congestion on bus travel time under current conditions, to calculate the cost of the increased time, and to forecast the impacts of future congestion.

The basic approach involved developing a model that estimates bus travel time rate (in minutes per mile) as a function of overall car travel time rate. Travel time rate (the time required to travel a mile) was used rather than a more traditional measure of congestion, such as volume to capacity ratio, because it was more feasible to collect the relevant data and because the main impact of congestion on bus operations is its impact on the time required to deliver service.

The model was used to estimate the increase in bus time due to the increase in traffic time. A separate model that estimates variable expenses as a function of vehicle hours of service was used to estimate the cost of the congestion. The project was conducted in three related tasks:

- Determine the impact of congestion on bus operations
- Calculate the financial cost of the congestion impact to New Jersey Transit
- Estimate the future impact of congestion based on a forecast of congestion

The report starts with a review of the literature on the impact of congestion on bus time and reliability. The third chapter describes how the bus and car travel time and related data were collected. The data are then described and analyzed. Separate chapters describe the development of the travel time and cost models and applied them to a sample route. In a separate chapter, the models are used to calculate the time and cost impacts for the overall New Jersey Transit bus system and to forecast future impacts. The final chapter presents the conclusions of the study.

BACKGROUND

Studies of bus stop spacing and bus speeds have been performed since the early 1900's. In the years following World War II, transit speed and delay studies were conducted in many cities as part of traffic engineering programs. In the last 30 years there has been a growing number of studies that analyzed the relation of bus speeds to stop spacing, dwell times at stops and traffic congestion. This chapter summarizes key studies dealing with bus speeds and impacts of traffic congestion on bus operations, travel time, and reliability.

Empirical Travel Time Studies

A 1974 study by Wilbur Smith and Associates with others[(2)] showed the general relationship between bus stop spacing and traffic congestion, but 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:

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

Levinson found that car speeds were generally 1.4 to 1.6 times as fast as bus speeds. The peak-hour bus travel times approximate 14 mi/h in suburbs, 10 mi/h in the city, and five mi/h in the central business district (CBD). The time in motion approximates 3.00 minutes per mile in the suburbs, 3.90 min/mile in the central city) and 5.50 min/mile in the CBD. The 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. The passenger dwell times range of from 30 to 60 seconds per stop in the CBD, and the acceleration and deceleration time loss per stop average 11.13 seconds in the CBD. (These relationships are illustrated in Figure 7, later in this report.)

The study recommends eliminating or decreasing the impact of congestion by improving general traffic flow or by providing bus lanes or in selected situations, bus signal preemption. However, reducing bus stop frequency from eight to six stops per mile and dwell time from 20 to 15 seconds would reduce travel times from 6.0 to 4.3 min/mile, a time saving greater than that achievable by eliminating traffic congestion.

A 1986 study by Urbitran with Levinson[(4)] reports that traffic congestion makes a relatively small contribution to low bus speeds, causing only six percent of total delay while much larger contributions are made by waiting at traffic signals (32-43%), waiting for other buses to clear bus stops (32%), and boarding and alighting passengers (21-62%).

According to a 1997 study of the congestion impact on bus service travel times in Manhattan by McKnight and Paaswell,[5] congestion affects bus speeds in several ways. The most obvious way is that the maximum speed at which the buses can operate between bus stops is limited by the flow of general traffic. Besides limiting the maximum speed of vehicles, heavy traffic causes additional delays due to a miscellany of situations such as double and triple parked cars and delivery vans, queues waiting to make right or left turns, taxis making sudden stops or turns to pick up passengers. The impact of these situations is often exacerbated for buses because of the buses' need for frequent access to the curb lane at bus stops.

In addition, several congestion impacts are unique to buses. Heavy traffic may delay buses trying to pull into traffic after stopping at a bus stop. When the streets are congested, many service and delivery vehicles that cannot find legal street parking or stopping space, use the bus stops for short stops or double park immediately before or after the bus stop requiring a difficult maneuver for the bus to access the stop. This study also found that the difference between bus and auto speeds is greater when the streets are more congested. At the maximum speeds recorded in the study, buses are moving at about 59 percent of the auto speed, while at the lowest speed, buses are moving at only 42 percent of auto speed. This 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.

Table 1. Midtown Manhattan Bus and Auto Travel Times and Speeds.[5]

	Times (min/mile)		Speeds (mi/h)		Difference	Ratio
	Bus	Auto	Bus	Auto	Auto-Bus	Bus/Auto
Average	11.0	6.1	5.5	9.8	4.3	0.56
Minimum	4.7	2.8	2.2	5.2	3.0	0.42
Maximum	27.0	11.5	12.7	21.4	8.7	0.59

McKnight and Paaswell[5] also developed a 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 (minutes per mile)
AT = automobile travel time (minutes per mile)

P = passengers boarding all buses per hour in route segment per mile
BS = bus stops per mile
NS = 1 for routes operating primarily north/south, 0 otherwise

Impact of Bus Stops

A substantial portion of bus travel time is spent decelerating for bus stops, waiting to allow boarding and alighting of passengers, waiting to re-enter the traffic stream, and accelerating. Buses usually do not reach their maximum attainable cruise speeds between stops when operating on city streets because of intersection interference, traffic controls, or street congestion. The fewer the stops, the greater the number of passengers who will need to board at a given stop. A balance is required between too few stops (which increase the distance riders must walk to access transit and increase the amount of time an individual bus occupies a stop) and too many stops (which reduce overall travel speeds due to the time lost in accelerating, decelerating and possibly waiting for a traffic signal after a stop is made).

In 1981, Turnquist[(6)] proposed reducing the number of stops made by each vehicle as a way to improve travel time, although he recognized that the fewer the stops, the greater the number of passengers who will need to board at a given stop. Turnquist did a series of simulations using the Reading Road corridor in Cincinnati as a test network to study the effects of stop spacing. For the simulation, 17 of 36 stops in the section were eliminated, which resulted in an average stop spacing of 0.23 mile. The results show that average bus speeds over the system increased from 8.8 mi/h to 9.0 mi/h but this change was not statistically significant. It was observed that eliminating stops had a small effect because buses were still being slowed by traffic signals. Turnquist suggested that simultaneous change in both stop density and signal operation would have a greater impact.

Turnquist[(6)] suggested that an alternative to reducing the number of stops each vehicle must make without increasing overall stop spacing is to divide a route into zones. In a zone system, a bus makes all local stops for its zone or part of the route and either runs express for the other parts or eliminates the parts outside its zone. Zone scheduling can improve both average bus speeds and reliability in two ways:

- Average in-motion time and variability can be reduced by the nonstop service offered for a portion of each bus run under a zone-scheduling scheme.

- The number of stops each bus makes can be reduced, which will lessen both average bus dwell time and variability in this time.

Turnquist has also studied the impact of zone scheduling on both service reliability and average wait and in-vehicle time. The results show that zone scheduling can effectively improve the quality and productivity of urban transit service.

Dwell Times

In field observations, the study team observed delays at the bus stops due to passengers requesting information from the driver, wheelchairs boarding and alighting, large numbers of passengers boarding at major transfer stops, and passengers exiting from front door instead of the rear door in addition to the time required for opening and closing doors and for paying the fare. Dwell times depend on the door configuration, fare structure, and number of boarding and alighting passengers.(7)

In order to reduce bus travel time, the passenger dwell time at bus stops should be minimized; in 1996, Levinson and St. Jacques(8) suggested many way, including rear-door passenger loading with street collectors, pay-as-you-leave fare collection, and possible prepayment of fares at busy stops.

Levinson and St. Jacques(8) also noted the importance of minimizing the variations in dwell times at key bus stops during peak travel periods and the desirability of separating local and express bus stops, because each service may have widely different dwell times. Kittelson & Associates(9) in 1999 showed similar results to the1991(7) and 1996(8) studies by Levinson et al. They found that the number of people boarding and/or alighting through the highest-volume door is the key factor in how long it will take for all passengers to be served. If standees are present on-board when the bus arrives at a stop, or if all seats become filled as passengers board, service times will be higher than normal because of congestion in the bus aisle. The mix of alighting and boarding passengers at a stop also influences how long it takes all passenger movement to occur.

The amount of time passengers spend paying fares is also a major factor in the total time required per boarding passenger. This time can be reduced by minimizing the number of bills and coins required to pay a fare; encouraging the use of pre-paid tickets, tokens, passes or smart cards; using a proof-of-payment fare-collection system; or developing an enclosed, monitored paid-fare area at high-volume stops. In addition to eliminating the time required for each passenger to pay a fare on-board the bus, proof-of-payment fare collection systems also allow boarding passengers to be more evenly distributed between doors, rather than being concentrated at the front door.

Encouraging people to exit via the rear door(s) on buses with more than one door decreases passenger congestion at the front door and reduces passenger service times. Auxiliary rear-door fare collection during the evening peak hours can expedite passenger loading. Low-floor buses decrease passenger service time by eliminating the need to ascend and descend steps. This is particularly true for the elderly, persons with disabilities and persons with strollers or bulky carry-on items.

In a 1983 study,(10) Guenthner and Sinha found that a significant deterrent to the use of public transportation is excessive travel time, including both out-of-vehicle and in-vehicle times. By using data from two routes in Milwaukee, Wisconsin and assuming different numbers of stops per mile, they determined the effect of the number of stops the bus makes and the dwell time at each stop on system operation.   They also analyzed the distribution of passengers boarding and alighting at stops along a route, and found that bus dwell time per passenger decreases with the natural logarithm of the number of passengers boarding and alighting at the stop.

Guenthner and Sinha[10] recommended that the negative binomial distribution is a better descriptor of passengers boarding and alighting over a range of ridership levels than the Poisson distribution. From these findings, they developed a procedure to determine the resulting bus delay and its effect on operating speed. An increase in the number of bus stops along a low-demand route will have only a minor effect on bus operating speed but will reduce the user's walking distance. Additional posted stops along a high-demand route will save walking distance at the cost of greater in-vehicle travel time; therefore an optimum number of posted stops per mile should be sought.

In 2002, Bertini and El-Geneidy[11] found that most delays for a bus route in Portland, Oregon, were a result of passenger activity (boarding and alighting). They also concluded that the trip time was affected by traffic control, traffic congestion and individual operator characteristics. Dwell time increased during the peak period and dropped during the off-peak period. Boarding and alighting of passengers with disabilities increased dwell time significantly. However, they noted in their study that long dwell times are not necessarily correlated with high passenger activity. There were times when the doors were opened but no passengers were served. They derived the following equation for dwell time:

$$\text{Dwell Time (seconds)} = 5.8 + 0.85\, N_a + 3.6\, N_b \qquad (2)$$

where

N_a = total number of passengers alighting the bus.

N_b = total number of passenger boarding the bus.

From this equation they concluded that approximately 5.8 seconds of lost time are attributable to each stop accompanied with a door opening regardless of how many passengers board and/or alight. An additional 0.85 seconds was attributed for each alighting passenger (through both doors) and approximately 3.6 seconds for each boarding passenger.

Bertini and El-Geneidy[11] also derived two other equations for dwell time; when passengers were only boarding the bus:

$$\text{Dwell Time (seconds)} = 5.0 + 3.5\, N_b \qquad (3)$$

and when only alighting passengers were recorded:

$$\text{Dwell Time (seconds)} = 7.6 + 0.64\, N_a \qquad (4)$$

Running Time Variations

Abkowitz and Engelstein[12,13] studied factors affecting running time on transit routes and methods for maintaining transit service regularity. These studies report on regression models of bus mean running time and running time deviation estimated from data collected on transit routes in Cincinnati, Ohio. Three running-time measures were used in the analysis:

- Mean-running time
- Running-time variation per link
- Cumulative running-time variation

They found that mean running time is highly influenced by trip distance, number of passengers boarding and alighting, and signalized intersections and to a lesser degree by parking restrictions on the route, time of day, and direction of travel. The number of bus stops was eliminated from the models because there was a high correlation between the number of passenger stops made and the boarding and alighting of passengers.

The running-time variation was found to be correlated with mean running time. Delays tend to accumulate once a vehicle falls behind schedule. Therefore, operators have more difficulty pinpointing expected vehicle arrival times at the destination terminal as route length increases. Long routes experience poor on time performance, posing problems for schedule reliability.

General Delays

According to Levinson and St. Jacques,[8] the interactions between dwell times at bus stops and delays at traffic signals serve to reduce speeds and to increase the variability of speed. Consequently bus speeds on downtown streets have coefficients of variation ranging from about 15 to 30 percent, as compared with about a 10 to 15 percent variation for general traffic. It was also found that traffic congestion has an important impact on bus travel times.

Observed bus volumes on urban freeways, arterial streets, and bus-ways clearly show the negative impact of bus stops on bus vehicle capacity. Kittelson & Associates[9] showed that the highest bus volumes experienced in a transit corridor in North America, 735 buses per hour through the Lincoln Tunnel and on the Port Authority Midtown Bus Terminal access ramps in the New York metropolitan area, are achieved on exclusive rights-of-way where buses make no stops. Where bus stops or layovers are involved, reported bus volumes are much lower. When intermediate stops are made, bus volumes rarely exceed 120 buses per hour. However, volumes of 180 to 200 buses per hour are feasible where buses use two or more lanes to allow bus passing, especially where stops are short. They also showed that the amount of green time provided on signalized streets affects the maximum number of buses that could potentially arrive at a bus stop during an hour. However, the number of buses that are scheduled to use a bus stop during one hour directly affects the number of buses that may need to use the stop at a given time. If insufficient loading areas are available, buses will queue for the stop. In this situation, passenger travel times will increase and the on-time reliability experienced by passengers will decrease. The study also concluded that speeds of buses operating in mixed traffic are influenced by bus stop spacing, dwell times, delays due to traffic signals and interferences from other traffic.

In their 1996 study of bus lanes on arterials, Levinson and St. Jacques[8] estimates the components of traffic delay for a mixed flow bus operation, a normal flow bus lane, and a contra-flow or dual bus lane (See Table 2).

Table 2. Estimated Traffic Delay (minutes/mile)

COMPONENT	CBD	City	Suburbs
Traffic signal	1.2	0.6	0.5
Right Turns	0.8	-	-
Traffic Congestion	1.0	0.3	0.2
Total for mixed flow bus operation	3.0	0.9	0.7
Normal flow bus lane	2.0	0.6	0.5
Contra-flow or dual bus lanes	1.2	0.6	0.5

The delays for normal flow bus lanes include the estimated delays due to right turns and traffic signals. The delays for contra-flow bus lanes only include traffic signal delays.

Table 3 shows the corresponding travel time rates for buses.

Bus speeds tend to decrease as bus volumes increase, especially when buses are not able to leave the bus lane. A 1986 study of bus priority proposals in New York City (cited in Levinson and St. Jacques[8]) found that delay due to bus-bus congestion accounted for about 15 percent of the total travel time along Fifth Avenue (220 buses per hour), and for less than one percent along Sixth Avenue (150 buses per hour).

Table 3. Estimated Travel Time Rates (minutes/mile)

COMPONENT	CBD	CITY	SUBURBS
Mixed Traffic			
Moving	5.50	3.90	3.00
Passenger Stops	3.30	1.20	0.50
Traffic Delay (signals, right turns, etc.)	3.00	0.90	0.70
Total	11.50	6.00	4.20
Normal Flow Bus lanes			
Moving	5.50	3.90	3.00
Passenger Stops	3.00	1.20	0.50
Traffic Delay (signals, right turns)	2.00	0.60	0.50
Total	10.50	5.70	4.00
Contra-Flow or Dual Bus Lanes			
Moving	5.50	3.90	3.00
Passenger Stops	3.00	1.20	0.50
Traffic Delays (signals)	1.20	0.60	0.50
Total	9.70	5.70	4.00

The Impact Of Congestion On Bus Reliability

Turnquist[6] defines bus reliability as the variability of a system performance measure over time. A reliable bus service is one where buses run on time along a route, where the space interval between successive buses is uniform and where the variations in schedule adherence are kept to a minimum. Service reliability is important to both the transit operator and the transit user. To the user, non adherence to schedule results in increased wait time, makes transferring more difficult, and causes uncertain arrival time at the destination. To the operator, unreliability in operations reduces productivity and increases costs due to the need to build substantial slack time into timetables in order to absorb deviations from the schedule.

During the past decades, transit agencies have monitored passenger loads and on-time performance by traffic checkers and street supervisors. However, several factors have brought new interest to improving service reliability. A growing body of research has identified the factors contributing to poor transit service reliability and the various ways to improve it. Longer bus routes and traffic congestion in some cities have made on-time performance more difficult; concerns over containing operating costs; and deficits to improve service monitoring and reliability, and the availability of AVLC systems (Automatic Vehicle Location and Control) affords new opportunities to systematize and improve service monitoring activities.[14]

No direct study of the impact of congestion on bus service reliability was found in the literature. However, many studies have been done on bus service reliability, which is believed to have a direct correlation with congestion. It is clear that congestion reduces the reliability of surface transit service. According to Cooper and Gould,[15] the predictability of service is an important factor in the choice of a particular transit mode. If a transit mode becomes unreliable, travel times become less predictable and the service becomes less attractive. The authors observed that congestion causes variations in travel times among different buses on the same route during the same time period. This increases passenger-waiting time and causes bus bunching which creates the impression that buses are unreliable. It is difficult to measure the impact of congestion in bus schedules because the location, duration and severity of congestion change from day to day.

Levinson[14] separated factors causing variation in bus running time into those related to the traffic stream and surrounding environment and those related to the transit system. The traffic-related factors include traffic signals, curb parking, variable traffic conditions, unexpected incidents, weather, and emergencies. Cars and commercial vehicles that park and unload along the curb often block moving travel lanes and impede bus flow. Such conditions are most acute along commercial streets in densely developed urban areas where off-street parking space is not adequate and demands for curb access are high. Transit-related factors that contribute to poor schedule adherence include fleet maintenance practices, route structure, bus stop patterns, passenger arrival rates, ridership variations and trends, scheduling practices, and driver selection, behavior, training, and supervision.

In order to better understand the relationship of congestion and reliability, Cooper and Gould[15] studied the variations between scheduled headways and actual headways, using linear regression. It was found that scheduled running time increases with the observed variations from the scheduled headways. The report did not include the regression equation, but a graph illustrating the equation indicates that a 15 percent increase in traffic travel time correlates with a 160 percent increase in variation from scheduled headway.

In 1988, Guenther and Hamat[16] found that one method of improving the operating efficiency of a bus system is to improve schedule reliability. In order to evaluate the effect of different strategies to improve reliability, they conducted a study of on-time performance on four bus routes of the Milwaukee County Transit System and analyzed the distribution of on-time performance. They found that many factors, such as the availability of seats, crime, and maintenance of vehicles, influence people's decision on whether to use bus transit regularly. However, one very important factor is passenger-waiting time. A shorter waiting time will make people more likely to ride buses or to become regular riders. One way to minimize passenger-waiting time is to have reliable bus schedule time adherence.

Guenther and Hamat studied the distribution of adjusted arrival time, which is defined as the difference between the observed arrival time and the scheduled arrival time at a bus stop along a route. The distribution of adjusted arrival time can be used either to measure on-time performance, or to estimate the probability of a bus being on time, or to model passenger waiting times, passenger arrivals and on time-performance. The study found that the differences between scheduled and actual arrival times follow a gamma distribution. Adjusted arrival times are a function of the distance along a route, the location of peak load point, and the headway. Buses in the morning and evening peaks tend to arrive late. However, midday buses tend to arrive early.

An analysis was also performed to compare the arrival times at different points along one route. It was found that there are many reasons that buses arrive earlier than the scheduled times. Traffic may be less congested in areas away from the CBD; and the distance between stops may be longer. Fewer passengers board the buses farther away from a peak load area. An incentive to arrive earlier at the end points is the extra time drivers can have to drink a cup of coffee or to read a newspaper.

In a 1978 study, Turnquist[(17)] found that increased reliability results in reductions not only of passenger loading variations but also of operating costs. In addition, he found that once regular passengers are confident that the bus will arrive on time, they plan their arrival at the bus stop so as to be there just before the bus arrives.

For evaluating transit services, two measures were examined in 1991 research by the Metropolitan Transportation Authority (MTA) Inspector General in New York City.[(18)] Apparently, service regularity measures for high-frequency transit are non-existent at many transit-operating agencies. The measures that are in use or those developed in theory are usually unsatisfactory because they do not control for the size of headways and therefore cannot be used to compare one route with another. In other words, they are not expressed on a normalized scale. The two measures that were examined for evaluating transit service were the headway regularity index and the passenger wait index.

Both indices control for the average headway and both are expressed on a normalized scale from 0 to 1.0. The regularity index is defined as one Gini's ratio and the passenger wait index is the ratio of the actual average wait to the minimum average wait (which occurs for perfect regularity). It was found that regularity measures offer a way to assess the inconvenience experienced by transit riders from all causes and provide a measure of progress in improving transit service. The wait index is a function of the headway variance and the regularity index refers exclusively to the headway distribution and ignores passenger arrival patterns.

Conclusion

Bus speeds and travel times along arterial streets are influenced by the number of bus stops, the number of passenger boarding and alighting, and the number of signalized intersections. Other factors were found to have less impact on bus running time. Traffic congestion has a small, but significant adverse impact on bus travel time.

Congestion was found to reduce bus service reliability significantly. Although no studies quantified the effects of congestion on bus service reliability, it is believed that variations between scheduled headways and actual headways, and between scheduled running times and actual running times are larger where street congestion is more severe. The literature also notes that passengers are more aware of service reliability problem than slow running times.

DATA COLLECTION

Bus and car travel time and other information by route and by route segment provide important inputs for analyzing the relationship of bus travel times to traffic congestion. This chapter describes the data collection and refinement procedures.

Travel Time as a Measure of Congestion

Travel time rate (the time required to travel one mile or the inverse speed) was used rather than a more traditional measure of congestion such as volume to capacity ratio (V/C), first because the impact of congestion on bus travel time was the prime concern. Modeling time or travel time rate of buses as a function of travel time rate of traffic is a more straightforward model than modeling it as function of V/C ratio. Second, the V/C ratio or traffic volumes were not available for all of the streets over which a typical NJ Transit bus route operates. (See the Appendix for the route segments for which traffic volumes were available.) It was much easier for the study team to collect travel time data than traffic volume data. Third, V/C ratio is by it nature a measure of one point along a route. Even if data at several points are collected, V/Cs characterize points along the route. The time to travel between two points along the route provides a measure for the length of the segment, not individual points. This particularly relevant for routes that change streets frequently.

That speed is a function of V/C ratio or congestion is well established in the literature. For example, Exhibits 15-8 to 15-11 of the Highway Capacity Manual[19] and Table 23 of the NCHRP Report 398, Quantifying Congestion[20] both show speed as a function of V/C. The decision to use travel time rate rather than speed is based again on the fact that increases in travel time is the primary impact of congestion on bus operations and because modeling bus speed as a function of traffic speed would entail a nonlinear relation with any additional independent variables that might be used. A multi-variable model of bus travel time would be simply additive. Travel time rate rather than travel time is used to account for differences in route segment length.

Potential Data Sources

The dependent variable in the travel time model was the bus travel time rate (minutes per mile) for a given length of route. The primary independent or explanatory variable was a measure of traffic level, expressed in the same form as bus travel time rate for the same length of route. In addition, variables that represent other causes for bus delays, such as passengers boardings and alightings, number of bus stops, number of traffic signals, and geometry of the roadways and route, were collected.

Four basic sources for bus travel times were explored:

Scheduled bus times at different times of day: The logic behind this is that traffic levels and passenger interchange vary across the day, and therefore, adjustments to the schedule over time would reflect both factors. However, there was little variation in scheduled run times at different times of day. For example, scheduled times between time points for Route 62 remain constant for most of the day; the times between some time points decline by two to three minutes early in the morning or late at night. With so little variation, the scheduled times are of little use for analysis.

A second approach looked at historic trends in scheduled times. New Jersey Transit keeps schedules for seven years. The schedule for Routes 59 and 62 in 1997 were compared to the current 2002 schedules. The largest increase in travel time for a route segment was three minutes; however, travel times for most segments did not change. Because of this and difficulty in getting traffic data for 1995, this comparison was not followed.

APC times: Eight NJ Transit buses are equipped with Automatic Passenger Counters (APC) that incorporate GPS equipment. The equipment records location (latitude and longitude) and exact times periodically and each time the bus turns, decelerates, closes its doors, and periodically as it is traveling along the route. At bus stops, it records the bus stop location, whether it is a time point, and the number of passengers boarding and alighting. APC data were available for Route 62, but mostly for route segments between Penn Station and Broad and Jersey Streets in Elizabeth. Additionally, there was some APC data for Route 59.

On board collection: Data for Routes 59 and 62 were also collected manually. Team members rode the buses for both Routes 59 and 62 and recorded the time at each bus stop and traffic signal, along with passenger boardings and alightings. This method provided additional information on other factors that affect the travel time (particularly the time that is spent dealing with passenger inquiries concerning fares and destinations) and relevant characteristics of the route were identified.

The final data set consisted of APC data supplemented with data collected by the study team on board the buses.

Data collection: Bus

Data were collected in one of three ways: 1. Variables were extracted from the APC records; 2. Variables were recorded by the study team while riding the bus; or 3. Variables were recorded by the study team while following the route in a car. When a car was used, two team members were involved, one to drive and one to record.

The required data was categorized as specific to the bus trip, to the characteristics of the route segment, or to the traffic. The bus trip characteristics were taken from or calculated from the APC data or from data sheets that the team used to collect on board data.

The basic unit of analysis was a route segment. A route segment was defined as a section of the route between two adjacent time points, a time point (TP) being the location at which the schedule has a recorded time. The time points have been numbered. For Route 62, the numbers were those shown in the schedule. For Route 59, the time points were numbered from 1 at Broad Street at Washington Park (in Newark) to 17 at North Avenue at Washington. A route segment was designated by the first time point, an underscore and the second time point. Thus, route segment 3_2 for Route 59 represents the section of the route from Broad and Lincoln Park (TP 3) to Broad and Branford (TP 2) for a bus traveling toward Newark.

Data Collection: Traffic and roadway

Roadway characteristics, such as the number of traffic signals on a road segment, were observed in the field. Average travel times by car between time points were recorded during several car trips. For Route 59, 10 outbound car trips and eight inbound car trips were made; for Route 62, there were eight outbound and nine inbound trips. The car trips were classified by time of day - AM peak (7 AM to 10 AM), Midday (10 AM to 4 PM), PM peak (4 PM to 7 PM), or post PM peak (after 7 PM). The times for each period were averaged and then converted to car travel time rates by dividing by the distance between time points

Data Refinement

The data were reduced as follows:

APC Data. The APC data were separated by bus and date. Then the records that represent the bus stopped at a time point were identified. (The time for this record was the time at which the door, either front or back, was closed.) Information between adjacent time points was associated with the specific route segment. However, often a particular time point was not in the records, presumably because the bus did not stop there to pick up or drop off passengers. This was more likely to happen at greater distances from downtown Newark. Sometimes the data for a particular bus run would simply end part way through the route. Thus, much of the data was not usable.

Bus travel time rates were calculated for each route segment from the APC data. Additionally, the relevant distance, total number of passengers boarding, total number of passengers alighting, and the total number of times that the bus stopped at a bus stop were calculated for the same route segment. Then the data was sorted by route segment and the range of distances was observed. In theory, the distance between time points is constant, but the distance that the bus actually travels will vary slightly depending on the number of times that the bus pulls over to a bus stop or changes lanes. In some cases, the differences were much larger than could be explained by these types of variations. All records for which the distance varied by more than a few tenths of a mile from the average for the route segment were eliminated from the analysis.

Both speed (mile per hour) and travel time rate (minutes per mile) were calculated for each route segment. A few cases were discarded because the calculated speeds and travel time rates were improbable.

On board data. The on-board data that the study team collected went through a similar process. Some incomplete or unlikely observations were eliminated from the data set. Distances based on the APC distances and distances recorded when following the route by car were used to calculate bus travel times.

Final Data Set

Once the data set was compiled, it was analyzed in several ways (see following chapter). During the preliminary analysis, anomalies in several of the records became evident. These records were studied to determine the cause of the anomalies, and in some cases, the records were eliminated from the data set. Common reasons for removal were that the bus was moving extremely slowly (e.g., two miles per hour) or the bus speeds were much higher than average car speeds for the same route segment. The process reduces the dataset from 748 records to 690 records. (Most of the models that were tried were run with both the smaller and larger data sets; the differences between coefficients were small, and the significances of the coefficients and the model overall were generally better with the smaller dataset.)

The final data set includes 690 records, each record representing one bus trip on one route segment. There are 27 route segments for route 59 in the data set, 13 for bus trips from Newark to Dunellen and 14 for bus trips from Dunellen to Newark. There are 11 route segments for route 62, six from Penn Station Newark to Elizabeth and five for trips from Elizabeth to Newark. Table 4 defines the route segments for the two routes. The Appendix includes more information for the individual route segments.

The preliminary analysis was done using Excel and the statistical package, SPSS, and modeling was done using SPSS.

Table 4. Route Segments
4a. Route 59

From Newark to Dunellen		From Dunellen to Newark	
1_2	Washington Park to Broad St. & Branford, Newark	17_16	Washington & North Ave. to Watchung & E. 4th, Plainfield
2_3	Broad & Branford to Lincoln Park, Newark	16_15	Watchung & E. 4th to Westfield & Park Aves., Scotch Plains
3_4	Lincoln Park to Meeker & Elizabeth, Newark	15_13	Westfield & Park to Broad & Elm Sts., Westfield
4_5	Meeker & Elizabeth to Broad St. & Ridgeway, Hillside	13_12	Broad & Elm to South & Central Aves., Westfield
5_6	N. Broad & Ridgeway to Broad & Grand, Elizabeth	12_11	South & Central Aves. to South Ave. & Center St., Garwood
6_7*	Broad & Grand to Broad & Jersey St., Elizabeth	11_10	South Ave. & Center St. to South & Walnut Aves., Cranford
7_8*	Broad & Jersey to Jersey & Elmora, Elizabeth	10_9	South & Walnut Aves. to 2nd Ave. & Chestnut St., Roselle
8_9	Jersey & Elmora to 2nd Ave. & Chestnut, Roselle	9_8	2nd Ave. & Chestnut St. to Jersey St. & Elmora Ave., Elizabeth
9_10	2nd Ave. & Chestnut to South & Walnut Aves., Cranford	8_7	Jersey St. & Elmora Ave. to Broad & Jersey Sts., Elizabeth
10_11	South & Walnut to South & Center St., Garwood	7_6*	Broad & Jersey Sts. to Broad & Grand, Elizabeth
11_12	South & Center to South & Central Ave., Westfield	6_5	Broad & Grand to N. Broad St. & Ridgeway Ave., Hillside
12_13	South & Central to Broad & Elm, Westfield	5_4	N. Broad & Ridgeway to Meeker & Elizabeth Aves., Newark
13_15	South & Central to Westfield & Park Aves., Scotch Plains	4_3	Meeker & Elizabeth Aves. to Lincoln Park, Newark
15_16	Westfield & Park to Watchung & E. 4th St., Plainfield	3_2	Lincoln Park to Broad St. & Edison Pl., Newark
16_17	Watchung & E. 4th to Washington & North, Dunellen	2_1	Broad St. & Edison Pl. to Washington Park, Newark

4 b. Route 62

From Newark to Elizabeth		From Elizabeth to Newark	
1_2	Penn Station to Broad St. & Branford Pl., Newark	6_5	Broad & Jersey Sts to IKEA, Elizabeth
2_3	Broad St. & Branford Pl. to NIA Terminal A, Newark	5_4	IKEA to S. Airport Rd. & Federal Express Dr., NIA
3_4	NIA Terminal A to S. Airport Rd. & Federal Express Dr., NIA	4_3	S. Airport Rd. & Federal Express Dr. to Terminal A, NIA
4_5	S. Airport Rd. & Federal Express Dr. to IKEA, Elizabeth	3_2	Terminal A to Broad St. & Edison Pl., Newark
5_6	IKEA to Broad & Jersey Sts., Elizabeth	2_1*	Broad St. & Edison Pl. to Penn Station, Newark

* These route segments were not included in the data set but are included in later analysis.

INITIAL ANALYSIS OF TRAVEL TIME DATA

This chapter describes the data and presents an initial analysis of how travel times vary by route and by time of day. Additionally, there is a discussion of dwell time. Figure 1 is a map showing the two routes, Routes 59 and 62.

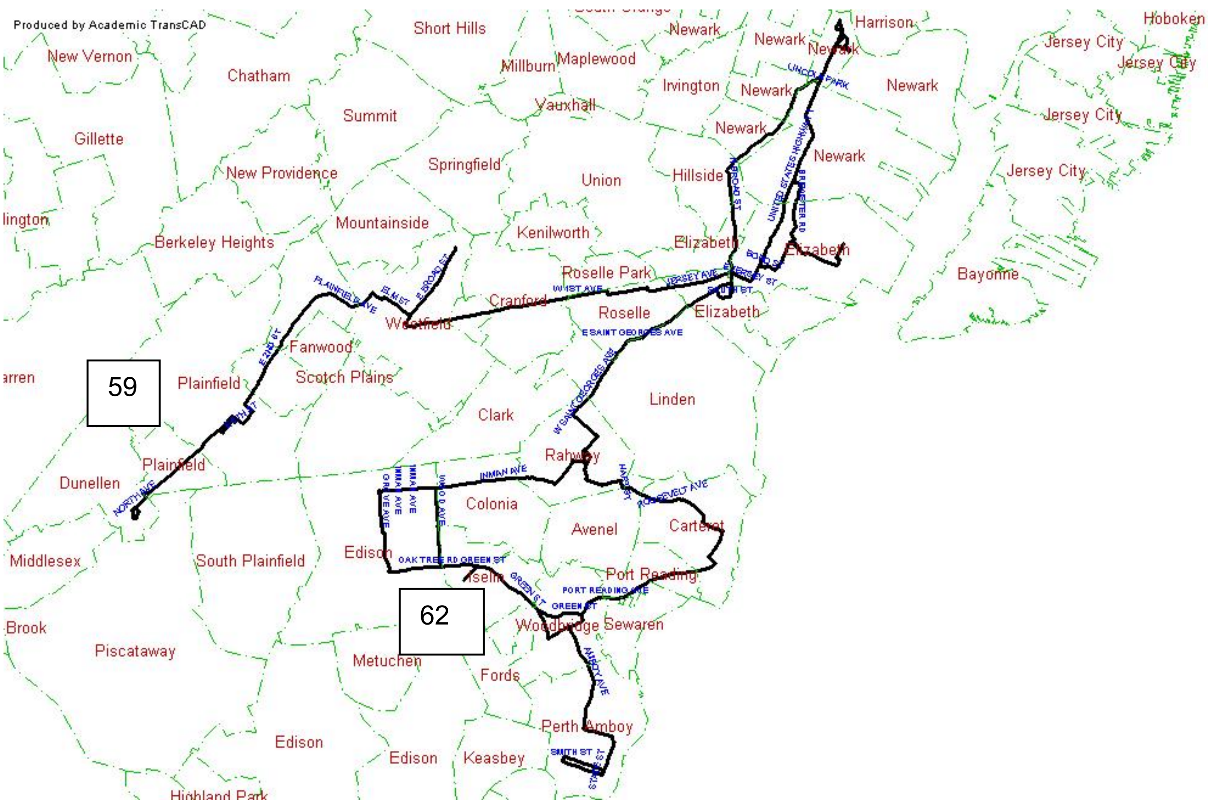


Figure 1. Map of Routes 59 and 62

Description of the Data

Table 5 presents the descriptive statistics for the basic variables. The variables included are:

Bus time	The time in minutes for a bus (during one trip) to travel the length of a route segment; the time is measured from the time the door closes at the first time point to the time it closes at the second time point
Distance	The length (in miles) of the route segment
Bus stops	The number of designated bus stops in the route segment; the bus may not have stopped at all of them in a specific observed trip

Actual stops	The number of times that the bus actually stopped at designated bus stops to load or unload passengers during an observed bus trip in the route segment
Ons	The number of passengers that boarded the bus during the observed trip in the route segment
Offs	The number of passengers that alighted from the bus during the observed bus trip in the route segment
Traffic signals	The number of signalized intersections in the route segment; this is not the number of times that the bus stopped at a signal
Left turns	The number of left turns in the route in the route segment

Note that distance, bus stops, traffic signals, and left turns are constant for a given route segment, while bus time, ons, and offs are specific to one bus trip and route segment.

The route segments varied from 0.48 miles to 5.31 miles in length, and the times that buses took to travel the segments varied from 1.73 minutes to over a half hour. (The variation in time reflects both differences in segment length and differences in bus speed on a specific segment.) The most variation (as measured by the segment-to-segment coefficient of variation) occurs in the numbers of passengers boarding a bus in one bus trip on one route segment, the numbers of passenger getting off a bus, and the number of left turns in a route segment.

Table 5. Descriptive Statistics of Basic Variables

	N	Minimum	Maximum	Mean	Standard deviation	Coefficient of variation
Bus time (minutes)	690	1.73	33.43	7.89	4.49	0.57
Distance (miles)	690	0.48	5.31	1.81	1.04	0.57
Bus stops	690	1	15	7.37	3.77	0.51
Actual stops	688	0	20	2.98	2.48	0.83
Ons	690	0	52	6.64	8.04	1.21
Offs	690	0	49	5.83	6.81	1.17
Traffic Signals	565	1	12	6.06	3.20	0.53
Left turns	660	0	5	1.20	1.41	1.18

To control for the differing lengths of the route segments, the variables were standardized by segment length. Table 6 presents the basic descriptive statistics for the standardized variables. Bus speeds vary from approximately four miles per hour to almost 33 miles per hour, while car speeds vary from about seven mi/h to 34 mi/h. While the minimum, maximum, and mean values for bus speeds are all lower than the respective statistics for cars, the ratio of bus travel time to car travel time is less than one for a few records. This can partially be explained by the fact that 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.

Table 6. 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 (mi/h)	690	4.05	32.88	14.48	5.10	0.35
Car speed (mi/h)	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

The coefficient of variation decreased for a few variables when the effects of differences in route segment length are removed. However, for most variables, the variation increased; this is probably because the time points are closer together in the busiest areas, for example in downtown Newark and Elizabeth.

To provide a greater understanding of how the variables are distributed, histograms of some of the variables are shown in Figure 2. Bus speeds and car speeds (Figures 2 c and 2 d) are both more normal in shape than the respective travel times (Figures 2 a and 2 b). The Passenger boardings per bus per mile (Figure 2 e) and alightings per bus per mile (not shown) are both dominated by segments with no activity, followed by those with on a few passenger movements.

Relationships between Variables

In Figure 3, bus travel time is plotted against potential explanatory variables. Figure 3 a shows bus travel time plotted against car travel time. While there is considerable “scatter,” a distinct positive relationship can be seen. The majority of the observations are above the 1=1 diagonal line, indicating that most buses were moving slower than the average car times recorded for the time period and route segment.

Bus travel time versus passenger boardings per mile (Figure 3 b) also shows a positive slope, although the most noticeable feature is the massive clustering at zero through about 10 boardings per mile. Alightings per mile (Figure 3 c) are more spread out, but any slope is much more difficult to detect.

The relation of bus travel times to bus stops per mile (Figure 3 d) is harder to interpret. There is more variation in bus times as the number of bus stops per mile increases;

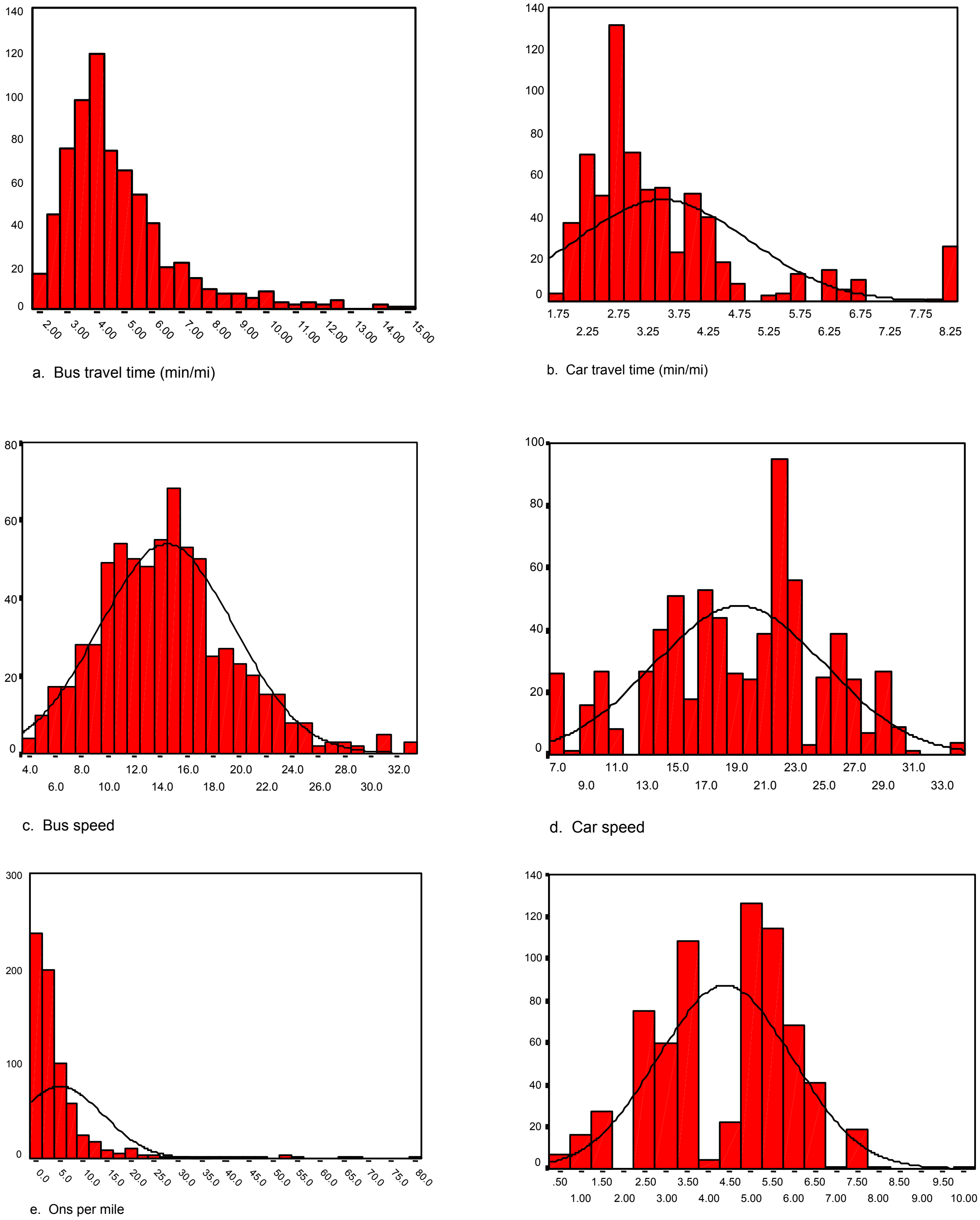


Figure 2. Histograms of Travel Time Variables

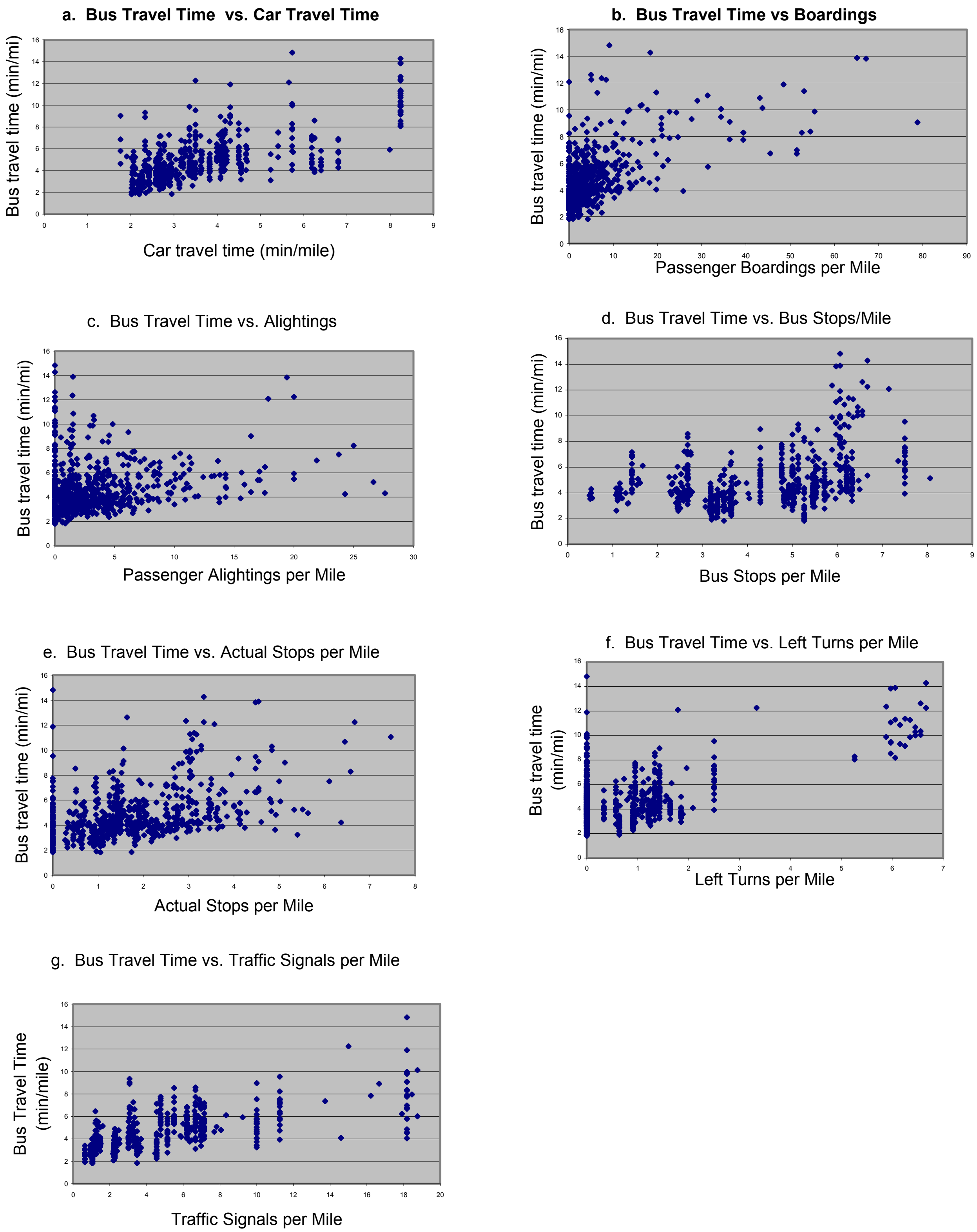


Figure 3. Relation of Bus Travel Time to Other Variables

a line through the midpoints of the variation would slope up, but also would be curved. The scatter plot of bus travel times against the number of times the bus actually stopped in the segment (Figure 3 e) is more uniform, but shows a weak relationship.

The graph of bus travel time versus left turns per mile (Figure 3 f) shows a distinct upward slope. Figure 3 g shows how bus travel times tend to increase as the signal density (signals per mile) increase.

Relation of Bus and Car Speeds

The mean overall ratio of bus travel time to car travel time (both expressed in minutes per mile) is 1.41 indicating that on average buses take about 40 percent longer than cars to travel a mile. Figure 4 show the relations of bus travel time to car travel time by segment. For most segments, the bus travel times follow a similar pattern to those of the cars except that they take longer. The one exception is segment 12_13 for route 59 (from South and Central Avenues to Broad and Elm in Westfield).

The graphs in Figure 4 indicate that, with the exception of downtown Westfield (commented on above), both buses and cars move slower at the beginning of the routes, which for both routes is in downtown Newark. This probably reflects greater traffic congestion and the large number of traffic signals in this area. Additionally, the *differences* between car and bus times are also greater near the beginning of the routes, probably due to greater passenger activity in the downtown Newark area.

Figure 5 shows the bus and car travel time rates by period of day. (The periods are defined as: AM peak = 7 AM to 10 AM; midday = 10 AM to 4 PM; PM peak = 4 PM to 7 PM.)

Route 59. Bus travel time rates inbound are greatest during the midday and PM peak, while outbound travel time rates are about the same throughout the day. The ratios of bus to auto travel time rates range from 1.15 to 1.40 inbound and 1.20 to 1.46 outbound.

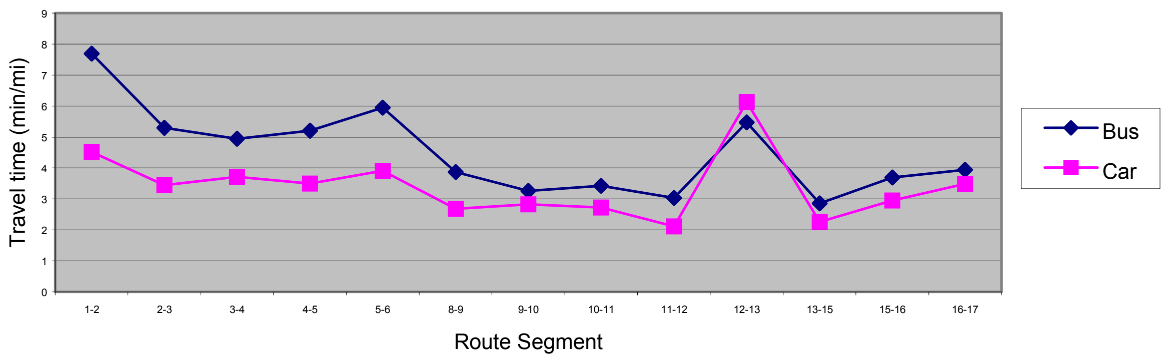
Route 62. Bus travel time rates inbound and outbound are greatest in the AM peak periods. The ratio of bus to auto time range from 1.28 to 1.59.

The graphs indicate that time of day does have an affect but it is not the major factor in determining travel times.

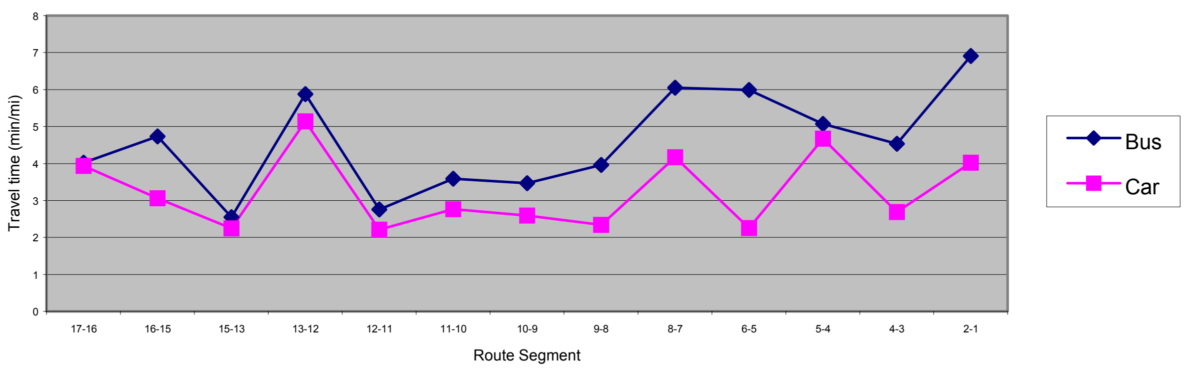
Reliability

An important issue for any bus operation is reliability of the service. Schedule reliability (that is, do the buses arrive at time points when they are scheduled to) was not looked at directly. However, the travel time rates between time points were analyzed. Figure 6

Route 59 from Newark



Route 59 to Newark



Route 62

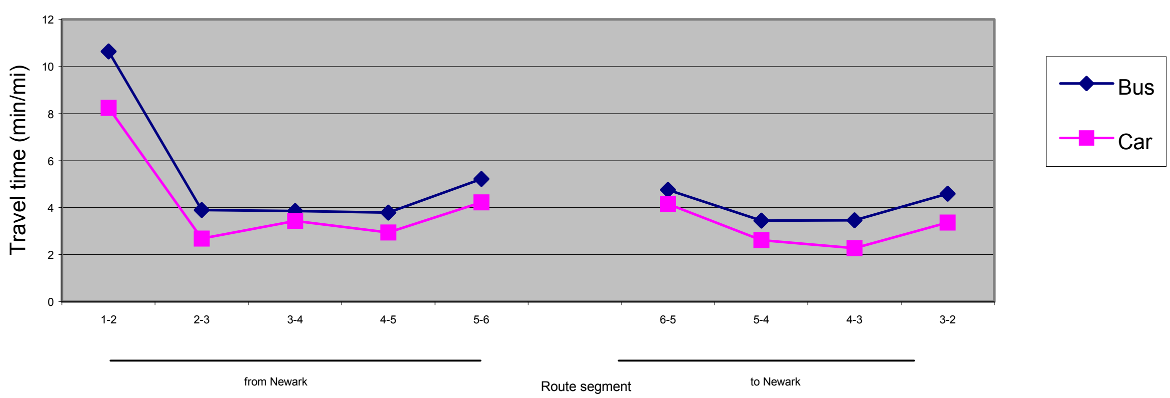
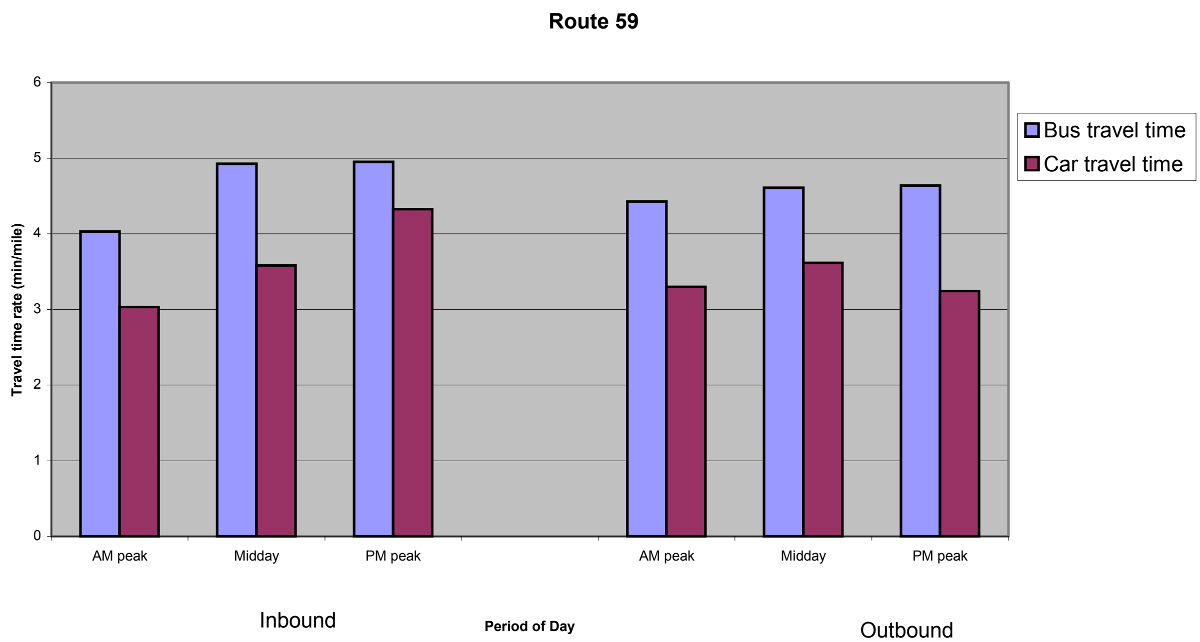


Figure 4. Bus and Car Travel Time Rates by Route Segment



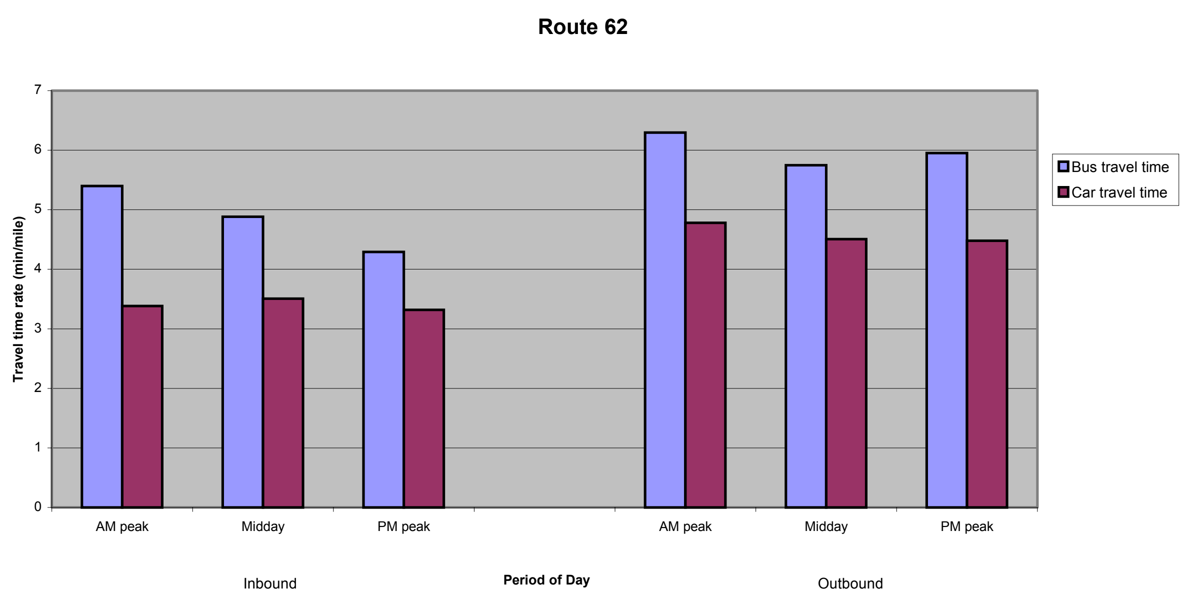
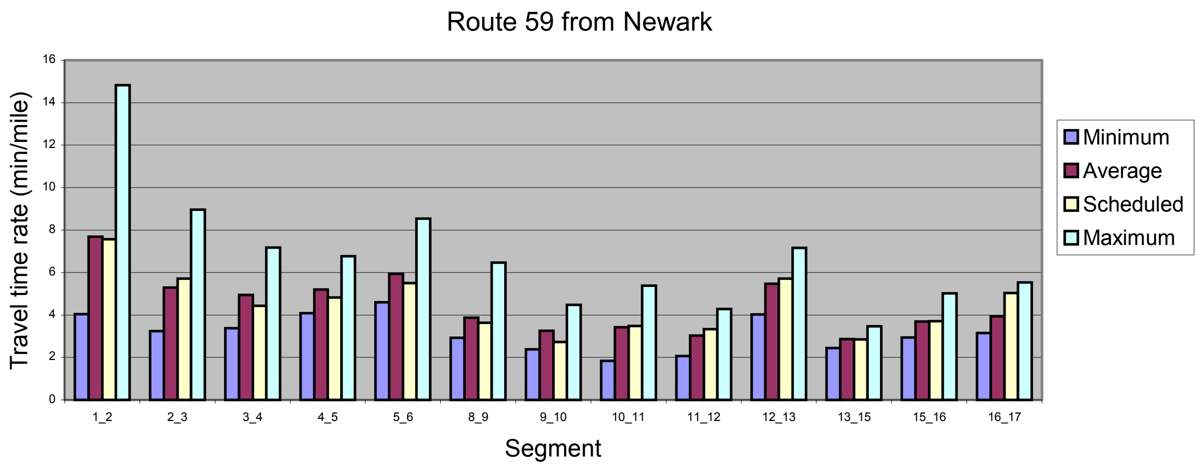
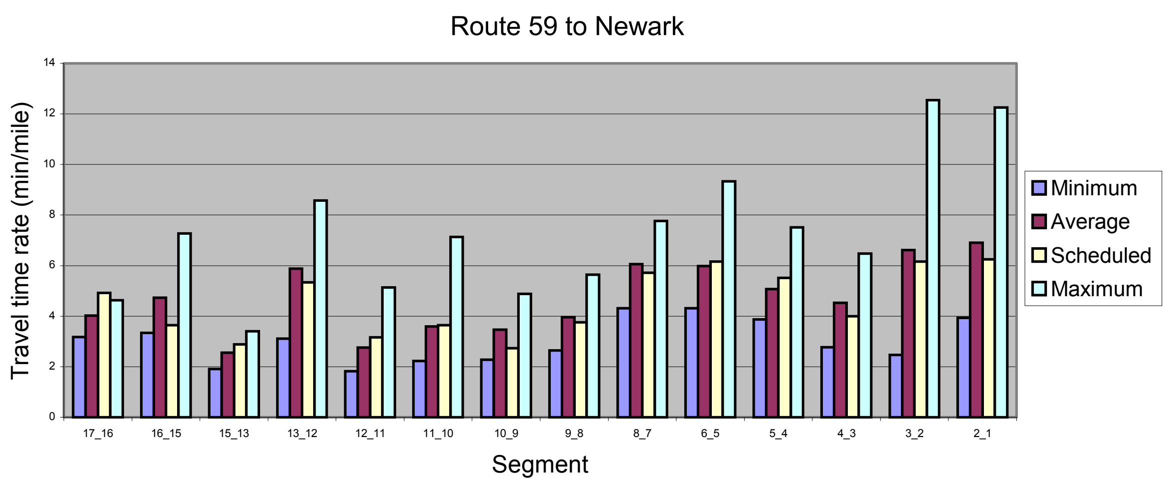


Figure 5. Bus and Car Travel Time Rates by Period of Day





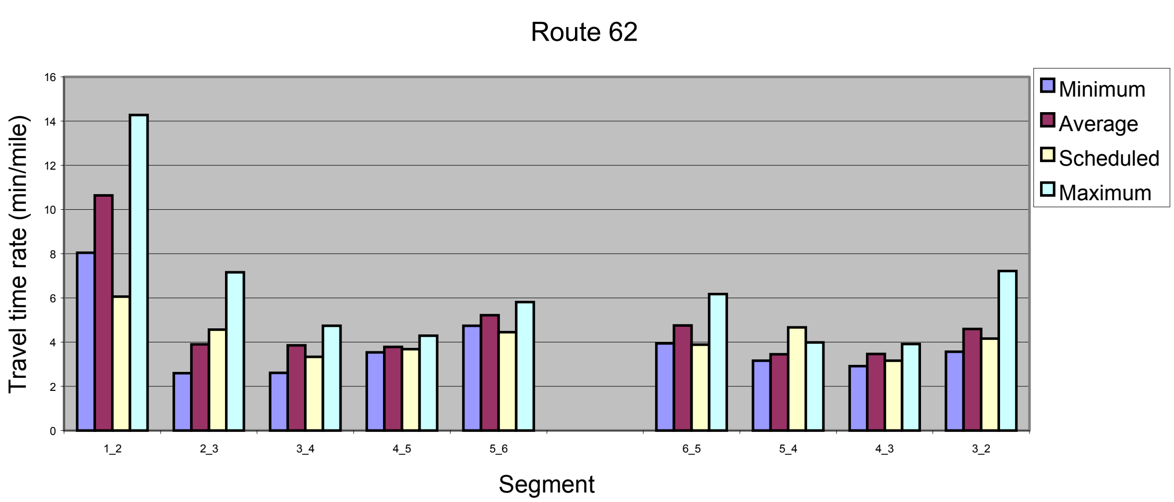


Figure 6. Variability of Bus Travel Time Rate by Route Segment

shows the variability of the travel time (in minutes per mile). For each segment, the two outer bars show the maximum and minimum travel times for the segment, the second bar is the average travel time and the third is the scheduled travel time. The average actual travel time was noticeably more than the scheduled time for about half of the segments for both routes 59 and 62. The difference between the minimum and maximum travel time appears to be greatest for route segments that are in or close to downtown Newark.

(For some bus services, drivers will slow down when they are approaching time points if they are ahead of schedule in order to not cross the time point early. The data were analyzed for any indication that this might be occurring for these two routes. Trips when the bus was ahead of schedule were analyzed to see if speeds were slower than for other trips. No indication of this was found.)

Travel Time by Activity

The total time that a bus operates is the sum of its time moving, time delayed due to traffic signals, and time stopped to pick up and let off passengers. Figure 7 shows the proportion of time that a bus on route 59 spends in each of these activities. As Levinson[(3)] showed, the both travel time (in minutes per mile) and the percent of time spent in each of these activities is affected by the environment (that is, CBD, city, or suburban) that the bus is operating in. Route 59 is operating in a combination of city and suburb. Both travel time and the break down between the activities falls in between the data city and suburbs shown by Levinson.

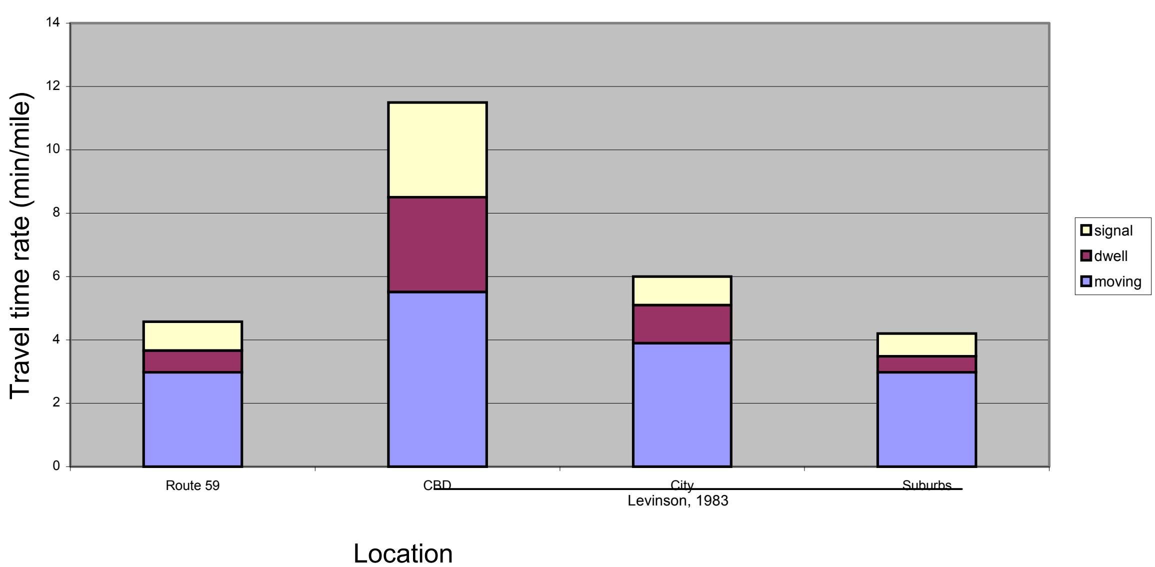


Figure 7. Components of Bus Travel Time

Dwell Time

One reason for long bus delays at stops was the time that passengers took while boarding to ask questions and pay fare. As a result, a regression analysis of dwell time was undertaken, relating the dwell time at a bus stop to the number of passenger boarding and alighting. This was done for Route 59 for which the times of arrival at and departure from the bus stop were available. There were 545 observations. The result was:

$$\underset{(12.1)}{DT = 11.3} + \underset{(17.5)}{6.0\,B} + \underset{(6.7)}{1.8\,A} \qquad (5)$$

$R^2 = 0.44 \qquad N = 545$

Where
DT = Dwell time (seconds)
B = Number of passengers boarding per bus
A = Number of passengers alighting per bus
Value in parentheses is t-value for coefficient

Thus the average passenger takes 6.0 seconds to board and 1.8 seconds to alight. This is longer than that normally encountered in urban bus service.

For boarding passengers only, the relation was

$$DT = \underset{(14.5)}{13.3} + \underset{(18.6)}{6.5\,B} \qquad (6)$$

$R^2 = 0.39$

These relationships were compared to the study by Bertini and El-Geneidy[(11)] of a bus route in Portland, Oregon (discussed on page 6). They derived three equations for dwell time; one for boarding, another for alighting and one for both boarding and alighting. Their equations were:

$$DT = 5.8 + 3.6\,B + 0.85\,A \qquad (2)$$

For Boarding

$$\text{Dwell Time (seconds)} = 5.0 + 3.5\,B \qquad (3)$$

An additional study[(21)] of dwell times on the New York City Transit route M15 found the relationship:

$$DT = 9.2 + 5.6\,B + 1.6\,A \qquad (7)$$
$$\quad (6.7)\ \ (23.7)\ \ (6.0)$$

$R^2 = 0.52$ $\quad F = 309$ $\quad N = 569$

The Transit Capacity and Quality of Service Manual[9] gives passenger boarding times ranging from 2.25 seconds per passenger for prepayment to 4.3 seconds per passenger for exact change. All of the times for NJ Transit route 59 are longer than all of these other sources. The longer New Jersey times reflect the more complex zonal fare system used in New Jersey.

To estimate the impact on the route time of the longer dwell times in New Jersey, the three equations were used to estimate total dwell time for one outbound trip of route 59. The average values for the number of boarding and alighting passengers and the number of times the bus stops in each route segment were added. (Note that this is a slight undercount because a very short segment is missing.) These numbers were used in each of the three equations that are shown in Table 7 below.

Table 7. Comparison of Dwell Time Models for Route 59

Model	Time due to				
	Boarding (seconds)	Alighting (seconds)	No. of Stops* (seconds)	Total time (seconds)	Difference (seconds)
NJT 59	408	132	426	966	-
NYCT M15	381	117	347	845	121
Portland, OR	245	62	219	526	440

* Number of stops accounts for the constant terms in the models.

Route 59 is scheduled to take 99 minutes in the outbound direction for most of the day. If the dwell time were similar to that for New York City, approximately two minutes would be eliminated (about 2 percent). If the dwell time were similar to that of Portland, Oregon, about 7 minutes and 20 seconds would be eliminated (7 to 8 percent).

MODEL OF BUS TRAVEL TIME

This chapter describes the modeling process, summarizes the models studied, lists the reasons for preferring one model over others, and discusses the implications of the selected model.

Modeling Process

In this task, the empirical relation between bus operations and traffic congestion was developed. The initial impact of traffic congestion is to increase the bus travel time, which results in an increase in the vehicle hours and number of peak buses required to operate a bus route at a specific level of service or at a specified headway. This translates to higher costs.

The time that a bus takes to travel between two points is the sum of travel time, the time to stop at bus stops (primarily the additional time for deceleration and acceleration), and the dwell time at the bus stops (assumed to be determined by the number of passengers boarding and alighting and the average service time per passenger). The impact of traffic congestion would primarily affect the time that the bus was actually moving, although there might be some impact on the time for acceleration due to difficulty of re-entering the traffic flow.

Multiple regression analysis was used to relate bus travel time to traffic level. The dependent variable was bus travel time rate for a route segment measured in minutes per mile. The average car travel time rate on the route 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, etc.

The names and descriptions of the variables are listed below:

Bus travel time	BTT	Time (minutes) for a bus to travel between time points divided by the segment length
Car travel time	CTT	Time (minutes) for a car to travel between time points divided by the segment length
Boardings/bus/mile	Ons	The number of passengers that boarded the bus in the route segment divided by segment length
Alightings/bus/mile	Offs	The number of passengers that boarded the bus in the route segment divided by segment length
Ons & offs/bus/mile	O&O	Total number of boarding and alighting passengers in the route segment divided by the segment length
Bus stops/mile	BS	Number of bus stops in the route segment divided by segment length (not necessarily actual stops)

Actual stops/ bus/mile	AS	Number of times that the bus actually stopped at bus stops to pick up or discharge passengers in the route segment divided by the segment length
Left turns/mile	LT	Number of left turns that the bus makes in the route segment divided by the segment length
Signals/mile	Sig	Number of traffic signals in the route segment divided by segment length

The correlations between these variables and the dependent variable, bus travel time per mile, is shown in Table 8, below. All of the variables show strong correlation with bus travel time (their correlations are significant at 0.99). However, most of the potential independent variables also have strong correlations with car travel time.

Table 8. 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

Summary of Models

Many linear regression models were tried, starting with the simplest one of bus travel time as a function of car travel time. A few non-linear forms were tried, but they were inferior to the linear models: further, the graphs of bus travel times versus the other variables (see previous chapter) did not suggest non-linear relations.

Table 9 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 right. Note that the number of records for the models varies because some records were missing data for either 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 percent of the variation in bus travel time per mile.

$$BTT = 1.38 + 0.96\ CTT \qquad (8)$$
$$\quad\ (9.3) \quad (24.4)$$

( ) is t-value of coefficient $R^2 = 0.46$ $F = 597$

By adding variables, the explanatory power of the models can reach 63 percent. The coefficient for car travel time decreases as additional independent variables are added because of the inter-correlation 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 because passenger activity is high in the same areas where vehicular traffic is high, e.g., downtown shopping areas.

Table 9. Summary of Models of Bus Travel Time
(numbers in cells are model coefficients)

Dependent Variable: Bus travel time (min/mi)

Constant	CTT	Ons	Offs	O&O	BS	AS	LT	Sig		R sqr	F	N	No. of var's
1.38	0.96									0.46	597	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
(0.40)	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.

Passenger activity was included in three forms: Passenger boardings per mile; the sum of passenger boardings and passenger alightings per mile; and 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).

Preferred Model

The model that will be used to estimate the impact of traffic congestion is:

$$\underset{(2.8)}{BTT = 0.52} + \underset{(19.5)}{0.73\ CTT} + \underset{(10.1)}{0.06\ Ons} + \underset{(9.8)}{0.31\ BS} \tag{9}$$

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

This relatively simple model includes the two primary ways that buses differ from other traffic: they stop at bus stops and they wait while passengers board. Using Ons and Offs instead of just Ons might seem more logical and it 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 R^2 and F). Also actual stops have to be estimated, while total bus stops is within the control of the agency and known.

Implications of the Model

The model has a straightforward logic. Bus travel time rates are roughly equivalent to 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 minutes per bus stop) represents 18 seconds loss during deceleration and acceleration. The coefficient for passenger boardings (0.06 minutes per boarding) represents 3.6 seconds service time per passenger and is within the range reported in the Transit Capacity and Quality of Service Manual.[9]

The impact of a specific variable on the bus travel time rate depends both on the coefficient and the magnitude of the variation of the variable. Table 10 shows how the explanatory variables impact bus travel time rate, using the 90 percent range (i.e., from the 5^{th} to 95^{th} percentiles) of the independent variables in the data base. (The top and bottom five percent were removed to reduce the influence of extremes; standard deviations were not used because the passenger boardings are skewed toward zero.) For example, the 90 percent range in car travel time rate of 4.7 minutes per mile would cause a 3.43 minute per mile variation in bus travel time rate. The table indicates that the car travel time rate has the greatest impact of the three explanatory variables; in fact, the potential impact of traffic time is more than twice as large as that of passenger boardings and bus stops.

Table 10. Relative Impact of Explanatory Variables on Bus Travel Time

	Car travel time (min/mile)	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 of range in variable on bus travel time rate	3.43	1.22	1.53

Figure 8 shows the impact of decreases of car speeds on bus speed and bus travel time, assuming four bus stops per mile and five boarding passengers per mile (these assumptions are close to the means in the database).

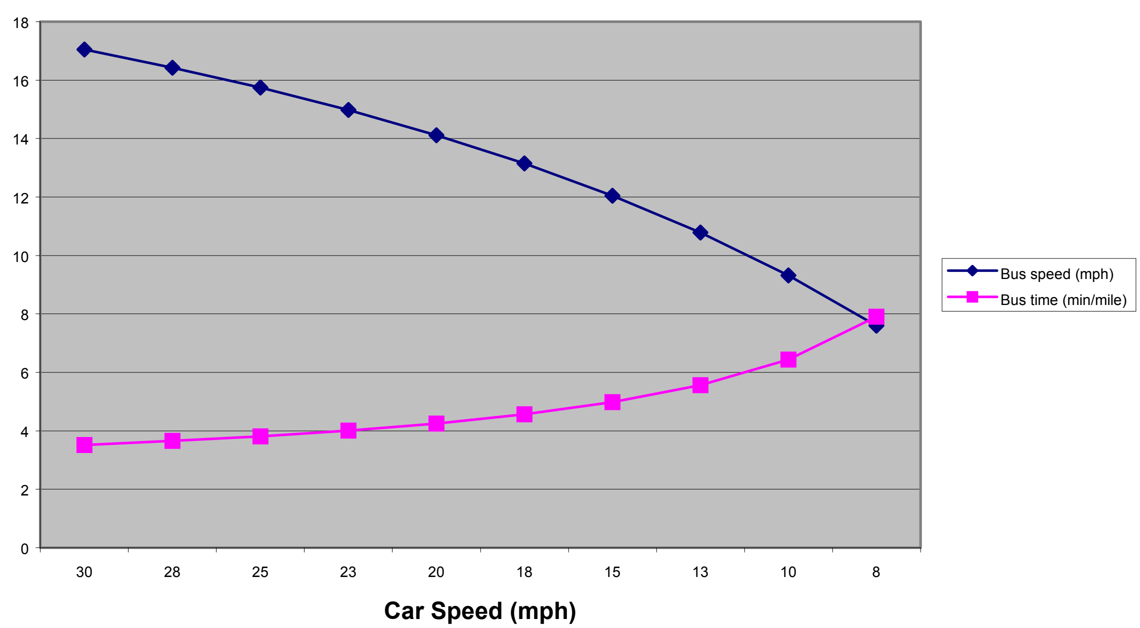


Figure 8. The Impact of Decreasing Traffic Speed on Bus Speed and Travel Time Rate

Table 11 shows the application of the preferred model to estimate bus travel times on Route 59 if there were no congestion. Free flow traffic speeds for each link in the route were determined based on the functional classification of the roadway, according to the

Highway Capacity Manual.[19] Route 59 operates on arterials; the free flow speeds were estimated to be 27 mi/h throughout the route, or 2.22 minutes per mile (see column 5 of table). Columns 6, 7, and 8 contain the means of the observed values for the three variables in the model. The model was used to estimate bus travel time per minute for each route segment, using the actual number of bus stops in each segment (column 7), the average of observed passenger boardings per bus in each route segment (column 6), and the calculated free flow car travel times for each segment (column 5). The predicted bus travel time rate under free flow conditions is shown in column 10.

[Note: Route segments 6 to 7 and 7 to 8 (from Broad and Grand to Jersey and Elmora, in Elizabeth) were combined because of difficulties collecting data; segment 6 to 7 was exceedingly short (less than a tenth of a mile).]

The calculated bus travel times were changed to total minutes for each segment by multiplying by the segment length (column 3). The result (column 11) is compared with the observed values (column 12) and the times based on the midday schedule (column 13).

The total predicted, observed and scheduled times are shown in the last row of the table. In the outbound direction (from Newark to Dunellen), the sum of the average observed times for the segments are about a minute longer than the scheduled time, while estimated time to traverse the route under free flow conditions is about 12 and 13 minutes less than the scheduled and observed times.

The difference between the predicted and observed bus times represent the degradation of bus times due to traffic congestion. The predicted bus times under free flow conditions (holding the number of boarding passengers constant) is about 12 minutes shorter than scheduled for the outbound direction (Newark to Dunellen) and ten minutes shorter than scheduled for the inbound direction (Dunellen to Newark).

Table 11. Estimated Bus Travel Time under Free Flow Conditions
Route 59

11a. Bus traveling from Newark

Route segment				Assumed			Observed			Bus times		
No.	Description Start/end	Distance (miles)	Observed CTT (min/mi)	free flow CTT (min/mi)	Observed boardings (per mi)	Observed bus stops (per mi)	bus travel time rate (min/mi) Mean	St dev	Predicted BTT (min/mi)	Predicted (minutes)	Observed (minutes)	Scheduled (minutes)
1	2	3	4	5	6	7	8	9	10	11	12	13
1	Washington Park											
1_2	to Branford Pl.	0.66	4.52	2.22	28.82	6.03	7.68	2.40	5.74	3.81	5.10	5
2_3	to Lincoln Park	0.68	3.45	2.22	5.92	4.43	5.29	1.36	3.87	2.64	3.61	4
3_4	to Meeker Ave.	1.59	3.71	2.22	3.15	6.29	4.95	0.86	4.28	6.81	7.86	7
4_5	to Ridgeway Ave.	1.45	3.50	2.22	4.65	6.21	5.21	0.67	4.35	6.30	7.55	7
5_6	to Elizabeth Arch	2.00	3.91	2.22	7.60	5.00	5.95	0.90	4.15	8.30	11.89	11
6_7	to Jersey St.											2
6_8	Grand to Elmora	1.08		2.22	10.34	7.41			5.06	5.46	7.96	
7_8	to Elmora Ave.											6
8_9	to Chestnut	1.64	2.68	2.22	2.25	5.51	6.05	1.01	3.99	6.52	6.32	6
9_10	to Walnut Ave.	2.19	2.83	2.22	0.94	3.19	3.26	0.58	3.19	6.99	7.14	6
10_11	to Center St.	1.14	2.73	2.22	0.72	3.51	3.43	0.69	3.27	3.73	3.91	4
11_12	to Central Ave.	0.90	2.12	2.22	0.98	3.33	3.03	0.56	3.23	2.91	3.95	3
12_13	to Elm St.	0.69	6.13	2.22	3.02	1.46	5.47	0.96	2.77	1.91	3.77	4
13-15	to Park Ave	3.15	2.26	2.22	0.50	3.17	2.86	0.29	3.16	9.94	9.01	9
15_16	to E. 4th St.	2.70	2.95	2.22	1.20	4.82	3.69	0.44	3.71	10.00	9.96	10
16_17	to North Ave	2.98	3.49	2.22	1.20	5.03	3.94	0.63	3.77	11.25	11.75	15
Totals		22.9								86.6	99.8	99

Table 11 continued. Estimated Bus Travel Time under Free Flow Conditions
Route 59

11b. Bus traveling toward Newark

Route segment				Assumed			Observed			Bus times		
			Observed	free flow	Observed	Observed	bus travel time rate		Predicted			
No.	Description	Distance	CTT	CTT	boardings	bus stops	(min/mi)		BTT	Predicted	Observed	Scheduled
	Start/end	(miles)	(min/mi)	(min/mi)	(per mi)	(per mi)	Mean	St dev	(min/mi)	(minutes)	(minutes)	(minutes)
1	2	3	4	5	6	7	8	9	10	11	12	13
17	Dunellen											
17_16	to E. 4th St.	3.05	3.93	2.22	4.37	4.92	4.03	0.36	3.93	11.98	12.28	15
16_15	to Park Ave.	2.75	3.06	2.22	4.39	5.45	4.73	0.93	4.10	11.27	13.01	10
15_13	to Elm St.	3.12	2.24	2.22	1.48	3.21	2.55	0.44	3.22	10.06	7.96	9
13_12	to Central Ave.	0.75	5.14	2.22	3.81	2.67	5.88	1.52	3.20	2.40	4.40	4
12_11	to Center St.	0.93	2.21	2.22	2.61	5.41	2.76	0.93	3.98	3.70	2.53	3
11_10	to Walnut Ave.	1.10	2.77	2.22	2.60	3.63	3.59	1.25	3.42	3.77	3.95	4
10_9	to Chestnut St.	2.17	2.59	2.22	4.45	3.69	3.47	0.67	3.55	7.71	7.50	6
9_8	to Elmora Ave.	1.58	2.34	2.22	6.53	5.08	3.96	0.76	4.11	6.48	6.23	6
8_7	to Jersey St.	1.05	4.17	2.22	7.14	4.76	6.05	1.01	4.05	4.25	6.35	6
7_6	to Elizabeth Arch	0.09		2.22	155.11	11.11			14.89	1.34	1.19	1
6_5	to Ridgeway Ave.	1.93	2.26	2.22	3.81	5.19	5.99	1.59	3.98	7.67	11.54	12
5_4	to Elizabeth Ave.	1.43	4.67	2.22	6.95	5.59	5.07	0.88	4.29	6.15	7.25	8
4_3	to Lincoln Park	1.71	2.69	2.22	1.51	5.87	4.53	0.96	4.05	6.93	7.70	7
3_2	to Edison Pl.	0.65	7.99	2.22	0.00	6.15	6.27	2.24	4.05	2.63	3.85	4
2_1	to Washington Park	0.79	4.02	2.22	0.79	7.63	6.90	1.83	4.56	3.60	5.39	5
Total		23.1								89.9	101.1	100

COST OF CONGESTION

The next step in determining the impact of congestion on bus service involved estimating the monetary savings of reducing the time that a bus would take to complete a route. New Jersey Transit estimates the cost of new service to be $56.80 per vehicle hour. This figure is appropriate when the additional time needed due to congestion requires adding a new bus, which is frequently the case. In some situations, the same schedule can be delivered using the same number of buses with the individual buses operating longer. One way to estimate the cost in the latter case is to calculate costs as a function of vehicle hours, vehicle miles and the number of vehicles needed for service. Then the cost of a change in any one of these variables can be determined.

Determining when additional buses will be needed, and how many are needed, as the time to drive a route increases requires a detailed analysis of each schedule. Instead, both the minimum cost (if no new buses are needed – an unlikely occurrence) and maximum costs (when buses need to be added for each route) are estimated in this chapter. The minimum or no-new-bus scenario requires the estimation of a cost allocation model. The next section describes the development of the model. The second section uses the model to estimate the no-new-bus cost of congestion. The final section estimates the full cost of congestion including the addition of new buses.

Model of Costs for No New Buses Case

The Data

The data were from an internal report, the LC Bus Line Summary: Revenue and Expenses report[22]. The report includes expenses for each route attributed to operational, facility, and administration. The operational cost is divided into variable and other. Additionally, the total passengers, vehicle hours, vehicle miles, trips, and peak vehicles for the relevant time period were included. The variables used to develop the model are:

- Operational variable expense (VC): This excludes expenses related to facilities or administration and any operation expenses that do not vary. It is a function of the amount of service that is actually operated.
- Vehicle hours (VH): The sum of all hours of service operated by all vehicles on the specific route.
- Vehicle miles (VM): The sum of all miles of service operated by all vehicles on the specific route.
- Peak vehicle days (PVD): The total vehicles that are needed to operate the service on one day (i.e., the peak vehicles) summed for all days of the year. Because of the differences in the peak vehicle requirements between weekday and weekend, and because of differences in the number of weekend days that

the routes operate, there is not a constant ratio between peak vehicle days and peak vehicles as usually defined.

Data from 92 routes operating out of 10 garages in Northern New Jersey were used for the analysis. (Note that some of the records represent several routes, rather than one route because they were grouped in the report.) Table 12 shows the averages and variation in variable cost per vehicle mile, vehicle mile and peak vehicle day as well as average speed and travel time (in minutes per mile). The cost figures use the operational variable expenses because this is the cost that would be affected by a reduction in travel time. Table 13 shows the averages of these variables for each garage.

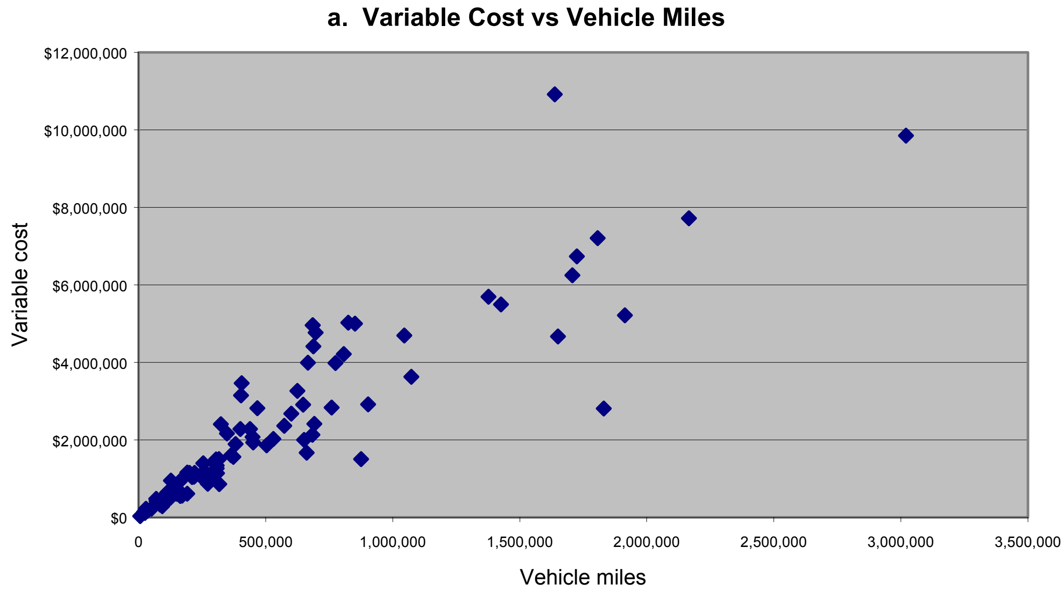
Table 12. Descriptive Statistics of Cost Variables

	N	Minimum	Maximum	Mean	Standard deviation	Coefficient of variation
Cost per vehicle mile	92	1.53	8.52	4.73	1.39	0.29
Cost per vehicle hour	92	44.65	71.05	54.33	5.44	0.10
Cost per peak vehicle day	92	172.71	1011.05	590.03	149.32	0.25
Speed (mi/h)	92	7.42	35.68	12.53	4.55	0.36
Travel time (min/mi)	92	1.68	8.08	5.22	1.35	0.26
Variable cost proportion	92	0.57	0.71	0.67	0.03	0.04

Table 13. Averages of Cost Variables for Individual Garages

	Cost per			Average Speed	Travel time
Garage	vehicle hour	vehicle mile	peak vehicle day	(mi/h)	(min/mi)
Big Tree	59.65	5.36	557.31	11.56	5.42
Fairview	59.62	5.89	583.15	10.29	5.93
Greenville	66.74	6.70	488.94	10.32	6.05
Hilton	54.54	4.87	639.09	12.01	5.36
Ironbound	59.47	4.68	717.34	14.52	4.68
Market St	48.83	4.22	558.58	11.77	5.19
Meadowlands	57.44	5.25	576.66	12.76	5.46
Oradell	48.95	3.79	541.33	13.04	4.63
Orange	49.05	4.90	560.46	10.23	5.99
Wayne	53.47	3.00	595.50	19.27	3.38

Figure 9 a, b, and c show how operational variable costs relate to vehicle miles, vehicle hours, and peak vehicle days. The graphs show a very strong linear relation of variable cost to the three variables, particularly to vehicle hours.



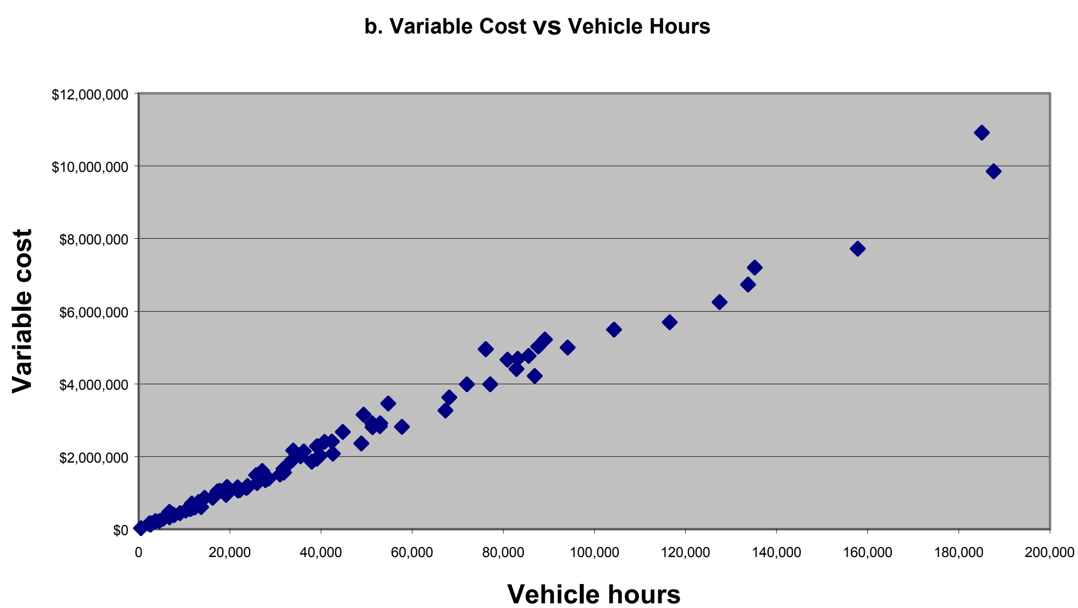


Figure 9. Relation of Variable Cost to Measures of Bus Service
(Figure continued on following page)

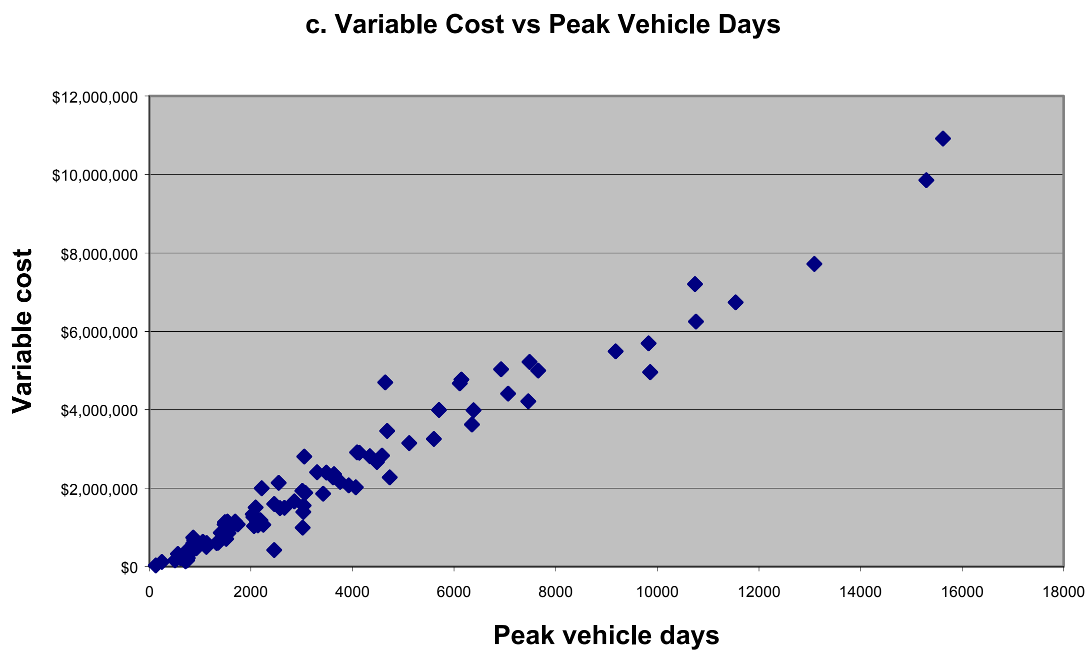


Figure 9. Continued

Developing the Model

Table 14 shows the correlation matrix for variable cost and the three measures of service, vehicle miles, vehicle hours, and peak vehicle days. As the graphs show, the three service variables are highly correlated with variable cost. However, they are also correlated with each other.

Table 14. Correlations of Cost Variables

	VC	VH	VM	PVD
VC: Variable cost	1			
VH: Vehicle hours	0.993	1		
VM: Vehicle miles	0.891	0.906	1	
PVD: Peak vehicle days	0.979	0.977	0.860	1

N=92

The possible models of variable cost as a function of one or more of the output measures are shown in Table 15. The high level of inter-correlation creates some irrationalities; in two of the models, vehicle miles has a negative coefficient, implying that costs would decrease with additional miles. If explaining costs were the only concern, the model that estimates variable cost as a function of vehicle hours would be a good model, given its high R^2 and simplicity.

Table 15. Summary of Cost Models

Dependent Variable: Variable Cost

constant	VM	VH	Pk Veh		R sqd	F	N	no. of variables
(-48325)			**631.23**		0.96	2039	92	1
(24612)		**53.51**			0.98	6113	92	1
446758	**3.46**				0.80	348	92	1
(25012)	(-0.165)	**55.58**			0.99	3093	92	2
(-7315)		**43.14**	**127.01**		0.99	3454	92	2
(-52575)	**0.74**		**525.32**		0.97	1313	92	2
(-5703)	(-0.066)	**44.44**	**121.23**		0.99	2285	92	3

However, to estimate the cost impact of a change in travel time, the model needs to separate the effect of time from other variables. Thus the model of variable cost as a function of vehicle hours and peak vehicle days is the best of these models.

$$\underset{}{VC = -7315 + 43.14\,VH + 127.01\,PVD} \qquad (10)$$
$$(-0.19) \quad (14.4) \qquad (3.5)$$

( ) is the t-value of the coefficient $\quad R^2 = 0.987 \quad F = 3454$

Logically, the constant would be zero. The combination of the constant's negative sign, its small size (relative to the variable cost, which varies from \$30,000 to \$10,000,000), and the fact that it is not statistically significance further support a zero constant. Suppressing the constant results in the following, similar model:

$$VC = + 43.18\,VH + 125.46\,PVD \qquad (11)$$
$$(14.5) \qquad (3.6)$$

In the next section, this model will be used for estimating the cost impact of increased travel time resulting from traffic congestion if no new buses were needed.

Cost of Congestion: No New Buses

Model (11) indicates that an increase in time needed to operate a route by one vehicle hour would increases costs by \$43.18. If an additional vehicle is needed to operate the route during the peak, it would cost \$125.46 per day or roughly \$30,700 per year in addition to \$43.18 per vehicle hour. (This assumes 245 days of weekday service, based on 261 weekdays per year minus 16 holidays on which New Jersey Transit operates reduced service.)

For Route 59, the additional time due to congestion for one round trip was estimated to be 22 minutes (12 minutes outbound and 10 minutes inbound – see Table 11). The estimated cost of this additional time would be $15.83 [that is, $43.18/VH X (22/60) VH].

To apply these estimates to the weekday schedule, the lines of the schedule were categorized as individual trips made up of specific segments. For example, the outbound schedule includes six trips from time point 1 to time point 7, seven trips from 1 to 11, nine trips from 1 to 13, etc. The time penalty for congestion for each trip category (in both directions) were calculated by summing the differences between scheduled segment times and times estimated under free flow conditions for the relevant route segments. This was done for all trips between about 6 AM and 6 PM. For example, the bus schedule for Route 59 has seven trips from the beginning of the route (time point 1) to time point 11. Table 16 shows the calculation of increased time due to congestion for one of these trips.

Table 16. Sample Calculation of Time Savings for Route 59

	All segments		Segments between time points 1 and 11	
Segment	Estimated bus time with no congestion (minutes)	Scheduled bus time (minutes)	Estimated bus time with no congestion (minutes)	Scheduled bus time (minutes)
1_2	3.81	5	3.81	5
2_3	2.64	4	2.64	4
3_4	6.81	7	6.81	7
4_5	6.30	7	6.30	7
5_6	8.30	11	8.30	11
6_7		2		2
6_8	5.46		5.46	
7_8		6		6
8_9	6.52	6	6.52	6
9_10	6.99	6	6.99	6
10_11	3.73	4	3.73	4
11_12	2.91	3		
12_13	1.91	4		
13_15	9.94	9		
15_16	10.00	10		
16_17	11.25	15		
Total	86.58	99	50.56	58
Increase in time due to congestion		**12.42**		**7.44**

For seven trips between time points 1 and 11, the total savings would be 7X7.22 minutes or about 52 minutes.

Repeating these calculations for all the trips in the period from 6 AM to 6 PM, the total estimated time due to congestion was 773 minutes or 12 hours and 53 minutes. The estimated weekday monetary cost of this time is $556. Assuming that the typical year has 245 non-holiday weekdays, this would be $136,000 per year. Thus, if there were no congestion, the costs of Route 59 would be $136,000 less, as shown in Table 17. Congestion has increased the operational variable expenses 4.9 percent and total expenses 3.4 percent.

Table 17. Impact of Congestion on Route 59 Costs
No Additional Buses

	Operational variable expense	Total expense
Current expenses	$2,911,313	$4,126,980
Expense due to congestion	$136,000	$136,000
Estimated expense with no congestion	$2,775,313	$3,990,980
Percent of expenses due to congestion	4.9%	3.4%

The method just described omits the effect of policy headways on scheduling. For Route 59, most trips from Dunellen leave at 40 minutes after the hour. Trips leaving Newark, typically leave on the hour or 30 or 40 minutes after the hour. This suggests that the schedule has been designed to make it easy for passengers to remember rather than to maximize utilization of buses and drivers. Under this policy, a few minutes saved in running time might be added to the layover time rather than used to reduce the total time that the bus and driver are needed. Thus the actual cost savings due to reduction in vehicle hours if there were no traffic congestion might be less (or might be more) than the $543 dollars indicated.

Cost of Congestion: Buses Added

If the increase in time due to congestion is a minute or two per bus trip, it may be absorbed in the layover time, allowing service to be maintained with the same number of buses. But as the time increment increases, one or more buses (with drivers) will need to be added to maintain the schedule and the capacity of the route. The cost of new service, including adding new buses, is $56.80 per vehicle hour. In this section, the cost of congestion on Route 59 is re-calculated using this figure. (See previous section for explanations of the calculations.)

For one round trip, the additional time of 22 minutes due to congestion would cost $20.83. For one weekday of service on Route 59, the cost would be $732. For a year of 245 non-holiday weekdays, the cost would be $179,000. Using these number, the cost of service without congestion is calculated as

Table 18. Impact of Congestion on Route 59 Costs
Additional Buses Needed

	Operational variable expense	Total expense
Current expenses	$2,911,313	$4,126,800
Expense due to congestion	$179,000	$179,000
Estimated expense with no congestion	$2,732,313	$3,947,980
Percent of expenses due to congestion	6.6%	4.5%

The two approaches to the cost, no new buses versus new buses needed to accommodate the increase in travel time due to congestion, produce two different cost figures, $136,000 and $179,000 (or $43,000 more per year for one route). The actual cost presumably falls somewhere between the two numbers. Given the pressures on bus schedulers to not waste resources, there is probably little slack in the schedules, so increases in running time will require additional vehicles and drivers. Thus, the higher figure is most likely closer to the real figure.

IMPACTS OF CONGESTION ON NEW JERSEY TRANSIT BUS OPERATIONS

The impact of congestion on the overall bus system in Northern New Jersey was estimated using the results from the models of bus travel time and cost along with some simplifying assumptions. The increment of the vehicle hours of service that is due to congestion is estimated in the first section. From these numbers, the increment of cost due to congestion is estimated in the second section. Finally, the increase in vehicle hours and costs in the next five years is estimated.

Increased Vehicle Hours of Service Due to Congestion

The model of bus travel time (Equation (9): BTT = 0.52 + 0.73 CTT + 0.06 Ons + 0.31 BS) implies that an increase in travel time rate for traffic in general will cause an increase in bus travel time equal to 0.73 times the traffic travel time increase (measured in minutes per mile). To apply this in general, the increase in travel time rate for any route due to congestion (assuming that the number of bus stops and passengers per mile remains the same) would be:

$$dBTT_{r\_ff} = 0.73 * (TTT_{r\_a} - TTT_{r\_ff}) \tag{12}$$

where
$dBTT_{r\_ff}$ = the increment in travel time rate (minutes per mile) due to congestion for buses on route r
TTT_{r_a} = the travel time rate for traffic under current conditions
TTT_{r_ff} = Travel time rate for free flow conditions

To determine the actual increment of time due to congestion (in hours rather than minutes per mile), the difference in bus travel time rate is multiplied by total vehicle miles on the route.

This was applied to 39 local routes in Northern New Jersey. The routes were taken from the New Jersey Transit Summary of Revenue and Expenses for FY2002.[22] The routes chosen were those with records that applied to one route only and for which the data represented the total route (that is, there were no routes that operated out of two garages or had changes during the year). Local routes (rather than commuter or other types of routes) were chosen in order to be able to assume that the buses operate mostly on arterials. This allows the assumed free flow speeds of 27 miles per hour with the travel time rate (TTT_{r_ff}) of 2.22 minutes per mile for general traffic.

In order to have a quick measure of current travel time rates, the travel rate indices from a study by New Jersey Institute of Technology[1] were used. The travel rate index (TRI) is a measure of the amount of extra time due to congestion to travel a link. For example, a TRI of 1.20 indicates that it will take 20 percent longer to travel a given distance than it would under uncongested conditions. For the purposes of this study:

$$TRI = TTT_{r\_a} / TTT_{r\_ff} \quad (13)$$

The NJIT study determined TRIs for freeways, principal arterials, and other arterials for all counties in New Jersey. The TRIs vary from 1.00 (for Atlantic and Cape May freeways) which indicates no congestion travel delay to 1.93 (for Somerset principal arterials) indicating a 93 percent increase in travel time due to congestion. The current travel time rates along bus routes were assumed to be the average of TRIs for the principal arterials and other arterials times the free flow travel time rate of 2.22. The TRI numbers are averages for a whole county. A bus route within a county may operate on streets that are more or less congested than the average for the county, but as with any use of an average, it is assumed that the positive and negative variations from the mean balance each other over the many routes. Table 19 shows the travel rate indices for the relevant counties from the NJIT report along with the averages (in third column) used in this analysis.

The county that the route operates in was assumed to be that of the garage from which it operates.

Table 19. Travel Rate Indices (TRIs) by County

County	Principal arterial	Other arterial	Average arterial*	All roadway**
Bergen	1.73	1.64	1.69	1.12
Essex	1.72	1.26	1.49	1.13
Union	1.51	1.14	1.33	1.13
Essex Union ***	1.62	1.20	1.41	1.13
Hudson	1.70	1.46	1.58	1.15
Passaic	1.60	1.25	1.43	1.15

* Average of principal and other arterial TRIs.
** Includes Freeway
*** Essex Union is the average of the two counties.

Based on the TRIs, the current travel time rate for traffic would be:

$$TTT_{r\_a} = TRI_c\,(TTT_{r\_ff}) \quad (14)$$

Where TRI_c = the travel time index for county c

Then equation (12) becomes:

$$dBTT_{r\_ff} = 0.73 * (TRI_c * TTT_{r\_ff} - TTT_{r\_ff}) \quad (15)$$

$$dBTT_{r\_ff} = 0.73 * TTT_{r\_ff} \ (TRI_c - 1) \quad (16)$$

If free flow speeds are assumed to be 27 miles per hour, the travel time rate is 2.22 minutes per mile and equation (16) becomes

$$dBTT_{r\_ff} = 0.73 * 2.22 \; (TRI_c - 1) = 1.62 \; (TRI_c - 1) \qquad (17)$$

Table20 shows the 39 local routes with the increase in bus travel time rate ($dBTT_{r\_ff}$) based on equation (17) and assumptions above. Columns 1 and 2 are data from the revenue and expenses summary.[22] Column 3 uses information in columns 1 and 2 to calculate a proxy BTT; it includes time and mileage for non-revenue time and for off-peak (e.g., early morning, late night, and weekend) periods, but is suggestive of the conditions on the routes. Column 4 contains the travel time index for the appropriate county (from Table 19). The variable dBTT (in column 5) was calculated from equation 17 and the TRIs in column 4. It represents the increase the bus travel time rate due to congestion for the route in minutes per mile. To estimate that part of the total vehicle hours that is due to congestion (dBT in column 6), dBTT (column 5) was multiplied by two thirds of the vehicle mileage (column 2) for the route. The factor two thirds was used to exclude service during non-congested times from the calculation. It was determined roughly from the Route 59 schedule by counting the trips during 7 AM to 7 PM on weekdays (approximately 200) and dividing by the total trips per week (approximately 300).

Column 7 in Table 20 represents the percent of vehicle hours for the route due to congestion as a percent of total vehicle hours for the route (column 6 divided by column 1). If the 7.9 percent for the 39 routes together is assumed to be representative for Northern New Jersey in general, it can be applied to the overall Northern New Jersey bus system, which recorded 4.42 million vehicle hours in fiscal year 2002[22] ; this indicates that approximately 349,000 of the vehicle hours are due to congestion.

Increased Cost Due to Congestion

According to the cost model (equation 11) every additional vehicle hour of service will cost an additional $56.80. Table 21 applies this factor to the increment of vehicle hours due to congestion for each route (from Table 20). For the 39 routes in the sample, this process indicates that $5.3 million or 5.7 percent of the total $93 million cost of the routes is due to congestion. Extrapolating to all of the Northern New Jersey bus routes, which cost $362 million in FY2002, the estimated increment due to congestion is $20.6 million.

Future Impacts of Congestion

The NJIT analysis of congestion in New Jersey[1] indicates that traffic levels will increase seven percent in the seven years from 1998 to 2005. Thus, in a five year period traffic level will increase approximately five percent.

Table 20. Estimated Increment of Travel Time Due to Current Congestion for Selected Northern New Jersey Local Bus Routes

Route	County	Vehicle hours (hours)	Vehicle miles (miles)	BTT (min/mi)	TRI	dBTT (min/mi)	dBT (hours)	Part of VH due to congestion (%)
		1	2	3	4	5	6	7
1	Essex/Union	94131	851865	6.63	1.41	0.66	6248	6.6%
5	Essex/Union	19162	162266	7.09	1.41	0.66	1190	6.2%
13	Essex/Union	87674	825310	6.37	1.41	0.66	6054	6.9%
21	Essex/Union	57808	467281	7.42	1.41	0.66	3428	5.9%
25	Essex/Union	82903	687676	7.23	1.41	0.66	5044	6.1%
26	Essex/Union	11948	111649	6.42	1.41	0.66	819	6.9%
34	Essex/Union	67305	624688	6.46	1.41	0.66	4582	6.8%
37	Essex/Union	16193	271837	3.57	1.41	0.66	1994	12.3%
40	Essex/Union	27131	364406	4.47	1.41	0.66	2673	9.9%
41	Essex/Union	28478	255020	6.70	1.41	0.66	1871	6.6%
42	Essex/Union	2802	26802	6.27	1.41	0.66	197	7.0%
43	Essex/Union	2412	33498	4.32	1.41	0.66	246	10.2%
52	Essex/Union	11186	115386	5.82	1.41	0.66	846	7.6%
58	Essex/Union	13160	148855	5.30	1.41	0.66	1092	8.3%
59	Essex/Union	51238	648212	4.74	1.41	0.66	4755	9.3%
70	Essex/Union	52942	759234	4.18	1.41	0.66	5569	10.5%
74	Passaic	48834	572885	5.11	1.43	0.69	4383	9.0%
80	Hudson	54721	406100	8.08	1.58	0.94	4240	7.7%
82	Hudson	2273	21920	6.22	1.58	0.94	229	10.1%
85	Hudson	16904	127747	7.94	1.58	0.94	1334	7.9%
87	Hudson	49379	402566	7.36	1.58	0.94	4203	8.5%
90	Essex/Union	21720	200873	6.49	1.41	0.66	1473	6.8%
94	Essex/Union	86922	807884	6.46	1.41	0.66	5926	6.8%
96	Essex/Union	9049	85087	6.38	1.41	0.66	624	6.9%
97	Essex/Union	4476	50670	5.30	1.41	0.66	372	8.3%
99	Essex/Union	40816	323910	7.56	1.41	0.66	2376	5.8%
303	Essex/Union	479	5737	5.01	1.41	0.66	42	8.8%
702	Passaic	12448	148142	5.04	1.43	0.69	1133	9.1%
703	Passaic	30996	316360	5.88	1.43	0.69	2420	7.8%
704	Passaic	21729	244746	5.33	1.43	0.69	1872	8.6%
705	Passaic	12204	155181	4.72	1.43	0.69	1187	9.7%
707	Passaic	10300	124849	4.95	1.43	0.69	955	9.3%
709	Passaic	23590	309240	4.58	1.43	0.69	2366	10.0%
712	Passaic	42617	448120	5.71	1.43	0.69	3428	8.0%
722	Passaic	6719	84813	4.75	1.43	0.69	649	9.7%
744	Passaic	23871	221091	6.48	1.43	0.69	1691	7.1%
748	Passaic	11257	164088	4.12	1.43	0.69	1255	11.2%
758	Bergen	11539	171118	4.05	1.69	1.11	2110	18.3%
770	Bergen	22181	221125	6.02	1.69	1.11	2726	12.3%
Totals		1191498	11968237	5.97			93601	7.9%

Table 21. Estimated Increment of Cost Due to Current Congestion for Selected Northern New Jersey Local Bus Routes

Route	Current		Due to congestion			
	Operational variable expenses ($)	Total expenses ($)	Vehicle hours (hours)	Cost ($)	Percent of variable cost	Percent of total cost
1	5,000,005	7,400,798	6248	354911	7.1%	4.8%
5	937,718	1,411,066	1190	67605	7.2%	4.8%
13	5,028,646	7,329,871	6054	343847	6.8%	4.7%
21	2,819,068	4,233,597	3428	194682	6.9%	4.6%
25	4,409,958	6,539,684	5044	286505	6.5%	4.4%
26	636,948	947,948	819	46516	7.3%	4.9%
34	3,262,275	4,861,824	4582	260263	8.0%	5.4%
37	865,783	1,286,191	1994	113255	13.1%	8.8%
40	1,604,948	2,332,746	2673	151822	9.5%	6.5%
41	1,392,818	2,090,054	1871	106248	7.6%	5.1%
42	160,054	255,206	197	11166	7.0%	4.4%
43	161,787	238,565	246	13956	8.6%	5.9%
52	594,013	876,001	846	48073	8.1%	5.5%
58	744,389	1,050,942	1092	62017	8.3%	5.9%
59	2,911,313	4,126,980	4755	270063	9.3%	6.5%
70	2,838,119	4,226,227	5569	316318	11.1%	7.5%
74	2,362,437	3,557,774	4383	248930	10.5%	7.0%
80	3,459,622	4,911,863	4240	240814	7.0%	4.9%
82	140,923	219,959	229	12998	9.2%	5.9%
85	949,709	1,382,005	1334	75753	8.0%	5.5%
87	3,149,801	4,519,684	4203	238718	7.6%	5.3%
90	1,149,535	1,697,317	1473	83689	7.3%	4.9%
94	4,217,241	6,291,271	5926	336587	8.0%	5.4%
96	438,822	654,684	624	35450	8.1%	5.4%
97	221,971	335,583	372	21111	9.5%	6.3%
99	2,403,607	3,492,352	2376	134950	5.6%	3.9%
303	30,556	45,739	42	2390	7.8%	5.2%
702	607,520	915,008	1133	64371	10.6%	7.0%
703	1,505,743	2,275,044	2420	137465	9.1%	6.0%
704	1,067,067	1,614,399	1872	106347	10.0%	6.6%
705	601,888	911,896	1187	67429	11.2%	7.4%
707	507,639	769,209	955	54249	10.7%	7.1%
709	1,136,877	1,681,924	2366	134371	11.8%	8.0%
712	2,077,908	3,157,244	3428	194717	9.4%	6.2%
722	326,834	491,256	649	36853	11.3%	7.5%
744	1,150,020	1,723,088	1691	96068	8.4%	5.6%
748	553,640	833,893	1255	71300	12.9%	8.6%
758	559,761	835,936	2110	119841	21.4%	14.3%
770	1,074,552	1,637,000	2726	154864	14.4%	9.5%
Totals	63,061,515	93,161,827	93601	5,316,514	8.4%	5.7%

The relation of travel time or travel impedance to traffic levels or volume to capacity (V/C) ratios from the Bureau of Public Roads study[(23)] provides a reasonable approximation for estimating changes in travel time due to future increases in traffic on a county-wide basis. The relationship is as follows:

$$TTT_{r\_a} = TTT_{a\_ff} [1 + 0.15 (V/C)^4] \tag{18}$$

Where V = peak hour volume
C = defined capacity

The effect that of different levels of traffic on travel time rates, assuming that the free flow rate is 2.22 minutes per mile is shown in Figure 10.

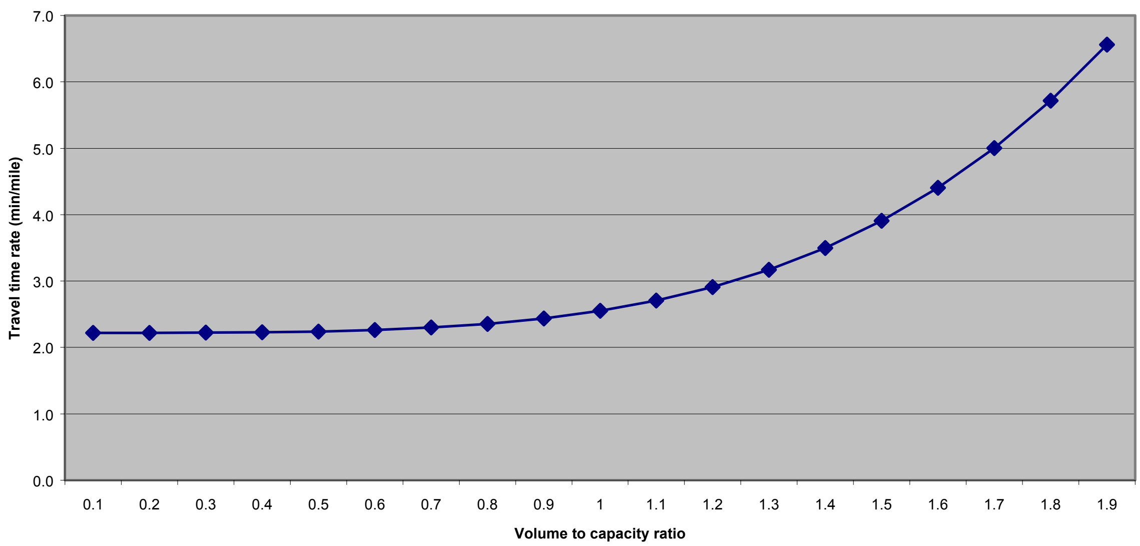


Figure 10. Relation of Travel Time Rate to Volume Capacity Ratio

From equations (1) and (18) travel time index has the following relations to V/C:

$$TRI = TTT_{r\_a} / TTT_{r\_ff} = 1 + 0.15 (V/C)^4 \tag{19}$$

The V/C ratios implied by the TRIs for each county are imputed using relationship (19). These are shown in the second column of Table 22. The third column shows the V/C ratio with a five percent increase in future traffic. The final column translate the future V/C ratio back to an estimate of the travel rate index in five years time, to be used for estimating the impact of future congestion.

Table 22. Current and Future Travel Rate Indices and V/C Ratios

County	Current TRI	Current V/C	Future V/C	Future TRI
Bergen	1.69	1.46	1.53	1.82
Essex	1.49	1.34	1.41	1.54
Union	1.33	1.22	1.28	1.40
Essex Union	1.41	1.29	1.35	1.50
Hudson	1.58	1.40	1.47	1.70
Passaic	1.43	1.30	1.37	1.53

Table 23 extrapolates this process to the 39 local bus routes to determine the future impact of congestion. The vehicle hours shown in the third column are the estimated vehicle hours that would be required in FY2002 if there had been no congestion. In other words, they are the vehicle hours recorded in FY2002 (column 1 of Table 19) minus the estimated number of hours due to congestion (column 7 of Table 19). The increment in vehicle hours in the last two columns of Table 23 are the increase over the estimated vehicle hours of operation under free flow conditions.

These estimates indicate that in five years time there will be an increment of 10.4 percent over the vehicle hours required for operating the service if there were no congestion. Adding the increase in vehicle hours to the estimated no-congestion vehicle hours indicates that the current level of service on these 39 routes will require 1.212 million vehicle hours to operate. This would be a 1.7 increase over the number of vehicle hours operated in FY2002.

Extrapolating to all Northern New Jersey routes indicates that there would be a congestion increment of 423,000 vehicle hours to operate current levels of service.

Table 24 determines the cost of the congestion in five years time in 2002 dollars. The current cost of congestion has been subtracted from current variable and total costs to determine today's costs if there were no congestion (see 2nd and 3rd columns of Table 23). The last row shows that congestion in five years time will increase variable operating costs of the 39 routes by 11.2 percent and total costs by 7.4 percent. For all Northern New Jersey bus routes, the increment in operating costs would be $26.8 million over what it would cost with no congestion.

Table 23. Estimated Increase in Bus Travel Time and Vehicle Hours Due to Future Congestion (Selected Routes in Five Years Time)

Route	County	Free Flow Vehicle hours	Future TRI	dBTT	dBT	Increase in time
		(hours)		(min/mi)	(hours)	(%)
1	Essex/Union	87882	1.50	0.81	7667	8.7%
5	Essex/Union	17972	1.50	0.81	1460	8.1%
13	Essex/Union	81620	1.50	0.81	7428	9.1%
21	Essex/Union	54381	1.50	0.81	4206	7.7%
25	Essex/Union	77859	1.50	0.81	6189	7.9%
26	Essex/Union	11129	1.50	0.81	1005	9.0%
34	Essex/Union	62723	1.50	0.81	5622	9.0%
37	Essex/Union	14199	1.50	0.81	2447	17.2%
40	Essex/Union	24458	1.50	0.81	3280	13.4%
41	Essex/Union	26607	1.50	0.81	2295	8.6%
42	Essex/Union	2606	1.50	0.81	241	9.3%
43	Essex/Union	2167	1.50	0.81	301	13.9%
52	Essex/Union	10340	1.50	0.81	1038	10.0%
58	Essex/Union	12068	1.50	0.81	1340	11.1%
59	Essex/Union	46483	1.50	0.81	5834	12.6%
70	Essex/Union	47373	1.50	0.81	6833	14.4%
74	Passaic	44452	1.53	0.86	5465	12.3%
80	Hudson	50481	1.70	1.13	5117	10.1%
82	Hudson	2045	1.70	1.13	276	13.5%
85	Hudson	15570	1.70	1.13	1610	10.3%
87	Hudson	45176	1.70	1.13	5072	11.2%
90	Essex/Union	20247	1.50	0.81	1808	8.9%
94	Essex/Union	80996	1.50	0.81	7271	9.0%
96	Essex/Union	8425	1.50	0.81	766	9.1%
97	Essex/Union	4105	1.50	0.81	456	11.1%
99	Essex/Union	38440	1.50	0.81	2915	7.6%
303	Essex/Union	436	1.50	0.81	52	11.8%
702	Passaic	11315	1.53	0.86	1413	12.5%
703	Passaic	28575	1.53	0.86	3018	10.6%
704	Passaic	19857	1.53	0.86	2335	11.8%
705	Passaic	11017	1.53	0.86	1480	13.4%
707	Passaic	9345	1.53	0.86	1191	12.7%
709	Passaic	21224	1.53	0.86	2950	13.9%
712	Passaic	39189	1.53	0.86	4275	10.9%
722	Passaic	6070	1.53	0.86	809	13.3%
744	Passaic	22179	1.53	0.86	2109	9.5%
748	Passaic	10001	1.53	0.86	1565	15.7%
758	Bergen	9429	1.82	1.33	2526	26.8%
770	Bergen	19455	1.69	1.11	2726	14.0%
Totals		1097897			114392	10.4%

Table 24. Estimated Increase in Costs Due to Future Congestion
(for Selected Routes in Five Years Time)

Route	Current with no congestion		Due to future congestion levels			
	Operational variable expenses	Total expenses	Vehicle hours	Cost	Increase in variable cost	Increase in total cost
	($)	($)	(hours)	($)		
1	4,668,953	7,069,746	7667	435473	9.3%	6.2%
5	874,658	1,348,006	1460	82950	9.5%	6.2%
13	4,707,914	7,009,139	7428	421898	9.0%	6.0%
21	2,637,473	4,052,002	4206	238874	9.1%	5.9%
25	4,142,713	6,272,440	6189	351540	8.5%	5.6%
26	593,559	904,559	1005	57075	9.6%	6.3%
34	3,019,509	4,619,058	5622	319341	10.6%	6.9%
37	760,142	1,180,550	2447	138963	18.3%	11.8%
40	1,463,332	2,191,130	3280	186284	12.7%	8.5%
41	1,293,712	1,990,948	2295	130366	10.1%	6.5%
42	149,639	244,790	241	13701	9.2%	5.6%
43	148,769	225,547	301	17124	11.5%	7.6%
52	549,172	831,160	1038	58985	10.7%	7.1%
58	686,541	993,094	1340	76095	11.1%	7.7%
59	2,659,405	3,875,072	5834	331366	12.5%	8.6%
70	2,543,066	3,931,174	6833	388120	15.3%	9.9%
74	2,126,444	3,321,782	5465	310430	14.6%	9.3%
80	3,238,676	4,690,917	5117	290638	9.0%	6.2%
82	128,997	208,033	276	15688	12.2%	7.5%
85	880,206	1,312,502	1610	91426	10.4%	7.0%
87	2,930,778	4,300,660	5072	288108	9.8%	6.7%
90	1,071,472	1,619,254	1808	102686	9.6%	6.3%
94	3,903,281	5,977,311	7271	412990	10.6%	6.9%
96	405,756	621,618	766	43496	10.7%	7.0%
97	202,279	315,891	456	25903	12.8%	8.2%
99	2,277,729	3,366,474	2915	165583	7.3%	4.9%
303	28,327	43,509	52	2933	10.4%	6.7%
702	546,495	853,983	1413	80274	14.7%	9.4%
703	1,375,423	2,144,724	3018	171427	12.5%	8.0%
704	966,247	1,513,579	2335	132621	13.7%	8.8%
705	537,963	847,972	1480	84088	15.6%	9.9%
707	456,209	717,779	1191	67652	14.8%	9.4%
709	1,009,489	1,554,537	2950	167568	16.6%	10.8%
712	1,893,310	2,972,647	4275	242824	12.8%	8.2%
722	291,896	456,318	809	45958	15.7%	10.1%
744	1,058,945	1,632,012	2109	119803	11.3%	7.3%
748	486,046	766,299	1565	88915	18.3%	11.6%
758	450,701	726,876	2526	143460	31.8%	19.7%
770	956,823	1,519,271	2726	154864	16.2%	10.2%
Totals	58,122,048	88,222,360	114,392	6,497,491	11.2%	7.4%

CONCLUSIONS

Traffic congestion has a significant impact on New Jersey Transit bus operations and costs. The decline in traffic speeds as traffic continues to grow due to increases in the population and growth of the economy will further decrease bus speeds and increase costs. The impacts of congestion on vehicle hours and operational costs currently and forecasted to five years hence are summarized in Table 25.

Table 25. Summary of Impacts of Congestion on Vehicle Hours and Costs

	Current			Future	
	Current (FY2002)	Part due to congestion	Current w/o congestion	Congestion increment	Total
Vehicle hours	4,419,836	349,000	4,070,836	423,367	4,494,203
Operational variable expense ($)	241,304,918	20,343,642	220,961,276	26,975,592	247,936,867
Total expense ($)	361,758,967	20,343,642	341,415,325	26,975,325	368,390,916

The bus travel time estimates show that car travel time, passenger boarding densities, and bus stop frequency contribute to the total bus travel time. Car speeds are a function of traffic volumes and signal density. The time lost entering and leaving bus stops depends on bus stop frequency, and the time spent at the bus stop depends on passenger service times. Therefore, to reduce bus travel times, improvements in each component are desirable.

REFERENCES

1. New Jersey Institute of Technology. Mobility and the Cost of Congestion in New Jersey. The Foundation of the New Jersey Alliance for Action. February 2000.

2. Wilbur Smith and Associates, Bus Rapid Transit Options for Densely Developed Areas, prepared for U.S. Department of Transportation, December 1974.

3. Levinson Herbert S, “Analyzing Transit Travel Time Performance.” Transportation Research Record 915, 1983.

4. Urbitran in association with H. S. Levinson, “Bus Priority Improvement Study: Analysis of Bus Priority Proposals.” November 1986.

5. McKnight C.E and Paaswell R.E. Impact of Congestion on New York Bus Service. UTRC for MTA New York City Transit. April 1997.

6. Turnquist Mark A, “Strategies for Improving Reliability of Bus Transit Service.” Transportation Research Record 818, 1981.

7. Levinson H.S, Lennon L, and Cheng J, “Downtown Space for Buses -The Manhattan Experience.” Transportation Research Record 1308, 1991.

8. Levinson H.S and St. Jacques Kevin, Operational Analysis of Bus Lanes on Arterials. Draft Final report prepared for TCRP A- 7, TRB, June 1996.

9. Kittelson & Associates, Inc. Transit Capacity and Quality of Service Manual, Transit Cooperative Research Program. January 1999.

10. Guenthner Richard P, Sinha Kumares C, “Modeling Bus Delays due to Passenger Boardings and Alightings.” Transportation Research Record 915, 1983.

11. Bertini R.L and El-Geneidy A.M, “Modeling Transit Trip Time Using Archived Bus Dispatch System Data.” Unpublished Draft. Portland State University. 2002

12. Abkowitz Mark, Engelstein Israel, “Factors Affecting Running Time on Transit Routes.” Transportation Research, Vol. 17A, No 2, pp 107-113, 1983.

13. Abkowitz Mark, Engelstein Israel, “Methods for Maintaining Transit Service Regularity.” Transportation Research Record 961, 1984.

14. Levinson Herbert S, Supervision Strategies for Improved Reliability of Bus Routes. NCTRP, Report 15, 1991.

15. Cooper Shoshana and Gould Larry, "Faster than Walking? Street Congestion and New York City Transit Buses." New York City Transit Authority, Operation Planning, 1994.

16. Guenthner Richard P, Hamat K, " Transit Dwell Time Under Complex Fare Structure." Journal of Transportation Engineering, Vol.114, 1998

17. Turnquist Mark A, "A Model for Investigating the Effects of Service Frequency and Reliability on Bus Passenger Waiting Time." Transportation Research Record 663, 1978

18. Henderson Garry; Kwong Philip, and Adkins Heba. "Regularity Indices for Evaluating Transit Performance." Transportation Research Record 1297, 1991.

19. Highway Capacity Manual, Special Report 209, TRB, National Research Council, Washington, D.C., 2000, page 11-4.

20. Tim Lomax, Shawn Turner, & Gordon Shunk, Quantifying Congestion, Volume 1, NCHRP Report 398, 1997.

21. Iqbal Asif, "Analysis of Travel Time for NYCT M 15 & M 96 Bus Service." Unpublished Masters Project, City College of New York, Department of Civil Engineering, December 2002.

22. New Jersey Transit, "LC Bus Line Summary Revenue and Expenses, Current Period: June-02-FY-02." Internal Document, 2002.

23. Huber M.J. et al., "Comparative Analysis of Traffic Assignment Techniques with Actual Highway Use," Highway Research Report 58, HRB, National Research Council, Washington, D.C., 1968, reported in Papacostas C.S. and Prevedouros, P.D., Transportation Engineering and Planning 2nd edition, Prentice Hall, 1993.

APPENDIX

Description of Route Segments
Route 59

Description of Route 59 Route Segments traveling from Newark to Dunellen

Segment	1*	1_2	2_3	3_4		4_5		5_6	
Municipality(s)	2	Newark	Newark	Newark		Newark	Hillside	Elizabeth	
Street(s) (for majority of segment)	2	Broad St	Broad St	Clinton	Elizabeth	Elizabeth	N. Broad	N. Broad	N Broad
Start	2	Washington Park	Branford	Lincoln Park	Clinton	Meeker Av	City line	Ridgeway	Newark Av
End	2	Branford	Lincoln Park	Elizabeth Av	Meeker Av	City line	Ridgeway	Newark Av	Grand
Lanes in route direction**	3	2T + 1B	2T + 1B	2T + 1P	2T + 1P	1T + 1P	1T + 1P	1T + 1P	2T + 1P
Segment length (mi)	4	0.66	0.68	1.6		1.4		2.0	
Traffic signals	3	12	7	11		9		9	
Left turns	5	0	0	0		0		0	
Bus stops	6	4	3	10		9		8	
Average speeds (mi/hr)									
Auto	7	14.0	19.3	16.2		17.3		15.5	
Bus	8	8.6	12	12.5		11.7		10.3	
Boarding passengers per mile	9	28.8	5.9	3.1		4.7		7.6	
Alighting passengers per mile	9	1.7	1	3.3		6		4.4	
Average bus travel time (min)	9	5.1	3.6	7.9		7.5		11.9	
Range of bus times	9	2.7 to 9.8	2.0 to 6.3	5.3 to 11.3		5.9 to 9.8		9.2 to 17.0	
Schedules bus travel time (min)	10	5	4	7		7		11	
AADT	11	33500	33500	14500	NA	NA	5518	NA	5518
AADT per traffic lane	12	8375	8375	3625			2759		1380

* Refers to note in Sources and Comments on Data (see last pages of Appendix).

* *T=traffic lane; B=bus lane; P=parking lane

NA = Not available

Continued on next page

Description of Route 59 Route Segments traveling from Newark to Dunellen – page 2

Segment	6_8		8_9		9_10		10_11
Municipality(s)	Elizabeth		Roselle		Roselle	Cranford	Cranford/Garwood
Street(s) (for majority of segment)	N. Broad	W. Jersey	Jersey Av	2nd Av	2nd Av	South Av E	South Av
Start	Grand	N. Broad	Elmora	Sheridan	Chestnut	City line	Walnut
End	Jersey	Elmora	Sheridan	Chestnut	City line	Walnut	Center
Lanes in route direction*	2T + 1P	1T + 1P	1T + 1P	1T + 1P	1T + 1P	1T** + 1P	1T + 1P
Segment length (mi)	1.1		1.6		2.2		1.1
Traffic signals	NA		2		5		4
Left turns	0		2		1		0
Bus stops	8		9		7		4
Average speeds (mi/hr)							
Auto	NA		22.4		21.2		22.0
Bus	8.3		15.9		19.0		18.2
Boarding passengers per mile	10.3		2.3		0.9		0.7
Alighting passengers per mile	10.2		6.1		2.5		3.6
Average bus travel time (min)	8.0		6.3		7.1		3.9
Range of bus times	3.4 to 14.0		4.8 to 10.7		5.2 to 9.8		2.1 to 6.2
Schedules bus travel time (min)	7		6		6		4
Notes	Commercial				Wide lanes at South Av some cars treat as 2 lanes		
AADT	NA	NA	NA	NA	NA	17020	NA
AADT per traffic lane						8510	

* T=traffic lane; B=bus lane; P=parking lane
NA = Not available

Continued on next page

Description of Route 59 Route Segments traveling from Newark to Dunellen – page 3

Segment	11_12		12_13		13_15	
Municipality(s)	Garwood/Westfield		Westfield		Westfield	Scotch Plains
Street(s) (for majority of segment)	South Ave.		South Ave.	E. Broad	Elm St. & Brightwood	Plainfield Av. & Westfield Av.
Start	Center St	City line	Central Av.	North Av	E. Broad	City line
End	City line	Central Ave.	Westfield	Elm St.	City line	Park Ave.
Lanes in route direction*	1T + 1P		1T + 1P		1 T	1 T
Segment length (mi)	0.90		0.69		3.2	
Traffic signals	2		5		3	
Left turns	0		1		2	
Bus stops	3		1		10	
Average speeds (mi/hr)						
Auto	28.4		10.0		26.6	
Bus	20.4		11.3		21.2	
Boarding passengers per mile	0.98		3.02		0.5	
Alighting passengers per mile	2.93		5.2		1.08	
Average bus travel time (min)	2.7		3.8		9	
Range of bus times	1.9 to 3.8		2.8 to 5.0		7.7 to 10.93	
Schedules bus travel time (min)	3		4		9	
Notes			Congestion at Elm St.		Single family suburban	
AADT	NA	NA	NA	NA	5907	18040
AADT per traffic lane					2954	9020

* T=traffic lane; B=bus lane; P=parking lane
NA = Not available

Continued on next page

Description of Route 59 Route Segments traveling from Newark to Dunellen – page 4

Segment	15_16		16_17	
Municipality(s)	Scotch Plains	Plainfield	Plainfield	Dunellen
Street(s) (for majority of segment)	E 2nd	E 2nd, Richmond & E. 4th	Front St.	North Av
Start	Park Ave	City line	E. 4th	City line
End	City line	Watchung Av	City line	Washington Av
Lanes in route direction*	1T + 1P		1T + 1P	
Segment length (mi)	2.7		3	
Traffic signals	4		9	
Left turns	5		1	
Bus stops	13		15	
Average speeds (mi/hr)				
Auto	20.3		17.3	
Bus	16.4		15.6	
Boarding passengers per mile	1.2		1.2	
Alighting passengers per mile	3.1		3.9	
Average bus travel time (min)	10		11.7	
Range of bus times	7.9 to 13.5		9.4 to 16.5	
Schedules bus travel time (min)	10		15	
AADT	NA	2312	12920	17420
AADT per traffic lane		1156	6460	8710

* T=traffic lane; B=bus lane; P=parking lane

NA = Not available

Description of Route 59 Route Segments traveling from Dunellen to Newark

Segment	17_16		16_15		15_13	
Municipality(s)	Dunellen	Plainfield	Plainfield	Scotch Plains	Scotch Plains	Westfield
Street(s) (for majority of segment)	North Av.	Front St.	E. 4th, Richmond & E. 2nd	E. 2nd St	Westfield Av & Plainfield Av	Brightwood & Elm St.
Start	Washington	City line	Watchung	City line	Park Av	City line
End	City line	E. 4th St.	City line	Park Av	City line	E. Broad
Lanes in route direction*	1T + 1P		1T + 1P		1T	1T
Segment length (mi)	3.0		2.8		3.1	
Traffic signals	7		9		2	
Left turns	5		3		2	
Bus stops	15		15		10	
Average speeds (mi/hr)						
Auto	15.8		19.7		26.8	
Bus	15.0		13.1		24.2	
Boarding passengers per mile	4.4		4.4		1.5	
Alighting passengers per mile	1.4		1.7		0.8	
Average bus travel time (min)	12.3		13.0		8.0	
Range of bus times	9.7 to 14.1		9.2 to 20.0		6.0 to 10.6	
Schedules bus travel time (min)	15		10		9	
AADT	17420	12920	2312	NA	18040	5907
AADT per traffic lane	8710	6460	1156		9020	2953.5

* T=traffic lane; B=bus lane; P=parking lane
NA = Not available

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Description of Route 59 Route Segments traveling from Dunellen to Newark – page 2

Segment	13_12		12_11		11_10	10_9	
Municipality(s)	Westfield		Westfield/Garwood		Garwood/Cranford	Cranford	Roselle
Street(s) (for majority of segment)	E. Broad St.	South Av	South Av		South Av.	South	2nd Av
Start	Elm St.	E. Broad Av	Central Av.	City line	Center St	Walnut Av.	City line
End	South Av	Central	City line	Center St	Walnut Av.	City line	Chestnut
Lanes in route direction*	1T + 1P	1T + 1P	1T + 1P		1T + 1P	1T + 1P	1T + 1P
Segment length (mi)	0.75		0.9		1.1	2.2	
Traffic signals	5		1		5	5	
Left turns	1		0		0	2	
Bus stops	2		5		4	8	
Average speeds (mi/hr)							
Auto	11.9		27.3		21.9	23.2	
Bus	10.9		23.8		18.2	17.9	
Boarding passengers per mile	3.8		2.6		2.6	4.4	
Alighting passengers per mile	1.7		0.9		1.0	1.4	
Average bus travel time (min)	4.4		2.5		4.0	7.5	
Range of bus times	2.3 to 6.4		1.7 to 3.8		2.5 to 7.9	5.0 to 10.8	
Schedules bus travel time (min)	4		3		4	6	
Notes						Wide lanes; some cars treat as two lanes	
AADT	NA	NA	NA	NA	NA	17020	NA
AADT per traffic lane						8510	

* T=traffic lane; B=bus lane; P=parking lane
NA = not available

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Description of Route 59 Route Segments traveling from Dunellen to Newark – page 3

Segment	9_8		8_7	7_6	6_5	
Municipality(s)	Roselle		Elizabeth	Elizabeth	Elizabeth	
Street(s) (for majority of segment)	2nd Av	Jersey Av	W Jersey St	Broad St	N. Broad St	N. Broad St.
Start	Chestnut	Sheridan	Elmora	W Jersey St	Grand St.	Fairway
End	Sheridan	Elmora	Broad St.	Grand St.	Fairway	Ridgeway
Lanes in route direction*	1T + 1P		1T + 1P	2T + 1P	2T + 1P	1T + 1P
Segment length (mi)	1.6		1.1	0.09	1.9	
Traffic signals	2		5	NA	6	
Left turns	2		1	0	0	
Bus stops	8		5	1	10	
Average speeds (mi/hr)						
Auto	25.7		14.5	NA	27.0	
Bus	15.7		10.2	0.9	10.6	
Boarding passengers per mile	6.5		7.1	7.9	3.8	
Alighting passengers per mile	2		12.8	13.5	5.9	
Average bus travel time (min)	6.2		6.4	6.2	11.5	
Range of bus times	4.2 to 9.0		4.5 to 8.2	4.1 to 8.2	8.3 to 18.2	
Schedules bus travel time (min)	6		6	1	12	
AADT					5518	NA
AADT per traffic lane					2759	

* T=traffic lane; B=bus lane; P=parking lane
NA = Not available

Continued on next page

Description of Route 59 Route Segments traveling from Dunellen to Newark – page 4

Segment	5_4		4_3		3_2	2_1
Municipality(s)	Hillside	Newark	Newark		Newark	Newark
Street(s) (for majority of segment)	N Broad	Elizabeth Av	Elizabeth Av.	Clinton Av.	Broad St.	Broad St.
Start	Ridgeway Av.	City line	Meeker Av.	Elizabeth	Lincoln Park	Branford
End	City line	Meeker Av	Clinton	Lincoln Park	Branford	Washinton Park
Lanes in route direction*	1T + 1P		2T + 1P	2T + 1P	2T + 1B	1B + 2T
Segment length (mi)	1.4		1.7		0.6	0.8
Traffic signals	9		9		0.6	9
Left turns	0		1		0	2
Bus stops	8		10		4	6
Average speeds (mi/hr)						
Auto	13.3		22.4		7.5	5.4
Bus	12.1		13.8		10.1	15.5
Boarding passengers per mile	6.9		1.5		0	0.8
Alighting passengers per mile	3.9		2.2		10.8	8.4
Average bus travel time (min)	7.3		7.7		4.18	5.4
Range of bus times	5.4 to 9.9		4.9 to 10.9		1.6 to 8.2	3.2 to 7.6
Schedules bus travel time (min)	8		7		4	5
AADT	5518	NA	NA	14500	33500	33500
AADT per traffic lane	2759			3625	8375	8375

* T=traffic lane; B=bus lane; P=parking lane
NA = not available

Sources and Comments on Data

1 Route segments are one directional sections of the route extending between two (usually adjacent) time points, shown on the NJ Transit schedule of the route. The time points are number from 1 to 17 starting from the beginning of the route at Washington Park in downtown Newark. Each route segment is identified by the numbers of the time points. For example, 1_2 is the route segment from Washington Park to the second time point at Broad St. and Branford Pl., in Newark. Route segment 13_12 is a section operating in the opposite direction, toward Newark, from Broad and Elm Streets to South and Central Avenues in Westfield.

2 Information on the municipality, the street that the buses are operating on, and the start and end points (identified by the intersecting streets) are from the published schedule and confirmed by a street map. When the route makes many turns and operates on many short street sections, usually only the streets that it operates on for several blocks are listed.

3 The number of lanes (traffic, parking, or bus lanes) and the number of traffic signals were determined by observation by a study team member, while riding on the bus or following the route in a car.

4 The segment length was measured using the odometer of a car, and following the route several times. The lengths between time points from the automatic passenger counters were also checked.

5 Lefts turns were determined by observation and checked against a street map.

6 Bus stops were determined by observation and from a list of bus stops provided by NJ Transit.

7 The speeds of automobile traffic was calculated from the segment length (see note 4) and the times recorded by study team members following the route in cars. Two members were in the car, one to drive and one to record times and odometer readings, along with other observations.

8 The bus speed was calculated from the segment length and times passing time points from both the automatic passenger counting data and from team members riding on the buses.

10 Passengers boarding and alighting from the buses within a segment and bus travel times came from both the automatic passenger counting data and for team members riding on the buses.

11 Scheduled bus times are from the midday section of the Route 59 bus schedule published by NJ Transit.

12 Traffic volumes are from the NJDOT traffic counts, previously on the NJDOT web page (www.state.nj.us/transportation/count/data/traffic.htm). Note that the traffic counts are at one point along the link, and may not be representative of the total length of the link.

13 The traffic volumes from the previous row were divided by the total number of traffic lanes in both directions.