To the Graduate Council:

I am submitting herewith a thesis written by Mohammed Jawad Al-Ani entitled "An Analysis Of Bus Delay In The Knoxville, Tennessee Central Business District". I recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Civil Engineering.

Frederick J. Wegmann
Major Professor

We have read this thesis and
recommend its acceptance:

Accepted for the Council:

Vice Chancellor
Graduate Studies and Research

.A556

AN ANALYSIS OF BUS DELAY IN THE KNOXVILLE, TENNESSEE CENTRAL BUSINESS DISTRICT

A Thesis

Presented for the

Master of Science

Degree

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Mohammed Jawad Al-Ani

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ABSTRACT

The purpose of the study was to investigate the causes and extent of delays confronting public transit buses operating in a six-block area of Gay Street in downtown Knoxville, Tennessee. The results of the field study indicate that bus delay varies according to three factors: time of day, location on Gay Street, and method of fare collection.

Also the field study indicate that traffic signals are the greatest cause of delay to buses on Gay Street. The percent of delay caused by traffic signals is approximately 57 percent of total delay during the morning and evening peak hours and approximately 52 percent during the mid-day hours.

Various alternatives were studied which could improve the efficiency of bus operations along Gay Street. In order to provide a preliminary estimate of the effectiveness of several alternatives a prototype hand-run simulation model was constructed. The results of the model, indicated that average bus travel time could be decreased, by introducting of alternative bus treatments. The benefits of each improvement as predicted by the model, are as follows:

1. A skip-stop operation would result in a total time savings of 20.8 percent.
2. Actuated traffic signals which extend the green phase by four or eight seconds would bring about respectively a 21.4 percent to 25.0 percent reduction in travel time.

3. Eliminating fare collection in the CBD would decrease travel times by 35.0 percent.
4. Using all of the alternatives simultaneously should result in a 38.0 percent reduction in bus travel time.

Although these time savings are in the magnitude of two minute periods, a side benefit of the treatments is a reduction in time variance thereby increasing reliability of bus operations.

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CHAPTER I

INTRODUCTION

Statement of Problem

A rising standard of living has resulted not only in increasing rates of car ownership, but also in higher levels of comfort and convenience being demanded from public transportation. A comprehensive program to provide public transit in a community must consider the needs of the captive riders as well as exploring the potential of attracting those people who normally drive their automobile. The primary strength of public transit lies in its ability to economically move large numbers of people along principle corridors of travel, especially those leading to the Central Business Districts (CBD's) of cities.

Within the past 25-30 years, public transit ridership in the United States has been steadily declining. As indicated by Figure 1, in 1950 there were 17,246,000 transit riders, but by 1973, this figure was reduced to 6,660,000 riders. Within the same time period, automobile registration in the United States increased from 49,300,000 automobiles in 1950 to 125,157,000 in 1973. (1) This national trend towards greater reliance on the private automobile has in part been caused by the fact that public transit systems are relatively inefficient and are truly competitive with the automobile. A particular gap exists for transit in providing door-to-door travel time and levels of comfort and

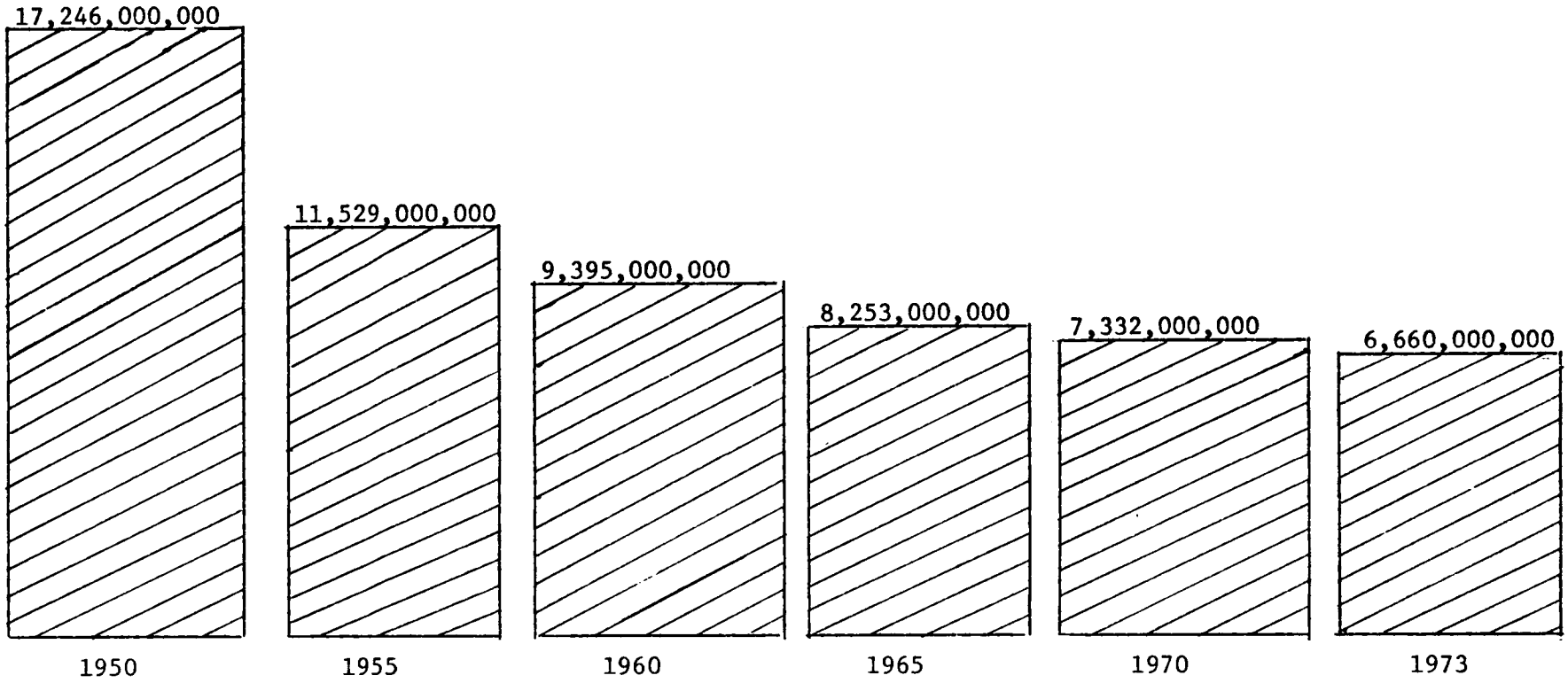


Figure 1. U. S. Transit Ridership (3,2)
1950-1973

convenience which are competitive with the automobile. Social changes such as the rapid growth of low density suburban areas outside the city center have also worked to the detriment of public transit.

Without preferential aids fixed-route, fixed-schedule, buses must share the roadway with other vehicles, and thus become exposed to possible delays due to accidents and vehicle congestion. Buses must operate at relatively low and inefficient speeds. For example, average speeds of buses operating along arterial highways and in the CBD's of medium sized American cities have been recorded at approximately seven to ten miles per hour. (8)

The national decline in transit ridership has had a disastrous effect on the public transportation industry, especially local bus lines which serve as the primary mode of public transportation in smaller cities. Over the last two decades, many lines have simply gone out of business. Even with a nationwide average fare increase of 73 percent between 1950 and 1973 (1), the vicious cycle continues: as ridership declines, service must be curtailed and capital improvements and maintenance programs deferred. Again costs increase, in turn leading to a further decline in ridership and service. The city of Knoxville has followed similar trends in the decline in public transit ridership. As noted in Figure 2, transit ridership has declined from 25,000,000 riders in 1950 to 3,400,000 riders in 1974. (3) In 1950 the fare was $.10 but despite a fare increase to $.30 by 1974, operations are still running at

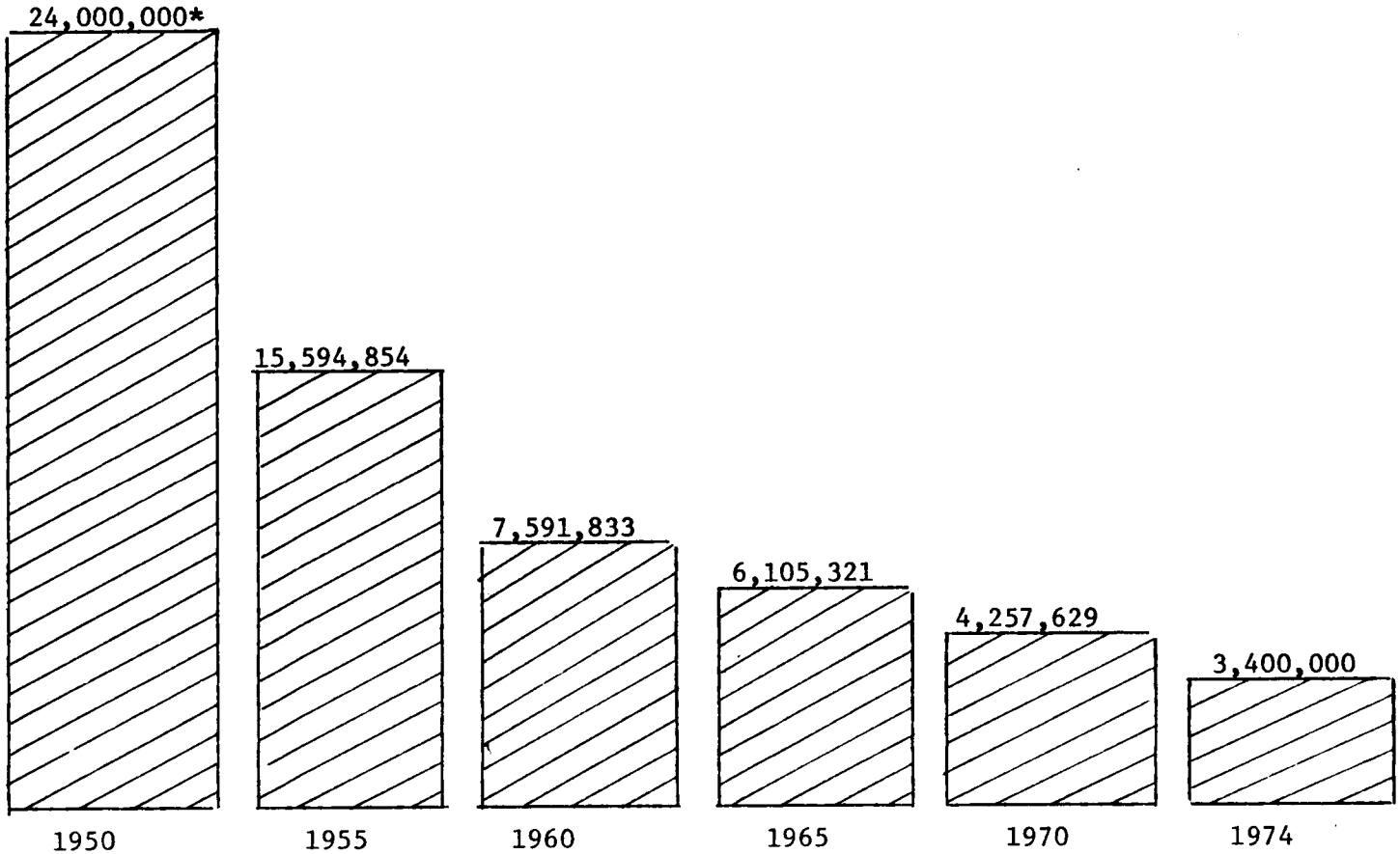


Figure 2. KTC Transit Ridership (3,2)
1950-1974

*number of passengers per year

an annual deficit of $601,000 for 1974.[1]

Although ridership trends on public transit have generally declined over the last 25 to 30 years, some people argue that the role of public transit in cities is as vital as ever. Recent studies have shown that about 23 percent of all households in the United States do not own a car. In central cities this figure is as high as 35 percent and jumps to 48 percent for households headed by persons over 65 years of age. More than half of all families with an annual income of less than $4,000 do not own an automobile. Other people who cannot move about freely in cities are the very old, the very young, and the physically handicapped, not to mention women in families with one car whose husbands take the car to work. These people must all depend upon mass transportation. (5)

It is estimated that by 1980, 100 million Americans will be either eighteen years old, too young to drive, or over sixty-five, only half of these people drive. Any attempts to solve these people's problems by means of the private automobile alone are impractical, if not impossible. (5)

In addition to the fact that a growing number of people are not able to drive and/or do not have access to an automobile, all Americans are now attempting to deal with a serious energy shortage. Public transit has a major contribution to make here since buses consume less than

---

[1]Since that time, however, ridership has increased from 2,740 riders in January of 1974 to 12,601 riders in December 1974, largely due to the introduction of express bus service.

half the amout of fuel consumed by automobiles per passenger-mile (Table 1).

No doubt the automobile is a marvelous device, and most of its disadvantages are curable. Automobiles generate about 94 percent of the passenger miles in American cities. However, cars are not the best option for trips within high density areas, because they take up a large amount of valuable space, both when moving and when stored. In fact, statistics presented by Ward, Figure 3, indicate that automobiles consume more land than any other mode of public transportation. (6) In the CBD, the automobile represents an inefficient use of high-priced, intensively developed real estate. The use of prime land for streets and parking is inefficient and incompatible with the desire to produce and intensively developed face-to-face person exchange environment. With an average of one third of the downtown area used for motor vehicle related purposes, it is not surprising that CBD's are plagued with severe congestion.

Various proposals have been made to improve transit service, including time and space separation of conflicting mobility systems. However, space separation requires multi-layer developments which are both expensive and difficult to construct in developed areas. Time separation systems have been attempted in the delivery of goods movement, the banning of private automobiles, and for certain sections of the day during the peak hours, but, overall, they have not been very practical or well received.

To utilize the efficiency of mass transit, the system must be made more attractive to automobile drivers in terms of convenience,

Table 1

Comparative Fuel Efficiency Of Various Modes
Of Passenger Transportation (4)

Vehicle	Fuel Efficiency MPG	Loading	Passenger Miles/Gallon
Auto	24	5 Pass.	120
	12	5 Pass.	60
		2.2 Pass.	26
		1.6 Pass.	19
Van Bus	15	12 Pass.	180
		8.4 Pass.	126
		2.2 Pass.	33
	10	12 Pass.	120
		4 Pass.	40
		2.2 Pass.	22
Transit Bus	4	60 Pass.	240
		25 Pass.	100
		10 Pass.	40

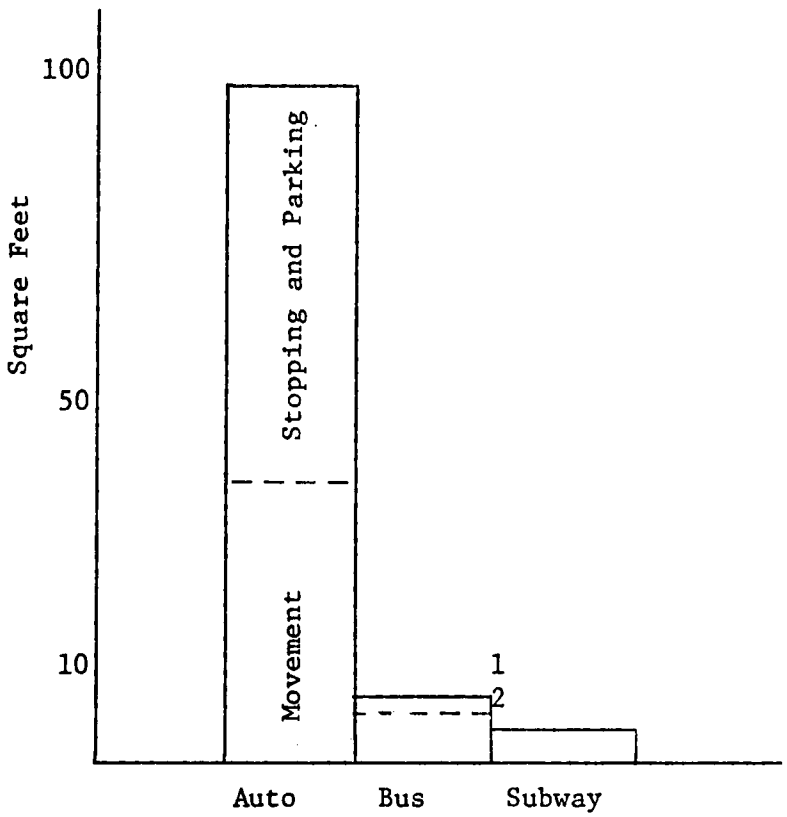


Figure 3. Area Consumed Per Passenger For Several Transit Alternatives (6)

[1]Bus on Arterial

[2]Bus on Busway. Source: 1972 National Transportation Report Figure s-4

dependability, and comfort, as well as reduced travel time.

The Department of Transportation's Federal Highway Administration has recently reported substantial progress in a variety of programs aimed at reducing congestion and decreasing the travel time of vehicles operating in the congested environment of the CBD and roads leading to the CBD. These programs include the provision of preferential treatment for buses, computerized traffic control systems, fringe area parking facilities for automobiles, and computerized buspool and carpool matching programs. The Department of Transportation has established a number of other programs to provide preferential treatment for buses, such as reserved curb or median bus lanes, contraflow bus lanes, and bus street. Frequently such programs are not feasible in medium-sized cities such as Knoxville, because lane capacities are not sufficient to warrant a reserved bus lane. Also, guidelines suggested by the Institute of Traffic Engineers require a minimum of 60 transit vehicles in a curb lane and 75 transit vehicles in a median lane during each peak-hour period in order to justify a reserved transit lane. (7)

Despite the fact that elaborate bus priority systems may not be feasible in medium-sized cities, such cities are nevertheless in desperate need of some treatment that will improve the efficiency of bus service in their CBD's. The operating speeds of buses in the CBD frequently do not exceed ten miles per hour. Bus delays in the CBD are typically caused by:

1. Passengers boarding and deboarding
2. Delays at traffic signals
3. Vehicles parked in loading zones blocking the transit vehicles

These delays are amenable to solution through various operating treatments. Since bus lines are concentrated in the BCD, it is possible that operating treatments such as skip-stop and limited capital projects such as traffic signal priority for buses might generate extensive benefits for the costs involved. Using such treatments would therefore reduce travel time. Any service improvement might be a step to encourage some automobile drivers to use public transit, thus reducing the number of cars and the amount of congestion on the existing streets.

Objective

The purposes of this study are (1), to investigate the cause and extent of delays confronting public transit buses operating on Gay Street, a major street where transit routes in downtown Knoxville, Tennessee converge and (2), to present a preliminary analysis of alternative treatments which might be used to reduce the delays.

CHAPTER II

THE CONCEPT AND APPLICATIONS OF BUS PRIORITY TREATMENTS

1. INTRODUCTION

Congestion in large cities is causing planners to look at alternatives to the automobile to find a quick and dependable means of transportation. However, buses do not presently fill the need as a truly viable alternative because they are slow, inconvenient, and often behind schedule. Despite their slowness, and inefficiency, buses nevertheless provide an important means of transportation in urban areas. They carry about 70 percent of the passengers moving through the CBD. Buses are considered the dominant form of public transport, even in cities which are served by rail transit facilities. For example, in large cities such as Dallas and Milwaukee, it is estimated that a 50 percent increase in peak-hour bus use on the approaches to the CBD could reduce automobile traffic by approximately 20 percent and CBD parking demands by about 6,000 spaces. (9)

Because of the importance of public transportation, buses should be made more efficient and competitive with the automobile in terms of travel time, costs, convenience, and service dependability. One of the most important ways of making buses more competitive is to provide bus priority treatments, such as traffic signal improvements, exclusive bus lanes, (normal-flow or contra-flow), bus streets, skip-stop

and an improved method of fare collection. Priority treatments must be subject to land use considerations and environmental constraints.

Within the last few years, more than 200 bus priority treatments have been proposed and implemented for American and European cities. These treatments have been mainly applied in the CBD's area because the CBD is the point of major congestion where space is limited in relation to traffic concentrations and pedestrian movement. Bus priority treatments vary according to the type of treatment and the number of people served. Specific examples of bus priority treatments related to urban roadways are noted in Appendix A. (9)

The idea of providing priority treatments for buses is not new. It can be represented as a recurring cycle in urban transportation planning, with some minor variations on the original theme. This cycle is shown in Figure 4. At the beginning of the cycle, streetcars were the major form of mass transit in American cities. A change from streetcars to buses took place for the following reasons:

1. Conflicts developed between automobiles and streetcars sharing the same row.
2. Bus routes could be modified more easily than streetcar routes.
3. Maintenance costs for buses were less than for streetcars.

But buses were not the final answer, either. A subsequent increase in conflicts developed between buses and automobiles because they were sharing the same roadway. This led to the concept of providing some type of special treatment for buses. An early concept of special treatment was that of reserved lanes for buses. Now, a number of recent

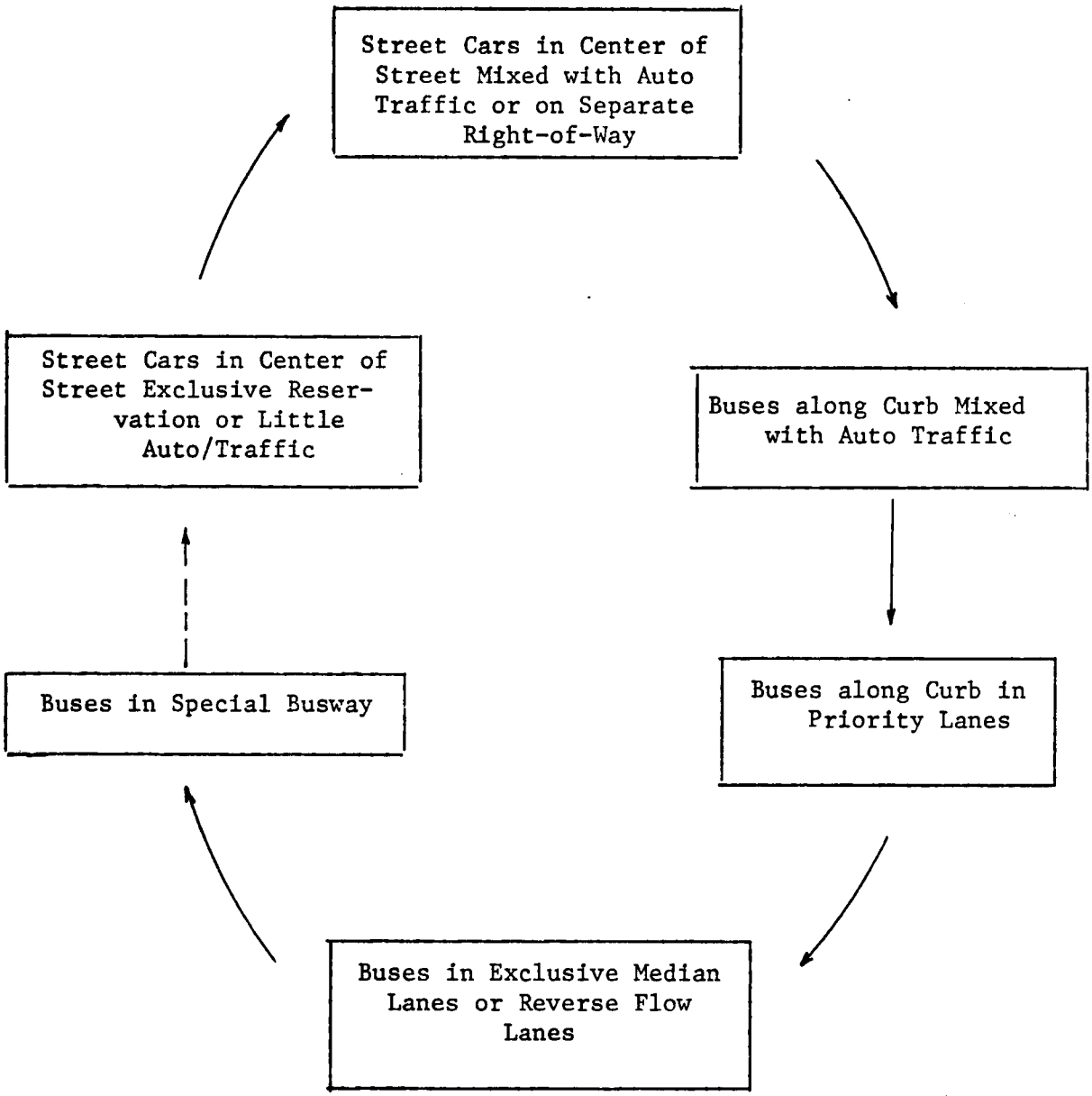


Figure 4. Transit Priority Cycle (9)

proposals and actions place buses on their own separate roadway. Most bus priority proposals are concerned with providing good access to the CBD perimeter but do not substantially improve service within the downtown core. For example, buses using the busways connected with Shirley Highway in Washington, D.C., have experienced most of their delays in downtown Washington. The total time it takes the bus to leave the downtown area is approximately fifteen minutes. (14)

The purpose of bus priority treatments in the CBD is to increase bus speed and reduce travel time and thus reduce the total person delay. Bus priority treatments can lead to monetary benefits for transit companies in terms of: (11)

1. An increase in ridership by making the service more attractive.
2. An increase in the reliability of service.
3. A reduction in the amount of time and fuel needed (up to several thousand gallons of fuel per year).
4. A reduction in accidents.
5. A reduction in the number of buses per route needed to maintain the same level of service.
6. Because of the reduction in the number of buses needed, a reduction in maintenance and operating costs, and thus,
7. Increased profits.

In addition to providing monetary gains for transit companies, bus priority treatments are also beneficial to cities and city dwellers in the following general ways: (11)

1. By riding the faster, more efficient buses operating in

the CBD under bus priority treatments, passengers save money that they would have spent for fuel and a parking space for their automobile. They also save wear and tear on their automobile.

2. Because of easy access to the CBD by efficient buses, retail business in this area increases.
3. Easy access to the CBD by efficient buses also leads to recentralization of major economic activities such as office, hotel, retail, and residential facilities.

Bus priority treatments concentrate on spatially and/or temporarily separating bus traffic from other traffic. Bus priority treatment can be divided into two major groups: (12)

1. Treatments at intersections, and
2. Treatments between intersections.

Treatments At Intersections

Evans showed that 10 to 20 percent of all bus travel time and almost one-half of all delays are caused by traffic signals. (13) The average bus waiting time can be significantly reduced through the adjustment or modification of traffic signal timing at intersections. The major treatments at intersections are bus preemption and actuation of normal traffic signal phases.[2] Bus preemption of the signal may extend

[2]The difference between traffic signal preemption and actuated traffic signal treatments is that in preemption, the controller changes the traffic signal interval directly to green. In an actuation traffic signal treatment, the phase is changed to green only after a minimum amount of green time has elapsed on the side streets.

the green time when buses enter an intersection in order to minimize person-delay. This treatment can be used along a special roadway or in mixed traffic. Bus extension of the green time phase should be considered whereever the following conditions apply: (14)

1. Bus preemption reduces total person-delay. The objective is to reduce person-delay without affecting the coordination of the traffic signal network.
2. Ten to fifteen buses, carry 400 to 600 passengers, travel on a certain route during each peak-hour period or a hundred buses are in operation daily in the heavy-traffic area.

In traffic signal actuation treatment, priority vehicles can activate the initiation of a green phase or the extension of the green phase to enable the bus to clear the intersection. A simple radio devise has been used in experiments to test this concept. This treatment is very simple and effective and has been demonstrated in Kent, Ohio and Washington, D. C. (15)

Traffic signal priority is used in European cities such as Leceste, England; Wiesbaden, Germany; and Montpelier, France. Furthermore, the number of American cities that are modifying traffic signals is increasing. Significant examples of this treatment occur in Los Angeles, California and Louisville, Kentucky. In Louisville traffic signals were also modified in connection with a contra-flow bus lane. (9)

Traffic Signal Preemption

The Los Angeles Department of Traffic, Bureau of Traffic Research, as part of a study financed by the U. S. Department of Housing

and Urban Development in Conjuction with Wilbur Smith Associates, tested the effectiveness of one traffic signal preemption treatment in the CBD of Los Angeles. (13) The main objective of the experiment was to determine whether signal preemption for buses would shorten travel time and increase operating speed.

The experiment involved having a person manually actuate the traffic signal so that the green interval would begin earlier if a bus approached on the red interval. If the bus approached at the end of the green interval, the green interval would be extended long enough to allow the bus to clear the intersection. The Study was conducted at the edge of the Los Angeles CBD, on Broadway at First Street and Broadway at Second Street where the signals were interconnected. The cycle length was 70 seconds during the morning peak hours (7:00-9:00 a.m.) and 80 seconds during the noon peak period (11:00 a.m.-1:00 p.m.) and the evening peak period (4:00-6:00 p.m.). The average hourly volume of vehicles passing through the test area for these six hours were:

1. Vehicles other than buses

Broadway	1,040 vehicles
First Street	1,590 vehicles
Second Street	300 vehicles

2. Buses

Broadway at First Street	93 buses
Broadway at Second Street	109 buses

At First Street, this signal preemption treatment reduced the total bus-second delay from 10,000 seconds to under 3,000 seconds

during the three peak-periods combined, meaning an average time savings for each of nearly 15,000 bus passengers of 12.5 seconds, a reduction of 70 percent. At Second Street, the time saving per passenger was 10.1 seconds. The percent reduction in delay at Second Street amounted to 76 percent and was higher than at First Street. However, as a result of signal preemption for buses, delays to other vehicles increased 51 percent on First Street and 24 percent on Second Street. This study indicates that improved bus system performance can be achieved through the preemption of traffic signals, although to the detriment of automobile travel.

Actuated Traffic Signal

A test of the effectiveness of a bus actuated traffic signal priority system was conducted by Kent State University for the Urban Mass Transportation Administration. (15) The main objects of the study were to note any changes in bus travel time due to the installation of the priority system and to examine how the priority system affected the travel time of passengers in vehicles other than buses. The location of the study was Main Street, a four-lane street which runs through the city of Kent and borders the campus of Kent State University. During the peak hours on Monday through Friday, Main Street carries about 2,000 vehicles per day, excluding buses. Eighteen buses pass through the study section. These buses are operated by Kent State University and carry approximately 20,000 passengers over the route on each school day.

The three traffic signals in the study section were independent, fixed-time controllers with a cycle length of 80 seconds. The first improvement was to interconnect the three traffic controllers. The green

interval on the signals facing the side streets was converted to a semi-actuated signal, this providing enough green time on Main Street to permit the bus to clear the intersection. The second improvement was to install a bus signal priority device. The signal was activated by the driver when he pressed a foot pedal inside the bus. Upon activation of the signal, the green time on Main Street was extended seven seconds if it was already green. If the phase of the cycle on Main Street was red, activation of the signal provided for a return to green after a minimum amount of green phase had elapsed on the side streets.

A reduction in travel time for all vehicles was noticable after coordination of the traffic signals. For example, the average automobile speed increased from 20 to 30 miles per hour. Bus preemption of traffic signals, the second improvement made during the study, increased bus speed from 12.0 to 13.3 miles per hour. However, the bus-actuated signal caused a slight reduction in the travel speed of other vehicles during the five-minute peak period between classes on the Kent State campus. The reduction was caused by an increase in the length of the queuing lines on side streets from an average of six vehicles to an average of 19 vehicles.

The result of the study indicates that bus travel time can be reduced through improved traffic signal actuation. The study also suggests that electronic signal actuation is feasible and can function with the broader framework of a network of coordination of all signals.

At uncontrolled intersections, a few priority treatments which differ sharply from those tested in Los Angeles and Kent can be employed.

For instance, in central London buses use a special roadway to bypass a particular crossing section of the street and thus reduce their travel time. (9)

Treatments Between Intersections

The most common bus priority treatment between intersections is to establish reserved bus lanes. Bus lanes are sometimes implemented by converting a two-way street into a one-way street and then prohibiting curb parking. The bus lane is located in the former parking lane, and in this case, there is no net loss in street capacity. Transit companies have noted significant reduction in total travel time after the introduction of exclusive busways. The total amount of time saved in several cities is shown in Table 2. Bus lanes should carry as many people during peak-hour periods as are carried by cars in the adjacent lanes. The Institute of Traffic Engineering (ITE) recommends that a reserved lane be used by a minimum of 75 buses for a median bus lane and 60 buses for curb lane during each peak-hour period in order to justify the establishment of a lane.(14) In Great Britain, the Transport and Road Research Laboratory requires 40 buses or 2,000 passengers during each peak-hour. (10)

A number of theoretical simulation studies were carried out in France to determine the number of buses required to balance time losses and create a savings in public and private transport time if bus lanes were established. These studies indicate that the minimum number of buses required per hour depends on the number of traffic lanes available, the level of traffic saturation, and the average number of occupants in the buses. Table 3 summarizes the minimum number of buses required per

Table 2

Travel Time Before And After Implementation Of Exclusive Bus Lanes (9,16)

Location	Length of Exclusive Lane Facility	Travel Time Before (Time in Minutes) Auto	Bus	Travel Time After (Time in Minutes) Auto	Bus	Bus Time Savings Over Former Bus Travel Time Minute	Percent	Result
1 - Louisville								
Route 4:00 a.m.	2	26.4	40.5	26.4	30.0	10.5	26	Passenger ridership has continued to increase throughout the duration of service. Transit average time are better via the express service and contra-flow lanes than by local service.
Route 4:00 p.m.*	2	24.6	42.0	24.6	31.5	9.5	23	
Route 6:00 a.m.	2	31.9	41.0	31.9	35.5	5.5	13	
Route 6:00 p.m.*	2	31.3	43.5	38.5	31.5	12.0	28	
2 - Indianapolis		NO DATA						Accident rate decreased from 216 in 1968 to 105 in 1970 along College Street.
2 - San Juan	10.4	---	80	---	50	30	38	Bus speed increased from 5.37 mph to 8.6 mph.

*No exclusive lane.

Table 3

Minimum Number Of Buses Per Hour Required
To Justify A Reserved Bus Lane (17)

A. Same Direction; Buses Replacing a Normal Traffic Lane

Number of lanes from which the bus-only lane is taken	Over-saturated road			Non-saturated road	
	60-pass. bus	70-pass. bus	90-pass. bus	30-pass. bus	50-pass. bus
2	60	45	35	45	30
3	45	30	25	40	25
4	40	30	25	35	25
5	40	30	25	30	25

B. Reserved Lane; In Same Direction Replacing Parking Lane: 15-20 Buses/Hour

C. Reserved Lane; In Opposite Direction on One-Way Streets: 15-20 Buses/Hour

hour on saturated and nonsaturated roads. (17)

Contemporary practice suggests that established standards regarding the minimum number of buses required in a reserved lane should be broadened. There are many examples of apparently successful lanes and bus streets that carry fewer than 60 - even fewer than 30-buses per hour. From the standpoint of person carrying capacity, 20 to 30 buses per hour, (1600-2400 people), in an exclusive bus lane can accomodate more people than are usually carried by cars in an equivalent arterial street lane, (600-1200 people per hour). (14)

Where applied, bus lanes should be clearly delineated from other traffic lanes by either physical separation or painted lines. Painted lines cost less and are simpler to install, but it is easy for vehicles other than buses to use such bus lanes illegally. Traffic islands are rather costly, but they provide better pedestrian refuge areas.

There are various types of reserved bus lanes; either in the center of the street, (median lane), such as used in Chicago, Illinois, or at the curb side, as used by Washington, D. C. Median lanes are always with the general flow of traffic (normal-flow) where the curb lanes can be either with the general flow of traffic, (normal-flow), such as in Vancouver, B. C., or opposing the general flow of traffic, (contra-flow), such as Louisville, Kentucky.

Normal-Flow Bus Lanes

Normal-flow bus lanes, (including both curb and median types), are used in more than 20 cities in the United States and Canada. They are easy and relatively inexpensive to implement and involve minimum

street-routing changes. However, curb bus lanes should be installed only when the following conditions are met: (14)

1. During the time when a normal-flow curb bus lane is in effect, there is no parking or standing permitted along the curb lane.
2. Curb bus lanes should not reduce peak-hour, peak direction traffic capacity. Where curb parking was prohibited before the establishment of a curb bus lane, there should be no reduction in street capacity.
3. At least two other lanes must be available for general traffic moving in the same direction as the buses in the bus lane.
4. The number of existing and potential peak-hour bus passengers should equal or exceed the average number of passengers carried by cars in the adjacent lanes.
5. At least 30 to 40 buses and 1200 to 1600 people should travel one way during each peak-hour period. In addition, the bus flow rate during the heaviest 20 minute period should approach 60 buses per hour.

In 1967, the curb lane began to be reserved exclusively for buses along a six-block section of Georgia Street, a six-lane, two-way thoroughfare in Vancouver, British Columbia. The lane was reserved only during the evening peak hours (4:00 p.m.-6:00 p.m.). The bus lane area extended for six blocks along the north curb of the CBD from Burrard Street to Pender Street. This section has long been conjested because of the convergence of traffic on the approach to a three-lane bridge

which crosses Burrard Inlet. The result of this study indicated that the bus lane reduced the travel time of buses in the experimental six-block section by 20 percent, from 6.4 to 4.5 minutes per bus. Furthermore, a 12 percent increase in patronage was reported for the four months following the installation of the exclusive bus lane treatment. (9,15)

Contra-Flow Bus Lanes

This type of treatment is a relatively new concept. It enables buses to operate opposite to the normal traffic flow on a one-way street. Buses using Contra-flow bus lanes are separated from conflicts with other vehicles and are unaffected by peak-hour congestion or back-ups at signalized intersections. Contra-flow lanes are self-enforcing, thereby reducing bus travel time and they are the most widely used priority treatment used in European cities. They have proved especially successful in five different European and American cities: Derby, England; San Juan, Puerto Rico; Madison, Wisconsin; Indianapolis, Indiana; and Louisville, Kentucky.

It is recommended by ITE that contra-flow bus lanes should be installed only where the following general conditions apply: (9)

1. The bus lane should not reduce peak-hour street capacity.
2. Curb parking and standing is prohibited during the hours of operation.
3. At least two lanes remain free for traffic moving in the opposite direction.
4. During the time when the contra-flow lane is in effect, buses must carry at least as many persons as are carried by automobiles traveling in the opposite direction in the

opposite direction in the adjacent general flow lanes.

5. Forty to sixty buses or 1600 to 2400 persons must travel through the contra-flow bus lane during each peak-hour period. In addition, during the heaviest 20 minutes period, the bus flow rate should approach 60 buses per hour. If the contra-flow lane is in effect all day, at least 400 buses must use the lane per day.

In October of 1970, exclusive contra-flow bus lanes were installed on a pair of one-way traffic arteries in a north-south corridor entering and leaving the CBD of Louisville. (19) The contra-flow bus lane for north-bound buses along the east curb lane of Third Street was in effect from 7:00 a.m. to 9:00 a.m. The contra-flow lane for south-bound buses along the west curb lane of Second Street operated from 4:00 p.m. to 6:00 p.m., but the bus lane was eventually eliminated because the extra time needed for the bus to enter Second Street was inconvenient for the passengers. The contra-flow lanes had formerly been used for parking.

The study shows that the travel time for contra-flow buses was 25 percent less than before the establishment of the exclusive bus lane. There was an 18 percent increase in ridership for the contra-flow buses. Several other benefits were suspected but not documented, benefits such as increased reliability of buses in meeting their schedules, reductions in operating costs, and environmental improvements.

Bus Streets

Bus streets are a new type of bus priority treatment which can

be established between intersections. These streets are either used exclusively by buses or are shared with taxis and emergency vehicles. Bus streets are usually created by closing off either the two outer lanes or the two center lanes of a formerly four-lane street. The ITE recommended that bus streets should be installed only when the following conditions exist: (14)

1. Bus streets penetrate a major retail area.
2. At least 200 buses per day travel in each direction.
3. A minimum of 20 to 30 buses and/or 800 to 1200 people travel in each direction during each peak-hour.
4. No major parking garages are located along the bus street.

In 1968 an eight-block section of Nicollet Avenue in downtown Minneapolis was closed to all vehicular traffic except buses. (20) The entire street space, with the exception of two bus lanes, was landscaped and converted to a mall. The mall is a totally restructured area for pedestrians, buses, occasional taxis, and other special-purpose vehicles. The two-lane roadway is approximately 24 feet wide, and Nicollet Mall is considered one of the most important retail areas in Minneapolis. The objective of the mall bus system is to make public transportation more attractive and to provide service to this important retail area.

Initially, full-sized transit buses served the mall, but a quick-transit (QT) twelve to seventeen seat mini-bus service was added in March of 1971. The mini-buses ran in each direction along the mall during the peak-hours. Patronage ranges from 12,000 passengers per week

during slack periods to 18,000 per week during busy shopping times.

Even though the speed of buses in Nicollet Mall is relatively slow, due to pedestrians making frequent mid-block street crossings, the bus street project is considered a success because it has greatly reduced traffic congestion and air pollution in the downtown Minneapolis area.

In addition to the alternatives which already have been mentioned, there are two more treatments which improve transit service and reduce travel time. Improving fare collection and skip-stop are examples.

Fare Collection

There are several methods of collecting bus fares that would reduce travel time and improve service, including the following: (21)

1. A transit company employee would collect the fare on the bus after the passengers boarded. (This would require an extra employee on the bus).
2. The fare would be collected by machine at the station before the passengers boarded.
3. Passengers would purchase a limited-time pass from the transit company and would show this pass to the bus operator as they boarded the bus.
4. There would be no fare collection in the CBD.

Eriksen showed that a time savings of 12-18 percent over the convertional system (boarding through one door and using exact change) could be expected if the boarding process along Wisconsin Avenue utilized

both doors and no fares were collected.

Skip-Stop

The skip-stop operation can be implemented by eliminating one station at every other block or at every third block. Erikson found that a 3-18 percent time savings was brought about by instituting skip-stop service along Wisconsin Avenue in Milwaukee if the buses stop in the through lane. When bus bays are provided, the time savings from skip-stop was less. (21)

Economic Benefits of Bus Priority Treatments

The use of bus priority treatments generally reduces travel time and leads to certain clearly discernible economic benefits for transit companies. They are advantageous in a number of ways. They: (19)

1. Avoid capital-intensive building investments,
2. reduce transit companies' operating costs, and
3. save time, increase ridership, and thus increase revenues.

Through the use of priority bus treatments, the necessity to construct new and costly transportation facilities such as expressways or bypasses can often be avoided. Because a bus in a priority treatment situation arrives at its destination more rapidly, it can make more runs in a shorter time and thus reduce the need for more buses to service a particular route. The driver is also able to work efficiently for longer periods of time, since he does not have to compete with other vehicles in order to meet his schedule. Bus priority treatments also save wear and tear on the buses themselves, because the buses do not have to stop as frequently. This means that old buses have to be repaired

less often and that they last longer. Because the old buses stay in good working condition for a long period of time, new buses have to be purchased less often.

Bus priority treatments also save time. They do this by avoiding frequent stops and congestion. This time savings is helpful for people who already ride the bus, and as shown by demonstration projects, can serve to attract new passengers. This fact, in turn, is economically important for transit companies. For example, Chicago's Washington Street bus lanes save one bus run during each peak-hour period, resulting in an estimated annual saving of $25,000 to the transit company (100 miles per day, 250 days per year, $1.00 per bus-mile). (9)

Environmental Benefits of Bus Priority Treatments

The environmental benefits derived from bus priority treatments also appears to be considerable. (19) Such treatments reduce stop-and-go driving patterns for buses. Steady driving contributes to a higher level of efficiency in the buses' engines and thus to cleaner emissions from the combustion process. Buses can also carry passengers more efficiently than automobiles. For example, a maximum free flow of automobiles is approximately 2,000 vehicles per hour per lane, giving an average of 3,200 passengers per hour (assuming passenger occupants of 1.6). (22) But a maximum flow of buses is approximately 175 buses per hour per lane, which gives a maximum of 9,000 bus passenger seats per hour per lane. (Assuming 51 passengers per bus.)

2. SUMMARY

Through improvement of operating efficiency and reduction of travel time, public transit can become more competitive with the automobile for transportation within the city. Bus priority treatments can help transit companies achieve greater economy and efficiency. Table 4 summarizes the alternative treatments that were discussed in this chapter. It is proposed that some of these bus priority procedures be explored for possible application to downtown Knoxville, the subject of Chapter IV. These aids can take the form of selected bus priority and revised operation procedures. The literature has shown that such procedures provide noticeable improvement with minimal cost, bringing an immediate response which improves the bus flow into and through CBD areas.

Table 4

Various Bus Priority Treatments Used In North America

	Bus lane at Vancover B.C.	Contra-flow Louisville Kentucky	Bus Street Nic. Mall Minn.	Preemption Sig. Los Angelos Calif.	Actuated Signal Kent Ohio
Travel Time Saving	20%	25%	slow	70% First Street 76% Second St.	10% Increase Bus Speed
Ridership Increase	12%	18%[a]	28%	N. A.[b]	N. A.
Traffic Signal Priority	N. A.	Yes	N. A.	Actuated Signal-Priority	Actuated Signal Priority
Lane Type	Curb Lane Bus Only	Contra-Flow Bus Only	Bus Street & Emergen. Vehicles	Mixed Traffic	Mixed Traffic
Length of Treatment	0.5 Mile	2.0 Mile	0.68 Mile	2 Blocks	3 Blocks
Peak-Hour Bus-Flow	40	24	64	N. A.	18
Hours of Operation	4:00-6:00 p.m.	7:00-9:00 a.m.	24 Hours	N. A.	During School Day
Capital Cost	N. A.	$37,975	$177,120	N. A.	N. A.
Maintenance Cost	N. A.	$1.10/Mile	N. A.	N. A.	N. A.

[a]Local Buses Showed A Decrease Of 27% From November 1970 To March 1972.

[b]Not Available.

CHAPTER III

FIELD ANALYSIS OF BUS OPERATIONAL DELAYS

1. KNOXVILLE TRANSIT SYSTEM

Knoxville, Tennessee, is a medium-sized city[3] whose population in 1973 was 175,300. (23) Public transportation in the city is provided primarily by the Knoxville Transit Corporation (KTC) with eight routes. The routes in the CBD area fall into two typical patters: through routes and linear-loop combination routes. The through route pattern, shown in Figure 5, allows bus patrons to move between different parts of the city without incurring the inconvenience of a transfer. This pattern provides maximum coverage in residential areas. The second typical route pattern used by KTC is a linear-loop combination with one end of the loop terminating in the CBD and the other in a residential area (for example #4, Bearden and route #8, University of Tennessee Hospital). The linear-loop combination pattern is shown in Figure 6. Over the years the route patterns have been altered so that all routes now converge on Gay Street.

The Knoxville Transit Corporation owns eighty buses, but not all of these buses operate at all times. For example, during the morning peak period (7:00 - 9:00 a.m.), KTC operates only thirty-four buses.

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[3] A medium-size city is defined as one which has a population of 500,000 or fewer.

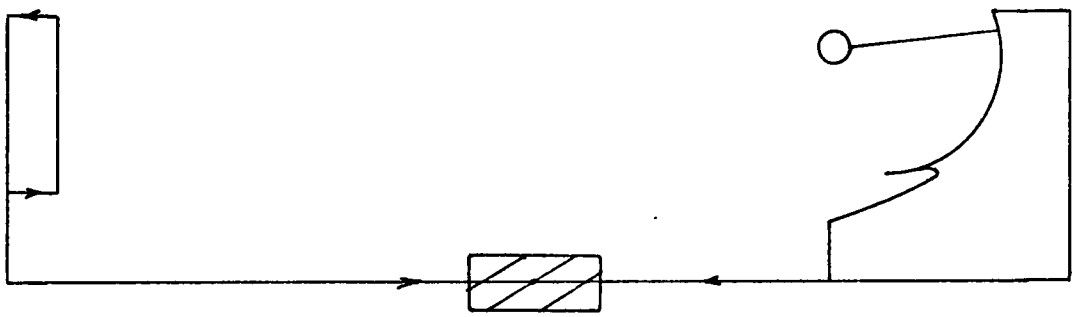


Figure 5. Through Route. Such as the route from Dandridge Avenue to Washington Avenue.

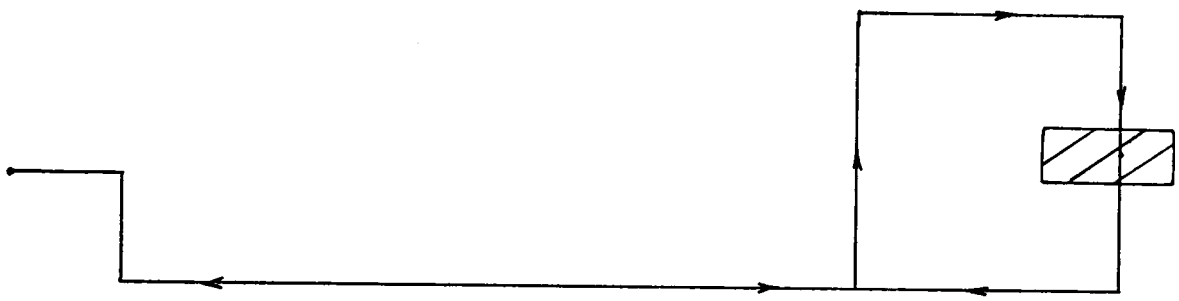


Figure 6. Linear/Loop Combination Route. Such as the route from Bearden to West Town.

During the evening peak period (4:00 - 6:00 p.m.), thirty-nine buses are in operation. In addition to those in regular operation during the peak hours, thirteen buses are used primarily for employees of the Tennessee Valley Authority (TVA) as express buses, and eight buses are used by the University of Tennessee to transport students to and from its Knoxville campus and also to and from various points on the campus. (24)

Since May 1, 1971, the basic bus fare in Knoxville has been thirty cents plus a five-cent zone fare, and five cents for a transfer. For high school students, KTC issues cards consisting of ten or forty rides at a cost of twenty cents per ride. It also issues cards which allow senior citizens to ride the bus at a cost of fifteen cents per ridge. There is also a commuter card consisting of forty rides at a cost of twenty-five cents per ride with a five-cent additional charge for each zone or transfer. In addition, the Tennessee Valley Authority offers discount cards to its employees as part of that firm's transit incentive program. The driver punches each card as high school students, senior citizens, TVA employees, or other card-carrying passengers board the bus. Other patrons pay the exact fare. (24)

Field Study

A field study was conducted in the spring of 1975 to investigate

bus delays[4] in a six-block area of Gay Street, a four-lane two-way throughfare in the BCD of Knoxville. The intersecting streets in the study area are Cumberland, Church, Clinch, Union, Wall, Commerce, and Vine (Figure 7), with block lengths ranging from 292 feet to 489 feet with a total length of the study area being 2,135 feet. Parking is prohibited at all times on both sides of Gay Street. The average number of vehicles and buses during the peak periods, plus the average daily traffic volume (ADT), are shown in Table 5. Each intersection on Gay Street has an independent fixed-cycle (pretimed) traffic signal. The length of the complete cycle is 90 seconds, but each cycle has a different ration of red and green intervals, as shown in Table 6.

Bus stops along Gay Street are located on the near side of each intersection. Each bus stop is sixty feet long, sufficient to allow one bus to park. Some of the bus stops, such as at Wall Street, serve as transfer points for passengers desiring to travel to other destinations in the city. One of the twelve bus stops, on the north side of Gay Street between Union and Commerce, is in the middle of the block because this block is longer than the others in the study area.

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[4]Delay in this study refers to any action which forces a bus to cease moving (i.e., stopping for a signal light, to load/unload patrons, to permit a pedestrian to cross, or to change lanes to pass a parked automobile or truck). Delay is not considered to include a reduced operating speed between stopping points due to increased vehicle/pedestrian/bus conflicts and general levels of traffic congestion. It is recognized that stopped delay consists of a necessary component such as loading passengers as well as an unnecessary component such as waiting for a signal light to change. However, it is desirable as an operating strategy to reduce stopped delay as much as possible while maintaining sufficient time to load/unload passengers.

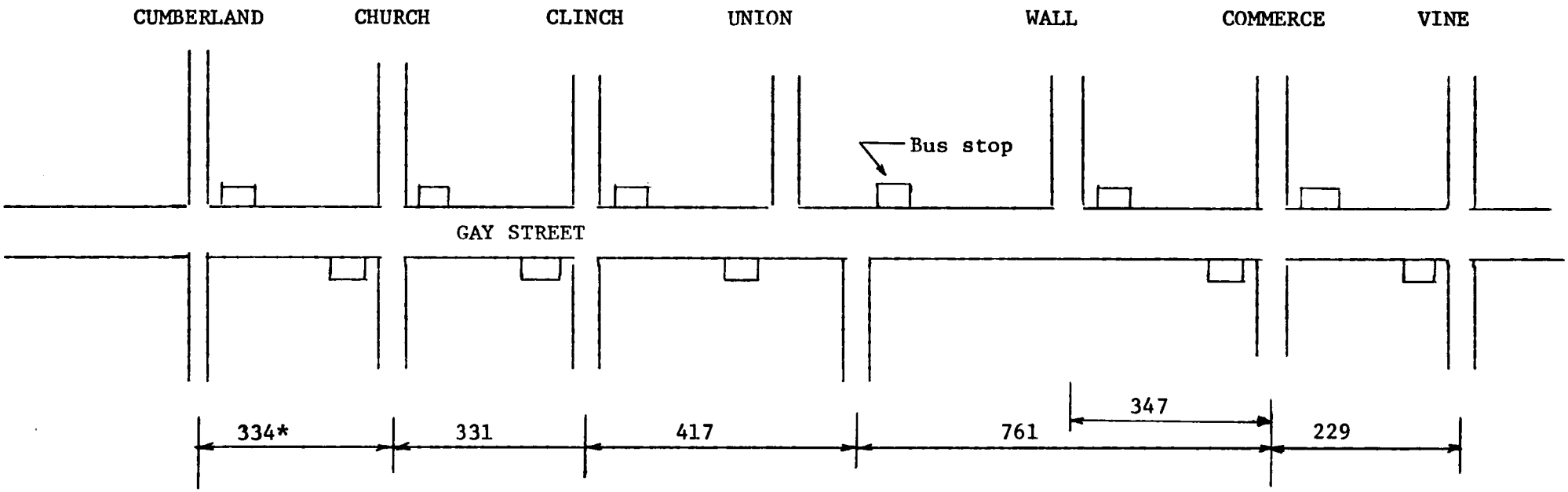


Figure 7. The Six-Block Study Area Of Gay Street In Downtown Knoxville.
*Distance in feet.

Table 5

Average Number of Vehicles, Including Buses, Traveling Through The Study Area During The Two Peak Periods And The Mid-day Hours (South-bound Direction Only). (25)

Study Period	No. of vehicles excluding buses	No. of buses
7:00 - 9:00 a.m.	1474	47
11:00 a.m. - 1:00 p.m.	986	39
4:00 - 6:00 p.m.	1932	52
Average daily traffic	11,365	259

Table 6

Traffic Signals In The Study Area

Gay Street at	Direction	Interval (sec.) Red	Amber	Green	Turn Arrows (sec.)	Number of Phases	Length of the Cycle (sec.)
Vine	South Bound	54	4	32	--	A, B	90
Commerce	South Bound	20	4	51	15	A, B	90
Wall	South Bound	45	4	41	--	A, B	90
Union	South Bound	36	4	44	6	A, B	90
Clinch	South Bound	36	4	50	--	A, B	90
Church	South Bound	34	4	52	13	A, B	90
Cumberland	South Bound	43	4	43	--	A, B	90
Cumberland	North Bound	32	4	45	9	A, B	90
Church	North Bound	47	4	39	--	A, B	90
Clinch	North Bound	36	4	50	--	A, B	90
Union	North Bound	41	4	45	--	A, B	90
Wall	North Bound	27	4	45	14	A, B	90
Commerce	North Bound	35	4	51	--	A, B	90
Vine	North Bound	54	4	32	--	A, B	90

The field study was conducted in two parts. The first efforts were devoted to determining the total travel time[5] for buses traveling through the six-block study area, and subsequent observations were made to document the stopped delay for buses at critical points in the study area. To determine the total travel time an observer was stationed at each end of the Gay Street study area and each bus was clocked as it entered and left the area.

To determine the stopped delay in each block, an observer recorded the total time it took for each bus to travel through that particular block and also document the delay caused by various factors such as traffic signals and bus stop loading-unloading.

Results of Field Study

It was found that bus travel time varies as a function of (a) time of day, (b) location along Gay Street, and (c) method of fare collection. It was found that there are considerably more operational delays[6] to buses on Gay Street during the two peak periods and the

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[5]Travel time is the total elapsed time of travel, including stops and delays, necessary for a vehicle to travel from one point to another over a specified route under existing traffic conditions. (26)

[6]Operational delay is the delay caused by interference from other components of the traffic stream. Time consumed while waiting at a stop sign for a gap in cross traffic is considered an operational delay. Time losses resulting from congestion, parking maneuvers, pedestrians, and turning movements are also examples of operational delays. (26)

mid-day hours than at other times. Table 7 shows the delay to buses during various periods. As can be noted in the table, an inordinately large amount of bus travel time is consumed by operational delays. For instance, during the morning peak period the average bus travel time through the six-block study area is 5.62 minutes. Of this time, 4.53 minutes are taken up by operational delays which are caused primarily by:

1. Traffic signals,
2. passengers boarding and deboarding (see Table 8), and
3. other factors such as vehicles parked or standing in the bus lane or vehicles trying to make right or left turns blocking the bus.

a. Temporal Pattern of Delay: Traffic signals are the greatest cause of delay to buses on Gay Street at all times of day. The percent of delay caused by traffic signals is approximately 57 percent of the total delay during the morning and evening peak hours and approximately 52 percent during the mid-day hours.

Passengers boarding/deboarding is another cause of delay at all times. Delay at bus stops comprises approximately 38 percent of the total

Table 7

Delay To Buses Caused By Traffic Signals And Loading In The Six-Block Area

Time of the Day	Number of Buses	Average Bus Travel Time (min.)	Average Bus Speed (feet/sec.)	Average Equivalent Auto Travel Time (min.)[a]	Average Delay Bus from Traffic Signals and Loading Period (minutes)
7:00 - 9:00 a.m.	27	5.62	6.33	2.10	4.53
11:00 a.m.-1:00 p.m.	22	5.50	6.47	2.00	4.79
4:00 - 6:00 p.m.	29	6.40	5.56	2.30	5.20

[a]Figured from an average of seven runs while floating with traffic and stopping for signals and other hindrances.

Table 8

Number Of Passengers Boarding And Deboarding At
Bus Stops In The Six-Block Study Area

Time of Day	Location of Bus Stop	Number of Passengers Boarding	Number of Passengers Deboarding
7:00-9:00 a.m.	Commerce at Gay	13	9
	Wall at Gay	82	128
	Union at Gay	66	94
	Clinch at Gay	149	129
	Church at Gay	73	126
	Cumberland at Gay	6	6
11:00 a.m. - 1:00 p.m.	Commerce at Gay	3	-
	Wall at Gay	38	60
	Union at Gay	47	43
	Clinch at Gay	74	20
	Church at Gay	7	3
	Cumberland at Gay	15	12
4:00-6:00 p.m.	Commerce at Gay	3	3
	Wall at Gay	162	100
	Union at Gay	135	39
	Clinch at Gay	122	20
	Church at Gay	65	44
	Cumberland at Gay	9	4

delay during the two peak periods and 26 percent during the mid-day hours. The amount of delay at individual bus stops changes from time to time during the day. Generally, the greatest bus delays were observed in the two blocks between Wall and Clinch during the period of 4:15 - 4:45 p.m.

Delays caused by other factors such as parked or standing vehicles or vehicles queuing for right or left turns both of which block the bus lane, were not substantial during the peak periods. However, parked vehicles were noticeable from 9:00 to 10:00 a.m. when trucks unload merchandise in front of Gay Street business establishments.

During the mid-day hours, delays often occur not because of pedestrian/traffic-bus conflicts, but because of bus layover time. If a bus arrives early at Gay Street, it regains its schedule by waiting. Some buses also wait for transfer buses which arrive late. Finally, during the mid-day hours, some bus-drivers shift are completed at Gay Street and delay occurs as drivers change buses.

b. Spatial Pattern of Delay: The causes of bus delay vary not only with time but also from block to block. Two blocks of Gay Street (Wall to Union and Union to Clinch, in both directions) are considered the most critical ones in terms of delay to buses caused by traffic signals, loading/unloading, parked vehicles, and conflicts between buses and pedestrians/automobiles. For example, during the evening peak-hour period, thirty buses pass through the critical block of Wall to Union. An average of 28 of these buses are delayed by either a traffic signal or the necessity to load-unload passengers at a bus stop, and in many instances both of the delays occur. During the study period, in the Wall

to Union block, approximately 33 percent of the total delay was attributable to traffic signals and 30 percent to passengers boarding/deboarding buses. Figures 8 and 9 identify the causes of bus delay in the two "critical" blocks throughout the day. As Figure 9 shows, the delay occurring during the off-peak time, 1:00 - 3:00 p.m., is greater than during the peak periods. This delay is caused by the previously discussed bus layover time. In addition to these two entire blocks, there are two single bus stops at which an unsually large number of passengers congregate causing a great deal of delay: one is at Gay and Wall and the other at Gay and Clinch, as noted in Figure 8.

Other factors, such as vehicles parked in loading zones, officer control, right and left turns, and queue lines formed by traffic signals were mainly of short duration and localized and did not cause substantial delay to buses.

c. Method of Fare Collection: The time spent in loading and unloading patrons at bus stops is related to the number of passengers, the mix of persons boarding and deboarding, and the method of fare collection. Since the field survey indicated that bus loading/unloading is a major factor in bus delays, and since fare collection is the most time-consuming part of loading/unloading, a special investigation was conducted to compare the time consumed in fare collection by city type and by fare collection discipline. For purposes of comparison with Knoxville, the author recorded the time required to load/unload passengers in the CBD of Chattanooga (population 119,082) and Nashville (population 447,877). All loading points in Knoxville, Chattanooga, and Nashville were observed on a typical week day during the two peak periods and the mid-day hours.

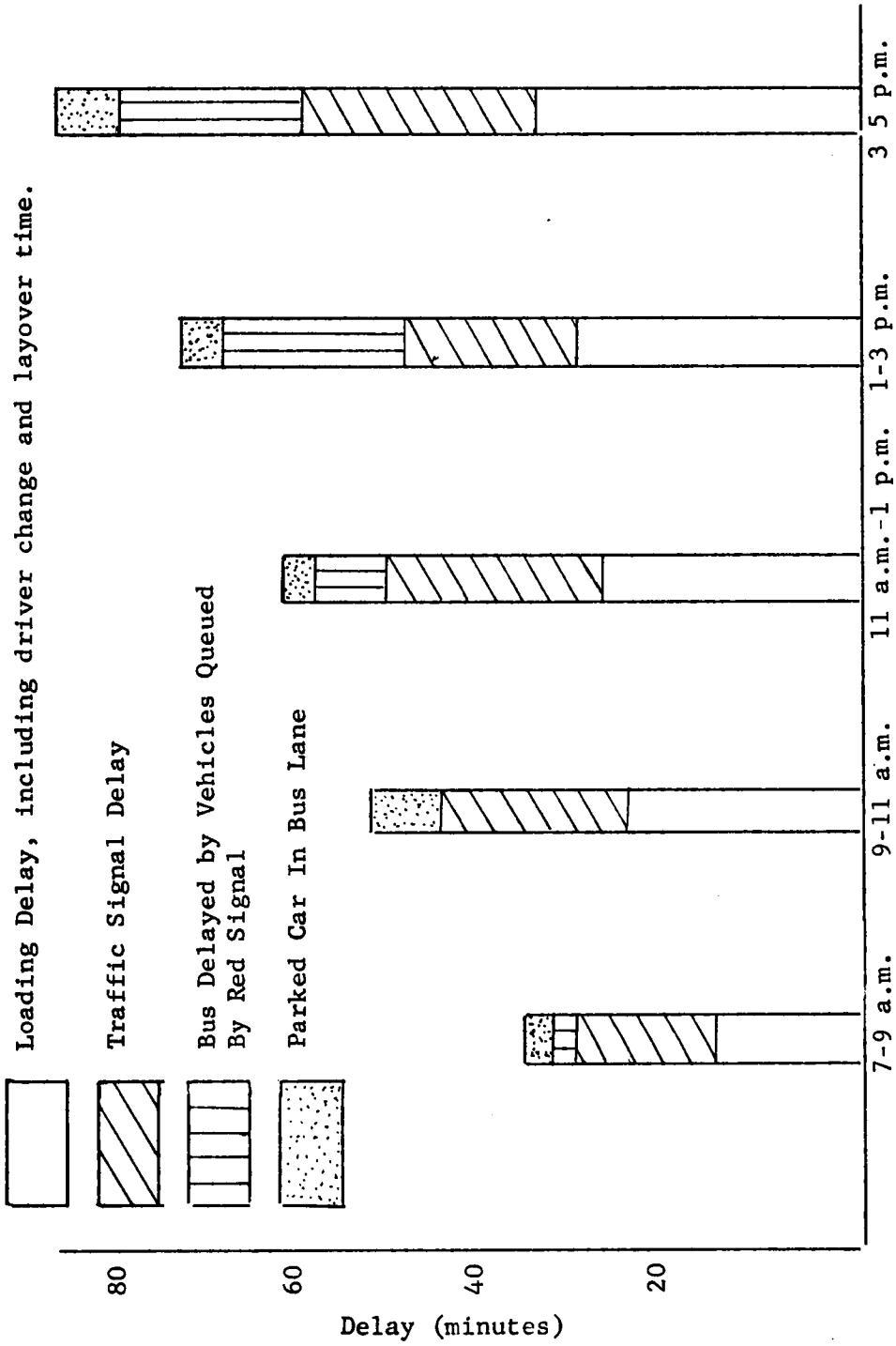


Figure 8. Bus Delay Throughout The Day In The Block Wall To Union.

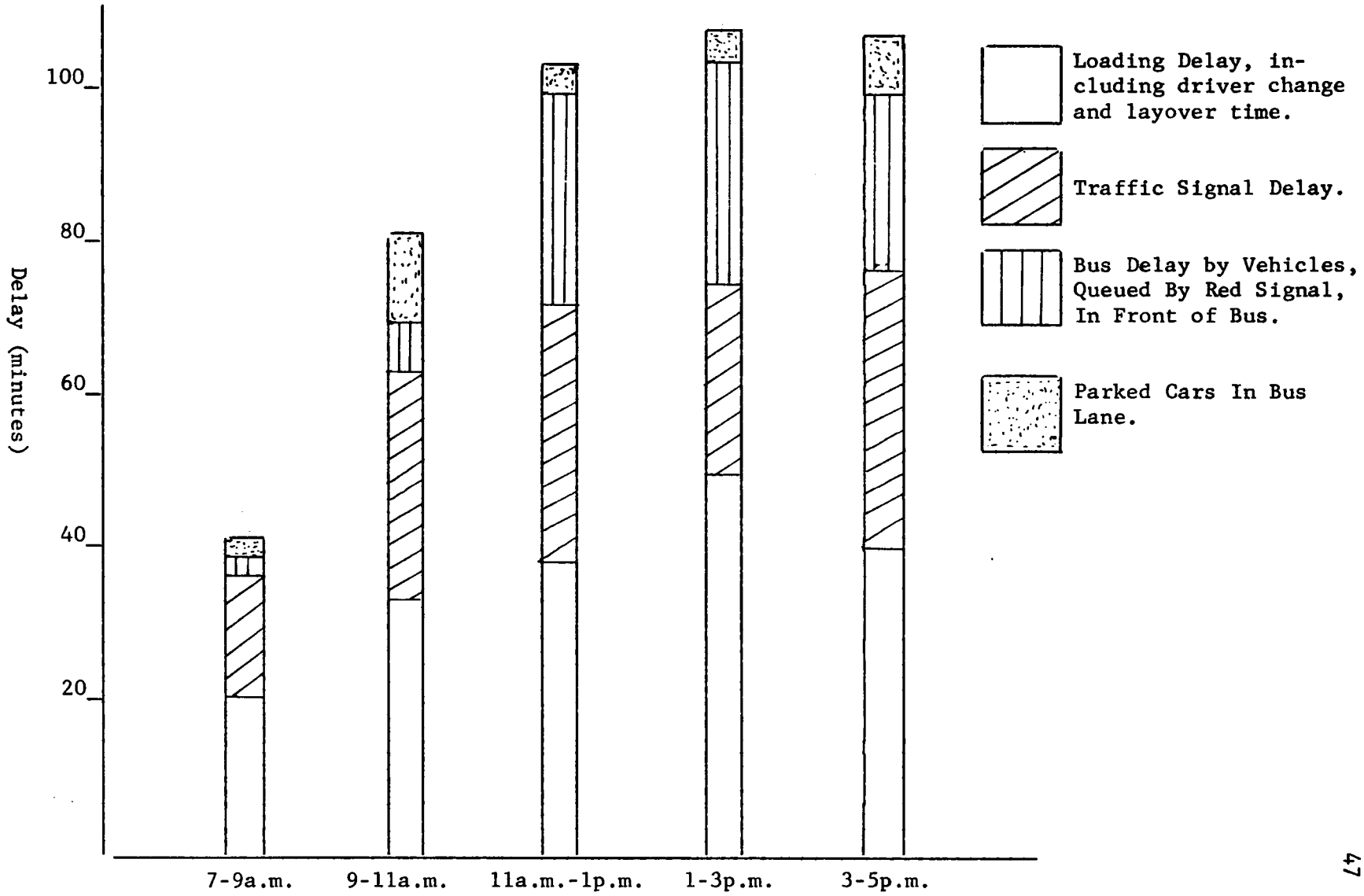


Figure 9. Bus Delay Throughout The Day In The Block Union To Clinch.

The results are recorded in Table 9 and graphed in Figure 10. The graph (Figure 10) relates the number of passengers boarding vs. time. The lines plotted in Figure 10 represent a least squares fit regression which was calculated from several observations, as reported in Table 9. As noted in Figure 10, it was found that the buses on Chattanooga's Market Street consume less time to load an equal number of passengers than those on Knoxville's Gay Street or those in Nashville's Union Street. This can be attributed in part to the type of fare collection used. For example,

1. Knoxville, Gay Street: The basic fare collection is exact change. Discounts are issued in the form of cards which need to be punched by the driver, and sometimes the transfers need to be punched at three places during the boarding/deboarding process.
2. Chattanooga: The fare collection system used in Chattanooga is exact change (thirty-five cents), tokens which are deposited in a box next to the fare collection box, and discount tickets. Neither the tokens, the discount tickets nor the transfers in the Chattanooga system need to be punched.
3. Nashville: The basic fare is exact change (forty cents). Discounts are issued in the form of tokens which must be dropped into the token fare bos. There are two types of transfer: a zone transfer which must be punched and a regular transfer with no punching necessary. As noted, systems which use tokens as exact fare tend to cause less delay than those which involve the driver punching tickets. Also, in Nashville the loading time is greater because the

Table 9

Regression And Bus Loading Times For Knoxville, Chattanooga, And Nashville

Location	Time of the Observation	Number of Observations Loading Bus	Equation of Least Square Regression	Standard Deviation	Correlation Coeffi. (R)
Knoxville at Gay Street	7:00-9:00 a.m. 11:00 a.m. - 1:00 p.m. 4:00-6:00 p.m.	72	Y=6.38 + 2.89 (X)	0.15	0.91
Chattanooga At Market and Ninth Street	11:00 a.m. - 1:00 p.m. 4:00-6:00 p.m.	72	Y= 10.5 + 2.66 (X)	0.15	0.90
Nashville at Arcade	11:00 a.m. - 1:00 p.m. 4:00-6:00 p.m.	62	Y=5.01 + 2.02 (X)	0.22	0.89

Y = Time in which loading was accomplished.

X = Number of passengers loaded.

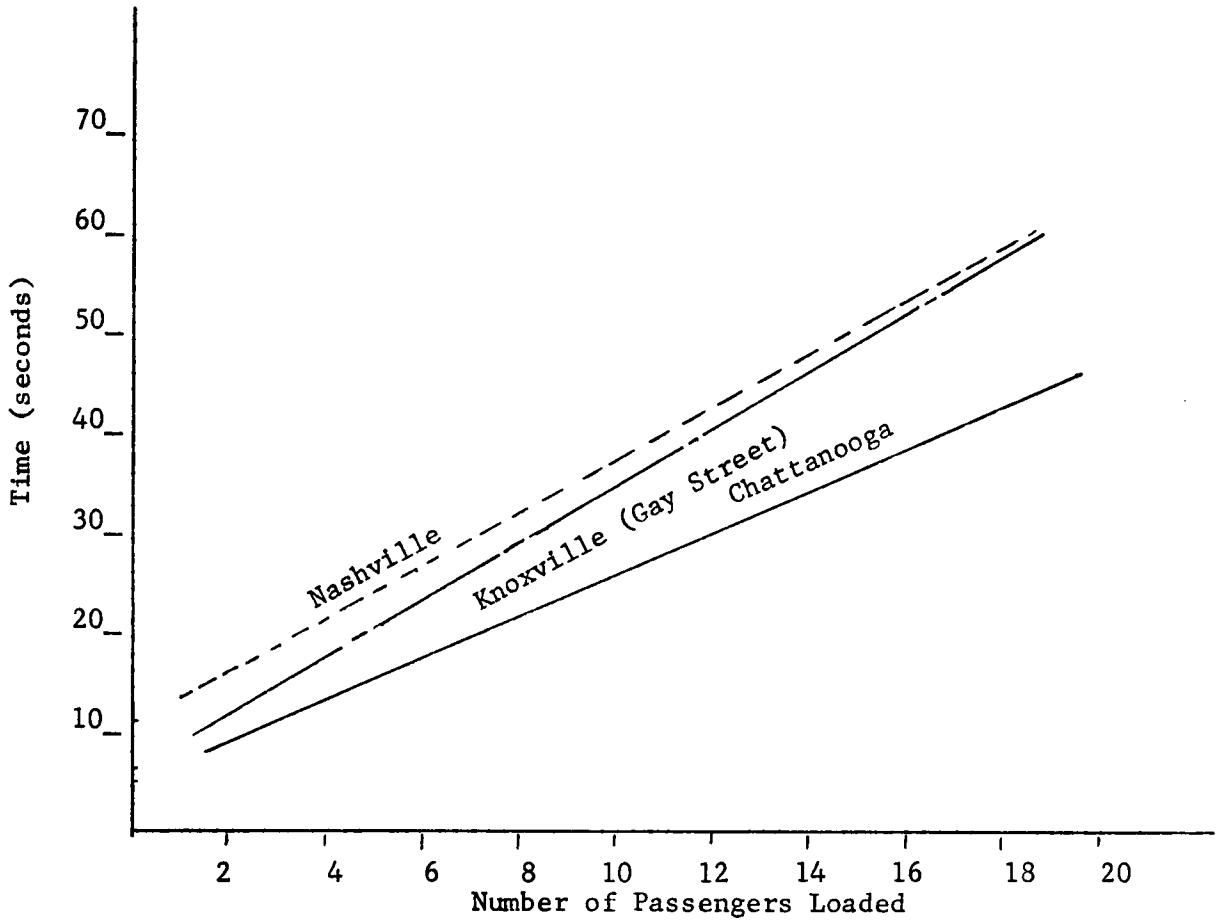


Figure 10. Average Time Required To Load A Bus (One Door Only) During The Peak Periods For Knoxville (Gay Street), Chattanooga, And Nashville.

large volume of passengers transported which cause standing. Typically, when a bus begins to fill up, passengers tend to remain next to the fare collection box after depositing their fare while looking for a seat. It was also found that the time a bus spends at a CBD bus stop is primarily a factor of loading, rather than unloading, since fares are collected during loading. And at major stops, passengers tend to be more inclined to exit via the rear door.

A supplemental analysis was conducted in Knoxville of two systems which use still different fare collection disciplines: The University of Tennessee students and TVA employees. The TVA loading point at Union and Market was observed during the evenint (4:45 - 5:00 p.m.) peak periods. The University of Tennessee site was observed during the heavy demand periods, 10:00 - 11:00 a.m. and 1:00 - 2:00 p.m. The results, shown in Table 10, were plotted relating the number of passengers boarding vs. the time required (see Figure 11). These lines represent a least squares fit regression which was calculated from several observations, as reported in Table 10. The boarding time for University of Tennessee is much less than for TVA. For example, ten passengers can board a U.T. bus in fifteen seconds, whereas it takes the same number of passengers forty-five seconds in the TVA express. This variation in boarding time can largely be attributed to the type of fare collection used. The fare collection disciphia utilized valued:

1. University of Tennessee: The boarding rate at U. T. is extremely rapid, because on U. T. buses no fares are collected and the patrons are generally college students.

Table 10

Regression Equations For Tennessee Valley Authority
And The University Of Tennessee Bus Loading Times

Location	Time of the Observation	Number of Observation Loading Bus	Equation of Least Square Regression	Standard Deviation	Correlation Coefficient (R)
Knoxville at Union (Tennessee Valley Authority), Employee Express Bus Route	4:45-5:00p.m.	37	Y = 2.97 + 4.78 (X)	0.23989	0.23
Knoxville at The University of Tennessee	10:00-11:00a.m. 1:00-2:00p.m.	30	Y = 1.07 + 1.55 (X)	0.17493	0.92

Y = Time in which loading was accomplished.

X = Number of passengers loaded.

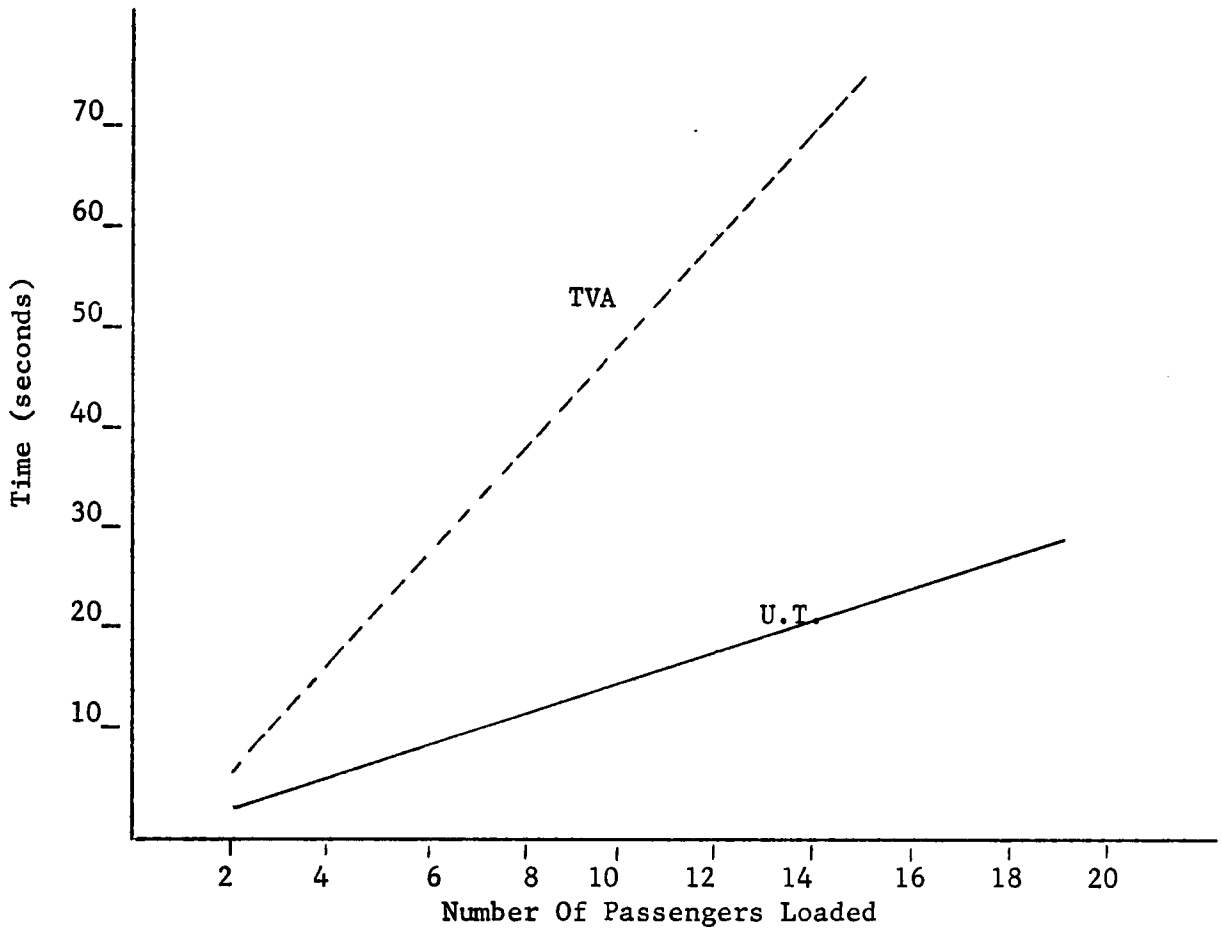


Figure 11. Average Time Needed For Boarding Using One Door Only During The Peak Periods For The U. T. And TVA Systems.

2. TVA: Almost all of the passengers boarding TVA buses own a discount card which the driver must punch at the proper place. This process, together with the large number of passengers loading, causes considerable delay.

The U. T. system is less time-consuming than the KTC system on Gay Street because of the unique fare collection method and the characteristics of the passengers. The TVA system, due to commuter tickets, is more time-consuming than the Gay Street KTC system.

2. SUMMARY

The field study indicated that bus delay varies according to time of day, location, and method of fare collection. Although the average delay per bus during the two peak periods is only 4.60 minutes, when aggragated this delay amounts to 133.4 minutes for the two peak periods. At all locations along Gay Street, traffic signals tend to be the most significant cause of delay, accounting for approximately 57 percent of the total delay. This delay could be reduced if the amount of green time for each signal were increased. For example, a 4-second increase in green time during the peak periods would enable about 29 percent of the buses to pass through the intersection without being delayed by the traffic signal. In the aggregate, such as increase in green time would save approximately twenty-nine minutes during the two peak periods. Although passengers boardings are an integral and necessary part of bus operations, it is nevertheless the second major cause of bus delay on Gay Street, accounting for approximately 38 percent of the total delay. The most time-consuming part of the boarding process is fare collection. Alternative methods of

fare collection might greatly improve the operational efficiency of buses traveling along Gay Street.

Alternative concepts should be tested in the Knoxville CBD in an attempt to reduce delay due to traffic signals, passengers boarding, and other delay-causing factors. A pilot elimation of the alternatives is the subject of Chapter IV.

CHAPTER IV

ANALYSIS

Various physical and operational improvements are available to improve bus operational efficiency in the CBD's of cities. This chapter will investigate the use of a prototype simulation model to conduct a preliminary assessment of possible alternatives for the Knoxville CBD. Due to data limitations, the analysis must be considered preliminary, but the analysis does highlight the relative effects of alternative treatments, thus limiting the alternatives for more complete analysis and a potential demonstration.

A simulation was made of buses operating over the four-block area of Wall to Church in downtown Knoxville. This area has four signalized intersections and four bus stops. The study period involves the evening (4:00 - 6:00 p.m.) peak period, because it was found that pedestrian and traffic movement during the afternoon peak period is considerably heavier than during the morning peak. A simulation model was used because such models can provide realistic representations of the movement of buses as they travel through a central city area and are effective in predicting in a simple and efficient manner performance consequences which can be expected from various alternatives.

The model used will be a hand-run prototype, with all parameters deterministic except the speed, which will be based on stochastic relations derived from empirical observations collected from the field study.

Deterministic Variables: Variables which can be precisely computed from other variable are called deterministic. In this model traffic signal timing, bus stop spacing, passenger boarding time, and the method of fare collection are such variables.

Stochastic Variables: Independent variables, have the value of one variable not depending on the value of any other variable. In this model, speed is a stochastic variable. The time it takes for a bus to travel from one point on Gay Street to another is based on several complex factors. It was necessary to obtain a number of enpurial observations, because buses in a mixed traffic flow are not traveling at a uniform speed. The enpurial determined a distribution of bus speeds, because the speeds are in a comparatively wide range, a statistical technique must be introduced into an analysis of speeds. The speeds were grouped and the data were recorded by indicating the number of buses which were observed to be traveling at each speed. The cumulative frequency distribution curve was developed for the four blocks (Commerce to Wall, Wall to Union, Union to Clinch, and Clinch to Church) during the evening peak. The cumulative frequency distributions are shown in Appendix B and is used in the stochastic simulation model.

Simulation Model: A simulation model can predict the changes would occur if various alternative treatments were applied. However, in order to construct a simulation model, it is necessary to identify the components of alternative treatments and made some basic assumptions about their characteristics, based on enpurial data. These data include travel time, type of fare collection, signal timing, and bus stop spacing. A flow diagram

of the protype hand-run simulation model is shown in Figure 12.

Alternatives

Several alternatives are available to improve the operating efficiency of buses in the Knoxville CBD. Three alternatives were considered in the simulation model: fare collection, traffic signals, and bus stop spacing.

Fare Collection Alternative: A serious cause of delay is the fare collection procedures imposed by the KTC. One way to have a bus system operate more efficiently in the congested CBD area is to have fares collected in non-CBD areas by issuing a ticket when a passenger boarded a bus outside the CBD area. This ticket surrended when the patron leave the bus would signify that the passengers had already payed the fare. A passenger boarding within the CBD would pay the fare at disembarkement.

Traffic Signal Alternatives: The traffic signals in the study are the independent (fixed-cycle) signals with their own controllers. The ratio of green to red time differs from signal to signal. As previously noted traffic signals are the most serious cause of delay to buses, and possible improvements include installation of preemption signals or bus-actuated signals.

Preemption Signals: This treatment permits a bus driver to change the light to green or hold it on green until the bus passes through the intersection. This very simple alternative can be instituted by providing buses with a transmitter which relays a signal to a receiver installed in the signal controller. A point of concern is that this form of signal control can shift delay to the side streets.

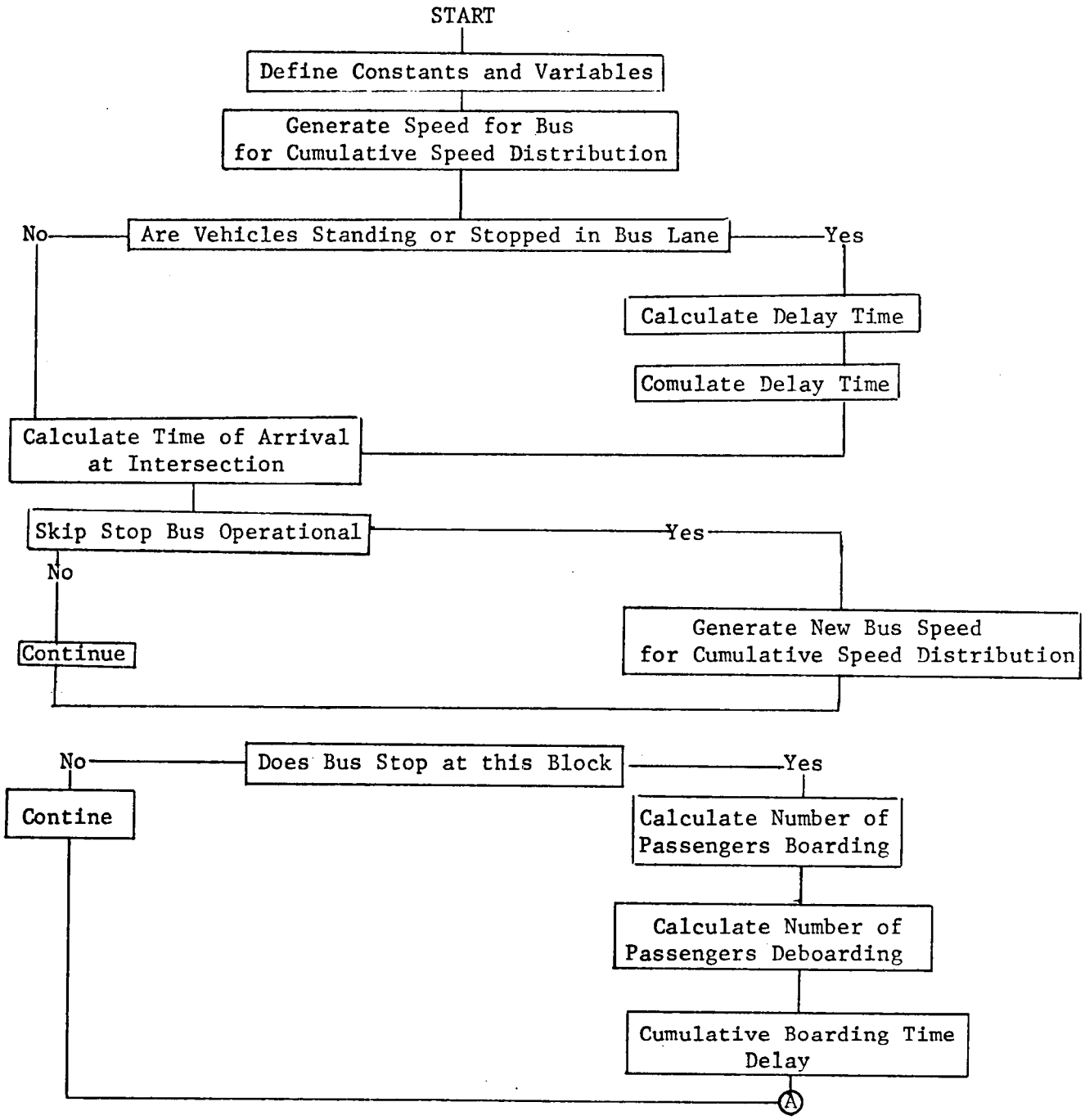


Figure 12. Flow Chart Diagram Of A Cumulative Model Bus Operating Over A Four-Block Section Of The Study Area Assuming All Operative Treatments

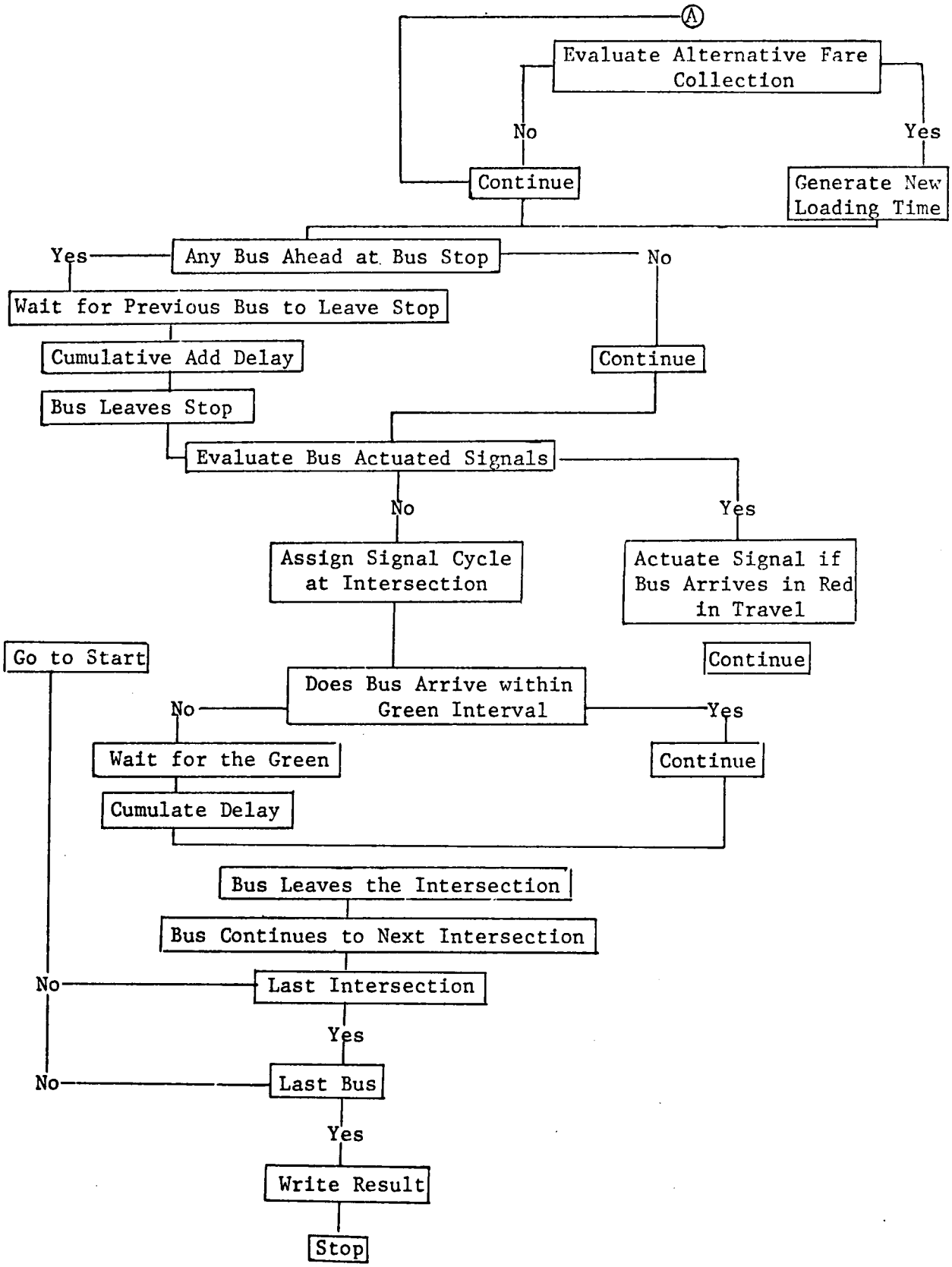


Figure 12. (continued)

Actuated Signals. This system would change a light to green or hold it on green only when side street traffic queues were manageable. This type of treatment would not cause any great delay on the side streets, because it would not hold a green light on Gay Street if traffic were extensively backed up on the side streets.

For the purposes of the simulation model it was assumed the pre-emption was operable with oxterius of four to eight seconds.

Bus Stop Spacing Alternative: To improve transit efficiency, the spacing between bus stops can be increased, such as by eliminating every other stop in areas where bus stops are located relatively close together (skip-stop). On Gay Street this process would involve increasing the average distance between stops from the present average of 410 feet to about 510 feet.

The preceding alternatives can be tested individually and then in combination in order to evaluate their relative efficiency in terms of the amout of time saved. Figure 13 shows a representation for one bus operating along Gay Street. The speed of the bus was calculated as a random variable, as shown in Appendix 8.

2. RESULTS

In order to insure that the simulation model was reliable, five simulation runs were made for each of the twenty-nine buses traveling through the four-block study area in the evening peak period. After each run, the average value of signal delay and loading delay were calculated. The results obtained from the simulation model are summarized in Table 11.

The results of various improvements, showing the average total

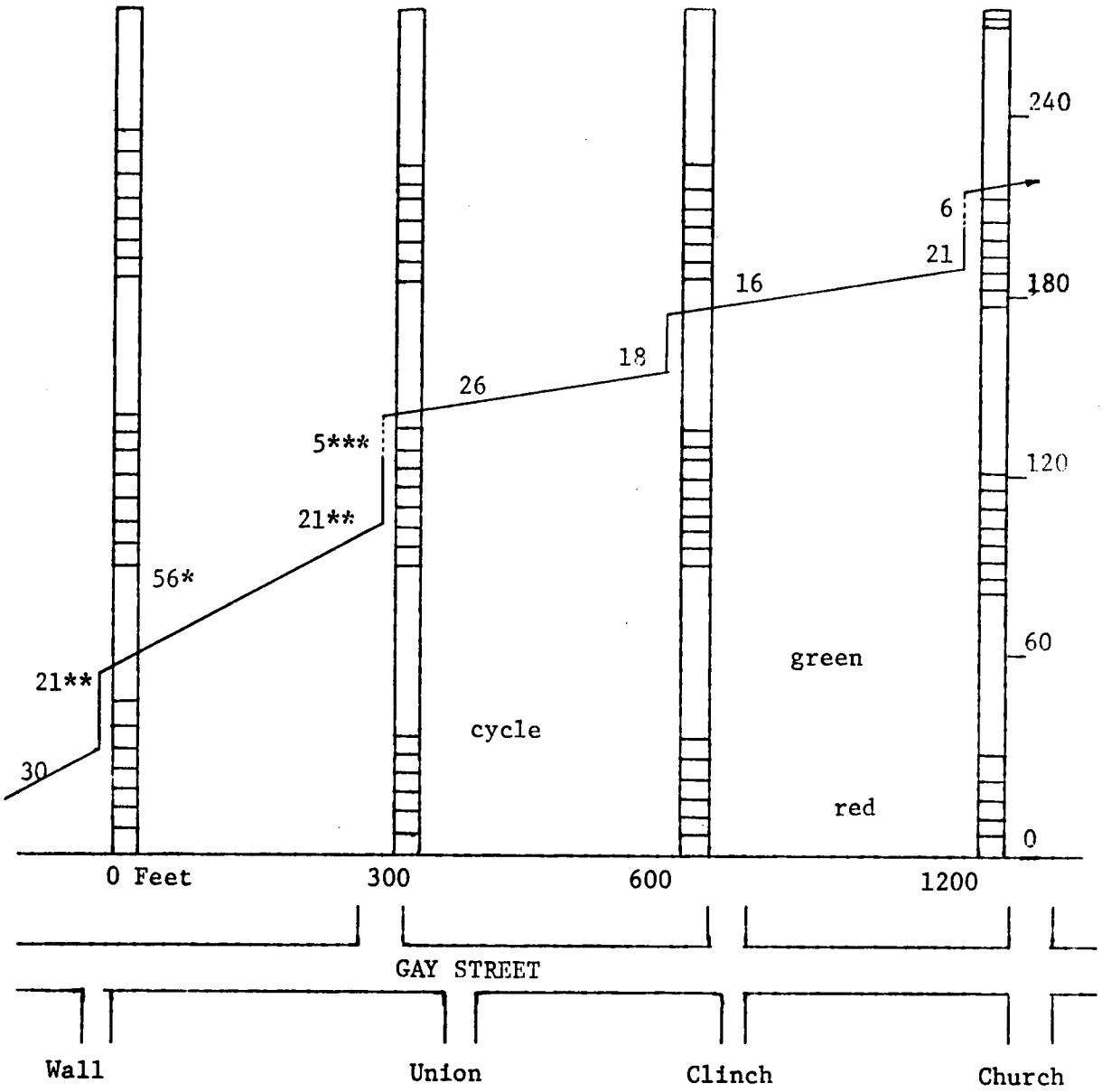


Figure 13. Simulation Model of Gay Street Transit Speed Profile (P.M. Peak Hour), Assuming All Treatments.

*travel time in seconds between bus stops obtained from cumulative speed distance (approx.)

**loading delay in seconds obtain from regression equations of (Chapter III) for fare collection discipline inposal (no fare collection)

***traffic signal delay in second assuming green time extended by bus driver

Table 11

Simulation Model Observations And Standard Deviations.

	A Existing System (Second)	B No Vehicles Parked in Bus Lane (Second)	C Skip-Stop Operation	D Actuated Traffic Signals with 4-Second	D Actuated Traffic Signals with 8-Second	E Improved Fare Collection	F All Treatments in Operation
The All Over Average Travel Time in Seconds	282.99	238.63	224.02	222.26	212.17	183.92	175.27
Standard Deviation	51.46	44.84	41.27	44.79	42.06	36.4	35.28

time used by all buses traveling through the four-block study area during the evening peak, are presented graphically in Figure 14. The average time required by buses decreases as a new treatment is introduced. For example the difference between columns A and B is attributed to enforcing restrictions on parked and stopped vehicles in the right-hand lane of Gay Street. In treatment C, the skip-stop operation is employed. In treatments D and E, the green time of the traffic signal is extended by four - eight seconds respectively through actuation. In treatment F, fares are not collected in the CBD[7], and in G all of the treatments are applied simultaneously.

Evaluation

The simulation model indicates that a time savings over the existing conditions can be expected from any of the treatments. For example a time savings of 15.68 percent should occur if automobiles were restricted from parking in the curb lane and a savings of 20.85 percent if a skip-stop operation were instituted. Both alternatives do not rely on precision of new facilities but rely on operating policies. A time savings of 21.46 and 25.0 percent respectively was estimated by the model from an actuated signal which would increase the green time by four and eight seconds respectively. By eliminating the fare collection process during loading and unloading in the CBD, the transit system should be

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[7]This is based on the data collected from observations made on the University of Tennessee campus where no fares are collected. This system was discussed in Chapter III.

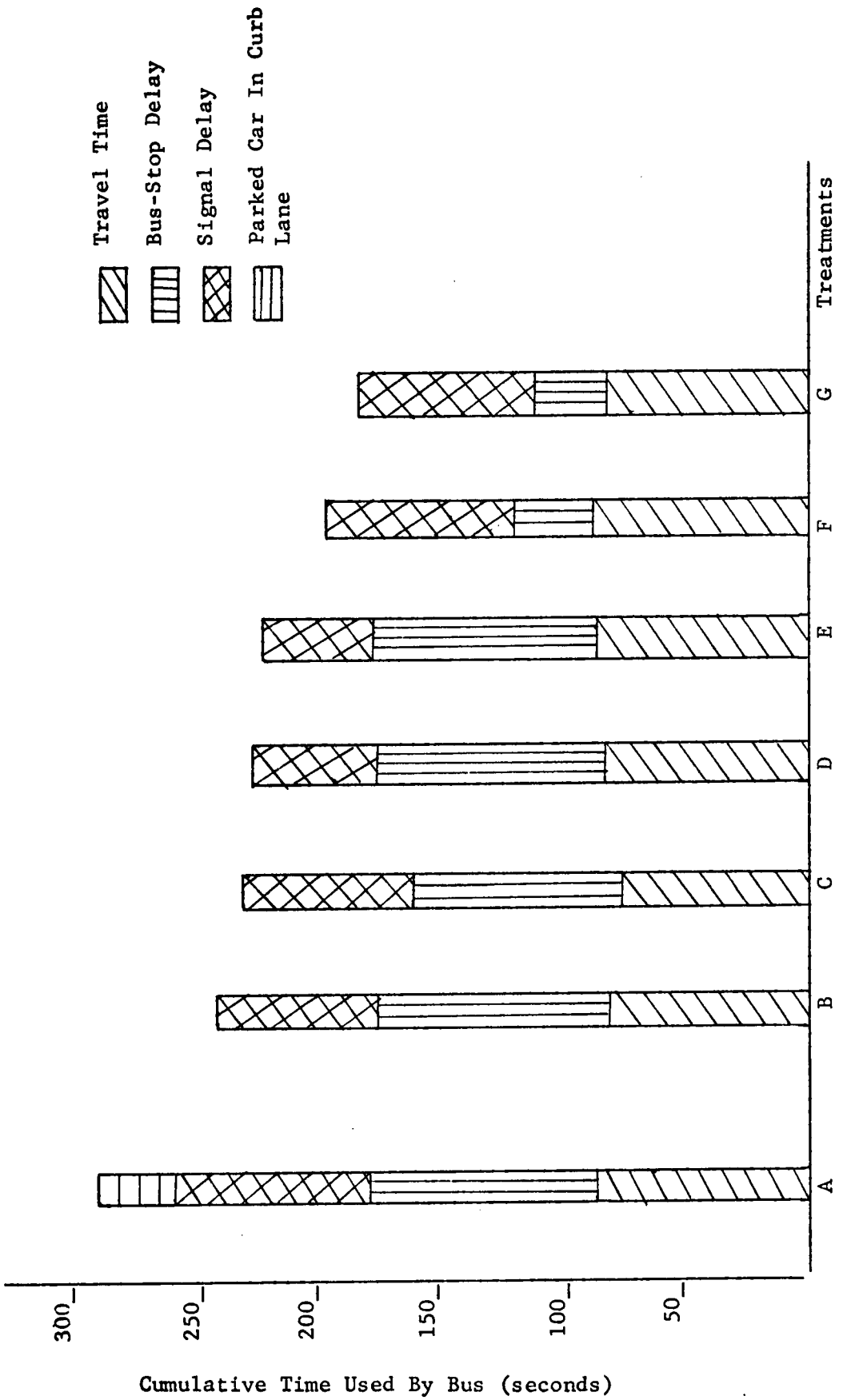


Figure 14. Simulation Model Results Represented Graphically.

able to realize a time savings of approximately 25.0 percent. If all of the treatments were instituted, a time savings of 38.0 percent could be expected.[8] The model indicates that eliminating fare collection in the Knoxville CBD would save almost as much time as applying all of the treatments together. Thus, elimination of fare collection in the CBD is the most significant single treatment which could be instituted.

In the selection of alternatives, cost as well as efficiency must be considered prior to implementation. Thus cost must be traded off against operating efficiency. Increasing the number of improvement treatments means an increase in cost and/or some inconvience to non-bus patrons[9], but a decrease in travel time and a more dependable public transportation system. Table 12 reviews several treatments and their estimated cost. The elimination of fare collection in the CBD would necessitate the expenditure of a minimal amount of funds and would save almost as much time as the application of all of the treatments simultaneously.

A consequence of all of the treatments discussed is to increase the operating speed of buses and decrease the number of stops, thus reducing travel time. There is general agreement that a savings in travel time for buses is economically valuable. However, it is difficult to

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[8]Assuming four seconds extreme of green time.

[9]Inconvenience to non-bus patrons was not considered as part of the model.

Table 12

Estimated Capital Cost Of Several Bus Operation Treatments In The Six-Block Study Area

Potential time savings during evening peak per bus (in seconds)	Estimated cost of treatment (in dollars)
45	Negative cost[a]
94	104.0[b]
56	120.0[c]
60	44,000[d]
74	44,000[d]
105	45,000[e]

[a]Restriction on vehicles parked in curb lane (policeman is already on duty in the study area).

[b]No-fare collection in CBD (22).

[c]Skip-stop operation (15).

[d]Actuated traffic signal by four to eight seconds respectively.

[e]All treatment combined.

assign an exact monetary value to time. In many cases, a savings of a few minutes in travel time may or may not reduce the cost associated with driver wages or rental buses. But with less starts and stops there is a definite reduction in operating costs (fuel, oil, tires, and bus repair and maintenance). A monetary savings resulting from increased operational efficiency is of value to transit company owners. But to transit patrons, comfort and convenience are also valuable, perhaps even more valuable than saving time or money. The value of convenience is being able to go to one's destination with a minimum of interference and discomfort. Also of major importance is increasing the relability of bus services. As noted in Table 6, page 39, bus stopped delays are reduced as factural are imposed, but also the standard deviation is reduced. This signifies a improvement in as time relability.

Recommendations

Some operational improvements to entice the efficiency of bus operations on Gay Street would be relatively simple and inexpensive to implement. With the help of the city government, the restriction on vehicles parked in the right-hand lane could be enforced. A skip-stop operation could be instituted at a minimal cost although it would cause some additional walking for bus patrons. Other treatments would be more expensive. The single most efficient treatment would be to refer the fare collection technique by the following measures could be taken:

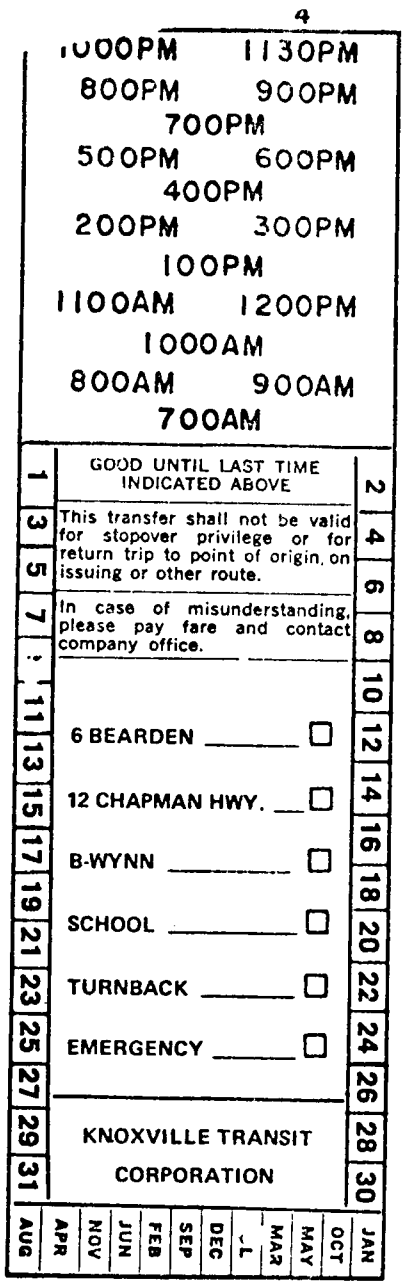
1. Supply tokens instead of a card to senior citizens, commuters, high school students, and other persons who qualify for discounts. As in Nashville, tokens could be dropped into a

separate bus located next to the fare collection box.

2. Issue a book of tickets instead of tokens. Each time a discount passenger boarded the bus, he would give the driver a ticket, this would be helpful for the driver in that he would not have to punch cards, and it would cause minimal inconvenience for the public.
3. To avoid the delay caused by the punching of transfers, KTC could reduce the number of items to be punched on transfers or eliminate the punch system completely by issuing a new transfer for each day and route, as shown in Figure 15.

Another treatment which could bring about a considerable time saving but would be more costly is instituting signal priority treatment which would control traffic signals in favor of buses and thus decrease the waiting time of buses at traffic signals. This system is still in the experimental stage, but it shows definite promise. Installation of priority treatments should be given full consideration and detailed study programs be conducted which alnoquier consideration to non-bus side street vehicles.

There are numerous other alternatives which could improve bus operation efficiency on Gay Street in downtown Knoxville, such as exclusive bus lanes or bus streets. Signal priority should be seriously considered, but they are probably too costly for Knoxville to install unless they could be intergrated as part of traffic improvement. An evaluation of joint sponsoring of such proposals should be given serious consideration.



Transfer Presently Used in Knoxville.

Destination
KTC transfer Stipulations
Commercial Announcement
Tuesday 20 June 1975
5 a.m. to 9 a.m.
9 0 10 15 11 a.m. 30 12 noon 45
1 p.m. 0 2 15 3 30 4 45
5 0 6 15 7 30 8 45 9 p.m. to 11:30 a.m.
EMERGENCY

Suggested New Type of Transfer.

Figure 15. Transfer Designs.

Summary

The prototype hand-run simulation model indicates that time savings can be accomplished in the Knoxville CBD area by implementing any one of the alternatives shown in Table 13. The most effective single treatment would be the elimination of fare collection (only the CBD). If all treatments were applied simultaneously, a time savings of 38.06 percent could be expected.

Table 13

Percent Of Stopped The Delay Saved For Each Treatment Tested In The Simulation Model

Type of Treatment	Average Percent of Time Savings
Strict enforcement of no vehicles in right-hand lane	15.68
Skip-stop operation in CBD area	20.84
Actuated signal extending green time by four seconds	21.46
Actuated signal extending green time by eight seconds	25.03
Fare collected eliminated in CBD area	35.01
All treatments applied simultaneously*	38.06

*Assume four second actuated signaling.

CHAPTER V

CONCLUSION

The objective of the study was to investigate the causes and extent of delay confronting public transit buses operating over a six block area of Gay Street in Knoxville. The results indicate that bus delay varies according to three factors:

1. Temporal pattern of delay: It was found that the most operational delays occured during the two peak periods and the mid-day hours. The major causes of stopped delay were a) traffic signals, which account for 57 percent of the total delay during two peak periods and 52 percent during the mid-day hours; b) passengers boarding-deboarding, which account for approximately 38 percent of the delay during the peak hours and 26 percent during the mid-day hours; and c) parked or standing vehicles, the delay from which was not substantial during the peak periods but was noticable from 9:00 to 10:00 a.m.
2. Spatial pattern of delay: The study also indicated that stopped delay varies from block to block. Two blocks of the study area (Wall to Union and Union to Clinch) were considered the most critical ones in terms of delay to buses. In these two blocks, 33 percent of the total delay

was attributed to traffic signals and 30 percent was attributed to passengers boarding-deboarding buses. The delay due to parked or standing vehicles was mainly of short duration and localized, and thus was not a major determent to bus movement.

3. Method of fare collection: Since the survey indicated that fare collection is the most time-consuming part of the loading/unloading process, a special investigation was conducted to compare the time consumed in fare collection in two transit systems outside Knoxville (Nashville and Chattanooga). In addition, a comparison was made of two different segments of the Knoxville service-regular routes and speciality routes used exclusively by 1) members of the University of Tennessee (U. T.) and 2) employees of the Tennessee Valley Authority (TVA). It was found that that most time was consumed by TVA, followed by Nashville, Knoxville, Chattanooga, and U. T.

4. Various alternatives were studied which could improve the efficiency of bus operations along Gay Street. In order to estimate the effectiveness of several alternatives on a preliminary basis, a prototype hand-run simulation model of alternative bus operations was constructed. This model showed that average bus travel time could be decreased, thus resulting in increased bus operating speeds, and greater reliability by the introduction of alternative bus treatments. The benefit of each singular improvement, as predicted by

by the model, are shown below:

a. A skip-stop operation would result in a stopped time delay saving of 20.84 percent.

b. Actuating traffic signals for the bus to extend the end of a green phase, should bring about a 21.46 percent savings for a four-second increase in green time and a 25.0 percent time savings for an eight-second increase in green time.

c. Eliminating fare collection in the CBD area while passengers are boarding should decrease stopped time delay 35.0 percent.

d. A 38.0 percent reduction in bus stopped time delay should be possible by using all of the alternatives simultaneously.

Although savings per bus are in the magnitude of two minutes, such time savings may assist in enhousing bus reliability as it permits bus catch-up on schedule. One major source of user complaints is buses running late in the p.m. peak.

1. RECOMMENDATIONS FOR FUTURE STUDIES

Further studies are needed to develop more sophisticated computer models which can:

1. Encompass the entire CBD area, include more stochastic variable, and examine all the possible alternatives for each individual component, such as boarding through two-doors as compared with one-door boarding, running buses

in an exclusive lane or on an elevated roadway, providing a bus bay loading system, or issuing tickets or tokens.

2. Investigate the effects of Gay Street bus treatments (actuated traffic signals) on side street traffic and vehicular traffic other than buses.
3. Investigate factors causing delay to Knoxville Transit Corporation buses outside the CBD area. Some delay worthy of investigation might be inefficient routing, and delays due to traffic signals, and blocked railroad crossings.

As a result of such studies, the problem of bus delay in Knoxville could be more effectively understood, to the benefit of both bus patrons and the bus companies.

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APPENDIX

APPENDIX A

Table 14

Examples of Bus Priority Treatments Related to Urban Roadways

City	Arterial Location	Vehicle Per Hour		Passengers Carried			Type of Treatment	Length Mile	Hour of Operation	Traffic Signal Controls	Benefit
		Bus	Auto	Bus	Auto	Percent Carried by Bus					
Atlanta, Georgia	Broad Street	48	290	1920	435	81.5	Bus Street	0.64	24 Hours	--	--
Baltimore, Maryland	Charles Street at Madison	33	1915	1480	3060	32.6	Normal Flow Curb Bus	1.50	4:00-6:30 p.m.	No	Buses Speeded up 21% a.m. Peak, 87% p.m. Peak, Other Traffic Speeded up by 39% a.m. 22% p.m. Peak
Baltimore, Maryland	St. Paul Street at Preston	45	2815	1375	4505	23.4	Normal Flow Bus Lanes	0.23	7:30-10:00 a.m. 4:00-6:00 p.m.	No	--
Baltimore, Maryland	Calvert Street at Lexington	39	2645	1185	4230	21.9	Normal Flow Bus Lanes	0.53	3:00-6:30 p.m.	No	--
Baltimore, Maryland	Lombard Street at Madison	42	1750	1335	2800	32.0	Normal Flow Bus Lanes	0.40	7:00-9:00 a.m.	No	--
Baltimore, Maryland	Pratt Street at Pace Street	64	2390	2215	3825	46.5	Normal Flow Bus Lanes	0.48	4:00-6:30	No	--
Birmingham, Alabama	Third Avenue	44	1400	2300	1950	54.0	Normal Flow Bus Lanes	0.80	7:00-9:00 a.m. 4:00-6:00 p.m.	--	27.7% Decrease in Bus Travel Time, 29% Decrease in Auto

Table 14 (continued)

City	Arterial Location	Vehicle Per Hour		Passengers Carried			Type of Treatment	Length Mile	Hour of Operation	Traffic Signal Controls	Benefit
		Bus	Auto	Bus	Auto	Percent Carried by Bus					
Chicago, Illinois	Washington Street at Wacker	108	1100	3800	1540	71.4	Curb Bus Lane	0.60	24 Hours	--	14-28% Speed up in Transit Operation
Chicago, Illinois	Sheridan	32	500	1100	706	61.0	Contra-Flow Bus Lane	1.25	7:00-9:30 a.m. 4:00-6:30 p.m.	No	--
Charlotte, North Carolina	Tryon Street	40	1150	1290	1835	41.3	Normal Flow Bus Lanes	1.30	7:00-9:00 a.m.	--	--
Dallas, Texas	Commerce Street	72	1415	3300	2120	61.0	Normal Flow Bus Lanes	0.70	4:30-6:30 p.m.	No	--
Dallas, Texas	Elm Street	80	1345	3500	1880	65.2	Normal Flow Bus Lanes	0.55	7:00-9:00 a.m. 4:30-6:00 p.m.	No	--
Dallas, Texas	Main Street, CBD	100	635	4400	900	83.0	Bus Street CBD	0.90	24 Hours	No	--
Hartford, Connecticut	Main Street	35	450	875	585	60.0	Normal Flow Bus Lanes	0.57	7:00-9:00 a.m. 4:00-6:00 p.m.	No	--
Louisville, Kentucky	Third Street	24	--	--	--	--	Contra-flow	1.50	7:00-9:00 a.m.	Yes	25% Decrease in Travel Time
Minneapolis, Minnesota	Nicollet Mall	64	--	2900	--	100.0	Bus Street	0.68	24 Hours	--	--
Nashville, Tennessee	Capitol Boulevard	---	--	--	--	--	Normal Flow	0.25	7:00-9:00 a.m. 4:00-6:00 p.m.	No	5% Reduction in Bus Running Time

Table 14 (continued)

City	Arterial Location	Vehicle Per Hour		Passengers Carried			Type of Treatment	Length Mile	Hour of Operation	Traffic Signal Controls	Benefit
		Bus	Auto	Bus	Auto	Percent Carried by Bus					
Newark, New Jersey	Market Street	100	--	--	--	--	Normal Flow	0.34	4:00-6:00 p.m.	--	7 Minute Time Saving Estimated Annual Benefit $87,000 to Bus Rider
New York, New York	Madison Avenue	96	2400	4800	3600	57.1	Normal Flow	1.12	7:00 a.m. 7:00 p.m.	No	42% Reduction in Bus Travel Time
New York, New York	Second Street	110	2800	5500	4200	56.8	Normal Flow	1.90	7:00-10:00 a.m. 4:00-7:00 p.m.	No	22% Reduction in Bus Travel Time
New York, New York	First Avenue	110	2800	5500	4200	56.8	Normal Flow	1.90	7:00-10:00 a.m. 4:00-7:00 p.m.	No	27% Reduction in Bus Travel Time
Philadelphia, Pennsylvania	Market Street	120	465	8300	695	92.5	Curb Bus Lane	0.65	24 Hours	No	--
Pittsburgh, Pennsylvania	Forbes Avenue	47	400	2300	560	79.5	Normal Flow	0.45	--	No	--
Pittsburgh, Pennsylvania	Fifth Avenue	47	420	2300	590	79.5	Normal Flow	0.40	--	No	--
Pittsburgh, Pennsylvania	Library Street	66	650	3250	910	78.2	Normal Flow	0.10	--	No	--
Pittsburgh, Pennsylvania	Smithfield Street	50	550	2450	770	76.0	Normal Flow	0.53	--	No	--

Table 14 (continued)

City	Arterial Location	Vehicle Per Hour		Passengers Carried			Type of Treatment	Length Mile	Hour of Operation	Traffic Signal Controls	Benefit
		Bus	Auto	Bus	Auto	Percent Carried by Bus					
Rochester, New York	Main Street	20	--	--	--	--	Normal Flow	1.50	All Day in CBD	No	--
San Francisco, California	Sutter Street	63	1300	2500	1700	59.5	Normal Flow	1.40	4:00-6:00 p.m.	No	--
San Francisco, California	Clay Street	26	650	1050	850	55.3	Normal Flow	0.43	7:00-9:00 a.m.	No	--
San Francisco, California	Geary Street	43	1250	1720	1630	51.4	Normal Flow	1.20	4:00-6:00 p.m.	No	--
San Francisco, California	Sacramento Street	25	410	1000	535	65.0	Normal Flow	1.30	4:00-6:00 p.m.	No	--
St. Louis, Missouri	Market Street	30	--	--	--	--	Normal Flow	0.50	7:00-9:30 a.m. 3:00-6:00 p.m.	No	--
Vancouver, British Columbia	Georaia Avenue	45	1200	2000	1600	55.5	Normal Flow	0.50	4:00-6:00 p.m.	No	20% Reduction in Bus Travel Time
Washington, D. C.	K Street, NW	130	1300	6500	1950	77.0	Normal Flow	0.90	a.m. and p.m.	No	--
Washington, D. C.	Eye Street, NW	104	1100	5200	1600	76.5	Normal Flow	0.15	4:00-6:00 p.m.	No	--

Table 14 (continued)

City	Arterial Location	Vehicle Per Hour		Passengers Carried		Percent Carried by Bus	Type of Treatment	Length Mile	Hour of Operation	Traffic Signal Controls	Benefit
		Bus	Auto	Bus	Auto						
Washington, D. C.	13th Street	101	1050	5000	1600	75.8	Normal Flow	0.20	7:00-9:00 a.m. 4:00-6:00 p.m.	No	--
Washington, D. C.	7th Street	80	1150	4000	1720	70.0	Normal Flow	0.40	7:00-9:00 a.m. 4:00-6:00 p.m.	No	--
Washington, D. C.	16th Street	80	1500	4000	2250	64.0	Normal Flow	0.40	7:00-9:00 a.m.	No	--

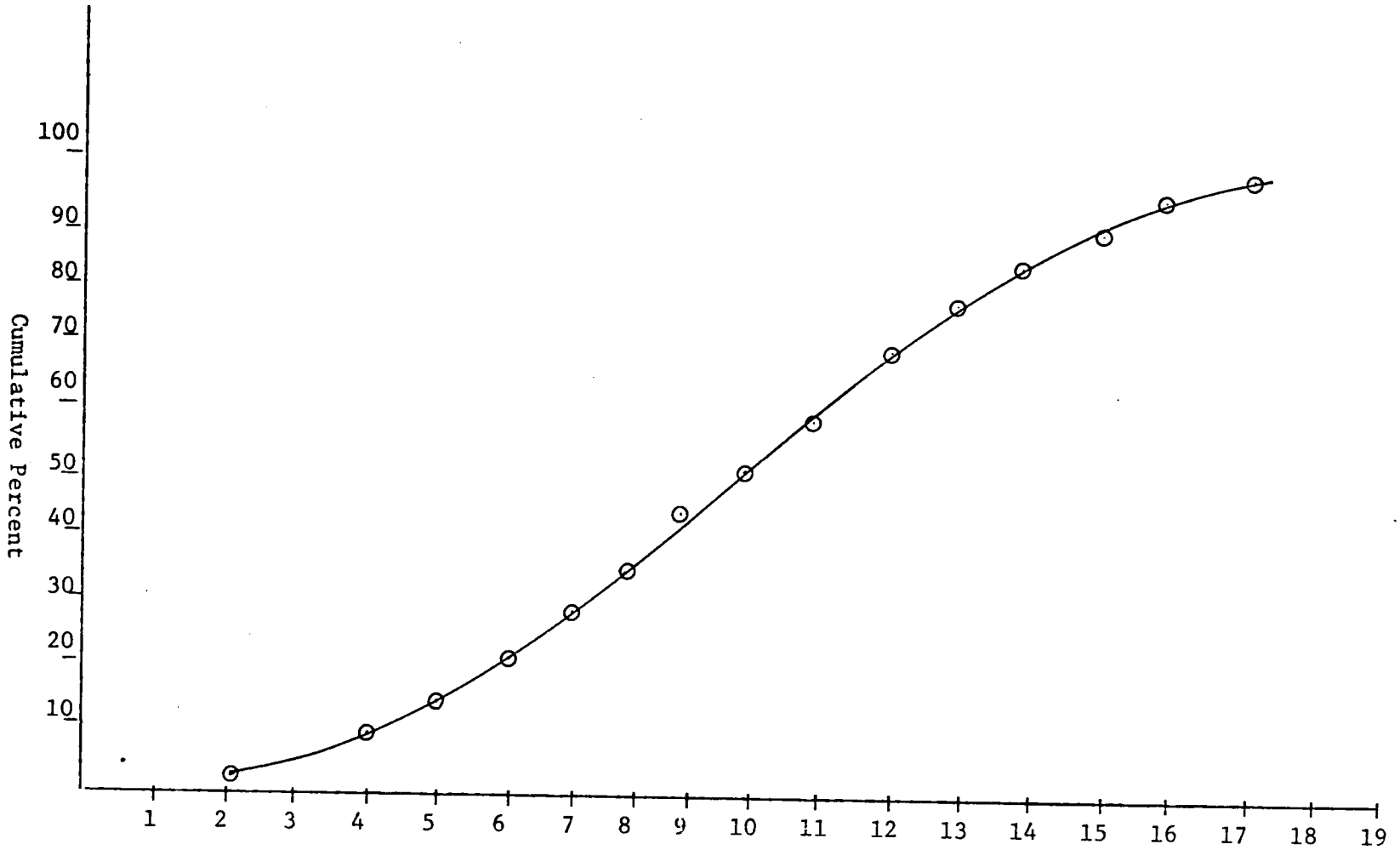


Figure 16. Simulation Model Used To Estimate Average Speed During The Evening Peak In The Commerce To Wall Block.

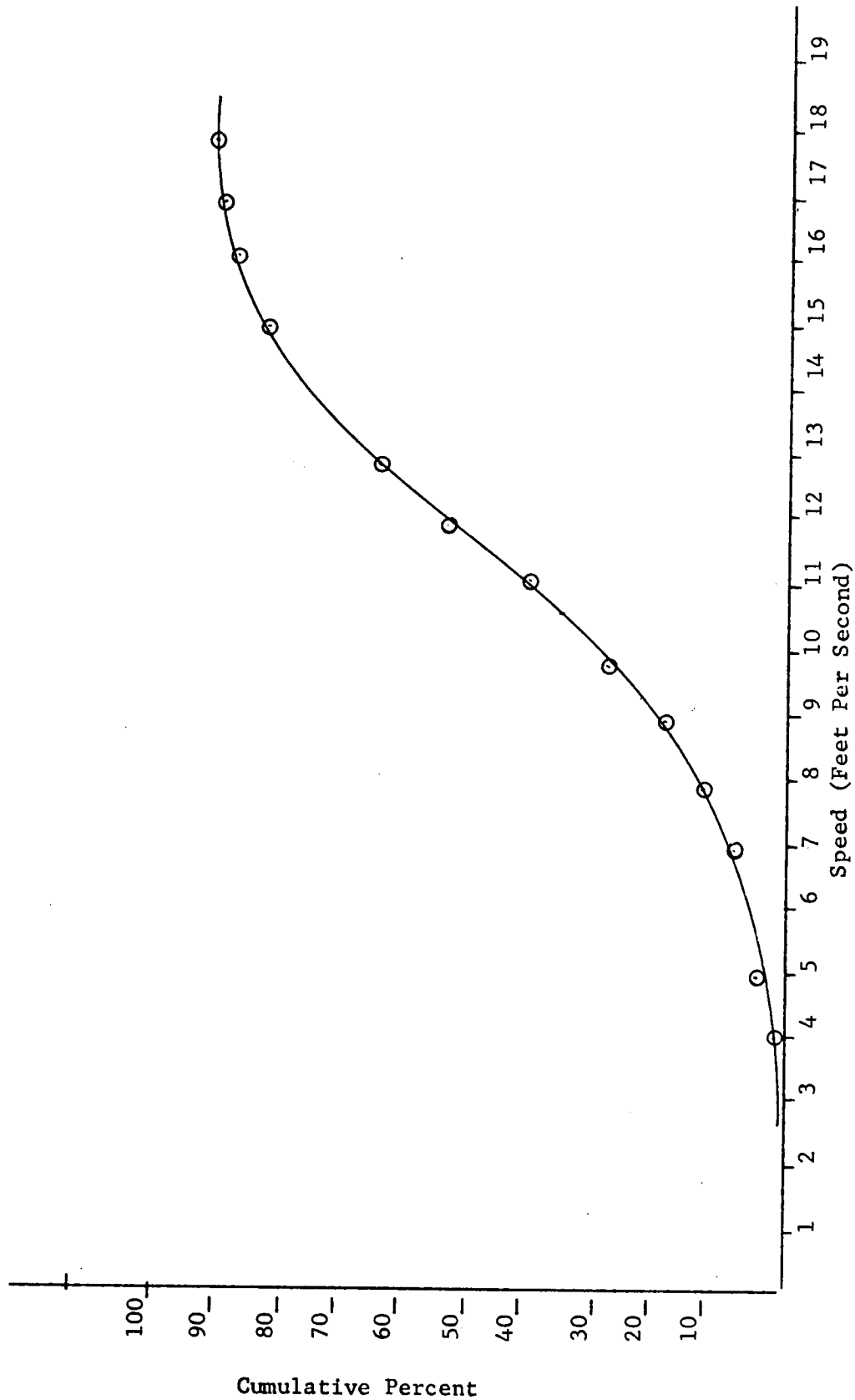


Figure 17. Simulation Model Used To Estimate Average Speed During The Evening Peak In The Wall To Union Block.

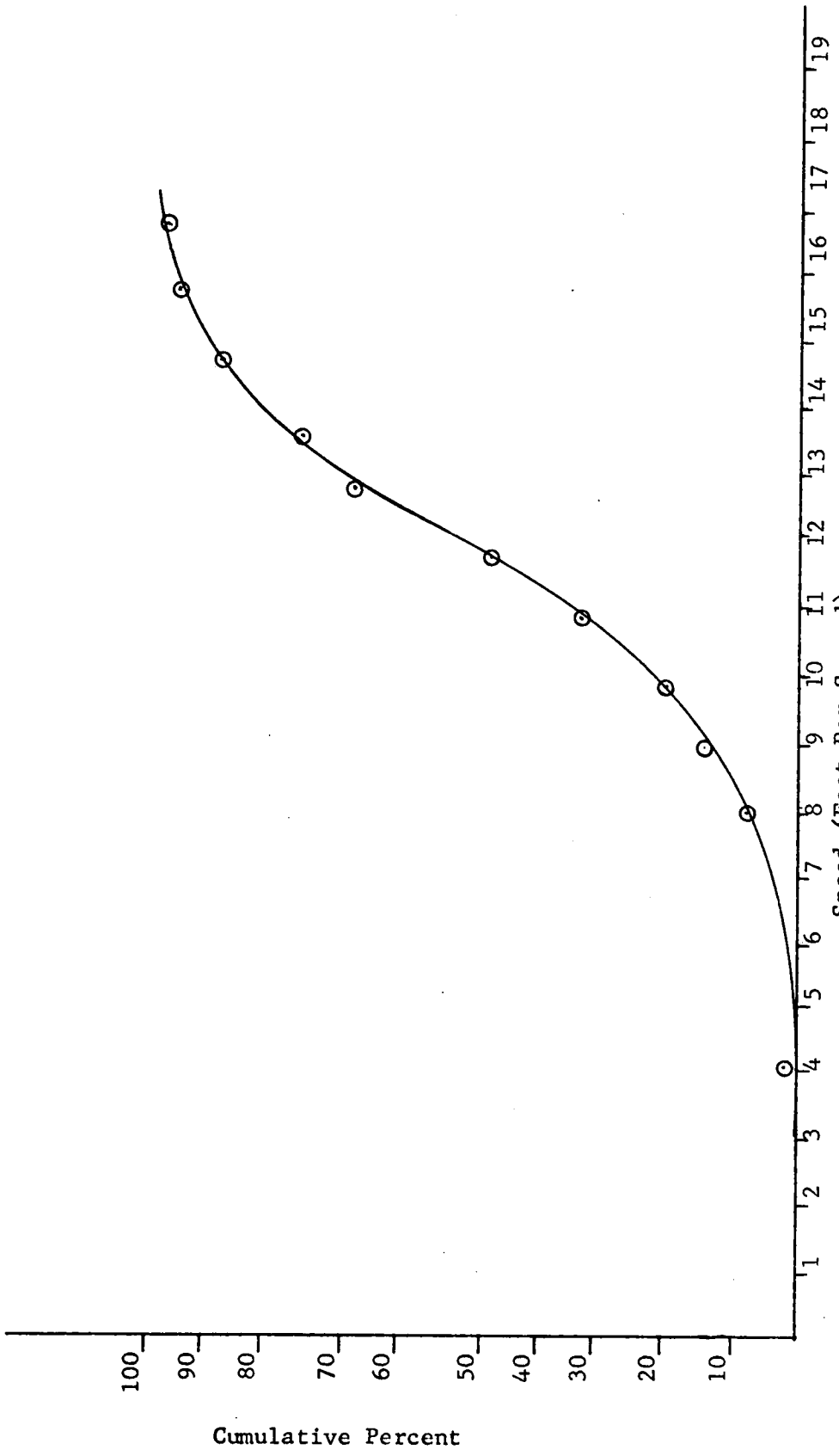


Figure 18. Simulation Model Used To Estimate Average Speed During The Evening Peak In The Union To Clinch Block.

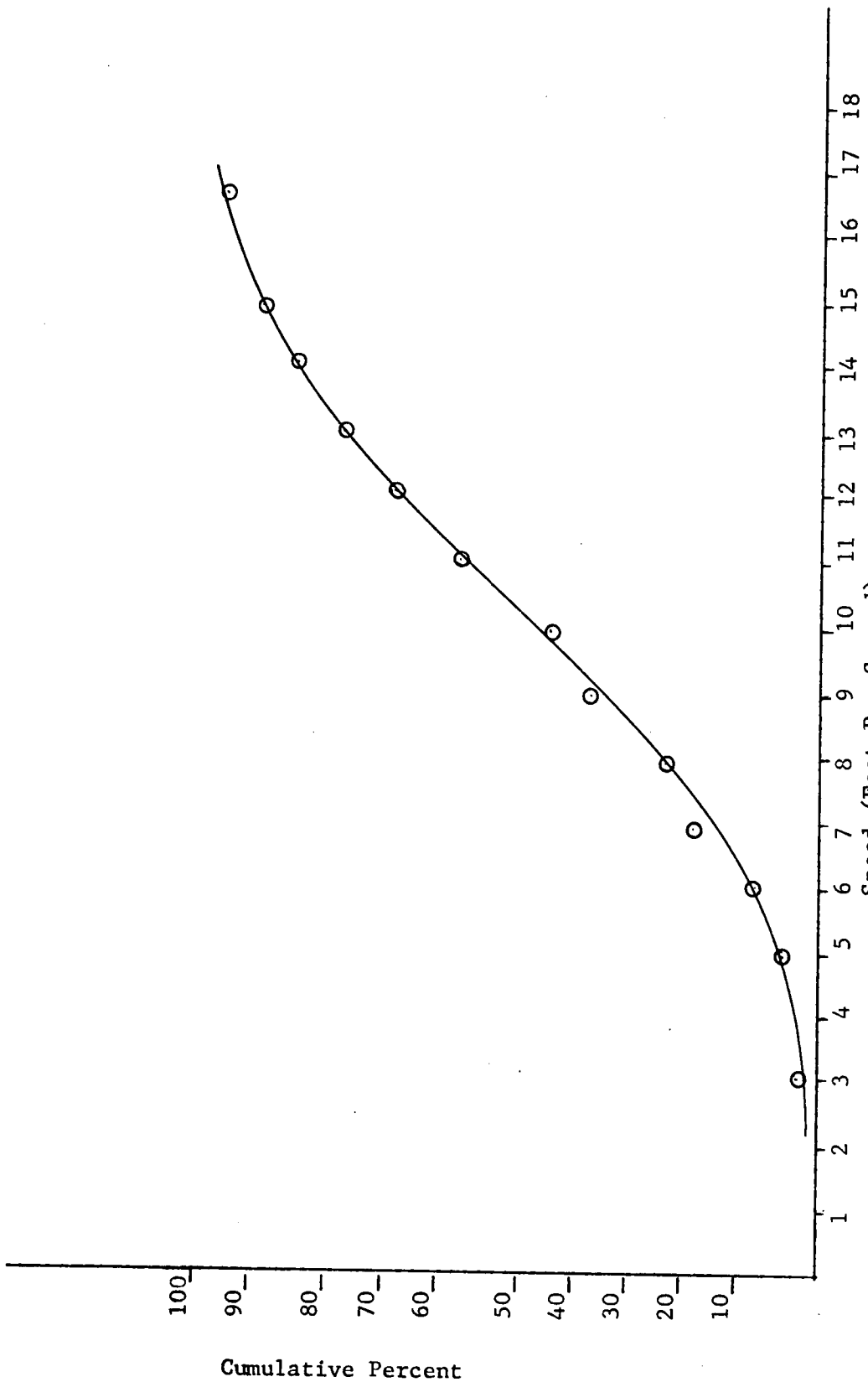


Figure 19. Simulation Model Used To Estimate Average Speed During The Evening Peak In The Clinch To Church Block.

VITA

Mohammed Jawad Al-Ani was born in Baghdad, Iraq, on December 27, 1948. He graduated from Al-Niethal High School in June, 1968. From January of 1970 to December of 1973, he studied at the West Virginia Institute of Technology. In December, 1973, he received his Bachelor of Science degree with a major in Civil Engineering.

In June of 1974, he entered the Graduate School at the University of Tennessee, Knoxville, and received the Master of Science degree with a major in Civil Engineering in December, 1975. He is a member of the Institute of Traffic Engineers and the American Society of Civil Engineers.